2009

The instrumental period

Robert Bindschadler

Eberhard Fahrbach

Jim Fastook

Jaume Forcarda

Josep-Maria Gili

See next page for additional authors

Publication Details

Adams, B et al, The Instrumental Period, chapter 4 in Antarctic climate change and the environment, Scott Polar Research Institute, Lensfield Road, Cambridge, UK: Scientific Committee on Antarctic Research, 183-298.

The instrumental period

Abstract
The instrumental period began with the first voyages to the Southern Ocean during the Seventeenth and Eighteenth centuries when scientists such as Edmund Halley made observations of quantities such as geomagnetism. During the early voyages information was collected on the meteorological conditions across the Southern Ocean, ocean conditions, the sea ice extent and the terrestrial and marine biology. The continent itself was discovered in 1820, although the collection of data was sporadic through the remainder of the Nineteenth Century and it was not possible to venture into the inhospitable interior of Antarctica. At the start of the Twentieth Century stations were first operated year-round and this really began the period of organised scientific investigation in the Antarctic. Most of these stations were not operated for long periods, which is a handicap when trying to investigate climate change over the last century.

Keywords
period, instrumental

Disciplines
Life Sciences | Physical Sciences and Mathematics | Social and Behavioral Sciences

Publication Details
Adams, B et al, The Instrumental Period, chapter 4 in Antarctic climate change and the environment, Scott Polar Research Institute, Lensfield Road, Cambridge, UK: Scientific Committee on Antarctic Research, 183-298.

Authors
Robert Bindschadler, Eberhard Fahrbach, Jim Fastook, Jaume Forcarda, Josep-Maria Gili, Nancy Bertler, D M. Bergstrom, Mauro Gugliemin, Julian Gutt, Hartmut Hellmer, F Hennion, Roberto Bargagli, Carlo Barbante, Karen Heywood, Dominic Hodgson, David Holland, Sungmin Hong, Angus Atkinson, Rob Arthern, Byron Adams, A H.L Huiskes, Steve Chown, Enrique Isla, Stan Jacobs, Anna Jones, David Bromwich, Claude Boutron, Josifino Comiso, Pete Convey, Alison Cook, Guido di Prisco, James Bockheim, Mark Stevens, Colin Summerhayes, Phil Trathan, John A. Turner, Kees van der Veen, David Vaughan, Mike Meredith, Paul Mayewski, Gareth Marshall, Cinzia Verde, Andrew Lenton, Howard Roscoe, Sharon A. Robinson, Steve Rintoul, Hans-Otto Portner, Sergio Rossi, Ted Scambos, Jon Shanklin, Lloyd Peck, Nicholas Metzl, Andrew Monaghan, David Webb, Christian Wiencke, Covadonga Orejas, Philip Woodworth, Tony Worby, Roger Worland, Kevin K. Newsham, Alberto Naveira-Garabato, Takashi Yamanouchi, Victor Smetacek, and Kevin Speer

Chapter 4

The Instrumental Period

Chapter Editor:

John Turner

Authors:

Byron Adams, Rob Arthern, Angus Atkinson, Carlo Barbante, Roberto Bargagli, Dana Bergstrom, Nancy Bertler, Robert Bindschadler, James Bockheim, Claude Boutron, David Bromwich, Steve Chown, Josifino Comiso, Pete Convey, Alison Cook, Guido di Prisco, Eberhard Fahrbach, Jim Fastook, Jaume Forcarda, Josep-Maria Gili, Mauro Gugliemin, Julian Gutt, Hartmut Hellmer, Françoise Hennion, Karen Heywood, Dominic Hodgson, David Holland, Sungmin Hong, Ad Huiskes, Enrique Isla, Stan Jacobs, Anna Jones, Andrew Lenton, Gareth Marshall, Paul Mayewski, Mike Meredith, Nicolas Metzl, Andrew Monaghan, Alberto Naveira-Garabato, Kevin Newsham, Covadonga Orejas, Lloyd Peck, Hans-Otto Pörtner, Steve Rintoul, Sharon Robinson, Howard Roscoe, Sergio Rossi, Ted Scambos, Jon Shanklin, Victor Smetacek, Kevin Speer, Mark Stevens, Colin Summerhayes, Phil Trathan, John Turner, Kees van der Veen, David Vaughan, Cinzia Verde, David Webb, Christian Wiencke, Philip Woodworth, Tony Worby, Roger Worland, Takashi Yamanouchi,

4.1 Introduction

The instrumental period began with the first voyages to the Southern Ocean during the Seventeenth and Eighteenth centuries when scientists such as Edmund Halley made observations of quantities such as geomagnetism. During the early voyages information was collected on the meteorological conditions across the Southern Ocean, ocean conditions, the sea ice extent and the terrestrial and marine biology.

The continent itself was discovered in 1820, although the collection of data was sporadic through the remainder of the Nineteenth Century and it was not possible to venture into the inhospitable interior of Antarctica.

At the start of the Twentieth Century stations were first operated year-round and this really began the period of organised scientific investigation in the Antarctic. Most of these stations were not operated for long periods, which is a handicap when trying to investigate climate change over the last century.

The International Geophysical Year (IGY) in 1957/58 saw the establishment of many research stations across the continent and this period marks the beginning of many of the environmental monitoring programmes. Thankfully many of the stations are still in operation today so that we now have some 50 year records of many meteorological parameters.

The ocean areas around the Antarctic have been investigated far less than the continent itself. Here we are reliant on ship observations that have mostly been made during the summer months. Satellite observations can help in monitoring the surface of the ocean, but not the layers below. Even here quantities such as sea ice extent have only been monitored since the late 1970s, when microwave technology could be flown on satellites.

4.2 Changes of Atmospheric Circulation

4.2.1 Modes of variability

4.2.1.1 Variability

Within the atmospheric circulation of the high southern latitudes several so-called modes of variability can be discriminated. These circulation patterns appear more frequently than would be expected in a random sample, and can 'describe' a significant proportion of the total circulation variability.

4.2.1.2 The Southern Annular Mode

As pointed out in Chapter 1, the Southern Annular Mode (SAM) is the principal mode of the Southern Hemisphere extra-tropical atmospheric circulation. It can be described either as a 'flip-flop' of atmospheric mass between mid- and high-latitudes, such that there are synchronous pressure (or geopotential height) anomalies of opposite sign in these two regions (e.g. Rogers and van Loon, 1982), or as a north-south shift in the mid-latitude jet resulting from both latitudinal vacillations in the jet and fluctuations in jet strength (Fyfe and Lorenz, 2005). When pressures are higher (lower) than average over the Southern Hemisphere mid-latitudes (Antarctica) the SAM is said to be in its positive phase (see Figure 4.1) and *vice versa*.

The spatial pattern of the SAM varies negligibly with height in the atmosphere and is revealed as the leading mode of variability in many atmospheric fields (see Thompson and Wallace (2000) and references therein). Model experiments demonstrate that the structure and variability of the SAM results from the internal dynamics of the atmosphere (e.g. Limpasuvan and Hartmann, 2000). Synoptic-scale (a horizontal scale of greater than 1,000 km) weather systems interact with the zonal mean flow to sustain latitudinal displacements of the mid-latitude westerlies. The SAM contributes a significant proportion of Southern Hemisphere climate variability (typically ~35%) from high-frequency to very low-frequency timescales, with this variability displaying a greater tendency to low frequency variability.

Gridded reanalysis datasets have been used to derive time series of the SAM (e.g. Renwick, 2004). Due to the poor quality of current reanalyses products at high southern latitudes prior to the assimilation of satellite sounder data in the late 1970s (Hines et al., 2000), long-term SAM time-series cannot be derived from them. Based on a definition by Gong and Wang (1999), Marshall (2003) produced a SAM index based on 12 appropriately located station observations in the extra-tropics and coastal Antarctica. This index itself is limited to the period following the IGY. Attempts have been made to reconstruct annual to century-scale records based on the SAM and associated atmospheric circulation features, such as surface pressure over Antarctica and the Southern Hemisphere westerlies. Souney et al. (2002a) used variability in Na concentrations from the Law Dome ice core, while Jones and Widmann (2003) employed tree-ring width chronologies: both these studies highlight the decadal variability in their derived SAM time series. Yan et al. (2005) reconstructed past behaviour of the Southern Hemisphere westerlies at the edge of the polar vortex using the variability in Ca concentrations from West Antarctic ice cores.

The SAM has shown significant positive trends over the past few decades, particularly during austral autumn and summer (e.g. Thompson et al., 2000; Marshall, 2003). The positive trend was especially pronounced from the mid-1960s until the end of the Twentieth Century, since when there has been a similar frequency of seasons with positive and negative SAM values (Figure 4.2). The positive trend in the SAM has resulted in a strengthening of the mean circumpolar westerlies of ~15% (Marshall, 2002), and contributed to the spatial variability in Antarctic temperature change (e.g. Thompson and Solomon, 2002; Kwok and Comiso, 2002; Schneider et al., 2004; Marshall, 2007), specifically a warming in the northern Peninsula region and a cooling over much of the rest of the continent. The SAM also impacts the spatial patterns of variability in precipitation across Antarctica (e.g. Genthon et al., 2003).

The imprint of SAM variability on the Southern Ocean system is observed as a coherent sea level response around Antarctica (Aoki, 2002; Hughes et al., 2003), and by its regulation of Antarctic Circumpolar Current (ACC) flow through the Drake Passage (Meredith et al., 2004). Modelling studies show that a positive phase of the SAM is associated with northward (southward) Ekman drift in the Southern Ocean (at 30°S) leading to upwelling (downwelling) near the Antarctic continent (~45°S) (Hall and Visbeck, 2002; Lefebvre et al., 2004). These changes in oceanic circulation impact directly on the thermohaline circulation and may explain recent patterns of observed oceanic temperature change in the Southern Ocean described by Gille (2002). Although the SAM is essentially zonal, a wave-number 3 pattern (three troughs and three ridges around the hemisphere) is superimposed, with a marked low pressure anomaly west of the Peninsula when the SAM is positive, leading to increased northerly flow and reduced sea ice in the region (Liu et al., 2004). Raphael (2003) reported that diminished summer sea ice may in turn feed back into a more positive SAM. However, modelling work by Marshall and Connolley (2006) showed that increased sea surface temperatures (SSTs) at high southern latitudes will warm the atmosphere, and, through thermodynamical processes, cause the atmospheric centre-of-mass to rise and geopotential height to increase thus producing a more negative SAM.

4.2.1.3 The Pacific-South American (PSA) pattern

The El Niño–Southern Oscillation (ENSO) phenomenon is the largest climatic cycle on Earth on decadal and sub-decadal time scales, and can influence the weather and climate well beyond the low-latitude Pacific Ocean where it is most marked. ENSO is a coupled atmosphere-ocean phenomenon that involves a major reversal of the atmospheric and oceanic flows across the tropical Pacific Ocean. During the La Niña phase there is intense storm activity close to Indonesia and strong westward moving atmospheric and ocean flow across the Pacific near the Equator. During the El Niño phase the storm activity moves close to the date-line, with deep convection giving upper atmosphere divergence. This results in a quasi-stationary Rossby Wave (atmospheric long wave) pattern becoming established in both hemispheres, so providing teleconnection patterns between high and low latitudes.

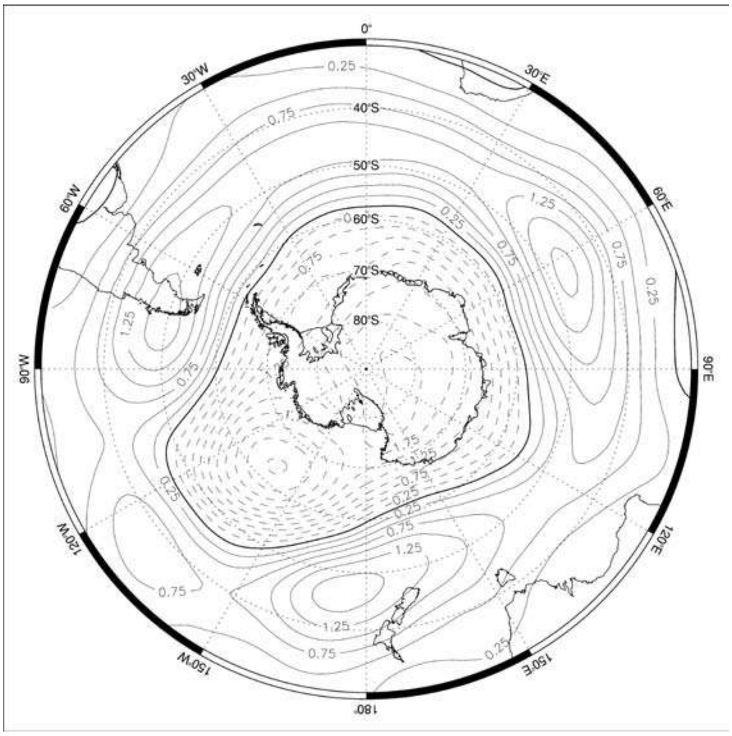


Figure 4.1 The austral summer SAM derived from gridded 500 hPa geopotential height monthly anomaly data (the 500 hPa surface is approximately at an elevation of 5 km above mean sea level) for 1989-2008. Here the SAM is in its positive phase with negative anomalies over the Antarctic and positive anomalies over the Southern Ocean.

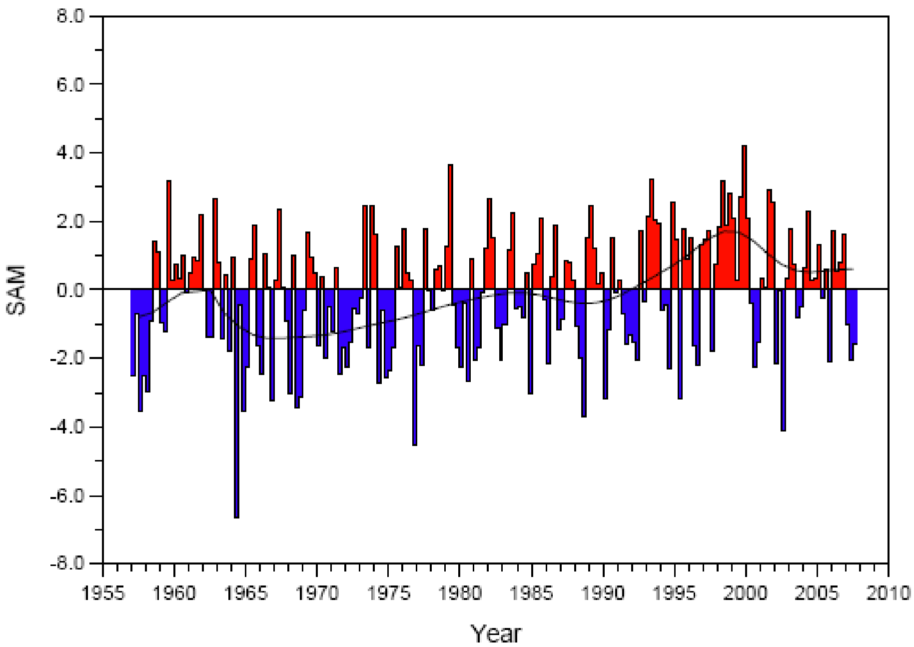


Figure 4.2 Seasonal values of the SAM index calculated from station data (Marshall, 2003). The smooth black curve shows decadal variations. This is an updated version of Figure 3.32 from IPCC (2007).

In the Southern Hemisphere, the Rossby wave train is known as the Pacific-South American Association (PSA) and it links the central tropical Pacific and the Amundsen-Bellingshausen Sea (ABS) (Figure 4.3). The most robust signals of ENSO are found across the South Pacific during winter and at this time of year, the wave train can be identified as anomalously high mean sea level pressure (MSLP) and upper level heights (heights of constant pressure surfaces) across the ABS, with anomalously low values to the east of New Zealand (Figure 4.4) (Karoly, 1989). Such circulation anomalies give generally colder temperatures across the Antarctic Peninsula, with more extensive sea ice, and warmer air arriving from the north across West Antarctica and the Ross Ice Shelf (Figure 4.4).

During the La Niña phase of the cycle these anomaly patterns are broadly reversed with more cyclonic activity over the ABS and warmer winters experienced over the Antarctic Peninsula (Turner, 2004) (Figure 4.4).

The PSA pattern is thought to be primarily related to ENSO. Nonetheless, it is prominent at many timescales even in the absence of a strong ENSO signal. Thus, the PSA may also be an internal mode of climate variability. Note that Mo and Higgins (1998) state that the PSA actually comprises two separate modes, each associated with enhanced convection in different parts of the Pacific and suppressed convection elsewhere.

An alternative mechanism for the PSA teleconnection was proposed by Liu et al. (2002). They suggest that the increased convection associated with El Niño events alters the mean meridional atmospheric circulation through longitudinal changes to the Hadley circulation and subsequent alterations of the subtropical jet position and strength. Yuan (2004) suggests that the two mechanisms operate in phase and are comparable in magnitude.

While there are general patterns of high-latitude climate anomalies that co-vary with ENSO, correlations suggest that teleconnections are small. A modelling study by Lachlan-Cope and Connolley (2006) shows that this is because (i) Rossby wave dynamics are not well-correlated to 'standard' definitions of ENSO, because the relationship between upper level divergence and SSTs via deep convection is complex, and (ii) natural variation in the zonal flow of Southern Hemisphere high-latitudes can swamp the ENSO signal. Moreover, Fogt and Bromwich (2006) demonstrated that a weaker high-latitude teleconnection in spring during the 1980s compared to the following decade was due to the out-of-phase relationship between the PSA and SAM at this time: subsequently, the tropical and extra-tropical modes of climate variability had an in-phase relationship.

Ice core records have provided insight into the tropical-Antarctic teleconnections in the pre-instrumental period. Schneider and Steig (2008) found positive temperature anomalies in West Antarctica over the period 1936-45, which they attributed to the major 1939-42 El Niño event.

Although apparent throughout the year, the PSA demonstrates the strongest teleconnections to the Antarctic region in austral spring and summer. During these seasons an El Niño (or a La Niña) event is associated with significantly more (or less) blocking events in the southeast Pacific (Renwick and Revell, 1999). This pressure anomaly in the ABS is primarily responsible for the Antarctic Dipole (ADP) in the interannual variance structure in the sea ice edge and SST fields of the Southern Ocean, which are characterised by an out-of-phase relationship between anomalies in the central/eastern Pacific (ABS) and the Atlantic (Weddell Sea) sectors (Yuan and Martinson, 2001: see Figure 4.4). In addition, the ADP sea ice anomalies are reinforced by ENSO-related storm track variability, which influences the Ferrel cell (the vertical circulation cell located between the Hadley Cell of the tropics and the Polar Cell of the high latitude areas) by changing the meridional heat flux divergence/convergence and shifting the latent heat release zone, which in turn modulates the mean meridional heat flux that impacts sea ice extent. Correlations with ENSO indices imply that up to 34% of the variance in sea ice edge is linearly related to ENSO (Yuan and

Martinson, 2000), while Gloersen (1995) showed that different regions of sea ice respond to ENSO at different periodicities. The strongest sea ice correlations associated with ENSO occur at 120-132º W (in the ABS) lagging the tropical temperature anomaly by 6 months; so the austral spring/summer ENSO signal is observed in the subsequent ice growth period in autumn/winter (Yuan and Martinson, 2000). Note that the temporal quasi-periodic nature of both ENSO and the ice anomalies prevents the identification of direction of causality. Kwok and Comiso (2002) state that recent trends in sea ice extent in both the Bellingshausen Sea and Ross Sea are related directly to ENSO variability.

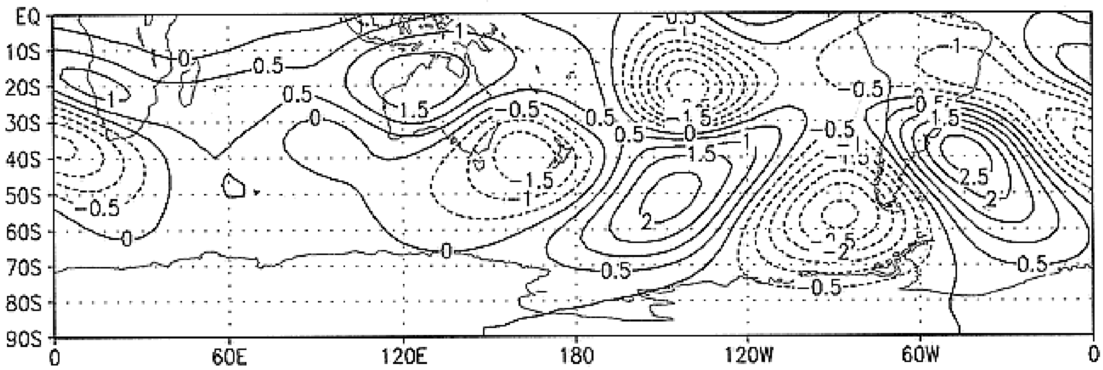


Figure 4.3 The PSA teleconnection pattern of positive and negative pressure anomalies (hPa) (after Mo and Higgins, 1998). Notice the chain of anomalies from Australia and the central Pacific and the 'centre of action' west of the Antarctic Peninsula.

4.2.1.4 The Antarctic Circumpolar Wave

The Antarctic Circumpolar Wave (ACW), first defined by White and Peterson (1996), is an apparent easterly progression of phase-locked anomalies in Southern Ocean surface pressure, winds, SSTs and sea-ice extent (Figure 4.5). It thus represents a coupled mode of the ocean-atmosphere system. The ACW has a zonal wavenumber of 2 (meaning a wavelength of 180°), and the anomalies propagate at a speed of 6-8 cm/sec such that they take 8-10 years to circle Antarctica, giving the ACW a period of 4-5 years. A similar feature has also been identified in sea surface height using satellite altimeter data (Jacobs and Mitchell, 1996). Given the much shorter response times of the atmosphere, these authors proposed that the ocean plays an important part in creating and maintaining the ACW. As there is little Antarctic multiyear ice, Gloersen and White (2001) suggested that the memory of the ACW in the sea ice pack is carried from one austral winter to the next by the neighbouring SSTs. White et al. (2004) showed a complex tropospheric response to sea ice anomalies that, for example, explained anomalous poleward surface winds and deep convection observed with negative sea ice edge anomalies.

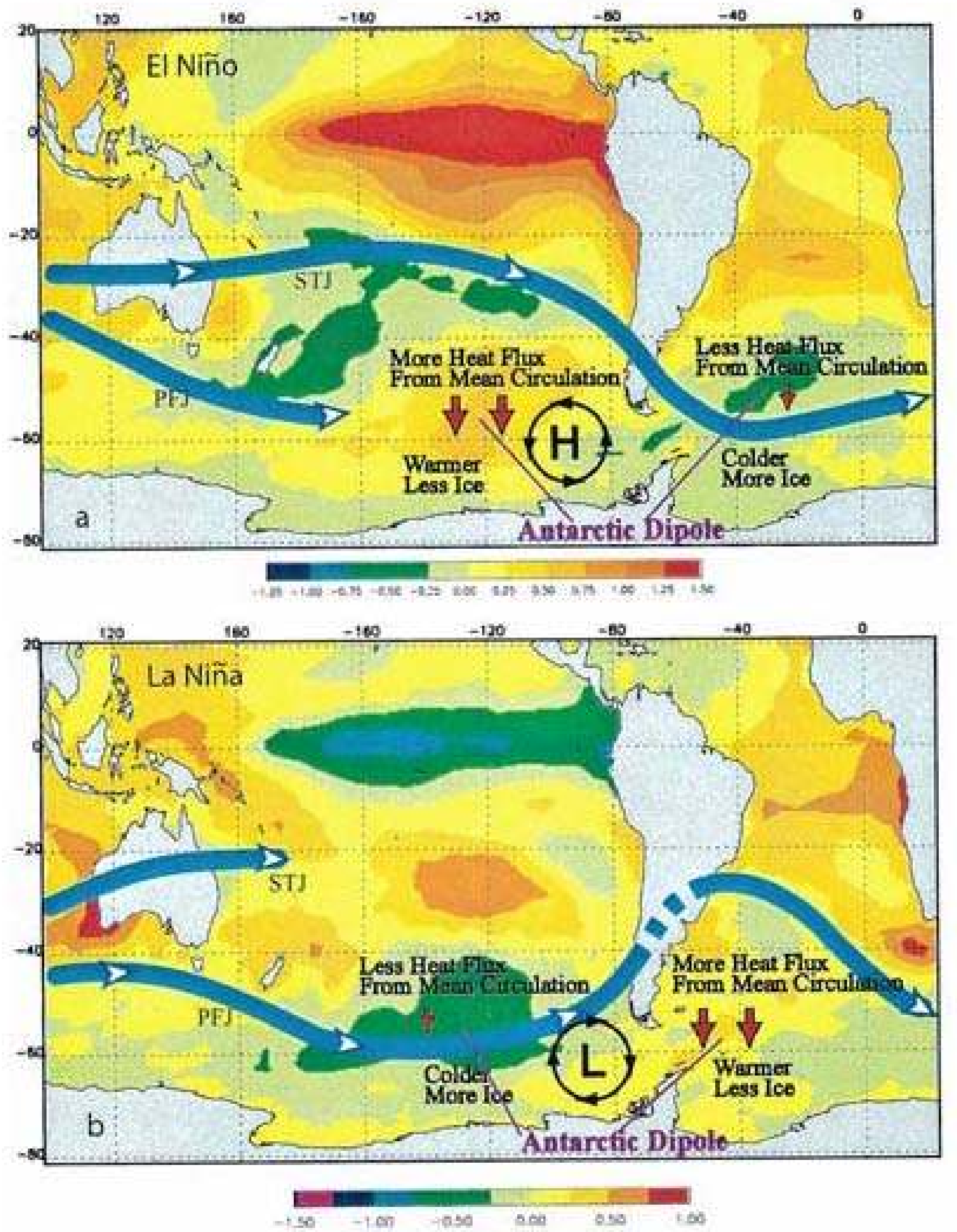


Figure 4.4 SST anomaly composites (°C) for (a) El Niño conditions and (b) La Niña conditions. Schematic jet streams (STJ is the subtropical jet and PFJ is the polar front jet), persistent anomalous high and low pressure centres, and heat fluxes are also marked. (Yuan, 2004).

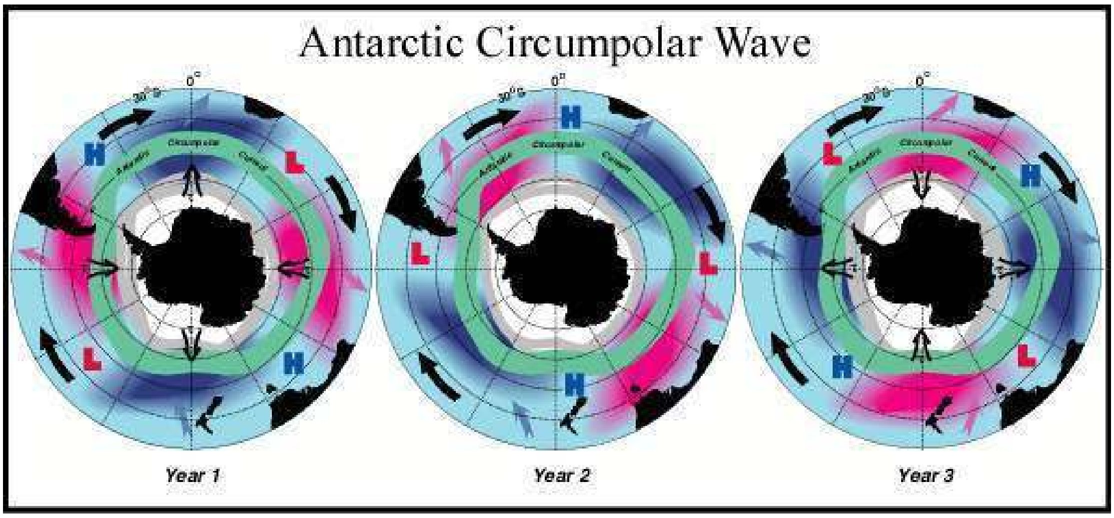


Figure 4.5 Simplified schematic summary of interannual variations in sea surface temperature (red, warm; blue, cold), atmospheric sea level pressure (bold H (high) and L (low)), and sea ice extent (grey line), together with the mean course of the Antarctic Circumpolar Current (green). Heavy black arrows depict the general eastward motion of the anomalies, and other arrows indicate communications between the circumpolar current and more northerly tropical gyres (White and Peterson, 1996).

Some authors have suggested that an ACW signal can be observed in an Antarctic ice core over the last 2000 years (Fischer et al., 2004). But, since the initial discovery of the ACW, others have questioned its persistence. Several observational and modelling studies have indicated that the ACW is not apparent in recent data before 1985 and after 1994 (e.g. Connolley, 2003), which is somewhat fortuitously the period that White and Peterson (1996) chose for their original analysis. In addition, there has been some discussion on one of its key characteristics, whether it really has a wave number 2 pattern. Many studies (e.g. Cai et al. 1999) have indicated that an ACW-like feature is apparent in GCM control runs but that it has a preferred wavenumber 3 pattern. Venegas (2003), using frequency domain decomposition, suggested that the ACW comprises two significant interannual signals that combine constructively/destructively to give the observed irregular fluctuations of ACW on interannual time scales, as also seen in GCM studies. The two signals comprise (i) a 3.3 year period of zonal wavenumber 3 and (ii) a 5 year period of zonal wavenumber 2, which was particularly pronounced during the period studied by White and Peterson.

However, most of the ACW debate has centred on its forcing mechanisms and, as a consequence, the very nature of its existence. For example, White et al. (2002) state explicitly that the ACW exists independently of the tropical standing mode of ENSO, and that its eastward propagation depends upon atmosphere-ocean coupling rather than on advection by the ACC: both these points have been refuted in the literature. The ADP (Yuan and Martinson, 2001), described previously, has the same wavelength as the ACW, but key differences are that the associated variability is twice that of the ACW, and that the dipole consists principally of a strong standing mode together with a much weaker propagating motion. Moreover, Yuan and Martinson (2001) state that the ADP is clearly associated with ENSO events. Several other authors have found that ENSO variability is important in driving a geographically fixed standing wave in Southern Ocean interannual variability, that is centred in the South Pacific and linked to the PSA pattern (Cai et al., 1999; Venegas, 2003; Park Y. et al., 2004).

Furthermore, several papers mention the ACC as the means of anomaly propagation. In an ocean model forced by realistic stochastic (random) anomalies, Weisse et al. (1999) showed that the ocean acts as an integrator of short-term atmospheric fluctuations (white noise) and turns them into a lower frequency signal (red noise); subsequently the average zonal velocity of the ACC determines the timescale of the oceanic variability and thus the propagation speed and period of the ACW (Cai et al., 1999; Venegas, 2003). The results of the study of Park Y. et al. (2004) indicated that any such propagating anomalies comprised only ~25% of interannual Southern Ocean SST variability and are often rapidly dissipated in the Indian Ocean, are intermittent in phase and frequently do not complete a circumpolar journey (Figure 4.6). Hence, they questioned the existence of the ACW, as originally described by White and Peterson (1996).

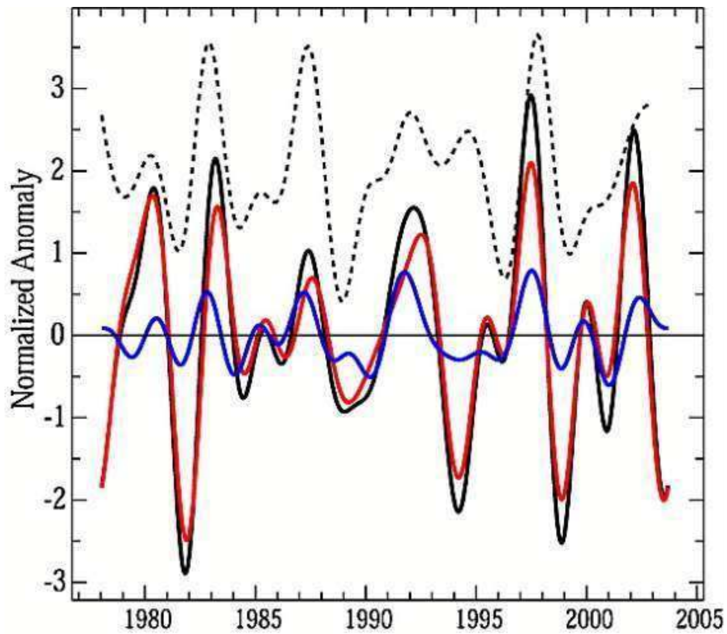


Figure 4.6 Temporal variations at 140°W of the total (black line), stationary (red line), and eastward (blue line) SST. Values are normalized by a standard deviation of the total SST. The Southern Oscillation Index (a measure of the phase of the El Niño – Southern Oscillation) is shown by a micro-dashed line, but with its sign being reversed and its zero axis being displaced by +2 to better compare with peaks of SST (Park Y. et al., 2004).

4.2.2 Depression Tracks

The paths of cyclones, known as depression or storm tracks, can be obtained using three broad methodologies. First, individual weather systems can be identified by their cloud signatures in satellite imagery or meteorological charts, and their subsequent paths can then be determined from further multitemporal imagery. The polar regions are well-suited to this kind of analysis because polar orbiting satellites provide many overlapping passes at high latitudes. Although attempts have been made to automate this process, most studies to date have been done manually, and the labour-intensive nature of this process means that the time periods covered are relatively short. For example, Turner et al. (1998) examined 12 months of AVHRR data in the Antarctic Peninsula sector during which 504 synoptic-scale lows were identified.

The availability of gridded data from numerical weather prediction (NWP) models and reanalyses allows entirely automated methods to be used that can provide climatological information on depression tracks, including trends. System-centred tracking is achieved by searching for local minima in certain fields, such as MSLP (e.g. Jones and Simmonds, 1993), or maxima in vorticity (e.g. Hoskins and Hodges, 2005). An example of the resultant tracks at high southern latitudes is shown in Figure 4.7a. A final methodology is to utilise Eulerian storm-track diagnostics by identifying the variance of vorticity at synoptic-timescales (2-6 days). Figure 4.7b is an equivalent figure to 4.7a using that method: note the significant difference in results in the circumpolar trough (CPT) with the system-centred approach finding a maximum, while the Eulerian method indicates relatively little cyclone activity at that site. The satellite-imagery study of Turner et al. (1998) reveals that there is indeed a maximum in cyclone activity at that site.

There is a marked difference between the main CPT storm track in austral summer and winter. In the summer it is nearly circular and confined to high-latitudes south of 50°S. In winter (Fig 4.7a) the storm track is more asymmetric with a spiral from the Atlantic and Indian Oceans in towards Antarctica, and a pronounced sub-tropical jet (STJ) - related storm track at ~35°S over the Pacific (e.g. Hoskins and Hodges, 2005). Simmonds and Keay (2000) found that the mean track length of winter systems (2,315 km) was slightly longer than in summer (1,946 km). The equinoctial seasons have depression track patterns intermediate between summer and winter. The CPT has a maximum in storm activity in the Atlantic and Indian Ocean regions at all times of year. While the previous description relates to the mean climatology, individual weather systems can behave differently; for example, many studies have shown cases where cyclones have a strong northerly track, particularly when associated with cold-air outbreaks from the Antarctic continent. The automated procedures can also be used for locating and tracking anticyclones. In such a study, Sinclair (1996) found that south of 50°S anticyclones were generally rare, but their tracks were associated with the main regions of blocking in the South Pacific as described previously.

Using gridded data, Simmonds and Keay (2000) showed that annual and seasonal numbers of cyclones have decreased at most locations south of 40°S during the 1958-97 period examined, and can be related to changes in the SAM. The latter is associated with a decline in pressure around Antarctica so there has been a trend to fewer but more intense cyclones in the circumpolar trough. One exception is the Amundsen-Bellingshausen Sea region where cyclonic activity has increased (Simmonds et al., 2003)

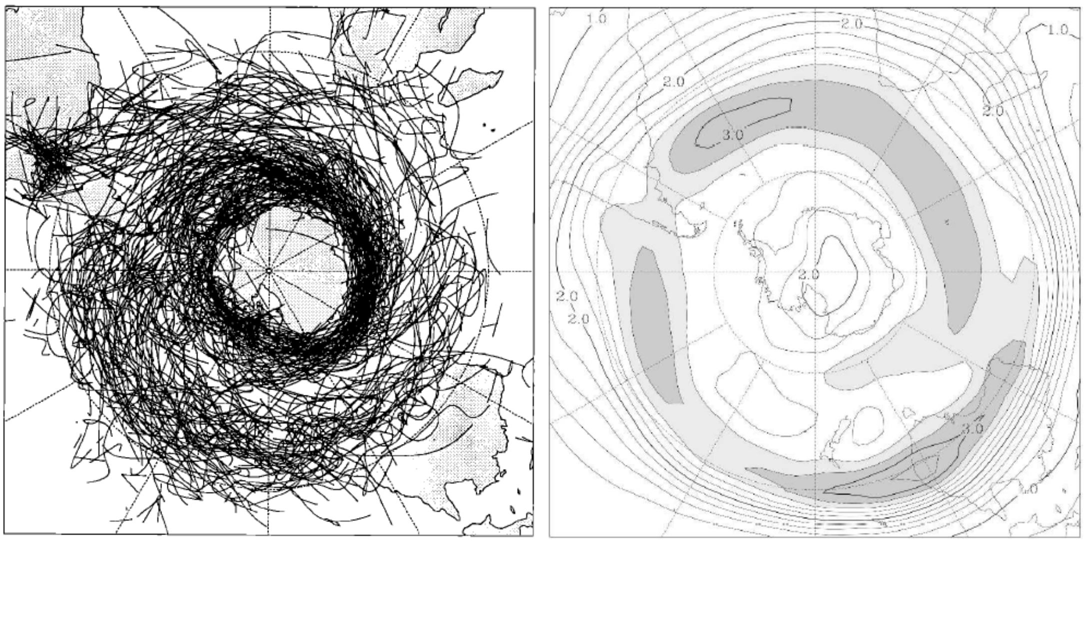


Figure 4.7 (a) Depression tracks for winter 1985-89. From Jones and Simmonds (1993). (b) Bandpass-filtered (2-6 day) variance converted to standard deviation for ξ_{250} for winter 1958-2002. This quantity provides a measure of storm activity and indicates the tracks of major storms. From Hoskins and Hodges (2005). The shaded areas show the large atmospheric variability associated with the frequent passage of depressions.

4.2.2.1 Depression formation and decline

Depression tracking studies can also show the locations where a weather system is first and last identified, respectively cyclogenesis and cyclolysis. By collating data from all cyclones examined, regions of preferred cyclogenesis and cyclolysis may be determined. Using data from the NCEP-NCAR reanalysis, Simmonds and Keay (2000) showed there to be a net creation of cyclones (i.e. cyclogenesis is greater than cyclolysis) north of 50°S and net destruction south of this. Most Southern Hemisphere cyclogenesis actually occurs at very high latitudes (~60°S) in the CPT but rates of cyclolysis there are even higher. Turner et al. (1998) found that about half the systems in the Antarctic Peninsula region formed within the CPT and half spiralled in from further north. Simmonds et al. (2003) also revealed the northern part of the Peninsula to be a region of high cyclogenesis. Some of these systems formed through lee cyclogenesis — a dynamical process associated with the passage of air over a barrier — to the east of the Antarctic Peninsula. Other important regions of cyclogenesis within the CPT are in the Indian Ocean sector, with a maximum at 65°S, 150°E (Hoskins and Hodges, 2005) at the edge of the sea ice. Cyclolysis is generally confined to the CPT, with maxima in the Indian Ocean and also the Bellingshausen Sea, where the steep, high Antarctic Peninsula often prevents weather systems passing further to the east: such areas are known as ‘cyclone graveyards’.

4.2.2.2 Blocking events

Normally, low pressure systems do not intrude into the high inland area. Sometimes, in winter, blocking events occur and depressions from lower latitudes are channelled south over the ice sheet (Enomoto et al., 1998; Hirasawa et al., 2000; Pook and Gibson, 1999; Schneider et al., 2004). During these blocking events, an abrupt increase of surface temperature up to 40ºC may occur within a few days, accompanied by a heavy snowfall, that significantly influences accumulation on the inland ice sheet. These events are not common, but may have a pronounced effect on the energy balance of inland areas and on the annual layer formation seen in ice cores.

4.2.3 Teleconnections

4.2.3.1 Atmospheric linkages

Section 4.2.1.3 described the teleconnections between the ENSO cycle of the tropical Pacific and the Antarctic. However, a problem is that while many of the El Niño and La Niña events give the atmospheric anomaly patterns described earlier, some of these events have resulted in very different conditions. For example, the 1982/83 El Niño event was one of the largest of the last century, but the region of positive MSLP/height anomaly was displaced towards the tip of South America so the Antarctic Peninsula had only average conditions rather than the low temperatures usually associated with El Niño events. In fact, the PSA is generally more variable than the Pacific North American Association, making it much more difficult to anticipate how the Antarctic atmosphere will respond as an El Niño event starts to become established.

In recent decades there has been a trend towards more frequent and more intense El Niño events. We could therefore expect MSLP values to have risen across the ABS and there to have been colder winter season temperatures across the Antarctic Peninsula and warmer conditions in the Ross Sea area. However, this has not happened, indicating that the winter warming on the western side of the Peninsula is not a direct result of changes in ENSO.

Bertler et al. (2004) noted a shift of the Amundsen Sea Low eastwards during some El Niño events and such a result would be consistent with the recent observed cooling in the Ross Sea area (Doran et al., 2002). However, this area has experienced jumps in the relationship between ENSO and West Antarctic precipitation (Cullather et al., 1996) indicating the variable nature of the teleconnections. In addition, the Antarctic Peninsula, far from cooling, has experienced the largest increase of temperature anywhere in the Southern Hemisphere (Turner et al., 2005a).

In summary, while the relatively short timeseries that we have of Antarctic meteorological observations and atmospheric analyses do suggest that tropical atmospheric and oceanic conditions affect the climate of the Antarctic and the Southern Ocean the connections do vary with time and are rather non-linear. Ice core proxies for El Niño are emerging to help fll this gap, notably the MSA proxy for the last 500 years of El Niño produced from a South Pole ice core (Meyerson et al., 2002). However, the teleconnections are not as robust as those in the Northern Hemisphere. In addition, many other factors in the Antarctic climate system, such as the variability in the ocean circulation, the development of the ozone hole and the large natural variability of the high latitude climate, all affect atmospheric conditions and can mask the tropical signals.

4.2.3.2 Oceanic Coupling

The atmospheric processes described above have strong impacts on the high latitude Southern Ocean, which can (via complex feedback mechanisms) produce changes to the large-scale coupled atmosphere/ocean/ice system. The atmospheric Rossby wave associated with ENSO (the PSA association) produces anomalies in SSTs across the Southern Ocean, via processes including changes to the surface heat budget associated with changes in clouds and radiation (Li, 2000). These changes are especially manifest in the South Pacific (Figure 4.4).

The SST anomalies so created lie largely within the domain of the ACC, and hence are subsequently advected eastward. A typical timescale for advection across the South Pacific and into the South Atlantic is 2 years. This eastward procession was previously associated with the concept of an Antarctic Circumpolar Wave (White and Peterson, 1996), whereby pairs of coupled anomalies in SST, sea ice concentration, winds etc propagate eastward around Antarctica. The potential ENSO trigger for such a wave was recognised early (e.g. Peterson and White, 1998), however it is now known that this phenomenon exists only during certain time periods, and is distorted or absent during others (Connolley, 2003).

Despite this, it is important to recognise that the SST anomalies that are advected around the Southern Ocean are subject to further air-sea interaction as they propagate, and will be magnified or diminished as a result. The southeast Pacific is one region very susceptible to ENSO forcing (see above), and Meredith et al. (2007) showed that the phasing of advection of SST anomalies across the South Pacific generally coincides with that of ENSO, such that positive reinforcement of the SST anomalies occurs here. This acts to sustain the anomalies as they propagate eastward. As ENSO-induced anomalies propagate eastward within the ACC, phased changes on comparable timescales occur further south within the subpolar gyres (e.g. Venegas and Drinkwater, 2001).

ENSO is not the only tropical/equatorial phenomenon with a teleconnection to high southern latitudes. The Madden-Julian Oscillation (MJO, Madden and Julian, 1994) is the dominant mode of intraseasonal variability in the tropical atmosphere, and is associated with large-scale convective anomalies that propagate slowly eastward from the Indian Ocean to the western Pacific with a period of approximately 30-70 days. Matthews and Meredith (2004) showed that during the southern winter the MJO has an atmospheric extratropical response that impacts on the surface westerly winds around the 60°S latitude band, which are the winds that drive the ACC. They were able to show that changes in the ACC were induced in response to tropical variability. The total timescale for MJO to influence ACC transport was of the order of 1-2 weeks.

In addition to teleconnections from lower latitudes influencing the Southern Ocean and Antarctica, it is now known that they can operate in the reverse direction also. Recent studies (e.g. Ivchenko et al., 2004; Blaker et al., 2006) have demonstrated that signals generated in regions such as the Weddell Sea by anomalies in the cover of sea ice or the upper-layers of the ocean can propagate through the Drake Passage to the western Pacific as fast ocean barotropic Rossby waves. The time scale for this propagation is just a few days, and subsequently the signal propagates as an oceanic Kelvin wave along the western boundary and the equator, reaching the equatorial western coast of South America after 2-3 months. This impact on the equatorial regions raises the prospect of a potential high-latitude influence on ENSO, and hence complex coupled ocean-atmosphere feedbacks between the equatorial Pacific and high latitude Southern Ocean. Ongoing research is investigating this possibility.

Studies with a coupled global climate model (Richardson et al., 2004) indicate a inter-hemispheric coupling on the time scale of 10 years. A freshwater anomaly generated in the Southern Ocean inhibits the ventilation of deep waters around Antarctica which causes the deep ocean to warm and the surface to cool. Cooling induces an increase of sea ice thickness and extent which causes cooling of the atmosphere. The cooling signal propagates in the Pacific to the Northern Hemisphere in less then a decade where it affects the North Atlantic Oscillation.

4.3 Temperature changes

4.3.1 Surface temperature

Surface temperature trends across the Antarctic can be determined using a number of different forms of data, including the in-situ observations, satellite infra-red imagery and ice core isotope measurements. In order to get a reasonable estimate of trends it is necessary to use all these data.

The in-situ observational record of Antarctic surface temperatures is rather sparse and sporadic before the IGY (see Appendix A in King and Turner, (1997)), although the Orcadas series from Laurie Island, South Orkney Islands began in 1903 and the Faraday Station/Argentine Islands record began in 1947. However, we are fortunate in having around 16 stations on the Antarctic continent or islands that have reported on a near-continuous basis since the IGY. In addition, a further six stations started reporting during the 1960s, so that we have around two dozen time series that allow the investigation of temperature trends. Unfortunately, the vast majority of the stations are in the Antarctic coastal region or on the islands of the Southern Ocean, with only Vostok and Amundsen-Scott Station being in the interior of the continent.

The in-situ record has been used by several workers to investigate temperature changes across the continent and Southern Ocean (Jacka and Budd, 1991; Jacka and Budd, 1998; Jones, 1995; Raper et al., 1984). Many of the records were scattered across a number of data centres and it was unclear as to the amount of quality control that had been carried out on the observations. SCAR therefore initiated the READER (Reference Antarctic Data for Environmental Research) project to bring as many of the observations together as possible, quality control the data and produce a new data base of monthly mean temperatures (Turner et al., 2004). The READER data base is available online at http://www.antarctica.ac.uk/met/READER/.

The READER data base has now been used in a number of studies concerned with the climate of the Antarctic, including that of Turner et al. (2005a), which considered changes since the start of the routine instrumental record. Here we will use the READER data base and the online meteorological data maintained by Dr. Gareth Marshall (http://www.antarctica.ac.uk/met/gjma/) to examine how Antarctic temperatures have changed over the period of the instrumental record.

Surface temperature trends from the station data since the early 1950s illustrate a strong dipole of change, with significant warming across the Antarctic Peninsula, but with little change across the rest of the continent (Figure 4.8a). The largest warming trends in the annual mean data are found on the western and northern parts of the Antarctic Peninsula. Here Faraday/Vernadsky Station has experienced the largest statistically significant (<5% level) trend of +0.53 ^{o} C/dec for the period 1951-2006. Rothera station, some 300 km to the south of Faraday, has experienced a larger annual warming trend, but the shortness of the record and the large inter-annual variability of the temperatures means that the trend is not statistically significant. Although the region of marked warming extends from the southern part of the western Antarctic Peninsula north to the South Shetland Islands, the rate of warming decreases away from Faraday/Vernadsky, with the long record from Orcadas on Laurie Island, South Orkney Islands only having experienced a warming of +0.20^{o}C/decade. This record covers a 100-year period rather than the 50 years for Faraday. For the period 1951-2000 the temperature trend was +0.13^{o}C/decade.

Determining temperature trends across the interior of the Antarctic is difficult as there are only two stations with long records. However, attempts have been made to extrapolate the station trends across the rest of the continent. Chapman and Walsh (2007) produced estimates of annual tends (Figure 4.8b) and found the greatest warming over the Antarctic Peninsula, but with a small warming (~0.1° C/dec) across West Antarctica and much of East Antarctica. However, they also found cooling in a swath from the South Pole to Halley Station.

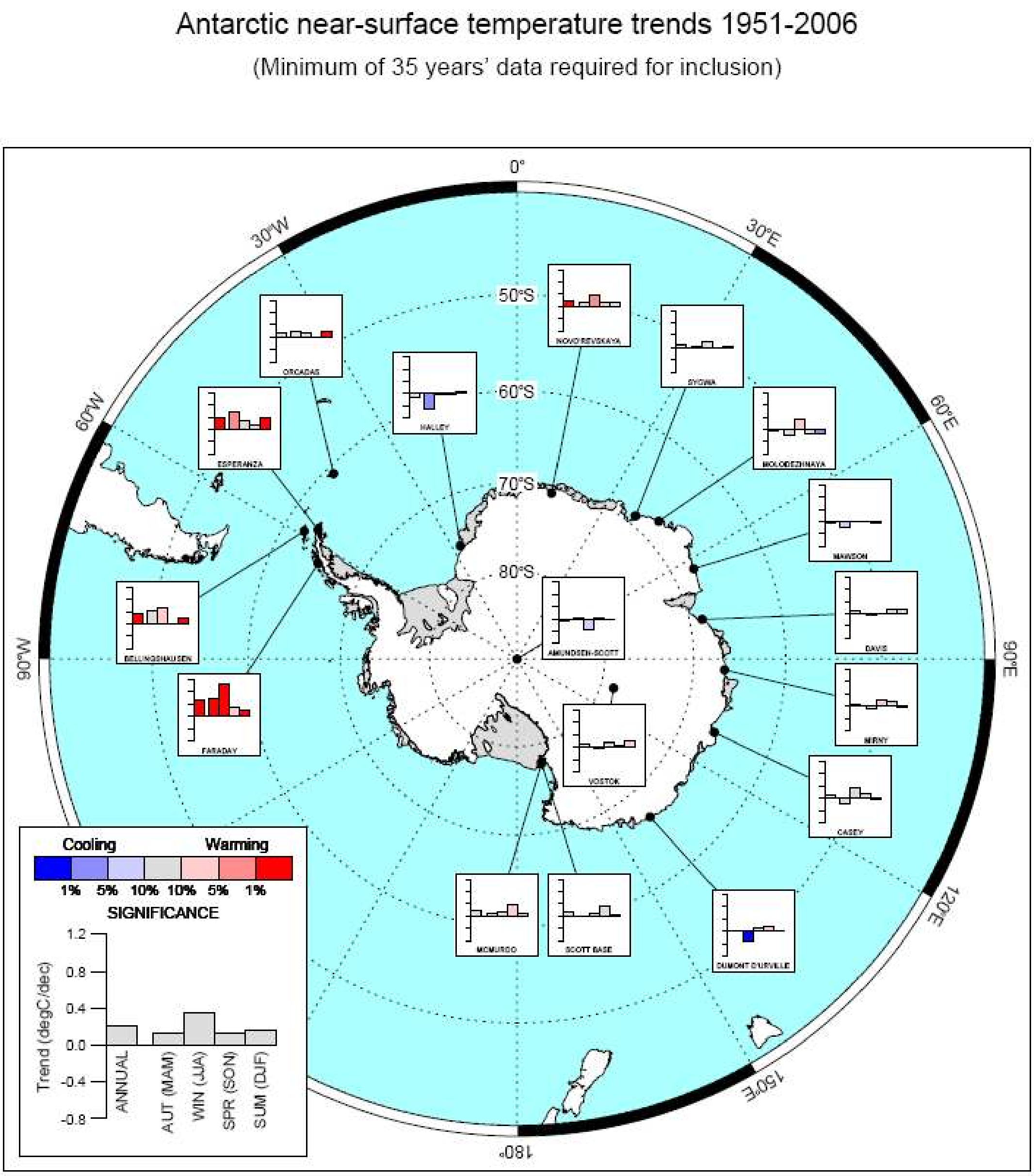
Steig et al. (2009) use statistical climate-field-reconstruction techniques to produce similar fields of trends for the seasons and the year as a whole. The annual trends (Figure 4.8c) show significant warming over most of West Antarctica with trends greater than 0.1° C/dec over the last 50 years. The trends are greatest during the winter and spring.

There has been a great deal of debate about the causes of the recent temperature changes across the continent. The summer warming on the eastern side of the Antarctic Peninsula has been shown to be a result of anthropogenic activity, and particularly the spring time loss of stratospheric ozone (Marshall et al., 2006). For the continent as a whole Gillett et al. (2009) carried out a formal attribution study to determine whether the observed changes were within the range of natural climate variability or whether they were a result of anthropogenic forcing. They found that recent changes were not consistent with internal climate variability or natural climate drivers alone, and were directly attributable to human influence.

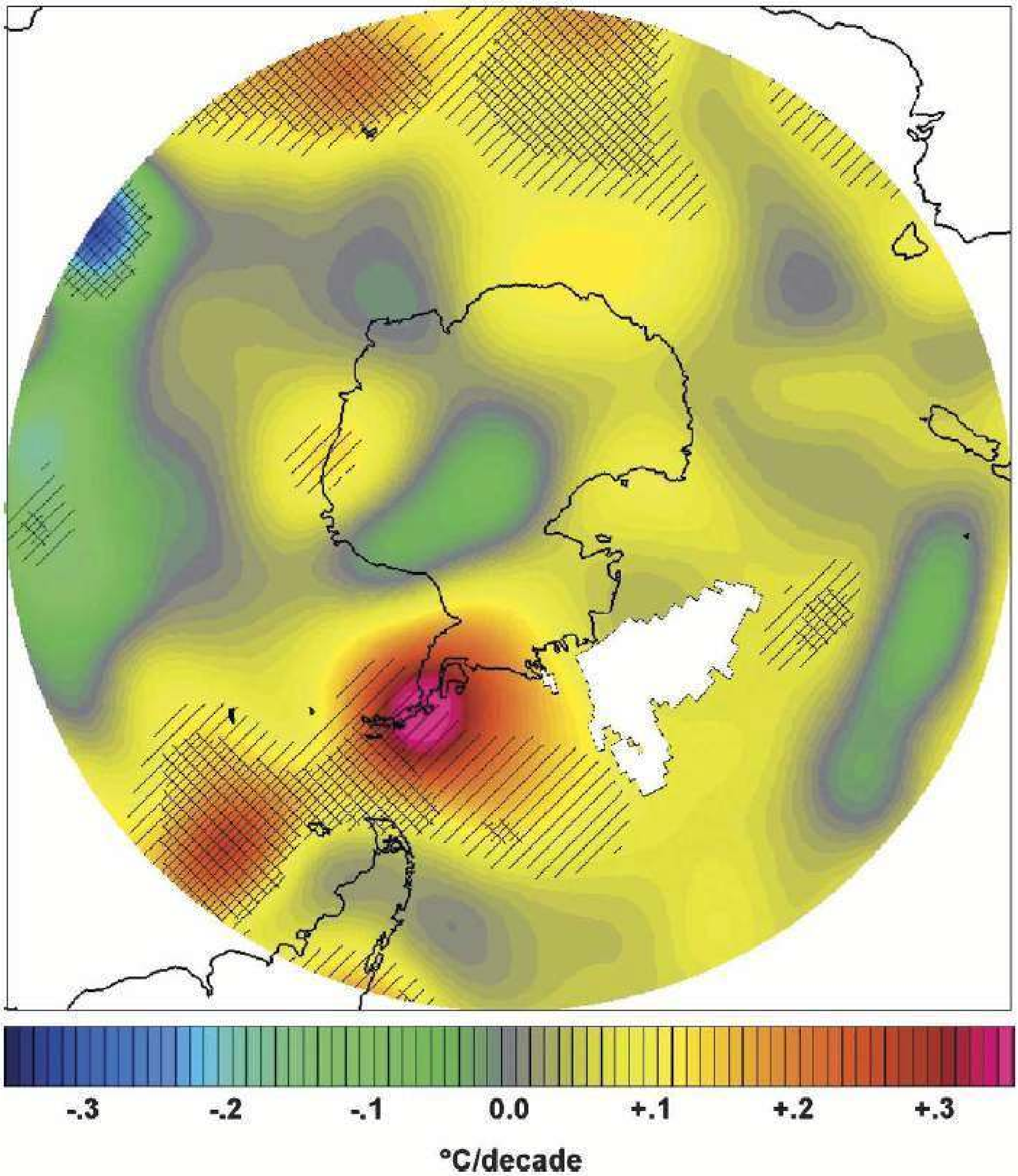
Prior to the establishment of the research stations in the middle of the Twentieth Century we are reliant on ice core data to investigate surface temperature changes. Many studies have used single and multiple cores to investigate changes at selected sites or to investigate regional change. However, ‘stacking’ multiple cores can provide insight into Antarctic-wide change. Schneider et al. (2006) stacked several isotope records from ice cores to obtain a continental pattern of temperature over the past 200 years. The ice core stack was found to be well correlated with annual mean temperature and the data suggested warming of 0.2º C since the late nineteenth century. The paper suggested that recent Antarctic cooling is superimposed on longer term warming, with the more recent cooling being attributed to the SAM strengthening.

There is also evidence of climatic changes over the Southern Ocean. In recent decades, instrumental data recorded at the South African Weather Service station on Marion Island (46º 32' S and 37º 30' E) shows that the local climate of this island has undergone significant changes since the 1960s, mostly in the austral summer. These include a decrease in rainfall, an increase in non-rainy days, changes in wind speed and direction, and an increase in maximum and minimum local air temperature and in nearshore SST. Research suggests that the changes are linked to the well-documented shift of the semiannual oscillation and SAM after about 1980 (Rouault et al., 2005).

(a)



(b)



(c)

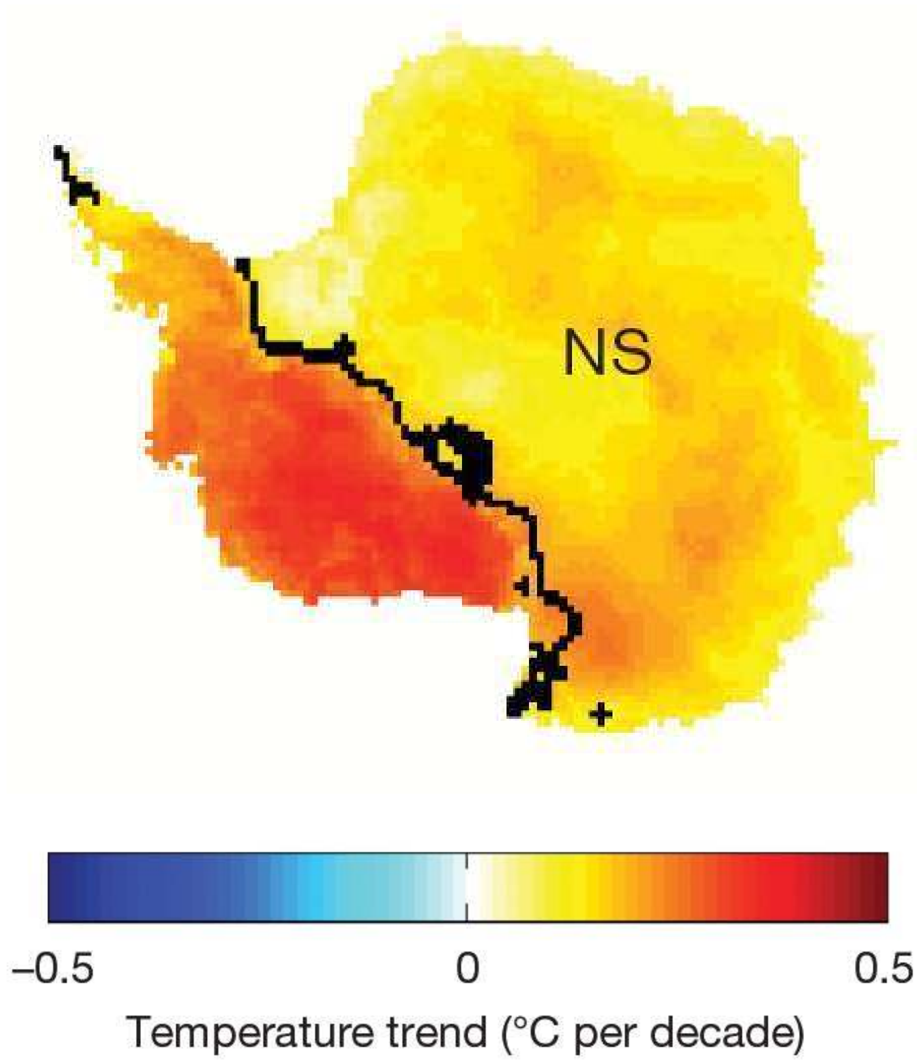


Figure 4.8. Estimates of Antarctic surface temperature trends. (a) Near-surface temperature trends for 1951-2006 based on station data. (b) Linear trends of annual mean surface air temperature (°C /dec) for the period 1958–2002. Greens and blues denote cooling; yellows and reds denote warming. Significant trends are indicated by hatching (95% = single hatching; 99% = crosshatching). From Chapman and Walsh (2007) (c) Winter season temperature trends reconstructed using infrared satellite data. NS indicates the trends are not significant in this area. From Steig et al. (2009).

Satellite-derived surface temperatures for the Antarctic have been used to investigate the extent of the region of extreme variability, since this was not possible with the sparse station data. King and Comiso (2003) found that the region in which satellite-derived surface temperatures correlated strongly with west Peninsula station temperatures was largely confined to the seas just west of the Peninsula. It was also found that the correlation of Peninsula surface temperatures with those over the rest of continental Antarctica was poor, confirming that the west Peninsula is in a different climate regime.

The warming on the western side of the Antarctic Peninsula has been largest during the winter season, with the winter temperatures at Faraday increasing by +1.03^{o}C/decade over 1950-2006. In this area there is a high correlation during the winter between the sea ice extent and the surface temperatures, suggesting more sea ice during the 1950s and 1960s and a progressive reduction since that time. King and Harangozo (1998) found a number of ship reports from the Bellingshausen Sea in the 1950s and 1960s when sea ice was well north of the locations found in the period of availability of satellite data, suggesting some periods of greater sea ice extent than found in recent decades. However, there is very limited sea ice extent data before the late 1970s, so we have largely circumstantial evidence of a mid-century sea ice maximum at this time. At the moment it is not known whether the warming on the western side of the Peninsula has occurred because of natural climate variability or as a result of anthropogenic factors.

Temperatures on the eastern side of the Peninsula have risen most during the summer and autumn months, with Esperanza having experienced a summer increase of +0.41°C/decade between 1946-2006. This temperature rise has been linked to a strengthening of the westerlies that has taken place as the SAM has shifted into its positive phase (Marshall et al., 2006). Stronger winds have resulted in more relatively warm, maritime air masses crossing the peninsula and reaching the low-lying ice shelves on the eastern side.

Around the rest of the Antarctic coastal region there have been few statistically significant changes in surface temperature over the instrumental period. The largest warming outside the Peninsula region is at Scott Base, where temperatures have risen at a rate of +0.29°C/decade, although this is not statistically significant. The high spatial variability of the changes is apparent from the data for Novolazarevskya and Syowa, which are 1,000 km apart. The former station has warmed at a rate of +0.25°C/decade between 1962–2000, which is significant at the 10% level, whereas the record from Syowa shows almost no change over this period.

One area of the Antarctic where marked cooling has been noted, at least over a relatively short time period, is the McMurdo Dry Valleys. Here automatic weather station (AWS) data for 1986-2000 shows that there has been a cooling of 0.7°C/decade, with the most pronounced cooling being in the summer (the December-February tend was 1.2°C/decade, statistically significant at the 2% level) and autumn (March-May trend of 2.0°C/decade, statistically significant at close to the 10% level). Winter (June-August) and spring (September-November) show small temperature *increases* of (0.6°C and 0.1°C/decade, which are not significant) (Doran et al., 2002). Bertler et al. (2004) suggest that this short-term cooling is associated with ENSO-driven changes in atmospheric circulation.

On the interior plateau, Amundsen-Scott Station at the South Pole has shown a small cooling in the annual mean temperature of -0.05° C/dec over 1958-2008, although this trend is not statistically significant. This small cooling is thought to be a result of fewer maritime air masses penetrating into the interior of the continent. The data show a cooling throughout the year, with the largest change being during the summer, however, only the annual change is statistically significant. The other plateau station, Vostok, has not experienced any statistically significant change in temperatures, either in the annual or seasonal data, since the station was established in 1958.

A recent analysis of the in-situ surface meteorological observations (Chapman and Walsh, 2007) gridded the available observations and analysed the trends. For the period 1958-2002 they found a modest warming over much of the 60°–90°S region, although the largest warming trends were over the Antarctic Peninsula. They also identified a zone of cooling stretching from Halley Station to the South Pole. They found overall warming in all seasons, with winter trends being the largest at +0.172°C/decade while summer warming rates were only +0.045°C/decade. For the 45 year period the temperature trend in the annual means was +0.082°C/decade. Interestingly the trends computed were very sensitive to start and end dates, with trends calculated using start dates prior to 1965 showing overall warming, while those using start dates from 1966 to 1982 show net cooling over the region. Because of the large interannual variability of temperatures over the continental Antarctic, most of the continental trends are not statistically significant significant through 2002.

The temperature records from the Antarctic stations suggest that the trends at many locations are dependent on the time period examined, with changes in the major modes of variability affecting the temperature data. Perhaps the largest change in climatic conditions across the high southern latitudes has been the shift in the SAM into its positive phase during austral summer and autumn (see Section 4.2.1.2). The SAM has changed because of the increase in greenhouse gases and the development of the Antarctic ozone hole, although the loss of stratospheric ozone has been shown to have had the greatest influence during Austral summer (Arblaster and Meehl, 2006). During austral autumn, the causality of the upward SAM trends is not well understood, as stratospheric ozone changes do not appear to play a major role (Fogt et al., In Press). As discussed at many points in this document, the changes in the SAM have influenced many aspects of the Antarctic environment over recent decades.

Thompson and Solomon (2002) considered the surface temperature trends over 1969-2000 and showed that the contribution of the SAM was a warming over the Antarctic Peninsula and a cooling along the coast of East Antarctica (Figure 4.9). They only considered the months of December to May, which was when the largest change in the SAM has taken place. They attributed the trends primarily to changes in the polar vortex as a result of the development of the Antarctic ozone hole. While the major loss of stratospheric ozone occurs in the spring, the greatest changes in the tropospheric circulation, such as the strengthening of the westerlies, has been in the summer and autumn. There is therefore a downward propagation of the vortex strengthening, with it starting in the spring in the stratosphere and moving down through the troposphere to the surface through the summer and autumn. As discussed earlier, the warming on the eastern side of the Antarctic Peninsula has been linked to the stronger westerlies associated with the changes in the SAM. However, the large winter-season warming on the western side of the peninsula appears to be largely independent of changes in the SAM.

It is very important to determine the surface temperature trends across the high Antarctic plateau, but as noted earlier, there are only two stations with long temperature records. Since the mid-1980s many AWSs have been deployed in the interior, filling important gaps in the observational network. These can provide valuable indications of temperature trends at remote locations, although few AWS systems have been maintained at the same locations since the 1980s and there can be gaps in the data when systems fail during the winter.

Another means of examining temperature trends is via the infra-red imagery from the polar orbiting satellites. Such imagery can only be used under cloud-free conditions, and provides data on the snow surface rather than at the standard meteorological level of 2 m above the surface, but with such high spatial coverage it provides a very valuable supplement to the in-situ observations. Comiso (2000) used the NOAA AVHRR imagery to investigate the trends in skin temperature across the Antarctic over the period 1979-1998. The satellite-derived temperatures were compared with the in-situ observations from 21 stations and found to be in good agreement with a correlation coefficient of 0.98. The trends showed a cooling across much of the high plateau of East Antarctica and across Marie Byrd Land (-0.1 to -0.2º C/yr), with the former being consistent with the trends derived by Thompson and Solomon (2002), although the Comiso trends are for annual data and the Thompson and Solomon study is concerned only with the summer and autumn.

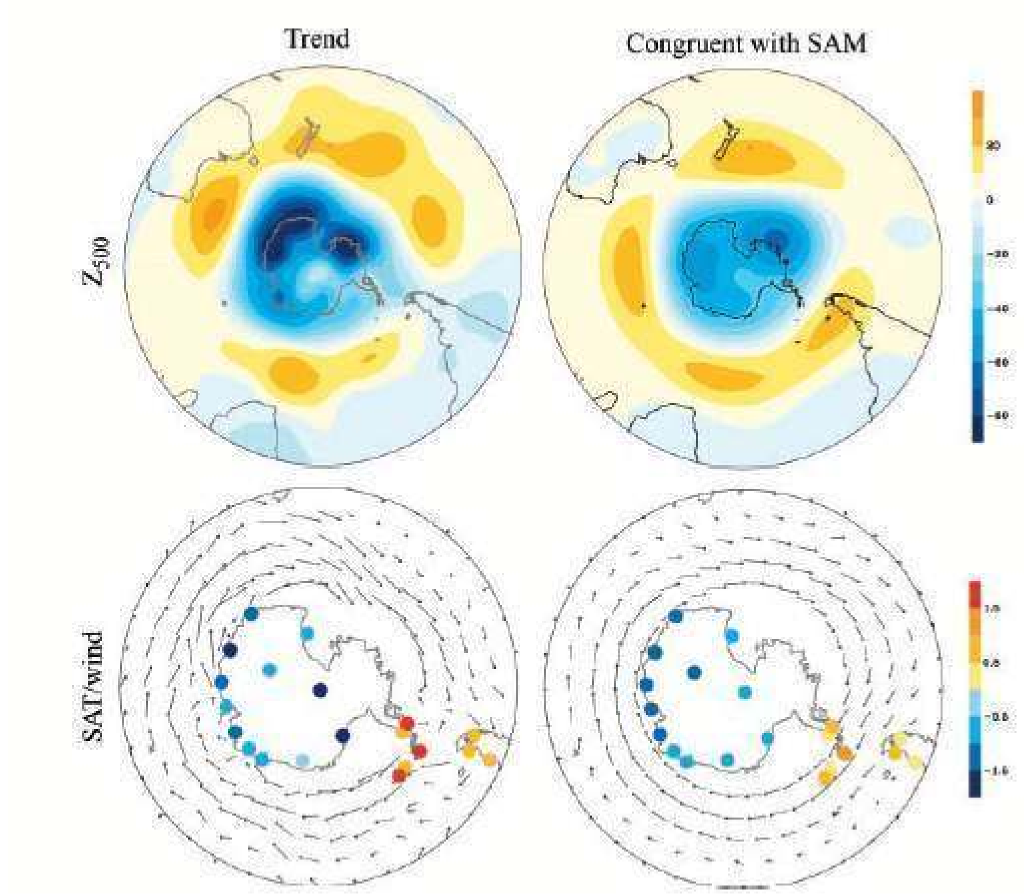


Figure 4.9. December-May trends (left) and the contribution of the SAM to the trends (right). Top, 22-year (1979-2000) linear trends in 500 hPa geopotential height. Bottom: 32-year (1969-2000) linear trends in surface temperature and 22-year (1979-2000) linear trends in 925 hPa winds. Shading is drawn at 10 m per 30 years for 500 hPa height and at increments of 0.5° K per 30 years for surface temperature. The longest vector corresponds to about 4 m/s. From Thompson and Solomon (2002).

In recent decades many relatively short ice cores have been drilled across Antarctica by initiatives such as the International Trans Antarctic Science Expedition (ITASE) (Mayewski et al, 2006). These provide data over roughly the last 200 years and therefore provide a good overlap with the instrumental data. Large-scale calibrations have been carried out between satellite-derived surface temperature and ITASE ice core proxies (Schneider et al., 2006). Their reconstruction of Antarctic mean surface temperatures over the past two centuries was based on water stable isotope records from high-resolution, precisely dated ice cores. The reconstructed temperatures indicated large interannual to decadal scale variability, with the dominant pattern being anti-phase anomalies between the main Antarctic continent and the Antarctic Peninsula region, which is the classic signature of the SAM. The reconstruction suggested that Antarctic temperatures had increased by about 0.2° C since the late nineteenth century. They found that the SAM was a major factor in modulating the variability and the long-term trends in the atmospheric circulation of the Antarctic.

4.3.2 Upper air temperature changes

Analysis of Antarctic radiosonde temperature profiles indicates that there has been a warming of the troposphere and cooling of the stratosphere over the last 30 years. This is the pattern of change that would be expected from increasing greenhouse gases, however, the mid-tropospheric warming in winter is the largest on Earth at this level. The data show that regional mid-tropospheric temperatures have increased most around the 500 hPa level with statistically significant changes of 0.5 – 0.7ºC/decade (Figure 4.10) (Turner et al., 2006). Figure 4.10 indicates warming at many of the radiosonde stations around the continent, but a clear pattern of winter warming is apparent around the coast of East Antarctica and at the pole.

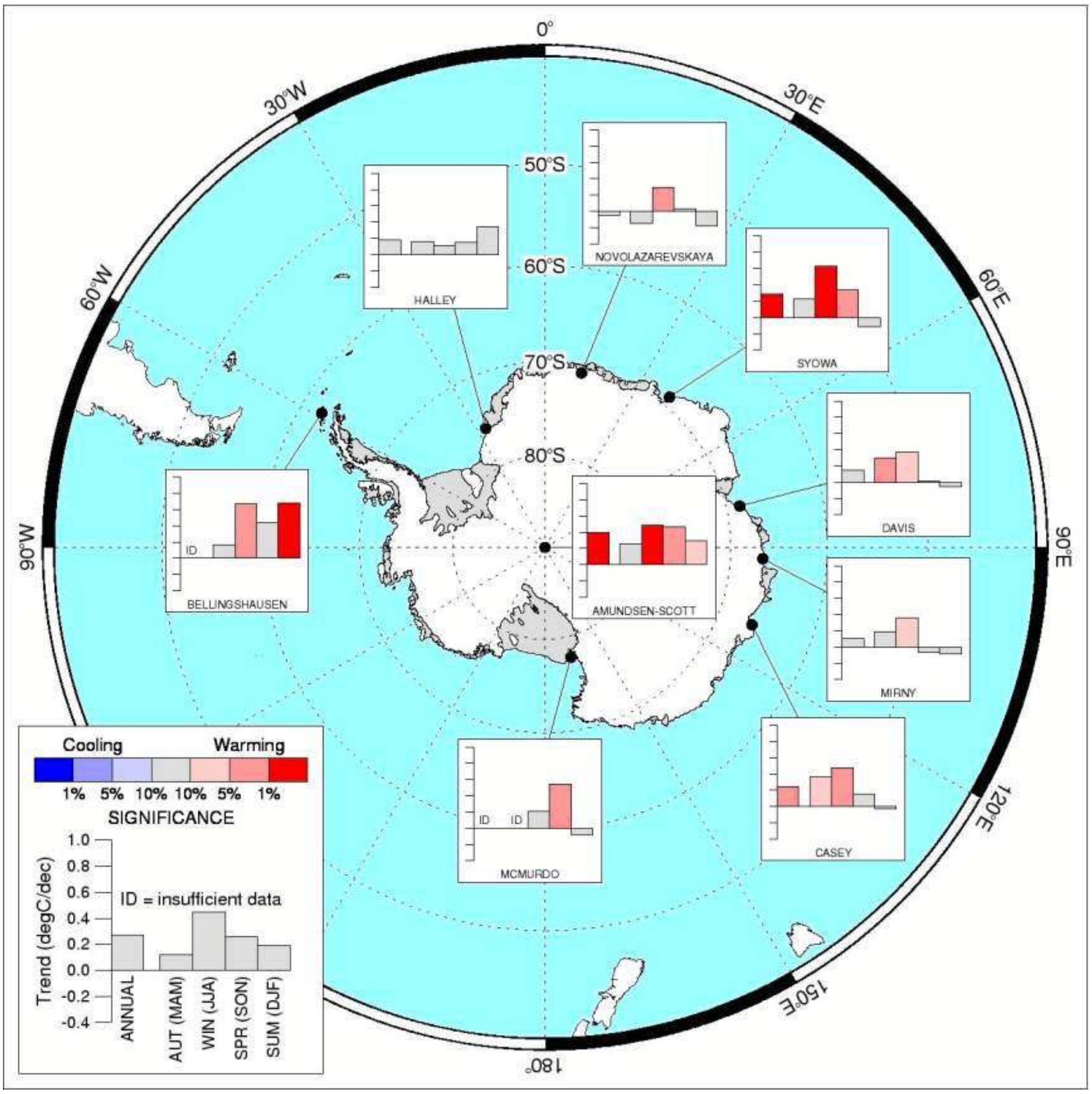


Figure 4.10. Annual and seasonal 500 hPa (approximately at 5 km above mean sea level) temperature trends for 1971-2003. From Turner et al. (2006).

The warming is represented in the ECMWF 40 year reanalysis, which is not surprising since the radiosonde ascents were assimilated into the system. In fact the warming trends are slightly larger than when computed from the radiosonde data, since there is a known slight cold bias in the early part of the reanalysis data set.

The exact reason for such a large mid-tropospheric warming is not known at present. However, it has recently been suggested that it may, at least in part, be a result of greater amounts of polar stratospheric cloud (PSC) during the winter (Lachlan-Cope et al., In press). PSCs are a feature of the cold Antarctic winter, forming at temperatures below about -78º C. However, the Antarctic stratosphere has cooled in recent decades because the greenhouse gas ozone is now missing from the lower stratosphere in spring, and the greenhouse gas carbon dioxide is concentrated in the troposphere and leads to further cooling of the stratosphere. Analysis of stratospheric temperatures in the reanalysis data sets suggest that over the last 30 years the area where PSCs might form in winter has increased in size, so promoting the formation of more PSCs. Once present, PSCs act like any other cloud, giving a warming below their level and cooling above. We have little data on the optical properties of PSCs, but modelling suggests that if the optical depth in the infrared is around 0.5 then a greater amount of PSCs could give a mid-tropospheric warming.

PSCs are not currently represented explicitly in climate models, but if further research shows that they are responsible for the large winter season mid-tropospheric warming they need to be represented more realistically in the models.

4.3.3 Attribution of change

Great advances have been made in our understanding of recent temperature changes across the Antarctic in the last few years. We now know that anthropogenic activity, and particularly the presence of the Antarctic ozone hole, has played a large part in the near-surface warming on the eastern side of the Antarctic Peninsula, and a formal attribution study (Gillett et al., 2009) found that that recent changes were not consistent with internal climate variability. However, we still do not know the reasons for the large winter season warming on the western side, although it is thought to be linked to a reduction in sea ice extent since the 1950s.

The recently discovered large mid-tropospheric warming above the continent in winter is not fully understood at present. If increasing amounts of PSCs are shown to be responsible this will be an interesting Antarctic amplification of the effect of greenhouse gas increases, along with being a side effect of the ozone hole. However, more research is needed to confirm this.

4.4 Changes in Antarctic Snowfall Over the Past 50 Years

4.4.1 General spatial and temporal characteristics of Antarctic snowfall

Snowfall accumulation, referred to as the surface mass balance (SMB), is the primary mass input to the Antarctic ice sheets, and is the net result of precipitation, sublimation/vapour deposition, drifting snow processes, and melt. Precipitation, which primarily occurs as snowfall, is dominant among these components (Bromwich 1988) and establishing its spatial and temporal variability is necessary to assess ice sheet surface mass balance. Comprehensive studies of snowfall characteristics over Antarctica are given by Bromwich (1988), Turner et al. (1999), Genthon and Krinner (2001), van Lipzig et al. (2002), Bromwich et al. (2004a), van de Berg et al. (2005), and Monaghan et al. (2006a). Snowfall is influenced to first order by the Antarctic topography, and ground-penetrating radar has shown that its spatial distribution is highly variable. Most of the snowfall occurs along the steep coastal margins (Figure 4.11) and is caused by orographic lifting of relatively warm, moist air associated with the many transient, synoptic-scale cyclones that encircle the continent (e.g. Bromwich et al. 1995; Genthon and Krinner, 1998). The synoptic activity decreases inward from the coast, and over the highest, coldest reaches of the continent the primary mode of snowfall is due to cooling of moist air just above the surface-based temperature inversion (Schwerdtfeger, 1970). This extremely cold air has little capacity to hold moisture, and thus the interior of the East Antarctic Ice Sheet is a polar desert, with a large area that receives less than 5 cm water equivalent of snowfall each year (e.g. Vaughan et al., 1999; Giovinetto and

Zwally, 2000). Large-scale atmospheric influences on Antarctic snowfall include the ENSO (Cullather et al., 1996) and the SAM (Genthon and Cosme, 2003; van den Broeke and van Lipzig; 2004). ENSO has an intermittent teleconnection with Antarctica (Genthon and Cosme, 2003) that especially impacts snowfall variability in West Antarctica (Cullather et al., 1996; Bromwich et al., 2000; 2004b; Guo et al., 2004). The response of Antarctic snowfall to SAM forcing is complex (Genthon et al., 2003), but may be linked to near-surface wind flow and temperature anomalies that are associated with the SAM (van den Broeke and van Lipzig, 2004).

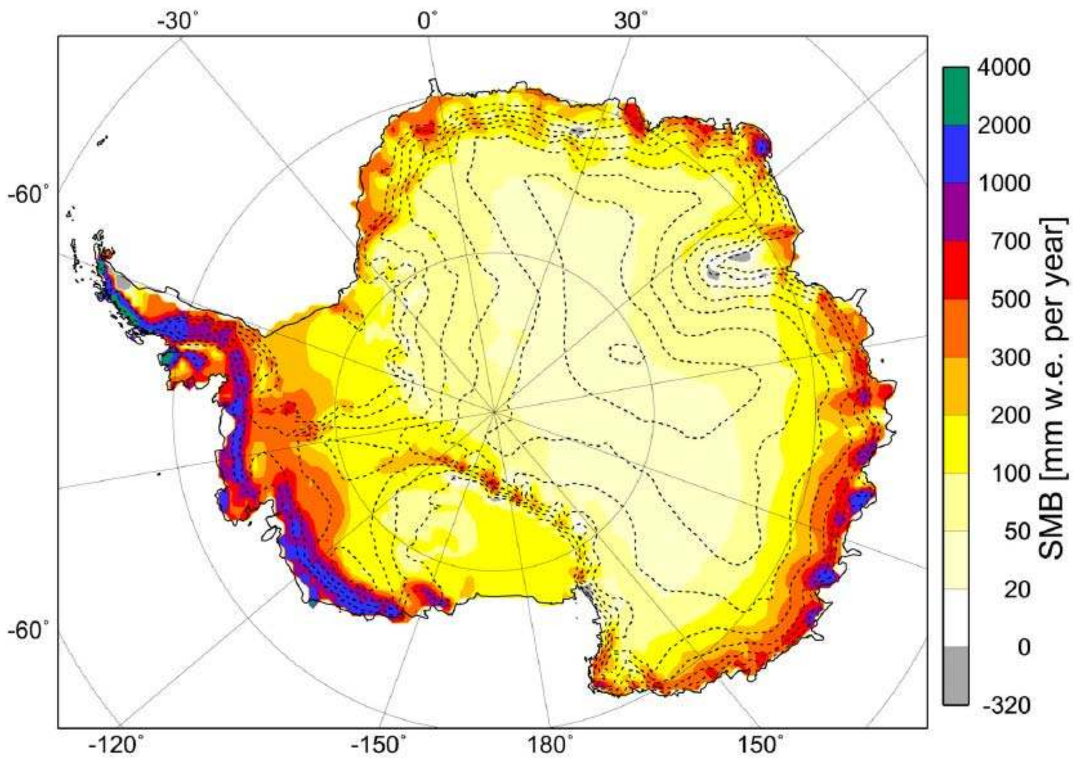


Figure 4.11. Annual Antarctic surface mass balance (mm/yr), from van de Berg et al. (2006).

4.4.2 Long-term Antarctic snowfall accumulation estimates

In recent decades, estimates of SMB over the Antarctic ice sheets have been made by three techniques: in-situ observations, remote sensing, and atmospheric modeling. Constructing a reliable data set of SMB over Antarctica for a long time period from these methods has been difficult for numerous reasons, including for example a sparse surface observational network (e.g. Giovinetto and Bentley, 1985); difficulties distinguishing between clouds and the Antarctic ice surface in satellite radiances (Xie and Arkin, 1998); and incomplete parameterizations of polar cloud microphysics and precipitation in atmospheric models (Guo et al., 2003). Considering the limitations of the techniques, it is not surprising that the long-term-averaged continent-wide maps of SMB over Antarctica yield a broad envelope of results. The long-term estimates of SMB from several studies range from +119 mm/yr (van de Berg et al., 2005) to +197 mm/yr (Ohmura et al., 1996) water equivalent (weq) for the grounded ice sheets (estimates for the conterminous ice sheets, which include the ice shelves, are generally ~10% higher). The large range of long-term SMB estimates has contributed to uncertainty in calculations of the total mass balance of the Antarctic ice sheets (e.g. van den Broeke et al., 2006), and thus an important future endeavour will be to narrow the gap between estimates of SMB. In general, the studies employing glaciological data are considered the most reliable; the study of Vaughan et al. (1999) approximates SMB as 149 mm/yr for the grounded ice sheets, although a recent study (van de Berg et al., 2006) shows evidence that the Vaughan et al. (1999) dataset may underestimate coastal accumulation, and gives an updated value of 171 mm/yr. Considering the large spread between estimates, it is not surprising that calculated temporal trends vary widely (Monaghan et al., 2006a).

4.4.3 Recent trends in Antarctic snowfall

On average, about 6 mm global sea level equivalent falls as snow on Antarctica each year (Budd and Simmonds, 1991). Thus, it is important to assess trends in Antarctic SMB, as even small changes can have considerable impacts on the global sea level budget. The latest studies employing global and regional atmospheric models to evaluate changes in Antarctic SMB show that no statistically significant increase has occurred since ~1980 over the entire grounded ice sheet, WAIS, or the East Antarctic Ice Sheet (EAIS) (Monaghan et al., 2006a; van de Berg et al., 2005; van den Broeke et al., 2006). A validation of the modeled-versus-observed changes (Monaghan et al., 2006a) suggests that the recent model records are more reliable than the earlier global model records that inferred an upward trend in Antarctic SMB since 1979 (Bromwich et al., 2004a). The new studies also clearly show that interannual SMB variability is considerable; yearly snowfall fluctuations of +/-20 mm/yr weq, i.e., +/-0.69 mm/yr GSL (global sea level) equivalent, are common (Monaghan et al., 2006a), and might easily mask underlying trends over the short record.

In contrast to modeling studies, satellite altimetry measurements by Davis et al. (2005) suggest that increased snowfall has recently caused the EAIS to thicken, mitigating sea level rise by about 0.12 mm/yr between 1992-2003. Zwally et al. (2005) also found a thickening over EAIS from satellite altimetry for a similar period, but it was a factor of three smaller than the Davis study. Zwally et al. (2005) argued that their method more accurately accounts for firn compaction and the interannual variability of surface height fluctuations. The difference between the positive trends from the satellite altimetry studies and the zero trends in the modeling studies may be in part due to different temporal and spatial coverage (satellite altimetry does not extend past 81.6°S and has limitations along the steep coastal margins).

To extend the length of the Antarctic SMB record, Monaghan et al. (2006b) used the spatial information provided by atmospheric model precipitation fields from ERA-40 to extrapolate a suite of ice core SMB records in space and time. The resulting spatially resolved SMB dataset spans 1955-2004, approximately doubling the length of the existing model-based records. An updated version of the dataset (Monaghan and Bromwich, 2008), now adjusted to reflect the ERA-40 snowfall variance at interannual timescales, indicates that the 1955-2004 continent-averaged trend is positive and statistically insignificant (0.19 ± 32 mm/yr), and is characterized by upward trends through the mid-1990s and downward trends thereafter (Figure 4.12). The shape of the time series in Figure 4.12 suggests that a cyclic signal with a period of about 50 years may be impacting Antarctic snowfall, but is inconclusive without a longer time series. The continent-averaged trend is the net result of both positive and negative regional trends, which in some drainage basins are weakly ($p<0.10$) statistically significant (Figure 4.13). The positive SMB trends on the western side of the Antarctic Peninsula have been attributed to a deepening of the circumpolar pressure trough, which has enhanced ascent in the region (Turner et al., 2005b).

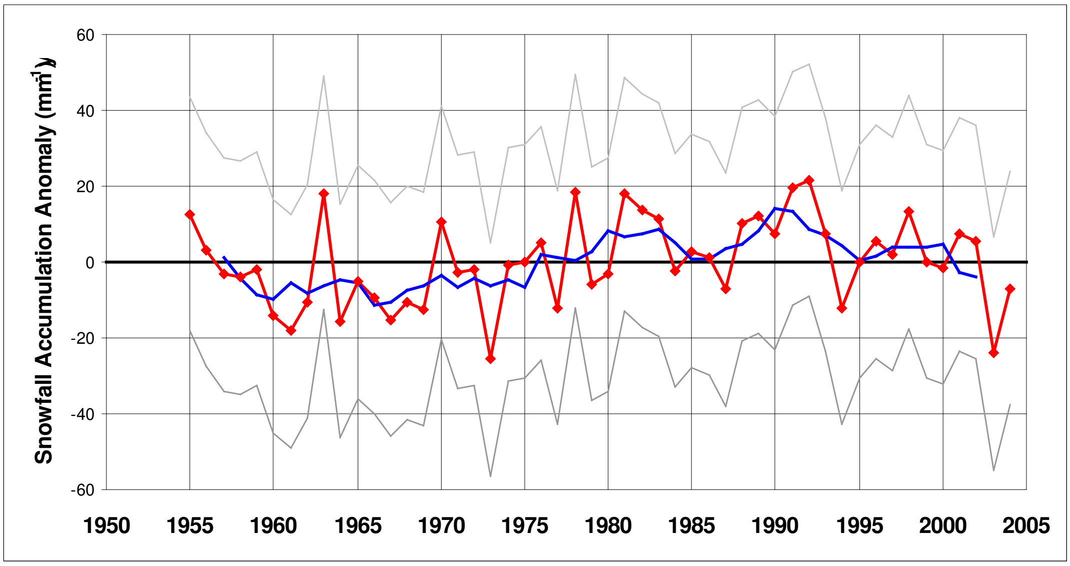


Figure 4.12 Annual Antarctic snowfall accumulation anomalies (mm/yr), in red) during 1955-2004, adapted from Monaghan et al. (2006b) and Monaghan and Bromwich (2008). Anomalies are with respect to the 1955-2004 mean. The five-year running mean is shown in blue. The ±95% confidence intervals for the annual anomalies are shown in grey. The statistical uncertainty accounts for the variance, as well as that due to the methodology and measurement error.

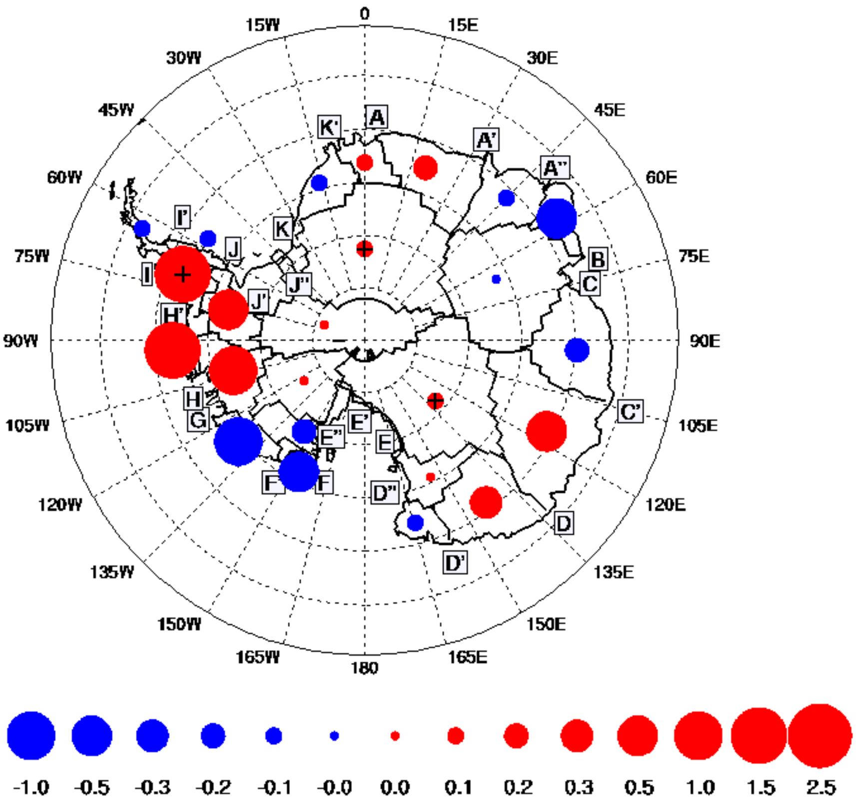


Figure 4.13 Linear trends of annual Antarctic snowfall accumulation (mm/year) for 1955-2004 in each of the Antarctic glacial drainage basins, adapted from Monaghan and Bromwich (2008). Statistical significance is represented by symbols: "+" is p<0.10; "*" is p<0.05; and "Δ" is p<0.01. The statistical uncertainty accounts for the variance, as well as that due to the methodology and measurement error.

4.5 Atmospheric Chemistry

4.5.1 Antarctic stratospheric ozone in the instrumental period

Historically ozone values were around 300 Dobson Units (DU) at the beginning of the winter (March), and similar at the end (August). The pattern began to change in the 1970s, following widespread releases of CFCs and Halons in the atmosphere (see below). Now, at the end of August values are about 10% less than they were in the 1970s, and decrease at about 1% per day to reach about 100 DU in October. Most of this loss occurs between 14 and 22 km altitude within the polar vortex, where virtually all ozone is now destroyed (Figure 4.14). Ozone values substantially recover with the warming in late spring, when the vortex dissipates and air from outside is mixed (Figure 4.15).

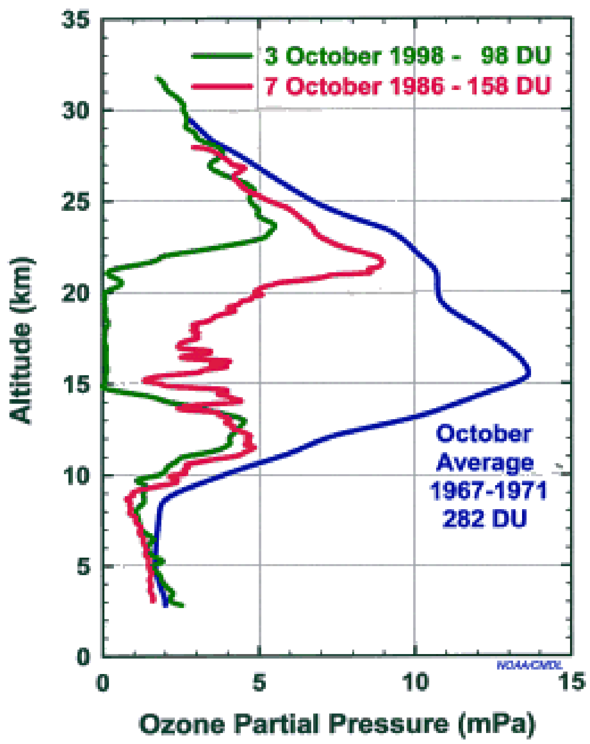


Figure 4.14 South pole ozone profiles, showing the progressive thinning of the ozone layer in late spring as the ozone hole developed during the 1980s and 1990s (courtesy NOAA/CMDL).

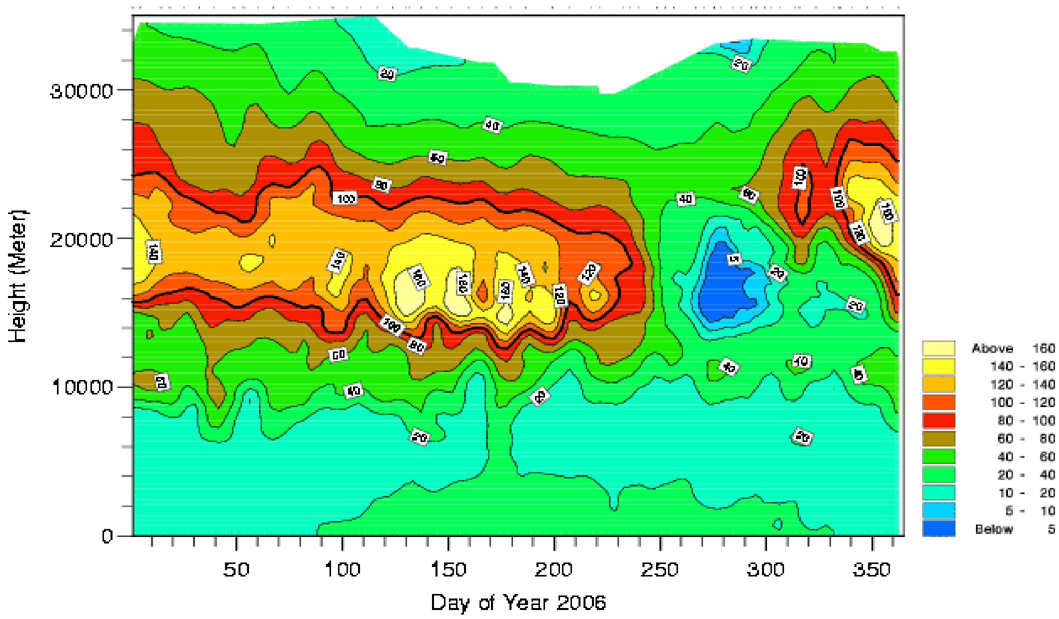


Figure 4.15 The annual cycle of ozone (nbar) in 2006 at Neumayer, 71°S (courtesy Alfred Wegener Institute).

The ozone hole is caused by reactive chlorine and bromine gases, formed from the breakdown products of CFCs and Halons, which were liberated in the troposphere from spray-cans, refrigerators and fire extinguishers. They have a typical stratospheric lifetime of 50 to 100 years. But the development of the ozone hole is also strongly linked to the dynamics of the polar vortex because it acts as a barrier (Figure 4.16a). During winter, lower stratospheric temperatures drop below –80°C, and at these temperatures clouds form despite the dryness of the stratosphere, initially composed of nitric acid trihydrate, but of ice if 5 to 10°C colder. On the cloud surfaces, the degradation products of the CFCs react to form chlorine gas:

$$HCl + ClNO_3 \text{ -> } HNO_3 + Cl_2$$

followed by photo-dissociation to chlorine atoms when sunlit, then reaction with ozone to form highly reactive ClO. Similar reactions take place involving the bromine compounds that result from degradation of halons. The highly reactive chlorine and bromine compounds then take part in a series of photochemical reactions such as:

$$Cl + O_3 \rightarrow ClO + O_2$$
$$ClO + O_3 \rightarrow Cl + 2O_2$$

in which in effect the Cl acts as a catalyst and gets recycled time and again. The net result of the catalysis is that:

$$2O_3 \rightarrow 3O_2$$

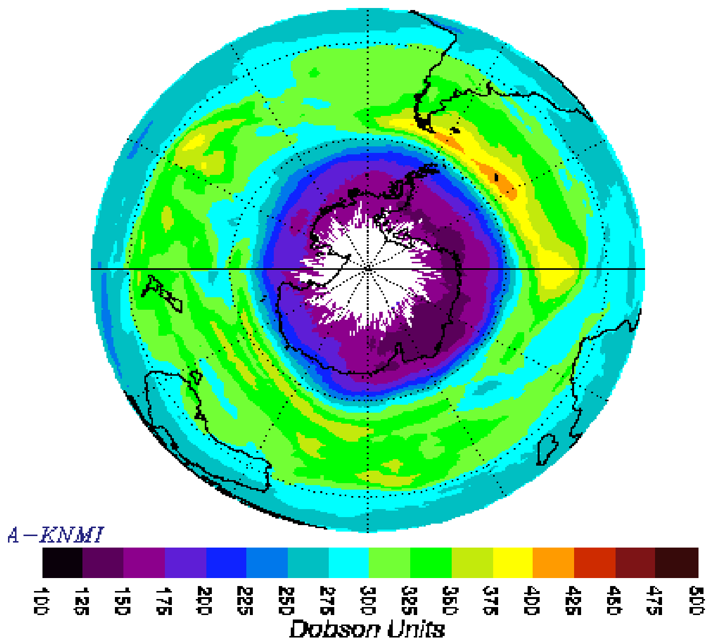
The process is helped by the absence of NO_2 (converted to HNO_3 and absorbed into the clouds), which would otherwise react with the ClO to recreate $ClNO_3$ and so remove reactive gases from the catalytic cycle.

As the vortex warms the clouds disappear, but the reactive chlorine and bromine compounds continue the ozone depletion for some weeks, until converted back to HCl and HBr. With further warming the vortex begins to break down and the sub-polar ozone-rich air sweeps across the continent.

The ozone hole is often offset from the pole towards the Atlantic, reaching as far north as 50°S. Ozone provides a screen against ultraviolet light of wavelength shorter than about 315 nm (UV-B), which can cause sunburn, cataracts and skin cancer in humans. Hence such an offset poses a serious health threat to the inhabitants of southern South America. It also poses a risk for flora and fauna, as UV-B can damage DNA, and can bleach chlorophyll that then becomes non-functional (see Section 4.12).

Another effect of the ozone hole is on the temperatures within the vortex, because ozone is a greenhouse gas that absorbs solar radiation. The absence of ozone has therefore resulted in significant reductions in temperature in spring (Figure 4.17), in November reaching a difference of up to 15°C in comparison with pre-ozone hole years.

The Montreal Protocol is an international agreement that has phased out production of CFCs, Halons, and some other organic chlorides and bromides, collectively referred to as Ozone Depleting Substances (ODSs). Because of its success, the amounts of ODSs in the stratosphere are now starting to decrease. However, there is as yet no convincing sign of any reduction in the size or depth of the ozone hole, although the sustained increases up the 1990s have not continued. Recent changes in measures of Antarctic ozone depletion have ranged from little change over the past 10 years (ozone hole area), to some signs of ozone increase (Bodeker et al., 2005). The halt in rapid ozone hole growth can be ascribed to the fact that almost all of the ozone between 12 and 24 km in the core of the vortex is now being destroyed (WMO, 2002), and is therefore comparatively insensitive to small changes in ODS amount.



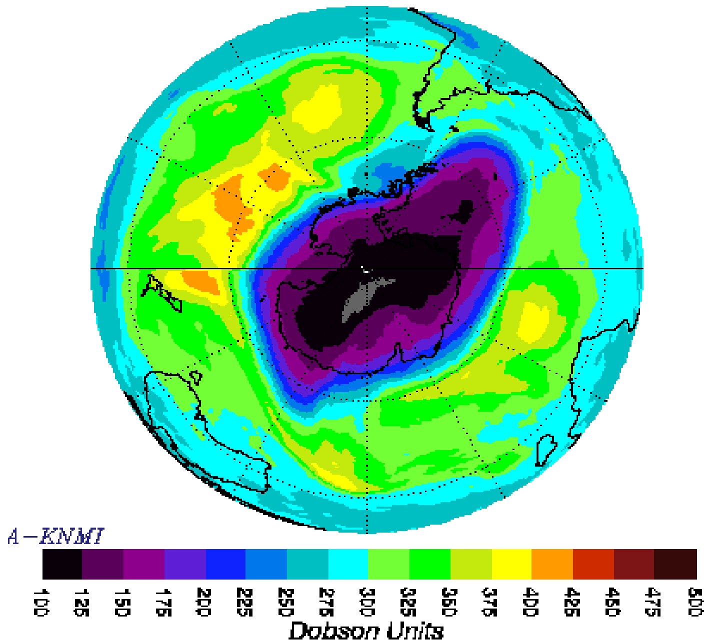


Figure 4.16 Measurements by the Ozone Monitoring Instrument on the Aura satellite, with a scale in DU. Top – on 14 September 2006, showing an almost symmetric ozone hole covering all of Antarctica. Bottom – on 10 October 2006, showing the ozone hole extending towards South America. (courtesy NASA/GSFC).

4.5.2 Antarctic Tropospheric Chemistry

Although often thought of as a single unit, the atmosphere is divided up into a number of regions. These are determined by the temperature gradient with height. The lowest region is referred to as the troposphere. In the troposphere, temperature generally decreases with height until a point is reached where this trend reverses. This upper limit is referred to as the tropopause. The height of the tropopause varies with latitude and is roughly at 8 km above hand or sea in the polar regions. The troposphere itself is nominally subdivided into layers; the lowest is the "boundary layer", a part of the troposphere that is directly influenced by the surface of the Earth in the exchange of heat, momentum and moisture. The height of the boundary layer is determined by physical constraints such as temperature and wind speed, and over Antarctica can vary considerably from tens to hundreds of metres. Above the boundary layer is the free troposphere, a region remote from the direct influence of the Earth's surface.

Over many regions of the world, the chemistry of the troposphere is studied in order to understand the effect of emissions from human activities. These might be direct emissions from industrial processes, or emissions associated with, for example, agriculture. Such activities release relatively reactive and short-lived trace gases into the atmosphere, and change it considerably from its natural state. Antarctica supports no major population centres and lies at a considerable distance from anthropogenic emission sources, so although some longer-lived pollutants do reach Antarctica, the Antarctic troposphere is a relatively unperturbed natural background atmosphere.

Compared with many other aspects of Antarctic science, the chemistry of the Antarctic troposphere has received relatively little attention. A primary reason for this was the perception that the chemical composition would be relatively uninteresting, with low concentrations of reactive trace gases like the hydroxyl (OH) or hydroperoxy (HO_2) radicals or the nitrogen oxides (NO and NO_2), and merely a sluggish chemistry dominated by unreactive reservoir gases that had been transported from distant source regions. Atmospheric chemists interested in studying a clean background atmosphere would naturally choose to work in a location that was more easily accessible and with more benign ambient conditions.

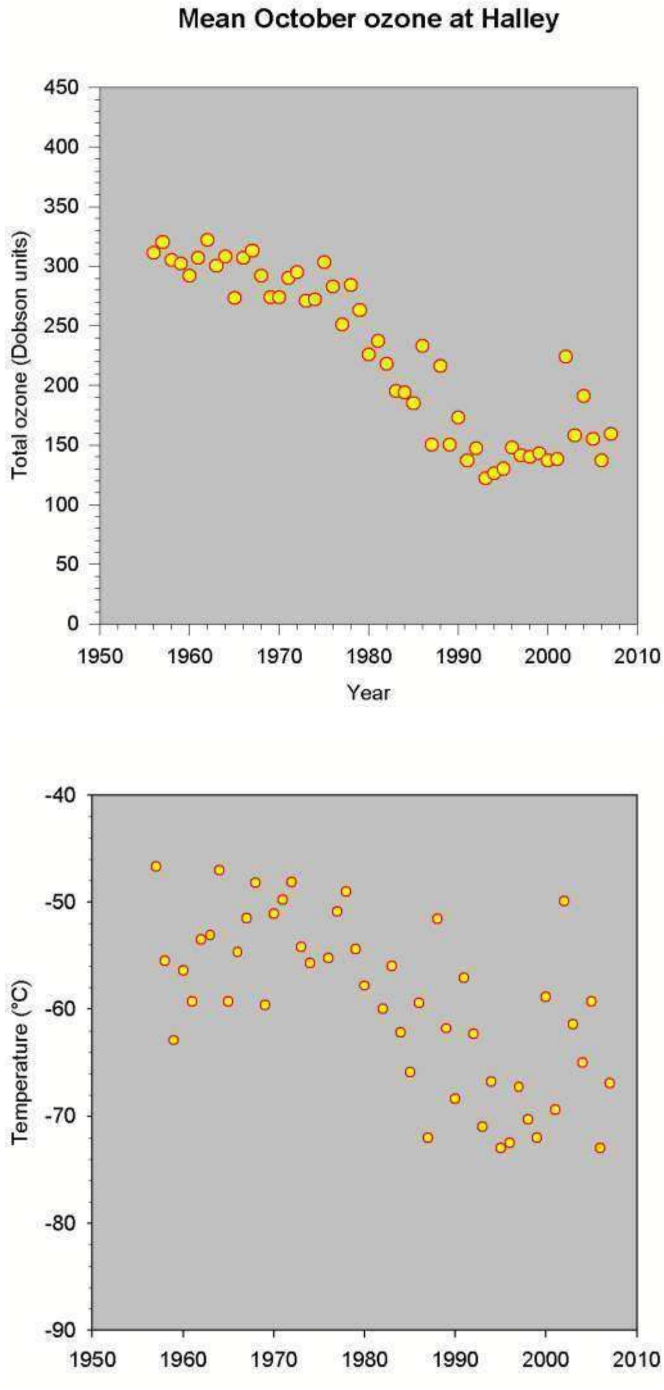


Figure 4.17 Time series of measurements at Halley (76°S) of (top) total ozone averaged over October of each year, and (bottom) temperature at 100 hPa averaged over November of each year (courtesy British Antarctic Survey). Although there is a lot of variability in the temperatures, they are now about 10°C colder than in the 1960s and 1970s, with the exception of 2002. The change in temperature is a maximum in November, later than the

maximum change in ozone, because there is more sunlight later in the year, and because the thermal time constant at 100 hPa exceeds a month. The anomalous results in 2002 were the result of an anomalous early breakdown of the vortex, they are not indicators of any large reduction in the chlorine and bromine gases that cause ozone loss.

Nevertheless, Antarctica is a significant part of the Earth system, and studies of Antarctic tropospheric chemistry have gradually become a recognised part of the work of national operators. A major driver has been the fact that deep ice cores are drilled from Antarctic ice sheets from which paleo-scientists strive to reconstruct changes in the Earth's atmospheric composition and climate through time. This work relies on analysing and interpreting changes in impurities held within the ice cores. A correct interpretation relies on knowing how the impurity entered the ice and any associated depositional or post-depositional effects. It would be cavalier to believe we could correctly reconstruct a past atmosphere from these chemical tracers without properly understanding the tropospheric chemistry of the present day.

The early studies of Antarctic tropospheric chemistry focused mainly on aerosols and long-lived radiatively and stratospherically important gases. Aerosols are important components of ice core impurities and can act as valuable proxies for environmental changes through time. For example, sea salt is a prime component of aerosol in coastal Antarctica, and sodium and chloride are both easily measured in ice cores. Studies of sea salt aerosol have been necessary to determine dominant sources and as a fingerprint for the behaviour of marine air masses. They have shown that, whereas for most of the globe the open ocean is the source of sea salt, in the polar regions most sea salt may be generated within and adjacent to the zone of newly-forming sea ice. This suggests that sea salt measured in ice cores might provide a proxy for assessing the extent of sea ice and how this varied under different climatic conditions. The records of long-lived gases have provided invaluable evidence of how the global atmosphere has recently changed. For example, the record of boundary layer carbon dioxide (CO_2), which has been measured at South Pole since 1957, has shown the massive rise in this potent greenhouse gas, and importantly, has bridged the gap between ice core records of CO_2 and present day ambient measurements. Also, systematic continuous measurements of the atmospheric CO_2 concentration at Syowa Station since 1984 revealed clear evidence for a seasonal cycle, a secular trend and interannual variations (Morimoto et al., 2003). The seasonal cycle varied from year to year, with especially large amplitudes in 1992 and 1998 and a large phase delay in 1993. A rapid increase in the CO_2 concentration was observed in 1987, 1994 and 1998 in association with ENSO events, and very low increase rate in 1991 to 1993, related to the Pinatubo eruption. From measurements of the stable carbon isotope ratio ($\delta^{13}C$) of atmospheric CO_2, it was found that the rapid increase of the CO_2 concentration was accompanied by a rapid decrease of $\delta^{13}C$. Considering the fact that the $\delta^{13}C$ values of terrestrial biospheric CO_2 are lower than those of atmospheric CO_2, the interannual variations of the CO_2 increase are ascribed primarily to changes of the CO_2 exchange between the atmospheric and terrestrial biosphere due to climate change in association with an ENSO event. It has been confirmed that long term continuous observations of greenhouse gases are essential in the Antarctic to monitor climate variations.

To clarify variations at the surface and in the transport of greenhouse gases, it was indispensable to know the vertical distributions of concentrations. Balloon-borne campaigns using a cryogenic sampler with a large balloon were carried out at Syowa Station in 1998 and 2003/04 to examine the vertical distribution of greenhouse gas concentrations up to 30 km in the stratosphere (Aoki et al., 2003). Together with bi-polar balloon-borne observations in the Arctic in 1997 and similar observations over Japan since 1985, stratospheric CO_2 above 20 – 25 km showed a secular increase with an average rate of 1.5 ppmv/yr, slightly less than the rate at the surface, and some increase of CO_2 age in the stratosphere. The O_2/N_2 ratio from these stratospheric air samples was analyzed to better understand the global carbon cycle

(Ishidoya et al., 2006). The vertical profile of O_2/N_2 showed a gradual decrease with height in the stratosphere, indicating the gravitational separation of molecules.

Beyond its role as an archive of global change, studies of the Antarctic troposphere have revealed a highly individual and active chemical system that is likely itself in the future to be an active player within a changing climate system. The rest of this section details this chemistry.

Of the more reactive trace gases, only surface ozone has historically been measured with any vigour. Year-round measurements were made at Halley station as early as 1958, but continuous records began considerably later, in 1975 at South Pole and in the 1980s at McMurdo/Arrival Heights and at Neumayer. Today, surface ozone is measured routinely at four coastal sites (those mentioned above plus Syowa) as well as at Sanae, some 170 km inland, and at South Pole on the Antarctic plateau (Helmig et al., 2007). The records show both interesting similarities and differences (see Figure 4.18). At nearly all stations, surface ozone reaches its maximum concentration during the winter months and is at its minimum during the summer. This is the classic seasonal cycle for a trace gas whose concentration is balanced by increases arising from air mass transport and destruction by the direct action of the Sun or by sunlight-initiated chemistry.

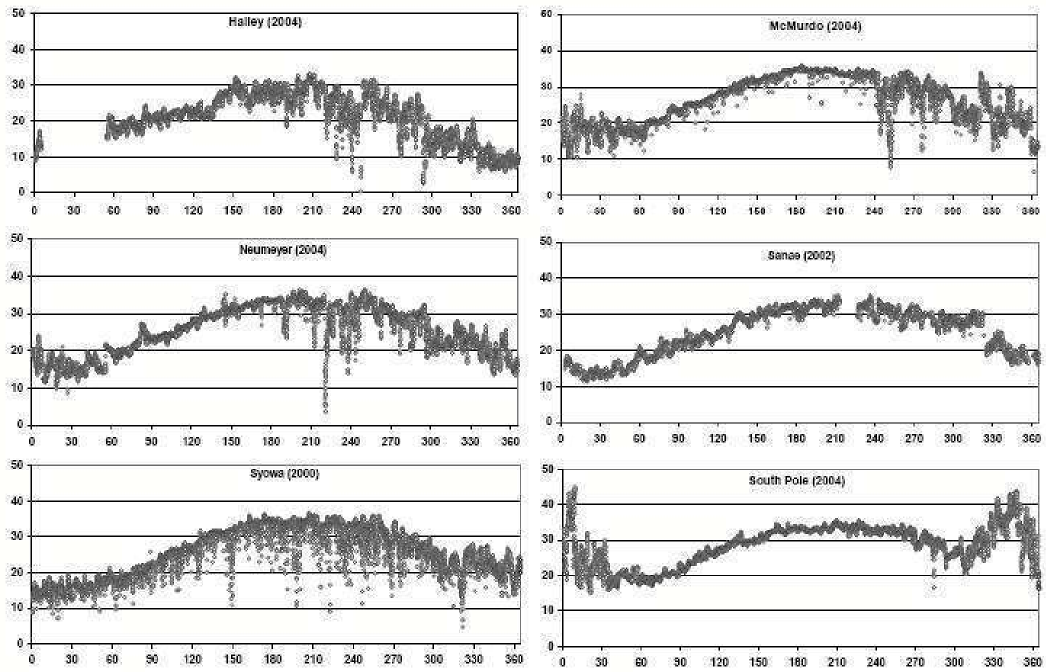


Figure 4.18 Annual records (against year calendar day) of surface ozone (in parts per billion by volume (ppbv)) for the Southern Hemisphere stations Halley, MacMurdo, Neumayer, Sanae, Syowa and South Pole, reproduced from Helmig et al. (2007).

During the Antarctic spring, however, significant differences are evident between the coastal sites and those lying inland. While at South Pole and Sanae, the decline from the winter maximum towards summertime values is essentially smooth, surface ozone at coastal sites exhibits extremely rapid and large episodic losses during the spring months (Wessel et al., 1998; Jones et al., 2006). These ozone depletion events (ODEs) can last for several days and ozone concentrations can drop as low as instrumental detection limits.

This behaviour is natural and occurs at coastal sites in both polar regions. The ozone loss is driven by reactions with halogen atoms, primarily bromine, in chemical cycles analogous to stratospheric ozone depletion. The following reactions were proposed to explain ODEs observed in the Arctic (Barrie et al., 1988):

$$2 \text{ x } (O_3 + Br \rightarrow BrO + O_2)$$
$$BrO + BrO \rightarrow 2Br + O_2$$

$$\text{net:} \quad 2\ O_3 \rightarrow 3\ O_2$$

Key to this process is the fact that bromine is recycled from bromine monoxide (BrO) to bromine atoms (Br) without the production of ozone. Ozone is therefore destroyed in a catalytic cycle whereby the bromine atoms responsible are regenerated and ready to react again with other ozone molecules. Other radicals, such as ClO, IO or HO_2 can also be involved in BrO recycling. For a full discussion see the review by Simpson et al. (2007).

Such recycling of course does not generate "new" halogens, so the important question is – what is the original source of the bromine atoms? Theoretical and laboratory studies have demonstrated that a series of reactions, widely referred to as the "Bromine Explosion" (shown schematically in Figure 4.19), are the source.

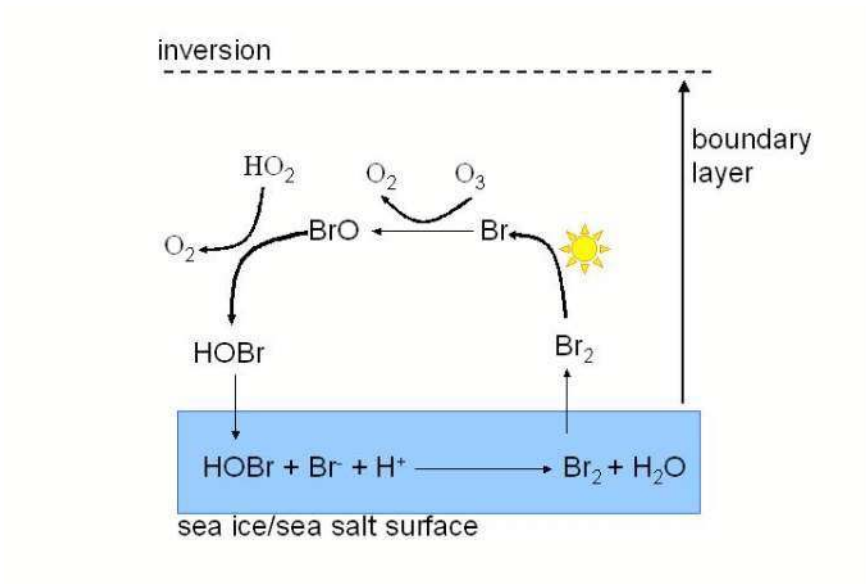


Figure 4.19 A schematic representation of the 'Bromine Explosion'.

Bromide (Br^-) is a ubiquitous ion found in sea water, albeit at concentrations ~280 times lower than chloride (Cl^-). Bromide derived from sea water reacts with HOBr, a molecule with a gas-phase source, and produces bromine molecules that are then released back into the boundary layer. The action of sunlight splits the bromine molecule into two bromine atoms, and ozone destruction can commence. The process is contained within the boundary layer. This reaction process requires a liquid (or "quasi-liquid") phase with concentrated sea salt brine, and the exact nature of this is still under debate. There is some evidence that this surface is associated with newly-forming sea ice (Rankin et al., 2002; Jones et al., 2006), and other evidence suggesting that sea salt-laden snow plays a role (McConnell et al., 1992; Simpson et al., 2007). Certainly, sea salt (*via* sea ice/aerosol etc.) is fundamental as the prime bromide source, and anything that might affect its availability is likely to affect the frequency of ozone depletion events.

The surface ozone records discussed above also reveal a second surprising feature. During the summer months at South Pole, surface ozone concentrations increase even above those measured during winter. This suggests that, rather than experiencing net destruction, ozone is being produced *in situ*. The only route for this within the troposphere is through photolysis of NO_2, but NO_2 is normally associated with polluted air and has low concentrations in pristine atmospheres. The questions then arise – what is the source of this ozone, and why, out of all the measurement locations, is it only evident at South Pole?

The answers lie within a new area of atmospheric science; that of snow photochemistry. The traditional view of polar snow was that it had an important influence on albedo, and also that it acted as a cap to exchange of trace gases between the boundary layer and the land or sea surfaces below. However, an active chemical role had not been anticipated. That view has now been overturned, and it has been shown through many chemical studies in the field, in the laboratory, and in modelling calculations, that snow is a major source of reactive trace gases to the polar boundary layer both through physical and photochemical release processes (see review by Grannas et al., 2007). For example, nitrate impurities within snow are photolysed to produce nitrogen oxides (NO and NO_2) (Honrath et al., 1999; Jones et al, 2000; Dibb et al., 2002; Beine et al., 2002a) that are released to the overlying boundary layer (Jones et al., 2001; Honrath et al., 2002; Beine et al., 2002b). Although this occurs across the Antarctic snowpack, the effects are particularly noticeable at South Pole because of the characteristically shallow boundary layer at this site. Emissions from snow are concentrated within a confined layer of the atmosphere, which accentuates the resultant chemistry (Davis et al., 2004). NO_2 released from snow, therefore, becomes a significant source of local ozone, accounting for the surface ozone measurements described above (Crawford et al., 2001).

The influence of the snowpack on boundary layer chemistry is enormous and, crucially, encompasses fast reactive photochemistry. As well as releasing NOx, the snow is a source of hydrogen peroxide (H_2O_2), formaldehyde (HCHO) and nitrous acid (HONO). These can be direct sources of OH, a highly reactive radical that reacts with numerous other trace gases thus driving tropospheric chemistry. Furthermore, enhanced concentrations of NO will generate OH through the reaction $NO + HO_2 \rightarrow NO_2 + OH$. As a result of snowpack emissions, the boundary layer above the snow-covered Antarctic is far from being quiescent, but contains a fast and reactive photochemical system.

Recent measurements at Halley station have shown that halogens are also major players in fast reactive photochemistry in the coastal boundary layer. As well as high concentrations of BrO measured during the spring, the seasonal cycle of iodine monoxide (IO) shows an equally high springtime peak, as well as significant concentrations during the summertime (Saiz-Lopez et al., 2007). Indeed, modelling studies based around field measurements have shown that at Halley, although snow photochemistry is active, it is the halogens that control the cycling of reactive radicals and hence the chemical pathways (e.g. Bloss et al., 2007). The origin of IO is not absolutely known, but the proposed source is from diatoms, marine phytoplankton that colonise the underside of sea ice.

The chemistry of the Antarctic troposphere is now known to be extremely complex and unusual. The sunlit months are characterised by fast photochemical systems with chemical origins associated with snow and sea ice. It is precisely this link, between the atmosphere and the cryosphere that makes present day tropospheric chemistry systems vulnerable to a changing climate.

4.5.3 Aerosol, clouds and radiation

Aerosol particles are known to cause significant effects on the radiative budget of the Earth, both directly, through scattering and absorption of shortwave and longwave radiation, and indirectly by acting as condensation nuclei. In polar regions, where the surface albedo can exceed 0.85 in areas covered by snow and ice, aerosols may produce appreciable warming at the surface due to multiple reflection if highly absorbing particles are suspended above these bright surfaces. It is important to determine the radiative properties of particles within the entire atmosphere column to evaluate accurately the radiative forcing. Large sets of radiometer (actinometer, pyrheliometer and sunphotometer) measurements have been carried out over the past 30 years at different Antarctic sites and examined to estimate ensemble average and long-term trends of background aerosol optical depth (AOD at 500 nm; Tomasi et al., 2007) (Figure 4.20). No significant trend was observed, except some large variation during the periods affected by the volcanic eruptions of El Chichon (1982), Pinatubo (1991) and Cerro Hudson (1971). To address topics related to the radiative forcing by polar aerosols in particular, a programme referred to as POLAR-AOD was conducted as a major project of the IPY 2007-2008.

Since the typical example of highly absorbing particles is black carbon (BC), behaviours of BC have been examined at several Antarctic stations. From the wintering intensive observations of aerosols at Syowa Station during 2004 and 2006, unique seasonal variation was obtained with a winter maximum, in contrast to the summer maximum obtained from observations at similar coastal stations as Halley or Neumayer (Wolff and Cachier, 1998), and in parallel to the results at Amsterdam Island (Pereirra et al., 2006). Also an interesting pathway of BC to Syowa was found in summer months, a high peak of BC concentration occurred with local katabatic wind maximum following trajectories coming from the continental side. As there would be no source of BC inland, those trajectories must have originated from South America or Africa in response to biomass burning, for example. These pathways were confirmed in the airborne campaign (ANTSYO-II) jointly conducted by AWI, Germany and NIPR, Japan with the AWI aircraft Polar 2, around Neumayer and Syowa stations in the 2006/07 season.

Clouds are an extremely important part of the Antarctic climate system and have a significant influence on the surface radiation balance and hence also on biological processes. Yet there are large uncertainties in quantifying their role, and there is little information on how cloud amount and cloud properties have changed in recent decades. Although the general distribution of clouds is well-known - with large amounts of cloud cover over sea ice or open water in the Southern Ocean, and low cloud amounts over the continent (King and Turner, 1997), we still have no reliable cloud climatology due to deficiencies in deriving cloud amounts from passive satellite sensor data over snow and ice surfaces (Yamanouchi and Kawaguchi, 1992; Kato et al., 2006). Determining trends in cloud amount from the station data is difficult because of jumps when the observers change. However, with careful assessment of the observations some trends have been estimated. The 50 years of observations from Syowa Station revealed a 10% increase in cloud cover over that period (Yamanouchi and Shudo, 2007), although no trend was detected in the observations from South Pole (Town et al., 2007).

The radiation budget is the key aspect of studies of Antarctic climate, and the general features of the surface radiation budget at the stations on the continent have been described (Liljequist, 1956; Kuhn et al., 1977; Yamanouchi, 1983; Yamanouchi and Kawaguchi, 1984). High precision surface radiation budget measurements continue at Neumayer and Syowa stations as part of the global Baseline Surface Radiation Network (BSRN; Ohmura et al., 1998). From the global measurements a decline in solar radiation over the land surface was apparent up to 1990 - a phenomenon known as “global dimming”. Widespread “brightening” has been observed since the late 1980s globally and in the Antarctic (Wild et al., 2003), although there is no consensus yet on the Antarctic measurements (e.g. see Yamanouchi and Shudo, 2007). As for the top-of-atmosphere radiation budget, following the pioneer work by Raschke et al. (1973) using satellite data in the early stage, several measurements have been conducted as part of the Earth Radiation Budget Experiment (ERBE) and Clouds and the

Earth's Radiant Energy System (CERES). As yet there is no clear conclusion about radiation trends at that level in the Antarctic (Yamanouchi and Charlock, 1997; Kato et al., 2006).

4.5.3.1 Spatial variations in atmospheric chemistry suggested from snow cores

Ice core chemistry includes a broad range of measurements such as: major soluble ions, trace elements, radionuclides, and organic acids. The following is a synthesis of some of the major findings related to the understanding of the chemistry of the atmosphere over Antarctica as understood from the examination of the chemistry of ice cores.

An updated compilation of published and new data of major ion (Ca, Cl, K, Mg, Na, NO_3, SO_4) and methylsulfonate (MS) concentrations in snow from 520 Antarctic sites is provided by the national ITASE programmes of Australia, Brazil, China, Germany, Italy, Japan, Korea, New Zealand, Norway, United Kingdom, United States of America, and the national Antarctic programme of Finland (Bertler et al., 2005). The comparison shows that snow chemistry concentrations vary by up to four orders of magnitude across Antarctica and exhibit distinct geographical patterns (see example Na in Figure 4.21). This Antarctic-wide comparison provides a unique opportunity to improve our understanding of the fundamental factors that ultimately control the chemistry of a snow or ice sample.

As expected, the East Antarctic interior shows significantly lower values (~2 ppb to ~30 ppb) than the coastal sites (~75 ppb to 14,680 ppb). However, high values have also been reported from Marie Byrd Land at high elevation, and low concentrations in the vicinity of the East Antarctic coastlines (Kaiser Wilhelm Land and Terra Adélie). Furthermore, the change from very low to very high concentrations seems to occur within a narrow band in the vicinity of the coast. While high Na deposition is readily explained in coastal areas due to high sea salt input, the narrow zone of marine air mass intrusions (mesoscale cyclonic activity) coincides with the rapid decrease of Na concentrations in the Antarctic interior. Here the katabatic wind streams, transporting Na-depleted air masses from the interior towards the coast, compete with the Na-rich coastal air masses. In contrast, the Antarctic Peninsula shows overall high values and no trends, caused by strong sea salt input all year round and a secondary non-sea-salt contribution from ice-free mountain peaks. Most of the data points located on the Antarctic Peninsula are surface samples representing winter snow. As Na peaks in most regions of Antarctica during winter, the higher Na concentrations reported from the Antarctic Peninsula are partially caused by this bias. This and similar maps for Ca, Cl, K, Mg, NO_3, SO_4) and MS are available in Bertler et al. (2005).

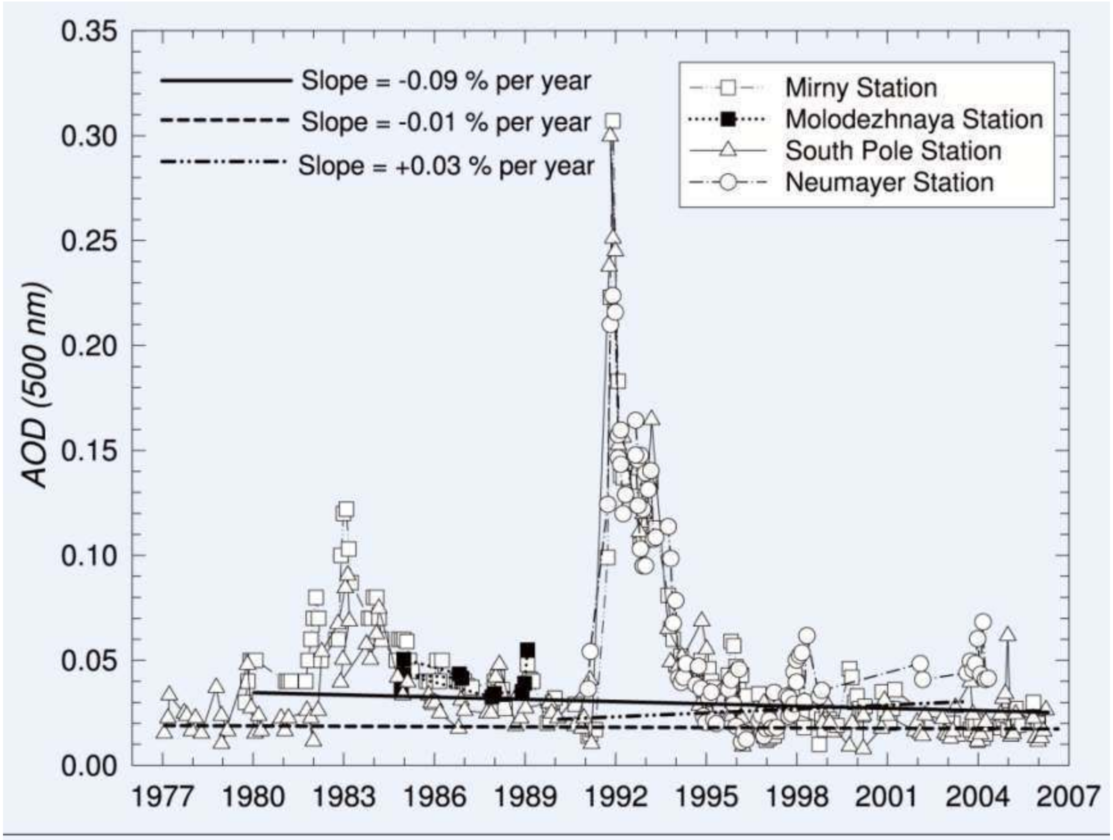


Figure 4.20 Time sequence of the monthly mean values of AOD (500 nm) derived from (1) filtered actinometer and sun photometer at Mirny from 1979/80 to 2005/06 (open squares), and at Molodezhnaya from 1985 to 1989 (solid squares); (2) filtered pyrheliometer and sun photometer at South Pole from 1977 to 2006 (open triangles); and from sun photometer measurements at Neumayer from 1991 to 2004 (open circles). The regression lines, defined separately for the Mirny, South Pole and Neumayer data sets without volcanic data are drawn to show the long-term trend of background aerosol extinction in Antarctica. (Figure 14 of Tomasi et al., 2007)

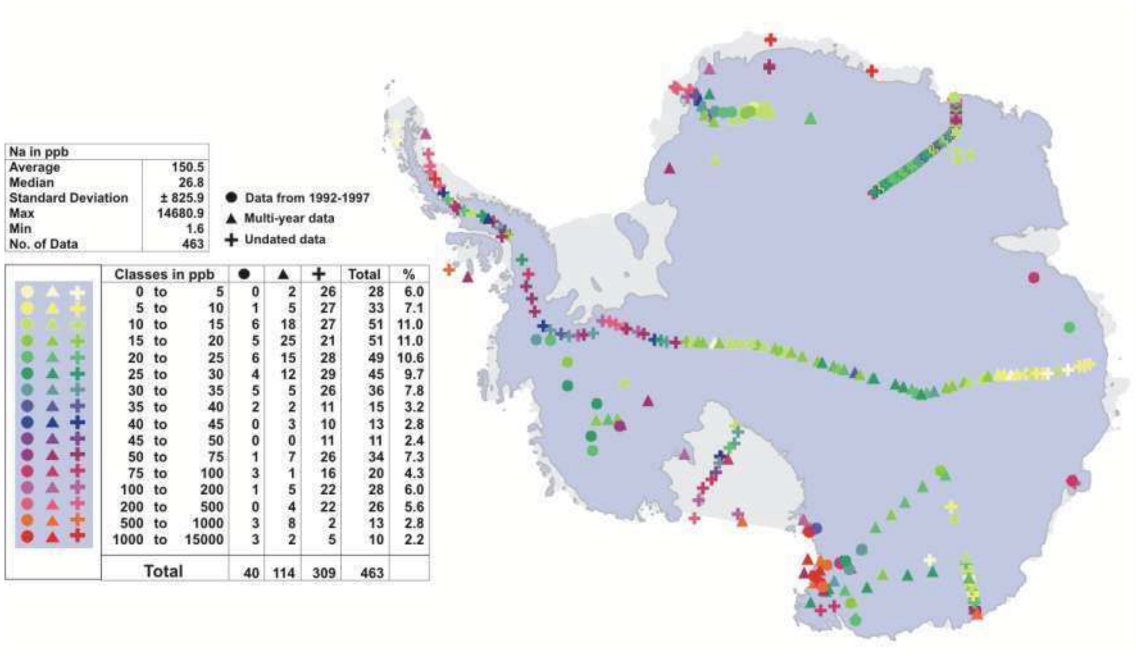


Figure 4.21 Spatial variability of Na^+ concentration measured in ppb. Solid circles represent data from 1992-1997. Solid triangles represent all other multi-year data. Crosses represent non-annual or undated samples. Spatial variability of Na^+ concentration ranges from 2 ppb to 14,680 ppb.

4.6 The Southern Ocean

4.6.1 Introduction

At first sight the Southern Ocean seems to be dominated by circumpolar symmetry mainly assured by the circumpolar current bands of the eastward flowing ACC covering mainly the mid latitudes (Figure 1.8) and the westward flowing Antarctic Coastal Current surrounding the continental margin in high latitudes. Superimposed on the zonal flow there are meridional circulation cells (Figure 1.9), the deep one related to sinking motion along the continental slope to form the Antarctic Bottom Water, and the shallow one forming Mode and Intermediate Waters in the mid latitudes. In spite of the current system linking the Atlantic, Indian and Pacific sectors, significant zonal differences are obvious and require a regional description of the variability and change in the Southern Ocean. Differences are related to the shape of the ocean basins and ridges which strongly affect the ocean currents, the shape of the continent with huge embayments, such as the Weddell and the Ross Seas giving rise to subpolar gyres (Figure 1.10), the distributions of ice shelves, the zonal structure of the forcing (storm tracks) and finally the different hydrographic conditions in the northward adjacent ocean basins.

The meridional circulation cells which can only schematically be represented in a two dimensional way (Figure 1.9), display clear zonal differences as well. They are obvious in the long term mean conditions, e.g. the horizontal distribution of the newly formed bottom water (Figure 4.22, Orsi et al., 1999) which result in the variable contributions of different sectors to the bottom water formation. It is estimated that 66% can be contributed to originate in the Weddell Sea, 25% in the Australian Sector and 7% in the Ross Sea (Rintoul, 1998). Due to the zonal differences in the hydrographic and forcing conditions, variations differ in the sectors as well, e.g. cooling and freshening of the newly formed bottom water in the

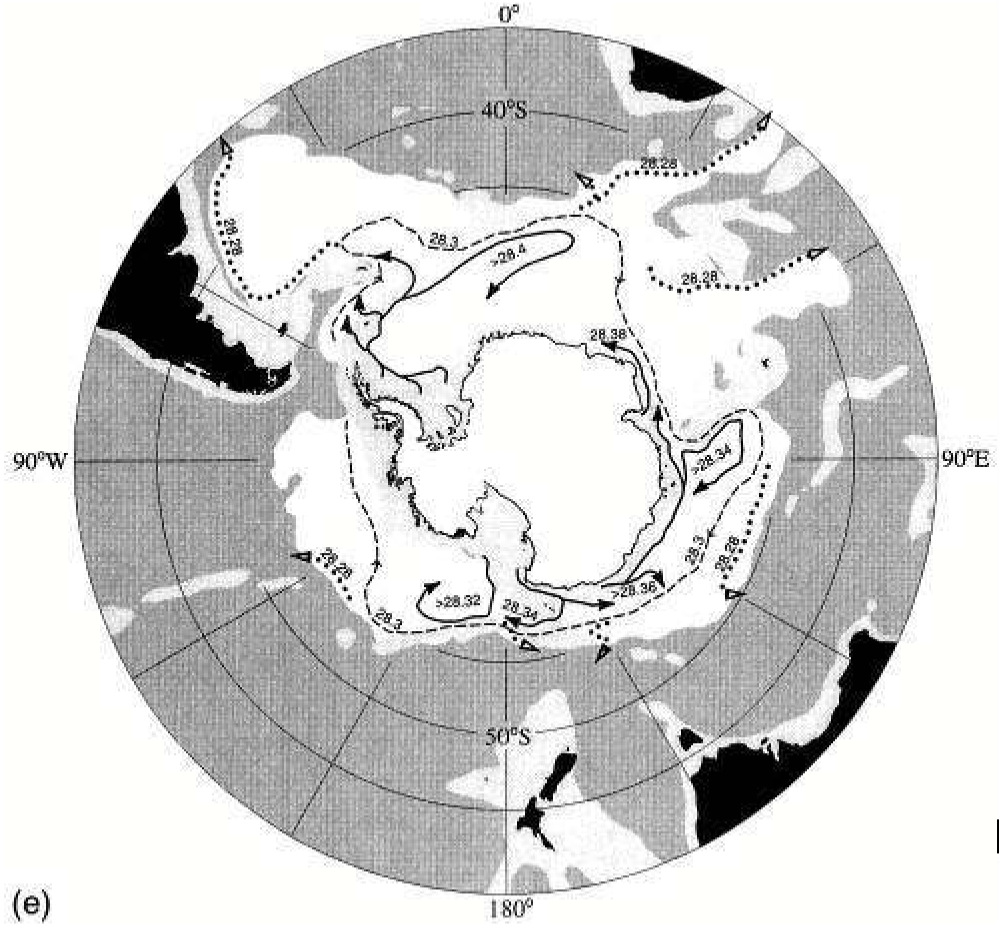
Australian sector (Rintoul, 2007) and warming and increase of salinity of bottom water on the prime meridian (Fahrbach et al., 2004). However, even within the basins different patterns are detected e.g. in the Weddell Sea (Fahrbach et al., 2004). To take into account the circumpolar differences in the observed variations the description of the Southern Ocean is arranged here zonally in different sectors. Since regional differences occur even on smaller scales than the three large ocean sectors, we focus on sub-areas where a particular type of variation is observed.

There is evidence that changes in the Antarctic Bottom Water propagate into the global ocean. Warming of the northward flow of Antarctic Bottom Water on a decadal time scale is observed in Vema Channel from the Argentine to the Brazil Basin (Zenk and Morozov, 2007). Large scale abyssal warming over decades is observed in the South Atlantic (Johnson and Doney, 2006) and the Pacific (Johnson et al., 2007).

Observation of change in surface waters is difficult to detect since there is an intensive seasonal cycle and only few observations. However, around South Georgia observations exist since 1925, which are frequent enough to resolve the annual cycle. They reveal significant trends in the upper 150 m, with 2.3°C of warming over 81 years, which are twice as strong in winter than in summer (Whitehouse et al., 2008).

Sub-Antarctic Mode Water is formed by winter cooling and convection just north of the Sub-Antarctic Front (McCartney, 1997, 1982). When it is subducted it becomes Antarctic Intermediate Water (Hanawa and Talley, 2001). This water mass is of particular interest due to its capacity to take up atmospheric CO_2 (Sabine et al., 2004). Significant warming (Wong, 2001; Gille, 2002; Aoki et al., 2003) and freshening was observed in these water masses (Wong, 1999; Curry et al, 2003; Bindoff et al., 2007; Böning et al., 2008) over the last decades. To understand the changes, the formation processes (e.g. Sallée et al., 2006) and the turbulent character of the field (Tomczak, 2007) need to be understood.

In a circumpolar view the ACC band has warmed in recent decades (Figure 4.23; Gille, 2002 and 2008; Levitus et al., 2000, 2005, Böning et al., 2008). The changes are consistent with a southward shift of the ACC (Gille, 2008). Some climate models suggest that the ACC shifts south in response to a southward shift of the westerly winds driven by enhanced greenhouse forcing (Fyfe and Saenko, 2006; Bi et al., 2002). A significant part of the changes in the wind system can be related to the positive trend in the SAM (e.g. Hughes et al., 2003). The poleward shift and intensification of winds over the Southern Ocean has been attributed to both changes in ozone in the Antarctic stratosphere (Thompson and Solomon, 2002) and to greenhouse warming (Fyfe et al., 1999). In addition to driving changes in the ACC, the wind changes have caused a southward expansion of the subtropical gyres (Cai, 2006) and an intensification of the Southern Hemisphere "supergyre" that links the three subtropical gyres (Speich et al., 2002, 2007). The "supergyre" provides the mechanism by which Sub-Antarctic Mode Water and Antarctic Intermediate Water is distributed between the ocean basins (Ridgway and Dunn, 2007). In the area of the formation of Antarctic Intermediate Water north of the Subantarctic Front freshening is observed. Surprisingly the changes are rather similar all along the ACC (Figure 4.23; Böning et al., 2008).



(e)

Figure 4.22 Schematic presentation of the formation areas and pathways of Antarctic Bottom Water as evidenced by water mass properties, in particular the concentration of the anthropogenic tracer CFC. It is injected into the ocean at the surface and indicates, by concentration maxima, recently ventilated water sinking to the sea bottom and spreading there from the formation areas for different densities here displayed as neutral density where the most dense water with neutral density > 28.4 kg/m^3 is found in the Weddell Sea (Orsi et al., 1999).

4.6.2 Australian Sector

Knowledge of the circulation in the Australian sector of the Southern Ocean has increased significantly in the last decade. Repeat hydrographic sections (Figure 4.24), moorings and satellite altimeter measurements have provided new insights into the structure, variability and dynamics of the ACC, water mass formation and the overturning circulation. The mean baroclinic transport of the ACC south of Australia is 147±10 Sv (Rintoul and Sokolov, 2001), consistent with recent estimates of the flow leaving the Pacific basin through Drake Passage (136±8 Sv, Cunningham et al., 2003) and the Indonesian Throughflow (Meyers et al., 1995). A multi-year time series derived from XBT sections and altimetry shows significant interannual variability (with a standard deviation of 4.3 Sv) but no trend in transport (Rintoul et al., 2002). High resolution hydrographic sections reveal that the ACC fronts consist of multiple jets, aligned with streamlines that can be traced using maps of absolute sea surface height (Sokolov and Rintoul, 2002, 2007). Eddy fluxes estimated from current meter moorings confirm that the eddies transport heat poleward and zonal momentum downward (Phillips and Rintoul, 2000). A cyclonic gyre lies between the ACC and the Antarctic continent, closed in the west by a northward boundary current along the edge of the Kerguelen Plateau (McCartney and Donohue, 2007).

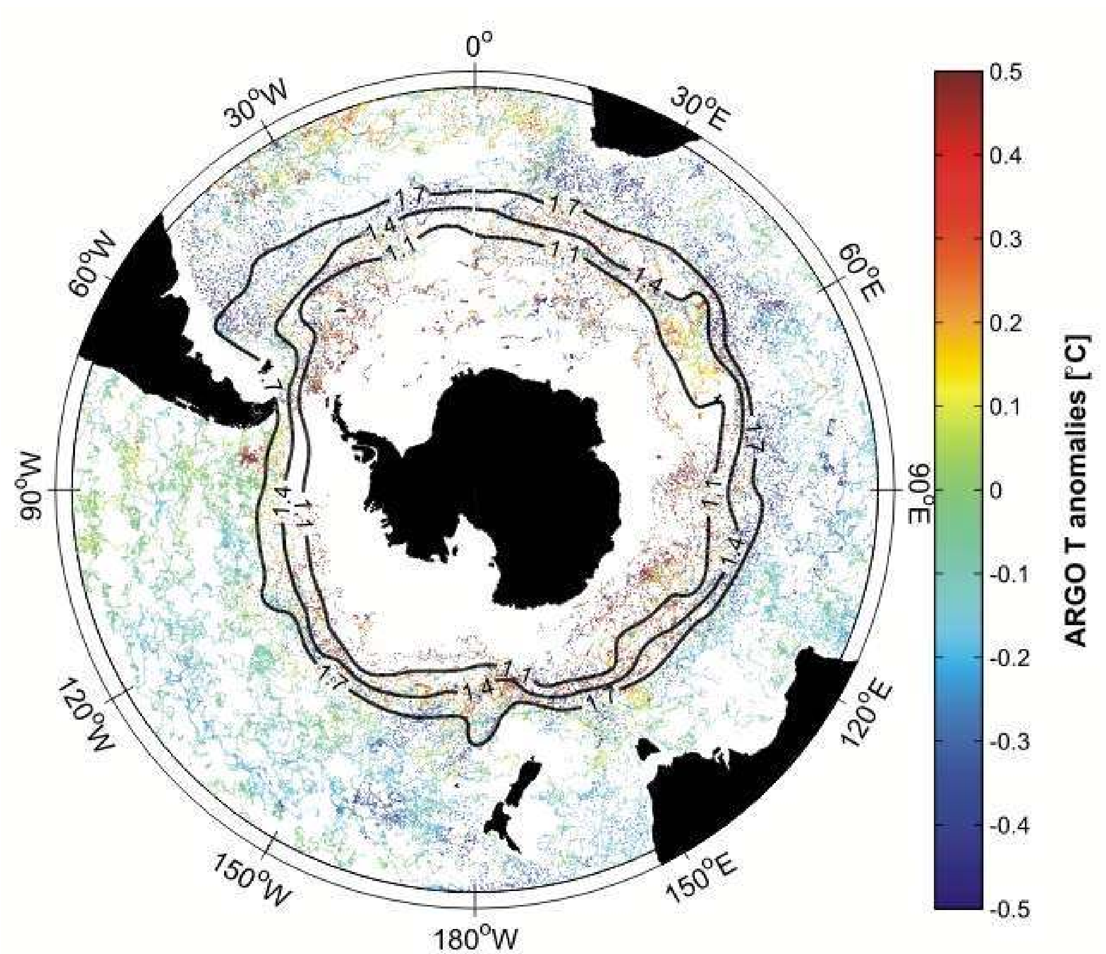


Figure 4.23 Temperature differences between measurements from Argo floats deployed after 2001, presented as dots, and the climatological mean from CARS in the density layers of the ACC show an increase of potential temperature of the water masses on the souhward flank of the ACC and a freshening on the northward side. On surfaces of constant densities freshing becomes visible as cooling, since the density loss by less salt is compensated by a density gain due to colder temperature. The major fronts representing ACC branches are displayed as dynamic height contours where the 1.4-m-dynamic-height contour is related to the Polar Front and 1.7-m one to the Subantarctic Front (Böning et al., 2008)

The ACC belt in the Australian sector has warmed in recent decades, as found elsewhere in the Southern Ocean (Gille, 2002, 2008; Levitus et al., 2000, 2005; Willis et al., 2004; Böning et al., 2008). The southward shift of the ACC fronts has caused warming through much of the water column, resulting in a strong increase in sea level south of Australia between 1992 and 2005 (Sokolov and Rintoul, 2003; Morrow et al., 2008). However, there is no observational evidence of the increase in ACC transport also predicted by the models (Böning et al., 2008). Recent studies suggest the ACC transport is insensitive to wind changes because the ACC is in an “eddy-saturated” state, in which an increase in wind forcing causes an increase in eddy activity rather than a change in transport of the current (Hallberg and Ganandesikan, 2006; Meredith and Hogg, 2006).

Changes have been observed in several water masses in the Australian sector between the 1960s and the present (Aoki et al., 2005). Waters north of the ACC have cooled and freshened on density surfaces corresponding to intermediate waters (neutral densities between 26.8 and 27.2 kg m^{-3}). South of the ACC, waters have warmed and become higher in salinity and lower in oxygen on neutral density surfaces between 27.7 and 28.0 kg m^{-3} (the Upper Circumpolar Deep Water –UCDW). The changes south of the ACC are consistent with a shoaling of the interface between the warm, salty, low oxygen UCDW and the cold, fresh, high oxygen surface water that overlies it. The pattern of water mass change observed in the Australian sector is consistent with the "fingerprint" of anthropogenic climate change in a coupled climate model (Banks and Bindoff, 2003).

The Antarctic Bottom Water (AABW) in the Australian Antarctic basin has freshened significantly since the early 1970s. Whitworth (2002) detected a shift toward fresher AABW after 1993, concluding that "two modes" of AABW were present in the basin, with the fresher mode becoming more prominent in the 1990s. More recent studies have documented a monotonic trend toward fresher, and in most cases warmer, bottom water between the late 1960s and the present rather than a bi-modal distribution. Aoki et al. (2005) used a hydrographic time series with nearly annual resolution between 1993 and 2002 to show a steady decline in salinity of the bottom water at 140ºE. By using repeat observations from the same location and same season, they could demonstrate that the trend was not the result of aliasing of spatial or temporal variability. Rintoul (2007) showed that the deep potential temperature – salinity relationship of the entire basin had shifted towards lower salinity between the early 1970s and 2005. The average rate of freshening at 115°E is 7 ppm/decade, which can be compared to a mean freshening rate of 12 ppm/decade in the North Atlantic, at similar distances downstream of the source of dense water (Dickson et al., 2002). These results suggest that the sources of dense water in both hemispheres have been responding to changes in high latitude climate.

The abyssal layers of the Australian Antarctic Basin are supplied by the two primary sources of bottom water that lie outside of the Weddell Sea: a fresh variety formed along the Adélie Land coast (144º E) and a salty variety produced in the Ross Sea (Rintoul, 1998). The changes observed in the Australian Antarctic Basin therefore reflect freshening of the AABW formed in the Indian and Pacific sectors of the Southern Ocean, which accounts for about 40% of the total production of AABW (Orsi et al., 1999).

The cause of the freshening of AABW in the Australian sector is not yet fully understood. Changes in precipitation, sea ice formation and melt, ocean circulation patterns, and melt of floating glacial ice around the Antarctic margin could all influence the salinity where dense water is formed. Oxygen isotope measurements in the Ross Sea indicate that an increase in the supply of glacial melt-water has contributed to the large freshening of shelf waters observed there in recent decades (Jacobs et al., 2002). The most likely source of the increased supply of melt-water is the rapidly thinning glaciers and ice shelves of the Amundsen Sea, including the Pine Island Glacier (Jacobs et al., 2002), where enhanced basal melt has been linked to warmer ocean temperatures (Rignot and Jacobs, 2002; Shepherd et al., 2004). While most of the ice sheet in East Antarctica appears to be gaining mass, glaciers draining parts of the Wilkes Land coast where the Adélie Land bottom water is formed have decreased in elevation (Shepherd and Wingham, 2007), and the floating ice in this sector thinned between 1992 and 2002 (Zwally et al., 2005). Therefore increased supply of glacial melt-water may have played a role in the freshening of both the Adélie Land and Ross Sea Bottom Water.

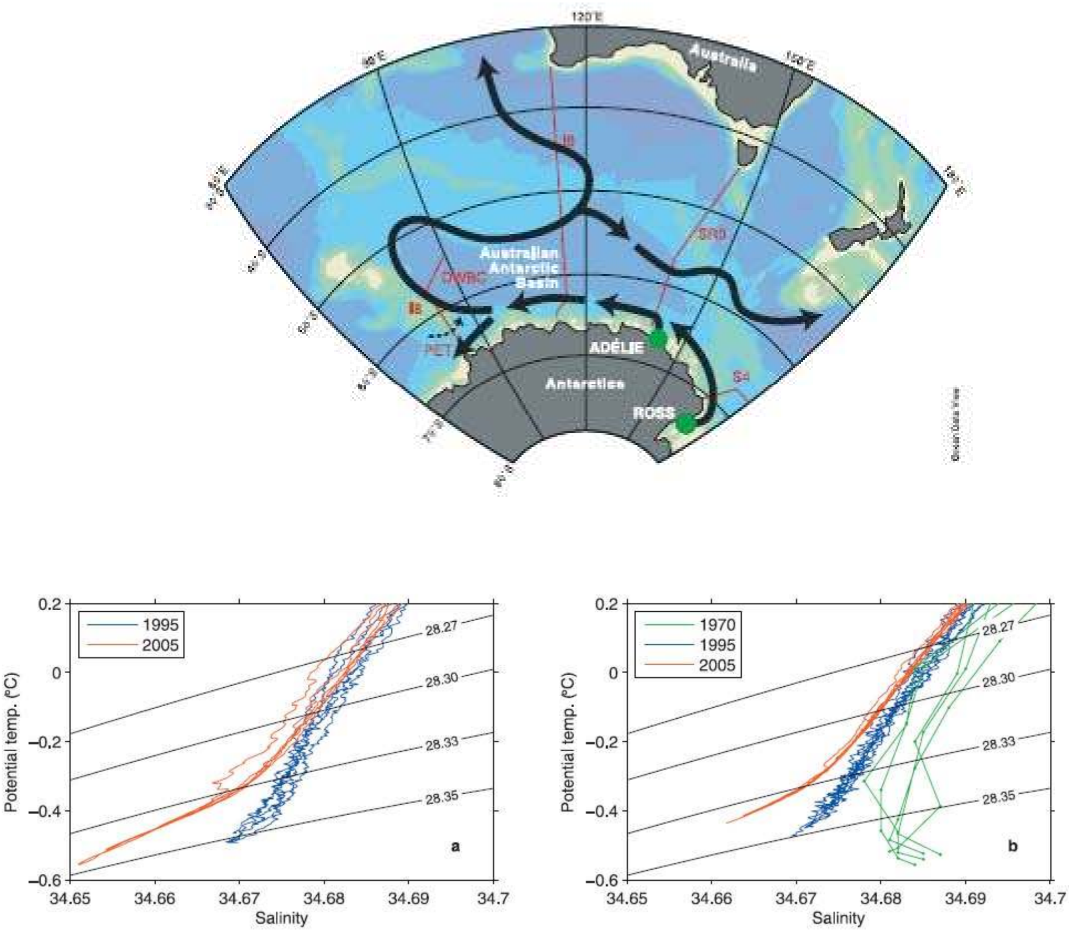


Figure 4.24 Top) Map indicating location of repeat sections along which changes in bottom water properties have been assessed. The Australian Antarctic Basin is supplied by two sources of Antarctic Bottom Water: the Ross Sea and Adélie Land. Lower) Changes in the deep potential temperature – salinity curves along 115°E, over the continental rise (61-63.3°S, left) and further offshore (56.5 - 61°S, right). From Rintoul (2007).

4.6.3 The Amundsen/Bellingshausen Seas

The southeast Pacific Ocean (70°W – 150°W) deserves enhanced scientific interest because of the significant alterations it faces or is supposed to face in a changing climate. Since 1951 annual mean atmospheric temperatures rose by almost 3°C at the Antarctic Peninsula (King, 1994; Turner et al., 2005a) which can be linked to changes in the Bellingshausen Sea, like sea ice retreat (Jacobs and Comiso, 1993), increased ocean surface summer temperatures of more than 1°C, enhanced upper-layer salinification (Meredith and King, 2005), the disintegration of smaller ice shelves (Doake and Vaughan 1991), and accelerated retreat of glaciers (Cook et al., 2005). The changes can be related to atmospheric variability including the Antarctic Circumpolar Wave (White and Peterson, 1996) or the SAM (Hall and Visbeck, 2002; Lefebvre et al., 2004), which both exhibit extreme values in the southeast Pacific Ocean. Different hydrographic conditions have a severe impact on marine species (e.g., the Antarctic krill) which use the Bellingshausen Sea for breeding and nursery before the larvae mainly drift eastward to the southern Scotia Sea/northwestern Weddell Sea (Siegel, 2005). A comprehensive field study on Antarctic krill in the Amundsen Sea has yet to be conducted.

Connected via the westward flowing, and in this part, weak coastal current, changes in the Bellingshausen Sea also influence the Amundsen Sea (100°W – 150°W) which is fringed to the south by the outlets of major ice streams draining the West Antarctic Ice Sheet. A possible collapse of the latter would result in a 5-6 m global sea level rise threatening many low-lying coastal areas around the globe including millions of their residents (Rowley et al., 2007), but is not likely in the next 100 years. The southernmost position of the ACC southern front (Orsi et al., 1995) together with a relative narrow continental shelf crisscrossed by numerous channels (Figure 4.25) allows Upper Circumpolar Deep Water (UCDW) with temperatures near 1°C to reach the ice shelf edges in the Amundsen and Bellingshausen Seas (Figure 4.26). This ocean heat could fuel melting of up to tens of metres per year at deep ice shelf bases. A linear relationship between melt rates beneath Antarctic ice shelves and ocean temperature is roughly linear at 1 m/yr per 0.1°C ocean warming derived from observations of 23 glaciers (Rignot and Jacobs, 2002). The change of ice melt rate to a change in ocean temperature may not follow this same relationship. In a simple box model Olbers and Hellmer (2009) confirm this rate to be consistent with the involved physical processes and investigate the sensitivity. Numerical modeling of ice-ocean interaction beneath Pine Island Glacier (Payne et al., 2007) concludes that the observed thinning at a rate of 3.9 $\pm$ 0.5 m/yr between 1992 and 2001 (Shephard et al., 2002) would correspond to a different rate of ~ 0.25°C warming of the UCDW underneath Pine Island Glacier. Such warming has not been observed on the Amundsen Sea continental shelf, but a 40-year long temperature time series from the nearby Ross Sea exhibits a warming of the off-shore temperature maximum (190-440 m depth) of ~ 0.3°C (Jacobs et al., 2002). Temperature variability correlated with changing freshwater fluxes due to basal melting is likely at the fringe of the West Antarctic Ice Sheet. Upper Southern Ocean temperatures increased since the 1950's (Gille, 2002; Böning et al., 2008), but the few oceanographic snapshots (e.g., Hofmann and Klinck, 1998; Walker et al., 2007) from the Amundsen/Bellingshausen Sea continental margin are insufficient to identify the time scales and strengths of variability or any trends.

4.6.4 Variability and change in Ross Sea shelf waters

The circulation in the Ross Sea is dominated by a wind-driven cyclonic gyre (Treshnikov, 1964) visible as a depression in the steric height transporting Circumpolar Deep Water to the south where by interaction with shelf and slope water Antarctic Bottom Water is produced. It is located south of the mid-ocean ridge between 170° E and 140°W (e.g. Gouretski, 1999) with its centre at about 68°S, 164°W shifting to the southeast with depth. The baroclinic transport of 8.5 Sv is significantly smaller than the one of the Weddell gyre. The eastern boundary is given by a southward deflection of the ACC due to the bottom topography. At the southern limb, westward flow transports water as warm as 1.6°C. From property maps Reid (1986) included the extension up to the Antarctic Peninsula. Antipov et al. (1987), Maslennikov (1987) and Locarini (1994) locate the eastern boundary at 140°W. The continental shelf area is relatively well sampled due to the normally weak ice cover in summer and the presence of several Antarctic stations (Jacobs and Giulivi, 1999).

Shelf waters' include a variety of low-temperature, ice-modified, high- and low-salinity water masses found below the ocean surface layers on the Antarctic continental shelf (Whitworth et al., 1998). Summer salinity profiles spanning about 20 years in High Salinity Shelf Water (HSSW) near Ross Island displayed gradual salinity increases below 200 m and interannual water column shifts that were several times the measurement accuracy and half the annual cycle in McMurdo Sound (Jacobs, 1985). Atmospheric forcing, sea ice production, HSSW residence time, ice shelf melting and intrusion of Modified Circumpolar Deep Water onto the continental shelf were considered as possible agents of change. Hellmer and Jacobs (1994) noted that salinity decreases could also result from fresher upstream source waters.

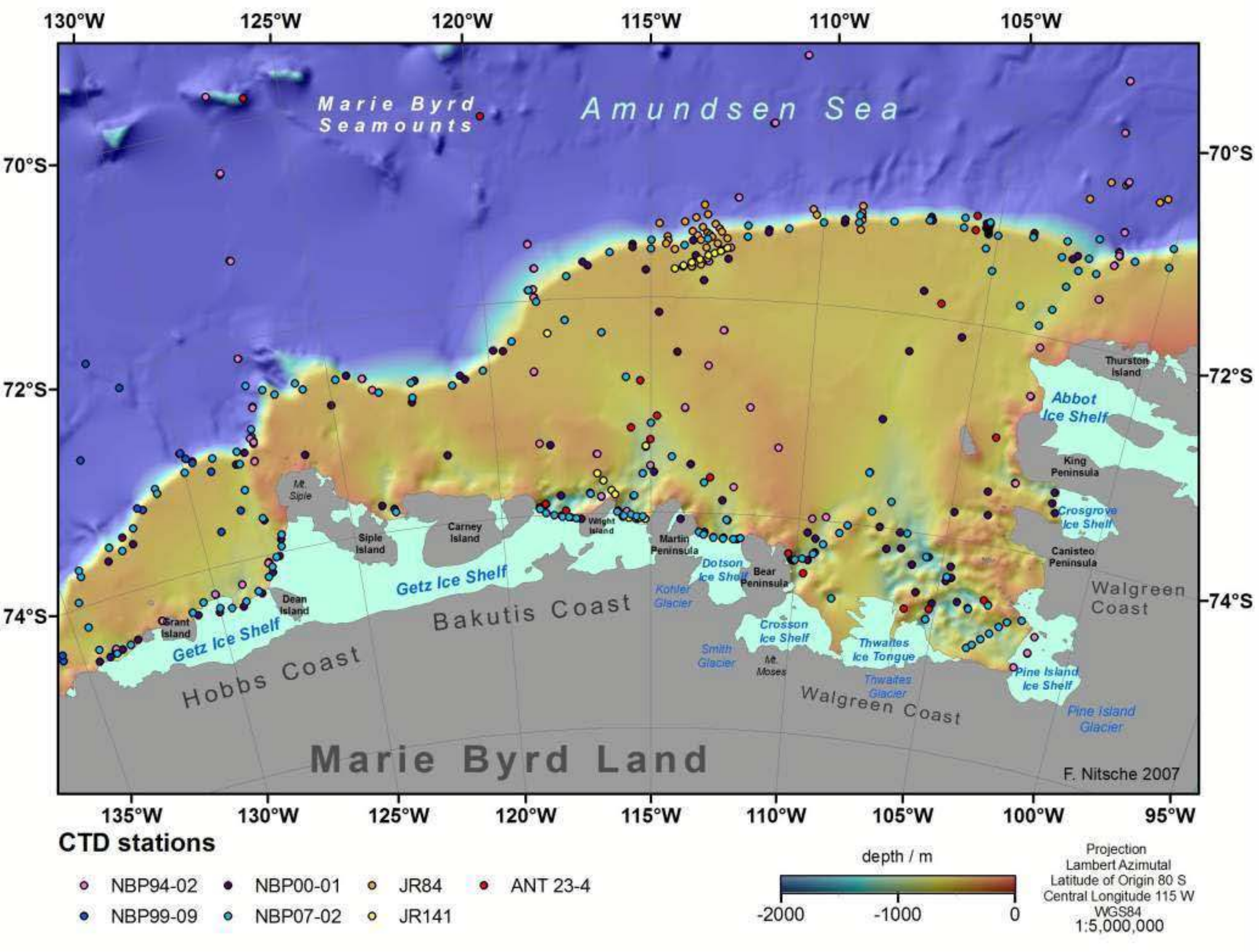


Figure 4.25 Bathymetric chart of the Amundsen Sea continental shelf and adjacent deep ocean spotted with the distribution of hydrographic stations of different cruises (colour coded). Fringing ice shelves and glaciers draining the West Antarctic Ice Sheet in light blue (Nitsche et al., 2007). The CTD station identifiers refer to the Nathaniel B. Palmer (NBP), the James Clark Ross (JCR) and the Polarstern (ANT).

Attempts to link observed HSSW changes to multiyear variability in regional sea ice extent, winds and air temperatures revealed the need for longer time series. The data base largely consists of sporadic summer measurements, and both modelers and observers have noted the possibility of aliasing in this shelf water record due to undersampling of a variable inflow. In addition, most measurements were in or near an HSSW eddy, another potential source of variability. Nonetheless, the deep HSSW trend in that area has closely tracked changes at depth along the Ross Ice Shelf and near 500 m throughout the western Ross Sea (Jacobs and Giulivi, 1998; Smethie and Jacobs, 2005).

Record low salinities at the site in February 2000 led to analyses that more strongly implicated changes in ice-ocean interactions upstream in the Amundsen and Bellingshausen Seas (Jacobs et al., 2002). Assmann and Timmermann (2005) successfully modeled averaged HSSW salinity profiles, and inferred that the freshening resulted from a Bellingshausen Sea thermal anomaly. Their periodic signal upwelled in the Amundsen Sea, reduced brine drainage near the sea ice edge and induced a subsurface salinity decrease that was advected into the Ross Sea. Interannual salinity variability is high, but the overall trend has been statistically significant and qualitatively consistent with freshening over a much wider area (Jacobs, 2006).

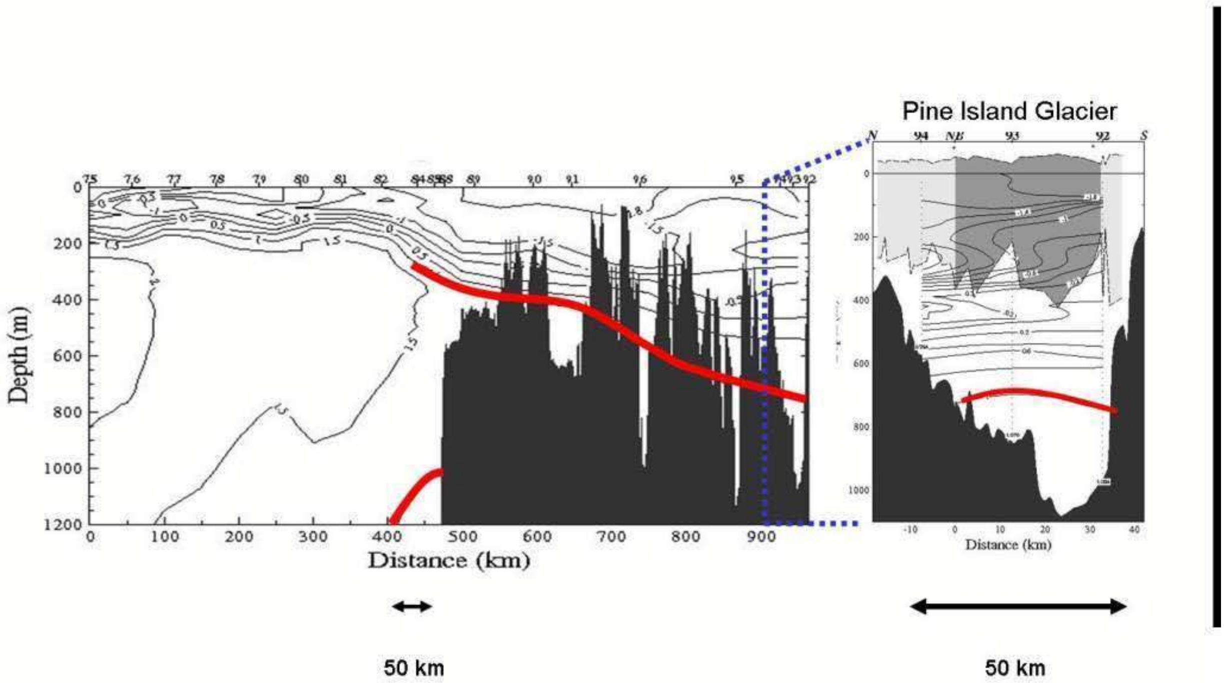


Figure 4.26 A cross-section showing penetration of warm water to the sub-ice shelf cavity in Pine Island Bay. Potential temperature of the upper 1,200 m along a band between 100°W and 105°W projected on a strait transect from the open ocean (left) to Pine Island Bay (right) measured during NBP9402 (see Figure 4.25 for station locations). Due to the ice conditions the stations could not be done along a straight line. The sea floor depth was extracted from the ship's 3.5 kHz echosounder data. Right figure depicts the temperature field in front of Pine Island Glacier with its draft shaded in gray. This short line is along the line of pink dots (sample stations) shown in Figure 4.25. The 1°C isotherm on the continental shelf and slope is marked in red (modified from Hellmer et al., 1998). The solid black area indicates the sea bed.

The record of summer shelf water thermohaline properties has recently been extended to 50 years (Figure 4.27), and the study area widened to include profiles in McMurdo Sound. The 50 year salinity trend continues to be near -0.03/decade, while slightly warming temperatures have remained consistent with HSSW formation by surface freezing in winter. HSSW near Ross Island thus serves as an index site to monitor change occurring in the Ross Sea and upstream (eastward) in the Antarctic Coastal Current. The salinity decline appears to derive mainly from increasing continental ice meltwater, and will subsequently change the properties if not the production rates of deep and bottom waters. Over regional areas the lower salinity has raised sea level via the halosteric component of seawater density.

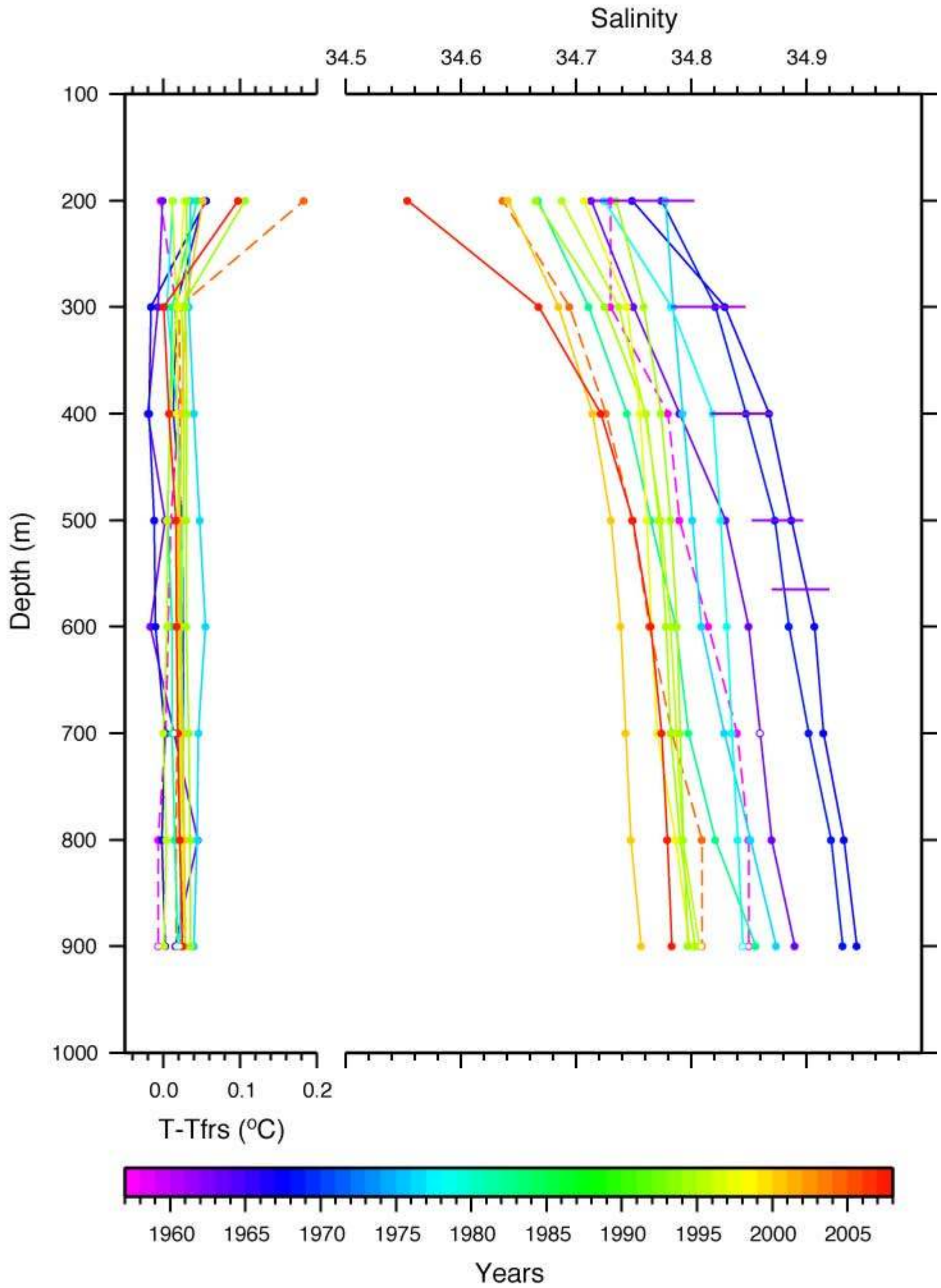


Figure 4.27 Summer temperature and salinity profiles over a 50 year period, some averaged from adjacent profiles, and dashed if more than 15 km from 168º 20'E, 77º 10'S, near Ross Island. Plotted values are 100 m averages/interpolations of CTD or bottle data, edited or extrapolated where shown by open circles. Horizontal lines depict the salinity ranges at six bottle casts in southern McMurdo Sound over 23 December 1960 – 9 February 1961 (Tressler and Ommundsen, 1963). Temperatures are referenced to the surface freezing point, ~-1.91°C at a salinity of 34.8. Tfrs is the surface freezing reference temperature.

4.6.5 The Weddell Sea Sector

The Weddell Sea hosts a subpolar gyre (e.g. Treshnikov, 1964), the Weddell Gyre (Figure 1.10), that brings relatively warm, salty circumpolar water (Warm Deep Water, WDW) south towards the Antarctic continent, and transports colder, fresher waters northward (Weddell Sea Deep and Bottom Waters, WSDW and WSBW, as well as surface waters). The transformation of this source water mass is one of the major climate-relevant processes in the Southern Hemisphere, affecting and involving ocean, atmosphere and cryosphere and a major contribution to the deep meridional overturning cell (Figure 1.9).

In respect to climate change, the most relevant property is the change in the intensity of the overturning circulation, i.e. the transport of shallow source water masses into the formation areas and the newly formed water masses leaving the Antarctic Systems into the world oceans. However, since these transport differences are relative small in comparison to the gyre scale circulation, the latter must be known to distinguish between recirculation and net transformation.

The cyclonic Weddell Gyre is bounded to the west by the Antarctic Peninsula, to the south by the Antarctic continent and to the north by a chain of roughly zonal ridges at ~60ºS. The eastern boundary is less well defined but is generally agreed to extend as far east as ~30º E (Gouretski and Danilov, 1993). The flow associated with the Antarctic Slope Front, a boundary current tied to the steep topography of the Antarctic continental slope, contributes a major proportion of the gyre transport. The Weddell Gyre is primarily driven by the cyclonic wind field (Gordon et al., 1981), leading to a doming of isopycnals in the centre of the gyre. The volume transport is still an ongoing topic of research, partly because it is dominated by the barotropic component (Fahrbach et al., 1991) so it is difficult to measure. Integrating the wind field in a Sverdrup calculation revealed a volume transport of 76 Sv (Gordon et al., 1981) while the first attempts to reference the geostrophic shear to current meters yielded a transport of 97 Sv (Carmack and Foster, 1975). For a section across the Weddell Gyre from the tip of the Antarctic Peninsula to Kapp Norvegia, transports have, uniquely, been referenced to a long time series current meter array, and this has produced lower transport estimates of 20-56 Sv (Fahrbach et al., 1991; Fahrbach et al. 1994). At the Greenwich meridian, larger transports of the order of 60 Sv were obtained from referencing shear to shipboard ADCP (Schröder and Fahrbach, 1999). Current meter arrays subsequently yielded 45 – 56 Sv (Klatt et al., 2005). The larger values at the Greenwich meridian may be due to recirculations within the central gyre not being captured by the Kapp Norgvegia section. However, a recent high resolution section at the Antarctic Peninsula also yielded ~46 Sv (Thompson and Heywood, 2008), and it is suggested that referencing the geostrophic shear across the steep Antarctic continental slope to a relatively widely spaced current meter array may have underestimated the barotropic contribution to the total volume transport.

WSBW is formed on the Antarctic continental shelves where they are wide. In the Weddell Sea, the Filchner-Ronne Ice shelf is one such source region (e.g. Foldvik et al., 2004), and recent evidence suggests formation also on the eastern side of the Peninsula near the Larsen Ice Shelf. The water on the Antarctic continental shelves is typically fresher than its warmer, salty source to the north; it is believed to freshen by the addition of sea ice melt, glacial ice melt from the Antarctic ice sheet and floating ice shelves, and from precipitation. This freshening is a necessary precursor to the bottom water formation process, which involves salinification from brine rejection during sea ice formation, together with cooling. One contributing process to WSBW involves mixing with Ice Shelf Water, and the other process involves mixing with HSSW. The WSBW descends the continental slope and entrains ambient water as it goes (Baines and Condie, 1998). The descent of the WSBW affects the structure of a series of fronts along the rim of the Weddell Gyre, in particular the Antarctic Slope Front and the Weddell Front.

The WSBW is too dense to be able to escape the Weddell Sea. It can only escape by mixing with the water above it, becoming warmer, saltier and less dense, and forming WSDW, which is sufficiently shallow to flow out through the passages in the topography surrounding the Weddell Sea. WSDW outside the Weddell Sea has the water mass properties of Antarctic Bottom Water, of which it is believed to be the major contributor. Estimates of the proportion of Antarctic Bottom Water originating in the Weddell Sea range from 50 to

90% (Orsi et al., 1999). An inflow of water of WSDW properties from the east has been documented (Meredith et al., 2000) that may form in the region of the Prydz Bay Gyre, or may even originate in the Australian Antarctic Basin and enter the Weddell Sea through the Princess Elizabeth Trough (Heywood et al., 1999).

The export of WSDW to the world ocean is of the order of 10 +/- 4Sv (Naveira Garabato et al., 2002). This can escape through gaps in the ridges to the north and east of the Weddell Sea, and subsequently invades all ocean basins.

Measurements of water mass transports exist in relation to climate time scales only as snapshots and not over a long enough times to be able to detect changes. Therefore, one has to measure water mass properties and derive from their variations conclusions about changes of transport and formation rates. Carefully validated models play a significant role here. Even for water mass properties observations in sufficient spatial resolution and accuracy last only over one to two decades. Therefore it is still not possible to unambiguously distinguish between a trend and decadal to multidecadal variation. In spite of the fact that the variability in the deep water masses seems to be relatively small in comparison to those of the surface water masses, it is importance, because the large volume of the deep waters can store significant heat quantities or dissolved substances even if the changes in property is only minor.

Considering its remote and inhospitable location, the Weddell Sea was well observed during WOCE and subsequently through CLIVAR, with (largely summer-time) hydrographic sections across the Weddell Gyre onto the Antarctic continental shelf, and with arrays of moorings. These sections indicate a number of decadal-scale changes in water mass properties. The WDW warmed by some 0.04º C during the 1990s (Robertson et al., 2002; Fahrbach et al., 2004) and has subsequently cooled (Fahrbach et al., 2004). This was accompanied by a salinification of about 0.004 (note salinity does not have any units), just detectable over the decade. A quasi-meridional section across the Weddell Gyre occupied in 1973 and 1995 revealed a warming of the WDW in the southern limb of the gyre by 0.2º C accompanied by a small increase in salinity, whereas there was no discernible change in the northern limb of the gyre (Heywood and King, 2002). There has been debate as to whether these changes to the warm inflow to the gyre are caused by advection of warmer circumpolar waters, and/or by changes in the wind field (Fahrbach et al., 2004, 2006; Smedsrud, 2005).

During the 1970s a persistent gap in the sea ice, the Weddell Polynya, occurred for several winters. The ocean lost a great deal of heat to the atmosphere during these events. The polynya strongly affected the mode of overturning in the Weddell Sea, shifting it from shelf and slope processes to open ocean convection (Gordon, 1978) with consequences for the overturning rates. After this one event the large polynya did not show up again, but weak ice cover was observed in the Maud Rise area several times and interpreted as a sign of possible emergence of a new polynya, though no such polynya emerged. In a recent study, Gordon et al. (2007) attribute the occurrence of the Weddell Polynya to variations in the SAM.

Weddell Sea Bottom Water is observed on the western continental slope and within the basin up to the Greenwich Meridian. Whereas the bottom water was warming and getting more saline in the basin (Fahrbach et al., 2004) it became colder and fresher on the slope in the western Weddell Sea (Heywood et al, in preparation). It is a matter of debate if such regional changes in phase are caused by the time lag of 5-10 years involved when freshly formed bottom water spreads across the basin.

Because much of the Weddell Sea is covered with sea ice for much of the year, there is a lack of observations on the continental shelf and slope, especially in winter. This was a priority area during IPY and moored arrays were deployed together with hydrographic sections to fill the observational gaps. Measurements beneath the sea ice in the Weddell Sea were obtained for the first time by acoustically tracked floats and by instruments carried by marine mammals such as elephant seals.

4.6.6 Small-scale processes in the Southern Ocean

The importance of small-scale processes in surface, bottom and lateral boundary layers is well known. In ice-covered oceans the surface boundary layer is of particular interest (McPhee, 2009) since it controls the heat and momentum exchange between ice and ocean. These exchanges affect ice growth, melt and motion as well as the heat budget of the ocean and the currents (McPhee et al., 2008). Appropriate quantification of such processes is a prerequisite for successful modelling the large scale conditions.

For a long time small-scale processes related to ocean turbulence in the interior were almost neglected in the consideration of large-scale ocean conditions. This resulted from lacking appropriate observation techniques and theoretical concepts for relating small-scale to large-scale processes. Normally a simple energy cascade providing turbulent energy from larger scale ocean current shear to small-scale mixing was assumed, which could be applied in large-scale models by properly selected mixing parameters. However, improved measurements of turbulence suggest that the amount of turbulent energy is much larger in the interior than previously assumed. There, internal waves, not only generated at the continental slope, but as well over rough bottom topography, play a major role in generating intensive mixing in the interior away from the well-known strongly mixed boundary layers. The intensity of internal mixing is so high, that it has to be taken into account to quantitatively understand the meridional overturning circulation. The understanding of spatially and timely important variations in the intensity of mixing and its significant role for large-scale processes prompted research with the aim of detecting by observations whether changes in small-scale processes could affect large-scale conditions i.e. the oceans role in climate.

It has been estimated (e.g., Wunsch, 1998) that up to one-third of the energy required to drive the global ocean’s overturning circulation (2-3 TW, see Wunsch and Ferrari (2004) for a review) stems from the work done by the wind on the ACC, and that the bulk of that energy is transferred to the mesoscale eddy field. Current conceptual and numerical models of the Southern Ocean overturning circulation (see Rintoul et al. (2001) and Olbers et al. (2004) for two reviews) unanimously highlight the eddies’ crucial role in transporting water masses and tracers along the sloping isopycnals (surfaces of constant density) of the ACC — particularly in the upper overturning cell — as well as in transporting the momentum input by the wind to the level of topographic obstacles, such as ridges, where it may be transferred to the solid Earth.

Physical processes occurring on length scales on which earth rotation is of similar importance to ocean stratification (the baroclinic Rossby radius of deformation), which are smaller than 5-20 km south of 40ºS, (see Chelton et al., 1998) play an important role in shaping and driving the circulation of the Southern Ocean. To represent ocean properties realistically measurements and models would need to resolve this scale. However this is normally not possible and the lack of resolution has to be compensated for by assumptions about processes at this scale and below.

For example, formation of the AABW filling the deepest layers of much of the global ocean abyss is crucially dependent on the convective (i.e. small scale) production of dense, high-salinity shelf waters over the Antarctic continental shelves during periods of sea ice growth (Morales Maqueda et al., 2004), as well as on the heat and freshwater exchanges between those waters and the adjacent ice shelves (e.g. Hellmer, 2004). The properties of Antarctic shelf waters are modified further by turbulent mixing associated with the dissipation of tidal energy taking place over the continental shelves fringing the continent (Egbert and Ray, 2003), including the vicinity of the ice shelf front (Makinson et al., 2006) and sub-ice-shelf cavities (Makinson, 2002). A variety of small-scale processes underlies the conversion of tidal energy into turbulence, most prominent are the breaking of internal gravity waves generated by tidal flows impinging on rough ocean-floor topography (e.g., Robertson et al., 2003), and the formation of thick frictional boundary layers (e.g., Makinson, 2002). The importance of these processes is accentuated by the proximity of the Antarctic continental shelves to the critical latitude (where the tidal frequency is equal to the one of inertial oscillations imposed on ocean flow by the Earth's rotation) of the dominant tidal constituent (M_2), near which the generation of internal tides and frictional boundary layers is most efficient (Robertson, 2001; Pereira et al., 2002). In addition to their role in moulding the properties of shelf waters, tidal fluctuations regulate the flow of those waters across the ice shelf front (Nicholls et al., 2004) and the continental shelf break (e.g. Gordon et al., 2004), often steered by local topographic features such as canyons. On descending the continental slope in broad sheets or narrow plumes, shelf waters tend to focus in largely geostrophic boundary currents that entrain ambient surface and intermediate waters and detrain ventilated fluid in the offshore direction (Baines and Condie, 1998; Hughes and Griffiths, 2006). The shelf waters' descent is promoted further by other smaller scale processes, such as double-diffusion (instabilities due to different diffusivities of heat and salt) and interleaving (layer formation) across the shelf break zone (Foster and Carmack, 1976; Foster, 1987), as well as nonlinearities in the equation of state (thermobaricity and cabbeling) and instabilities of the Antarctic Slope Front, which have been reported to generate cyclonic eddies effecting a net downward transport of shelf water (see Baines and Condie, 1998 for a review). In subsequent stages of its northward journey, the newly formed AABW navigates numerous topographic obstacles and, in so doing, undergoes profound modification due to vigorous turbulent mixing with overlying water masses (e.g. Heywood et al., 2002). A large fraction of this modification is likely driven by flows over small sills in confined passages (Bryden and Nurser, 2003) and mid-ocean ridge-flank canyons (Thurnherr and Speer, 2003), although the breaking of internal tides (Simmons et al., 2004) and internal lee waves (Naveira Garabato et al., 2004) must contribute significantly too.

While theoretical considerations (Marshall and Naveira Garabato, 2007) and altimetric observations of an energy cascade from smaller to larger motions in the Southern Ocean (Scott and Wang, 2005) endorse the view that much of the eddy field's energy is ultimately transferred toward the ocean floor and dissipated by viscous bottom drag, measurements of oceanic fine structure (Naveira Garabato et al., 2004; Sloyan, 2005; Kunze et al., 2006) suggest that a substantial fraction of the energy is dissipated via the generation and breaking of internal lee waves. These waves induce intense turbulent mixing (Figure 4.28) and, in so doing, contribute to driving the lower cell of the Southern Ocean overturning. It thus appears that the upper and lower overturning cells, often treated as largely independent entities in descriptions of the ocean circulation, may be strongly coupled by smaller scale processes. This proposition is consistent with the concurrent intensification of eddy-driven upwelling along inclined surfaces of constant water density, and turbulent mixing of superimposed water layers of different density (diapycnal mixing) in ACC regions of complex topography. In this view, eddy dampening - which is required to sustain a vigorous meridional circulation in the upper ocean - may be connected to the topographic generation of internal lee waves in the abyss (Naveira Garabato et al., 2007). Although the patchy indirect evidence available to date points to topographic generation as the key agent in the transfer of eddy energy to the internal wave field in the ACC (Figure 4.28), other mechanisms are likely to enhance this transfer e.g. interaction between internal waves and mesoscale eddies (Polzin, 2007) and the generation of internal waves by unstable mesoscale processes (Molemaker et al., 2005). The occurrence of these processes is indicated by altimetric evidence of an energy cascade at rather small scales in the Pacific sector of the ACC (Scott and Wang, 2005). Nonetheless, it appears that diapycnal mixing in these upper layers of the ACC is primarily driven by the breaking of downward-travelling near-inertial internal waves generated by the wind in the upper-ocean mixed layer (Alford, 2003).

The key point emerging is that relatively small scale processes in the Southern Ocean exert an important influence on the large-scale behaviour of global ocean circulation over a wide range of time scales of climatic significance. This is a highly significant conclusion when one considers that these processes and interactions are often absent, or parameterized with coefficients tuned to the present ocean state, in the models used to simulate the ocean's evolution (see e.g. Wunsch and Ferrari (2004) for a discussion).

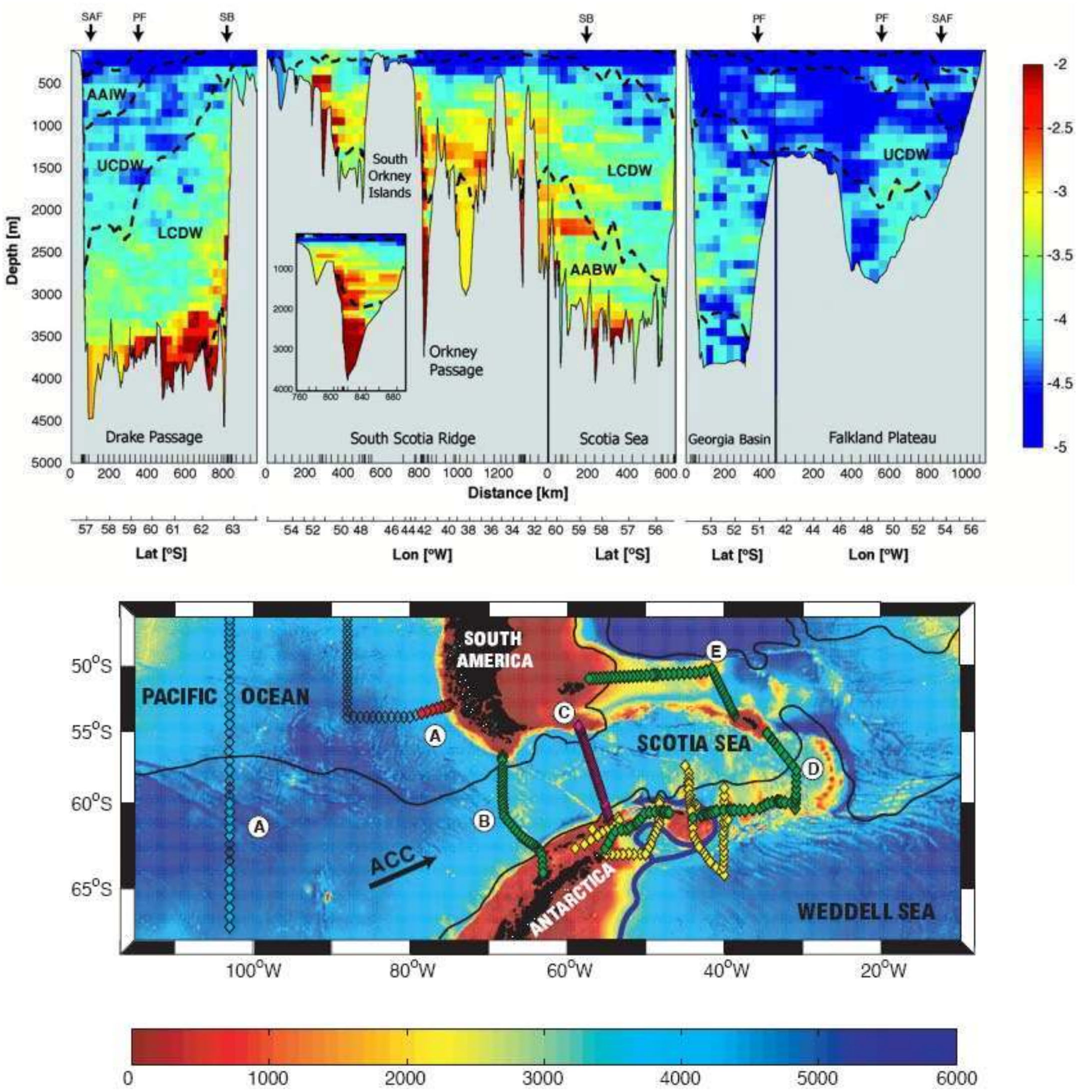


Figure 4.28 The level of turbulent energy is high over rough bottom topography up to a distance of several hundred kilometres and down into the deep ocean. As an indicator of turbulent mixing the vertical distribution of $\log_{10}$ of the turbulent diapycnal diffusivity (in m^2/sec) which can be measured (top), is displayed along a section following the rim of the Scotia Sea anticlockwise (green dots on the bottom graph). Density surfaces separating water masses (AAIW, Antarctic Intermediate Water; UCDW and LCDW, Upper and Lower Circumpolar Deep Water; AABW, Antarctic Bottom Water) are shown by the thick dashed lines. Crossings of the two main frontal jets of the ACC (SAF, Subantarctic Front; PF, Polar Front) and its southern boundary (SB) are marked in the upper axis. Station positions are indicated by tickmarks at the base of the topography. Reproduced from Naveira Garabato et al. (2004).

4.6.7 Dynamics of the circulation and water masses of the ACC and the polar gyres from model results

Observations are still not as frequent and spatially well distributed as needed to establish a well-proven view which would allow the unambiguous determination of forcing mechanisms that might be subject to change. To fill this gap, the dynamics are evaluated using results from models. However, the models themselves have shortcomings, so their results have to be considered with as much care as the ones derived from observations alone. Indeed, some models throw up contradictions that cannot be solved until new generations of models or observations become available.

A number of modelling studies, including both general circulation models (GCM) and simplified theoretical models, have been carried out in an effort to improve our understanding of the basic circulation of the ACC. These studies examined the controls on its transport strength and the mechanisms for import and export of various water masses. The GCM studies involved either the Southern Ocean only or fully global domains, and in most cases included the polar gyres, especially the cyclonic Ross Sea and the Weddell Sea Gyres. These gyres are intimately linked to the ACC, sharing their northern boundaries with the southernmost front of the ACC. Excluding the geographical areas covered by these two gyres, the ACC approaches close to the Antarctic continent (Orsi et al, 1995) and brings its relatively warm Circumpolar Deep Water (CDW) masses close to the edge of the Antarctic Ice Sheet.

A focus of most modelling studies has been to identify the forces that constitute the dynamical balance for the ACC. At the latitude of the Drake Passage, where the ACC is unbounded, the current receives a zonally-continuous momentum input from the dominantly westerly wind. Using the output from various OGCMs, efforts have been made to identify the leading dynamical process that can remove zonal momentum from the ACC at the same rate as the wind input. Given the unbounded nature of the current, it is perhaps not surprising that a classical Sverdrup balance is not able to balance the wind input (Gille et al., 2001), and that instead bottom form stress counteracts the input of momentum from the wind (Grezio et al., 2005). The amount of bottom stress is related to the representation in models of the bottom topography; models with a smoothed representation of topography produce less form stress and thus higher transport values for the ACC than those with rougher topography. Increasing the wind stress within the Southern Ocean increases the ACC transport (Gnandadesikan and Hallberg, 2000).

Eddies that result from hydrodynamic instability of the mean flow of the ACC also play a role in the momentum balance. At high latitudes the length scale at which oceanic flows are affected by the Earth's rotation is rather small - of the order of several kilometres - which means that energetic eddies are relatively small. Indeed they may be smaller than the typical grid cell in an OGCM. Most modelling studies have been carried out at a relatively coarse resolution, in which case they would not simulate eddies well. Some others, of higher resolution, do provide eddy-permitting simulations (e.g. Maltrud and McClean, 2005). The eddy-kinetic energy in OGCMs varies as a function of the model grid resolution, and this in turn has a significant influence on the simulated transport of the ACC. In some regions of the ACC, eddies cause an upgradient transfer of kinetic energy into the mean flow, while for the major part of the ACC the transfer is downgradient (Best et al, 1999). Because coarse-resolution models represent eddy processes and topography inadequately, they produce an unrealistic simulation of the ACC transport, and of the overall Southern Ocean circulation.

Under some scenarios of modelled climate change, there are significant changes in the wind field that drives the ACC. The response of the ACC to a change in the wind field occurs in the remarkably short period of two days (Webb and de Cuevas, 2006). The response is largely barotropic (induced by sea surface elevation) and controlled by the topography, with the changed wind stress quickly transferred by the barotropic flow into the bottom topography as form stress. This is an important finding in the context of climate change, as it suggests that changes in atmospheric circulation can be quickly transmitted into changes in ocean circulation. The ability of the ACC to respond quickly to the wind may explain the observed poleward shift of the ACC over recent decades. An analysis of an OGCM in which the observed poleward shift of the ACC was simulated lends support to the idea that human-induced climate change is currently influencing the ACC and will continue to do so over the coming century (Fyfe and Saenko, 2005).

Although numerical modelling of the ACC and adjacent polar gyres sheds some light on the behaviour of the ACC and its interaction with the gyres, at least two pressing questions remain poorly addressed. First, the transport volume of the ACC remains poorly constrained in different OGCMs, particularly so in models typically used in IPCC simulations, which show a wide discrepancy in transport values even where the external forcing is similar (Ivchenko et al., 2004). Analyzing the ACC transport in 18 coupled atmosphere-ocean models Russell et al (2006b) found that compared to the observed transport estimate of 135 Sv, the coupled models produced a spread ranging from a low of -6 Sv to a high of 336 Sv. They concluded that it is difficult, at present, to get the Southern Ocean “right” in coupled atmosphere-ocean models. This shortcoming reflects the lack of high resolution in many model simulations, and should be overcome as Southern Ocean eddy resolving ocean models become increasingly prevalent. Secondly it is currently difficult to model the interaction of the ACC and polar gyres with the edge of the Antarctic Ice sheet. To properly tackle this problem requires an OGCM to be coupled interactively to an ice sheet model.

4.7 Antarctic Sea Ice Cover during the Instrumental Period

4.7.1 Introduction

This section considers the variability and trend in Antarctic sea ice area and extent over the last century. This time splits into two very distinct periods. Since the 1970s microwave instruments on polar orbiting satellites have enabled sea ice observations to be made year-round and even during periods of complete cloud cover. Before that time, data were reliant on sparse ship observations that were mainly collected during the summer months.

4.7.2 Sea ice cover in the pre-satellite era

Detailed maps of the distribution of the sea ice cover at a good temporal resolution could not be made before the advent of the satellite era, because of the vast extent of sea ice in the region, general inaccessibility and adverse weather conditions. Observations of the sea ice cover were confined mainly to ship observations, such as those compiled by MacKintosh and Herman (1940). During the whaling period, the ships (which were not icebreakers) were normally located at or near the ice edge, the location of which was not precisely defined or consistently identified. The ice edge as defined using satellite passive microwave data is usually taken as the 15% ice concentration contour, and it is not known how well this would match the ice edge as observed by ships (Worby and Comiso, 2004). The whaling data were used by de la Mare (1997) to infer that the ice cover in the 1950s and 1960s was significantly more extensive than that seen in more recent times as revealed by satellite data.

A more direct comparison of the satellite monthly climatology for the period 1978 to 2007 with the MacKintosh monthly data set, as digitized from the original maps by Wadhams (personal communication, 2001), is presented in Figure 4.29. Assuming that the earlier ship observations provide a reasonably accurate representation of average ice edge locations, then the average locations of the ice edge during the satellite period were usually further south, showing that ice cover was more extensive in the 1950s and 1960s than later. These results are consistent with the observation that Antarctica has warmed during the same period (Steig et al., 2009). Interpretation of these results, however, has to be done in the context of the uncertainties as pointed out by Ackley et al. (2003).

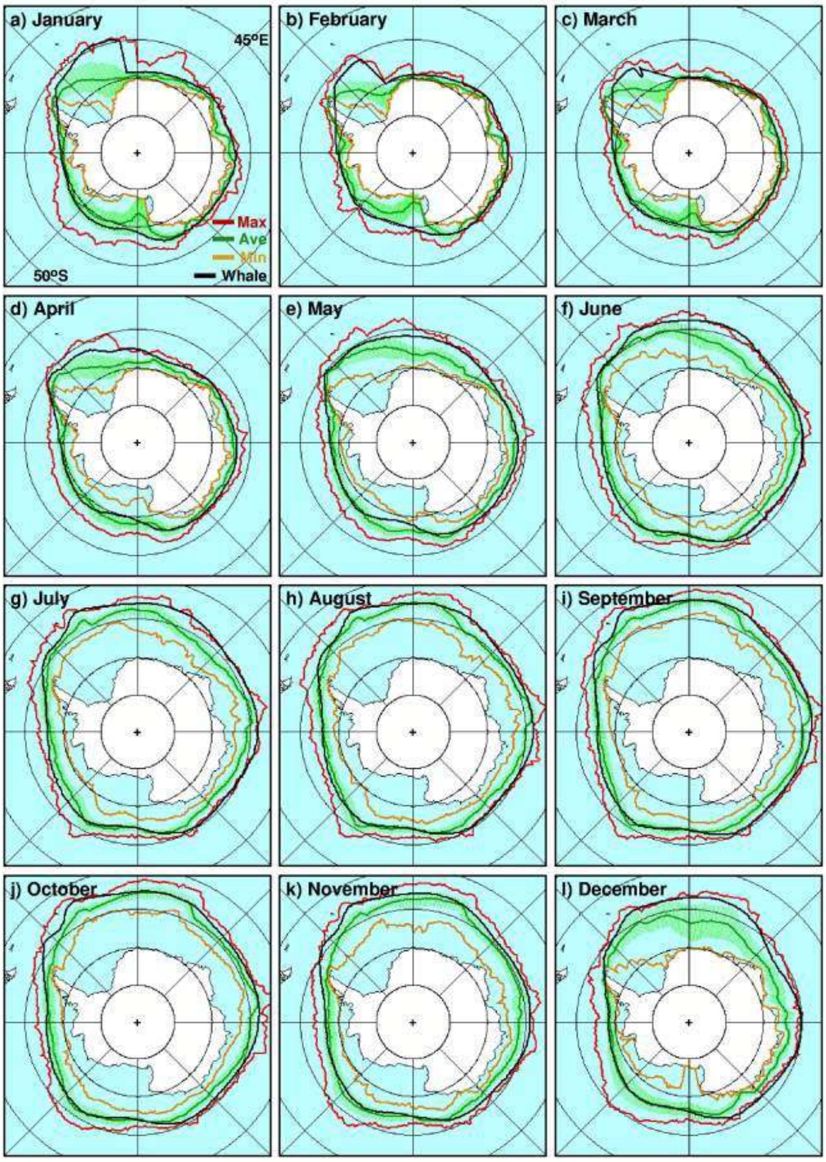


Figure 4.29 Average monthly location of the ice edge during the whaling period (1930s to 1940s) as compiled by MacKintosh (black), and as derived from satellite data for the period 1978 to 2007 (dark green). The standard deviation of the ice edge along different longitudes separated by one degree is shown in green, while the most northern and most southern locations are represented in red and gold, respectively. (Note: MacKintosh digital data was provided by P. Wadhams in 2001).

Simulations with the climate model LOVECLIM with simple data assimilation provides information on sea ice area during the Twentieth Century. It shows a decrease of 0.5 $\times 10^6$ km^2 from the 1960s to the early 1980s, but a slight increase from 1980 to 2000 (Goosse et al, 2008). Although we lack the sea ice data to confirm the early decrease, the model is consistent with available data from both atmosphere and ocean.

4.7.3 Variability and trends in sea ice using satellite data

The ESMR instrument flown on board the Nimbus-5 satellite was the first scanning microwave radiometer and therefore was first to provide the true spatial distribution of the ice cover at a reasonable time resolution. Although meant primarily for rainfall studies it found its best applications for sea ice studies because of the high contrast in the emissivity of sea ice and liquid water. While the data from this instrument are not used in the time series analysis presented below, the sea ice cover during this period was well documented (Zwally et al., 1983). The data led to the discovery of the existence of the large Weddell polynya about the size of California that persisted throughout winter and for three successive years from 1974 through 1976 (Zwally and Gloersen 1977). As discussed in Chapter 2, combining ESMR data with SMMR and SSM/I observations is difficult because (i) there is no overlap in data to ensure that the ESMR data provides the same ice edge and ice extent as in the other data sets; (ii) there are too many gaps including more than 3 months in succession in 1975; (iii) and inaccurate ice concentrations were recorded because of only one channel being available for the sensor, making it impossible to correct for spatial variations in emissivity and temperature. Qualitative analysis can be done: for example, a four-year average of the ESMR data can be compared with four-year averages of SMMR and SSM/I data during different periods, but, unless large changes are apparent, the comparison may be difficult to interpret. The following discussion concentrates on the period from 1978 when the SMMR data became available.

The large-scale seasonal variation of the sea ice cover in the Southern Hemisphere is depicted by the colour-coded multiyear monthly averages of the ice cover (Figure 4.30). The AMSR-E ice concentration data are gridded at 12.5 km to provide a more accurate spatial representation of the sea ice cover than the SMMR and SSM/I data, which are gridded at 25 km resolution. The maps were derived by taking the average of all data available for each month, using the dataset that starts in June 2002 and ends in December 2007. The monthly data set thus represents contemporary ice cover and could serve as a guideline for expected distribution of the Antarctic sea ice cover. The series of images starts in January, usually the warmest mid-summer month and the time of highest melt rate. The minimum extent usually occurs in late February or early March. There are two primary locations where ice survives in the summer: one in the Western Weddell Sea and the other in the Bellingshausen, Amundsen, and Ross Seas. The extents of the perennial ice in these two regions are comparable, but vary slightly in magnitude and location from one year to another. The period of most rapid growth is from April to June; by July it has reached close to its maximum extent, which is normally in September or October. Ice cover decays rapidly between November and January. Around the continent, sea ice advances the least from the coastline mainly in the Western Pacific (90°E to 150°E) and at the tip of the Antarctic Peninsula, where the coast is farthest to the north. The shape of the ice cover during ice maxima (September) is almost symmetrical around the continent, with a tendency to have a sharp corner at about 217°E, which is in part influenced by the shape of the bathymetry there.

Among the most distinctive features in the inner zone of the ice cover are the reduced ice concentrations (i) adjacent to the Ross Ice Shelf, (ii) at or near the Maud Rise (5ºE), and (iii) near the Cosmonaut Sea (45ºE). These are regions where short term (or transient) polynyas usually occur in mid-winter (Comiso and Gordon, 1996), and which have been associated with the initiation of deep ocean convection and the formation of the high salinity bottom water that drives the global thermohaline circulation. Because they normally appear during different times of the winter season and in different places they are not well represented in the winter climatological averages. The features are most evident in the images in late winter to spring (September to November) suggesting that the ice cover in these regions is vulnerable to divergence and melt because of relatively thinner ice and warmer water under the ice. Such regions have also been the scene of high productivity (Smith and Comiso, 2008) reflecting the possible influence of sea ice, as has been suggested previously (Smith and Nelson, 1986).

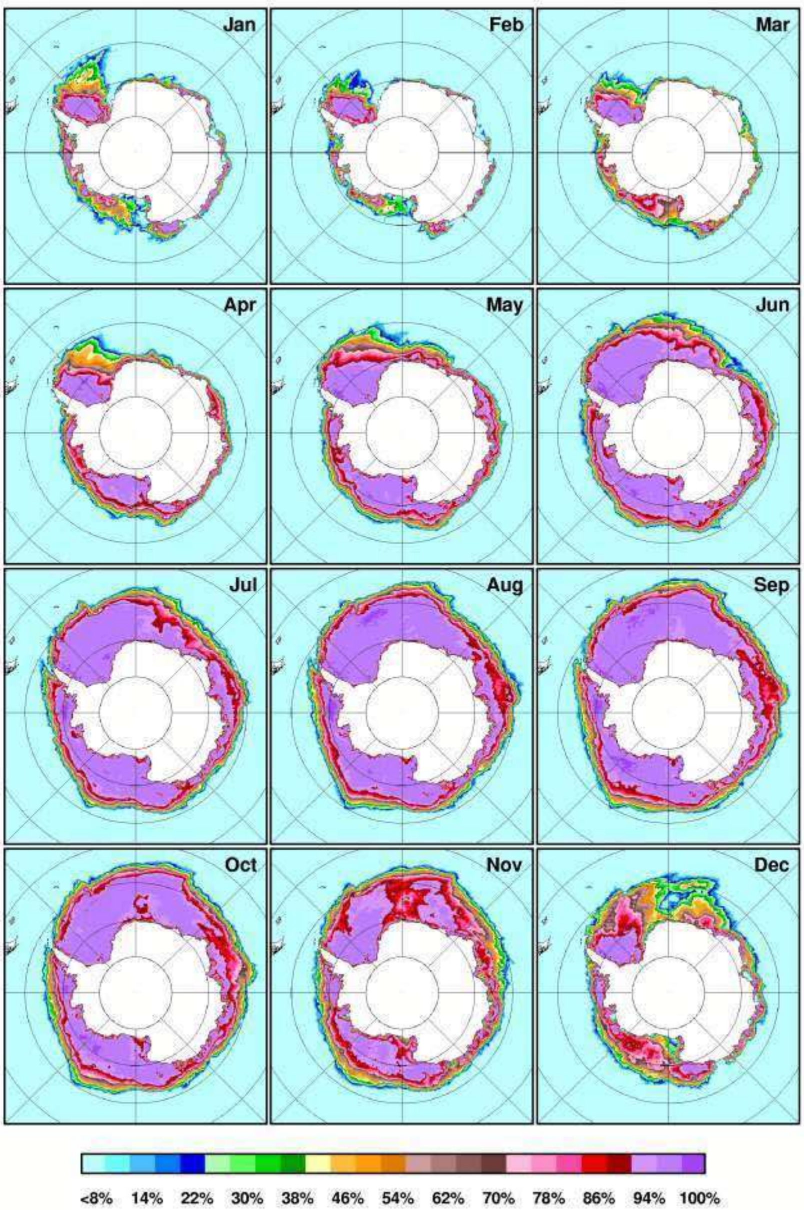


Figure 4.30 Monthly climatology of the sea ice concentration as derived from AMSR-E data (2002 to 2007). (derivation explained in text).

The parameters that have been used for quantifying the variability and trends in the sea ice cover are ice extent and ice area, both of which are derived from the passive microwave ice concentration data. Ice extent is defined as the integrated sum of the area of all the pixel elements with at least 15 % concentration, while ice area is the integrated sum of the area of each pixel multiplied by the ice concentration. Time series plots of monthly values of the ice area, ice extent and also average ice concentration as derived from SMMR and SSM/I data from November 1978 to December 2007 are presented in Figure 4.31. Over the 28-year period of consistently processed passive microwave data, the seasonal and yearly variations in the sea ice extent and ice areas appear to be very similar. The annual maxima and minima vary only slightly despite relatively large interannual variations in average ice concentrations, especially during the summer period. In the summer, the large fluctuation may be caused by the vulnerability of the ice cover to divergence due to winds, waves and other forcings, because of relatively smaller extents. For example, more ice could be advected further north where the water is warmer during some years when southerly winds are prominent. The average ice concentration is almost constant in the winter, at about 83%, while the average ice concentration in the summer ranges from 59% to 69%. The distributions of ice extents vary consistently with the ice area, with the latter being somewhat lower, as expected.

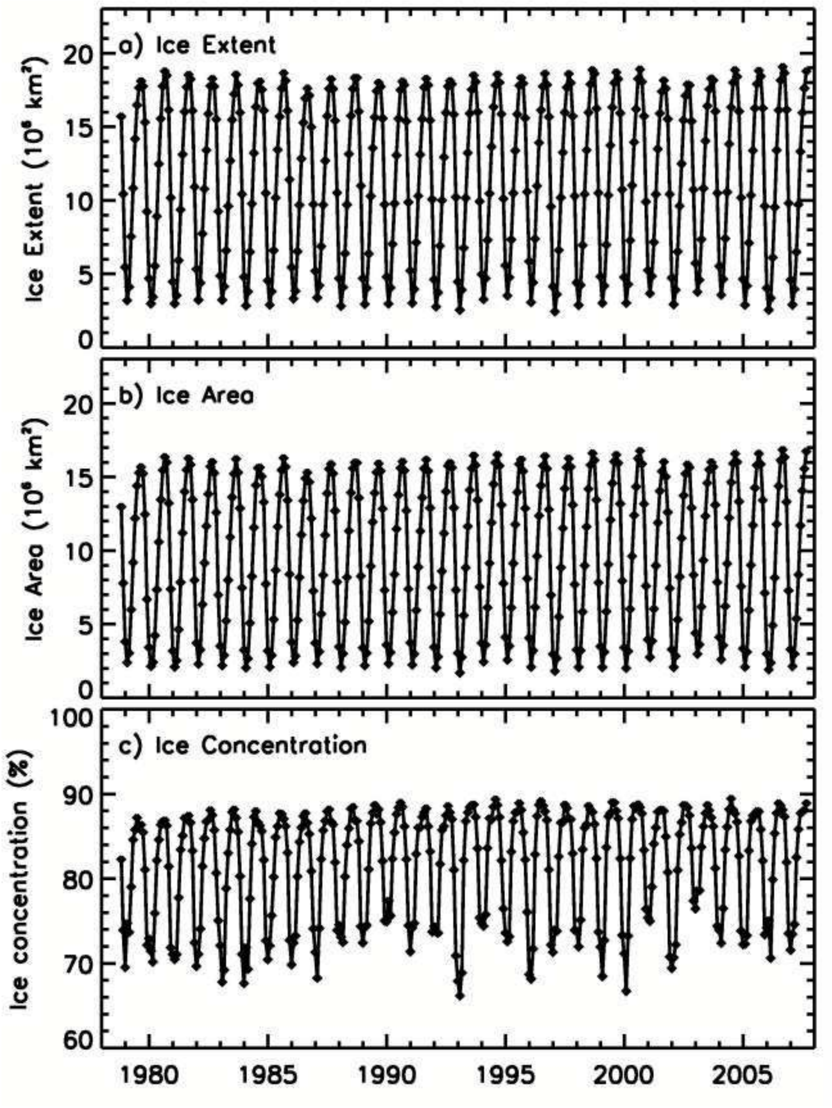


Figure 4.31 Monthly extent (the total area of sea ice and leads within the 15% sea ice concentration limit), area (the integrated area of sea ice within the 15% sea ice concentration limit), and average ice concentration in the Southern Hemisphere.

During the years when the monthly ice extent and area in the winter were most expansive (1980) or least expansive (1986), the corresponding values in the subsequent summer were not the most expansive or least expansive, respectively. Thus the decay patterns are not significantly influenced by the extent of ice during the preceding winter period. Conversely, the growth patterns are also not significantly influenced by the extent of ice during the preceding summer. This counter-intuitive phenomenon is more apparent on a regional basis. For example, in the Weddell Sea, anomalously extensive ice cover in winter is usually followed by anomalously low ice cover area in the summer and vice-versa (Zwally et al., 1983).

To assess interannual changes and trends in the sea ice extent and ice area, monthly anomalies are used, as in previous studies (e.g., Zwally et al., 2002a). The monthly anomalies were estimated by subtracting monthly climatologies from each month from November 1978 to December 2007. The monthly climatologies were generated by taking the average of all satellite data available for each of the months. For consistency only SMMR and SSM/I data during the period were used. The sea ice extent shows a positive trend of 0.9 ± 0.2% per decade for the Southern Hemisphere for the period January 1979 to December 2008. This is consistent with the 1.0 ± 0.4% per decade reported by Zwally et al. (2002a) for the 1979 to 1998 period. The trend in ice area is slightly more positive at 1.6 ± 0.2%/decade, in part because of a positive trend in ice concentration at about 0.93 ± 0.13%/decade. The errors cited are the statistical error as provided by the standard deviation of the slopes in the regression analysis. Unknown biases that may be associated with different calibration and resolution of the SMMR and SSM/I sensors are not reflected by this error. Assuming that the latter is small, as inferred from the overlap of SMMR and SSM/I data of about a month, the positive trend is small but significant. This is consistent with observed cooling in parts of the Antarctic during the period (Comiso, 2000; Kwok and Comiso, 2002).

Trend analysis of the ice extent in different Antarctic sectors (as defined in Zwally et al., 2002a) (see Figure 4.32) yields positive trends of varying magnitude in all except in the Bellingshausen/Amundsen Seas sector. The trend is least positive in the Western Pacific and the Weddell Sea sector at 0.7 ± 0.6 and 0.8 ± 0.5%/decade followed by the Indian Oceans sectors at 1.9 ± 0.6%/decade. The most positive is the Ross Sea sector at 4.3 ± 0.7%/decade; an increase that was simulated by the LOVECLIM model (Goosse et al., 2008). The trend in the Bellingshausen/Amundsen Seas sector is -6.8 ± 1.0%/decade, which serves to balance the relatively high trend in the Ross Sea. Since these two sectors are adjacent to one another, the opposite trends in the two sectors are in part caused by the advection of ice from one sector to the other. This pattern of change has been linked to the recent deepening of the Amundsen Sea Low as a result, primarily, of the loss of stratospheric ozone (Turner et al., 2009).

The Antarctic Peninsula adjacent to the Bellingshausen/Amundsen Seas sector is an area of marked warming, as described previously by King (1994) and Jacobs and Comiso (1997). Also, the variability of ice in the Ross Sea region is associated with the influence of ENSO (Ledley and Huang, 1997) and the continental area adjacent to it has been experiencing some cooling during the last two decades (Comiso, 2000; Doran et al., 2002). The positive trend in the Ross Sea, which is the site of a major coastal polynya, suggests increased ice production and a more important role of the region in bottom water formation.

Yearly maximum and minimum ice extent and ice area were estimated for each year using 5 day running averages of daily data and the results are presented in Figure 4.33. While interannual changes in wind circulation can be a significant factor, these parameters are basically associated with the thermal state of the ice-covered ocean and adjacent seas. The plots for maximum extents and areas are shown to be basically stable with very little interannual variability. Relatively high ice extents occurred in 1980, 1998, 2000, 2005 and 2006 while relatively low values occurred in 1986 and 2002. The high and low values in the ice area maxima are relatively the same but the variability varies slightly because of interannual changes in sea ice concentration. The interannual fluctuations in the ice minimum are much higher with relatively high values in ice extents occurring in 1982, 1983, 1986, 1987, 1994, 1995, 2001 and 2003 while relatively low values occurred in 1993, 1997, and 2006. The interannual changes in ice area minima are similar but there are significant differences, such as the changes from 1982 to 1983 and from 1986 to 1987 where the ice extent shows an increase from one year to the next while the ice area shows a decrease. Such a phenomenon is likely caused by divergences associated with wind conditions that can cause an increase in ice extent but not in ice area. Trend analysis of the data yielded results very similar to those of the overall trend, with the trends of maximum ice values being 0.9 ± 0.4%/decade and 1.5 ± 0.4%/decade for ice extent and ice area, respectively. The trends of minimum ice values are 0.6 ± 2.7 and 1.5 ± 3.0%/decade for ice extent and ice area, respectively. These results show that the trends of maximum ice extents and areas are similar to the corresponding minimum ice extents and areas but with higher statistical variability for the latter.

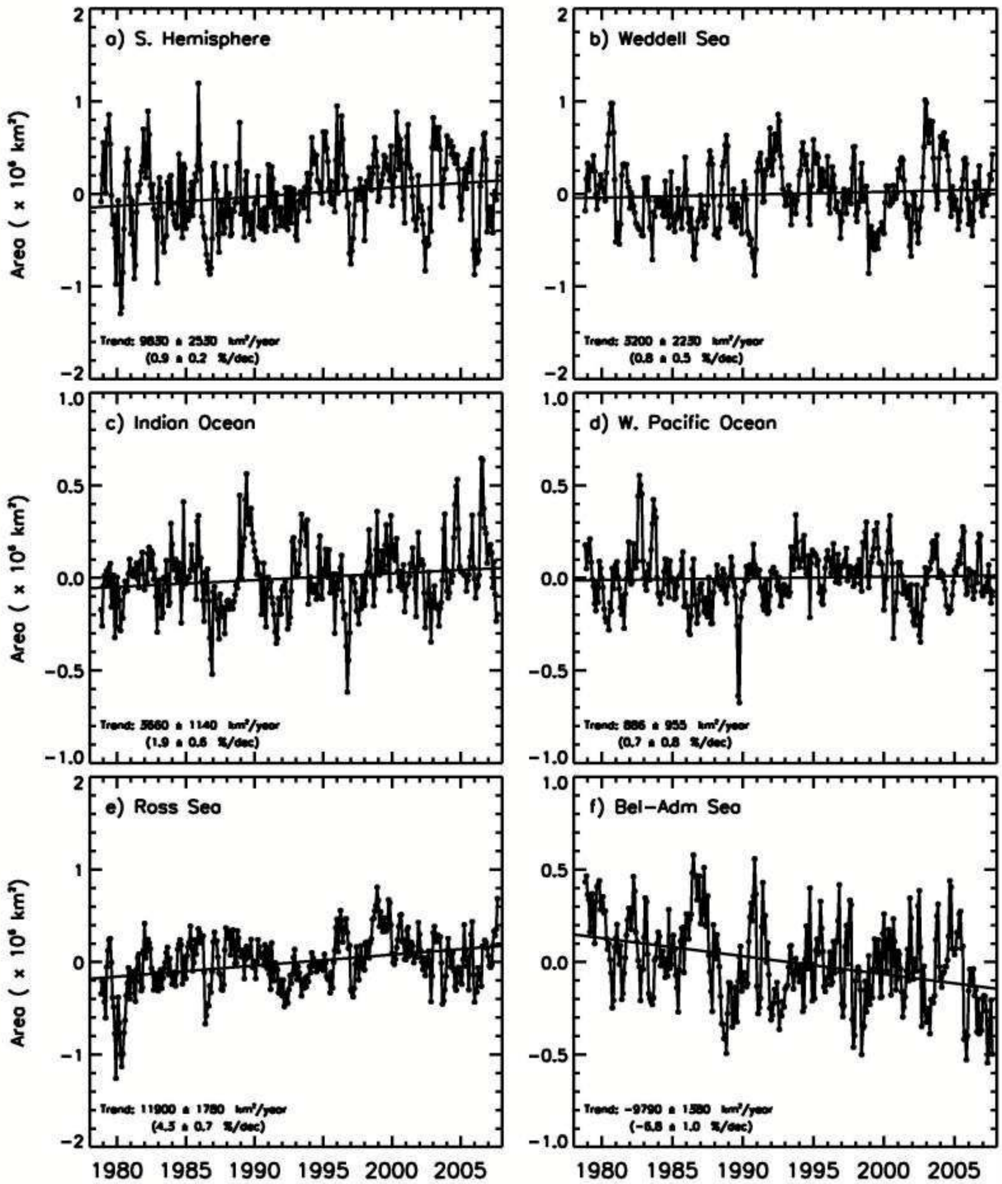


Figure 4.32 Ice Extent monthly anomalies and trend lines for (a) the Southern Hemisphere; (b) Weddell Sea; (c) Indian Ocean; (d) W. Pacific Ocean; (e) Ross Sea; and (f) Bellingshausen/Amundsen Seas Sectors

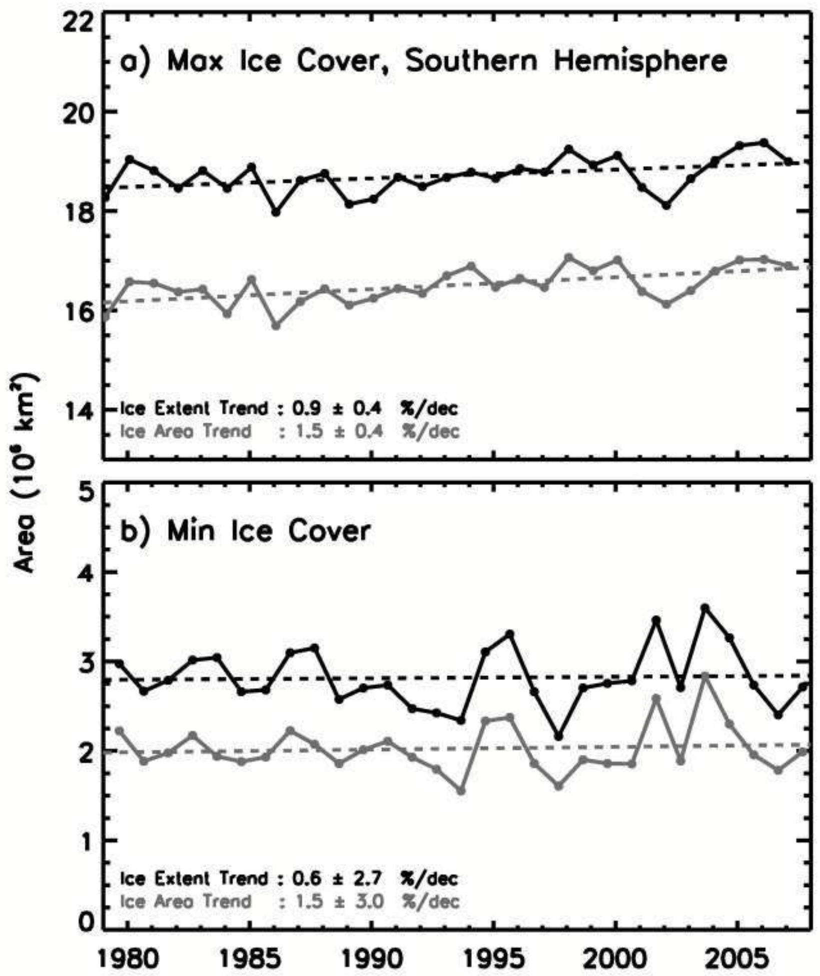


Figure 4.33 Yearly maximum and minimum extent and area of the ice cover in the Southern Hemisphere and trend results.

4.8 The ice sheet and permafrost

4.8.1 Introduction

Ice sheets are to some degree self-regulating systems. Increasing snowfall over the ice sheet will act to increase the ice thickness, but that will then increase the rate of ice-flow towards the coasts and thus remove the extra snowfall. Thus the ice sheet will evolve towards a shape and pattern of flow specific to the current climate, where flow exactly compensates the spatial pattern of ice accumulation (snowfall and frost deposition) and ice ablation (melting, wind erosion and calving).

This equilibrium state is a useful concept, but it is rarely realised; the driving environmental parameters of climate are themselves constantly changing, which continually modifies the equilibrium state sought by the ice sheet. At any given time, the changes in the ice sheet reflect responses to both recent and long-term changes in climate, and for this reason, areal extent, magnitude and duration of changes, as well as time scale must be carefully considered in any discussion of ice-sheet change.

Until the era of satellites, large-scale changes in the ice sheet were considered likely to unfold over thousands of years (Payne et al., 2006). Now, significant accelerations and decelerations of large outlet glaciers and ice streams have been observed on much shorter timescales (Bindschadler et al., 2003; Rignot and Kanagaratnam, 2006; Truffer and Fahnestock, 2007). In Antarctica, these changes affect a complex drainage system of ice streams and tributaries whose full extent has only become appreciated through satellite observations (Joughin et al., 1999; Bamber et al., 2000). Since the 1970s, there have been competing hypotheses concerning the influence of ice shelves on the flow rates of upstream glaciers. Satellites have confronted these hypotheses with empirical measurements for the first time. Another important contribution of satellites has been to identify two key regions of change in Antarctica; one near the northern tip of the Antarctic Peninsula, another within the rarely visited Amundsen Sea sector of West Antarctica.

Despite a good understanding of the complexity of the issues, its importance to understanding sea level rise has meant that measurement of the ice sheet's mass balance has been a primary goal of Antarctic science since the early efforts following the IGY (1957/58). Many of these were based on accounting methods involving calculations of the imbalance between net snow accumulation and outflow of ice over particular domains. Such efforts have always been hampered by the intrinsic uncertainty in measuring these parameters, and very few have produced measurements of ice-sheet imbalance that do not plausibly allow changes in a particular domain to be either positive or negative. So while there have been a few notable exceptions (e.g. Joughin and Tulaczyk, 2002; Rignot and Thomas, 2002; Rignot, 2008), and future efforts based on satellite data may prove to be valuable, our best measurements of change across the majority of the Antarctic ice sheet come not from accounting methods, but rather from those techniques that seek to measure the changing volume of the ice-sheet directly.

The most successful of these techniques of direct measurement has been the use of satellite altimetry (Figure 4.34). A number of research groups have evaluated data beginning in the early 1980s. Spanning data from multiple satellite altimeters, they have produced broadly consistent results (e.g., Wingham et al., 1998, 2006a; Davis et al., 2005; Zwally et al., 2005). These results illustrate that separate catchment basins within the ice sheet behave somewhat independently. What altimetry often fails to capture are the largest changes at the ice sheet margins, where steep slopes lead to large errors of measurement, and the large thickness changes on the floating ice shelves at the perimeter, where elevation changes represent only 1/8 of the full thickness change.

More recently, measurements of changes in the Earth's gravity field have been made using GRACE (Gravity Recovery and Climate Experiment). These satellites have confirmed that the Amundsen Sea sector is losing mass to the ocean (Velicogna and Wahr, 2006; Ramillien et al., 2006; Chen et al., 2006). The GRACE system works by tracking the range between two orbiting satellites: their differential accelerations provide a sensitive measure of how the distribution of mass across the Earth's surface is changing. The system is unable to distinguish separately the changes in ice, rock, and air; so the flows within the Earth's mantle and atmosphere must be removed to reveal changes in the ice sheets. So far this correction has been derived using models of the atmospheric and lithospheric mass flows, but observations of isostatic uplift measured in the field using GPS receivers mounted on exposed rock outcrops should provide a better constraint, especially if GRACE observations are combined with altimetric observations (Velicogna and Wahr, 2002). Chen et al. (2006) report a localised region of mass increase in East Antarctica. This could either be anomalously high snowfall, leading to growth of ice in this region, or an artefact of un-modelled post-glacial rebound. The system has only been in operation for a few years, and snowfall is variable from year to year, so the long-term significance of the available results can be questioned. However there is little doubt that longer records from these satellites will eventually provide extremely valuable information on the changes in the mass of ice sheets.

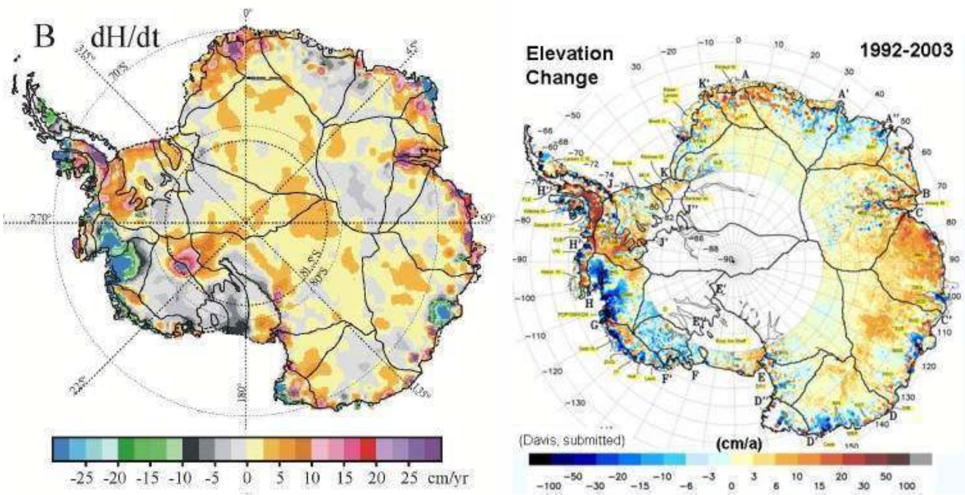


Figure 4.34 Elevation change Zwally (left) and Davis (right).

Antarctica's ice shelves and ice tongues ('ice tongues' are narrowly-confined ice shelves bounded by fjord walls) are particularly sensitive to climate change because both the upper and lower surface of the ice plate are exposed to different systems, each with a potential to cause rapid change: these are the atmosphere and the ocean. The ice-atmosphere system affects the ice shelf through changing surface accumulation, dust and soot deposition, and surface melt; the ice-ocean system controls basal melting or freezing, tidal flexure, and wave action. Moreover, it is now recognized that sea ice, which is not part of the ice sheet, but is viewed more properly as a component of the atmosphere-ocean system, has a large impact on the local climate and dynamics of the ice shelf front, controlling regional surface energy balance, moisture flux, and the presence or absence of ocean swell at the front.
Antarctica's ice shelves have provided the most dramatic evidence to date that at least some regions of the Antarctic are warming significantly, and have shown, what has been suspected for long time (e.g. Mercer, 1978), namely that changes in floating ice shelves can cause significant changes in the grounded ice sheet. This evidence has led to an ongoing re-assessment of how quickly greenhouse-driven climate changes could translate into sea level rise (Meehl et al, 2007).

Ice shelves in two regions of the Antarctic Ice Sheet have shown rapid changes in recent decades: the Antarctic Peninsula and the northern region of West Antarctica draining into the Amundsen Sea. Because there is such spatial variety in the observed changes, and because the causes of the changes likely vary regionally, changes over the past 50 years are discussed below according to province. A review of events in these two regions will introduce two main mechanisms by which climate change is thought to lead to changes in ice sheet mass balance: surface summer melt increase, leading to ponding, fracturing and disintegration: and basal melting of the ice shelves, leading to shelf thinning and grounding line retreat.

4.8.2 The Antarctic Peninsula

The Antarctic Peninsula north of 70°S represents less than 1% of the area of the entire grounded Antarctic ice sheet, but receives nearly 10% of its snowfall (van Lipzig, et al., 2004a). A third of this area lies close to the coast and below 200 m elevation, where summer temperatures are frequently above 0°C, so that this is the only part of continental Antarctica that experiences substantial summer melt. About 80% of its area is classed as a percolation zone (Rau and Braun, 2002), and melt water run-off is a significant component in its mass balance (Vaughan, 2006).

Beginning in the early 1990s, climatologists noted a pronounced warming trend present in the instrumental record from the Antarctic Peninsula stations (King, 1994; Vaughan and Doake, 1996; Skvarca et al., 1998). This region has the highest density of long-term weather observations in the Antarctic, dating back to 1903 for Orcadas Station. Rates of warming on the Antarctic Peninsula are some of the fastest measured in the Southern Hemisphere (~3ºC in the last 50 years) (King, 2003; Vaughan, et al., 2003) and there has been a clear increase in the duration and intensity of summer melting conditions by up to 74% since 1950 (Vaughan, 2006).

A recent study has shown that circa 2005, the Antarctic Peninsula was contributing to global sea level rise through enhanced melt and glacier acceleration at a rate of 0.16 ± 0.06 mm/yr (which can be compared to an estimated total Antarctic Peninsula ice volume of 95,200 km^3, equivalent to 242 mm of sea-level) (Pritchard and Vaughan, 2007). Although it is known that Antarctic Peninsula glaciers drain a large volume of ice, it is not yet certain how much of the increased outflow is balanced by increased snow accumulation. One estimate of mass change due primarily to temperature-dependent increases in snowfall on the peninsula suggested a contribution to sea level of approximately -0.003 mm/yr (Morris and Mulvaney, 2004).

4.8.2.1 Glaciers

The ice-cover on the Antarctic Peninsula is a complex alpine system of more than 400 individual glaciers that drain a high and narrow mountain plateau. The tidewater/marine glacier systems in this region (excluding ice shelves and the former tributary glaciers of Larsen A, B and Wordie ice shelves) have an area of 95,000 km^2 and a mean net annual accumulation of 143 ± 29 Gt/yr (after van Lipzig et al., 2004a). Changes in the ice margin around the Antarctic Peninsula based on data from 1940 to 2001 have been compiled (Ferrigno et al., 2002, 2006; Cook et al. 2005). Analysis of the results revealed that of the 244 marine glaciers that drain the ice sheet and associated islands, 212 (87%) have shown overall retreat since their earliest known position (which, on average, was 1953). The other 32 glaciers have shown overall advance, but these advances are generally small in comparison with the scale of retreats observed.

The glaciers that have advanced are not clustered in any pattern, but are evenly scattered down the coast (Figure 4.35). Examination of the timing of changes along the peninsula indicates that from 1945 until 1954 there were more glaciers advancing (62%) than retreating (38%). After that time, the number retreating has risen, with 75% in retreat in the period 2000-2004. The results indicate a transition between mean advance and mean retreat; a southerly migration of that transition at a time of ice shelf retreat and progressive atmospheric warming; and a clear regime of retreat which now exists across the Antarctic Peninsula (Figure 4.36). The rapidity of the migration suggests that atmospheric warming may not be the sole driver of glacier retreat in this region. Glaciers with fully grounded marine termini exhibit unusually complex responses to changing mass balance because in addition to the normal forcings they are also subject to oceanographic forcing and subglacial topography. Future analysis of changes in all boundary conditions may reveal why the glaciers have responded in this way.

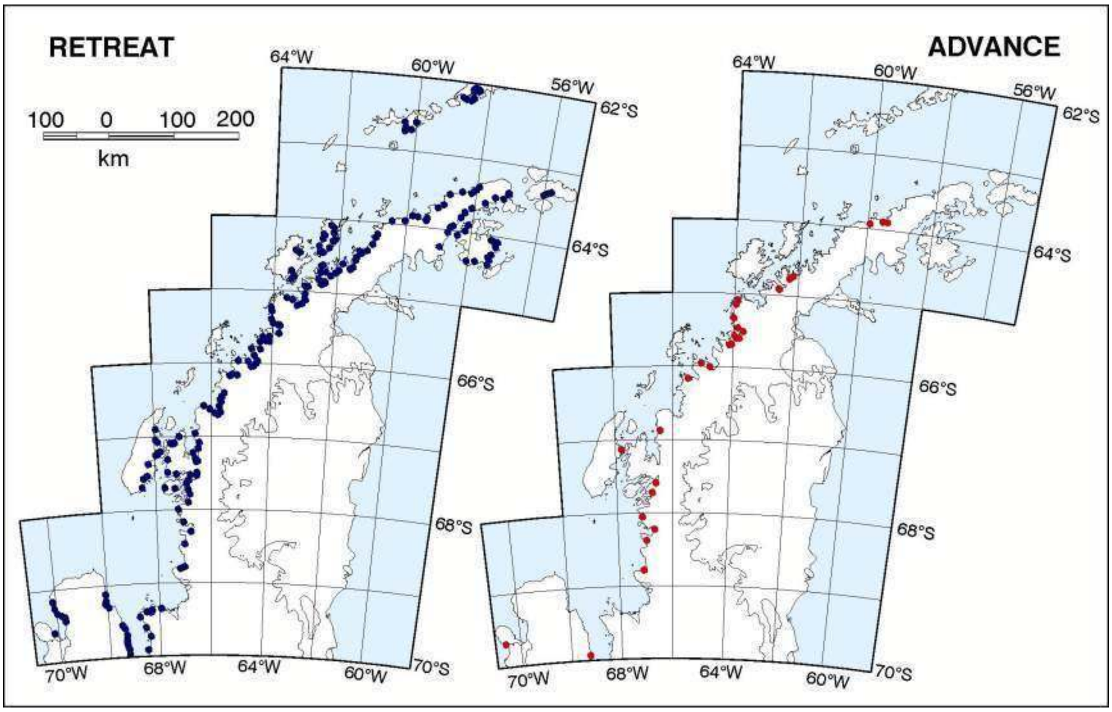


Figure 4.35 Overall change observed in glacier fronts since earliest records. (From Cook et al., 2005).

A recent study of flow rates of tidewater glaciers has revealed a widespread acceleration of ice flow across the Peninsula (Pritchard and Vaughan, 2007). This widespread acceleration trend was attributed not to meltwater-enhanced lubrication or increased snowfall but to a dynamic response to frontal retreat and thinning. Measurements were taken from over 300 glaciers on the west coast through nine summers from 1992 to 2005. They showed that overall flow rate increased by 10% and that this trend is greater than the seasonal variability in flow rate. A comparison of measurements between the years 1993 and 2003 only (with profiles tailored to optimize coverage in just these years) revealed a slightly greater overall acceleration of 12.4 ± 0.9%.

The loss of ice shelves (Section 4.8.2.2) has caused acceleration of the glaciers that fed them (Rignot et al., 2004a, 2005; Rott et al., 1996; Scambos et al., 2004) creating locally high imbalances in ice mass. Immediately after break-up, glaciers flowing into the now-collapsed sections of the Larsen Ice Shelf accelerated to speeds of 2 to 8 times the pre-disintegration flow rate (Rignot et al., 2004a; Scambos et al., 2004). The glaciers flowing into the Wordie Ice Shelf also accelerated following ice shelf loss, and have been losing mass to the ocean over the last decade (Rignot et al., 2005). One of these, Fleming Glacier, accelerated by about 50% during the period 1974-2003, and the region was losing mass at 18±5.4 Gt/yr. A field campaign carried out in December 2008 using GPS measurements and an airborne laser survey confirmed that the glacier maintains these high flow rates and experiences a pronounced ice thinning (Wendt et al., In Press). The ice flux increase may be partially offset by increased precipitation in the western Peninsula (Turner et al., 2005b), but both ice shelves (Fox and Vaughan, 2005) and glaciers in the west (Pritchard and Vaughan, 2007) continue to retreat. The combined estimate of mass loss (as of 2005) was 43±7 Gt/yr, but a more recent assessment of the region suggests this rate has slowed (28±45 Gt/yr, Rignot et al., 2008). In addition to the increase in flow rates, a recent study has revealed profound dynamic thinning of collapsed-ice shelf tributary glaciers flowing from the Antarctic Peninsula plateau to both east and west coasts (Pritchard et al., submitted). Analysis of ICESat laser altimeter data, processed along-track for the period 2003-2007, showed how surface elevation has changed over the whole of the Antarctic Peninsula. The high, central plateau and slow flowing ice caps thickened at rates as high as 1 m/yr. In contrast, some of the highest rates of thinning recorded either in Antarctica or Greenland (up to tens of metres per year) are occurring on glaciers that flowed into ice shelves that have now disappeared. Glacier tributaries feeding the intact but thinning ice shelves of Larsen C and remnants of Larsen B, plus George VI Ice Shelf and the little-studied Larsen D also thinned at rates up to several metres per year. This behaviour confirms that glaciers are very sensitive to ice shelf thinning as well as collapse, and that shelf collapse leads not just to short-term and localized adjustment but to sustained, widespread and substantial loss of grounded ice from tributary glaciers (Pritchard et al., submitted).

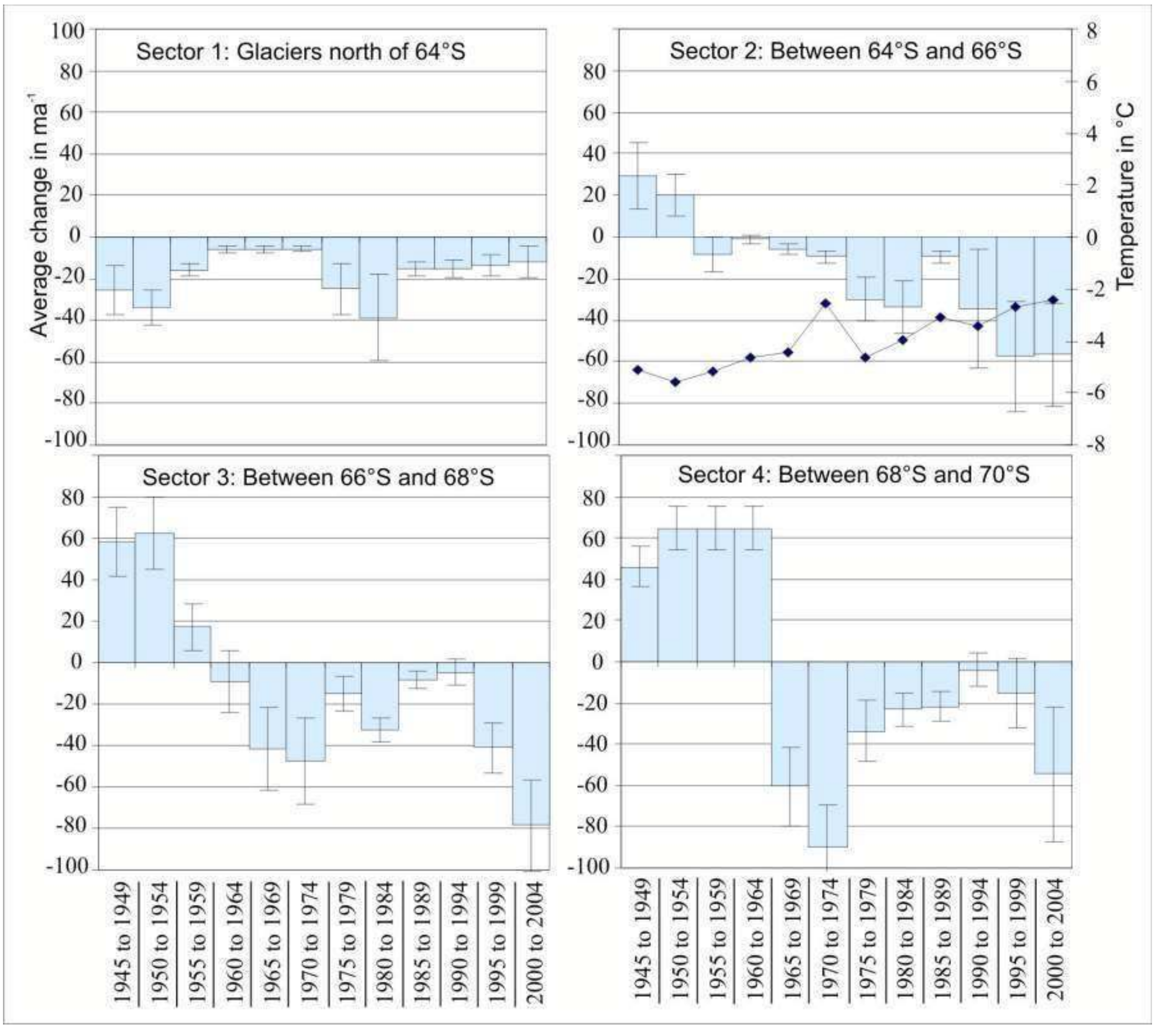


Figure 4.36 Change in Antarctic Peninsula glaciers over time and by latitude. Prior to 1945 the limit of glacier retreat was north of 64°S; in 1955 it was in the interval 64-66°S; in 1960 between 66-68°S and in 1965 between 68-70°S. (from Cook et al., 2005).

4.8.2.2 Ice shelves

Retreat of several ice shelves on either side of the Peninsula was already occurring when scientific observations began in 1903. Since that time, ice shelves on both the east and west coasts have suffered progressive retreat and some abrupt collapse (Morris and Vaughan, 2003; Scambos et al., 2000). Ten ice shelves have undergone retreat during the latter part of the 20th Century (Cooper, 1997; Doake and Vaughan, 1991; Fox and Vaughan, 2005; Luchitta and Rosanova, 1998; Rott et al., 1996, 2002; Scambos et al., 2000, 2004; Skvarca, 1994; Ward, 1995) (Table 4.1). Wordie Ice Shelf, the northernmost large (>1,000 km^2) shelf on the western Peninsula, disintegrated in a series of fragmentations through the 1970s and 1980s, and was almost completely absent by the early 1990s. The Wordie break-up was followed in 1995 and 2002 by spectacular retreats of the two northernmost sections of the Larsen Ice Shelf (termed Larsen 'A' and Larsen 'B' by nomenclature proposed by Vaughan and Doake, 1996) and the last remnant of the Prince Gustav Ice Shelf (Figure 4.37). A similar 'disintegration' event was observed in 1998 on the Wilkins Ice Shelf (Scambos et al., 2000), but much of the calved ice remained until 2008 when dramatic calving removed about 1,400 km^2 of ice. The ice bridge connecting the Wilkins Ice Shelf to Charcot Island disintegrated in early April 2009. In all these cases, persistent seasonal retreats by calving (Cooper, 1997; Skvarca, 1993; Vaughan, 1993) culminated in catastrophic disintegrations, especially for the Larsen A (Rott et al., 1996; Scambos et al., 2000) and Larsen B (Scambos et al., 2003).

The sequence of events leading up to the collapse of the Larsen B ice shelf suggests the processes responsible for the ultimate disintegration. In the 35-day period from 31 January 2002, satellite images recorded by the Moderate Resolution Imaging Spectroradiometer (MODIS) revealed a disintegration of a 5,700 km^2 section of the Larsen B ice shelf. The January MODIS images showed that prior to its disintegration, the Larsen B ice shelf was subject to more extensive ponding of meltwater than in previous years (Scambos et al., 2004). As this water drained into pre-existing crevasses, and filled them, the water pressure would have been sufficient to propagate the cracks through the entire thickness of the ice shelf (Weertman, 1973; Scambos et al. 2000). Satellite radar interferometry has been used with ice flow models to show that the ice shelf sped up considerably in the period before its final collapse because of weakening within its margins, perhaps as a consequence of this mechanism (Vieli et al., 2007). Once the Larsen B ice shelf had disintegrated into icebergs, the forces set up as they toppled against one another drove them rapidly apart (MacAyeal et al., 2003). A MODIS image taken on 7 March 2002 (Figure 4.37) shows a plume of icebergs being ejected, clearing the bay that was previously occupied by the ice shelf.

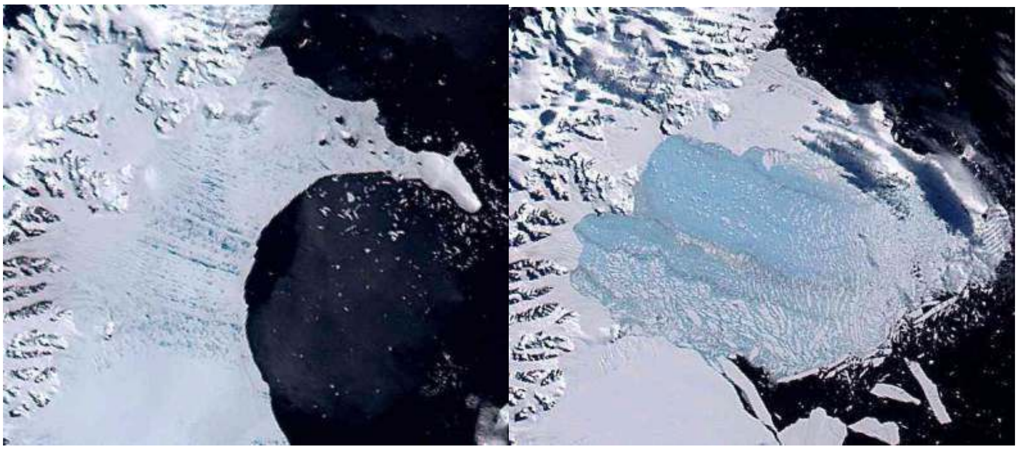


Figure 4.37 Rapid disintegration of Larsen B ice shelf. Image on left collected on January 31, 2002 and on right collected on March 7, 2002.

The latest results reveal an overall reduction in total ice shelf area on the Antarctic Peninsula by over 27,000 km^2 in the last 50 years. As discussed in the previous section, recent findings (and studies of similar events in the southern Greenland ice sheet; see Howat et al., 2007) have fostered new appreciation of the importance of floating ice on controlling ice flow, and the rapidity with which loss of floating ice could cause an acceleration in the contribution to sea level rise.

The direct cause of the Peninsula ice shelf retreats is thought by many to be a result of increased surface melting, attributed to atmospheric warming. Increased fracturing via melt-water infilling of pre-existing crevasses explains many of the observed characteristics of the break-up events (Scambos et al., 2000; 2003), and melting in 2002 on the Larsen B was extreme (van den Broeke, 2005).

Observations of northward-drifting icebergs support the theory that surface melt ponds or surface firn saturated with melt-water can rapidly culminate in disintegration of either ice shelves or icebergs (Scambos et al., 2004).

Ice Shelf	First recorded date	Last recorded date	Area on first recorded date (Km²)	Area on last recorded date (Km²)	Change (Km²)	*% of original area* remaining	Reference
Müller	1956	1993	80	49	-31	61	*Ward (1995)*
Wordie	1966	1989	2,000	700	-1,300	35	*Doake and Vaughan (1991)*
Wordie	1989	2009	700	96	-600	5	*Wendt et al. (In Press)*
Northern George VI	1974	1995	~ 26,000	~ 25,000	-993	96	*Luchitta and Rosanova (1998)*
Northern Wilkins	1990	1995	~ 17,400	~ 16,000	-1,360	92	*Luchitta and Rosanova (1998)*
	1995	1998			-1,098	85	*Scambos et al. (2000)*
Jones	1947	2003	25	0	-25	0	*Fox and Vaughan (2005)*
Prince Gustav	1945	1995	2,100	~ 100	-2,000	5	*Cooper (1997)*
	1995	2000		47		2	*Rott et al. (2002)*
Larsen Inlet	1986	1989	407	0	-407	0	*Rott et al. (2002)*
Larsen A	1986	1995	2,488	320	-2,168	13	*Rott et al. (1996)*
Larsen B	1986	2000	11,500	6,831	-4,669	59	*Rott et al. (2002)*
	2000	2002		3,631	-3,200	32	*Scambos et al. (2004)*
Larsen C	1976	1986	~ 60,000	~ 50,000	-9,200	82	*Skvarca (1994) and Vaughan and Doake (1996)*

Table 4.1 Summary of changes observed in ten ice shelves located on the Antarctic Peninsula. The figures were obtained from references that recorded the measured area of a particular ice shelf on both the earliest and most recent dates available.

Specific mechanisms of ice shelf break-up are still debated. The role of subsurface waters circulating beneath the shelves in thinning and/or warming the ice remains undetermined. Others have suggested that a change to negative surface mass balance (Rott et al., 1998), or reduced fracture toughness due to a thickening temperate ice layer (Vaughan and Doake, 1996), or basal melting (Shepherd et al., 2002) caused the break-up. Recent modeling and observational studies have shown that the Larsen B, at least, was pre-conditioned to a retreat and breakup by faster flow, increased rifting, and detachment from the coast (Vieli et al., 2007; Glasser and Scambos, 2008); all these are consistent with a thinning shelf in the years leading up to disintegration.

The pattern of ice shelf retreat on the Antarctic Peninsula appears to be consistent with the existence of a thermal limit on ice-shelf viability (Morris and Vaughan, 2003; Vaughan and Doake, 1996) (Figure 4.38). The limit of ice shelves known to have retreated during the last 100 years is bounded by the $-5^{o}C$ and $-9^{o}C$ isotherms (calculated for 2000 A.D.) suggesting that the retreat of ice shelves in this region is consistent with the observed warming trend of $3.5 \pm 1.0^{o}C$/century (Morris and Vaughan, 2003).

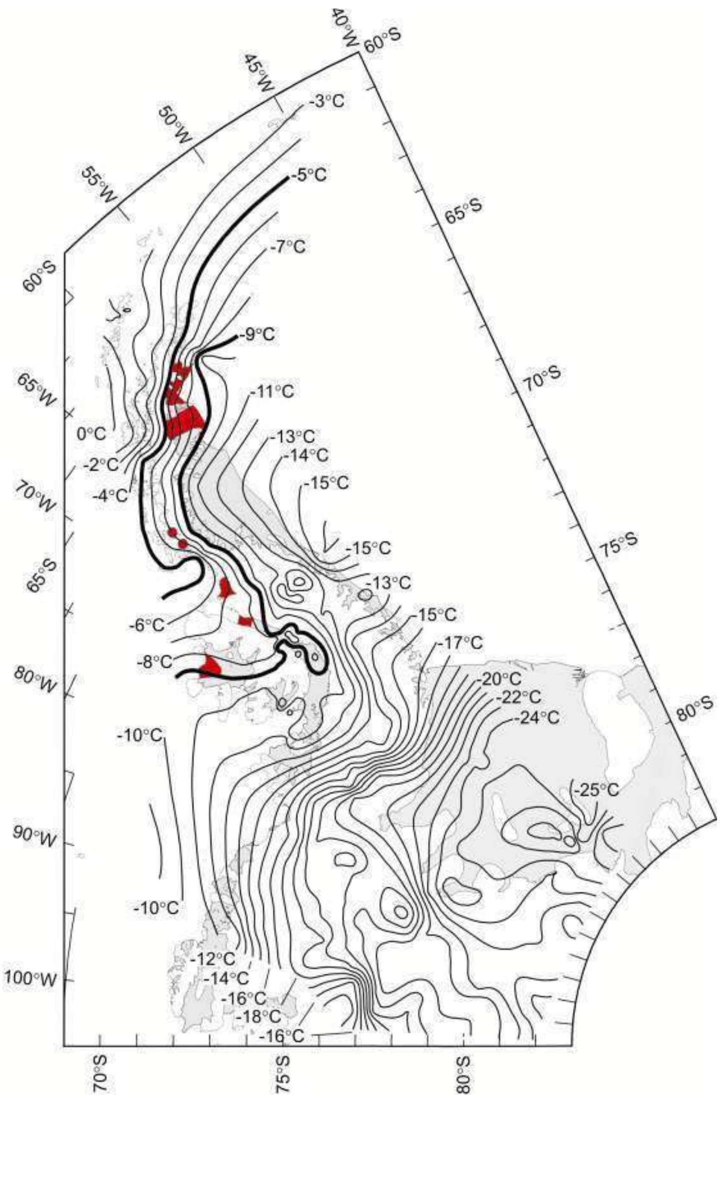


Figure 4.38 Contours of interpolated mean annual temperature. Currently existing ice shelves are shown in grey. Portions of ice shelves that have been lost through climate-driven retreat are shown in red (From Morris and Vaughan, 2003).

4.8.2.3 Sub-Antarctic Islands

Glaciers on the sub-Antarctic islands of Heard Island (53°S, 73°30'E), Kerguelen Islands (49°15'S, 69°35'E) and South Georgia (54°30'S, 36°30'W) have shown accelerating rates of retreat over the past half-century. The glaciers on Heard Island have shown extensive retreat since the 1940s (Allison and Keage, 1986; Kiernan and McConnell, 1999, 2002; Budd, 2000). After a period of advance between 1963-71, most of the recession occurred since 1970 (Allison and Keague, 1986). The total glacierized area has reduced by 11%, and several coastal lagoons have been formed as a result. The rapid glacier recession reflects a temperature rise on the island of about 1.3°C during the last 50 years (Budd, 2000). Of the twelve major glaciers and several minor glaciers on the island, current research includes two specific examples: Stephenson Glacier and Brown Glacier. Historical records, recent observations, and geomorphological evidence indicate that rates of retreat and downwasting of the tidewater Stephenson Glacier, and concurrent expansion of ice-marginal melt-lakes, has increased by an order of magnitude since 1987 (Kiernan and McConnell, 2002). In addition, Brown Glacier retreated 50 metres since 2000/01, contributing to a retreat of approximately 1.1 km since 1950 (a decrease in total volume of about 38%) (Australian Antarctic Division 2005: http://www.heardisland.aq/). Similarly at Kerguelen, glacier recession has accelerated since the early 1970s (Frenot et al., 1993, 1997).

Glaciers, ice caps and snowfields cover over 50% of the island of South Georgia. In a recent study, the changing positions of the 103 coastal glacier fronts on South Georgia were mapped using archival aerial photographs and satellite imagery dating from the 1950s to the present (Cook et al., in submission). Of these, 97% have retreated since their earliest recorded position (which, on average, was 1961). The majority (64%) of the glaciers retreated by between 0 and 500 m since their first observations. Two glaciers stand out as having retreated the most: Neumayer Glacier by 4.4 km since 1957, and the ice front fed by Ross and Hindle Glaciers, by 2.14 km since 1960. The rate of retreat for all 103 glaciers has increased from (on average) 8 m/yr in the late 1950s, to 35 m/yr at present, revealing an accelerating rate of retreat since the 1990s. The recent rapid increase in the average rate is largely due to large increases in retreat rates of glaciers in the north-east of the island, which are currently showing an average of 60 m/yr retreat. The glaciers along the south-west coast of the island, however, are significantly different in their rate of change, due to dissimilar weather patterns caused by orographic effects (Gordon et. al., 2008). They have been in retreat slowly since the 1950s, but this has remained at a constant rate of approximately 8 m/yr. This retreat rate may now be gradually increasing, although on a much smaller scale (currently 12 m/yr). The climate records from South Georgia (recorded at Grytviken from 1905 until 1988, and subsequently from 2001 until 2008) show that in the early 1900s the summer temperatures were relatively high, lower between the 1920s to the 1940s, and higher from the 1950s to the present (Gordon et al., 2008). The retreat of South Georgia glaciers over the past half-century coincides with the recent period of climate warming that began in the 1950s. Acceleration in retreat rates of glaciers on the north-east coast has occurred in the past decade as the climate has continued to warm, and although the glaciers on the south-west side have been slow to respond, their retreat rates may now also be on the increase (Cook et al., in submission).

4.8.3 West Antarctica

West Antarctica has received particular attention because it remains as the last "marine-based" ice sheet, a configuration that was suggested to be inherently unstable, fated to oscillate between fully extended to the edge of the continental shelf or completely lost, having suffered accelerating retreat (Weertman, 1974). Mercer (1968) suggested that full collapse of the West Antarctic ice sheet had occurred as recently as the last interglacial, 125,000 years ago and the concern driving much of the research of the West Antarctic ice sheet was whether such an eventuality was inevitable or even underway.

The West Antarctic ice sheet is conveniently divided into three sectors, each feeding ice into one of the major surrounding seas: the Ross Sea, the Amundsen Sea and the Weddell Sea. Being closest to the US research station at McMurdo, major US field research proceeded on the ice streams of the Ross Sea sector along the Siple and Gould Coasts. Meanwhile, UK field research was focused on the ice streams of the Weddell Sea sector that were similarly closer to their major station at Rothera. Ironically, the largest changes were observed by satellite to be occurring in the Amundsen Sea sector. Each area is discussed in the following sections, beginning with the area exhibiting the largest changes.

4.8.3.1 Amundsen Sea Embayment

The Amundsen Sea sector represents approximately one third of the entire WAIS. Recent observations have shown that this is currently the most rapidly changing region of the entire Antarctic ice sheet. Long before these observations were available the vulnerability and potential significance of retreat in this area was highlighted in a prescient paper by Hughes (1973).

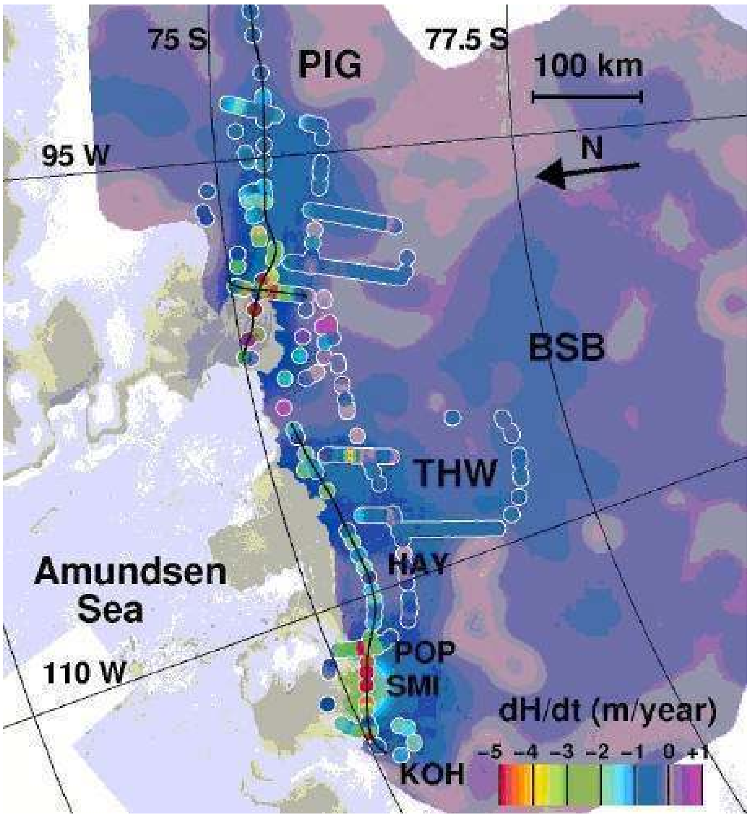


Figure 4.39 Recent and longer term thinning of the Amundsen Sea Embayment sector ice sheet. Regional colours represent rate of elevation change derived from two decades of satellite radar altimetry. Circled colours represent recent elevation changes derived from

airborne altimetry flown in 2002. The difference in the two surveys indicates a recent increase in the rate of thinning (from Thomas et al., 2004b)

Thinning of the ice in the Amundsen Sea sector occurred because of an increase in the discharge of several major outlet glaciers (Figure 4.39). Rignot (1998b) first reported flow acceleration and subsequent grounding line retreat of Pine Island Glacier, one of the two largest West Antarctic outlet glaciers draining into the Amundsen Sea. This retreat has been accompanied by thinning of the ice sheet at a rate of 10 cm/year averaged over a drainage basin twice the area of Great Britain (Wingham et al., 1998). Thinning rates reach well over 1 m/yr at the coast (Shepherd et al., 2001). This discovery of a 10% increase in flow speed in 4 years was anticipated based on oceanographic evidence of very high and increasing basal melt rates beneath the ice tongue fronting the glacier (Jacobs et al., 1996; Jenkins et al., 1997). Later direct measurement of elevation loss near the grounding line and an assumption of flotation at hydrostatic balance, revealed rates as high as 58 $\pm$ 8 m/yr with an ice shelf wide average of 24 $\pm$ 4 m/yr. (Rignot, 2006), exceeding the previously value of 15 m/yr (Shepherd et al., 2004). As basal melt increased, the grounding line retreated, possibly in two stages—during the 1980s and in 1994-96 - each leading to a separate increase in speed (Rignot, 1998b; Joughin et al., 2003). Most recently Rignot (2008a) has shown that the grounding line at Pine Island has retreated still further, with a simultaneous increase in both speed and acceleration. Pine Island Glacier is now moving at speeds nearly double those in the 1970s. No data are available to determine if an earlier period of acceleration occurred, however, a study of past images of Pine Island Glacier's ice shelf indicate that thinning, possibly by as much as 134 metres, occurred in 28 years with significant shifts to the lateral margins, including a major flow shift, beginning perhaps as early as 1957 (Bindschadler, 2001).

Other glaciers in the Amundsen Sea sector have been similarly affected: Thwaites Glacier is widening on its eastern flank, and there is accelerated thinning of four other glaciers in this sector to accompany the thinning of Thwaites and Pine Island Glaciers (Thomas et al., 2004a). Where flow rates have been observed, they too show accelerations, e.g., Smith Glacier has increased flow speed 83% since 1992.

Calculations of the current rate of mass loss from the Amundsen Sea embayment range from 50 to 137 Gt/yr with the largest number accounting for the most recent faster glacier speeds (Lemke et al., 2007; Rignot et al., 2008). Data sources and methodologies vary, but generally when uncertainties and the time intervals analyzed are considered, the estimates are consistent with accelerating rates of loss, in concert with the accelerations of the primary discharging glaciers. These rates are equivalent to the current rate of mass loss from the entire Greenland ice sheet. The Pine Island and adjacent glacier systems are currently more than 40% out of balance, discharging 280 ± 9 Gt/yr of ice, while they receive only 177 ± 25 Gt/yr of new snowfall (Rignot et al., 2008; see also Thomas et al, 2004b). The increasingly negative mass balance is confirmed by several recent radar altimetry assessments of reduction in surface elevation of the Pine Island catchment (e.g., Zwally et al., 2005; Rignot et al., 2008).

Summer temperatures in the Amundsen Sea embayment rarely reach melting conditions, and there is little reason to assume that atmospheric temperatures have had any strong role to play in the changes that have occurred there. Similarly, the patterns of thinning, which are very clearly concentrated on the most dynamic parts of the glaciers, indicate that the changes are not the result of anomalous snowfall. The most favoured explanation for the changes (e.g. Payne et al., 2004) is a change in the conditions in the sea into which this portion of West Antarctica flows (Figure 4.40). ITASE ice core research indicates that marine air mass transport in the Amundsen Sea sector of the WAIS has increased in intensity as of recent decades (Dixon et al., 2005. While there are no adjacent measurements of oceanographic change that can support this hypothesis, it appears to be the most likely option, and the recent observations of relatively warm Circumpolar Deep Water on the continental shelf and in contact with the ice sheet in this area suggest it is a reasonable one.

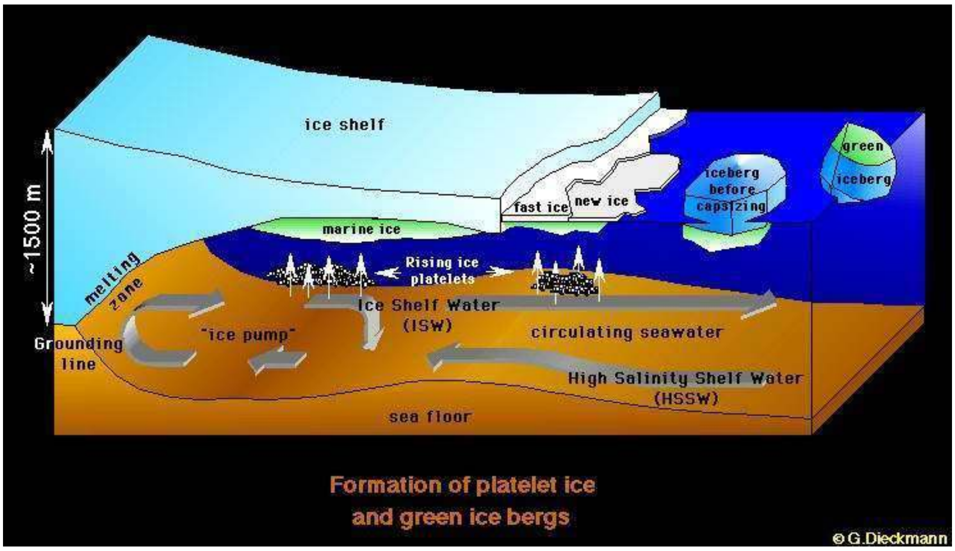


Figure 4.40 Water masses in the Antarctic coastal zone. (Dieckmann, unpublished)

4.8.3.2 Ross Sea Embayment

Elsewhere within West Antarctica, the changes are not as extreme. Among the ice streams feeding the Ross Ice Shelf, there is a rich history of change on millennial and shorter time scales. A major event approximately 150 years ago was the stagnation of Kamb Ice Stream (formerly ice stream C) (Retzlaff and Bentley, 1993). Since that time, ice upstream of the stagnated trunk has been thickening at a rate of nearly 50 cm/yr over an area tens of kilometres across. The next largest change is the gradual deceleration of the Whillans Ice Stream, immediately south of Kamb Ice Stream, at rates of between 1 and 2% annually (Joughin et al., 2002).

Aside from these two phenomena, the remainder of the ice flow in the region appears to be near equilibrium. Overall, Whillans and Kamb ice streams skew the cumulative mass balance calculations in the region to a net positive, indicating slight growth. An earlier estimate of 26.8 $\pm$ 14.9 Gt/yr by Joughin and Tulaczyk (2002) has only been slightly modified to 34 $\pm$ 8 Gt/yr recently by Rignot et al. (2008a), but the errors overlap, indicating consistency. The ocean-ice system of the Ross Sea is shown in Figure 4.41.

4.8.3.3 The Weddell Sea Embayment

This final third of the WAIS is about equal in size to the Amundsen and Ross Sea sectors, but appears to be more stable, at least for the past millennium. The ice streams are deeper than within the other sectors, but show few signs of flow rates or directions far out of the present equilibrium. The most recent calculation of its mass balance of -4 $\pm$ 14 Gt/yr (Rignot et al.,

2008) varies insignificantly from an earlier calculation of +9 $\pm$ 8 Gt/yr by Rignot and Thomas (2002).

Satellite altimeter records suggest, that there may be some areas within this sector (e.g. Rutford Ice Stream) where, in the last decade, there has been an excess of snow accumulation, although such records are too short to imply any likely ongoing change (Wingham et al, 2006a).

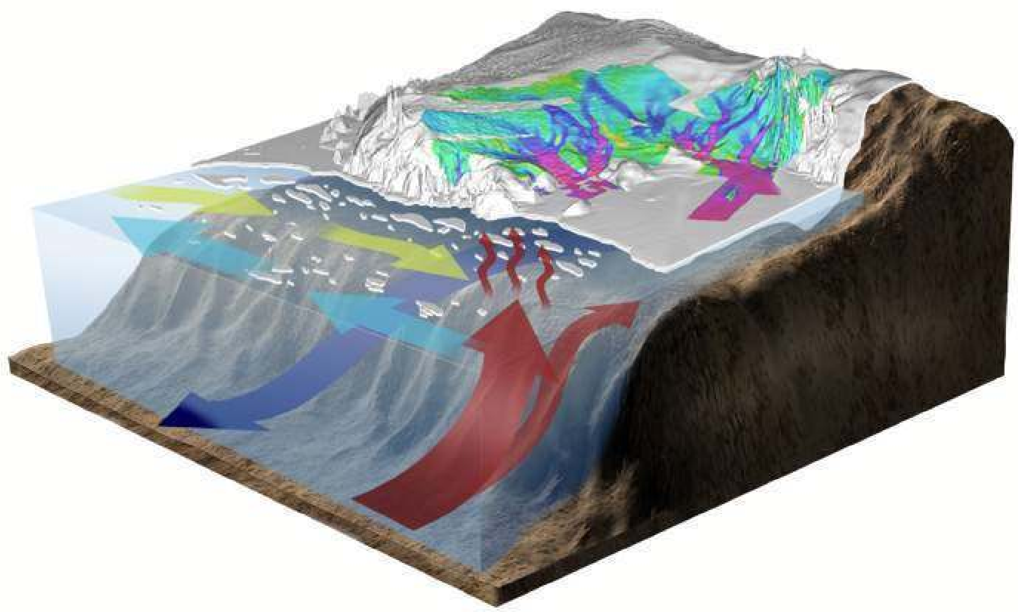


Figure 4.41 Pictoral view of the ocean-ice system of the Ross Sea. Colours on the ice sheet indicate flow speed with speed increasing from yellow to green to blue to magenta (see Figure 1.6). Colour in the ocean represents the major currents: light blue and yellow are the surface flows of the Antarctic Circumpolar Current and the opposing boundary current, respectively; red is CDW upwelling to reach the continental shelf and dark blue is the sinking Ice Shelf Water exiting from beneath the floating ice shelf. As CDW rises, some loses heat to the atmosphere (wavy vertical line) while the remainder circulated under the floating ice shelf causing basal melting. (illustration courtesy of National Geographic)

4.8.4 East Antarctica

Changes are less dramatic across most of the East Antarctic ice sheet with the most significant changes concentrated close to the coast. Increasing coastal melt is suggested by some recent passive microwave data (Tedesco, 2008). Satellite altimetry data indicate recent thickening in the interior that has been attributed to increased snowfall likely because of year-to-year and decade-to-decade fluctuations in snowfall (Davis et al., 2005), but ice core data do not show recent accumulation changes as significantly higher than during the past 50 years (Monaghan et al., 2006a). A resolution of this apparently conflicting evidence may be that there is a long-term imbalance in this area, which could possibly reflect a response to much more ancient climate changes. An alternate suggestion, based on direct accumulation measurements at South Pole, is that this thickening represents a short period of increased snowfall between 1992 and 2000 (Thompson and Solomon, 2002). The absence of significant atmospheric warming inland, distinct from the global trend of warming atmospheric temperatures, may have forestalled an anticipated increase in snowfall associated with the global trend.

The only significant exceptions to this broad-scale quiescence of the East Antarctic ice sheet occur on the Cook Ice Shelf and in the mouth of the Totten Glacier where thinning rates in excess of 25 cm/year have been measured (Shepherd and Wingham, 2007). It remains unknown whether these events are recent, or indeed, whether they are related to changing adjacent ocean conditions, as in the case of the Amundsen Sea outlets, or whether they are just longer-term responses of a regional dynamic origin. Both these areas are the outlets of the ice sheet occupying the two major marine basins lying beneath the ice sheet (Lythe et al., 2001).

The mass balance of the East Antarctic ice sheet has been calculated by many research teams with various sensors and methodologies: +22 $\pm$ 23 Gt/yr (Rignot and Thomas, 2002); -4 $\pm$ 61 (Rignot et al., 2008); 0 $\pm$ 56 (Velicogna and Wahr, 2006); and +15.1 $\pm$ 10.7 (Zwally et al., 2005). The results range from near zero to slightly positive with some of the variations dependent on the time interval investigated. One of the most significant factors giving rise to this uncertainty is that, at present, an *ad hoc* interpretation of the thickness changes must be made to determine whether they represent changes in snow surface accumulation, and thus changes in low-density snow and firn, or whether they are dynamic in origin and represent a change in ice, which has a much higher density.

4.8.5 Calving

Aside from the catastrophic ice shelf disintegration events already discussed, available data suggest that major rift-driven calving events have neither increased nor decreased on the major ice shelves (the Ross, Flichner-Ronne, or Amery). Rather there is ample evidence that their calving patterns continue to follow quasi-repetitive patterns extending back to the Nineteenth Century, when the ice fronts were first mapped (e.g. Jacobs et al., 1986; Keys et al, 1990; Lazzara et al., 1999; Budd, 1966; Fricker et al., 2005; see also Frezzotti and Polizzi, 2002, and Kim et al., 2007). So while the periodic calving of massive icebergs that appear to represent, in some cases, many decades of ice shelf advance, may appear dramatic, there is no reason to believe that they are not part of the normal fluctuations in a ice sheet that is, in the long-term, close to equilibrium.

4.8.6 Sub-glacial Water Movement

Regional surface elevation changes confined to areas of a few kilometres have been interpreted as manifestations of subglacial water movements (Gray et al., 2005; Wingham et al., 2006b; Fricker et al., 2007). These observations are interpreted to reflect the activity of a subglacial hydrologic system permitting faster ice flow that is more active than previously thought (Figure 4.42). While those earlier studies lacked simultaneous measurements of ice flow to accompany these likely shifts in water mass, a recent study of Byrd Glacier identified a period of 10% faster flow that fell within a period where the nearby subglacial lakes discharged water that probably exited the system by traveling underneath Byrd Glacier (Stearns et al., 2008). Improvements to numerical ice flow models are including subglacial water, but the specific nature of its role in ice sheet dynamics remains undetermined.

4.8.7 Other changes in the ice sheet

Much attention is focused on accelerating changes and instability, yet sediment deposited beneath fast moving outlet glaciers might provide some stability to ice sheet retreat driven by rising sea level. Recent observations and modeling suggest that wedges of sediment deposited near the grounding line may be important in stabilizing the ice sheet against sea level rise (Anandakrishnan et al. 2007; Alley et al, 2007). This stabilization is conditional on the position of the grounding line with respect to the crest of the wedge: should the grounding line retreat from the sediment wedge an unstable retreat analogous to that seen in tidewater glaciers could occur (Weertman, 1974; Schoof, 2007). It is becoming clear that rates of erosion and sediment transport can be large, as shown by the appearance of drumlin-scale sedimentary features underneath the ice sheet within just a few years (Smith et al., 2007a). Predictive models of the ice sheet will need to include sediment transport, as well as forces imposed by ice shelves, since these effects may compete to determine the stability or instability of the ice sheet margin.

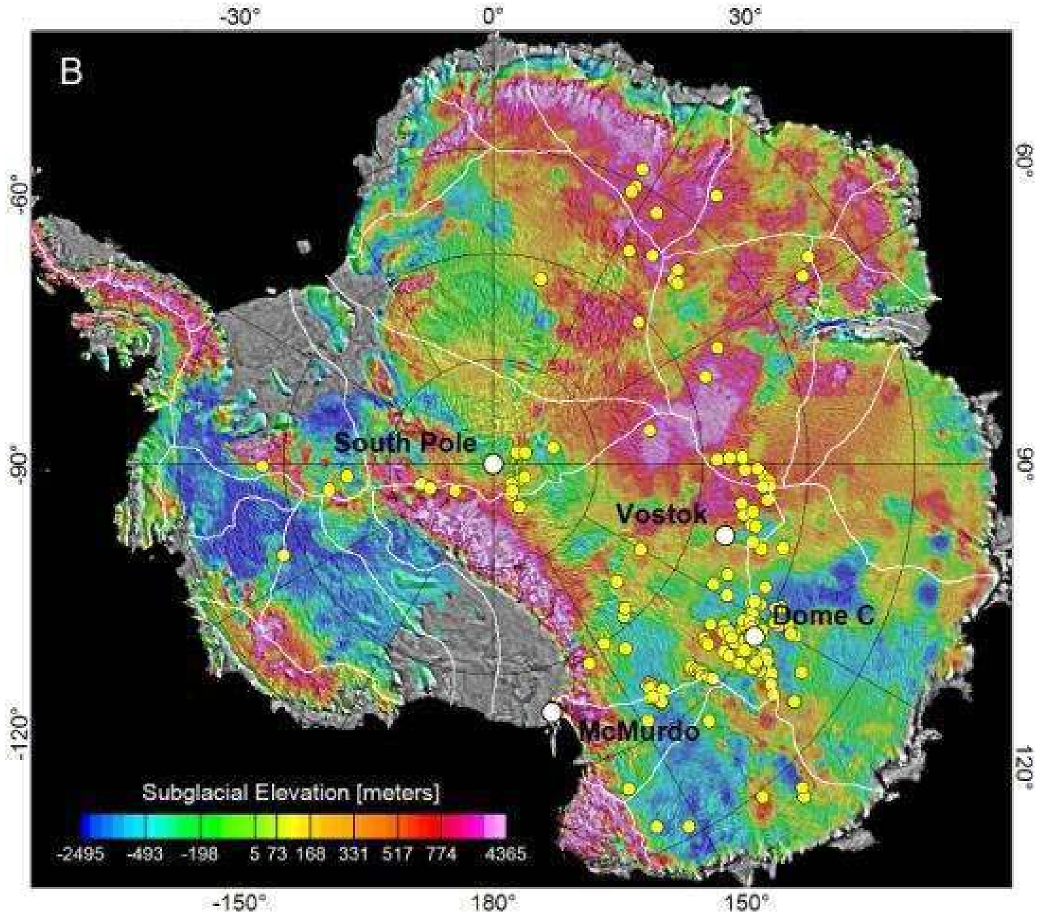


Figure 4.42 Locations of Antarctic sub-glacial lakes are indicated by the yellow circles. Over 145 subglacial lakes have been discovered with the majority clustered in the Dome C area of East Antarctica. Colours represent subglacial elevation. There is no clear correspondence between the subglacial topography and subglacial lake occurrence.

4.8.8 Attribution of changes to the ice sheet

The Antarctic ice sheet is known to respond slowly to large and sustained climate changes, but the new awareness that it can also respond rapidly to other changes makes it difficult to attribute a particular change in the ice sheet to a particular causal event or events such as recent/anthropogenic climate change. The inescapable fact is that ice sheet behaviour manifests itself as the superposition of multiple responses on multiple time scales to multiple environmental changes.

Further complicating the situation is that we do not know the changes that were occurring in the ice sheet prior to the period of satellite observations (which in the case of ice sheets began in earnest in 1992), let alone a century ago, and we have very little knowledge as to whether natural changes in the ice sheet over past millennia were smooth or step-wise and abrupt. The context for current changes must be understood by inference. Caution must be used in extrapolating current changes into the future.

The two areas of most rapid glaciological change are the Antarctic Peninsula ice shelves and the Amundsen Sea sector outlet glaciers. A possible trigger for the sudden collapse of ice shelves in the Antarctic Peninsula is pressurisation of crevasses filled with surface meltwater (Weertman, 1973; Scambos et al., 2000). The supply of meltwater increases with surface warming, placing a limit on the regions where ice shelves are viable (Vaughan and Doake, 1996). Some of the observed surface warming in the northern Antarctic Peninsula can be attributed to changes in global circulation, specifically to changes in the SAM (Marshall et al., 2006). The SAM exhibits considerable decadal variability, but 40-year trends similar to those observed are reproduced in global climate models forced by a combination of ozone depletion, and increasing greenhouse gas concentrations (Arblaster and Meehl, 2006). The stronger circumpolar westerlies bring warmer, northwesterly winds across the northern Antarctic Peninsula. In the eastern Peninsula, this trend is further amplified because northwesterly winds lead to downslope Föhn winds across the ice shelves, promoting warmer winter temperatures and longer melt seasons in summer (e.g. Van den Broeke, 2005). The loss of sea ice cover in the Amundsen and Bellingshausen seas (Jacobs and Comiso, 1997) may also affect the climate of the Antarctic Peninsula, and the viability of its ice shelves. Thinning from enhanced melting by ocean heat supply at the base of the ice shelf (Shepherd et al., 2004), or softening at the margins (Vieli et al., 2007; Khazendar et al., 2007), may have weakened ice shelves and predisposed them to collapse. While they are present, the ice shelves impart forces on the grounded glaciers that drain into them. Once ice shelves have disintegrated, these forces are removed, and the grounded glaciers accelerate (Rott et al., 2002; De Angelis and Skvarca, 2003; Rignot et al., 2004a) and start to thin (Scambos et al., 2004). This increases their discharge of ice into the ocean, and contributes to sea level rise.

The cause of the glaciological changes in the Amundsen Sea embayment is still an open topic of research. Ice sheet models have been used to show that changes similar to those observed can be caused by loss of basal friction in a small part of the ice sheet near the grounding line, perhaps caused by floatation as the grounding line retreats (Payne et al., 2004; Thomas et al., 2004a). Thinning of ice shelves by basal melt (Walker et al., 2007), softening of their margins (Vieli et al., 2007; Khazendar et al., 2007), or shortening by iceberg-calving (Dupont and Alley, 2005a) would also affect the force imposed on upstream glaciers. The ice shelves in the Amundsen Sea Embayment have been thinning (Shepherd et al., 2004; Bindschadler, 2002), and the grounding line of Pine Island Glacier has retreated as sections have thinned and gone afloat (Rignot, 1998b). This thinning, together with the observation that many independent ice streams are behaving similarly, has been taken to imply that changes in the heat supplied from the ocean are responsible for glaciological change in this sector (Payne et al., 2004). One mechanism for a variable supply of heat is episodic delivery of relatively warm CDW onto the continental shelf (Dinniman and Klink, 2004). CDW water occupies a deep layer, below the continental shelf break (700 to 1,100 m), but can be induced to upwell onto the continental shelf, especially via troughs (Walker et al., 2007), where it becomes available for basal ice shelf melting. Water layers in the depth of 700 to 1100 m are observed to be warming significantly further off shore (Gille, 2002), and there is evidence from salinity and other measurements over the past 40 years that increased melting is resulting from heat supplied by warmer CDW to northern West Antarctic ice shelves (Jacobs et al., 2002). According to coupled ocean atmosphere models, the upwelling of CDW is partly controlled by atmospheric circulation patterns (Hall and Visbeck, 2002). There is some correspondence between periods of enhanced heat supply predicted by a coupled model, and periods of observed glacier acceleration (Thoma et al., 2008). Direct observation of temporal changes in the delivery of circumpolar deep water to the ice shelf, and of the consequences for inland ice sheet flow are needed to test such models. To attribute the glaciological changes in the Amundsen Sea sector to a particular climate forcing will require a better understanding of the variability in ice sheet flow, how that flow is influenced by melting beneath ice shelves, and how the oceanic heat delivered to the ice shelves can change under the different atmospheric circulation patterns produced by various scenarios of radiative forcing.

4.8.9 Conclusions regarding the ice sheet

The Antarctic ice sheet is not behaving in a uniform manner – this is not surprising considering its enormous size, but the complexity and disparity of responses between different areas that has become observable in recent years might have been considered unlikely even a decade ago. The geographic extent of the ice sheet places different parts in markedly different positions within the global climate system and subjects them to different environmental drivers.

The most isolated portion is the East Antarctic ice sheet, primarily an extremely cold, high elevation plateau of ice, difficult for moisture-laden storms to reach. Recent atmosphere warming, pervasive throughout the rest of the planet, has not yet arrived, but slight increases in ice thickness are underway, likely an ongoing response on a centennial or millennial time scale to much older changes in climate.

Around the edges of the Antarctic ice sheet, the current state of the ocean is influencing the Amundsen Sea sector of West Antarctica and is likely also responsible for similarly behaving, but smaller, regions of East Antarctica. Here, the ocean appears to be the primary driving force, thinning the narrow fringing ice shelves, leading to rapid thinning and acceleration of the grounded ice. What happens at depth in the ocean matters to the ice sheet, and is itself strongly determined by the overlying atmospheric circulation, highlighting the complex climate interactions in this region. Other sectors of the West Antarctic ice sheet also contain fast moving ice streams, but aside from the now-stagnant Kamb Ice Stream and the decelerating Whillans Ice Stream, their current behaviour is far less extreme.

Ice on the Antarctic Peninsula is behaving quite differently from the rest of the continental ice sheet, in that it is engaged in an active interaction with a currently warming climate. Its north-south topography is the only barrier to the east-west atmospheric and oceanic circulation at these latitudes. Here, high rates of snow accumulation and melting drive a more vigorous glaciological regime. Recent observations have captured the sudden, and very likely recently induced, succession of ice shelf disintegrations followed by the dramatic acceleration of the glaciers that fed them. Perhaps more than any other single phenomenon, these events heighten concern about the near-future impact on global sea level of change in much larger ice reservoirs.

The attribution of ice loss on the Antarctica Peninsula to human-driven warming is now strong, and although not yet proved conclusively, there is a strong hypothesis that a similar case can be made for West Antarctic thinning. The thickening on parts of East Antarctica is an expected consequence of climate change, but it is not yet possible to make a satisfactory attribution of the changes there to any specifically observed climate change.

4.8.10 Changes in Antarctic permafrost and active layer over the last 50 years

4.8.10.1 Introduction

Permafrost temperatures and active layer depth are sensitive indicators of climate because they integrate different climatic factors (i.e. air temperature, seasonal snow cover, wind), which interact with each other and with the ground surface characteristics (i.e. vegetation, surface microrelief).

Permafrost temperatures and active layer thickness respond to the climate variations at different time scales because the permafrost thermal regime reacts: a) seasonally above the depth of zero annual amplitude (ZAA), b) annually at the ZAA, and c) from years to millenia at progressively greater depth. The active layer thickness responds seasonally to the climate input. Different methods are needed to monitor the permafrost thermal regime and the active layer thickness.

4.8.10.2 Changes in the last 50 years

Permafrost monitoring in Antarctica is a relatively new topic, although monitoring began in the 1960s at Signy Island in the South Orkney Islands.

More recently, new data were obtained on the thermal active layer (Cannone et al., 2006; Guglielmin et al., 2007). Comparing the new data with those collected at the same location four decades earlier, Cannone et al. (2006) show that the active layer thickness increased around 30 cm over the period 1963–90 (a period of warming on Signy Island), but then decreased by the same amount over the period 1990–2001 when Signy Island had a series of particularly cold winters.

The site of Boulder Clay (McMurdo Sound) represents the longest and most continuous data series of permafrost and active layer temperature (Guglielmin, 2004; 2006). Figure 4.43 shows the temperature recorded near the permafrost table (at a depth of 30 cm) and at the end of the borehole (360 cm deeep).

The permafrost temperature is stable at 360 cm, while at the permafrost table it shows a slight decrease of 0.1°C/year (Figure 4.43). This slight decrease (Guglielmin, In Prep.) is mainly related to the decrease of the air temperature and the decrease of the snow cover in the winter.

The decrease of ground surface temperature in relation to the decrease of surface air temperature confirms the pattern for the Dry Valleys by Doran et al. (2002) for the period 1986 to 1999 at Lake Hoare.

Five km north of Boulder Clay, at the MZS station, a borehole 15.5 m deep was drilled in bedrock in 1999 and monitored manually once a year and, since 2003, automatically all year round (Guglielmin, 2006). In the summer 2005/2006 a new borehole 30 m deep, just some metres away, was drilled as a template for the new IPY-ANTPAS monitoring network. The thermal profile obtained in the 30 m borehole (Figure 4.44) suggests at least two periods of cooling (around 14-15 m), following a previous period of warming. Guglielmin (2007, in prep) describes these quite short fluctuations of the ground surface temperature at MZS in the last 30 years.

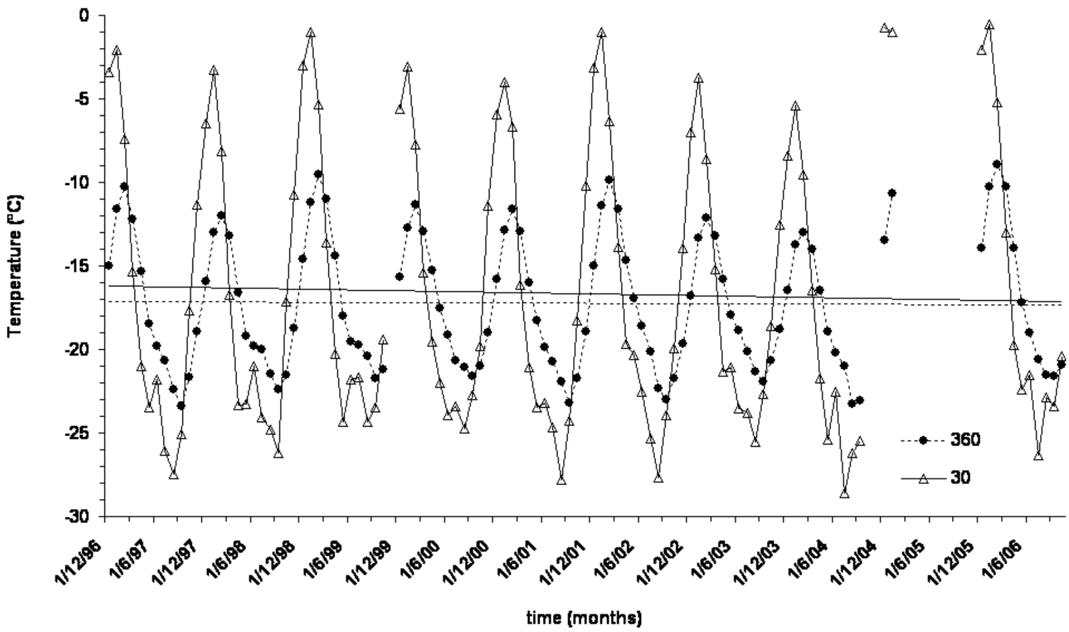


Figure 4.43 Monthly mean temperatures at depths of 30 and 360 cm at Boulder Clay since 1996. Note that the depth of 30 cm is very close to the permafrost table. The linear regression lines for 30 cm depth (solid line) and for 360 cm (dashed line) are also reported.

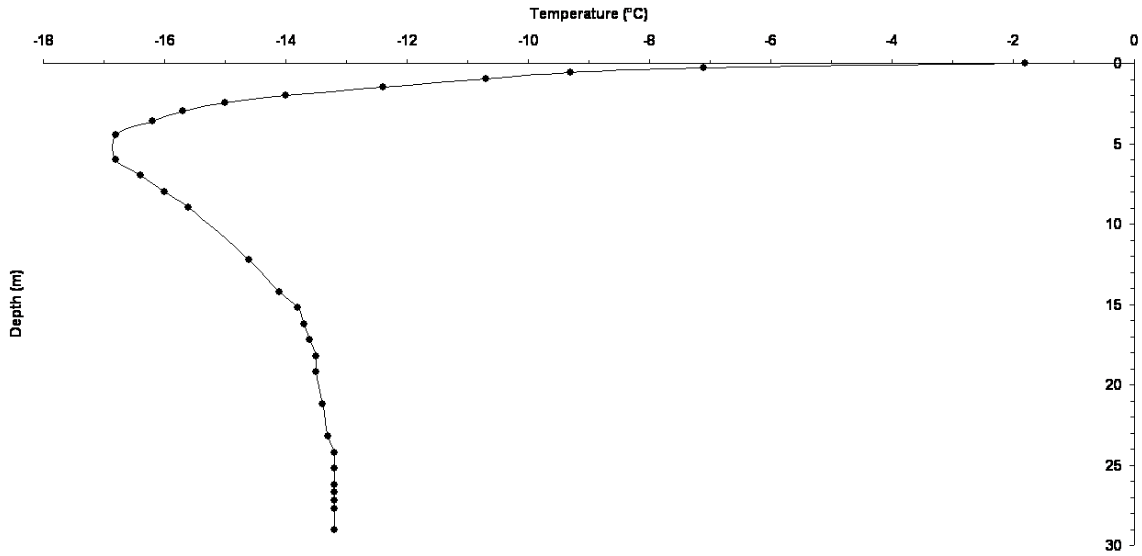


Figure 4.44 Permafrost profile recorded in the borehole at Oasi on 7 November 2006. The borehole was drilled through a homogenous granite outcrop on a gentle slope at 80 m a.s.l.

4.9 Long Term Sea Level Change

The first three assessment reports of the IPCC arrived at similar conclusions with regard to global sea level change during the Twentieth Century. For example, the third report (Church et al., 2001) concluded that global sea level had changed within a range of uncertainty of 1-2 mm/yr. Since then, there have been major workshops (e.g. World Climate Research Programme workshop on Sea Level Rise and Variability, Church et al., 2007), reviews by individual scientists (e.g. Woodworth et al., 2004), and, most recently, the publication of the ocean climate and sea level change chapter within the IPCC Fourth Assessment Report (Bindoff et al., 2007). A consensus seems to have been achieved that the Twentieth Century rise in global sea level was closer to 2 than 1 mm/year, with values around 1.7 mm/yr having been obtained for the second half of the last century in the most recent studies (e.g. Church et al., 2004; Holgate and Woodworth, 2004). However, it should be noted that the Antarctic contribution to sea level now is small compared to what it was following the LGM Transition and through the Holocene.

Fluctuations in the size of Antarctic and Greenland ice sheets during the glacial/interglacial cycles resulted in sea level variations of over 120 m. However, in spite of the enormous sea level-equivalent of the ice stored in the two ice sheets (Table 11.3 of Church et al., 2001), both seem to have played relatively minor roles in sea level change during the last two centuries. The major contributions to Twentieth Century sea level rise are believed to have originated from ocean thermal expansion and the melting of glaciers and ice caps. Antarctica's contribution appears to have been of the order of 0.1-0.2 mm/yr over the last few decades with some evidence for a slightly larger value in the 1990s (Bindoff et al., 2007).

The most recent data (i.e. from the 1990-2000s) from tide gauges and satellite altimeters suggest that global sea level is now rising at a rate of 3 mm/yr or more (e.g. Holgate and Woodworth, 2004; Beckley et al., 2007). The IPCC's 4th Assessment Report cites 3.1 mm/yr for 1993-2003 (IPCC, 2007). However, according to Cazenave et al., (2009), and based on GRACE and altimetric satellite data and Argo ocean float data from 2003-2008, the rate has slowed to 2.5 mm/yr; this reflects a significant slow down in the thermosteric component, balanced by an increase in ice contributions (half from mountain glaciers and half from ice sheets). This is still a higher rate than typical for the Twentieth Century. As pointed out by Milne (2009) the latest results are not the last word and we need longer time series to be confident in the magnitude of the trend.

Figure 4.45 shows a time series of annual mean sea level values from Vernadsky, suggesting an upward trend (uncorrected for local land movements) of 1.6 ± 0.4 mm/year, with a dip in the 1970s for which one has to be concerned about instrumental problems, and no evidence for recent acceleration. As an aside, one may note that observed Southern Hemisphere Twentieth Century sea level trends tend to be generally lower than Northern Hemisphere ones (e.g. see the long southern records studied by Hunter et al., 2003 and Woodworth et al., 2005).

4.10 Marine Biology

4.10.1 The open ocean system

The area covered by winter sea ice in the Southern Ocean has not changed significantly over the past decades suggesting that the impact of global warming on Antarctic ecosystems is not as severe as it is in the Arctic. There the sea ice cover is declining in both thickness and extent at a rapid rate, profoundly affecting the structure and functioning of Arctic marine ecosystems, particularly mammal and bird populations. For a comprehensive and most recent review with additional relevant literature see Nichol (2008). In the Antarctic, comparable shrinking of the winter ice cover has occurred only along the western side of the Peninsula and adjoining seas. This is a relatively small region but home to the well-known whale-krill-diatom food chain. Based on data shown in Figure 4.46, Atkinson et al. (2008) calculated that

70% of the total krill stock resides in the sector 0°-90° W, a region characterised by rapid regional changes both in water temperature (Meredith and King, 2005; Whitehouse et al., 2008) and winter sea ice cover (Parkinson, 2004).

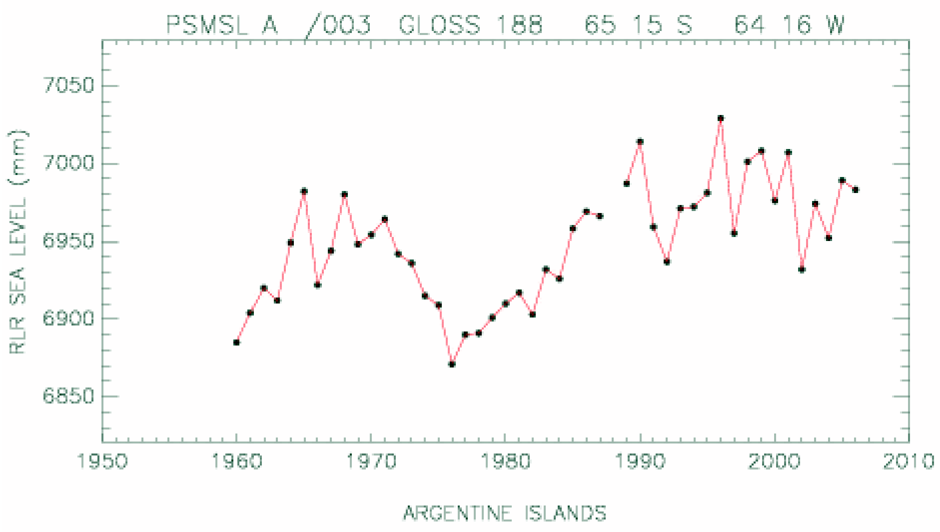


Figure 4.45 PSMSL Revised Local Reference (RLR) annual mean sea level time series for Vernadsky/Faraday (called Argentine Islands in the PSMSL data set)

Following near-extinction of the whale populations, the krill stock was expected to increase as a result of release from grazing pressure. Although predation pressure by seals and birds increased, the total biomass remained only a few percent of that of the former whale population. About 300,000 blue whales alone were killed within the span of a few decades equivalent to more than 30 million tonnes of biomass. Most of these whales were killed on their feeding grounds in the southwest Atlantic in an area of at most 2 million km^2 (10 % of the entire winter sea ice cover), which translates to a density of one blue whale per 6 km^2. Today's whale watchers would be thrilled. A 100 tonne blue whale (adults weigh 150 tonnes) contains about 10 tonnes of carbon, so the biomass of the whales on their feeding grounds would have amounted to 1.5 g C m^{-2} which is equivalent to the average coastal zooplankton biomass. Adding the biomass of krill estimated to have been annually eaten by the whales (150 million tonnes) to the m^2 calculation, we get 12 g C m^{-2} just for blue whales and their annual food intake. This number is equivalent to the biomass of an average phytoplankton bloom or, to take an example of more familiar grazers, to 240 cows of 500 kg each grazing on one km^2 of meadow.

The actual krill stock, from which the 150 million tonnes were being eaten, will have been at least three times higher prior to whaling. The magnitude of primary production required them to fulfil their food demands at the trophic transfer rule of thumb (10:1) would be around 300 g C m^{-2} yr^{-1} which is about that estimated for the North Sea, hence this does not leave much scope for other grazers such as protozoa and copepods. What percentage of the production was exported then from the surface through the mesopelagial habitat and ultimately to the deep-sea benthos, hence also sequestered as carbon, is an interesting but open question.

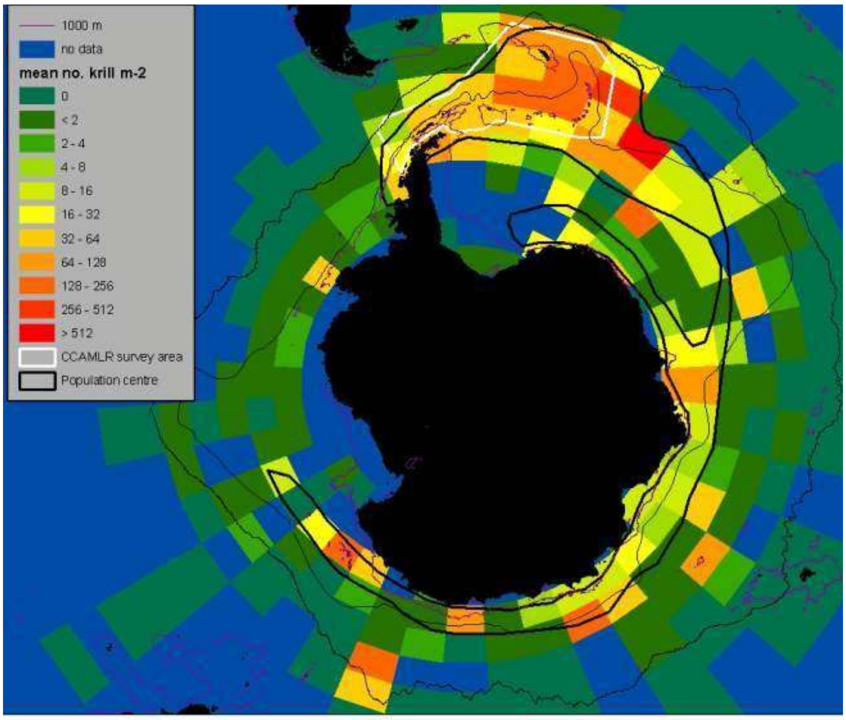


Figure 4.46 Circumpolar distribution of Antarctic krill, *Euphausia superba*. based on standardised data from KRILLBASE (8,789 stations). Black lines (from north to south) show Antarctic Polar Front and Southern Boundary of the Antarctic Circumpolar Current. Population centres drawn by eye, relative to the Commission for the Conservation of Antarctic Living Resources (CCAMLR) Survey (from Atkinson et al., 2008, © Atkinson et al., and InterResearch).

The above calculations indicate that krill stocks in the whale feeding grounds were close to the carrying capacity of the ecosystem prior to whaling. That being the case, when less krill was eaten by whales, enabling more krill to survive, many of the survivors would have starved. This would explain why a krill surplus, at least equivalent to the amount annually eaten by whales, was not recorded. At their former high stock sizes, and given the tendency of krill schools to appear at the very surface and discolour the water, they were commonly observed from ship decks, as noted for example by the scientists of the Discovery cruises (Hardy, 1967). Since that time, despite a significant increase in the numbers of observers, from cruise ships to research vessels, krill swarms are now rarely seen from ships decks. A thorough statistical assessment of all net catches has been carried out for different sectors of the Southern Ocean. The analysis suggests a 38 - 81% decline in krill stocks of the southwest Atlantic accompanied by an increase in salp populations (Figure 4.47, Atkinson et al., 2004; Ross et al., 2008). The extent of the krill decline and the underlying factors are under vigorous debate (Ainley et al., 2007; Nicol et al., 2007), because of difficulties in unravelling the effects of industrial whaling from those of sea ice retreat; there are also discrepancies between the abundances of krill as measured by net and acoustic methods, and enormous intra-annual as well as spatial variability has to be considered (Hewitt et al., 2003; Saunders et al., 2007). However, a significant negative correlation between krill density (30°W to 70°W) and mean sea surface temperature at South Georgia has been found for the period 1928-2003, which implies a large-scale response not only of krill but of the entire open ocean ecosystem to climate change (Whitehouse et al., 2008).

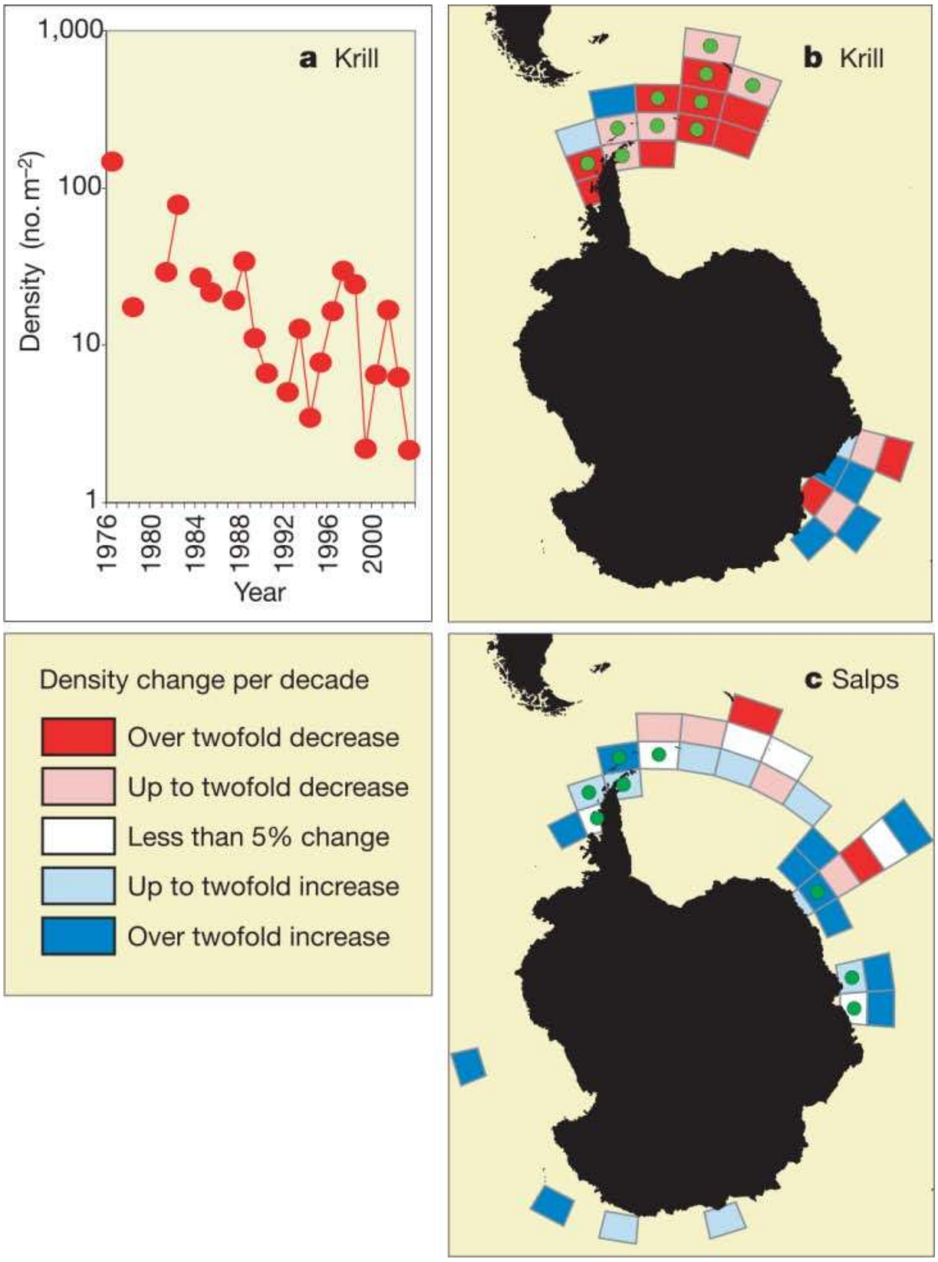


Figure 4.47 Temporal change of krill and salps. a, Krill density in the southwest Atlantic sector, 30^{o} – 70^{o}W. Illustrated temporal trends include b, post 1976 krill data from scientific trawls; c, 1926-2003 circumpolar salp data. Green spots denote grid cells useable in a spatio-temporal model, with data subdivided according to sampling method (Atkinson et al., 2004). This model revealed significant decreases in krill density within the southwest Atlantic sector since 1976 and a significant increase in salp densities at high latitudes since 1926. Reprinted by permission from Macmillan Publishers Ltd: Nature (Atkinson et al., 2004), © 2004

If former krill stocks were close to the carrying capacity provided by primary production, then a decrease in grazing pressure should have resulted in a “phytoplankton surplus”, but there is also little evidence for that. Unfortunately, a comparison with phytoplankton stocks recorded during the Discovery era is not possible because the methods used at that time soon became obsolete. Nevertheless, the impression gained by the Discovery scientists is one of large diatom stocks: “...extremely rich production, which will probably be found to exceed that of any other large area in the world …" (Hart, 1934). The Discovery scientists were familiar with North Sea phytoplankton, which today has much higher biomass levels than those recorded for the Scotia Sea in recent decades. That comparison makes it likely that phytoplankton production has indeed decreased with that of krill stocks, a conclusion supported by the increase in the salp population. In contrast to krill, which are equipped to deal with the characteristically spiny and heavily silicified diatoms of the Southern Ocean, salps are adapted to feed on the lower biomass concentrations typical of the iron-limited microbial food webs. Their encroachment into the former krill habitat is an indication of declining phytoplankton, in particular diatom stocks.

A decline in phytoplankton concentrations can be explained by a corresponding decline in the supply of iron. There is reason to believe that the reduction in sea ice formation has resulted in a decrease in iron input from the continental margins of the Western Peninsula. In contrast, the simultaneous retreat of glaciers should have increased run-off, and possibly also iron input, from the land along the coasts of the Peninsula and adjacent islands. Comparisons of the chlorophyll concentrations recorded by the CZCS satellite of the 1980s with those from the current SeaWifs satellite indicate a decline along the Antarctic ice edge and particularly in the Scotia Sea, the only region of the globe where production has declined, but no major change along the coast (Gregg and Conkright, 2002). Production was found to have increased by 50%, off the Patagonian shelf, so it is also possible that the wind field transporting Patagonian dust from mud fields laid bare by retreating glaciers has changed, reducing the aeolian iron supply to the Scotia Sea. Also, the westerlies have intensified and would carry more dust. Whatever the mechanism, a reduction in phytoplankton biomass can only be explained by a corresponding reduction in iron supply combined with light limitation by deep mixed layers and heavy grazing pressure on phytoplankton stocks. Recently, five mesoscale, *in situ* iron fertilization experiments, carried out in the Pacific and southeast Atlantic Sectors of the Southern Ocean, have unambiguously demonstrated that plankton biomass is limited by iron availability. It follows that the higher productivity of coastal regions, including the southwest Atlantic, is maintained by input of iron supplied from land-masses, and from the sediments by deep mixing and upwelling along the continental margin. The presence of excess nutrients in these regions allows the assumption that iron supply limits productivity over most of the year throughout the Southern Ocean. The ramifications of this finding for the structure and functioning of Antarctic ecosystems have yet to be adequately explored, particularly because ongoing global change will affect coastal hydrography and hence the supply of iron.

An alternative but not mutually exclusive explanation for the phytoplankton decline can be a decrease in the rate of recycling of the iron entering the system. It is now well established that primary production in microbial food webs is based on recycling by grazers feeding on pico- and nano-phytoplankton, which are in turn eaten by predators such as ciliates and copepod larvae. The latter are the preferred prey of copepods, whereas filter-feeding salps consume all the components *en masse*. In the Southern Ocean the microbial community is characteristic of the iron-limited HNLC (high nutrient, low chlorophyll) area, where chlorophyll concentrations remain below 0.5 mg-Chl/m^2 throughout the year. These regions support a surprisingly high zooplankton biomass, comprising slow growing copepods and fast-growing salps, throughout the year, suggesting that they are an integral part of a recycling system that also regenerates iron in addition to ammonium (Barbeau et al., 1996).

Local increases in production above this level are invariably due to accumulation of diatoms and *Phaeocystis* colonies, and will be caused by input of new iron, whether from above or from below. The fate of these diatom blooms is under debate: are they consumed and their nutrients recycled in the surface or sub-surface layer, or does a significant portion sink to greater depths or to the sea floor? The latter fate is of particular interest in the light of proposals for large-scale ocean fertilization to sequester atmospheric CO_2.

Given the high densities of the former krill stocks, their rate of recycling will have been as effective as that in the microbial food web today, but on a much larger scale. Predation by whales will have contributed significantly to the iron recycling pool. That is because, except in the case of pregnant and lactating females, whales convert krill protein into blubber (hydrocarbons), so retaining energy but excreting nutrients, including iron. Whale faeces are liquid and rise to the surface where they are likely to have released iron, thereby increasing the efficiency of recycling. Krill also have a high (50%) lipid content, and krill excretion releases large amounts of iron (Tovar-Sanchez et al., 2007). It follows that the exceptionally productive ecosystem characterised by the food chain of the giants was maintained by the recycling of iron by krill and whale feeding. An alternative, but mutually inclusive hypothesis in which large whale stocks promoted the development of large stocks of their prey (krill) by dispersing them over a larger area has been recently suggested.

It is now acknowledged that large terrestrial herbivores (megafauna) condition ecosystems by promoting a vegetation cover conducive to their demands, e.g. grassland instead of forest by elephants. The removal of those herbivores leads to profound changes in landscape. Similarly, the top predators in lakes can determine the structure of the ecosystem down to the composition and biomass of the phytoplankton. Predation pressure on upper trophic levels is propagated down the food web by mechanisms known as trophic cascades. Although the effects of top-down control have been demonstrated for shallow benthic environments from many coastal regions, comparable mechanisms are only now coming to light from planktonic ecosystems, such as the reported worldwide increase in gelatinous plankton after removal of dominant fish stocks. Whether such changes can cascade down to the level of phytoplankton is not known. We simply do not know what effect the removal of whales (and seals) through hunting had on the ocean ecosystem around Antarctica. The belief that marine phytoplankton productivity is determined primarily by bottom-up driving forces is entrenched in the marine biological literature, but why the interaction between marine plankton and whales around Antarctica should be fundamentally different from that between their non-polar lake counterparts has yet to be addressed. The fact is that the processes driving annual cycles of phytoplankton production, biomass and species composition in the marine environment remain largely unknown. It is time to explore new approaches.

The linkages between phytoplankton and bacterioplankton in the Southern Ocean are not well understood. The timing of spring phytoplankton blooms and bacterioplankton activities are not necessarily linked, as they are in other pelagic systems, though there may just be a lag in this linkage that is longer than in lower latitude systems (Ducklow et al., 2007). Even less is known of the relationships between phytoplankton species and bacterioplankton species composition (e.g. whether particular bacteria are associated with diatom vs. cryptophyte phytoplankton). Considerations of phytoplankton primary productivity, linkages to CO_2 drawdown, and grazer populations are also linked to phytoplankton species composition. Phytoplankton species are susceptible to changes in sea ice duration and position of the ice edge, and shifts in water column properties such as the depth of the mixed layer. Shifts in phytoplankton species composition from diatom-dominated communities to more diverse communities dominated by cryptomonads and flagellates occurs following the ice edge retreat and spring diatom bloom in the Western Antarctic Peninsula (Moline and Prezelin, 1996), and will be (or already are) potentially more common occurrences as a result of warming in this region (Clarke et al., 2007). The linkages between phytoplankton and zooplankton populations are tight, as krill tend to dominate the zooplankton assemblages when diatoms are abundant, and zooplankton dominance can shift to salp dominance when the community is cryptomonad or flagellate dominated. One study in the Western Antarctic Peninsula recently reported that there has been a shift from krill-dominated waters to salp dominance since 1999 This trend may also be potentially representative of the longer term trends referred to above.

Acquiring a mechanistic understanding of the structure and functioning of the ecosystems surrounding Antarctica is a prerequisite for predicting their performance under the influence of global warming. Hypothetical conceptual frameworks of relevant mechanisms need to be developed that can be tested by comparing intact ecosystems with those where top-predators have been depleted both regionally and, where baseline data are available, temporally. Satellite data have vastly extended the scales accessible to such regional studies. Larger scale in situ iron fertilization experiments open up an exciting new avenue to study the effects of bottom-up versus top-down factors on higher trophic levels, and if carried out over several years, also on krill populations and on the underlying deep sea and benthos. Such experiments provide an ideal background to study the relationship between ecology and biogeochemistry at the species level, which in turn will improve interpretation of sedimentary proxies, in particular microfossils, for reconstruction of past climate change. Conceptual frameworks emerging from field studies and experiments can be explored, tested and refined with new generations of 4D mathematical models.

4.10.1.1 Iron fertilization experiments

It has been suggested that one way in which the rise of carbon dioxide in the atmosphere may be mitigated is to fertilise the ocean with iron so as to stimulate the production of plankton and hence the draw-down of carbon dioxide from the atmosphere into the ocean (Boyd et al., 2007a). These ideas are based on the results of a limited number of experiments in which different parts of the ocean, including the Southern Ocean, were seeded with iron (Boyd et al., 2007b). This current debate (e.g. see Oceanus, 24 June 2009, http://www.whoi.edu/oceanus/viewArticle.do?id=34167) may at some time shift its focus to exploring how to maximise the efficiency of the process and minimise harmful side effects. The hypothesis could be tested by a new generation of iron fertilization experiments carried out at larger scales and longer periods on the former whale feeding grounds. Given the apparent high rates of krill decline and a steady southward encroaching ocean warming there is a pressing need to develop an integrated understanding of how this ecosystem functioned not only in the recent past but also in the glacial ocean, in order to predict future changes in the pelagic and underlying benthic ecosystems around Antarctica. In situ iron fertilization experiments provide one methodology for testing ecosystem models, by enabling the study of interactions within ecosystems with a full complement of grazers and pathogens. The effect of iron fertilisation on higher trophic levels will depend on the locality and duration of the experiment. A regional survey of the underlying benthos prior to fertilization would yield a baseline to monitor possible changes in this ecosystem. Preliminary surveys of the deep-sea benthos of the Peninsula region have shown the presence of communities with high biomass and species numbers (Brandt et al., 2007) but their areal extent is not known. Deep carbon export flux has been shown to be above global average and to have a high regional variability in the Southern Ocean (Boyd and Trull, 2007; Sachs, 2008). Since fertilization will be carried out offshore, it is quite unlikely that shelf and coastal benthos are significantly affected.

An added incentive to carrying out such experiments is that they would offer an ideal training ground for the kind of large-scale international, interdisciplinary research taking a whole Earth System Science approach to investigating global change. Such large-scale experiments would not only provide a wealth of new insights into the structure and functioning of pelagic and underlying benthic ecosystems. They could also provide more reliable data for parameterising current and new coupled ecological-biogeochemical ocean-circulation models for use in assessing the Southern Ocean as a sink for anthropogenic CO_2. There is a concern that the incentive offered by the carbon credit market could result in excessive fertilization which could lead to unacceptable harm to Southern Ocean ecosystems (Chisholm et al., 2001). Three United Nation bodies, the Intergovernmental Oceanographic

Commission (IOC), the International Maritime Organization (IMO), and the Convention on Biological Diversity (CBD) agreed that proposals to use ocean fertilization to sequester carbon in the ocean give cause for concern due to unknown negative impact to the ecosystems (http://ioc3.unesco.org/oanet/OAdocs/INF1247-1.pdf). The two latter organizations recently argued that large operations are currently not justified and should not be allowed (www.cbd.int/decisions/?m=COP-09&id=11659&lg=0, www.maritime-connector.com/NewsDetails/2203/lang/.wshtml, www.ioccp.org). Scientists emphasized the necessity for independent research on small scale fertilisation studies (Buesseler et al., 2008). In addition it must be considered that once done such large global experiments with unknown outcomes would be very difficult or impossible to reverse.

4.10.2. Sea ice ecosystems

It is now clear that decreasing sea ice cover in the southwest Atlantic is due to a decline in ice production along the Peninsula. This can significantly reduce the supply of iron to the surface layer. The formation and presence of sea ice has several effects on the underlying water column and benthos. Deep convection due to brine discharge during ice formation can mix the entire water column down to the sea floor. Downward transported organic particles from the productive surface layer thus become available to benthic filter feeders. This mechanism will be a major source of food supply to the sponge-dominated fauna of Antarctic shelves and explains the apparent lack of gearing of reproduction of the shelf benthos to the ice–free period, when vertical particle flux from the overlying water column is at its maximum. Upward mixing of water that has contacted the sediment surface will bring iron to the surface layer. This mechanism of convective upward iron transport and subsequent fuelling of surface phytoplankton blooms has been reported from the Peninsula and around islands with shallow shelves where convective winter mixing is sufficient to reach the sediment surface without ice formation. It follows that the ongoing retreat of winter sea ice along the western Peninsula will result in declining depths of winter mixing and hence also in the supply of iron to the water column overlying deeper shelves, where surface warming reduces ice formation. A decrease in downstream spring productivity can be expected, which might be a factor contributing to krill decline in this region. However, it cannot be the only factor because the krill decline began before the retreat of the sea ice.

4.10.3 ENSO links and teleconnections to vertebrate life histories and population

Biological impacts with consequences for upper trophic levels in the southwest Atlantic region occur at the same time as the rapid warming observed to the west of the Antarctic Peninsula, in the Amundsen Sea and across the Bellingshausen Sea, and to the east of the Peninsula across the northwestern Weddell Sea, where the sea ice season has decreased (Parkinson, 2004). Food webs in these regions are dominated by euphausids, and in particular by Antarctic krill, *Euphausia superba*, which provide ecosystem structure and function, supporting the energetic demands of abundant predator populations (Croxall et al., 1988) and also a commercial fishery. As shown above, the relative density of krill across the region has shown a significant negative trend over the last 30 years, during which summer mean krill density correleated positively with the duration of sea ice the previous winter (Atkinson et al., 2004).

The strong connections between sea ice and ENSO variability across the southwest Atlantic result in correlations between ENSO variation and krill recruitment and abundance; quasi-cyclic sea ice variation is related to cycles in krill population (Fraser and Hofmann, 2003; Quetin and Ross, 2003). Recent studies have shown how ENSO related fluctuations in SST and winter sea ice extent affect the recruitment and dispersal of Antarctic krill. Delayed effects of sea ice conditions on abundance relate to the production, survival and development of the larval and juvenile krill. Same-year effects of spring and summer temperatures probably reflect a distribution and dispersal effect across the Scotia Sea and the degree of influence of cooler polar waters in northern regions around South Georgia (Murphy et al., 1998, 2007).

These effects cascade, bottom-up, to upper trophic levels. With few exceptions, periods of reduced predator breeding performance in this region are the result of low prey availability rather than direct local weather or oceanic effects (Croxall et al., 1988; Fraser and Hofmann, 2003; Forcada et al., 2005, 2006; Trathan et al., 2006; Hinke et al., 2007; Murphy et al., 2007).

For Adélie penguins breeding on the western Antarctic Peninsula, changes in sea ice extent during the breeding season covary positively with krill abundance and negatively with penguin foraging effort (Fraser and Hofmann, 2003). In the South Shetland Islands, krill recruitment covaries positively with Adélie penguin recruitment, which has declined dramatically (Hinke et al., 2007). The population trends of Adélie and Chinstrap penguins appear to be affected by a winter krill deficit. This deficit also affects the Gentoo penguins, but their population trends are positive (Figure 4.48, Ducklow et al., 2007). Similar results on population trends at the South Orkneys suggest the loss of buffering against the changing sea ice environment by the more abundant and ice-dependent Chinstrap and Adélie penguins, and positive population consequences through habitat improvement for the less ice-related Gentoo penguin (Forcada et al., 2006).

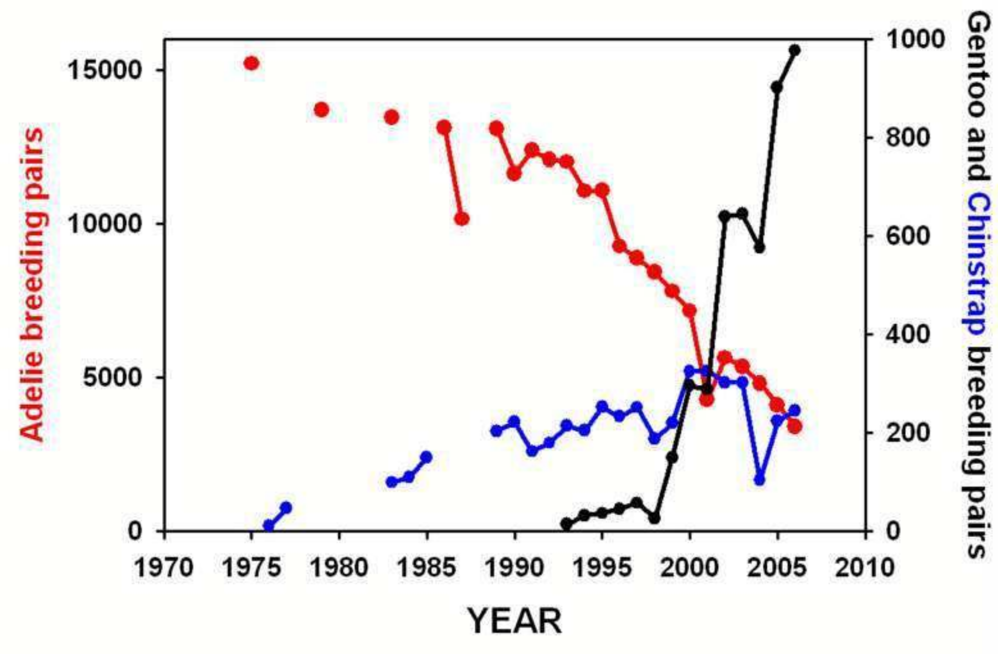


Figure 4.48 Population trends for three penguin species in the Anvers Island vicinity (West Antarctic Peninsula), 1975-2003, 1975-2006. Graph courtesy of W.R. Fraser and Palmer LTER, see also Ducklow et al., 2007)

Other krill dependent predators have shown comparable responses to the propagation of ENSO variability. Breeding outputs of Gentoo penguins and Antarctic fur seals at Bird Island, South Georgia (Forcada et al., 2005; Trathan et al., 2006) and southern right whales (*Eubaleana australis*), which feed in the waters around South Georgia (Leaper et al., 2006), correlate negatively with SST anomalies. Low chick and pup production and survival in penguins and fur seals result from a reduced food supply, usually of krill and krill-dependent fish species, such as mackerel icefish.

Signals of climate change related to ENSO variability are also observed elsewhere in the Southern Ocean. However, the consequences for ecosystem fluctuation are less well understood. In the Indian Ocean, and in particular in regions of the Antarctic continent, long-term reductions in sea ice extent have occurred in parallel with reductions of the Southern Oscillation Index (and an opposite trend in ENSO) (Barbraud and Weimerskirch, 2006). Long-term increases in sea ice season duration have possibly reduced the quantity and accessibility of the food supplies available in early spring for upper trophic levels. This would partly explain the delays in phenology observed in a guild of seabird species (Barbraud and Weimerskirch, 2006). While little is known about the marine ecosystem structure and food web interactions, there have been major fluctuations in the late 1970s suggesting a regime shift with repercussions for lower trophic levels (Hunt et al., 2001), but also for upper trophic levels, and in particular Emperor penguins, which suffered a major population decline (Weimerskirch et al., 2003). Long-term environmental effects in breeding success were further explored in long-term data sets of seabirds, including southern fulmars, snow petrels and emperor penguins in Terre Adélie. The observed population fluctuation in these species had a periodicity of 3-5 years, consistent with that in sea ice anomalies and the SOI (and hence ENSO). The observed cyclical patterns also indicated significant change since 1980, consistent with a regime shift, although these populations have remained stable since then.

In the Antarctic sector of the Pacific Ocean, and in particular the Ross Sea sector, trends in surface temperatures are less apparently correlated with ENSO, although there has been a decrease in the SOI. The impacts may be less evident or may even be the reverse of those observed in the Atlantic and the Indian Oceans. Annual estimates of breeding population size for Adélie penguin colonies on Ross Island, in the Ross Sea, show significant inter-annual variability, consistent with ENSO and the propagation of its variability through the ACW (Wilson et al., 2001; Ainley, 2005). Lagged correlations with a sea ice index and the SOI (ENSO) suggest demographic cycles, with reverse population trends to those observed in the Southwest Atlantic. However the consequences for Adélie penguins changed between the 1970s and the 1980s, with a concurrent increase in population trend and in the sea ice polynya providing improved penguin habitat. Like the Emperor Penguins in Terre Adélie, in the Indian Ocean, populations of Weddell seals at McMurdo Sound, in the Ross Sea, declined in the early 1970s, to become stable later on (Ainley et al., 2005). This suggests that ENSO impacts have not been so obvious in the Pacific sector as in the Atlantic Ocean and Indian Ocean sectors of the Southern Ocean. Based on long-term studies, Dayton (1989) and Barry and Dayton (1988) speculated about ENSO-related hydrodynamic processes supporting the explosive growth of fast growing sponges in McMurdo Sound with significant consequences for the entire benthic assemblage.

4.10.4 Invertebrate physiology

Decadal-scale variations in the coupled ocean-atmosphere system have an impact on animal communities and populations in marine ecosystems (Cushing, 1982; Beamish, 1995; Bakun, 1996; Finney et al., 2002). Present-day effects of global warming on the biosphere are associated with shifts in the geographical distribution of ectothermic (cold-blooded) animals along a latitudinal cline or with poleward or high-altitude extensions of geographic species ranges (Walther et al., 2002; Parmesan and Yohe, 2003; Root et al., 2003). Temperature means and variability associated with the climate regime can be interpreted as major driving forces on the large scale biogeography of marine water breathing animals. These relationships lead us to expect that climate warming will have a significant impact on ecosystems at both poles.

The marine Antarctic has cold temperatures that are close to freezing in several areas, and which have the lowest temperature variability at high latitudes (Clarke, 1998; Peck, 2005). Thus, Antarctic marine ectotherms live at the low end of the aquatic temperature continuum and within a narrow temperature window (making them highly stenothermal) (Somero and De Vries, 1967; Peck and Conway, 2000; Somero et al., 1996, 1998; Pörtner et al., 1999, 2000; Peck et al. 2002, 2006). Climate-induced changes in mean temperature and its variability should influence the survival of such organisms. That begs the questions – (i) to what extent has stenothermy in Antarctic species and phyla been overestimated? and (ii) how may species differ with respect to their respective levels of stenothermy and their capacities to acclimate to thermal change? Recent data show that Antarctic fish can undergo thermal acclimation and shift their physiological characters accordingly, e.g. in a zoarcid (Lannig et al., 2005) and a notothenioid (Seebacher et al., 2005).

A comparison of the mechanisms characterizing thermal intolerance between and within species of marine invertebrates and fish has led to the development of a unifying physiological concept of thermal limitation and adaptation. The first line of thermal intolerance in animals, which restricts performance in behaviour, growth and reproduction, is the limit on the capacity of oxygen supply mechanisms (Pörtner, 2001, 2002; Pörtner et al., 2001). Thermally induced reduction in oxygen supply capacity can take place at both high and low temperature extremes, before any biochemical stress indicators are affected. Between these extremes is a temperature window in which there is maximum scope for the aerobic activity and associated performance needed for successful survival in the wild. These thresholds were defined as critical temperatures (Tc) (see review by Pörtner, 2001). At more extreme low and high temperatures, there is a transition to anaerobic mitochondrial metabolism as the capacity for oxygen supply diminishes. This is seen in crustaceans (Frederich and Pörtner, 2000) and other invertebrate phyla (Pörtner, 2001, 2002), in temperate and Antarctic fish like zoarcids (temperate *Zoarces viviparus*, Antarctic *Pachycara brachycephalum*) and in sub-Arctic fish like Atlantic cod (*G. morhua*) (Mark et al., 2002; Zakhartsev et al., 2003; Lannig et al., 2004) (see also Van Dijk et al., 1999; Pörtner et al., 2004).

Recent evidence demonstrated the ecological relevance of oxygen limited heat tolerance through its effect at ecosystem level (Pörtner and Knust, 2007). Heat stress in the wild reduced performance (Pörtner and Farrell, 2008, Figure 4.49) and enhanced mortality even before critical temperatures were reached. These findings emphasize the early effect and crucial role of limitation in oxygen supply in compromising fitness.

Antarctic marine invertebrates may be more thermally sensitive than fish (Pörtner et al., 2007). The critical temperature in the infaunal bivalve *Laternula elliptica* lies at about 6°C (Pörtner et al., 1999; Peck et al., 2002). Before reaching that temperature this species develops systemic hypoxia (hypoxemia), which reduces whole organism performance. Early reductions in aerobic scope include a complete loss of ability to burrow in *L. elliptica* or to self-right in the limpet *Nacella concinna* at 5°C (Figure 4.50), and a 50% loss of capability at temperatures between 2°C and 3° C (Peck et al., 2004). The scallop, *Adamussium colbecki* was even more thermally constrained, being totally incapable of swimming when temperatures rose to 2°C. The early loss of performance and a progressive reduction in haemolymph oxygenation suggests that thermal thresholds are close to 0°C in *L. elliptica* (Peck et al., 2004; Pörtner et al., 2006). The thermally most sensitive Antarctic invertebrate to date is the bivalve *Limopsis marionensis* from the Weddell Sea, with a critical temperature of 2°C (Pörtner et al., 1999). Mortality tests confirm the fatal effect of oxygen limited thermal tolerance and the inability of invertebrates to acclimate to higher temperatures. In epifaunal scallops (*A. colbecki*), half of the specimens died after 19 days at 4°C (D. Bailey, pers.

commun.). In infaunal clams (*L. elliptica*), half died in 2 months at 3°C, and in the brittle star *Ophionotus victoriae* half died in less than 1 month at 3°C (L. Peck, pers. obs.). It appears that Antarctic stenotherms, especially among the invertebrates, live close to their thermal optimum, while others, like Antarctic fish, may live permanently below their optimum. For example, the Antarctic eelpout (*P. brachycephalum*) grows optimally at around 5°C, well above ambient temperatures (Brodte et al., 2006), in accordance with its ability to acclimate to warmth (Lannig et al., 2005).

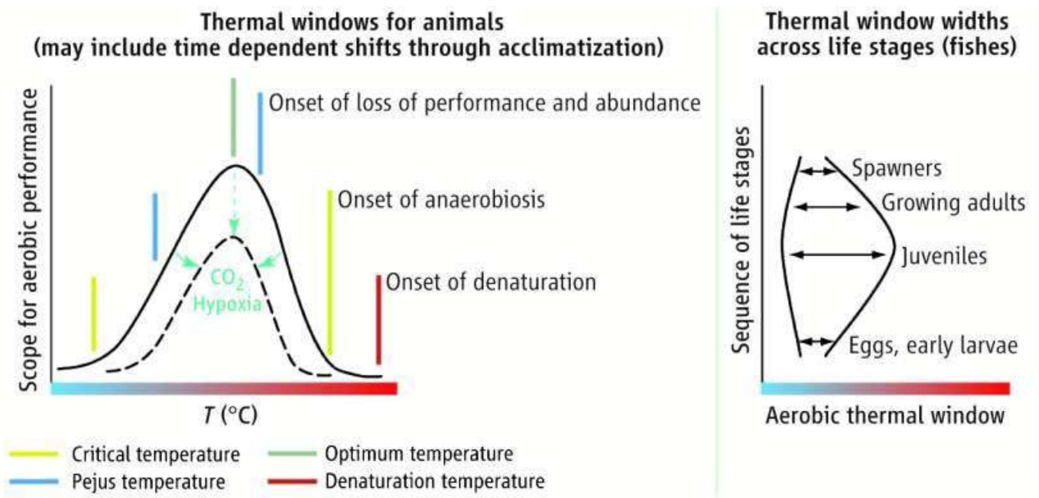


Figure 4.49 Temperature effects on aquatic animals. The thermal window of aerobic performance (left) display optima and limitations by pejus ("turning worse"), critical, and denaturation temperatures, when tolerance becomes increasingly passive and time-limited. Seasonal acclimatization involves a limited shift or reshaping of the window by mechanisms that adjust functional capacity, endurance, or protection. Positions and widths of windows on the temperature scale shift with life stage (right). Synergistic stressors like ocean acidification and hypoxia narrow thermal windows according to species-specific sensitivities (broken line), further modulating biogeographies, coexistence ranges, and other interactions. From: Pörtner, H.-O. and Farrel, A.P. (2008) Pysiology and Climate Change. Science 322:690-692; reprinted with permission from AAAS.

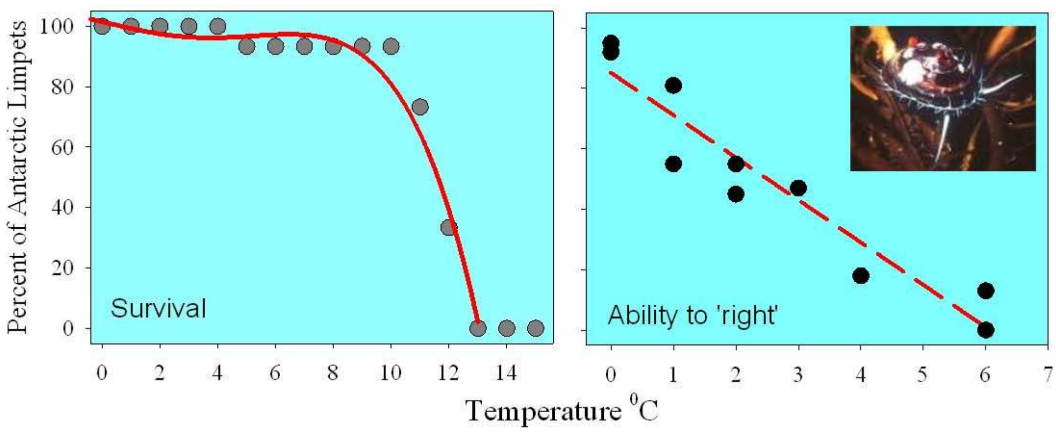


Figure 4.50 Acute temperature influences on Antarctic invertebrates. Survival and ability to 'right' (turn back over) of the Antarctic limpet *Nacella concinna*. Data from Peck (2005, unpublished).

Several Antarctic marine invertebrate species dwell in the intertidal zone and may experience elevated temperatures in summer. They likely use metabolic depression strategies and anaerobic metabolism to survive in response to temperature-induced hypoxemia (Pörtner, 2002). A role for hypoxia in metabolic depression was also evident during the winter season (Morley et al., 2007) and is known in temperate zone invertebrates (Grieshaber et al., 1994).

Under field conditions, the loss of aerobic performance capacity at higher temperatures limits the survival of invertebrates in warmer summers. Data from physiological and other laboratory studies suggests that further warming of the marine environment by as little as 1°C will exceed the thermal tolerance of some marine invertebrate species. These polar ectotherms clearly do not have the opportunity to retreat to cooler, i.e. higher latitude waters, which leads to the expectation of fatal consequences not only for individual species but possibly also for characteristic properties of ecosystem structure and functioning. While the apparent stability of Antarctic foodweb structures in response to potential species losses may at least temporarily buffer such changes (Jacob, 2006), it cannot prevent the potential loss of typical Antarctic fauna.

Functional or physiological aspects of meiofauna in general, and nematodes in particular, remain poorly known. Studies of the trophic position of meiobenthos in temperate and tropical areas have led to conflicting results (van Oevelen et al., 2006 and references therein) and studies in Antarctic and sub-Antarctic sediments are preliminary and restricted to a limited number of habitats (Moens et al., 2007). Biomarker analysis of bulk sediment organic matter and of nematodes in different regions and sediment types was carried out to assess the energy source of meiobenthic fauna in Antarctic shelf sediments (Moens et al., 2007). The results of this study suggested substantial selectivity of the metazoan meiobenthos for specific components of the sedimented organic matter, such as ice algae or flagellates, with this selectivity differing between sites and sediments. Laboratory experiments on a number of selected species from temperate regions showed that reproductive success, growth and metabolic activity of nematodes largely depend on temperature, the quality and quantity of food, and to a lesser extent salinity, with different species thriving under different conditions (Moens and Vincx, 2000a,b). A better understanding of the current functionality of the meiobenthic communities in different habitats is needed, and will allow for assessment of how these processes can be affected by changes in the environment. These changes might also impact structural aspects of the meiobenthic, and more specific the nematode communities, such as community composition and diversity, but also densities and biomass.

Examining physiological responses to temperature change is difficult for free-swimming pelagic organisms such as Antarctic krill, which do not behave naturally in captivity. For krill an alternative approach has been taken to look at temperature effects. Somatic growth rates can be determined in a manner largely free from laboratory artefacts, making them useable as a field-derived index of physiological health (Atkinson et al., 2006). By performing many such experiments across krill's temperature range during the summer growth period, the various factors affecting growth (chiefly food, krill size and temperature) can be teased apart. These results showed that, having adjusted for food and krill size, growth was highest at low temperatures and decreased substantially above 3°C (Figure 4.51). This stenothermy has implications for krill at their northern limits, for example at South Georgia. Surface layer temperatures have already warmed there by about 1°C in the last 80 years (Whitehouse et al., 2008) and future increases could make this region increasingly unsuitable for krill in summer.

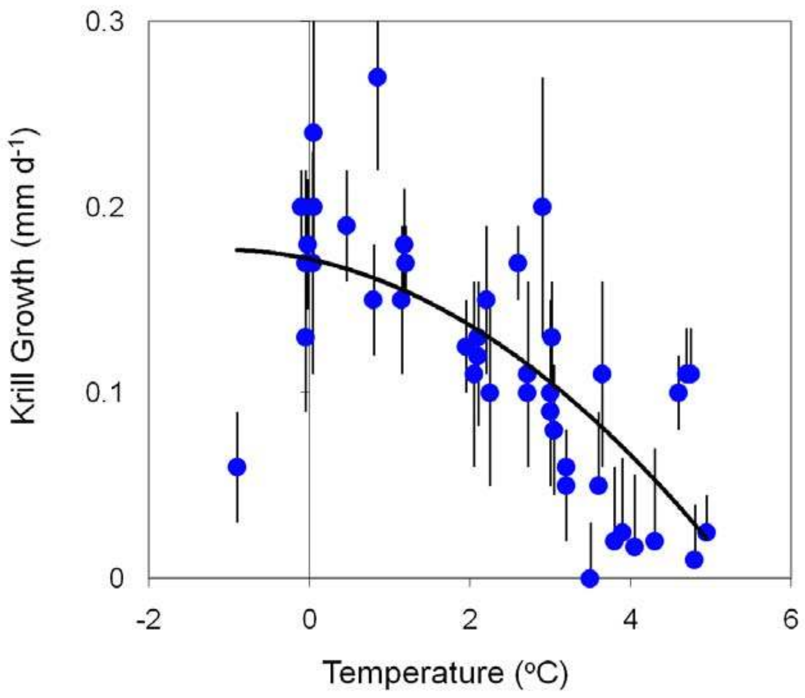


Figure 4.51 Daily growth rates of krill in the Scotia Sea/South Georgia region measured in January-February, and having been adjusted for effects of variable food availability and krill size via a mixed model (re-drawn from Atkinson et al., 2006). Each point represents a growth experiment derived for a swarm of krill, sampled across nearly the full range of summer surface temperatures that they occupy.

4.7.2.5 Seasonality Effect on the high Antarctic benthic shelf communities?

The Antarctic spring is one of the planet's principal episodes of oceanic primary production (Hense et al., 2003), reaching maximum values of 0.1 mg Chl/l in just a few weeks. As more than 10^7 km^2 of sea ice melts, it releases a huge trapped biomass (Thomas and Dieckmann, 2002). Sunlight continues to increase from spring to summer, driving notable changes within an ecosystem just emerging from a long, dark winter. This explosion of life is immediately followed by a growth spurt in the life cycle of the krill, the organism standing at the base of the food chains for nearly all Antarctic marine vertebrates. As winter approaches, the continental shelf and large areas of the open ocean pass back towards a seasonal coverage of ice more than a metre thick, which is why most of the large predators abandon the high Antarctic at the start of the long austral winter.

This pattern led to the conception of a long-lasting paradox – that the ocean around Antarctica experienced pronounced marine seasonality (Clarke, 1988), with a period of low activity in winter as a consequence of reduced food availability, despite the fact that the sea water temperature remained practically constant all year round.

While the marked environmental seasonality naturally does influence and condition life in the water column, the first inklings that the Antarctic paradox might not be entirely accurate arose after the discovery of the rich marine fauna that dwells on the continental shelves in the high Antarctic (Gutt et al., 1992). Over the past twenty years, the region has been shown to host one of the most diverse, high-biomass benthic communities in the ocean (Clarke and Johnston, 2003). Suspension feeders constitute the bulk of these communities, which depend on the particles settling down from the upper layers of the water column or laterally advected to them by currents. Due to low temperatures, a large number of species have slow metabolic rates, associated with a low energy demand, yet they still attain considerable age and size (Peck et al., 2006). This and other traits connected with reproduction patterns would at first glance appear to be in harmony with the tenets of the Antarctic paradox, rooted in the dormant state thought to prevail in winter. However, new features forcing the scientific community to reconsider the Antarctic Paradox have recently come to light. For instance, quite a few species exhibit reproduction rates similar to those in other regions, while others demonstrate higher growth rates than expected by quickly occupying areas scraped clean by icebergs (Teixidó et al., 2004). Experimental observations have furnished earlier selected results (Barnes and Clarke, 1994, 1995) supporting the assumption that the long Antarctic winter may not be as inactive as hitherto thought. These findings include:

1. The existence of “food banks” extending over hundreds of kilometres, offering a potential food source for numerous bottom-dwelling organisms (Mincks et al., 2005). This phenomenon also known as “green carpets” tends to form at the beginning of the austral spring, when the high primary production generated by melting ice is not immediately exploited by planktonic grazers and settles on the shelf seabed in a time span of hours to days (Gutt et al., 1998).

2. Widespread distribution of seabed sediment with high nutritive quality and grain sizes suitable for the anatomic structures of benthic suspension feeders. On average, measured concentrations of protein (3 mg/g) and lipids (2 mg/g) are higher than on other continental shelves and similar to the contents found in settling particles (Smith et al., 2006).

3. Tides acting as an incessant mechanism to resuspend the “food banks” and supply particles to suspension feeders throughout the year (Smith et al., 2006).

4. Benthic suspension feeders on Antarctic shelves feeding on small-sized particles in contrast to species from other latitudes that mainly ingest zooplankton (Orejas et al., 2003).

The new evidence of the physical-chemical conditions on the shelf seabed at Antarctic latitudes makes it necessary to reconsider the paradox that had formerly served as a cornerstone for understanding polar ecosystems. After the summer, resuspension by tidal currents and the high nutritional quality of the seabed sediment allow benthic trophic conditions to remain almost constant throughout the year, which provides the basis for a new model of Antarctic seasonality. The new model helps to explain the high diversity and high biomass of benthic communities around Antarctica, even when the food input from the euphotic zone becomes scarce when ice covers the ocean surface during the winter months. These new findings must be taken into account when planning future research on the Antarctic bottom-dwelling fauna. Special emphasis should be placed on carrying out studies during the austral winter, when processes occurring near the seabed (Figure 4.52) could be a key to understanding both the high productivity of the system in the early spring and the high biodiversity of the benthic ecosystem (Gili et al., 2006).

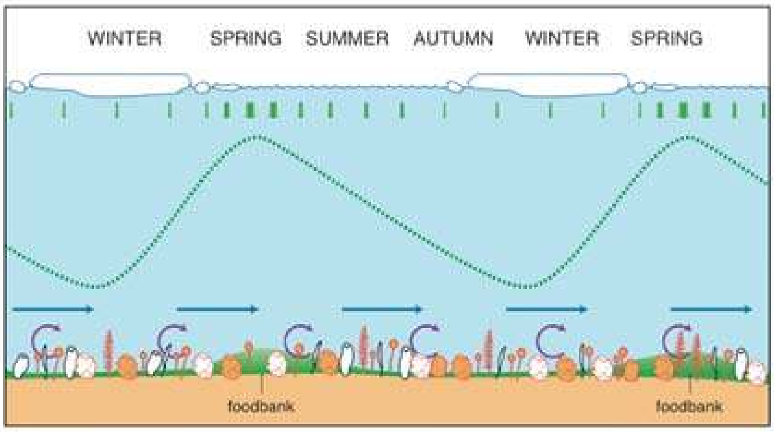


Figure 4.52 Synoptic view of the processes described in the text showing the seasonal vertical flux of new organic matter originated mainly at the beginning of spring (green line), the seasonal variation of food banks and the lateral and resuspension transport just above the seabed (arrows close the bottom).

4.7.2.6 Macroalgal physiology and ecology

Many Antarctic macroalgae, especially from the subtidal zone, are adapted to low temperatures (Wiencke et al., 1994, 2007), especially those endemic to the Antarctic. For example, the red algae *Georgiella confluens* (Figure 4.53), *Gigartina skottsbergii* and *Plocamium cartilagineum* grow only at 0°C and not at 5°C, and exhibit upper survival temperatures (USTs) as low as 7 to 13-14°C, respectively (Bischoff-Bäsmann and Wiencke, 1996). Other Antarctic red algae grow at temperatures up to 5 or 10°C and have USTs of up to 19°C. Macroscopic growth stages of endemic Antarctic brown algae grow up to 5°C and exhibit USTs of 11 to 13°C. Their reproductive microscopic stages grow up to 10 or 15°C and have USTs between 15 and 18°C (Wiencke and Dieck, 1989). Antarctic cold-temperate species (especially from the intertidal) are characterised by higher temperature requirements (Wiencke and Dieck, 1990).

This adaptation of Antarctic macroalgae to low temperatures is also reflected in photosynthesis. The photosynthetic capacities of endemic Antarctic species measured at 0°C are as high as in temperate algae measured at higher temperatures (Thomas and Wiencke, 1991; Wiencke et al., 1993; Weykam et al., 1996; Eggert and Wiencke, 2000). However, optimum temperatures for photosynthesis are clearly above the Antarctic water temperatures. The lowest temperature optima have been recorded in *Ascoseira mirabilis* (1 to 10°C). The other species tested so far are characterised by higher values between 10 and 20°C. Temperature optima for dark respiration are higher than those for photosynthesis (Drew, 1977; Wiencke et al., 1993; Eggert and Wiencke, 2000).

Due to global warming the geographic distribution of stenothermal cold water species will be limited in future to the coasts of the Antarctic continent itself. Species presently occurring today predominantly in the cold-temperate region and rarely in the Antarctic will become more established in the Antarctic region (Müller et al., submitted). This can cause unforeseeable changes in the ecology of Antarctic shallow water communities.

Light determines significantly the depth zonation and survival of macroalgae. Antarctic seaweeds are able to tolerate dark periods of up to one year without suffering damage, and their light requirements for growth are very low (Wiencke, 1990). In juvenile sporophytes of

Antarctic Desmarestiales, growth is light saturated at ≤ 20 µmol photons/m^2/s^1 (Wiencke and Fischer, 1990). The low light requirements for completion of the life cycle and for growth of Antarctic seaweeds are based on the low light requirements for photosynthesis (Wiencke et al., 1993; Weykam et al., 1996; Eggert and Wiencke, 2000). As a result, light compensation (I_c) and saturation (I_k) points are very low in Antarctic species and mostly range between 1 and 15 and between 14 and 52 µmol photons/m^2/s^1, respectively (Wiencke et al., 1993; Weykam et al., 1996; Brouwer, 1996; Eggert and Wiencke, 2000). These low light requirements allow Antarctic macroalgae to grow down to considerable depths. Theoretically, growth of some species is possible at water depths down to approximately 75 m (Wiencke, 1990; Wiencke et al., 1993).

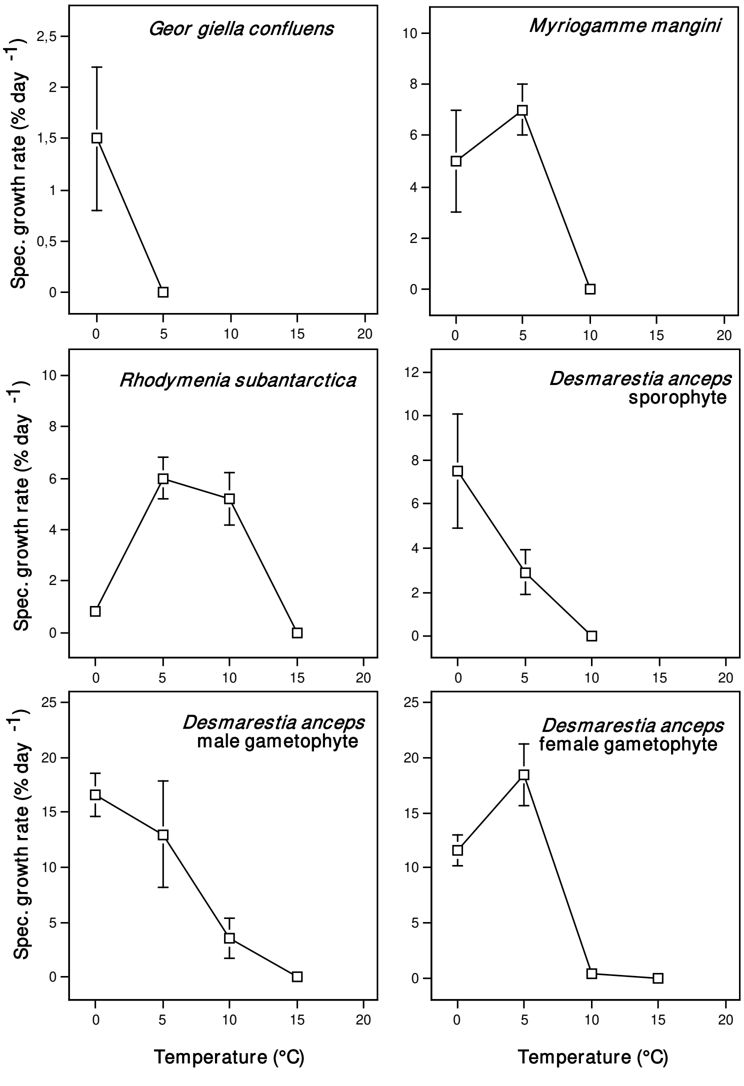


Figure 4.53 Physiological temperature adaptation of Antarctic macroalgae (after Wiencke and Clayton, 2002)

Antarctic algae are not only low light adapted but can also cope with high light conditions in summer due to their ability for dynamic photoinhibition, a photoprotective mechanism by which excessive energy absorbed is rendered harmless by thermal dissipation. The capability for dynamic photoinhibition is related to the depth distribution of the individual species. Species from the eulittoral, upper and mid sublittoral show a more or less pronounced decrease in photosynthetic activity during high light stress, and full recovery during subsequent exposure to dim light. In contrast, deep water and understory species recover only slightly and slowly indicating photodamage, especially after exposure to UV radiation. Recent studies indicate that the effect of UV radiation is not limited to the physiological and organism level. Rather, it influences the biodiversity, structure and function of macroalgal communities (Zacher et al., 2007; Campana et al., submitted). The effects on the community level depend on the UV susceptibility of the unicellular propagation units of the seaweeds (Roleda et al., In Press Zacher et al., 2009). So UV radiation represents an important factor for the determination of the upper distribution limit on the shore. The obtained results are of great importance for the estimation of the effects of enhanced UV radiation due to stratospheric ozone depletion. UV induced changes in algal zonation and biodiversity make changes in the trophic relations of coastal ecosystems very probable.

4.10.3 Marine/terrestrial pollution

Increasing concern about global changes and environmental protection is promoting international efforts to assess future trends and to mitigate the main causes and effects of climatic and environmental changes. In the last century the economic and industrial development of the Northern Hemisphere has had a dramatic impact on the global environment. Antarctica, the remotest continent in the Southern Hemisphere, has thus become a symbol of the last great wilderness and pristine environment. However, the world's future population growth and industrial development will occur in countries of the Southern Hemisphere. The rapidly changing global pattern of persistent anthropogenic contaminants and greenhouse gases may reduce the value of Antarctica and the surrounding Southern Ocean for research on evolutionary and ecophysiological processes and as an ideal archive of data for better understanding global processes (Bargagli, 2005).

Antarctica has a very small, non-native population and is protected by natural "barriers" such as the Antarctic Circumpolar Current and the zone of circumpolar cyclonic vortex, which reduce the entry of water and air masses from lower latitudes and the consequent import of propagules and persistent contaminants. Nonetheless, the recurring appearance of the "ozone hole" and the rapid regional warming of the Antarctic Peninsula indicate that Antarctica and the Southern Ocean are inextricably linked to global processes and that they are not escaping the impact of local and global anthropogenic activities.

Exploration, research, sealing and whaling have drawn people to Antarctica since the early 1900s, and the development of research, tourism and fishing in the last 50 years has driven a striking increase in human presence. Local impacts due to the presence of humans, such as contamination of air, ice, soil, marine sediments and biota through fuel combustion (for transportation and energy production), waste incineration, oil spillage and sewage, are inevitable, especially near operational bases. Another serious anthropogenic impact, especially in the sub-Antarctic islands (where climatic and environmental conditions are less extreme) is the introduction of alien organisms (Frenot et al., 2005). Although the number of tourists visiting Antarctica is usually two-three times greater than that of the logistic and scientific personnel, the latter reside for a longer time in permanent or semi-permanent stations. Most stations are located in coastal areas and until twenty years ago refuse was dumped into landfill sites or the sea or burnt in the open air. Several accidental spills of oil, lubricants and foreign chemical compounds have occurred at and around Antarctic stations; unfortunately, in the Southern Ocean there have also been significant oil spills, such as the release in January 1989 of about 550 m^3 of diesel fuel during the sinking of the Argentine supply ship *Bahia Paraiso,* near Anvers Island (Antarctic Peninsula).

4.10.3.1 Local-scale pollution

The IGY (1957-1958), with the involvement of 12 countries and over 5,000 persons occupying 55 stations in the continent and the islands of the Southern Ocean, marked the beginning of significant local detrimental impacts on the Antarctic environment. Although concern about local environmental pollution has been expressed since the 1970s (e.g. Cameron, 1972), the value of the Antarctic environment to science was only definitively acknowledged in 1991 with the adoption of the Madrid Protocol to the Antarctic Treaty. The Protocol marked the exclusion of Antarctica from the geopolitics of the Cold War period, territorial claims and the possible exploitation of natural resources. It provided strict guidelines for environmental management and protection, and established the obligation to clean-up abandoned work sites. Some countries began to document environmental pollution at abandoned stations and waste-disposal sites, and developed strategies for clean-up and remediation (e.g., Kennicutt et al., 1995; Deprez et al., 1999; COMNAP-AEON, 2001; Webster et al., 2003; Stark et al., 2006). Trace metals and several Persistent Organic Pollutants (POPs) such as Polycyclic Aromatic Hydrocarbons (PAHs) and other by-products of combustion and incineration processes, including Polychlorinated Dibenzo-p-Dioxins (PCDDs), Polychlorinated Dibenzofurans (PCDFs) and Polychlorinated Biphenyls (PCBs), were among the most common persistent contaminants in terrestrial and marine ecosystems within a few hundred metres of scientific stations (UNEP, 2002). However, despite existence of the Protocol, its translation into practice is patchy at best, and much remains to be achieved even to quantify direct human impacts on the Antarctic, let alone effective mitigation where required (Tin et al., 2009).

Most ice-free areas of continental Antarctica are cold desert environments with sparse biotic communities, comprising few species of microorganisms, cryptogams and invertebrates. Although there are several reports on the distribution of persistent contaminants in Antarctic soils, mosses and lichens (e.g. Bacci et al., 1986; Claridge et al., 1995; Bargagli, 2001), possible long-term (biotic and abiotic) effects of persistent contaminants in Antarctic terrestrial ecosystems are largely unknown. There is evidence that hydrocarbon spillage in soils can result in an increase in hydrocarbon-degrading microbes and concomitant decrease in the diversity of the soil microbial community (Aislabie et al., 2004). However, the "in situ" biodegradation rate is probably very low, because aliphatic and aromatic compounds can be detected in soils more than 30 years after a spill.

In striking contrast with the extremely reduced number of species in terrestrial biotic communities, most Antarctic marine ecosystems have a rich variety of species and a high biomass. Contaminants are introduced in the coastal marine environment through waste water, leachates from dump sites, and deposition of particulates from station activity and ship operations. The accumulation of metals and POPs has been reported in samples of water, sediments and organisms collected in the vicinity of several Antarctic stations (e.g. UNEP, 2002; Bargagli, 2005). Throughout the 1970s, wastes from McMurdo station were routinely discharged along the eastern shoreline of Winter Quarter Bay, which also provided docking facilities for ships. In 1988 the US National Science Foundation began a dumpsite cleanup and abatement programme and the bay became one of the most studied marine environment in Antarctica. Concentrations of PAHs, PCBs, Polichlorinated Terphenyls (PCTs) and metals such as Ag, Pb, Sb and Zn in sediments from the bay were much higher than in samples from outside the area (Risebrough et al., 1990; Lenihan et al., 1990; Kennicutt et al., 1995).

In Antarctica, evolutionary processes in isolation contributed to the development of rich communities of coastal benthic organisms such as sponges, hydroids, tunicates, polychaetes, molluscs, actinarians, echinoderms, amphipods and fish. These organisms are characterized by a high degree of endemism and ecophysiological adaptations to peculiar physico-chemical features of the Southern Ocean. As many species are long-lived, have low metabolic rates, lack the pelagic larval phase and need longer development time, Antarctic benthic organisms are more exposed to the long-term effects of environmental contaminants than are temperate or tropical species. Significant disturbance of benthic communities has generally been reported in the proximity of the most polluted coastal sites (e.g., Lenihan and Oliver, 1995; Conlan et al., 2000; Stark et al., 2003). Organism responses to the combined effects of toxic pollutants and organic enrichment from sewage disposal usually involve a decrease in the abundance and diversity of benthic fauna and an increase in resistant and opportunistic species. Research on polluted sediments near Casey Station (Cunningham et al., 2005) has revealed that benthic diatom communities are good indicators of anthropogenic metal contamination and may be useful in monitoring the success of environmental remediation strategies in polluted Antarctic sites.

In recent years there has been considerable interest in astrobiology and microbial forms living in extreme environments. Antarctica has become one of the most important places for research on bacteria that thrive on ice or in subglacial lakes. One of the main challenges for such research is the contamination of ice, especially by drilling fluids. These fluids are a complex mixture of aliphatic and aromatic hydrocarbons and foranes that coat the ice surface and may penetrate into the interior of the ice through micro-fissures. As a rule, the fluid is not sterilized during use, and Alekhina et al. (2007) isolated bacteria of the genus *Sphingomonas* (a well-known degrader of polyaromatic hydrocarbons) as well as bacteria attributable to human and soil sources from specimens of the deepest (3,400 and 3,600 m) ice borehole at Lake Vostok.

4.10.3.2 Global-scale contaminants

Today, human activity is one of the most important parameters affecting the chemical composition of the atmosphere. The most marked recent changes in the chemistry of the atmosphere over Antarctica are associated with greenhouse gases, notably the largely anthropogenically caused decrease in stratospheric ozone, and increases in anthropogenically sourced CO_2 (380 ppmv), CH_4 (1755 ppbv), and N_2O (319 ppbv). Anthropogenically sourced radionuclides stemming from above ground nuclear bomb testing are also present throughout Antarctica, as is evidence of the Chernobyl nuclear accident (Dibb et al., 1990), and have even been used to provide dating control within long-lived biological systems (Clarke, 2008).

Of particular concern also is how to unravel human-induced changes in the atmospheric cycles of heavy metals entering the Antarctic atmosphere. The chemical analysis of snow and ice deposited over time in polar ice caps gives unique information on the pollution of the atmosphere with heavy metals over the last centuries. It should however be emphasized that these Antarctic archives mainly reflect pollution emitted in the Southern Hemisphere, especially in South America and South Africa. This is because pollution emitted in the Northern Hemisphere is less likely to penetrate into the Southern Hemisphere and ultimately to reach Antarctica. Deciphering these frozen archives is very difficult. Antarctic snow is so clean that the utmost precautions are required to collect the samples without contaminating them. As an example, one thousand tonnes of Antarctic snow typically contains no more than a few milligrams of lead. Heavy metals, metals or metalloids associated with contamination and potential toxicity, are derived from both natural and anthropogenic sources. While the main natural sources of heavy metals include rock and soil, volcanoes, sea-salt spray, wild forest fires, and continental and marine biogenic activities (Nriagu, 1989), anthropogenic toxic metals come mainly from industrial and domestic activities such as the mining and smelting of metals, the combustion of fossil fuels and refuse incineration (Nriagu and Pacyna, 1988).

Local emissions of heavy metals from human activities in Antarctica have the potential to give rise to environmental contamination in local areas. Major anthropogenic emissions within Antarctica are related to fuel burning for operation of Antarctic stations, snowmobiles, heavy vehicles, ships and aircraft (Boutron and Wolff, 1989). Although local effects may be confined to an area close to the site of such activities, special attention has to be given to local pollution related to stations and regularly utilized traverse routes (Qin et al., 1999, because human activities within Antarctica are increasing in number, magnitude, and intensity. An inventory of these emissions is needed for assessing the discharges of heavy metals into the Antarctic environment.

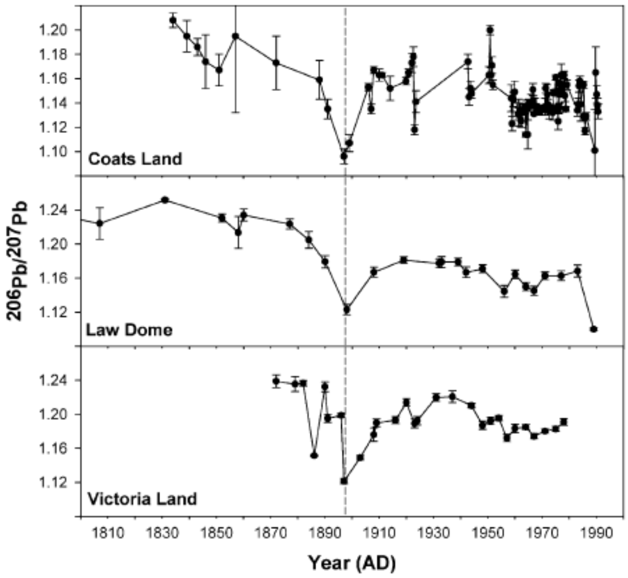


Figure 4.54 A comparison of $^{206}Pb/^{207}Pb$ ratios at Coats Land, Law Dome and Victoria Land over the past 200 years (Van de Velde et al., 2005).

Amongst the most spectacular results obtained so far is the reconstruction of past changes in lead pollution achieved by analyzing a series of snow samples collected in Coats Land, Victoria Land and Law Dome (Van de Velde et al., 2005). Lead isotopic profiles (Figure 4.54) show that lead pollution of Antarctica started as early as the 1880s. This early pollution was at least partially linked with non-ferrous metal production activities in South America, South Africa and Australia. Another important contribution was from coal-powered ships that crossed Cape Horn en route between the Atlantic and Pacific Oceans, as well as whaling ships and shore based stations along the Antarctic coast and Southern Ocean islands. This lead pollution then declined in the 1920s, correlated with the opening of the Panama Canal in 1914, which resulted in a pronounced decrease in ship traffic around the southern tip of South America. Lead pollution then increased again after World War II because of the very large rise in the use of leaded petrol in various countries in the Southern Hemisphere, combined with the continuous increase in non-ferrous metal production in South America, South Africa and Australia. Finally, lead concentrations strongly declined from the mid 1980s onwards, because of the fall in the use of leaded petrol in modern cars.

There is growing evidence from Antarctic snow and ice sampling highlighting the fact that Antarctica is already significantly contaminated with other metals such as Cr, Cu, Zn, Ag, Bi and U as a consequence of long-distance transport from surrounding continents (Wolff and Suttie, 1994; Wolff et al., 1999; Planchon et al., 2002; Vallelonga et al., 2002; Van de Velde et al., 2005)

POPs, pesticides and industrial chemicals, are ubiquitous anthropogenic compounds that are released around the world and found in the remote polar regions far distant from their primary sources, due to long-range atmospheric transport. Because they are hydrophobic, persistent and toxic, the trend of their distribution and their concentration are urgently needed to assess environmental contamination. The distribution pattern and levels of POPs such as PCBs and chlorinated pesticides such as Dichlorodiphenyltrichloroethane (DDT) and hexachloribenzene (HCB) are reported in the Antarctic environment (Fuoco et al., 1996; Carsolini et al., 2002; Weber and Goerke, 2003; Montone et al., 2003). Changing levels of some compounds of POPs in living organisms such as fish species reflect global redistribution and increasing transfer to Antarctic waters probably due to recent usage in the Southern Hemisphere and climate change (Weber and Goerke, 2003).

Despite increasing documentation, our ability to quantify environmental contamination from natural and industrial sources and to clarify the effects of various physico-chemical processes controlling atmospheric cycles of anthropogenic pollutants in the Antarctic is still limited because of weaknesses in the available scientific database.

Although some human activity in Antarctica, such as ship or aircraft transportation or the release of weather and research balloons can have widespread effects, scientists, tourists and fishermen are generally the main causes of local disturbance of the Antarctic environment. As pesticides have neither been produced nor applied in the continent, the discovery of DDT and its congeners in Antarctic marine biota in the 1960s and in the environment in the 1970s proved that persistent contaminants in the region come from other continents. Since then, HCB, Hexachlorocycloexanes (HCHs), aldrin, dieldrin, chlordane, endrin, heptachlor and other POPs have all been detected in Antarctica and the Southern Ocean. These chemicals are persistent, hydrophobic and lipophilic, accumulate in organisms and biomagnify in marine food chains (UNEP, 2002). While early ecotoxicological studies concentrated mainly on eggshell thickness and reproductive potential of birds, more recent evidence suggests that several POPs are also immunotoxic, endocrine disrupters and tumor promoters.

Although migrating species of marine birds and mammals may contribute to the southward transfer of POPs, their transport to the Southern Ocean and Antarctica mainly occurs through atmospheric and marine pathways. The Antarctic atmosphere loses more heat by radiative cooling than it gains by surface energy exchange and the deficit is balanced by atmospheric transport of heat, gases, moisture and aerosols from lower latitudes. The global transport of radiatively important trace gases such as CO_2, CH_4 and CFCs contribute for instance, to climate change and springtime ozone depletion events. Particles and reactive gases in air masses are partly removed by cyclonic storms in the belt of "westerlies" and are deposited in the Southern Ocean (Shaw, 1988). However, during the austral summer the circumpolar vortex disappears and long-term records of mineral dust, black carbon and ^{210}Pb at the South Pole and at some coastal Antarctic stations indicate an enhanced poleward transport of air masses (Wolff and Cachier, 1998). For instance, the contamination of Antarctic aerosol and snow by Pb and Cu has been widely documented (e.g., Barbante et al., 1998) and has usually been attributed to leaded petrol, non-ferrous metal mining and smelting and other anthropogenic sources in South America, Africa and Australia. Moreover, although during the last decades the deposition of Pb in Antarctic snow is decreasing, that of Cu, Zn and other elements is increasing (Planchon et al., 2002).

As the two hemispheres of the Earth have separate circulation systems through much of the atmosphere, there is probably a limited input of anthropogenic contaminants from the Northern Hemisphere to Antarctica. However, the profiles of radioactive debris deposition in Antarctic snow and ice during the 1950s and 1960s showed the presence of fission products released in the Northern Hemisphere (Koide et al., 1979). Under ambient temperatures POPs may volatilize from water, soils and vegetation into the atmosphere, where they are unaffected by breakdown reactions and may be transported over long distances before re-deposition. Volatilization/deposition cycles may be repeated many times and according to the theory of cold condensation and global fractionation (Wania and Mackay, 1993) the most volatile compounds such as HCHs, HCB and low-chlorinated PCBs can redistribute globally. Although their concentrations in Antarctic biota are usually below those documented to have reproductive effects in related species in temperate and Arctic regions, organisms living under harsh Antarctic conditions may be more stressed and more vulnerable to the adverse effects of pollutants than those in temperate regions (Bonstra, 2004; Corsolini et al., 2006). There is evidence that in some Antarctic marine organisms concentrations of Cd, Hg and other pollutants can be relatively high (e.g., Bargagli, 2001; Bustnes et al., 2007); furthermore, POP accumulation in marine sediments is increasing their availability and accumulation in benthic fish species feeding on benthic invertebrates (Goerke et al., 2004).

While there is serious concern related to protection of the Antarctic environment, major efforts in international legislation that will help to safeguard the Antarctic environment are underway. The Stockholm Convention on Persistent Organic Pollutants (2004) is a global treaty designed to protect the environment from chemicals that remain intact in the environment for long periods, such as POPs. This legislation follows in the footsteps of international legislation that protects Antarctica such as the Montreal Protocol (1989). The Montreal Protocol is designed to protect the ozone layer by phasing out the production of a number of substances believed to be responsible for ozone depletion.

4.10.3.3 Concern about the future impact of human activity

New classes of global pollutants are emerging, such as perfluorinated compounds (PFCs) that have a wide range of industrial applications. These compounds have been shown to be toxic to several species of aquatic organisms and to occur in biota from various seas and oceans, including the Arctic and the Southern Ocean (Yamashita et al., 2005). Catalytic converters in motor vehicles are increasing global emissions of Pt and other companion elements such as Pd, Rh, Ru, Os and In. Increased concentrations of Rh, Pd and Pt with respect to ancient Greenland ice samples were measured in surface snow from the Alps, Greenland and Antarctica (Barbante et al., 1999).

Climate change and global warming could enhance the transport and deposition of persistent contaminants in Antarctica. The oceanic transport of persistent contaminants is often considered to be much less important than atmospheric transport; however, models which combine the transport of semi-volatile chemicals in air and water, and consider continuous exchange between the two compartments indicate that the overall transport of POPs to remote regions is accelerated with respect to models treating air and water separately (Beyer and Matthies, 2001). The rapid regional climatic warming of the Antarctic Peninsula has also been detected in oceanic waters to the west (e.g. Meredith and King, 2005). The warming of surface water can affect POP volatilization and transport. In contrast to organisms in temperate and tropical seas, those in the Southern Ocean are well adapted to narrow ranges of water temperature close to the freezing point. Slight increases in temperature may have disproportionate influence on the properties of cell membranes and biological processes involved in the uptake and detoxification of environmental pollutants.

Although for continental Antarctica there is as yet no significant trend in meteorological temperature, a loss of ice shelves such as that in the Antarctic Peninsula (six ice shelves have largely disappeared in the last 50 years) could have dramatic effects on atmospheric precipitation (i.e. the deposition of contaminants) and the biogeochemical cycle of trace elements such as Hg. Mercury emitted by anthropogenic and natural sources occurs in the atmosphere mostly in the gaseous elemental form (Hg^0), which has a long lifetime in tropical and temperate regions. Once deposited in terrestrial and aquatic ecosystems the metal is partly re-emitted into air, thus assuming the characteristics of global pollutants such as POPs. The metal is now acknowledged to be one of the most serious contaminants in polar ecosystems because of the springtime Hg depletion events that have been reported in the high Arctic (Schroeder et al., 1998) and Antarctica (Ebinghaus et al., 2002). In polar regions, after sunrise, the globally-distributed Hg^0 undergoes photochemically-driven oxidation by reactive halogen radicals (from sea-salt aerosols) and rapidly deposits on snow and on terrestrial and marine ecosystems. Field evidence of enhanced Hg accumulation in soil and cryptogamic organisms from terrestrial ecosystems facing the Terra Nova Bay coastal polynya raises concern that Antarctica may become an important sink in the global Hg cycle (Bargagli et al., 2005). By changing the sea ice cover and increasing the availability of reactive halogens, warming could enhance the role of Antarctica as a "cold trap" for Hg through an increase in the out-gassing of the metal from continents and oceans. Furthermore, while the use of Hg and many POPs has declined or ceased in North America and Europe since the 1990s and earlier, the growing demand for energy, the burning of coal and biomass, the extraction of gold, intensive agriculture, the spraying of pesticides for disease vector control, and the lack of emission control technologies in South America, Africa and Asia will likely increase the atmospheric burden of Hg and many other persistent contaminants.

4.11 Biogeochemistry - Southern Ocean Carbon Cycle Response to Historical Climate Change

4.11.1 Introduction

The Southern Ocean, with its energetic interactions between the atmosphere, ocean and sea ice, plays a critical role in ventilating the global oceans and regulating the climate system though the uptake and storage of heat, freshwater and atmospheric CO_2 (Rintoul et al., 2001; Sarmiento et al., 2004a). The Southern Ocean is dominated by the eastward flowing ACC. The surface of the ACC is characterized by a northward Ekman flow creating a divergent driven deep upwelling south of the ACC and convergent flow north of the ACC. In the southern part, the upwelling of mid-depth (2-2.5 km) water to the surface provides a unique connection between the deep ocean and the atmosphere while in the northern part the downwelling provides a strong connection to water masses that resurface at lower latitudes e.g. Sarmiento et al. (2004a). These connections make the Southern Ocean extremely important in controlling the storage of carbon in the ocean and a key driver in setting atmospheric CO_2 levels (Caldeira and Duffy, 2000).

4.11.2 CO_2 fluxes in the Southern Ocean

The Southern Ocean carbon cycle response uptake can be described as a combination of seasonal and non-seasonal variability. In the Southern Ocean seasonal variability is the dominant mode of variability, and the mechanisms that drive the air-sea CO_2 fluxes are well known but their magnitudes remained poorly constrained (Metzl et al., 2006 and references therein). The seasonal cycle of CO_2 uptake is a complex interplay between the biological and physical pumps and can be described both in terms of its magnitude and phase. A recent climatological synthesis of more than 3 million measurements of surface pCO_2 measurements provides important insights into Southern Ocean behaviour at the seasonal timescales (Takahashi et al., 2009). During the austral summer biological production reduces surface ocean pCO_2 through photosynthetic activity and then exports part of this organic matter to the deep ocean. This reduction in surface pCO_2 is offset by the changes in the physical pump that reduce the capacity of the surface water to store CO_2 through upper ocean warming, which lowers solubility, thereby increasing the surface ocean pCO_2. The net result of this competition between the biological and physical pumps is that the Southern Ocean acts a sink of atmospheric CO_2 in the summer in the sub-Antarctic zone (SAZ; nominally 40°S – 50°S) and south of the Polar Front (PF; ~50°S; Figure 4.55). During the austral winter, a picture of two distinct zones separated by the PF is evident. South of the PF relatively little biological activity occurs in winter (deep mixing and light limitation); therefore surface pCO_2 values are set by the competition within the physical pump between deep winter mixing bringing up CO_2 water from the carbon rich deep ocean, leading to increased pCO_2 surface levels, and a cooling that increases the ability of the surface waters to store CO_2. As the deep winter mixing dominates in this region a net out-gassing of CO_2 to the atmosphere occurs. North of the PF during the austral winter the same cooling and mixing processes that occur further south exist, but with the addition of biological activity during the period, albeit at a reduced rate, reducing the pCO_2 in surface waters. The result of the combined responses of the biological and physical pumps means this region acts as a weak sink of atmospheric CO_2 during the austral winter.

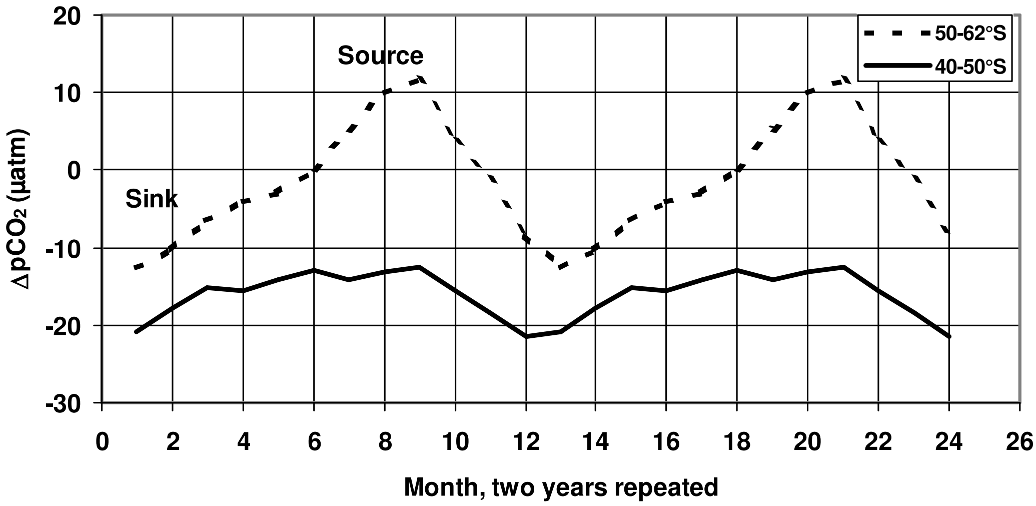


Figure 4.55 The annual cycle of ΔpCO_2 (pCO_2^{ocean}-pCO_2^{atm}; i.e. negative/positive = atmospheric CO_2 sink) in the Southern Ocean for the regions 40°-50°S (black line) and 50°-62°S (dashed line; Takahashi et al., 2009). The Sub-Antarctic zone (40°-50°S) acts a permanent CO_2 sink but at higher latitudes the ocean acts as an atmospheric sink during summer and a source during winter (Metzl et al., 2006).

When the observed winter and summer fluxes are integrated, the annual mean uptake is small south of 50°S (about -0.08 PgC/yr); conversely the SAZ (40°S-50°S) behaves as a strong sink (-0.74 PgC/yr) (Takahashi et al, 2009; see comments below). The response of the SAZ is consistent with other studies that suggest the SAZ is also a strong CO_2 sink approaching -1 PgC/yr (McNeil et al., 2007; Metzl et al., 1999) and an important region of mode and intermediate water formation and transformation. In comparison to the total uptake of 2 GtC/yr for the global ocean, the Southern Ocean south of 40°S takes up more than 40% of the total uptake. Note in these calculations we have used the gas transfer coefficent of Wanninkhof (1992) with the dataset of Takahashi et al., (2008).

Significant progress has been made in recent years in simulating the annual mean uptake of CO_2 by the Southern Ocean as precursor to understanding interannual to decadal variability. Figure 4.56 shows that the spatial pattern of the annual mean uptake is well represented in comparison with that simulated from the current class of ocean biogeochemical models (e.g. OPA/PISCES model; Aumont and Bopp, 2006)). Although different models do contain different representations of the magnitude of the seasonal cycle, the phase between each model and observations shows good agreement. This suggests that seasonal processes that drive this variability are well captured, and that as a result, we are in a better position to explore changes at interannual and longer timescales.

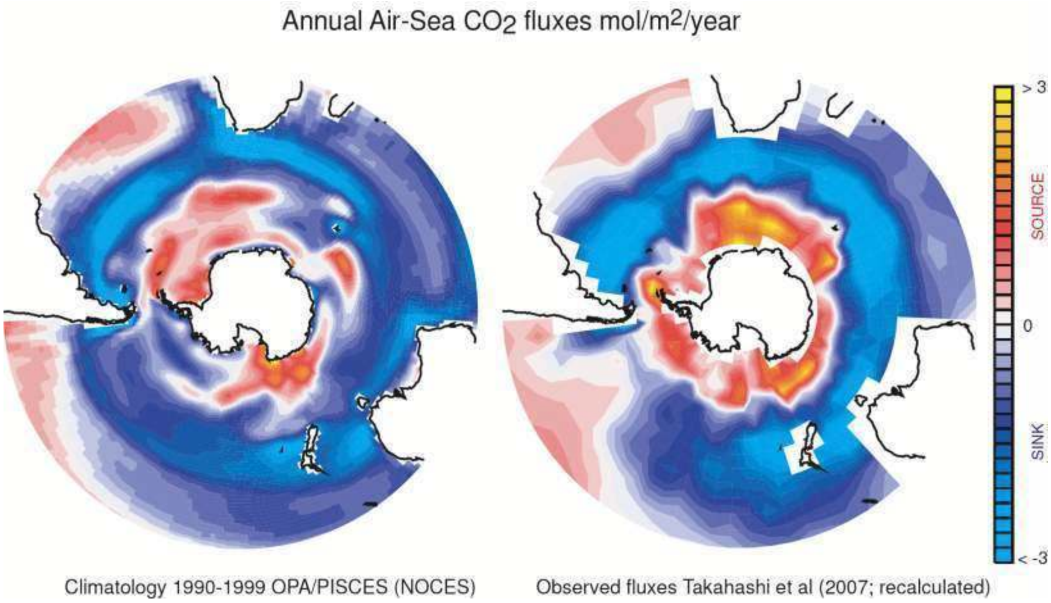


Figure 4.56 Annual mean uptake of air-sea CO_2 fluxes as calculated from OPA/PISCES 1990-1999 (Lenton et al., 2006) and that from the new climatology of Takahashi et al. (2009). The sub-Antarctic region (40-50°S) represents a strong sink (blue colors), whereas south of 50°S, large regions act as a CO_2 source for the atmosphere (red).

4.11.3 Historical Change - Observed Response

The Southern Ocean has undergone significant changes in response to climate changes; such as a net increase in heat and freshwater fluxes, and a poleward movement and intensification of winds e.g. Thompson and Solomon (2002). The major driver of these changes has been the SAM that is associated with changes in the Antarctic Vortex, primarily in response to depletion of stratospheric ozone and increasing atmospheric greenhouse gas concentrations (Arblaster and Meehl, 2006). While the SAM is a significant driver of variability it cannot explain all the variability present, as it has both linear and non-linear interactions with other climatic modes such as ENSO and Indian Ocean Dipole (IOD) that drives diverse responses in different regions. These physical changes impact directly on the physical pump and to a lesser extent on the biological pumps, therefore on the concentration of CO_2 in surface waters and the magnitude of both uptake and export of CO_2 from the atmosphere to the deep ocean.

In the Southern Ocean the interannual to decadal changes in biological production, ocean dynamics and thermodynamics that drive oceanic pCO_2 and air-sea CO_2 exchanges remain poorly understood and very undersampled. Decadal and interannual variations have been observed at high latitudes, but at only very few locations and during the austral summer (Jabaud-Jan et al., 2004; Brévière et al., 2006, Borges et al., 2008). Although these analyses provide important information on the response of the ocean to climate variability in the Southern Hemisphere, there is no clear detection of the decadal trends of oceanic CO_2 and associated air-sea CO_2 fluxes, unlike the situation in the north Atlantic or the north and equatorial Pacific where there are long-term time series of such data (e.g. Bates, 2001; Feely et al., 2002). Takahashi et al. (2009) have recently constructed a pCO_2 data synthesis, from which a significant increase of oceanic pCO2 during winter has been calculated, about +2.1±0.6 µatm/yr, which is close to or faster than the growth rate in the atmosphere (1.7 ppm/yr) over the period 1986-2007.

Repeat underway measurements of surface pCO_2 have been made regularly in the Southern Indian Ocean since the 1990s (e.g. Metzl et al.,1999). Although these measurements are quite often confined to regions where ships travel to resupply Antarctic and sub-Antarctic bases, they represent a valuable timeseries for exploring the evolution of the surface ocean. A recent study by Metzl (2009; Figure 3.68) in the South Western Indian Ocean calculated surface trends of pCO_2 between 1991-2007 and showed that oceanic pCO_2 increased at all latitudes south of 20°S (1.5 to 2.4 µatm/yr depending the location and season). More specifically, at latitudes of less than 40°S, they determined that oceanic pCO_2 increased faster than in the atmosphere since 1991, suggesting the strength of the oceanic sink decreased. In addition, when pCO_2 data are normalized to temperature, removing the effect of solubility on CO_2, this analysis showed that the system is increasing much faster in the winter than in the summer (Figure 4.57). These results suggest that the increase may be due to changes in ocean dynamics, given that the largest response occurs in the austral winter, when the winds are strongest. In the recent period (since the 1980s) the increase of pCO_2 appeared to be faster compared to the trends based on historical observations from 1969-2002 (Inoue and Ishii, 2005), suggesting that the Southern Ocean CO_2 sink has continued to evolve in response to climate change.

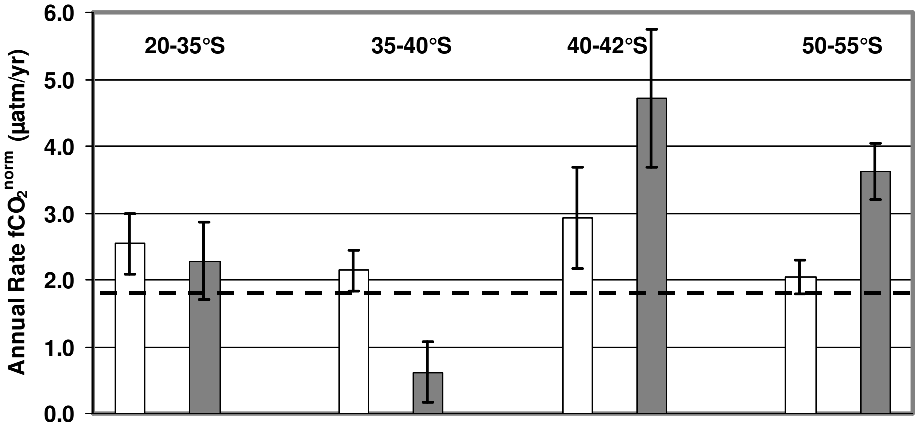


Figure 4.57 Annual mean trends of temperature normalized *f*CO_2 in 4 regions of the South-Western Indian Ocean (based on summer and winter observations in 1991-2007). The open bars indicate the growth rates estimated for summer and black bars for winter. Standard errors associated to each trend are also indicated. The dashed line indicates the atmospheric CO_2 annual growth rate (figure reproduced from Metzl, 2009).

As oceanic pCO_2 in recent years has been observed to be increasing close to, or faster than in the atmosphere, the signature of these changes in atmospheric CO_2 data should be detectable, as has been observed in the Equatorial Pacific during ENSO events (e.g. Peylin et al., 2005). At latitudes south of 40°S the ocean has a very large surface and it is expected that continental carbon source/sink variability has a low imprint in atmospheric CO_2 records (compared to the tropics and north hemisphere). This is clearly seen in the CO_2 record at La

Nouvelle Amsterdam Island (in the South-Indian Ocean), for example, where the seasonality of atmospheric CO_2 is very low. A recent study by Le Quéré et al. (2007) using a combination of atmospheric observations and inverse methods reported that in the period 1981-2004, the strength of the Southern Ocean CO_2 sink (south of 45°S) was reduced (Figure 4.58). Although this result remains controversial (e.g. Law et al., 2008), it does suggest that the observed increase in oceanic pCO_2 acts to reduce the strength of the air-sea CO_2 gradient (ΔpCO_2) and this in turn translates to reduction in the strength of the Southern Ocean CO_2 sink. This result is significant as it was expected in response to strengthening air-sea CO_2 gradient that the Southern Ocean CO_2 uptake would increase. These results are also consistent with a number of recent modeling studies, that have also suggested a decrease in uptake in the last decades and which attributed the upper ocean pCO_2 values to increases in the wind speed increasing the ventilation of carbon rich deep waters e.g. Lenton and Matear (2007).

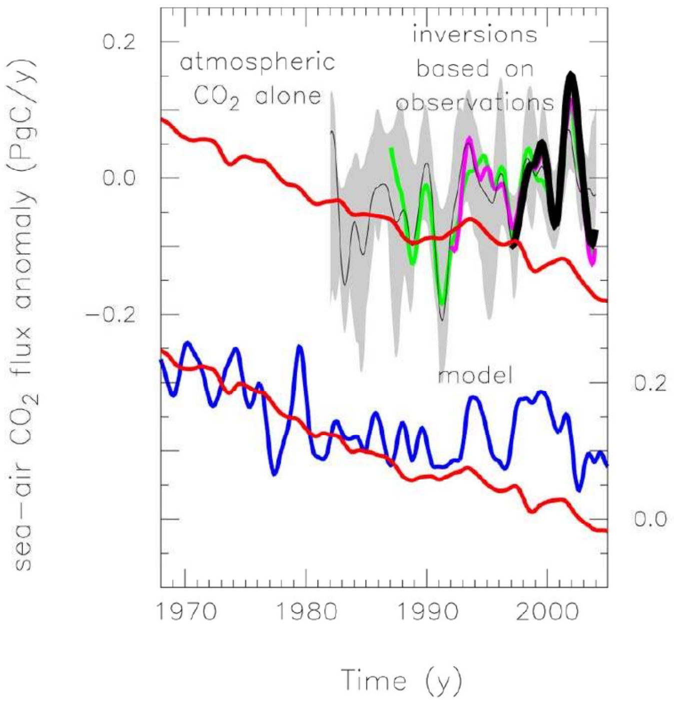


Figure 4.58 Sea-air CO_2 flux anomalies in the Southern Ocean (PgC/y, >45°S) based on atmospheric CO_2 data and inversed transport model (on top) and a global biogeochemical ocean model (bottom). Compared to experiments that do not take into account the climate variability (in red), both approaches suggest a stabilization or reduction of the ocean CO_2 sink since the 1980s (LeQuéré et al., 2007).

4.1.4 Historical Changes – Simulated View

To explore how changes in Southern Ocean air-sea CO_2 fluxes have responsed to historical climate change between 1948-2003. Matear and Lenton (2008) used a biogeochemical ocean model driven with observed changes (NCEP R1; Kalnay et al., 1996). They explored how the total carbon cycle as well as the natural and anthropogenic carbon uptake responded to the observed increases in windstress, heat and freshwater fluxes (Figure 4.59). Their results show a complex picture: when only either heat or freshwater fluxes increase, the total uptake is slightly greater than the total CO_2 flux response (with all fields increasing). In contrast, when only the wind speed increased, the total uptake was less than the total response. In addition, the anthropogenic response was always much smaller than the natural carbon cycle response and hence the natural response dominated the total response. The natural carbon sink dominates the total response over the last 50 years for two reasons: (i) because wind stress changes are larger than the corresponding changes in heat and freshwater flux, therefore changes in solubility are dominated by changes in ocean dynamics; and ii) the CO_2 gradient between the atmosphere and the ocean due to anthropogenic emissions is strong enough over this period to counter the increased CO_2 in surface waters caused by winds bringing up water rich in dissolved inorganic carbon from the deep ocean. Although there is some question of the validity of the changes in the pre-satellite era (1948-1979; Marshall, 2003), the largest changes occur in the later period 1979-2003, as seen in Figure 4.58.

As reanalysis products used in Matear and Lenton (2008) are assimilated products, all climate modes/variability are represented. Other studies using different ocean models and experiments to explore the response of the Southern Ocean air-sea CO_2 flux to the SAM alone e.g. Lenton and Matear (2007), Lovenduski et al. (2007) are very consistent with the view determined using all the superposition of all the climatic modes. This is not surprising given that these studies suggest that more than 40% of the total variance in CO_2 flux is be explained by the SAM in the recent period Lenton and Matear (2007).

Over the period only a small increase in primary production and export production is evident, suggesting only a weak link between atmospheric forcing and export production, despite the increased upwelling of deep waters in response to increased winds (i.e. supplying also macro and micro nutrients). The largest response was on the northern boundary of the High Nutrient Low Chlorophyll (HNLC) area of the Southern Ocean. Over the rest of the Southern Ocean, very little response was seen, demonstrating only a weak link between atmospheric forcing and production.

The increased ventilation of the Southern Ocean from simulations does not only alter the concentration of upper ocean CO_2 and the air-sea CO_2 fluxes, it also alters the carbonate chemistry of the upper ocean. These changes in carbonate chemistry affect the ability of the ocean to take up atmospheric CO_2, through changes in the Revelle factor (Revelle and Suess, 1957) and through the lowering of seawater pH. This pH reduction, or ocean acidification, reduces the ability of organisms that use calcite to build shells, potentially adversely impacting the marine ecosytem (Feely et al., 2004). In response to ocean acidification, a key carbon parameter is the aragonite saturation state (Ω_A), which influences the rate of calcification of marine organisms (Riebesell et al., 2000; Langdon and Atkinson, 2005). Simulations show that the observed increases and variability in heat, freshwater fluxes and in particular wind stress in the last 50 years, has moved the saturation horizon closer to the surface (Orr et al, 2005), potentially already impacting on the ecosystems in the Southern Ocean, although we do not yet have the observational evidence to support this hypothesis.

4.11.5 Changes in CO_2 inventories

In the previous sections, we focused on the changes of the air-sea CO_2 fluxes as observed and simulated over the last 50 years. When discussing the capacity of the ocean to reduce the impact of climate changes, the change in anthropogenic CO_2 in the water column since the pre-industrial era must be evaluated. This is important not only to estimate the global ocean's capacity to absorb anthropogenic CO_2 emissions, but also to detect the changes in carbonate saturation levels and the potential increase of ocean acidity, especially in the Southern Ocean (Feely et al., 2004; Orr et al., 2005). It has been estimated that in recent decades 30% of the total uptake since the preindustrial period has been taken up by Southern Ocean mode waters (Sabine et al., 2004). The anthropogenic CO_2 in the ocean (C_{ant}) cannot be directly measured, but under several assumptions, it can be derived from *in-situ* observations. This was first suggested by Brewer (1978) and Chen and Millero (1979), and in the last ten years several data-based methods have been investigated at regional and global scales (see a review in Wallace 2001; Sabine et al., 2004; Waugh et al., 2006; Lo Monaco et al., 2005). Comparisons of data-based methods (Lo Monaco et al., 2005) clearly show that all methods converge to estimate large inventories associated with mode and intermediate waters (Figure 4.60). Meanwhile in Southern Ocean uptake south of 50°S uncertainties in C_{ant} still exist, but these differences appear to reflect techniques that have been recognized to underestimate anthropogenic carbon in deep and bottom waters along the Antarctic coast (Lo Monaco, personal communication).

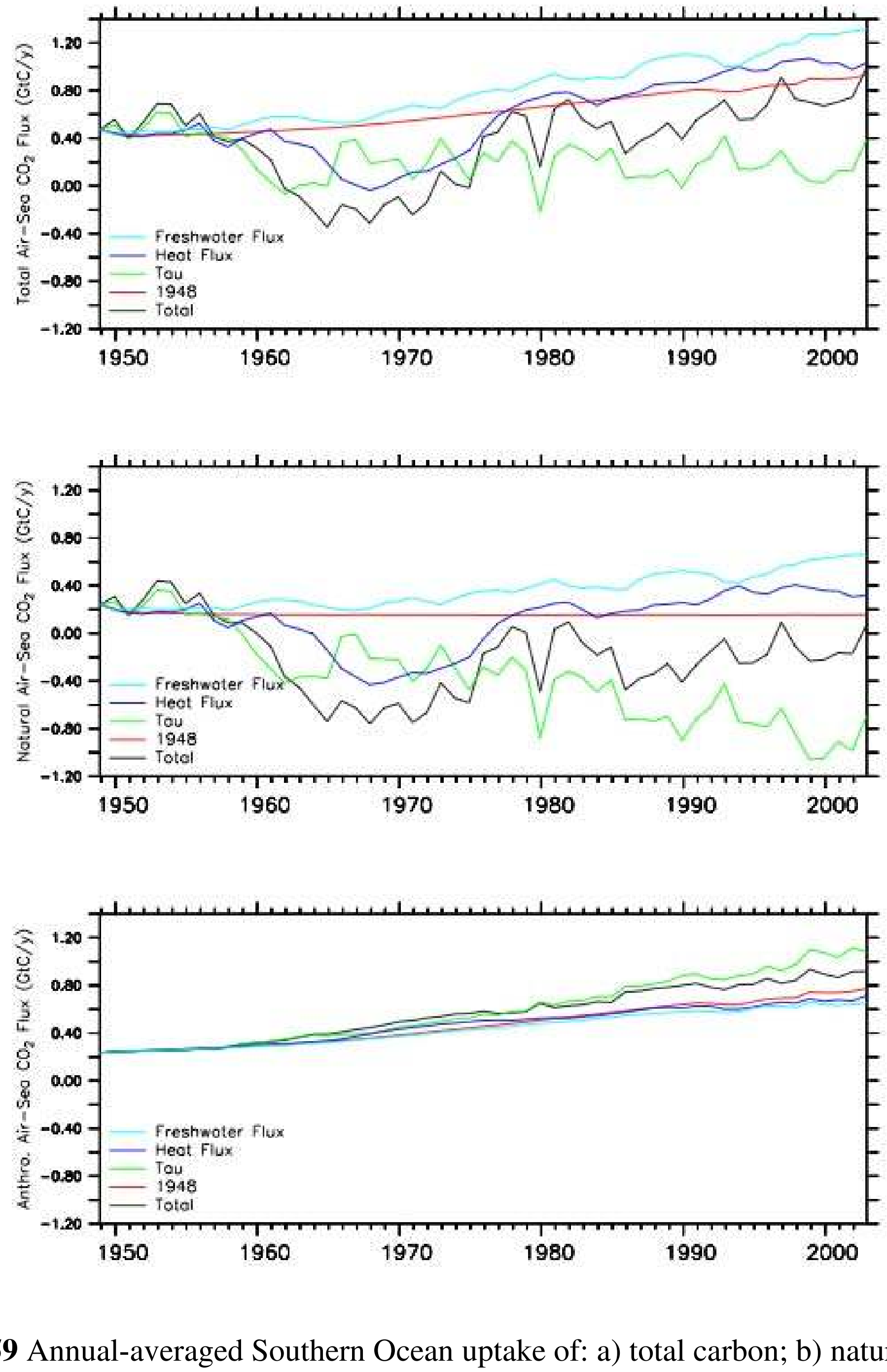


Figure 4.59 Annual-averaged Southern Ocean uptake of: a) total carbon; b) natural carbon; c) anthropogenic carbon. The different experiments use the following colour coding, total experiment (black line), 1948 (red line), wind stress (tau, green line), heat flux (blue line) and freshwater flux (cyan line).

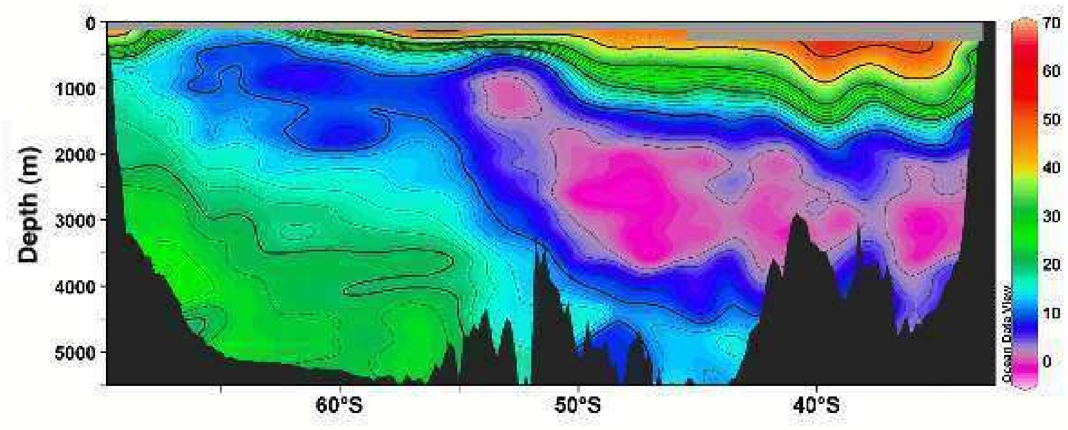


Figure 4.60 Anthropogenic carbon concentrations (colour scale, in umol/kg) derived using a back-calculation method in the Indian Ocean sector of the Southern Ocean between Antarctica (left) and Africa (right) (redrawn from Lo Monaco et al., 2005).

4.11.6 Concluding Remarks

The Southern Ocean plays a critical role in the uptake of atmospheric CO_2, accounting for more that 40% of the annual mean CO_2 uptake. Modelling and observational studies show that the Southern Ocean has undergone significant changes in the last 50 years; these views appear to be converging towards a coherent view. The largest change has been a reduction in the total CO_2 uptake in recent decades in response to the observed changes in climatic forcings, particularly changes in wind speed. The increased wind speed drives strong changes in the physical carbon pump, specifically through ocean dynamics, rather than through changes in solubility or in the Revelle factor; this view is further reinforced by only a weak response in the biological pump. In the future, in response to climate change, both the biological and physical pumps are expected to be impacted (see Section 5.8 for details).

4.12 Terrestrial Biology

Contemporary terrestrial and freshwater ecosystems within Antarctica occupy only 0.34% of the continental area (British Antarctic Survey, 2004), the remainder being permanent ice and snow. The combined land area of the isolated sub-Antarctic islands is likewise small. Individual areas of terrestrial habitat are typically ‘islands’, whether in the true sense of the word, being surrounded by ocean, or in the sense of being surrounded and isolated by terrain inhospitable to terrestrial biota in the form of ice (Bergstrom and Chown, 1999). While the most biologically developed and most studies of terrestrial exposures are found in coastal regions of the continent, particularly along the Antarctic Peninsula and in Victoria Land, terrestrial habitats exist in all sectors of the continent, and both in coastal and inland locations.

Terrestrial biological research within Antarctica has, however, been much more spatially limited, with major areas of activity restricted to the South Orkney and South Shetland Islands, Anvers Island, the Argentine Islands and Marguerite Bay along the Antarctic Peninsula/Scotia Arc, and the Dry Valleys and certain coastal locations in Victoria Land. Terrestrial and freshwater research along the continental Antarctic coastline has largely been limited to areas in the vicinity of the Schirmacher Oasis, Windmill Islands and Davis

Station, Casey Station, and mountain ranges in Dronning Maud Land. Sporadic biological records exist from more widely dispersed locations, but in most cases these relate to single short field visits to these locations, often by non-biologists or non-specialists. Indeed, there remain many instances where the only biological records available, or only species descriptions that exist, derive from the original exploring expeditions of the 'heroic era'. Even where terrestrial biological research is undertaken within a region or by a national operator, both taxonomic and process-based research coverage is extremely uneven across different regions or operators.

All Antarctic terrestrial ecosystems are simple in global terms, lacking or with low diversity in specific taxonomic or biological functional groups (Block, 1984; Smith, 1984; Convey, 2001). It is therefore likely that they lack the functional redundancy that is typical of more diverse ecosystems, raising the possibility of new colonists (arriving by both natural and, more recently, human-assisted means) occupying vacant ecological niches. Such colonists could include new trophic functions or levels, threatening the structure and function of existing trophic webs (Frenot et al., 2005, 2007; Convey, 2008). Responses of indigenous biota will be constrained by their typically 'adversity-selected' life history strategies, which have evolved in an environment where abiotic environmental stresses and selection pressures (i.e. properties of the physical environment) far outweigh in importance biotic stresses and pressures (i.e. competition, predation, etc.) (Convey, 1996).

The growth and life cycle patterns of many invertebrates and plants are fundamentally dependent on regional temperature regimes and their linkage with patterns of water availability (Convey et al., 2006). In detail, the interaction between regional macroclimate and smaller scale ecosystem features and topography define the microclimate within which an organism must live and function. There has to date been remarkably little effort to identify connections between macro and microclimatic scales, or to probe the application of large-scale macroclimatic trends and predictions at microclimatic scale. Distinct patterns in sexual reproduction are evident across the Antarctic flora and are most likely a function of temperature variation - indeed recent increase in the frequency of successful seed production in the two maritime Antarctic flowering plants (Convey, 1996) is proposed to be a function of warming in this region. In addition, phenology of flowering plants is cued to seasonality in the light regime. In regions supporting flowering plants, wind is assumed to play a major role in pollination ecology of grasses and sedges resulting in cross-pollination. The lack of specialist pollinators in the native fauna, combined with high reproductive outputs in non-wind pollinated species implies a high reliance on self-fertilisation.

The Antarctic biota shows high development of ecophysiological adaptations relating to cold and desiccation tolerance, and displays an array of traits to facilitate survival under environmental stress (Hennion et al., 2006). While patterns in absolute low temperatures are clearly important in determining survival, perhaps more influential is the pattern of the freeze-thaw regime, with repeated freeze-thaw events being more damaging than a sustained freeze event (Brown et al., 2004; Sinclair and Chown, 2005). How these patterns change in the future will be an area of major importance.

The response of Antarctic plants to increased UV-B radiation (280-315 nm) associated with the ozone hole, provides an illustration of another suite of ecophysiological/biochemical strategies. Reported responses vary widely between studies, ranging from negative effects on chlorophyll concentrations in tissues, on growth, and evidence of DNA damage in some species (e.g. Ruhland and Day, 2000; Xiong and Day, 2001; Robinson et al., 2005; Turnbull and Robinson, 2008), through little change (e.g. Björn, 1999; Lud et al., 2002; Boelen et al., 2006) to consistent positive effects, such as increased concentrations of UV-B screening pigments (Newsham et al., 2002). Previously it has been suggested that higher plants and bryophytes could differ in their abilities to synthesize UV-B screening pigments (Gwynn-Jones et al., 1999), but most recent data from Antarctic studies do not support this proposition (e.g. Newsham et al., 2002; Newsham, 2003; Newsham et al., 2005; Dunn and Robinson, 2006; Clarke and Robinson, 2008). The majority of Antarctic bryophytes studied have potential UV screening compounds inside their cells and/or attached to their cell walls (Clarke and Robinson, 2008), suggesting widespread UV screening potential in these species. A recent study has estimated that the cost of synthesising new protective pigment molecules on exposure to UV-B represents approximately 2% of the carbon fixated by a common Antarctic liverwort, analogous to estimates of 1-10% of biomass invested in cryoprotectants or desiccation protectants by many Antarctic terrestrial invertebrates and microbes (Snell et al., 2009).

	Entire sub-Antarctic	Maritime Antarctic	South Georgia	Marion	Prince Edward	Crozet	Kerguelen	Heard	Mac Donald	Macquarie
Dicotyledons	62	0	17	6	2	40	34	0	0	2
Mono-cotyledons	45	2	15	7	1	18	34	1	0	1
Pteridophytes	1	0	1	0	0	1	1	0	0	0
Total non-indigenous plants	108	2	33	13	3	59	69	1	0	3
Invertebrates	72	2-5	12	18	1	14	30	3	0	28
Vertebrates	16	0	3	1	0	6	12	0	0	6

Table 4.2 The occurrence of alien non-indigenous terrestrial species across Antarctic biogeographical zones (extracted from Frenot et al. (2005); see also Greenslade (2006) for a detailed description of established and transient alien species, and species recorded only synanthropically, from sub-Antarctic Macquarie Island).

A meta-analysis of the response of polar vegetation to UV-B radiation concludes that Antarctic bryophytes and vascular plants respond in a similar fashion to vegetation from other regions, with UV-B exposure leading to decreased above-ground biomass and height and increased DNA damage (Newsham and Robinson, 2009). Plants also appear able to protect themselves from elevated UV-B radiation through the induction of UV screening pigments (Newsham and Robinson, 2009), although this likely comes at a cost to biomass production (Snell et al., 2009). However this meta-analysis does suggest that the method by which UV-B radiation is applied to plants plays an important part in determining the strength of plant response to UV-B.

The final suite of life history traits includes elements relating to competition and predation. Their potential significance is illustrated by reference to ecosystem changes caused through the introduction of new predatory invertebrates to certain sub-Antarctic islands (e.g. Table 4.2). The introduction of carabid beetles to parts of South Georgia and Îles Kerguelen, where such predators were previously absent, is leading to extensive changes to local community structure, which threatens the continued existence of some indigenous and/or endemic invertebrates (Ernsting et al., 1995; Frenot et al., 2005, 2008). Regional warming has also been predicted to rapidly increase the impact of certain indigenous predators (Arnold and Convey, 1998). Providing an analogous impact within the decomposition cycle, detailed studies on Marion Island indicate that indigenous terrestrial detritivores are unable to overcome a bottleneck in the decomposition cycle, hence illustrating a further ecosystem service likely to be strongly influenced by recently introduced non-indigenous species (Slabber and Chown, 2002).

The lack of attention to these traits to date is unfortunate, particularly with respect to the understanding of alien species' impacts. It is already well known that Antarctic terrestrial biota possess very effective stress tolerance strategies, in addition to considerable response flexibility. The exceptionally wide degree of environmental variability experienced in many Antarctic terrestrial habitats, on a range of timescales between hours and years, means that predicted levels of change in environmental variables (particularly temperature and water availability) are often small relative to the range already experienced. However, as illustrated above with biochemical responses to UV-B exposure, any change in the balance of use of specific strategies carries a quantifiable cost, and carries implications for changes in the allocation of resources within the organism.

Given the absence of more effective competitors, predicted and observed levels of climate change may be expected to generate positive responses from resident biota of the maritime and continental Antarctic, and this is confirmed in general terms both by observational reports of changes in maritime Antarctic terrestrial ecosystems, and the results of manipulation experiments mimicking the predictions of climate change (Convey, 2003, 2007). Over most of the remainder of the continent, biological changes are yet to be reported, as might be expected given the weakness or lack of evidence for clear climate trends over the instrumental period. Potentially sensitive indicators of change have been identified amongst the biota of this region (e.g. Wasley et al., 2006), particularly in the context of sensitivity to changes in desiccation stress (Robinson et al., 2003). More local scale and short-term trends of cooling over recent decades in the Dry Valleys of Victoria Land have been associated with reductions in abundance of the soil fauna (Doran et al., 2002). The picture is likely to be far more complex on the different sub-Antarctic islands as, in addition to various different trends being reported in a range of biologically important variables, many also already host (different) alien invasive taxa, some of which already have considerable impacts on native biota (Frenot et al., 2005; Convey, 2007, Table 4.2).

The best-known and frequently reported example of terrestrial organisms interpreted to be responding to climate change in the Antarctic is that of the two native Antarctic flowering plants (*Deschampsia antarctica* and *Colobanthus quitensis*) (Figure 4.61) in the maritime Antarctic (Fowbert and Smith, 1994; Smith, 1994; Grobe et al., 1997; Gerighausen et al., 2003). At the Argentine Islands numbers of plants increased by two orders of magnitude between the mid 1960s and 1990 (Fowbert and Smith, 1994), although it is often overlooked that these increases have not involved any change in the species' overall geographic ranges, limited in practice by extensive ice cover south of the current distribution. These increases are thought to be due to increased temperature encouraging growth and vegetative spreading of established plants, in addition to increasing the probability of establishment of germinating seedlings. Additionally, warming is proposed to underlie a greater frequency of mature seed production (Convey, 1996b), and stimulate growth of seeds that have remained dormant in soil propagule banks (McGraw and Day, 1997). However, since 1990, there has been no further increase in the Argentine Islands populations, while there has also been no significant warming trend in either the annual or seasonal air temperature data record at this location over the period 1990-2008, which might suggest the link between environmental conditions and plant responses is even closer than initially thought (Parnikoza et al., in press).

Figure 4.61 The only two flowering plants native to the Antarctic continent are both restricted to the Antarctic Peninsula. The grass *Deschampsia antarctica* may develop into swards covering several to tens of square metres (left), while the pearlwort *Colobanthus quitensis* more typically is encountered as individual cushions (right) (photos P. Convey).

Changes in both temperature and precipitation have already had detectable effects on limnetic ecosystems through the alteration of the surrounding landscape and of the time, depth and extent of surface ice cover, water body volume and lake chemistry (with increased solute transport from the land in areas of increased melt) (Quesada et al., 2006; Lyons et al., 2006; Quayle et al., 2002, 2003. The latter authors highlight that some maritime Antarctic lake environmental changes actually magnify those seen in the atmospheric climate, highlighting the value of these locations as model systems to give 'early warning' of potential changes to be seen at lower latitudes. Predicted impacts of such changes will be varied. In shallow lakes, lack of surface ice cover will lead to increased wind–induced mixing and evaporation and increases in the diversity at all levels of the ecosystem. If more melt water is available, input of freshwater into the mixolimna of deeper lakes will increase stability and this, associated with increased primary production, will lead to higher organic carbon flux. Such a change will have flow–on effects including potential anoxia, shifts in overall biogeochemical cycles and alterations in the biological structure and diversity of ecosystems (Lyons et al., 2006).

Alien microbes, fungi, plants and animals, introduced directly through human activity over approximately the last two centuries, already occur on most of the sub-Antarctic islands and some parts of the Antarctic continent (Frenot et al., 2005, 2007; Greenslade, 2006; Convey, 2008, Table 4.2). The level of detail varies widely between locations and taxonomic groups (although at the microbial level, knowledge is virtually non-existent across the entire continent). On sub-Antarctic Marion Island and South Atlantic Gough Island it is estimated that rates of establishment through anthropogenic introduction outweigh those from natural colonization processes by two orders of magnitude or more. Introduction routes have varied, but are largely associated with movement of people and cargo in connection with industrial, national scientific programme and tourist operations. Although it is rare to have a record available of a specific introduction event, and there are undoubtedly instances of natural colonization processes resulting in new establishment, the impact of undoubted human-assisted introductions to some sub-Antarctic islands (particularly South Georgia, Kerguelen, Marion, Macquarie) is substantial and probably irreversible. Thus a range of introduced vertebrates and plants have led to large shifts in ecosystem structure and function, while in terms of overall diversity some islands now host a greater number of non-indigenous than indigenous species of plant. The large majority of aliens are European in origin.

ARZEL, O., FICHIFET, T. AND GOOSSE, D.H. 2006. Sea ice evolution over the 20th and 21st centuries as simulated by current AOGCMs. *Ocean Modelling*, **12,** 401-415.

ASHWORTH, A.C. and CANTRILL, D.J. 2004. Neogene vegetation of the Meyer Desert Formation (Sirius Group), Transantarctic Mountains, Antarctica, *Palaeogeography, Palaeoclimatology, Palaeoecology,* **213**, 65-82.

ASHWORTH, A.C., LEWIS, A.R., MARCHANT, D.R., ASKIN, R.A., CANTRILL, D.J., FRANCIS, J.E., LENG, M.J., NEWTON, A.E., RAINE, J.I., WILLIAMS, M. and A.P. W. 2007. The Neogene biota of the Transantarctic Mountains - Online Proceedings of the ISAES X, edited by A.K. Cooper and C.R. Raymond et al., USGS Open-File Report 2007-1047, Extended Abstract 071, 4 p.

ASSMANN, K., HELLMER, H.H. AND BECKMANN, A. 2003. Seasonal variation in circulation and water mass distribution on the Ross Sea continental shelf, *Antarctic Science*, **15** (1), 3–11 (doi: 10.1017/S0954102003001007).

ASSMANN, K.M. and TIMMERMANN, D.R. 2005. Variability of dense water formation in the Ross Sea, *Ocean Dynamics,* **55**, 68-87.

ATKINSON, A. SHREEVE, R.S, TARLING, G.A., HIRST, A.G., ROTHERY, P., POND, D.W., MURPHY, E.J. and WATKINS, J.L. 2006. Natural growth rates of Antractic krill (Euphausia superba): II: Predictive models based on food, temperature, body length, sex, and maturity stage, *Limnology and Oceanography,* **51**, 973-987.

ATKINSON, A., PAKHOMOV, E., ROTHERY, P., SIEGEL, V. 2004. Long-term decline in krill stocks and increase in salps within the Southern Ocean, *Nature,* **432** (7013), 100-103.

ATKINSON, A., SIEGEL, V., PAKHOMOV, E.A., ROTHERY, P., LOEB, V., ROSS, R.M., QUETIN, L.B., SCHMIDT, K., FRETWELL, P., MURPHY, E.J., TARLING, G.A. and FLEMING, A.H. 2008. Oceanic circumpolar habitats of Antarctic krill, *Mar. Ecol. Prog. Ser*, **362**, 1-23.

AUMONT, O. and BOPP, L. 2006. Globalizing results from ocean in situ iron fertilization studies, *Global Biogeochemical Cycles*, **20**, doi:10,029/2005GB002519.

AUSTIN, J., WILSON, J., LI, F. and VÖMEL, H. 2006. Evolution of water vapor and age of air in coupled chemistry climate model simulations of the stratosphere, *J. Atmos. Sci.*, in press.

AZAM, F., BEERS, J.R., CAMPBELL, L., CARLUCCI, A.F., HOLM-HANSEN, O., REIS, F.M.H. and KARL, D.M. 1979. Occurrence and metabolic activity of organisms under the Ross Ice Shelf, Antarctica, at station J9, *Science,* **203**, 451-453.

BABALOLA, O.O., KIRBY, B.M., LE ROES-HILL, M., COOK, A.E., CARY, S.C., BURTON, S.G. and COWAN, D.A. 2009. Phylogenetic analysis of actinobacterial populations associated with Antarctic Dry Valley mineral soils, *Environm. Microbiol*, **11**, 566-576.

BACCI, E, CALAMARI, D., GAGGI, C., FANELLI, R., FOCARDI, S. and MOROSINI, M. 1986. Chlorinated hydrocarbons in lichen and moss samples from the Antarctic Peninsula, *Chemosphere*, **15,** 747-754.

BAILEY, D.M., JOHNSTON, I.A., PECK, L.S. 2005. Invertebrate muscle performance at high latitude: swimming activity in the Antarctic scallop, *Adamussium colbecki, Polar Biol*, **28**, 464-469.

BAINES, P.G. and CONDIE, S. 1998. Observations and modelling of Antarctic downslope flows: a review. In *Ocean, Ice and Atmosphere: Interactions at the Antarctic Continental Margin*, AGU *Antarctic Research Series* Vol. **75**, S.S. Jacobs and R. Weiss editors, 29-49.

BAKUN, A. 1996. Patterns in the Ocean-Ocean Processes and Marine Population Dynamics. California Sea Grant College System, La Jolla.

BAMBER, J. L., RIVA, R. E. M., VERMEERSEN, B. L. A. and LEBROCQ A. M. 2009. Reassessment of the Potential Sea-Level Rise from a Collapse of the West Antarctic Ice Sheet, *Science,* **324** (5929), 901. [DOI: 10.1126/science.1169335].

BAMBER, J., VAUGHAN, D.G. and JOUGHIN, I. 2000. Widespread complex flow in the interior of the Antarctic ice sheet, *Science,* **287**, 1248–1250, (doi:10.1126/science.287.5456.1248).

BAMBER, J.L., GOMEZ-DANS, J. L. and GRIGGS, J. A. 2008., A new 1 km digital elevation model of the Antarctic derived from combined satellite radar and laser data. Part I: Data and methods, *The Cryosphere Discuss.,* 2(6).

BANKS, H. T. and BINDOFF, N.L. 2003. Comparison of observed temperature and salinity changes in the Indo-Pacific with results from the coupled climate model HadCM3: processes and mechanisms, *J. Climate*, **16**, 156-166.

BANKS, J.C., CARY, S.C. and HOGG, I.D. 2009. The phylogeography of Adelie penguin faecal flora, *Environm. Microbiol*, **11**, 577-588.

BANO, N., RUFFIN, S., RANSOM, B. and HOLLIBAUGH, J. T. 2004. Phylogenetic composition of Arctic Ocean archaeal assemblages and comparison with antarctic assemblages, *Appl. Environ. Microbiol,* **70**, 781-789.

BARBANTE, C., COZZI, G., CAPODAGLIO, G., VAN DE VELDE, K,, FERRARI, C., VEYSSERY, A., BOUTRON, C.F., SCARPONI, G. and CESCON, P. 1999. Determination of Rh, Pd, and Pt in polar and Alpine snow and ice by double-focusing ICP-MS with microcentric nebulization, *Anal. Chem.,* **71**, 4125-4133.

BARBANTE, C., TURETTA, C., GAMBARO, A., CAPODAGLIO, G. and, SCARPONI, G. 1998. Sources and origins of aerosols reaching Antarctica as revealed by lead concentrations profiles in shallow snow, *Ann. Glaciol.,* **27**, 674-678.

BARBEAU, K., MOFFETT, J.W., CARON, D.A., CROOT, P.L. and ERDNER, D.L. 1996. Role of protozoan grazing in relieving iron limitation of phytoplankton, *Nature,* **380**, 61-64.

BARBER, D.C., DYKE, A., HILLAIRE-MARCEL, C., JENNINGS A.E., ANDREWS, J.T., KERWIN, M.W., BILODEAU, G., MCNEELY, R., SOUTHON, J., MOREHEAD, M.D. and GAGNON, J.M. 1999. Forcing of the cold event of 8,200 years ago by catastrophic drainage of Laurentide lakes, *Nature,* **400**, 344-348.

BARBRAUD, C. and WEIMERSKIRCH, H. 2001. Emperor Penguins and climate change, *Nature,* **411**, 183-186.

BARBRAUD, C. and WEIMERSKIRSCH, H. 2006. Antarctic birds breed later in response to climate change, *Proceedings of the National Academy of Sciences*, **103**, 6248-6251.

BARD, E., HAMELIN, B., ARNOLD, M., MONTAGGIONI, L., CABIOCH, G., FAURE, G. and ROUGERIE, F. 1996. Deglacial sea-level record from Tahiti corals and the timing of global meltwater discharge, *Nature,* **382**, 241-244.

BARGAGLI, R. 2001. Trace metals in Antarctic organisms and the development of circumpolar biomonitoring networks, *Rev Environ Contam Toxicol,* **171**, 53-110.

BARGAGLI, R. 2005. Antarctic Ecosystems: Environmental Contamination, Climate Change, and Human Impact. Sprnger-Verlag, Berlin, 395 pp.

BARGAGLI, R., AGNORELLI, C., BORGHINI, F. and MONACI, F. 2005. Enhanced deposition and bioaccumulation of mercury in Antarctic terrestrial ecosystems facing a coastal polynya, *Environ. Sci. Technol.,* **39**, 8150-8155.

BARGELLONI, L., MARCATO, S., ZANE, L. and PATARNELLO, T. 2000a. Mitochondrial phylogeny of notothenioids: a molecular approach to Antarctic fish evolution and biogeography, *Syst. Biol.,* **49**, 114-129.

BARGELLONI, L., RITCHIE, P.A., PATARNELLO, T., BATTAGLIA, B., LAMBERT, D.M. and MEYER, A. 1994. Molecular evolution at subzero temperatures: mitochondrial and nuclear phylogenies of fishes from Antarctica (suborder Notothenioidei), and the evolution of antifreeze glycopeptides, *Molecular Biology and Evolution,* **11**, 854-863.

BARGELLONI, L., ZANE, L., DEROME, N., LECOINTRE, G. and PATARNELLO, T. 2000b. Molecular zoogeography of Antarctic euphausiids and notothenioids: from species phylogenies to intraspecific patterns of genetic variations, *Antarctic Sci.,* **12**, 259-268.

BARINGER, M.O. and PRICE, J.F. 1997. Momentum and Energy Balance of the Mediterranean Outflow, *Journal of Physical Oceanography*, **27** (8), 1678–1692.

BARKER, P.F. and BURRELL, J. 1977. The opening of Drake passage, *Marine Geology,* **25**.

BARKER, P.F., DIEKMANN, B. and ESCUTIA, C. 2007. Onset of Cenozoic Antarctic Glaciation, *Deep Sea. Research,* **54**, 2293-2307.

BARNES, D.K., HODGSON, D.A., CONVEY, P., ALLEN, C.S. and CLARKE, A.C. 2006. Incursion and excursion of Antarctic biota: past, present and future, *Global Ecol Biogeogr*, **15**, 121-142.

BARNES, D.K.A. and CLARKE, A. 1994. Seasonal variation in the feeding activity of four species of Antarctic bryozoa in relation to environmental factors, *J. Exp. Mar. Biol. Ecol.,* **181,** 117-133.

BARNES, D.K.A. and CLARKE, A. 1995. Seasonality of feeding activity in Antarctic suspension feeders. *Polar Biol.,* **15**, 335-340.

BARNES, D.K.A. and FRASER, K.P.P. 2003. Rafting by five phyla on man-made flotsam in the Southern Ocean, *Mar. Ecol. Prog. Ser.,* **262**, 289-291.

BARNES, D.K.A. and GRIFFITHS, H.J. 2008 Biodiversity and biogeography of southern temperate and polar bryozoans, *Global Ecology and Biogeography*, **17**, 84-99.

BARNES, D.K.A. and PECK, L.S. 2008. Vulnerability of Antarctic shelf biodiversity to predicted climate change, *Climate Research*, **37**, 149-163.

BARNES, D.K.A., HODGSON, D.A., CONVEY, P., ALLEN, C.S. and CLARKE, A. 2006a. Incursion and excursion of Antarctic biota: past, present and future, *Global Ecology and Biogeography*, **15** (2), 21-142.

BARNES, D.K.A., FUENTES, V., CLARKE, A., SCHLOSS, I.R. and WALLACE, M.I. 2006b. Spatial and temporal variation in shallow seawater temperature around Antarctica, *Deep-Sea Res. II,* **53**, 853-865.

BARNES, D.K.A., KAISER S, GRIFFITHS H.J., and LINSE K. 2008. Marine, intertidal, fresh-water and terrestrial biodiversity of an isolated polar archipelago, *Journal of Biogeography,* **36**, 756-769.

BARNES, D.K.A., WEBB, K.E. and LINSE, K. 2007. Growth rate and its variability in erect Antarctic bryozoans, *Polar Biol.,* **30**, 1069-1081.

BARONI, C. and OROMBELLI, G. 1994. Abandoned pengiun rookeries as Holocene paleoclimatic indicators in Antarctica, *Geology,* **22**, 23-26.

BARRETT, P.J. 1996. Antarctic palaeoenvironment through Cenzoic times - a review, *Terra Antartica,* **3**, 103-119.

BARRETT, P.J. 2006. The second great climate shift in the last 65 million years. In: Chapman, R., Boston, J., and Schwass, M., (ed) *Confronting Climate Change: Critical Issues for New Zealand*, Victoria University Press, Wellington, 6 pp.

BARRETT, P.J. 2007. Cenozoic climate and sea-level history of glacimarine strata off the Victoria Land coast, Cape Roberts Project, Antarctica. In: Hambrey, al. e (eds) *Glacial Sedimentary Processes and Products.* International Association of Sedimentologists, Special Publication.

BARRETT, P.J. 2008. Chapter 3 - A history of Antarctic Cenozoic glaciation - view from the continental margin. In: Florindo F, Siegert M (eds) *Antarctic Climate Evolution, Developments in Earth and Environmental Science*, Vol **8**. Elsevier, Amsterdam.

BARRIE, L.A., BOTTENHEIM, J.W., SCHNELL, R.C., CRUTZEN, P.J. and RASMUSSEN, R.A. 1988. Ozone destruction and photochemical reactions at polar sunrise in the lower Arctic atmosphere, *Nature*, **334**, 138-141.

BARRY, J.P. and DAYTON, P.K. 1988. Current patterns in McMurdo Sound, Antarctica, and their relationship to local biotic communities, *Polar Biol.*, **8**, 367-376.

BASSETT, S.E., MILNE, G.A., BENTLEY, M.J. and HUYBRECHTS, P. 2007. Modelling Antarctic sea-level data to explore the possibility of a dominant Antarctic contribution to meltwater pulse IA, *Quaternary Science Reviews,* **26**, 2113-2127.

BATES, M.L., ENGLAND, M.H. and SIJP, W.P. 2005. On the multi-century Southern Hemisphere response to changes in atmospheric CO2-concentration in a global climate model, *Meteorol. Atmos. Phys.*, **89**, 17-36.

BATES, N. 2001. Interannual variability of oceanic CO_2 and biogeochemical properties in the Western North Atlantic subtropical gyre, *Deep-Sea Research II*, ***48*,** 1507-1528.

BEAGLEY, S.R., DE GRANDPRÉ, J., KOSHYK, J.N., MCFARLANE, N.A. and SHEPHERD, T.G. 1997. Radiative-dynamical climatology of the first-generation Canadian Middle Atmosphere Model, *Atmos. Ocean*, **35**, 293-331.

BEAMAN, R.J. and HARRIS, P.T. 2005. Bioregionalization of the George V Shelf, East Antarctica, *Cont. Shelf Res.,* **25**, 1657-1691.

BEAMISH, R.J. 1995. Climate Change and Northern Fish Populations. *Canadian Special Publication of Fisheries and Aquatic Science,* **121**, 739 pp.

BECKLEY, B.D., LEMOINE, F.G., LUTCHKE, S.B., RAY, R.D. and ZELENSKY, N.P. 2007. A reassessment of global and regional mean sea level trends from TOPEX and Jason-1 altimtery based on revised reference frame and orbits, *Geophysical Research Letters*, **34**, L14608, doi:10.1029/2007GL030002.

BECKMANN, A., HELLMER, H.H. and TIMMERMANN, R. 1999. A numerical model of the Weddell Sea: large-scale circulation and water mass distribution, *J. Geophys. Res*. **104**(C10), 23375-23,391.

BEHRENFELD., M., O'MALLEY, R., SIEGEL, D., MCCLAIN, C., SARMIENTO, J., FELDMAN, G., MILLIGAN, A., FALKOWSKI, P., LETELIER, R. and BOSS, E. 2006. Climate-driven trends in contemporary ocean productivity, *Nature,* **444**, 752-755.

BEHRENFIELD, M.J. and FALKOWSKI, P.G. 1997. A consumers guide to phytoplankton primary production models, *Limnol. Oceanogr.*, **47**, 1479-1491.

BEINE, H.J., DOMINÉ, F., SIMPSON, W.R., HONRATH, R.E., SPARAPANI, R., ZHOU, X. and KING, M. 2002a. Snow-pile and chamber experiments during the Polar Sunrise Experiment 'Alert 2000': Exploration of nitrogen chemistry, *Atmos. Environment*, **36**(15-16), 2707-2719.

BEINE, H.J., HONRATH, R.E., DOMINÉ, F., SIMPSON, W.R. and FUENTES, J.D. 2002b. NO_x during background and ozone depletion periods at Alert: Fluxes above the snow surface, *J. Geophys. Res.*, **107**(D21), 4584, doi:10.1029/2002JD002082.

BELEM, A.L. 2002. Modeling physical and biological processes in Antarctic sea ice. Ph.D. thesis, Alfred Wegener Institute for Polar and Marine Research, Bremerhaven.

BELL, R.E., BLANKENSHIP, D.D., FINN, C.A., MORSE, D.L., SCAMBOS, T.A., BROZENA, J.M. and HODGE, S.M. 1998, Influence of subglacial geology on the onset of a West Antarctic ice stream from aerogeophysical observations, *Nature* **394**, 58-62.

BELT S, MASSE, G., ROWLAND, S.J., POULIN, M., MICHEL, C. and LEBLANC, B. 2007. A novel chemical fossil of palaeo sea ice: IP25, *Organic Geochemistry,* **38**, 16-27.

BELT, S.T., MASSÉ, G., VARE, L.L., ROWLAND, S.J., POULIN, M., SICRE, M.-A., SAMPEI, M. and FORTIER, L. 2008. Distinctive 13C isotopic signature distinguishes a novel sea ice biomarker in Arctic sediments and sediment traps, *Marine Chemistry,* **112**, 158-167.

BENDER, M.L. 2002. Orbital tuning chronology for the Vostok climate record supported by trapped gas composition, *Earth and Planetary Science Letters,* **204**, 275-289.

BENGTSSON, L., HODGES, K. and ROECKNER, E. 2006. Storm tracks and climate change, *J. Climate*, **19**, 3518–3543.

BENTLEY, M.J and ANDERSON, J.B. 1998. Glacial and marine geological evidence for the ice sheet configuration in the Weddell Sea-Antarctic Peninsula region during the last glacial maximum, *Antarctic Science,* **10**, 309-325.

BENTLEY, M.J. 1999. Volume of Antarctic Ice at the Last Glacial Maximum, and its impact on global sea level change, *Quaternary Science Reviews,* **18**, 1569-1595.

BENTLEY, M.J., FOGWILL, C.J., KUBIK, P.W. and SUGDEN, D.E. 2006. Geomorphological evidence and cosmogenic 10Be/26Al exposure ages for the Last Glacial Maximum and deglaciation of the Antarctic Peninsula Ice Sheet, *GSA Bulletin,* **118**, 1149–1159.

BENTLEY, M.J., HODGSON, D.A., SMITH, J.A. and COX, N.J. 2005a. Relative sea level curves for the South Shetland Islands and Marguerite Bay, Antarctic Peninsula, *Quaternary Science Reviews,* **24**, 1203-1216.

BENTLEY, M.J., HODGSON, D.A., SMITH, J.A., Ó COFAIGH, C., DOMACK, E.W., LARTER, R.D., ROBERTS, S.J., BRACHFELD, S., LEVENTER, A., HJORT, C., HILLENBRAND, C-D. and EVANS, J. 2009. Mechanisms of Holocene palaeoenvironmental change in the Antarctic Peninsula region, *The Holocene,* **19**, 51-69.

BENTLEY, M.J., HODGSON, D.A., SUGDEN, D.E., ROBERTS, S.J., SMITH, J.A., LENG, M.J. and BRYANT, C. 2005b. Early Holocene retreat of the George VI Ice Shelf, Antarctic Peninsula, *Geology,* **33**, 173-176.

BERG, W. and AVERY, S.K. 1995. Evaluation of monthly rainfall estimates derived from the special sensor microwave/imager (SSM/I) over the tropical Pacific, *J. Geophys. Res*., **100**, 1295-1315.

BERGER, A. and LOUTRE, M.F. 1991. Insolation values for the climate of the last 10 million years, *Quaternary Sciences Reviews,* **10**, 297-317.

BERGSTROM, D.M. and CHOWN, S.L. 1999. Life at the front: history, ecology and changes on southern ocean islands, *Trends in Ecology and Evolution,* **14,** 427-477.

BERKMAN, P.A., ANDREWS, J.T., BJORCK, S., COLHOUN, E.A., EMSLIE, S.D., GOODWIN, I.D., HALL, B.L., HART, C.P., HIRAKAWA, K., IGARASHI, A., INGOLFSSON, O., LOPEZ-MARTINEZ, J., LYONS, W.B., MABIN, M.C.G., QUILTY, P.G., TAVIANI, M. and YOSHIDA, Y. 1998. Circum-Antarctic coastal environmental shifts during the late Quaternary reflected by emerged marine deposits, *Antarctic Science,* **10,** 345-362.

BERTEAUX, D., RÉALE, D., MCADAM, A.G. and BOUTIN, S. 2004. Keeping pace with fast climate change: can Arctic life count on evolution? *Integrative Comp Biol.,* **44**, 140-151.

BERTLER, N.A.N. and 53 others. 2005. Snow Chemistry across Antarctica, *Annals of Glaciology,* **41**, 167-179.

BERTLER, N.A.N., BARRETT, P.J., MAYEWSKI, P.A., FOGT, R.L., KREUTZ, K.J. and SHULMEISTER, J. 2004. El Niño suppresses Antarctic warming, *Geophys. Res. Lett*., **31**, L15207, doi:10.1029/2004GL020749.

BEST, S.E., IVCHENKO, V.O., RICHARDS, K.J., SMITH, R.D. and MALONE, R.C. 1999. Eddies in numerical models of the Antarctic Circumpolar Current and their influence on the mean flow, *J. Phys. Oceanogr.*, **29**(3), 328-350.

BEYER, A. and MATTHIES, M. 2001. Long-range transport potential of semivolatile organic chemicals in coupled air-water systems, *Environ. Sci. Pollut. Res.,* **8**,173-179

BI, D., BUDD, W.F., HIRST, A.C. and WU, X. 2002. Response of the Antarctic circumpolar current transport to global warming in a coupled model, *Geophys. Res. Lett.,* **29** (24), 2173, doi:10.1029/2002GL015919.

BI, D.H., BUDD, W.F., HIRST, A.C. and WU, X.R. 2001. Collapse and reorganisation of the Southern Ocean overturning under global warming in a coupled model, *Geophys. Res. Let.,* **28** (20), 3927-3930.

BILLETT, D.S.M., BETT, B.J., RICE, A.L., THURSTON, M.H., GALERON, J., SIBUET, M. and WOLFF, G.A. 2001. Long-term change in the megabenthos of the Porcupine Abyssal Plain (NE Atlantic), *Progress in Oceanography*, **50**, 325-348.

BINDOFF, N., WILLEBRAND, J., ARTALE, V., CAZENAVE, A., GREGORY, J., GULEV, S., HANAWA, K., LE QUÉRÉ, C., LEVITUS, S., NOJIRI, Y., SHUM, C., TALLEY, L. and UNNIKRISHNAN, A. 2007. Observations: oceanic climate change and sea level. In Climate Change 2007: The Physical Science Basis. Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (eds. S. Solomon, D. Qin, and M. Manning). *Cambridge University Press*. United Kingdom and New York, NY, USA.

BINDSCHADLER, R. 2006. The environment and evolution of the West Antarctic ice sheet: setting the stage, *Phil. Trans. R. Soc. A,* **364**, 1583–1605, doi:10.1098/rsta.2006.1790.

BINDSCHADLER, R. A., KING, M.A., ALLEY, R.B., ANANDAKRISHNAN, S. and PADMAN, L. 2003, Tidally controlled stick-slip discharge of a West Antarctic ice stream, *Science,* **301**, 1087–1089.

BINDSCHADLER, R., 2001. Flow History of Pine Island Glacier from Landsat Imagery, *Eos Transactions* (Fall 2001).

BINDSCHADLER, R.A. and VORNBERGER, P.L. 1998. Changes in West Antarctic ice sheet since 1963 from Declassified Satellite Photography, *Science*, **279**, 689-692.

BINDSCHADLER, R.A. 2002. History of lower Pine Island Glacier, West Antarctica, from Landsat. imagery, *J. Glaciol.*, **48** (163), 536-544.

BINTANJA, R. and VAN DE WAL, R.S.W. 2008. North American ice-sheet dynamics and the onset of 100,000-year glacial cycles, *Nature,* **454**, 869-872.

BINTANJA, R., VAN DE WAL, R.S.W. and OERLEMANS, J. 2005. Modelled atmospheric temperatures and global sea levels over the past million years, *Nature,* **437**, 125-128.

BISCHOFF, B. and WIENCKE, C. 1995a. Temperature ecotypes and biogeography of Acrosiphoniales (Chlorophyta) with Arctic-Antarctic disjunct and Arctic/cold-temperate distributions, *European Journal of Phycology,* **30**, 19-27.

BISCHOFF, B. and WIENCKE, C. 1995b. Temperature adaption in strains of the amphi-equatorial green alga *Urospora penicilliformis* (Acrosiphoniales) biogeographical implications, *Mar. Biol.,* **122**, 681-688.

BISCHOFF-BÄSMANN, N. and WIENCKE, C. 1996. Temperature requirements for growth and survival of Antarctic Rhodophyta, *Journal of Phycology,* **32**, 525-535.

BITZ, C.M., GENT, P.R., WOODGATE, R.A., HOLLAND, M.M. and LINDSAY, R. 2006. The influence of sea ice on ocean heat uptake in response to increasing CO_2, *J. Clim*., **19**, 2437-2450.

BIUW, M., BOEHME, L., GUINET, C., HINDELL, M., COSTA, D., CHARRASSIN, J.-B., ROQUET, F. BAILLEUL, F., MEREDITH, M., THORPE, S.R., TREMBLAY, S., MCDONALD, Y., PARK, B., RINTOUL, Y.-H., BINDOFF, N., GOEBEL, M., CROCKER, D., LOVELL, P., NICHOLSON, J., MONKS, F. and FEDAK, M.A. 2007. Variations in behaviour and condition of a Southern Ocean top predator in relation to in situ oceanographic conditions, *Proceedings of the National Academy of Sciences*, **104**, 34, 13705-13710.

BJÖRCK, S., HÅKANSSON, H., OLSSON, S., BARNEKOW, L., and JANSSENS, J. 1993. Palaeoclimatic studies in South Shetland Islands, Antarctica, based on numerous stratigraphic variables in lake sediments, *Journal of Paleolimnology,* **8**, 233-272.

BJÖRCK, S., HÅKANSSON, H., ZALE, R., KARLEN, W. and JONSSON, B.L. 1991a. A late Holocene sediment sequence from Livingston Island, South Shetland Islands, with palaeoclimatic implications, *Antarctic Science*, **3,** 61-72.

BJÖRCK, S., HJORT, C., INGÓLFSSON, Ó. and ZALE R., J.I. 1996. Holocene deglaciation chronology from lake sediments. Geomorphological map of Byers Peninsula LIBGSSS-A120. British Antarctic Survey, Cambridge.

BJÖRCK, S., MALMER, N., HJORT, C., SANDGREN, P., INGÓLFSSON, O., WALLEN, B., SMITH, R.I.L. and JONSSON, B.L. 1991b. Stratigraphic and paleoclimatic studies of a 5500-year-old moss bank on Elephant Island, Antarctica, *Arctic and Alpine Research,* **23**, 361-374.

BJÖRCK, S., OLSSON, S., ELLIS-EVANS, J.C., HÄKANSSON H, HUMLUM O, DE LIRIO JM. 1996. Late Holocene palaeoclimatic records from lake sediments on James Ross Island, Antarctica, *Palaeogeography Palaeoclimatology Palaeoecology*, **121**, 195-220.

BJÖRN, L.-O. 1999. Ultraviolet-B Radiation, the Ozone Layer and Ozone Depletion. In Rozema, J. ed. *Stratospheric Ozone Depletion: the effects of enhanced UV-B radiation on terrestrial ecosystems.* Leiden, the Netherlands: Backhuys Publishers, 21-37.

BLAKER, A.T., SINHA, B., IVCHENKO, V.O., WELLS, N.C. and ZALESNY, V.B. 2006. Identifying the roles of the ocean and atmosphere in creating a rapid equatorial response to a Southern Ocean anomaly, *Geophys. Res. Lett.*, **33**, L06720, doi:10.1029/2005GL025474.

BLANKENSHIP, D.D., BENTLEY, C.R., ROONEY, S.T. and ALLEY, R.B. 1986. Seismic measurements reveal a saturated porous layer beneath an active Antarctic ice stream, *Nature,* **322**, 54–57.

BLECK, R., ROOTH, C., HU, D. and SMITH, L.T. 1992. Ventilation patterns and mode water formation in a wind- and thermodynamically driven isopycnic coordinate model of the North Atlantic, *Journal of Physical Oceanography,* **22**, 1486-1505.

BLOCK, W. 1984. Terrestrial microbiology, invertebrates and ecosystems. – In: R.M. Laws (ed), *Antarctic ecology*, Academic Press, London, 163-236.

BLOOM, S., D.A., SILVA, A., DEE, D., BOSILOVICH, M., CHERN, J.-D., PAWSON, S. SCHUBERT, S., SIENKIEWICZ, M., STAJNER, I., TAN, W.-W. and WU, M.-L. 2005. "Documentation and Validation of the Goddard Earth Observing System (GEOS) Data Assimilation System, Version 4", *NASA/TM-2005-104606*, *26*, 187 pp., NASA Goddard Space Flight Center, Greenbelt, Md.

BLOSS, W. J., LEE, J.D., HEARD, D.E., SALMON, R.A., BAUGUITTE, S.J.-B., ROSCOE, H.K. and JONES, A.E. 2007. Observations of OH and HO_2 radicals in coastal Antarctica, *Atmos. Chem. Phys*., **7**, 4171-4185.

BLUMBERG, A.F. and MELLOR, G.L. 1987. A description of a three-dimensional coastal ocean circulation model, In *Three-Dimensional Coastal Ocean Models*, Heaps, N.S. (Ed.), 1-16, American Geophysical Union, Washington, DC.

BLUNIER, T. and BROOK, E.J. 2001. Timing of millennial-scale climate change in Antarctica and Greenland during the last glacial period, *Science,* **291**, 109-112.

BLUNIER, T., SCHWANDER, J., STAUFFER, B., STOCKER, T., DALLEBACH, A., INDERMÜHLE, A., TSCHUMI, J., CHAPPELLAZ, J., RAYNAUD, D. and BARNOLA, J.M. 1997. Timing of the Antarctic Cold Revearsal and the atmospheric CO_2 increase with respect to the Younger Dryas event, *Geophys. Res. Letters,* **24**, 2683 - 2686.

BLUNIER, T., SPAHNI, R., BARNOLA, J.M., CHAPPELLAZ, J., LOULERGUE, L., SCHWANDER, J. 2007. Synchronisation of ice core records via atmospheric gases, *Climate of the Past,* **3**, 325-330.

BOCKHEIM, J.G. and HALL, K.J. 2002. Permafrost, active layer dynamics and periglacial environments of continental Antarctica, *South Afr. J. Sci.,* **98**, 82-90.

BOCKHEIM, J.G., I.B. CAMPBELL, and M. MCLEOD. 2007. Permafrost distribution and active-layer depths in the McMurdo Dry Valleys, Antarctica. Permafrost and Periglacial Processes: In Press.

BODEKER, G.E., SHIONA, H. and ESKES, H. 2005. Indicators of Antarctic ozone depletion, *Atmos. Chem. Phys.*, **5**, 2603-2615.

BOEBEL, O., KLINCK, H., KINDERMANN, L. and EL NAGAR, S. 2008. PALAOA: Broadband recordings of the Antarctic cosatal soundscape, *Bioacoustics,* **17**, 19-21.

BOELEN, P., DE BOER, M.K., DE BAKKER, N.V.J., and ROZEMA, J. 2006. Outdoor studies on the effects of solar UV-B on bryophytes: Overview and methodology, *Plant Ecology,* **182**(1-2), 137-152.

BÖNING, C. W., A. DISPERT, M. VISBECK, S. R. RINTOUL, and F. SCHWARZKOPF, 2008. Observed multi-decadal ocean warming and density trends across the Antarctic Circumpolar Current, Submitted.

BONN, W.J., GINGELE, F.X., GROBE, H., MACKENSEN, A. and FÜTTERER, D.K. 1998. Palaeoproductivity at the Antarctic continental margin: opal and barium records for the last 400 ka. *Palaeogeography, Palaeoclimatology, Palaeoecology,* **139**, 195-211.

BONSTRA, R. 2004. Coping with changing northern environments: the role of the stress axis in birds and mammals, *Integr. Comp. Biol.,* **4**, 95-108.

BOPP, L., MONFRAY, P., AUMONT, O., DUFRESNE, J.L., LE TRUET, H., MADEC, G., TERRAY, L. and ORR, J.C. 2001. Potential impact of climate change on marine export production, *Global Biogeochemical Cycles*, **15**, 81-99.

BORGES, A.V., TILBROOK, B., METZL, N., LENTON, A. and DELILLE, B. 2008. Inter-annual variability of the carbon dioxide oceanic sink south of Tasmania, *Biogeosciences*, **5**, 141-145.

BORZATTA, E. and TROMBOTTO, D. 2003. Analysis of permafrost thickness in Antarctica using VES and MTS data. In: Haeberli, W. and D. Brandova (eds.) *Permafrost; extended abstracts reporting current research and new information.* Eigth Internat. Conf.on Permafrost, Zurich, Switzerland.

BOUTRON, C.F. and WOLFF, E.W., 1989. Heavy metal and sulphur emissions to the atmosphere from human activities in Antarctica, *Atmospheric Environment,* **23**, 1669-1675.

BOUTRON, C.F., GÖRLACH, U., CANDELONE, J.P., BOLSHOV, M.A. and DELMAS, R.J., 1991. Decrease in anthropogenic lead, cadmium and zinc in Greenland snows since the late 1960s, *Nature,* **353**, 153-156.

BOWMAN, J.P., REA, S.M., MCCAMMON, S.A. and MCMEEKIN, T.A. 2000. Diversity and community structure within anoxic sediment from marine salinity meromictic lakes and a coastal meromictic marine basin, Vestfold Hilds, Eastern Antarctica, *Environ. Microbiol.,* **2**, 227-237.

BOYD, P.W. and TRULL, T.W. 2007. Understanding the export of biogenic particles in oceanic waters: Is there consensus? *Progress in Oceanography,* **72**, 276-312.

BOYD, P.W., DONEY, S.C., STRZEPEK, R., DUSENBERRY, J., LINDSAY, K. and FUNG, I. 2007. Climate-mediated changes to mixed-layer properties in the Southern Ocean: assessing the phytoplankton response, *Biogeosciences Discussions*, **4**(6), 4283-4322.

BOYD, P.W., JICKELLS, T., LAW, C.S., BLAIN, S., BOYLE, E.A., BUESSELER, K.O., COALE, K.H., CULLEN, J.J., DE BAAR, H.J.W., FOLLOWS, M., HARVEY, M., LANCELOT, C., LEVASSEUR, M., OWENS, N.P.J., POLLARD, R., RIVKIN, R.B., SARMIENTO, J., SCHOEMANN, V., SMETACEK, V., TAKEDA, S., TSUDA, A., TURNER, S. and WATSON, A.J. 2007. Mesoscale iron enrichment experiments 1993-2005: Synthesis and future directions, *Science,* **315**, 612-617.

BOYSEN-ENNEN, E. and PIATKOWSKI, U. 1988. Meso- and macrozooplankton communities in the Weddell Sea, *Polar Biol*., **9**, 17-35.

BRACEGIRDLE, T.J., CONNOLLEY, W.M. and TURNER, J. 2008. Antarctic climate change over the Twenty First Century, *Journal of Geophysical Research – Atmospheres,* **113**, D03103, doi:03110.01029/02007JD008933.

BRACHFELD, S., DOMACK, E., KISSEL, C., LAJ, C., LEVENTER, A., ISHMAN, S., GILBERT, R., CAMERLENGHI, A. and EGLINTON, L.B. 2003. Holocene history of the Larsen-A Ice Shelf constrained by geomagnetic paleointensity dating, *Geology,* **31**, 749-752.

BRAMBILLA, E., HIPPE, H., HAGELSTEIN, A., TINDALL, B.J. and STACKEBRANDT, E. 2001. 16S rDNA diversity of cultured and uncultured prokaryotes of a mat sample from Lake Fryxell, McMurdo Dry Valleys, Antarctica, *Extremophiles,* **5**, 23-33.

BRANCH, T.A., MATSUOKA, K. and MIYASHITA, M. 2004. Evidence for increases in Antarctic blue whales based on Bayesian modelling, *Marine Mammal Science*, **20** (4), 726-754.

BRANDEFELT, J. and KÄLLÉN, E. 2004: The response of the Southern Hemisphere atmospheric circulation to an enhanced greenhouse gas forcing, *J. Climate*, **17**, 4425–4442.

BRANDT, A., GOODAY, A.J., BRANDAO, S.N., BRIX, S., BROKELAND, W., CEDHAGEN, T., CHOUDHURY, M., CORNELIUS, N., DANIS, B., DE MESEL, I., DIAZ, R.J., GILLIAN, D.C., EBBE, B., HOWE, J.A., JANUSSEN, D., KAISER, S., LINSE, K., MALYUTINA, M., PAWLOWSKI, J., RAUPACH, M. and VANREUSEL, A. 2007. First insights into the biodiversity and biogeography of the Southern Ocean deep sea, *Nature,* **447**, 307-311.

BRANDT, A., GOODAY, A.J., ET AL. 2007. First insights into the biodiversity and biogeography of the Southern Ocean deep sea, *Nature,* **447**(7142), 307–311.

BRÉVIÈRE, E., METZL, N., POISSON, A. and TILBROOK, B. 2006. Changes of the oceanic CO2 sink in the Eastern Indian sector of the Southern Ocean, *Tellus B*, *58B*, 438-446.

BREWER, P.G. 1978. Direct observation of oceanic CO2 increase, *Geophys. Res. Let.*, **5**, 997-1000.

BRIERLEY, A.S. and THOMAS, D.N. 2002. On the ecology of Southern Ocean pack ice. *Advances in Marine Biology,* **43**, 171–278.

BRIERLEY, A.S., FERNANDES, P.G., BRANDON, M.A., ARMSTRONG, F., MILLARD, MCPHAIL, S.D., STEVENSON, P., PEBODY, M., PERRETT, J., SQUIRES, M., BONE, D.G. and GRIFFITHS, G. 2002. Antarctic Krill under sea ice: elevated abundance in a narrow band just south of ice edge, *Science,* **295**, 1890–1892.

BROADY P. 1996. Diversity, distribution and dispersal of Antarctic terrestrial algae, *Biodiv. Conserv*, **5**, 1307-1335.

BRODTE, E., KNUST, R. and PÖRTNER, H.O. 2006. Temperature dependent energy allocation to growth in Antarctic and boreal eelpout (Zoarcidae), *Pol. Biol.,* **30**, 95–107.

BRÖKELAND W. and RAUPACH M. 2008. A species complex within the isopod genus *Haploniscus* (Crustacea: Malacostraca: Peracarida) from the Southern Ocean deep sea: a morphological and molecular approach**,** *Zoological Journal of the Linnean Society,* **152**, 655-702.

BROMWICH, D. H., CASSANO, J.J., KLEIN, T., HEINEMANN, G., HINES, K.M., STEFFEN K. and BOX, J.E. 2001. Mesoscale modeling of katabatic winds over Greenland with the Polar MM5, *Mon. Wea. Rev.,* **129**, 2290-2309.

BROMWICH, D.H. 1988. Snowfall in High Southern Latitudes, *Rev. Geophys.*, **26**(1), 149–168.

BROMWICH, D.H., CARRASCO, J.F., LIU, Z. and TZENG, R.T. 1993. Hemispheric atmospheric variations and oceanographic impacts associated with katabatic surges across the Ross Ice Shelf, Antarctica, *Journal of Geophysical Research*, **98** (D7), 13,045-13,062.

BROMWICH, D.H., FOGT, R.L., HODGES, K.I. and WALSH, J.E. 2007. A tropospheric assessment of the ERA-40, NCEP, and JRA-25 global reanalyses in the polar regions, *J. Geophys. Res.*, **112,** Art. No. D10111.

BROMWICH, D.H., GUO, Z., BAI, L. and CHEN, Q-S. 2004a. Modeled Antarctic precipitation. Part I: spatial and temporal variability, *J. Climate,* **17**, 427-447.

BROMWICH, D.H., MONAGHAN, A.J. and GUO, Z. 2004b. Modeling the ENSO modulation of Antarctic climate in the late 1990s with the Polar MM5, *J. Clim.*, **17**, 109–132.

BROMWICH, D.H., ROBASKY, F.M., CULLATHER, R.I. and VAN WOERT, M.L. 1995. The atmospheric hydrologic cycle over the Southern Ocean and Antarctica from operational numerical analyses, *Mon. Wea. Rev.*, **123**, 3518-3538.

BROMWICH, D.H., ROGERS, A.N., KALLBERG, P., CULLATHER, R.I., WHITE, J.W.C. and KREUTZ, K.J. 2000. ECMWF analyses and reanalyses depiction of ENSO signal in Antarctic precipitation, *J. Climate,* **13**, 1406-1420.

BRONGE, C. 1992. Holocene climatic record from lacustrine sediments in a freshwater lake in the Vestfold Hills, Antarctica, *Geografiska Annaler*, **74A**, 47-58.

BROOK, E.J., WHITE, J.W.C., SCHILLA, A.S.M., BENDER, M.L., BARNETT, B., SEVERINGHAUS, J.P., TAYLOR, K.C., ALLEY, R.B. and STEIG, E.J. 2005. Timing of millenial-scale climate change at Siple Dome, West Antarctica, during the last glacial period, *Quarternary Science Reviews,* **24**, 1333-1343.

BROUWER, P.E.M. 1996. *In situ* photosynthesis and estimated annual production of the red macroalga *Myriogramme mangini* in relation to underwater irradiance at Signy Island (Antarctica), *Antarct. Sci.*, **8**, 245-252.

BROWN, C.L., BALE, J.S. and WALTERS, K.F.A. 2004. Freezing induces a loss of freeze tolerance in an overwintering insect. *Proceedings of the Royal Society of London series B,* **271**, 1507-1511.

BRYAN F.O., DANABASOGLU, G., GENT, P.R. and LINDSAY, K. 2006. Changes in ocean ventilation during the 21st century in the CCSM3, *Ocean Model.*, **15**, 141-156.

BRYAN, K. and COX, M.D. 1968. A non-linear model of an ocean drivem by wind and differential heating: Part 1. Description of the Three-dimensional velocity and density fields, *Journal of the Atmospheric Sciences*, **25** (6), 945-967.

BRYDEN, H. L. and NURSER, A.J.G. 2003. Effects of strait mixing on ocean stratification, *J. Phys. Oceanogr.,* **33,** 1870-1872.

BRYDEN, H.L. 1979. Poleward heat flux and conversion of available potential energy in Drake Passage, *Journal of Marine Research*, **37**, 1-22.

BUDD, G.M. 2000. Changes in Heard Island glaciers, king penguins and fur seals since 1947. *Papers and Proceedings of the Royal Society of Tasmania,* **133**, 47–60.

BUDD, W. 1966. The dynamics of the Amery Ice Shelf, *Journal of Glaciology,* **6**, 335-358.

BUDD, W.F. and SMITH, I.N. 1982. Large-scale numerical modeling of the Antarctic Ice Sheet, *Annals of Glaciology,* **3**, 42-49.

BUDD, W.F., and SIMMONDS, I. 1991 The impact of global warming on the Antarctic mass balance and global sea level. *In Proceedings of the International Conference on the Role of the Polar Regions in Global Change, Vol. 1*, University of Alaska Fairbanks, Alaska, 11-15 June 1990, 489-494.

BUDD, W.F., JENSSEN, D. and RADOK, U. 1971. *Derived Physical Characteristics of the Antarctic Ice Sheet.* ANARE Interim Report, Series A(IV), Glaciology Publication no. 18, University of Melbourne.

BUESSELER, K.O., DONEY, S.C., KARL, D.M., BOYD, P.W., CALDEIRA, K., CHAI, F., COALE, K.H., DE BAAR, H.J.W., FALKOWSKI, P.G., JOHNSON, K.S., LAMPITT, R.S., MICHAELS, A.F., NAQVI, S.W.A., SMETACEK, V., TAKEDA, S. and WATSON, A.J. 2008. Ocean Iron Fertilization--Moving Forward in a Sea of Uncertainty, *Science,* **319**, 162.

BURGESS, J.S., SPATE, A.P. and SHEVLIN, J. 1994. The onset of deglaciation in the Larsemann Hills, eastern Antarctica, *Antarctic Science,* **6**, 491 – 495.

BUSTNES, J.O., TVERAA, T., VARPE, Ø, HENDEN, J.A. and SKAARE, J.U. 2007. Reproductive performance and organochlorine pollutants in an Antarctic marine top predators: the south polar skua, *Environ. Int*., **33**, 911-918.

CAI, W. 2006. Antarctic ozone depletion causes in intensification of the Southern Ocean super-gyre circulation, *Geophys. Res. Lett.*, **33**, doi:10.1029/2005GL024911.

CAI, W., BAINES, P.G. and GORDON, H.B. 1999. Southern mid- to high-latitude variability, a zonal wavenumber-3 pattern, and the Antarctic circumpolar wave in the CSIRO coupled model, *J. Climate*, **12**, 3087-3104.

CAI, W., WHETTON, P.H. and KAROLY, D.J. 2003. The response of the Antarctic Oscillation to increasing and stabilized atmospheric CO_2, *J. Climate*, **16**, 1525–1538.

CAI, W.J. and COWAN, T. 2007. Trends in Southern Hemisphere circulation in IPCC AR4 models over 1950-99: Ozone depletion versus greenhouse forcing, *J. Climate*, **20**, 681-693.

CAILLON, N., SEVERINGHAUS, J.P., JOUZEL, J., BARNOLA, J.M., KANG, J.C. and LIPENKOV, V. 2003. Timing of atmospheric CO2 and Antarctic temperature changes across termination III, *Science,* **299**, 1728-1731.

CALDEIRA, K. and DUFFY, P.B. 2000. The role of the Southern Ocean in uptake and storage of anthropogenic carbon dioxide, *Science*, **287**, 620-622.

CAMERON, R.E. 1972. Pollution and conservation of the Antarctic terrestrial ecosystems. In: Parker BC (ed) *Proc Coll Conservation Problems in Antarctica*. Allen Press, Lawrence, Kansas, 267-305.

CAMPANA' G., ZACHER' K., FRICKE' A., MOLIS' M., ANELA WULFF' A., QUARTINO, M.L. and WIENCKE' C. (submitted) Succession in polar benthic macro- and microalgal communities. *Bot. Mar*.

CAMPBELL, I.B. and CLARIDGE. G.G.C. 2006. Permafrost properties, patterns, and processes in the Transantarctic Mountains region of Antarctica. *Permafrost and Periglacial Processes*, **17**, 215-232.

CAMPBELL, I.B., CLARIDGE, G.G.C., BALKS, M.R. and CAMPBELL. D.I. 1997. Moisture content in soils of the McMurdo Sound and Dry Valley region of Antarctica, pp. 61-76. In: Lyons, W.B., C. Howard-Williams, and I. Hawes (eds.) *Ecosystem processes in Antarctic ice-free landscapes*, Balkema, Rotterdam.

CANADELL, J.G., AND 9 OTHER AUTHORS. 2007. Contributions to accelerating atmospheric CO2 growth from economic activity, carbon intensity, and efficiency of natural sinks, *PNAS*, doi:10.1073/pnas.0700609104.

CANNONE, N., ELLIS EVANS, J. C., STRACHAN, R. and GUGLIELMIN, M. 2006. Interactions between climate, vegetation and active layer in Maritime Antarctica, *Antarctic Science*, **18**(3), 323-333.

CARLETON, A.M. 2003. Atmospheric teleconnections involving the Southern Ocean, *Journal of Geophysical Research - Oceans,* **108**, 8080.

CARMACK, E.C. and T.D. FOSTER. 1975. On the flow of water out of the Weddell Sea, *Deep-Sea Res*., **22**, 711-724.

CARSEY, F., BEHAR, A., LANE, A.L., REALMUTO, V. and ENGELHARDT, H. 2002. A borehole camera system for imaging the deep interior of ice sheets, *J. Glaciol.,* **48** (163), 622–628.

CARSOLINI, S., ROMEO, T., ADEMOLLO, N., GRECO, S. and FOCARDI, S. 2002. POPs in key species of marine Antarctic ecosystem, *Microchemical Journal,* **73**, 187-193.

CASTEBRUNET H., GENTHON, C. and MARTINERIE, P. 2006. sulfur cycle at Last Glacial Maxium. model results versus Antarctic ice core data, *Geophys. Res. Lett*., **33**, doi:10.1029/2006GL027681.

CATANIA, G.A., CONWAY, H., RAYMOND, C.F. and SCAMBOS, T.A. 2006. Evidence for floatation or near floatation in the mouth of Kamb Ice Stream, West Antarctica, prior to stagnation, *J. Geophys. Res.*, **111**, F01005, doi:10.1029/2005JF000355.

CAZENAVE, A., DOMINH, K., GUINEHUT, S., BERTHIER, E., LLOVEL, W., RAMILLIEN, G., ABLAIN, M. and LARNICOL, G. 2009. Sea level budget over

2003–2008: A reevaluation from GRACE space gravimetry, satellite altimetry and Argo, *Global and Planetary Change,* **65**, 83–88.

CHAMBERS, D.P, MEHLTAFF, C.A., URBAN, T.J., FUJII, D. and NEREM, R.S., 2002. Low frequency variations in global mean sea level:1950-2000, *Journal of Geophysical Research,* **107**, 10.1029/2001JC001089.

CHAMBERS, M.J.G. 1967. Investigations of patterned ground at Signy Island, South Orkney Islands: II, Temperature regimes in the active layer. *British Antarctic Survey Bulletin*, **10**, 71-83.

CHAPMAN.W.L. and WALSH, J. E. 2007. A Synthesis of Antarctic Temperatures, *Journal of Climate,* **20**, 4096-4117.

CHAPPELLAZ, J., BLUNIER, T., RAYNAUD, D., BARNOLA, J.M., SCHWANDER, J. and STAUFFER, B. 1993. Synchronous changes in atmospheric CH_4 and Greenland climate between 40 and 8 kyr B.P., *Nature,* **366**, 443–445.

CHARLSON, R.J., LOVELOCK, J.E., ANDREAE, M.O. and WARREN, S.G. 1987. Oceanic phytoplankton, atmospheric sulphur, cloud albedo and climate, *Nature* (**323**), 655-661.

CHASSIGNET, E.P. and VERRON, J. 2006. Ocean Weather Forecasting: An Integrated View of Oceanography. (Eds.). Springer, 577pp.

CHASSIGNET, E.P., HURLBURT, H.E., SMEDSTAD, O.M., HALLIWELL, G.R., WALLCRAFT, A.J., METZGER, E.J., BLANTON, B.O., LOZANO, C., RAO, D.B., HOGAN, P.J. and SRINIVASAN, A. 2006. Generalized vertical coordinates for eddy-resolving global and coastal ocean forecasts. *Oceanography*, **19,** 20-31.

CHASSIGNET, E.P., HURLBURT, H.E., SMEDSTAD, O.M., HALLIWELL, G.R., HOGAN, P.J., WALLCRAFT, A.J., BARAILLE, R. and BLECK, R. 2007. The HYCOM (HYbrid Coordinate Ocean Model) data assimilative system, *Journal of Marine Systems*, **65**, 60-83.

CHAVEZ, F.P., RYAN, J., LLUCH-COTA, S.E. and NIQUEN, M. 2003. From Anchovies to Sardines and Back: Multidecadal Change in the Pacific Ocean, *Science*, **299**, 217-221 .

CHELTON, D.B., DESZOEKE, R.A., SCHLAX, M.G., EL NAGGAR, K. and SIWERTZ, N. 1998. Geographical variability of the first-baroclinic Rossby radius of deformation, *J. Phys. Oceanogr.,* **28**, 433-460.

CHEN, C.T. and F.J. MILLERO. 1979. Gradual increase of oceanic CO_2, *Nature*, **277,** 205-206.

CHEN, J. L., WILSON, C.R., BLANKENSHIP, D.D. and TAPLEY, B.D. 2006. Antarctic mass rates from GRACE, *Geophys. Res. Lett.*, **33**, L11502, doi:10.1029/2006GL026369.

CHEN, L., DEVRIES, A.L. and CHENG, C.H.C. 1997a. Evolution of antifreeze glycoprotein gene from a trypsinogen gene in Antarctic notothenioid fish, *Proceedings of the National Academy of Sciences,* **94**, 3811-3816.

CHEN, L.B., DE VRIES, A.L. and CHENG, C-H.C. 1997b. Convergent evolution of antifreeze glycoproteins in Antarctic notothenioid fish and Arctic cod, *Proceedings of the National Academy of Sciences of the USA,* **94**, 3817-3822.

CHEN, W.J., BONILLO, C. and LECOINTRE, G. 1998. Phylogeny of the Channichthyidae (Notothenioidei, Teleostei) based on two mitochondrial genes. In: di Prisco G, Pisano E, Clarke A (eds) *Fishes of Antarctica: a biological overview*. Springer-Verlag Italia, Milan, 287-298.

CHEN, X. 1993. Permafrost around CGWS, Antarctica. In: *International Conference on Permafrost, Proceedings*, **6**(1), 84-88.

CHENG, C-H.C. and CHEN, L.B. 1999. Evolution of an antifreeze glycoprotein, *Nature,* **401**, 443–444.

CHENG, C-H.C. and DETRICH III, H.W. 2007. Molecular ecophysiology of Antarctic notothenioid fish, *Philosophical Transactions of the Royal Society B, Biol. Sci*., **362**, 2215-2232.

CHENG, C-H.C. 1998. Origin and mechanism of evolution of antifreeze glycoproteins in polar fishes. In: di Prisco G, Pisano E, Clarke A (Eds) *Fishes of Antarctica. A Biological Overview*, Springer, Milano, 311-328.

CHENG, C-H.C., CHEN, L., NEAR, T.J. and JIN, Y. 2003. Functional antifreeze glycoprotein genes in temperate-water New Zealand nototheniid fish infer an Antarctic evolutionary origin, *Mol. Biol. Evol.,* **20**, 1897-1908.

CHEUNG, W.W.L., LAM, V.W.Y., SARMIENTO, J.L., KEARNEY, K., WATSON, R. and PAULY, D. 2009. Projecting global marine biodiversity impacts under climate change scenarios, *Fish and Fisheries*, DOI: 10.1111/j.1467-2979.2008.00315.x.

CHISHOLM, S., FALKOWSKI, P. and CULLEN, J. 2001. Dis-crediting ocean fertilization, *Science,* **294**, 309-310

CHISHOLM, S.W. 2000. Stirring times in the Southern Ocean, *Nature*, **407**, 685-687.

CHOWN, S.L. and CONVEY, P. 2006. Biogeography. *Trends in Antarctic Terrestrial and Limnetic Ecosystems: Antarctica as a Global Indicator*, eds. Bergstrom, D.M**,** Convey, P. and Huiskes, A.H.L. Springer, Dordrecht, 55-69.

CHOWN, S.L. and CONVEY, P. 2007. Spatial and temporal variability across life's hierarchies in the terrestrial Antarctic, *Philosophical Transactions of the Royal Society of London, series B*, **362**, 2307-2331.

CHRISTNER, B.C., KVITKO, I.I. and REEVE, J.N. 2003. Molecular identification of bacteria and eukarya inhabiting an Antarctic cryoconite hole, *Extremophiles,* **7**, 177-183.

CHRISTOFFERSEN, P. and TULACZYK, S. 2003. Response of subglacial sediments to basal freeze-on, 1. Theory and comparison to observations from beneath the West Antarctic Ice Sheet, *J. Geophys. Res*., **108**(B4), 2222, doi:10.1029/2002JB001935.

CHURCH, J., WHITE, N., HUNTER, J., MCINNES, K., COWELL, P. and O'FARRELL, S. 2008. Sea level Rise. Chapter 12 in *Transitions: pathways towards sustainable development in Australia*, ed. P. W Newton, Springer and CSIRO publishing.

CHURCH, J., WILSON, S., WOODWORTH, P. and AARUP, T. 2007. Understanding sea level rise and variability. Meeting report. *EOS Transactions of the American Geophysical Union*, **88**(4), 23 January 2007, 43.

CHURCH, J.A. and WHITE, N.J. 2006. A 20th century acceleration in global sea-level rise, *Geophysical Research Letters*, **33**, L01602, 10.1029/2005GL024826.

CHURCH, J.A., GREGORY, J.M., HUYBRECHTS, P., KUHN, M., LAMBECK, K. NHUAN, M.T., QIN, D. and WOODWORTH, P.L. 2001. Changes in sea level. In *Climate change 2001: the scientific basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell and C.A. Johnson, eds. Cambridge University Press, Cambridge, 881pp.

CHURCH, J.A., WHITE, N.J., AARUP, T., WILSON, W.S., WOODWORTH, P.L., DOMINGUES, C.M., HUNTER, J.R. and LAMBECK, K. 2008. Understanding global sea levels: past, present and future, *Sustainability Science*, **3**, 9-22, doi:10.1007/s11625-008-0042-4.

CHURCH, J.A., WHITE, N.J., COLEMAN, R., LAMBECK, K. and MITROVICA, J.X. 2004. Estimates of the regional distribution of sea-level rise over the 1950 to 2000 period, *Journal of Climate*, **17**, 2609–262.

CHURCH, M.J., DELONG, E.F., DUCKLOW, H.W., KARNER, M.B., PRESTON, C.M. and KARL, D.M. 2003. Abundance and distribution of planktonic Archaea and Bacteria in the waters west of the Antarctic Peninsula, *Limnology and Oceanography,* **48**, 1893-1902.

CLAPHAM, P.J. and BAKER, C.S. 2002. Whaling, modern. In: Perrin WF, Wursig B, Thewissen JGM ed. *Encyclopaedia of Marine Mammals*. San Diego, CA, *Academic Press.,* 1328-1332.

CLARIDGE, G.G.C., CAMPBELL, I.B., POWELL, H.K.J, AMIN, Z.H. and BALKS, M.R. 1995. Heavy metal contamination in some soils of the McMurdo region, Antarctica, *Antarct. Sci.,* **7**, 9-14.

CLARK, M.S., CLARKE, A., COCKELL, C.S., CONVEY, P., DETRICH, H.W. III, FRASER, K.P.P., JOHNSTON, I.A., METHE, B., MURRAY, A.E., PECK, L.S., RÖMISCH, K. and ROGERS, A.D. 2004. Antarctic genomics, *Comp. Funct. Genomics,* **5**, 230–238.

CLARK, M.S., FRASER, K.P.P. and PECK, L.S. 2008a. Antarctic marine molluscs do have an HSP70 heat shock, *Cell Stress and Chaperones,* **13**, 39-49.

CLARK, M.S., FRASER, K.P.P. and PECK, L.S. 2008b. Lack of an HSP70 heat shock response in two Antarctic marine invertebrates, *Polar Biology,* **31**, 1059-1065.

CLARK, P.U., MCCABE, A.M., MIX, A.C. and WEAVER, A.J. 2004. Rapid rise of sea level 19,000 years ago and its global implications, *Science,* **304**, 1141-1144.

CLARK, P.U., MITROVICA, J.X., MILNE, G.A. and TAMISIEA, M.E. 2002. Sea-level fingerprinting as a direct test for the source of global meltwater pulse IA, *Science,* **295**, 2438-2441.

CLARKE, A. and CRAME, J.A. 1989. The origin of the Southern Ocean marine fauna. In: J.A. C (ed) *Origins and evolution of the Antarctic biota*. Geological Society Special Publications. vol. 7. The Geological Society; London, UK, p 253-268.

CLARKE, A. and JOHNSTON, N.M. 2003. Antarctic marine benthic diversity, *Oceanogr. Mar. Biol. Ann. Rev.,* **41**, 47-114.

CLARKE, A. and, TYLER, P.A. 2008. Adult antarctic krill feeding at abyssal depths, *Current Biology,* **18**, 282-285.

CLARKE, A. 1988. Seasonality in the Antarctic marine environment, *Comp. Biochem. Physiol.,* **90**(B), 461-473

CLARKE, A. 1991a. Cold adaptation, *J. Zool.,* **225**, 691–699.

CLARKE, A. 1991b. What is cold adaptation and how should we measure it? *Amer. Zool.,* **31**, 81–92.

CLARKE, A. 1992. Reproduction in the cold: Thorson revisited, *Invert. Reprod. and Dev.,* **22**, 175-184.

CLARKE, A. 1998. Temperature and energetics: a review of cold ocean physiology. In Cold Ocean Physiology (eds HO Pörtner, RC Playle), *Soc. Exp. Biol. Seminar Ser.,* **66**, 3–30.

CLARKE, A., ARONSON, R.B., CRAME, J.A., GILI, J-M. and BLAKE, D.B. 2004. Evolution and diversity of the benthic fauna of the Southern Ocean continental shelf, *Antarctic Sci.,* **16**, 559-568.

CLARKE, A., BARNES, D.K.A. and HODGSON, D.A. 2005. How isolated is Antarctica? *Trends in Ecology and Evolution,* **20**, 1-3.

CLARKE, A., MURPHY, E.J., MEREDITH, M.P., KING, J.C., PECK, L.S., BARNES, D.K.A. and SMITH, R.C. 2006. Climate change and the marine ecosystem of the western Antarctic Peninsula, *Phil. Trans. R. Soc. B,* **362**, 149-166.

CLARKE, L.J. 2008. Resilience of the Antarctic moss *Ceratodon purpureus* to the effects of elevated UV-B radiation and climate change. PhD thesis, U. Wollongong; L.S. Peck and T. Brey 1996, *Nature,* **380**, 207-208.

CLARKE, L.J., and ROBINSON, S.A. 2008. Cell wall-bound ultraviolet-screening compounds explain the high ultraviolet tolerance of the Antarctic moss, *Ceratodon purpureus*, *New Phytologist,* **179**, 776-783.

CLAUSSEN, M. ET AL. 2002. Earth system models of intermediate complexity: closing the gap in the spectrum of climate system models, *Clim. Dyn*., **18**, 579-586.

CLAYTON, M.N., WIENCKE, C. and KLÖSER, H. 1997. New records and sub-Antarctic marine benthic macroalgae from Antarctica, *Polar Biol*., **17**, 141-149.

CLIMAP. 1981. Seasonal Reconstructions of the Earth's Surface at the Last Glacial Maximum. Map Chart Series MC-36, Geological Society of America, Boulder, CO.

COCCA, E., RATNAYAKE-LECAMWASAM, M., PARKER, S.K., CAMARDELLA, L., CIARAMELLA, M., DI PRISCO, G. and DETRICH, H.W. III. 1995. Genomic remnants of α-globin genes in the hemoglobinless Antarctic icefishes, *Proc. Natl. Acad. Sci. USA,* **92**, 1817-1821.

COLHOUN, E.C. 1991. Geological evidence for changes in the East Antarctica ice sheet (60°-120°E) during the last glaciation, *Polar Record,* **27**, 345-355.

COLLINS, M. and THE CMIP MODELLING GROUPS. 2005. El Niño- or La Niña-like climate change? *Climate Dynamics*, **24**, 89-104.

COLLINS, W.D. and COAUTHORS. 2006. The Community Climate System Model Version 3 (CCSM3), *Journal of Climate*, **19**, 2122-2143.

COMISO, J.C. and GORDON, A.L. 1996. Cosmonaut polynya in the Southern Ocean: Structure and variability, *Journal of Geophysical Research-Oceans*, **101**, Issue C8, 18297-18313.

COMISO, J.C. 2000. Variability and trends in Antarctic surface temperatures from in situ and satellite infrared measurements, *Journal of Climate,* **13**, 1674-1696.

COMISO, J.C., CAVALIERI, D.J. and MARKUS, T. 2003. Sea ice concentration, ice temperature, and snow depth using AMSR-E data, *IEEE Trans Geosci Remote Sensing*, **41**, 243, doi:210.1109/TGRS.2002.808317.

COMNAP-AEON. 2001. Summary and environmental monitoring activities in Antarctica. Council of Managers of National Antarctic Programs, Hobart.

CONIL, S. and MENÉNDEZ, C.G. 2006. Climate fluctuations of the Weddell Sea and its surroundings in a transient climate change scenario, *Clim. Dyn.,* **27** (1), 83-99.

CONLAN, K.E., RAU, G.H., MCFETERS, G.A. and KVITEK, R.G. 2000. Influence of McMurdo Station sewage on Antarctic marine benthos: evidence from stable isotopes, bacteria, and sewage on Antarctic marine benthos: evidence from stable isotopes, bacteria, and biotic indices. In: Davison W, Howard-Williams C, Broady P (eds) *Antarctic Ecosystems: Models for Wider Ecological Understanding*. Caxton Press, Christchurch, 315-318.

CONNOLLEY, W.M. and BRACEGIRDLE, T.J. 2007. An Antarctic assessment of IPCC AR4 coupled models, *Geophys. Res. Lett.*, **34**, L22505, doi:10.1029/2007GL031648.

CONNOLLEY, W.M. 2002. Long term variability of the Antarctic Circumpolar Wave, *Journal of Geophysical Research - Oceans*, **108**, 8076.

CONNOLLEY, W.M. 2003. Long-term variation of the Antarctic Circumpolar Wave, *J. Geophys. Res.,* **108**, 8076, doi:10.1029/ 2000JC000380.

CONVEY, P. and MCINNES, S.J. 2005. Exceptional, tardigrade dominated, ecosystems from Ellsworth Land, Antarctica, *Ecology,* **86**, 519-527.

CONVEY, P. and STEVENS, M.I. 2007. Antarctic Biodiversity, *Science,* **317**, 1877-1878.

CONVEY, P. 1996a. The influence of environmental characteristics on life history attributes of Antarctic terrestrial biota, *Biological Reviews of the Cambridge Philosophical Society*, **71,** 191-225.

CONVEY, P. 1996b. Reproduction of Antarctic flowering plants, *Antarct. Sci.,* **8**, 127-134.

CONVEY, P. 2001. Antarctic Ecosystems. In: *Encyclopedia of Biodiversity*, ed. S.A. Levin. Academic Press, San Diego, Vol. 1, 171-184.

CONVEY, P. 2003. Maritime Antarctic climate change: signals from terrestrial biology. In: Antarctic Peninsula Climate Variability: Historical and Palaeoenvironmental Perspectives, eds. E. Domack, A. Burnett, A. Leventer, P. Convey, M. Kirby and R. Bindschadler, pp. 145-158. *Antarctic Research Series* vol. **79**, American Geophysical Union.

CONVEY, P. 2006. Antarctic climate change and its influences on terrestrial ecosystems. *Trends in Antarctic Terrestrial and Limnetic Ecosystems: Antarctica as a Global Indicator*, eds. Bergstrom, D.M**,** Convey, P. and Huiskes, A.H.L. Springer, Dordrecht, 253-272.

CONVEY, P. 2007a. Antarctic Ecosystems. In Levin, S.A. (ed), *Encyclopedia of Biodiversity*, 2nd Edition, Elsevier, San Diego (in press).

CONVEY, P. 2007b. Influences on and origins of terrestrial biodiversity of the sub-Antarctic islands, *Papers and Proceedings of the Royal Society of Tasmania,* **141**, 83-93.

CONVEY, P. 2008. Non-native species in Antarctic terrestrial and freshwater environments: presence, sources, impacts and predictions. *Non-native species in the Antarctic Proceedings*, ed. M. Rogan-Finnemore, 97-130. Gateway Antarctica, Christchurch, New Zealand.

CONVEY, P., CHOWN, S.L., WASLEY, J. and BERGSTROM, D.M. 2006a. Life history traits. *Trends in Antarctic Terrestrial and Limnetic Ecosystems: Antarctica as a Global Indicator*, eds. Bergstrom, D.M**,** Convey, P. and Huiskes, A.H.L. Springer, Dordrecht, 101-127.

CONVEY, P., FRENOT, F., GREMMEN, N. and BERGSTROM, D. 2006b. Biological invasions. *Trends in Antarctic Terrestrial and Limnetic Ecosystems: Antarctica as a Global Indicator*, eds. Bergstrom, D.M, Convey, P. and Huiskes, A.H.L. Springer, Dordrecht, 193-220.

CONVEY, P., GIBSON, J.A.E., HILLENBRAND, C-D., HODGSON, D.A., PUGH, P.J.A., SMELLIE, J.L. and STEVENS, M.I. 2008. Antarctic terrestrial life - challenging the history of the frozen continent? *Biological Reviews,* **83**, 103-117.

CONVEY, P., STEVENS, M.I., HODGSON, D.A., SMELLIE, J.L., HILLENBRAND, C-D., BARNES, D.K.A., CLARKE, A., PUGH, P.J.A., LINSE, K. and CARY, S.C. Submitted. Exploring biological constraints on the glacial history of Antarctica. *Quaternary Science Reviews*.

CONWAY, H., HALL, B.L., DENTON, G.H., GADES, A.M., WADDINGTON, E.D. 1999. Past and future grounding-line retreat of the West Antarctic Ice Sheet. *Science* **286**:280-283.

COOK, A., FOX, A., VAUGHAN, D. and FERRIGNO, J. 2005, Retreating glacier fronts on the Antarctic Peninsula over the past half-century, *Science,* **308**, 541-544.

COOK, A.J., PONCET, S., COOPER, A.P.R., HERBERT, D.J. and CHRISTIE, D. (Submitted). Glacier retreat and the risk of rat spread on South Georgia.

COOPER, A.P.R. 1997. Historical observations of Prince Gustav Ice Shelf, *Polar Record*, **33**(187), 285-294.

CORLETT, G.K., BARTON, I.J., DONLAN, C.J., EDWARDS, M.C., GOOD, S.A., HORROCKS, L.A., LLEWELLYN-JONES, D.T., MERCHANT, C.J., MINNETT, P.J., NIGHTINGALE, T.J., NOYES, E.J., O'CARROLL, A.G., REMEDIOS, J.J., ROBINSON, I.S., SAUNDERS, R.W. and WATTS, J.G. 2006. The accuracy of SST retrievals from AATSR: An initial assessment through geophysical validation against in situ radiometers, buoys and other SST data sets, *Advances in Space Research*, **37** (4), 764-769.

CORR, H.F.J., JENKINS, A., NICHOLLS, K.W. and DOAKE, C.S.M. 2002. Precise measurement of changes in ice-shelf thickness by phase-sensitive radar to determine basal melt rates, *Geophys. Res. Lett.,* **29**(8), 10.1029/2001GL014618.

CORSOLINI, S., COVACI, A., ADEMOLLO, N., FOCARDI, S., SCHEPENS, P. 2006. Occurrence of organochlorine pesticides (OCPs) and their enantiometric signature, and concentrations of polybrominated diphenyl ethers (PBDEs) in the Adélie penguin food web, Antarctica, *Environ. Pollut*., **140**, 371-382.

COULSON, S.J. 2007. The terrestrial and freshwater invertebrate fauna of the High Arctic archipelago of Svalbard, *Zootaxa,* **1448**, 41–68.

COVEY, C., ACHUTARAO, K.M., CUBASCH, U., JONES, P., LAMBERT, S.J., MANN, M.E., PHILLIPS, T.J. and TAYLOR, K.E. 2003. An overview of results from the Coupled Model Intercomparison Project (CMIP), *Global Planet. Change*, **37**, 103–133, doi:10.1016/S0921-8181(02)00193-5.

COWAN, E.A., BRACHFELD, S.A., POWELL, R.D. and SCHOOLFIELD, S.C. 2006. Terrane-specific rock magnetic characteristics preserved in glacimarine sediment from southern coastal Alaska, *Canadian J. Earth Sci.,* **43**(9), 1269–1282.

COWARD, A. and DE CUEVAS, B. 2005. The OCCAM 66 level model: model description, physics, initial conditions and external forcing, Tech. rep., Southampton Oceanography Centre, Internal Document No. 99, 83 pp. (http://eprints.soton.ac.uk/18792).

COX, M.D. 1984. A primitive equation 3-dimensional model of the ocean. Tech. Rep. 1, Geophys. Fluid Dyn. Lab, Natl. Oceanic and Atmos. Admin., Princeton Uni. Press, Princeton, N.J.

COXALL, H., WILSON, P.A., PALIKE, H., LEAR, C.H. and BACKMAN, J. 2005. Rapid stepwise onset of Antarctic glaciation and deeper calcite compensation in the Pacific Ocean, *Nature,* **433**, 53-57.

CRAME, J.A. 1994. Evolutionary history of Antarctica. In: Hempel, G. (ed) *Antarctic Science*. Berlin: Springer, 188-214.

CRAME, J.A. 2001. Taxonomic diversity gradients through geological time, *Diversity and Distributions,* **7**, 175-189.

CRAVEN, M., ALLISON, I., BRAND, R., ELCHEIKH, A., HUNTER, J., HEMER, M. and DONOGHUE, S. 2004. Initial borehole results from the Amery Ice Shelf hot-water drilling project, *Ann. Glaciol.,* **39**, 531-539.

CRAWFORD, J.H., DAVIS, D.D., CHEN, G., BUHR, M., OLTMANS, S., WELLER, R., MAULDIN, L., EISELE, F., SHETTER, R., LEFER, B., ARIMOTO, R. and HOGAN. 2001. Evidence for photochemical production of ozone at the South Pole surface, *Geophys. Res. Lett*., **28**, 3641-3644.

CREMER, H., GORE, D., MELLES, M., ROBERTS, D. 2003. Palaeoclimatic significance of late Quaternary diatom assemblages from southern Windmill Islands, East Antarctica, *Palaeogeography Palaeoclimatology Palaeoecology*, **195**, 261-280.

CREMER, H., HEIRI, O., WAGNER, B. and WAGNER-CREMER, F. 2007. Abrupt climate warming in East Antarctica during the early Holocene, *Quaternary Science Reviews,* **26**, 2012-2018.

CROMER, L., GIBSON J.A.E., SWADLING, K.M. and HODGSON, D.A. 2006 Evidence for a lacustrine faunal refuge in the Larsemann Hills, East Antarctica, during the Last Glacial Maximum, *Journal of Biogeography,* **33,** 1314-1323.

CROMER, L., GIBSON, J.A.E., SWADLING, K. and RITZ, D.A. 2005. Faunal microfossils: Indicators of Holocene ecological change in a saline Antarctic lake, *Palaeogeography, Palaeoclimatology, Palaeoecology,* **221**, 83-97.

CROSTA, X., DEBRET, M., DENIS, D., COURTY, M-A. and THER, O. 2007 Holocene long- and short-term climate changes off Adelie Land, East Antarctica. *Geochemistry Geophysics Geosystems*, **8**, Q11009, doi:11010.11029/12007GC001718.

CROSTA, X., DENIS, D. and THER, O. 2008. Sea ice seasonality during the Holocene, Adelie Land, East Antarctica, *Marine Micropaleontology*, **66**, 222-232.

CROSTA, X., PICHON, J.J. and BURCKLE, L.H. 1998. Reappraisal of Antarctic seasonal sea-ice at the Last Glacial Maximum, *Geophysical Research Letters,* **25**, 2703-2706.

CROSTA, X., PICHON, J-J. and BURCKLE, L.H. 1998a. Application of Modern Analog Technique to marine Antarctic diatoms: Reconstruction of maxiumum sea ice extent at the Last Glacial Maximum, *Paleoceanography,* **13**, 284-297.

CROSTA, X., STURM, A., ARMAND, L. and PICHON, J.J. 2004. Late Qaternary sea ice history in the Indian sector of the Southern Ocean as record by diatom assemblages, *Marine Micropaleontology*, **50**, 209-223.

CROWLEY, T.J. and KIM, K. 1995. Comparison of long-term greenhouse projections with the Geologic Record, *Geophysical Research Letters,* **22**, 933-936.

CROXALL, J.P., MCCANN, T.S., PRINCE, P.A. and ROTHERY, P. 1988. Reproductive performance of seabirds and seals at South Georgia and Signy Island, South Orkney Islands, 1976-1987: implications for Southerrn Ocean monitoring studies. In *Antarctic Ocean resources variability* (ed. D Sahrhage), 261–285. Berlin, Germany: Springer.

CSATHO, B., AHN, Y., YOON, T., VAN DER VEEN, C.J., VOGEL, S., HAMILTON, G., MORSE, D., SMITH, B. and SPIKES, V.B. 2005. ICESat measurements reveal complex pattern of elevation changes on Siple Coast ice streams, Antarctica, *Geophys. Res. Lett.*, **32**, L23S04, doi:10.1029/2005GL024289.

CULLATHER, R.I., BROMWICH, D.H. and VAN WOERT, M.L. 1996. Interannual variations in Antarctic precipitation related to El Nino southern oscillation, *Journal of Geophysical Research,* **101**, 19109-19118.

CULLATHER, R.I., BROMWICH, D.H. and VAN WOERT, M.L. 1998. Spatial and temporal variability of Antarctic precipitation from atmospheric methods, *J. Climate*, **11**, 334–367.

CUNNINGHAM, L., RAYMOND, B., SNAPE, I. and RIDDLE, M.J. 2005. Benthic diatom communities as indicators of anthropogenic metal contamination at Casey Station, Antarctica, *J. Paleolimnol.,* **33**, 499-513.

CUNNINGHAM, S.A., ALDERSON, S.G., KING, B.A. and BRANDON, M.A. 2003. Transport and variability of the Antarctic Circumpolar Current in Drake Passage. *J. Geophys. Res.*, **108** (C5), 8084, doi:10.1029/2001JC001147.

CURRAN, M.A.J., VAN OMMEN, T.D., MORGAN, V.I., PHILLIPS, K.L. and PALMER, A.S. 2003. Ice core evidence for Antarctic sea ice decline since the 1950s, *Science,* **302**, 1203-1206.

CURRY, R., DICKSON, B. AND YASHAYAEV, I. 2003. A change in the freshwater balance of the Atlantic Ocean over the past decades, *Nature*, **426**(6968), 826-829.

CUSHING, D.H. 1982. Climate and Fisheries. Academic Press, London.

DALY, K.L. 2004. Overwintering growth and development of larval *Euphausia superba*: an interannual comparison under varying environmental conditions west of the Antarctic Peninsula, *Deep-Sea Research II,* **51**, 2139-2168.

DAMERIS, M., GREWE, V., PONATER, M., DECKERT, R., EYRING, V., MAGER, F., MATTHES, S., SCHNADT, C., STENKE, A., STEIL, B., BRÜHL, C. and GIORGETTA, M.A. 2005. Long-term changes and variability in a transient simulation with a chemistry-climate model employing realistic forcing, *Atmos. Chem. Phys.*, **5**, 2121-2145.

DARTNALL, H.J.G. 2005. Freshwater invertebrates of subantarctic South Georgia, *J. Nat. Hist.,* **39**, 3321-3342.

DARTNALL, H.J.G., HOLLWEDEL, W. and DE PAGGI, J.C. 2005. The freshwater fauna of Macquarie Island, including a redescription of the endemic water-flea *Daphnia gelida* (Brady) (Anomopoda: Crustacea), *Polar Biol.,* **28**, 922-939.

DAVEY, M.C. 1997. Effects of continuous and repeated dehydration on carbon fixation by bryophytes from the maritime Antarctic, *Oecologia,* **110**, 25-31.

DAVEY, M.K., HUDDLESTON, M., SPERBER, K., BRACONNOT, P., BRYAN, F., CHEN, D., COLMAN, R., COOPER, C., CUBASCH, U., DELECLUSE, P., DEWITT, D., FAIRHEAD, L., FLATO, G., GORDON, C., HOGAN, T., JI, M., KIMOTO, M., KITOH, A., KNUTSON, T., LATIF, M., LE TREUT, H., LI, T., MANABE, S., MECHOSO, C., MEEHL, G., POWER, S., ROECKNER, E., TERRAY, L., VINTZILEOS, A., VOSS, R., WANG, B., WASHINGTON, W., YOSHIKAWA, I., YU, J., YUKIMOTO, S. and ZEBIAK, S. 2002. STOIC: A study of coupled model climatology and variability in tropical ocean regions, *Clim. Dyn.*, **18**, 403–420.

DAVIS, C.H., LI Y., MCCONNELL, J.R., FREY, M.M. and HANNA, E. 2005. Snowfall-driven growth in East Antarctic Ice Sheet mitigates recent sea-level rise, *Science,* **308**, 1898–1901.

DAVIS, D., CHEN, G., BUHR, M., CRAWFORD, J., LENSCHOW, D., LEFER, B., SHETTER, R., EISELE, F., MAULDIN, L. andHOGAN. 2004. A.: South Pole NO_x chemistry: an assessment of factors controlling variability and absolute levels, *Atmos. Environ.*, **38**, 5375-5388.

DAYTON, P.K. 1989. Interdecadal variation in an Antarctic sponge and its predators from Oceanographic climate shifts, *Science,* **245**, 1484-1486

DAYTON, P.K., MORDIDA, B.J. and BACON, F. 1994. Polar marine communities, *Am. Zool.*, **34**, 90–99.

DE ANGELIS, H. and SKVARCA, P. 2003. Glacier surge after ice shelf collapse, *Science,* **299**, 1560-1562.

DE BROYER, C., LOWRY, J.K., JAZDZEWSKI, K. and ROBERT, H. 2007. Census of marine Life. Synopsis of the Amphipoda of the Southern Ocean. Vol. 1: Part 1. Catalogue of the Gammaridean and Corophiidean Amphipoda (Crustacea) of the Southern Ocean with distribution and ecological data. *Institut Royal des Sciences Naturelles de Belgique, Bruxelles*, 325 pp.

DE LA MARE, W.K. 1997. Abrupt mid-twentieth century decline in Antarctic sea-ice extent from whaling records, *Nature*, **389** (6646), 57-61.

DE LA TORRE, J.R., GOEBEL, B.M., FRIEDMANN, E.I. and PACE, N.R., 2003. Microbial diversity of cryptoendolithic communities from the McMurdo Dry Valleys, Antarctica, *Appl. Environ. Microbiol.,* **69**, 3858-3867.

DE LOS RIOS, A., GRUBE, M., SANCHO, L.G. and ASCASO, C. 2007. Ultrastrucutral and genetic characterization of endolithic cyanobacterial and genetic characteristics of endolithic cyanobacterial biofilms colonizing Antarctic granite rocks. *FEMS Microbol. Ecol.*, **59**, 386-395.

DE MESEL, I., LEE, H.J., VANHOVE, S., VINCX, M., VANREUSEL, A. 2007. Species diversity and distribution within the deep-sea nematode genus *Acantholaimus* on the continental shelf and slope in Antarctica, *Polar Biol.*, **29** (10), 860-871.

DE SZOEKE, R.A. AND LEVINE, M.D. 1981. The advective flux of heat bymean geostrphic motions in the Southern Ocean, *Deep-Sea Research,* **28**, 1057-1085.

DEACON, G.E.R. 1937. The hydrology of the Southern Ocean, *Discovery Reports,* **15,** 1-124.

DECKER, E.R. and BUCHER, G.J. 1977. Geothermal studies in Antarctica, *Antarctic Journal of the United States,* **12**(4), 102-104.

DECKER, E.R. 1974. Preliminary geothermal studies of the Dry Valley Drilling Project holes at McMurdo Station, Lake Vanda, Lake Vida, and New Harbor, Antarctica, *Bulletin - Dry Valley Drilling Project (DVDP)*, **4**, 22-23.

DECONTO, R., POLLARD, D. and HARWOOD, D. 2007. Sea ice feedback and Cenozoic evolution of Antarctic climate and ice sheets, *Paleoceanography,* **22**, doi: PA3214, doi:10.1029/2006PA001350.

DECONTO, R.M. and POLLARD, D. 2003. Rapid Cenozoic glaciation of Antarctica induced by declining atmospheric CO_2, *Nature,* **421**, 245-249.

DELONG, E.F., WU, K.Y., PREZELIN, B.B. and JOVINE, R.V.M. 1994. High abundance of Archaea in Antarctic marine picoplankton, *Nature,* **371**, 695-697

DELWORTH, T.L., BROCCOLI, A.J. , ROSATI, A., STOUFFER, R.J., BALAJI, V., BEESLEY, J.A., COOKE, W.F., DIXON, K.W., DUNNE, J., DUNNE, K.A., DURACHTA, J.W., FINDELL, K.L., GINOUX, P., GNANADESIKAN, A., GORDON, C.T., GRIFFIES, S.M., GUDGEL, R., HARRISON, M.J., HELD, I.M., HEMLER, R.S., HOROWITZ, L.W., KLEIN, S.A., KNUTSON, T.R., KUSHNER, P.J., LANGENHORST, A.R., LEE, H.C., LIN, S.J., LU, J., MALYSHEV, S.L., MILLY, P.C.D., RAMASWAMY, V., RUSSELL, J., SCHWARZKOPF, M.D., SHEVLIAKOVA, E., SIRUTIS, J.J., SPELMAN, M.J., STERN, W.F., WINTON,

M., WITTENBERG, A.T., WYMAN, B., ZENG, F. and ZHANG, R. 2006. GFDL's CM2 Global Coupled Climate Models. Part I: Formulation and Simulation Characteristics, *J. Climate*, **19**, 643–674.

DENTON, G.H. and KARLÉN, W. 1973. Holocene climatic variations: Their pattern and possible cause, *Quaternary Research,* **3**, 155-205.

DENTON, G.H. and MARCHANT, D.R. 2000. The geologic basis for a reconstruction of a grounded ice sheet in McMurdo Sound, Antarctica, at the last glacial maximum, *Geografiska Annaler Series a-Physical Geography*, **82A**, 167-211.

DENTON, G.H., BROECKER, W.S. and ALLEY, R.B. 2006. The mystery interval, 17.5 to 14.5 kyrs ago, *PAGES news,* **2**, 14-16.

DENTON, G.H., PRENTICE, M.L. and BURCKLE, L.H. 1991. Cainozoic history of the Antarctic ice sheet. In: Tingey (ed) *Geology of Antarctica*. Oxford University Press, New York, 365-433.

DEPREZ, P.P., ARENS, M. and LOCHER, E. 1999. Identification and assessment of contaminated sites at Casey Station, Wilkes Land, Antarctica, *Polar Record,* **35**, 299-316.

DETRICH, H.W. III, JOHNSON, K.A. and MARCHESE-RAGONA, S.P. 1989. Polymerization of Antarctic fish tubulins at low temperature: energetic aspects, *Biochemistry,* **28**, 10085–93.

DETTAÏ, A, DI PRISCO, G., LECOINTRE, G., PARISI, E. and VERDE, C. 2008. Inferring evolution of fish proteins: the globin case study, *Methods Enzymol.,* **436**, 539-570.

DETTAÏ, A. and LECOINTRE, G. 2004. In search of notothenioid (Teleostei) relatives, *Antarctic Sci.,* **16**, 71-85.

DEVRIES, A.L. 1971. Glycoproteins as biological antifreeze agents in Antarctic fishes, *Science,* **172**, 1152–1155.

DEVRIES, A.L. 1982. Biological antifreeze agents in coldwater fishes, *Comparative Biochemistry and Physiology,* **73A**, 627-640.

DI PRISCO, G. 2000. Life style and biochemical adaptation in Antarctic fishes, *J. Mar. Syst*., **27**, 253-265.

DI PRISCO, G. 1998. Molecular adaptations in Antarctic fish hemoglobins. In: di Prisco G, Pisano E and Clarke A (Eds) *Fishes of Antarctica. A Biological Overview*, Springer, Milano, 339-353.

DI PRISCO, G., COCCA, E., PARKER, S.K. and DETRICH, H.W. 2002. Tracking the evolutionary loss of hemoglobin expression by the white-blooded Antarctic icefishes, *Gene*., **295**, 185-191.

DI PRISCO, G., D'AVINO, R., CARUSO, C., TAMBURINI, M., CAMARDELLA, L., RUTIGLIANO, B., CARRATORE, V. and ROMANO, M. 1991. The biochemistry of oxygen transport in red-blooded Antarctic fish. In: di Prisco G, Maresca B, Tota B (eds) *Biology of Antarctic Fish*, Springer, Berlin, 263–281.

DI PRISCO, G., D'AVINO, R., CARUSO, C., TAMBURRINI, M., CAMARDELLA, L., RUTIGLIANO, B., CARRATORE, V. and ROMANO, M. 1991. The biochemistry of oxygen transport in red-blooded Antarctic fishes. In: di Prisco G, Maresca B and Tota B (Eds) *Biology of Antarctic Fish*. Springer-Verlag, Berlin, Heidelberg, New York, 263-281.

DI PRISCO, G., EASTMAN, J.T., GIORDANO, D., PARISI, E. and VERDE, C. 2007. Biogeography and adaptation of Notothenioid fish: hemoglobin function and globin-gene evolution, *Gene.,* **398**, 143-155.

DIBB, J. E., ARSENAULT, M., PETERSON, M.C. and HONRATH, R.E. 2002. Fast nitrogen oxide photochemistry in Summit, Greenland snow, *Atmos. Environ.*, **26**, 2501-2511.

DIBB, J., MAYEWSKI, P.A., BUCK, C.F. and DRUMMEY, S.M. 1990. Beta radiation from snow, *Nature,* **344** (6270), 25.

DICKSON, B., I. YASHAYAEV, J. MEINCKE, B. TURRELL, S. DYE and J. HOLFORT. 2002. Rapid freshening of the deep North Atlantic Ocean over the past four decades, *Nature*, **416**, 832-837.

DINNIMAN, M.S., KLINCK, J.M. and SMITH JR., W.O. 2007. Influence of sea ice cover and icebergs on circulation and water mass formation in a numerical circulation model of the Ross Sea, Antarctica, *Journal of Geophysical Research*, **112**, C11013, (doi:10.1029/2006JC004036).

DIVENERE, V.J., KENT, D.V. and DALZIEL, I.W.D. 1994. Mid-Cretaceous paleomagnetic results from Marie Byrd Land, WestAntarctica: a test of post-100 Ma relative motion between East and West Antarctica, *Journal of Geophysical Research,* **99**, 15115-15139.

DIXON, D., MAYEWSKI, P.A., KASPARI, S., SNEED, S. and HANDLEY, M. 2006. Connections between West Antarctic ice core sulfate and climate over the last 200+ years, *Annals of Glaciology,* **41**, 155-156.

DIXON, D.A., MAYEWSKI, P.A., GOODWIN, I.D., FREEMAN, R., MAASCH, K.A. and SNEED, S.B. In review. Behaviour of the Southern Hemisphere westerlies from the mid Holocene to the present.

DOAKE, C.S.M. and VAUGHAN, D.G. 1991. Rapid disintegration of the Wordie Ice shelf in response to atmospheric warming, *Nature*, **350**, 328-330.

DOMACK, E. 2002. A synthesis for site 1098: Palmer Deep. In: Barker PF, Camerlenghi A, Acton GD, Ramsay ATS (eds) *Proceedings of the Ocean Drilling Program, Scientific Results*, **178**. Ocean Drilling Program, Texas A and M University, College Station TX 77843-9547, USA.

DOMACK, E., DURAN, D., LEVENTER, A., ISHMAN, S., DOANE, S., MCCALLUM, S., AMBLAS, D., RING, J., GILBERT, R. and PRENTICE, M. 2005. Stability of the Larsen B ice shelf on the Antarctic Peninsula during the Holocene epoch, *Nature,* **436**, 681-685.

DOMACK, E., LEVENTER, A., BURNETT, A., BINDSCHADLER, R., CONVEY, P. and KIRBY, M. 2003a. Antarctic Peninsula Climate Variability: Historical and Paleoenvironmental Perspectives, *Antarctic Research Series*, **79.** American Geophysical Union.

DOMACK, E., LEVENTER, A., DUNBAR, R.B., TAYLOR, F., BRACHFELD, S., SJUNNESKOG, C. and PARTY, O.L.S. 2001. Chronology of the Palmer Deep site, Antarctic Peninsula: a Holocene palaeoenvironmental reference for the circum-Antarctic, *The Holocene,* **11**, 1-9.

DOMACK, E., O'BRIEN, P., HARRIS, P., TAYLOR, F., QUILTY, P.G., DE SANTIS, L. and RAKER, B. 1998. Late Quaternary sediment facies in Prydz Bay, East Antarctica and their relationship to glacial advance onto the continental shelf, *Antarctic Science,* **10**, 234-244.

DOMACK, E.W., ISHMAN, S.E., STEIN, A.B., MCCLENNEN, C.E and JULL, A.J.T. 1995. Late Holocene Advance of the Muller Ice Shelf, Antarctic Peninsula - Sedimentological, Geochemical and Paleontological Evidence, *Antarctic Science,* **7**, 159-170.

DOMACK, E.W., JULL, A.J.T., ANDERSON, J.B. and LINICK, T.W. 1991. Mid-Holocene ice sheet recession from the Wilkes Land continental shelf, East Antarctica. In: Thomson MRA, Crame JA, Thomson JW (eds) *Geological Evolution of Antarctica,* Cambridge University Press, Cambridge, 693-698.

DOMACK, E.W., JULL, A.J.T., ANDERSON, J.B., LINICK, T.W. and WILLIAMS, C.R. 1989. Application of tandem accelerator mass-spectrometer dating to late Pleistocene-Holocene Sediments of the East Antarctic continental shelf, *Quaternary Research,* **31**, 277-287.

DOMACK, E.W., LEVENTER, A., ROOT, S., RING, J., WILLIAMS, E., CARLSON, D., HIRSHORN, E., WRIGHT, W., GILBERT, R. and BURR, G. 2003b. Marine Sedimentary Record of Natural Environmental Variability and Recent Warming in the Antarctic Peninsula. In: Domack EW, Leventer A, Burnett A, Bindschadler R, Convey P, Kirby M (eds) *Antarctic Peninsula climate variability: historical and paleoenvironmental perspectives,* Antarctic Research Series **79**. American Geophysical Union, Washington, 205-222.

DOMACK, E.W., O'BRIEN, P., HARRIS, P., TAYLOR, F., QUILTY, P.G., DE SANTIS, L. and RAKER, B. 1999. Late Quaternary sediment facies in Prydz Bay, East Antarctica and their relationship to glacial advance onto the continental shelf, *Antarctic Science,* **10**, 236-246.

DOMINGUES, C.M., CHURCH, J.A., WHITE, N.J., GLECKLER, P.J., WIJFFELS, S.E., BARKER, P.M. and DUNN, J.R. 2008, Improved estimates of upper-ocean warming and multi-decadal sea-level rise, *Nature,* **453**, 1090-1093.

DORAN, P.T., PRISCU, J.C., LYONS, W.B., WALSH, J.E., FOUNTAIN, A.G., MCKNIGHT, D.M., MOORHEAD, D.L., VIRGINIA, R.A., WALL, D.H., CLOW, G.D., FRITSEN, C.H., MCKAY, C.P. and PARSONS, A.N. 2002. Antarctic climate cooling and terrestrial ecosystem response, *Nature,* **415**, 517-520.

DOSCHER, R. and BECKMAN, A. 2000. Effects of a Bottom Boundary Layer Parameterization in a Coarse-Resolution Model of the North Atlantic Ocean, *Journal of Atmospheric and Oceanic Technology*, **17**(5), 698-707.

DOWDESWELL, J.A. and BAMBER, J.L. 2007. Keel depths of modem Antarctic icebergs and implications for sea-floor scouring in the geological record, *Marine Geology,* **243** (1-4), 120-131.

DOWDESWELL, J.A., Ó COFAIGH, C. and PUDSEY, C.J. 2004. Continental slope morphology and sedimentary processes at the mouth of an Antarctic palaeo-ice stream, *Marine Geology,* **204**, 203-214.

DREW, E.A. 1977. The physiology of photosynthesis and respiration in some Antarctic marine algae, *Br. Antarct. Surv. Bull.*, *46*, 59-76.

DREWRY, D.J. 1983. Antarctica: Glaciological and Geophysical Folio. Drewry, D.J. *ed.* Cambridge: Scott Polar Research Institute, University of Cambridge.

DUCKLOW, H., MORAN, X. and MURRAY, A.E. In press. Bacteria in the Greenhouse: marine microbes and climate change. In*: Environmental Microbiology*. Editors: R. Mitchell and J-D Gu.

DUCKLOW, H.W., BAKER, K., MARTINSON, D.G., QUENTIN, L.B., ROSS, R.M., SMITH, R.C., STAMMERJOHN, S.E., VERNET, M. and FRASER, W. 2007. Marine pelagic ecosystems: the West Antarctic Peninsula, *Phil. Trans. R. Soc. B*, **362**, 67-94.

DUNBAR, G.B., NAISH, T.R., BARRETT, P.J., FIELDING, C.R. and POWELL, R.D. 2008. Constraining the amplitude of late Oligocene bathymetric changes in western Ross Sea during orbitally-induced oscillations in the East Antarctic Ice Sheet: (1) Implications for glacimarine sequence stratigraphic models, *Palaeogeography, Palaeoclimatology, Palaeoecology,* In Press.

DUNN, J.L. and ROBINSON, S.A. 2006. Ultraviolet B screening potential is higher in two cosmopolitan moss species than in a co-occurring Antarctic endemic moss: implications of continuing ozone depletion, *Global Change Biology,* **12**, 2282-2296.

DUPONT, S. and THORNDYKE, M.C. 2009. Impact of CO_2-driven ocean acidification on invertebrates early life-history – What we know, what we need to know and what we can do, *Biogeosciences Discuss*, **6**, 3109-3131.

DUPONT, T., and ALLEY, R.B. 2005a. Assessment of the Importance of Ice-Shelf Buttressing to Ice-Sheet Flow, *Geophysical Research Letters,* **32**(4), LO4503.

DUPONT, T., and ALLEY, R.B. 2005b. The importance of small ice shelves in sea-level rise. *Geophysical Research Letters,* **33**, LO9503.

DYURGEROV, M.B. and MEIER, M.F. 2000. Twentieth century climate change: evidence from small glaciers, *Proc. Natl. Acad. Sci. USA,* **97**, 1406-1411.

EASTMAN, J.T. and CLARKE, A. 1998. A comparison of adaptive radiations of antarctic fish with those of nonantarctic fish. In: Prisco G. di, Pisano, E., Clarke, A. (eds) *Fishes of Antarctica*. Springer, Milan, 3-26.

EASTMAN, J.T. and MCCUNE, A.R. 2000. Fishes on the Antarctic continental shelf: evolution of a marine species flock? *Journal of Fish Biology,* **57**, 84-102.

EASTMAN, J.T. 1993. Antarctic Fish Biology. Evolution in a Unique Environment. Academic Press, San Diego, USA, 322 pp.

EASTMAN, J.T. 1997. Comparison of the Antarctic and Arctic fish faunas. *Cybium,* **12**, 276-287.

EASTMAN, J.T. 2000. Antarctic notothenioid fishes as subjects for research in evolutionary biology, *Antarctic Sci.,* **12**, 276-287.

EASTMAN, J.T. 2005. The nature of the diversity of Antarctic fishes, *Polar Biology,* **28**, 1432-2056.

EBINGHAUS, R., KOCK, H.H., TEMME, C., EINAX, J.W., RICHTER, A., BURROWS, J.P. and SCHROEDER, W.H. 2002. Antarctic springtime depletion of atmospheric mercury, *Environ. Sci. Technol.,* **36**, 1238-1244.

EGBERT, G.D. and RAY, R.D. 2003. Semi-diurnal and diurnal tidal dissipation from TOPEX/Poseidon altimetry, *Geophys. Res. Lett.,* **30**, doi:10.1029/2003GL017676.

EGGERT, A., WIENCKE, C. 2000. Adaptation and acclimation of growth and photosynthesis of five Antarctic red algae to low temperatures, *Polar Biol.,* **23**, 609-618.

EISEN, O., FREZZOTTI, M., GENTHON, C., ISAKSSON, E., MAGAND, O., VAN DEN BROEKE, M.R., DIXON, D. A., EKAYKIN, A., HOLMLUND, P., KAMEDA, T., KARLOF, L., KASPARI, S., LIPENKOV, V.Y., OERTER, H., TAKAHASHI, S. and VAUGHAN, D.G. 2008. Ground-based measurements of spatial and temporal variability of snow accumulation in east Antarctica, *Reviews of Geophysics,* **46** (1), doi:10.1029/2006RG000218.

ELLIS-EVANS, J.C. 1996. Microbial diversity and function in Antarctic freshwater ecosystems, *Biodivers. Converv*., **5**, 1395-1431.

ELVEBAKK, A. and HERTEL, H. 1996: Part 6. Lichens. *In* Elvebakk, A. and Prestrud, P. (eds), *A Catalogue of Svalbard Plants, Fungi and Cyanobacteria*. Norwegian Polar Institute Skrifter 198. Norwegian Polar Institute, Tromsø: pp. 271–359.

EMSLIE, S.D., COATS, L. and LICHT, K. 2007. A 45,000 Yr Record of Adelie Penguins and Climate Change in the Ross Sea, Antarctica, *Geology,* **35**, 61-64.

EMSLIE, S.D., WOEHLER, E.J. 2005. A 9000-year record of Adélie penguin occupation and diet in the Windmill Islands, East Antarctica, *Antarctic Science*, **17**, 57-66.

ENGELHARDT, H. 2005. Thermal regime and dynamics of the West Antarctic ice sheet, *Ann. Glaciol*., **39**, 85-92.

ENOMOTO, H., and 8 COLLABORATORS. 1998. Winter warming over Dome Fuji, east Antarctica and semi-annual oscillation in the atmospheric circulation, *J. Geophys. Res.,* **103**, 23103-23111.

EPICA 2004. Eight glacial cycles from an Antarctic ice core, *Nature,* **429**, 623-628.

EPICA COMMUNITY MEMBERS. 2006. One-to-one coupling of glacial climate variability in Greenland and Antarctica, *Nature,* **444**, 195-198.

ERICKSON, A.W., SINIFF, D.B., CLINE, D.R. and HOFMAN, R.J. 1971. Distributional ecology of Antarctic seals. In *Symposium on Antarctic Ice and Water Masses*: (G. Deacon, ed.), 55-76. SCAR, Cambridge.

ERNSTING, G., BLOCK, W., MACALISTER, H. and TODD, C. 1995. The invasion of the carnivorous carabid beetle *Trechisibus antarcticus* on South Georgia (subantarctic) and its effect on the endemic herbivorous beetle *Hydromedion spasutum*, *Oecologia,* **103**, 34-42.

ETHERIDGE, D.M., STEELE, L.P., LANGENFIELDS, R.J. FRANCEY, J.M. BARNOLA and MORGAN, V.I. 1996. Natural and anthropogenic changes in atmospheric CO_2 over the last 1000 years from air in Antarctic firn and ice, *J. Geophys. Res*., **101**, 4115-4128.

EVANS, J., DOWDSWELL, J.A., O'COFAIGH, C., BENHAM, T.J. and ANDERSON, J.B. 2006. Extent and dynamics of the West Antarctic Ice Sheet on the outer continental shelf of Pine Island Bay during the last glaciation, *Marine Geology,* **230**, 53-72.

EVANS, J., PUDSEY, C.J., O'COFAIGH, C., MORRIS, P. and DOMACK, E. 2005. Late Quaternary Glacial History, Flow Dynamics and Sedimentation Along the Eastern Margin of the Antarctic Peninsula Ice Sheet, *Quaternary Science Reviews,* **24**, 741-774.

FAHNESTOCK, M.A., SCAMBOS, T.A., SHUMAN, C.A., ARTHERN, R.J., WINEBRENNER, D.P. and KWOK, R. 2000. Snow Megadune Fields on the East Antarctic Plateau: Extreme Atmosphere-Ice Interaction, *Geophys. Res. Lett.*, *27(22)*, 3719 - 3722.

FAHRBACH, E., HOPPEMA, M., ROHARDT, G., SCHRODER, M. and WISOTZKI, A. 2006. Causes of deep-water variation: Comment in the paper by L.H. Smedsrud, 2005, "Warming of the deep water in the Weddell Sea along the Greenwich Meridian: 1997-2001", *Deep-Sea Research I*, **53**, 574-577.

FAHRBACH, E., HOPPEMA, M., ROHARDT, G., SCHRÖDER, M. and WISOTZKI, A. 2004. Decadal-scale variations of water mass properties in the deep Weddell Sea, *Ocean Dynamics*, **54,** 77-91.

FAHRBACH, E., KNOCHE, M. and ROHARDT, G. 1991. An estimate of water mass transformation in the southern Weddell Sea, *Mar. Chem.,* **35**, 25-44.

FAHRBACH, E., ROHARDT, G., SCHRODER, M. and STRASS, V. 1994. Transport and structure of the Weddell Gyre, *Ann. Geophysicae*, **12**, 840-855.

FALKOWSKI, P.G. and OLIVER, M.J. 2007. Mix and match: how climate selects phytoplankton, *Nature Reviews of Microbiology,* **5**, 813-819.

FALKOWSKI, P.G., BARBER, R.T. and SMETACEK, V. 1998. Biogeochemical controls and feedbacks on ocean primary production, *Science,* **281**, 200-206.

FARMAN, J.C., GARDINER, B.G. and SHANKLIN, J.D. 1985. Large losses of total ozone in Antarctica reveal seasonal ClO_X/NO_X interaction, *Nature*, **315**, 207-210.

FASTOOK, J. and SARGENT, A. 2004. Better physics in embedded models. In *Eleventh Annual West Antarctic Ice Sheet Initiative Workshop*, Sterling, Virginia.

FEELY, R.A., BOUTIN, J., COSCA, C.E., DANDONNEAU, Y., ETCHETO, J., INOUE, H.Y., ISHII, M., LE QUERE, C., MACKEY, D.J., MCPHADEN, M., METZL, N., POISSON, A. and WANNINKHOF, R. 2002, Seasonal and interannual variability of CO2 in the equatorial Pacific, *Deep-Sea Research Part II - Topical Studies in Oceanography*, **49**, 2443-2469.

FEELY, R.A., SABINE, C.L., LEE, K., BERELSON, W., KLEYPAS, J., FABRY, V.J. and MILLERO, F.J. 2004. Impact of Anthropogenic CO_2 on the $CaCO_3$ System in the Oceans, *Science*, **305**, 362-366.

FELL, D. 2002, *Campbell Island, Land of the Blue Sunflower*. Bateman, Auckland: 143 pp.

FERRIGNO, J.G., COOK, A.J., FOLEY, K.M., WILLIAMS, R.S. JR., SWITHINBANK, C., FOX, A.J., THOMSON, J.W. and SIEVERS, J. 2006. Coastal-Change and Glaciological Maps of the Trinity Peninsula area, Antarctica: 1843-2002 *(USGS map number I-2600-A).*

FERRIGNO, J.G., WILLIAMS, R.S. JR. and THOMSON, J.W. 2002. Joint U.S. Geological Survey – British Antarctic Survey Fact Sheet FS-017-02, 2p.

FINK, D., MCKELVEY, B., HAMBREY, M.J., FABEL, D. and BROWN, R. 2006. Pleistocene Deglaciation Chronology of the Amery Oasis and Radok Lake, Northern Prince Charles Mountains, Antarctica. *Earth and Planetary Science Letters,* **243**, 229-243.

FINLAYSON-PITTS, B.J. and PITTS, J.N. 1999. Chemistry of the Upper and Lower Atmosphere, *Academic Press*.

FINNEY, B.P., GREGORY-EAVES, I., DOUGLAS, M.S.V. and SMOL, J.P. 2002. Fisheries productivity in the northeastern Pacific Ocean over the past 2,200 years, *Nature,* **416**, 729-733.

FISCHER, A.H., ROTT, H. and BJÖRNSSON, H, 2003. Observation of recent surges of Vatnajökull, Iceland, by means of ERS SAR interferometry, *Annals of Glaciology*, **37**, 69-76.

FISCHER, H., FUNDEL, F., RUTH, U., TWARLOH, B., WEGENER, A., UDISTI, R., BECAGLI, S., CASTELLANO, E., MORGANTI, A., SEVERI, M., WOLFF, E.W., LITTOT, G.C., RÖTHLISBERGER, R., MULVANEY, R., HUTTERLI, M.A., KAUFMANN, P., FEDERER, U., LAMBERT, F., BIGLER, M., HANSSON, M., JONSELL, U., DE ANGELIS, M., BOUTRON, C., SIGGAARD-ANDERSEN, M.L., STEFFENSEN, J.P., BARBANTE, C., GASPARI, V., GABRIELLI, P. and WAGENBACH, D. 2007. Reconstruction of millennial changes in dust emission, transport and regional sea ice coverage using the deep EPICA ice cores from the Atlantic and Indian Ocean sector of Antarctica, *Earth and Planetary Science Letters,* **260**, 340-354.

FISCHER, H., TRAUFETTER, F., OERTER, H., WELLER, R. and MILLER, H. 2004. Prevalence of the Antarctic Circumpolar Wave over the last two millenia recorded in Dronning Maud Land ice, *Geophys. Res. Lett.*, **31**, L08202, doi:10.1029/2003GL019186.

FISCHER-BRUNS, I., VON STORCH, H., GONZALEZ-ROUCO, J.F. and ZORITA, E. 2005. Modelling the variability of midlatitude storm activity on decadal to century time scales, *Clim. Dyn.*, **25**, 461–476.

FISHER, D.A., WAKE, C., KREUTZ, K., YALCIN, K., STEIG, E., MAYEWSKI, P., ANDERSON, L., ZHENG, J., RUPPER, S., ZDNAOWICZ, C., DEMUTH, M., WASKIEWICZ, M., DAHL-JENSEN, D., FOGT, R.L. and BROMWICH, D.H. 2006. Decadal variability of the ENSO teleconnection to the high latitude South Pacific governed by coupling with the Southern Annular Mode, *J. Climate*, **19**, 979-997.

FISHER, D.A., WAKE, C.P., KREUTZ, K.J., YALCIN, K., STEIG, E., MAYEWSKI, P.A., ANDERSON, L., ZHENG, J., RUPPER, S., ZDANOWICZ, C., DEMUTH, M., WASZKIEWICZ, M., DAHL-JENSEN, D., GOTO-AZUMA, K., BOURGEOIS, J.B., KOERNER, R.M., SEKERKA, J., OSTERBERG, E., ABBOT, M.B., FINNEY, B.P. and BURNS, S.J. 2004. Stable isotope records from Mount Logan, Eclipse ice cores and nearby Jellybean Lake. Water cycle of the North Pacific over 2000 years and over five vertical kilometers: sudden shifts and tropical connections, *Geographie Physique et Quaternaire,* **58**, 9033-9048.

FOGT R.L., PERLWITZ, J., PAWSON, S., and OLSEN, M.A. 2009a. Intra-annual relationships between polar ozone and the SAM, *Geophys. Res. Lett.*, **36**, L04707, doi:10.1029/2008GL036627.

FOGT, R.L. and BROMWICH, D.H. 2006. Decadal Variability of the ENSO Teleconnection to the High-Latitude South Pacific Governed by Coupling with the Southern Annular Mode, *J. Climate*, **19**, 979–997.

FOGT, R.L., PERLWITZ, J., MONAGHAN, A.J., BROMWICH, D.H., JONES, J.M. and MARSHALL, G.J. 2009b. Historical SAM Variability. Part II: 20th century variability and trends from reconstructions, observations, and the IPCC AR4 models, *J. Climate*, In Press.

FOLDVIK, A., GAMMELSROD, T., OSTERHUS, S., FAHRBACH, E., ROHARDT, G., SCHRODER, M., NICHOLLS, K.W., PADMAN, L. and WOODGATE, R.A. 2004. Ice shelf water overflow and bottom water formation in the southern Weddell Sea, *J. Geophys. Res.*, **109**, C02015, doi:10.1029/2003JC002008.

FONSECA, G., VANREUSEL, A. and DECRAEMER, W. 2006. Taxonomy and biogeography of *Molgolaimus* Ditlevsen, 1921 (Nematoda : Chromadoria) with reference to the origins of deep sea nematodes, *Antarct. Sci.*, **18** (1), 23-50.

FORCADA, J., TRATHAN, P.N. and MURPHY, E.J. Submitted. Life history buffering in Antarctic mammals and birds against changing patterns of climate and environmental variation, *Global Change Biol.*

FORCADA, J., TRATHAN, P.N., REID, K. and MURPHY E.J. 2005. The effects of global climate variability in pup production of Antarctic fur seals, *Ecology,* **86**, 2408–2417.

FORCADA, J., TRATHAN, P.N., REID, K., MURPHY, E.J. and CROXALL, J.P. 2006. Contrasting population changes in sympatric penguin species with climate warming, *Global Change Biology*, **12**, 411–423.

FOREMAN, C.M., WOLF, C.F. and PRISCU, J.C. 2004. Impact of episodic warming events on the physical, chemical and biological relationships of lakes in the McMurdo Dry Valleys, Antarctica, *Aquatic Geochemistry,* **10**, 239-268.

FOSTER, A.F.M., CURRAN, M.A.J., SMITH, B.T., VAN OMMEN, T.D. and MORGAN, V.I. 2006. Covariation of sea ice and methanesulphonic acid in Wilhelm II Land, East Antarctica, *Annals Glaciol.*, **44**, 429-432.

FOSTER, T.D. and CARMACK, E.C. 1976. Temperature and salinity structure in the Weddell Sea, *J. Phys. Oceanogr.,* **6**, 36–44.

FOSTER, T.D. 1987. Mixing and bottom water formation in the shelf break region of the southern Weddell Sea, *Deep-Sea Res.* **34**, 1771–1794.

FOWBERT, J.A. and SMITH, R.I.L. 1994. Rapid population increases in native vascular plants in the Argentine Islands Antarctic Peninsula, *Arctic and Alpine Research*, **26**, 290-296.

FOX, A.J. and COOPER, A.P.R. 1994. Measured properties of the Antarctic Ice Sheet derived from the SCAR Antarctic Digital Database, *Pol. Rec.*, **30**(174), 201-206.

FOX, A.J. and CZIFERSZKY, A. In press. Unlocking the time-capsule of historic aerial photography to measure changes in Antarctic Peninsula glaciers. *Photogrammetric Record,* **23** (121), 51-68.

FOX, A.J. and VAUGHAN, D.G. 2005. The retreat of Jones Ice Shelf, Antarctic Peninsula, *J. Glaciol.*, **51**(175), 555-560.

FRAM GROUP (WEBB, D.J. ET AL). 1991. An Eddy-Resolving Model of the Southern Ocean. *EOS, Transactions, American Geophysical Union*, **72**(15), 169-174.

FRANCIS, J.A. 1994. Improvements to TOVS retrievals over sea ice and applications to estimating Arctic energy fluxes, *Journal of Geophysical Research*, **99**, 10395 – 10408.

FRANCIS, J.E. and HILL, R.S. 1996. Fossil plants from the Pliocene Sirius Group, Transantarctic Mountains: evidence for climate from growth rings and fossil leaves. *Palaios,* **11**, 389-396.

FRANCIS, J.E. and POOLE, I. 2002. Cretaceous and early Tertiary climates of Antarctica : evidence from fossil wood, *Palaeogeography, Palaeoclimatology, Palaeoecology,* **182**, 47-64.

FRANCIS, J.E., ASHWORTH, A., CANTRILL, D.J., CRAME, J.A., HOWE, J., STEPHENS, R., TOSOLINI, A-M. and THORN, V. 2008a. 100 million years of Antarctic climate evolution: evidence from fossil plants. In: Cooper AK, Barrett PJ, Stagg H, Storey B, Stump E, Wise W (eds) *Antarctica: A Keystone in a Changing World. Proceedings of the 10th International Symposium on Antarctic Earth Sciences.* The National Academies Press, Washington, DC, 19-27.

FRANCIS, J.E., MARENSSI, S., LEVY, R., HAMBREY, M., THORN, V.T., MOHR, B., BRINKHUIS, H., WARNAAR, J., ZACHOS, J., BOHATY, S. and DECONTO, R. 2008b. From Greenhouse to Icehouse - The Eocene/Oligocene in Antarctica. In: Florindo F, Siegert M (eds) *Antarctic Climate Evolution, Developments in Earth and Environmental Science,* Vol **8**. Elsevier, Amsterdam.

FRASER, K.P.P., CLARKE, A. and PECK, L.S. 2002. Feast and famine in Antarctica: seasonal physiology in the limpet *Nacella concinna*, *Mar. Ecol. Prog. Ser.,* **242,** 169–177.

FRASER, W.R. and HOFMANN, E.E. 2003. A predator's perspective on causal links between climate change, physical forcing and ecosystem response, *Marine Ecology Progress Series*, **265**, 1-15.

FREDERICH, M. and PÖRTNER, H.O. 2000. Oxygen limitation of thermal tolerance defined by cardiac and ventilatory performance in the spider crab *Maja squinado*, *Amer. J. Physiol.,* **279**: R1531-R1538.

FRENOT, Y., CHOWN, S.L., WHINAM, J., SELKIRK, P., CONVEY, P., SKOTNICKI, M. and BERGSTROM, D. 2005 Biological invasions in the Antarctic: extent, impacts and implications, *Biological Reviews,* **80**, 45-72.

FRENOT, Y., CONVEY, P., LEBOUVIER, M., CHOWN, S.L., WHINAM, J., SELKIRK, P.M., SKOTNICKI, M. and BERGSTROM, D.M. 2008. Antarctic biological invasions: sources, extents, impacts and implications. *Non-native species in the Antarctic Proceedings*, ed. M. Rogan-Finnemore, 53-96. Gateway Antarctica, Christchurch, New Zealand.

FRENOT, Y., GLOAGUEN, J.-C. and TRÉHEN, P. 1997. Climate change in Kerguelen Islands and colonization of recently deglaciated areas by Poa kerguelensis and P. annua. In: Battaglia, B., Valencia, J., Walton, D.W.H. (Eds.), *Antarctic Communities. Species, Structure and Survival.* Cambridge University Press, Cambridge, 358–366.

FRENOT, Y., GLOAGUEN, J.-C., PICOT, G., BOUGÈRE, J. and BENJAMIN, D. 1993. Azorella selago Hook used to estimate glacier fluctuations and climatic history in the Kerguelen Islands over the last two centuries, *Oecologia,* **95**, 140–144.

FREZZOTTI, M. and POLIZZI, M. 2002. 50 years of ice-front changes between the Adélie and Banzare Coasts, East Antarctica, *Annals of Glaciology*, **34**, 235-240.

FREZZOTTI, M. AND 13 OTHERS 2005. Spatial and temporal variability of snow accumulation in East Antarctica from traverse data. *J. Glaciol.,* **51**(172), 113–124.

FREZZOTTI, M., GANDOLFI, S. and URBINI, S. 2002. Snow megadune in Antarctica: Sedimentary structure and genesis, *J. Geophys. Res*. **107** (D18) 4344, doi:10.1029/2001JD000673.

FREZZOTTI, M., POURCHET, M., FLORA, O., GANDOLFI, S., GAY, M., URBINI, S., VINCENT, C., BECAGLI, S., GRAGNANI, R., PROPOSITO, M., SEVERI, M., TRAVERSI, R., UDISTI, R. and FILY, M. 2004. New estimations of precipitation and surface sublimation in East Antarctica from snow accumulation measurements, *Climate Dynamics,* **23**, 803-813.

FRICKER, H., WARNER, R. and ALLISON, I. 2000. Mass balance of the Lambert Glacier–Amery Ice shelf system, East Antarctica: a comparison of computed balance fluxes and measured fluxes, *J. Glaciol*., **46** (155), 561–570.

FRICKER, H.A., SCAMBOS, T.A., BINDSCHADLER, R. and PADMAN, L. 2007. An Active Subglacial Water System in West Antarctica Mapped from Space, *Science*, **315**, 1544, doi: 10.1126/science.1136897.

FRICKER, H.A., YOUNG, N.W., ALLISON, I. and COLEMAN, R. 2002. Iceberg calving of the Amery Ice Shelf, East Antarctica: New field and remote sensing data, *Annals of Glaciology*, **34**, 81-88.

FRICKER, H.A., YOUNG, N.W., COLEMAN, R., BASSIS, J.N. and MINSTER, J.-B. 2005. Multi-year monitoring of rift propagation on the Amery Ice Shelf, East Antarcitca, *Geophysical Research Letters,* **32**, L02502, doi:10.1029/2004GL021036.

FRIEDLINGSTEIN, P., COX, P., BETTS, R., BOPP, L., VON BLOH, W., BROVKIN, V., CADULE, P., DONEY, S., EBY, M., FUNG, I., BALA, G., JOHN, J., JONES, C., JOOS, F., KATO, T., KAWAMIYA, M., KNORR, W., LINDSAY, K., MATTHEWS, H.D., RADDATZ, T., RAYNER, P., REICK, C., ROECKNER, E., SCHNITZLER, K. G., SCHNUR, R., STRASSMANN, K., WEAVER, A.J., YOSHIKAWA, C. AND ZENG, N. 2006. Climate-carbon cycle feedback analysis: Results from the C4MIP model intercomparison, *Journal of Climate*, **19**, 3337-3353.

FRITSEN, C.H., ACKLEY, S.F., KREMER, J.N. and SULLIVAN, C.W. 1998. Flood-freeze cycles and microalgal dynamics in Antarctic pack ice. In: Lizotte MP, Arrigo K (eds) *Antarctic sea ice: biological processes, interactions and variability*, vol 73. American Geophysical Union, Washington, DC, 1–21.

FUJII, Y., YAMANOUCHI, T., SUZUKI, K. and TANAKA, S. 1987. Comparison of the surface conditions of the inland ice sheet, Dronning Maud Land, Antarctica, derived from NOAA/ AVHRR data with ground observation, *Annals of Glaciology*, **9**, 72-75.

FULFORD-SMITH, S.P. and SIKES, E.L. 1996. The evolution of Ace Lake, Antarctica, determined from sedimentary diatom assemblages, *Palaeogeography Palaeoclimatology Palaeoecology,* **124**, 73-86.

FUNDEL, F., FISCHER, H., WELLER, R., TRAUFETTER, F., OERTER, H. and MILLER, H. 2006. Influence of large-scale teleconnection patterns on methane sulfonate ice core records in Dronning Maud Land, *Journal of Geophysical Research,* **111**, D04103.

FUOCO, R., COLOMBINI, M. P., CECCARINI, A. and ABETE, C. 1996. Polychlorobiphenyls in Antarctica, *Microchemical Journal,* **54**, 384-390.

FURUKAWA, T., KAMIAYAMA, K. and MAENO, H. 1996. Snow surface features along the traverse route from the coast to Dome Fuji Station, Queen Maud Land, Antarctica, *Proc. NIPR Symp. Polar Meteorol, Glaciol.*, **10**, 13-24.

FYFE, J.C. and LORENZ, D. 2005. Characterizing midlatitude jet variability: Lessons from a simple GCM, *Journal of Climate*, **18**, 3400-3404.

FYFE, J.C. and SAENKO, O. 2005. Human induced change in the Antarctic Circumpolar Current, *J. Clim.,* **18**, 3068-3073.

FYFE, J.C. and SAENKO, O.A. 2006. Simulated changes in extratropical Southern Hemisphere winds and currents, *Geophys. Res. Letters*, **33**, L06701, doi:10.1029/2005GL025332.

FYFE, J.C. 2003. Extratropical southern hemisphere cyclones: Harbingers of climate change? *J. Climate*, **16**, 2802–2805.

FYFE, J.C. 2006. Southern Ocean warming due to human influence, *Geophys. Res. Let.,* **33,** L19701, doi:10.1029/2006GL027247 .

FYFE, J.C., BOER, G.J. and FLATO, G.M. 1999. The Arctic and Antarctic oscillations and their projected changes under global warming, *Geophys. Res. Lett*., **26**, 1601-1604.

GAMBI, M.C. and BUSSOTTI, S. 1999. Composition, abundance and stratification of soft-bottom macrobenthos from selected areas of the Ross Sea shelf (Antarctica). *Polar Biol* **21**: 347-354

GARDINER, B.G. and SHANKLIN, J.D. 1989. Measurements of solar and terrestrial radiation at Faraday and Halley, British Antarctic Survey Report, ISBN 0-85665-139-7.

GARRISON, D.L. and BUCK, K.R. 1989. Protozooplankton in the Weddell Sea, Antarctica: abundance and distribution in the ice-edge zone, *Polar Biology*, **9**, 341–351.

GARRISON, D.L. and BUCK, K.R. 1989. The biota of Antarctic pack ice in the Weddell sea and Antarctic peninsula regions, *Polar Biol.,* **10,** 211-219.

GARRISON, D.L. and BUCK, K.R. 1991. Surface-layer sea ice assemblages in Antarctic pack ice during the austral spring: Environmental conditions, primary production and community structure, *Marine Ecology Progress Series,* **75**, 161-172.

GARRISON, D.L. 1991. Antarctic sea ice biota, *Am. Zool.,* **31,** 17-33.

GARRISON, D.L., CLOSE, A.R. and REIMNTZ, A. 1989. Algae concentrated by frazil ice: evidence from laboratory and field measurements, *Antarctic Sci.,* **1,** 313-316.

GASPAR, P., GREGORIS, Y., and LEFEVRE, J.-M. 1990. A simple eddy kinetic energy model for stimulations of the oceanic vertical mixing: tests at station Papa and Long-Term Upper Ocean Study Site, *Journal of Geophysical Research*, **95**, 16179-16193.

GENT, P.R, WILLEBRAND, J., MCDOUGALL, T.J. and MCWILLIAMS, J.C. 1995. Parameterizing eddy-induced tracer transports in ocean circulation models, *Journal of Physical Oceanography*, **25**, 463–474.

GENT, P.R. and MCWILLIAMS, J.C. 1990. Isopycnal mixing in ocean circulation models, *Journal of Physical Oceanography*, **20**, 150–155.

GENTHON C., KRINNER, G. and CASTEBRUNET, H. 2008. Antarctic precipitation and climate change in the IPCC models: Horizontal resolution and margin vs plateau issues, *Annals of Glaciology, in press*.

GENTHON, C. and COSME, E. 2003. Intermittent signature of ENSO in west-Antarctic precipitation, *Geophys. Res. Lett.*, **30**, 2081, doi:10.1029/2003GL018280.

GENTHON, C. and KRINNER, G. 1998. Convergence and disposal of energy and moisture on the Antarctic polar cap from ECMWF reanalyses and forecasts, *J. Climate*, **11**, 1703-1716.

GENTHON, C. and KRINNER, G. 2001. Antarctic surface mass balance and systematic biases in general circulation models, *J. Geophys. Res.*, **106**, 20653-20664.

GENTHON, C., 2004: Space-time Antarctic surface mass-balance variability from climate models, *Ann. Glaciol.*, **39**, 271–275.

GENTHON, C., KASPARI, S. and MAYEWSKI, P.A. 2005. Inter-annual variability of surface mass balance in West Antarctica from ITASE cores and ERA40 reanalyses, *Climate Dynamics,* **21**, DOI10.1007/s00382-003-0329-1.

GENTHON, C., KRINNER, G. and SACCHETTINI, M. 2003. Interannual Antarctic tropospheric circulation and precipitation variability, *Clim. Dyn.,* **21**, 289-307.

GENTILE, G., GIULIANO, L., D'AURIA, G., SMEDILE, F., AZZARO, M., DE DOMENICO, M. and YAKIMOV, M.M. 2006. Study of bacterial communities in Antarctic coastal waters by a combination of 16S rRNA and 16S rDNA sequencing, *Environ. Microbiol.,* **8**, 2150-2161.

GERIGHAUSEN, U., BRÄUTIGAM, K., MUSTAFA, O. and PETER, H-U. 2003. Expansion of vascular plants on Antarctic Islands a consequence of climate change? In: *Antarctic Biology in a Global context* (eds Huiskes, AHL, Gieskes WWC, Rozema J, Schorno RML, van der Vies SM, Wolff WJ), 79-83, Backhuys, Leiden.

GERSONDE, R., CROSTA, X., ABELMANN, A. and ARMAND, L. 2005. Sea-surface temperature and sea ice distribution of the Southern Ocean at the EPILOG Last Glacial Maximum-a circum-Antarctic view based on siliceous microfossil records, *Quaternary Science Reviews,* **24**, 869-896.

GIBSON, J.A.E. and BAYLY, I.A.E. 2007. New insights into the origins of crustaceans of Antarctic lakes, *Antarctic Science,* **19**, 157–164.

GIBSON, J.A.E. and ZALE, R. 2006. Holocene development of the fauna of Lake Boeckella, northern Antarctic Peninsula, *The Holocene*, **16**, 625-634.

GILBERT, R., NIELSEN, N., MOLLER, H., DESLOGES, J.R. and RASCH, M. 2002. Glacimarine sedimentation in Kangerdluk (Disko Fjord) West Greenland, in response to a surging glacier, *Mar. Geol.,* **191**, 1-18.

GILES, K.A., LAXON, S.W. and WORBY, T. 2006. Validating Satellite Radar Altimetry Estimates of Antarctic sea ice Thickness Using the ASPeCt Data set, *Proceedings of 2006 American Geophysical Union Fall Meeting*.

GILI, J-M., ARNTZ, W.E., PALANQUES, A., OREJAS, C., CLARKE, A., DAYTON, P., ISLA, E., TEIXIDÓ, ROSSI, S. and LÓPEZ-GONZALES, P.J. 2006. A unique assemblage of epibenthic sessile suspension feeders with archaic features in the high-Antarctic, *Deep-Sea Res. II,* **53**, 1029-1052.

GILICHINSKY, D.A., WILSON, G.S. AND 21 OTHER AUTHORS. 2007. Microbial populations in Antarctic permafrost: biodiversity, state, age, and implications for astrobiology, *Astrobiology,* **7**, 275-311.

GILLE, S.T. and SANDWELL, D.T. 2001. Gravity, Bathymetry, and Mesoscale Ocean Circulation from Altimetry, *AVISO newsletter*, **8**, September.

GILLE, S.T. 2002. Warming of the Southern Ocean since the 1950s, *Science,* **295**(5558), 1275-1277, doi:10.1126/science.1065863.

GILLE, S.T. 2008. Decadal-scale temperature trends in the Southern Hemisphere ocean, *J. Clim.*, **21**(18), 4749-4765.

GILLE, S.T., STEVENS, D.P., TOKMAKINA, R.T. and HEYWOOD, K.J. 2001. Antarctic Circumpolar Current response to zonally averaged winds. *J. Geophys. Res.*, **106(**C2), 2743-2760.

GILLE, S.T., YALE, M.M. and SANDWELL, D.T. 2000. Correlation of mesoscale ocean variability with seafloor roughness from satellite altimetry, *Geophys. Res. Lett.*, **27**, 1251-1254.

GILLETT, N.P., STONE, D.A., STOTT, P.A., NOZAWA, T., KARPECHKO, A.Y., HEGERL, G.C., WEHNER, M.F. and JONES, P.D. 2009. Attribution of polar warming to human influence, *Nature Geoscience,* **1**, 760-764.

GIORDANO, D., BOECHI, L., VERGARA, A., MARTÍ, M.A., SAMUNI, U., DANTSKER, D., GRASSI, L., ESTRIN, D.A., FRIEDMAN, J.M., MAZZARELLA, L., DI PRISCO, G. and VERDE, C. 2009. The hemoglobins of the sub-Antarctic fish *Cottoperca gobio,* a phyletically basal species. Oxygen-binding equilibria, kinetics and molecular dynamics, *FEBS J.,* **267**, 2266-2277.

GIORDANO, D., PARRILLI, E., DETTAÏ, A., RUSSO, R., BARBIERO, G., MARINO, G., LECOINTRE, G., DI PRISCO, G., TUTINO, L. and VERDE, C. 2007. The truncated hemoglobins in the Antarctic psychrophilic bacterium *Pseudoalteromonas haloplanktis* TAC125, *Gene,* **398**, 143-155.

GIORDANO, D., RUSSO, R., COPPOLA, D., DI PRISCO, G. and VERDE, C. 2009b. Molecular adaptation in hemoglobins of notothenioid fishes, *J. Fish Biol.,* (invited review, submitted).

GIOVINETTO, M.B. and BENTLEY, C.R. 1985. Surface balance in ice drainage systems of Antarctica, *Ant. J. U. S.*, **20**, 6-13.

GIOVINETTO, M.B. and ZWALLY, H.J. 2000. Spatial distribution of net surface accumulation on the Antarctic ice sheet, *Ann. Glaciol.,* **31**, 171–178.

GIOVINETTO, M.B., YAMAZAKI, K., WENDLER, G. and BROMWICH, D.H. 1997. Atmospheric net transport of water vapor and latent heat across 60 degrees S, J. *Geophys. Res.,* **102**, 11171-11179.

GLASSER, N. and SCAMBOS, T.A. 2008. A structural glaciological analysis of the 2002 Larsen B ice shelf collapse, *Journal of Glaciology,* **54** (184), 3-16.

GLOERSEN, P. and WHITE, W.B. Reestablishing the circumpolar wave in sea ice around Antarctica from one winter to the next, *J. Geophys. Res*., **106**, 4391–4395, 2001.

GLOERSEN, P. 1995. Modulation of hemispheric ice cover by ENSO events, *Nature*, **373**, 503-505.

GLOERSEN, P., CAMPBELL, W.J., CAVALIERI, D.J., COMISO, J.C., PARKINSON, C.L. and ZWALLY, H.J. 1992. Arctic and Antarctic Sea Ice, 1978-1987, 290 pp, Washington, DC, NASA.

GNANADESIKAN, A., GRIFFIES, S.M. and SAMUELS, B.L. 2007. Effects in a climate model of slope tapering in neutral physics schemes, *Ocean Modelling*, **16**, 1-16.

GNANDADESIKAN, A. and HALLBERG, R.W. 2000. On the relationship of the circumpolar current to southern hemisphere winds in coarse-resolution ocean models, *J. Phys. Oceanogr*., **30**, 2013-2034.

GOERKE, H.., WEBER, K., BORNEMANN, H., RAMDOHR, S. and PLÖTZ, J. 2004. Increasing levels and biomagnification of persistent pollutants (POPs) in Antarctic biota, *Mar. Pollut. Bull.,* **48**, 295-302.

GONG, D. and WANG, S. 1999. Definition of Antarctic Oscillation index, *Geophys. Res. Lett.*, **26**, 459–462.

GONZALEZ-CABRERA, J.J., DOWD, F., PEDIBHOTLA, V.K., ROSARIO, R., STANLEY-SAMUELSON, D. and PETZEL, D. 1995. Enhanced hypo-osmoregulation induced bt warm acclimation in Antarctic fish is mediated by increased gill and kidneyNa^+/K^+-ATPase activities, *J. Exp. Biol.,* **198**, 2279-2291.

GOODWIN, I., DE ANGELIS, M., POOK, M. and YOUNG, N.W. 2003. Snow accumulation variability in Wilkes Land, East Antarctica and the relationship to atmospheric ridging in the 130° to 170° E region since 1930, *Journal of Geophysical Research,* **108**, D21, 4673, doi:10.1029/2002JD002995.

GOODWIN, I.D. 1993. Holocene deglaciation, sea-level change, and the emergence of the Windmill Islands, Budd Coast, Antarctica, *Quaternary Research,* **40**, 70-80.

GOODWIN, I.D. 1996. A mid to late Holocene re advance of the Law Dome ice margin, Budd Coast, East Antarctica, *Antarctic Science,* **8**, 395-406.

GOODWIN, I.D., VAN OMMEN, T.D., CURRAN, M.A.J. and MAYEWSKI, P.A. 2004a. Mid latitude winter climate variability in the south Indian and south-west Pacific regions since 1300 AD, *Climate Dynamics,* **22**, 783-794, DOI:10.1007/S00382-*004-0403-3.*

GOOSSE, H. and RENSSEN, H. 2001. A two-phase response of Southern Ocean to an increase in greenhouse gas concentrations, *Geophysical Research Letters,* **28**, 3469-3473.

GOOSSE, H., LEFEBVRE, W., DE MONTETY, A., CRESPIN, E. and ORSI, A. 2009. Consistent past half-century trends in the atmosphere, the sea ice and the ocean at high southern latitudes, *Climate Dynamics,* DOI 10.1007/s00382-008-0500-9.

GOOSSE, H., MASSON-DELMOTTE, V., RENSSEN, H., DELMOTTE, M., FICHEFET, T., MORGAN, V., VAN OMMEN, T., KHIM, B.K. and STENNI, B. 2004. A late medieval warm period in the Southern Ocean as a delayed response to external forcing? *Geophysical Research Letters,* **31**, L06203, doi:06210.01029/02003GL019140.

GORDON, A.L. 1978. Weddell Polynya, Gyre and Deep-Water Convection, *Transactions-American Geophysical Union*, **59**(4), 292-292.

GORDON, A.L., MARTINSON, D.G. and TAYLOR, H.W. 1981. The wind-driven circulation in the Weddell-Enderby Basin, *Deep-Sea Res*., **28**, 151-163.

GORDON, A.L., VISBECK, M. and COMISO, J.C. 2007. A possible link between the Weddell Polynya and the Southern Annular Mode, *Journal of Climate*, **20**(11), 2558-2571.

GORDON, C., COOPER, C., SENIOR, C.A., BANKS, H., GREGORY, J.M., JOHNS, T.C., MITCHELL, J.F.B. and WOOD, R.A. 2000. The simulation of SST, sea ice extents and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments, *Clim. Dyn.,* **16**, 147-168.

GORDON, D.A., PRISCU, J. and GIOVANNONI, S. 2000. Origin and phylogeny of microbes living in permanent Antarctic lake ice, *Microb. Ecol.* **39**, 197-202.

GORDON, J.E., HAYNES, V.M. and HUBBARD, A. 2008. Recent glacier changes and climate trends on South Georgia, *Global and Planetary Change,* **60**, 72-84.

GORDON, A. L., ZAMBIANCHI, E., ORSI, A., VISBECK, M., GIULIVI, C. F., WHITWORTH III, T. and SPEZIE, G. 2004. Energetic plumes over the western Ross Sea continental slope, *Geophys. Res. Lett*., **31***,* doi: 10.1029/2004GL020785.

GORE, D.B. 1997. Blanketing snow and ice; constraints on radiocarbon dating deglaciation in East Antarctic oases, *Antarctic Science,* **9**, 336-346.

GORE, D.B., RHODES, E.J., AUGUSTINUS, P.C., LEISHMAN, M.R., COLHOUN, E.A. and REES-JONES, J. 2001. Bunger Hills, East Antarctica: Ice free at the Last Glacial Maximum, *Geology,* **29**, 1103-1106.

GORING, D.G. and PYNE, A. 2003. Observations of sea-level variability in Ross Sea, Antarctica, *New Zealand Journal of Marine and Freshwater Research*, **37**, 241-249.

GOURETSKI, V. 1999. The large-scale thermohaline structure of the Ross Gyre, In: Eds G. Spezie and G.M.R. Manzella, *Oceanography of the Ross Sea Antarctica*, Springer-Verlag Italia, Milano, 77-100.

GOURETSKI, V.V. and DANILOV, A.I. 1993. Weddell Gyre: Structure of the eastern boundary, *Deep Sea Res*., *Part I*, **40**, 561–582.

GRAF, W., OERTER, H., REINWARTH, O., STICHLER, W., WILHELMS, F., MILLER, H. and MULVANEY, R. 2002. Stable isotope records from Dronning Maud Land, Antarctica, *Annals of Glaciology*, **35**, 195–201.

GRANNAS, A.M. AND 34 OTHERS. 2007. An overview of snow photochemistry: evidence, mechanisms and impacts, *Atmos. Chem. Phys. Discuss*., **7**, 4165-4283.

GRANT, S., CONSTABLE, A., RAYMOND, B. and DOUST, S. 2006. Bioregionalisation of the Southern Ocean, *Report of Experts Workshop, Hobart, September 2006*. WWF-Australia and ACE CRC.

GRAY, J.S. 2001. Antarctic marine benthic diversity in a world-wide context, *Polar Biol.,* **24**, 473-485.

GRAY, L., JOUGHIN, I., TULAZCYK, S., SPIKES, V.B., BINDSCHADLER, R. and JEZEK, K. 2005. Evidence for subglacial water transport in the West Antarctica Ice Sheet through three-dimensional satellite radar interferometry, *Geophysical Research Letters*, **32**, L03501, doi:10.1029/2004GL021387,.

GRAY, L.; SHORT, N.; BINDSCHADLER, R.; JOUGHIN, I.; PADMAN, L.; VORNBERGER, P.; KHANANIAN, A. 2002. Radarsat interferometry for Antarctic grounding-zone mapping, *Annals of Glaciology*, **34**, 269-276.

GREENSLADE, P. 2006: *The Invertebrates of Macquarie Island*. Australian Antarctic Division, Kingston, Tasmania, xvi, 326 pp.

GREGG, W.W. and CONKRIGHT, M.E. 2002. Decadal changes in global ocean chlorophyll, *Geophys. Res. Lett.,* **29**, 21-24.

GREGORY, J. and HUYBRECHTS, P. 2006. Ice-sheet contributions to future sea-level change, *Philosophical Transactions of the Royal Society A***,** 1709-1731.

GREGORY, J.M., 2000. Vertical heat transport in the ocean and their effect on time-dependent climate change, *Clim. Dyn*., **16**, 501-515.

GRESSITT, J.L. (ed.). 1970. Subantarctic entomology, particularly of South Georgia and Heard Island, *Pacific Insects Monograph,* **23**, 1-374.

GREZIO, A., WELLS, N.C., IVCHENKO, V.O. and DE CUEVAS, B.A. 2005. Dynamical budgets of the Antarctic Circumpolar Current using ocean general-circulation models, *Quart. J. Roy. Met. Soc*., **131**(607), 833-860.

GRIESHABER, M.K., HARDEWIG, I., KREUTZER, U. and PÖRTNER, H.O. 1994. Physiological and metabolic responses to hypoxia in invertebrates, *Rev. Physiol. Biochem. Pharmacol.,* **125**, 43-147.

GRIFFIES, S.M. 1998. The Gent–McWilliams Skew Flux, *Journal of Physical Oceanography*, **28**, 831-841.

GRIFFIES, S.M. 2006. Some ocean model fundamentals. in: *Ocean Weather Forecasting: an integrated view of Oceanography*. E. P. Chassignet and J. Verron, eds., Berlin, Germany: Springer, 19-74.

GRIFFIES, S.M., BONING, C., BRYAN, F.O., CHASSIGNET, E.P., GERDES, R., HASUMI, H., HURST, A., TREGUIER, A-M, and WEBB, D.J. 2000. Developments in ocean climate modelling, *Ocean Modelling*, **2**, 123-192.

GRIFFIES, S.M., GNANADESIKAN, A., DIXON, K.W., DUNNE, J.P., GERDES, R., HARRISON, M.J., ROSATI, A., RUSSELL, J.L., SAMUELS, B. L., SPELMAN, M.J., WINTON, M. and ZHANG, R. 2005. Formulation of an ocean model for global climate simulations, *Ocean Science*, **1**, 45-79.

GRIFFIES, S.M., HARRISON, M.J., PACANOWSKI, R.C. and ROSATI, A. 2004. A technical guide to MOM4. GFDL ocean group technical report No. 5. NOAA/Geophysical Fluid Dynamics Laboratory, Princeton, USA.

GRIFFITHS, H.J., BARNES, D.K.A. and LINSE, K. 2009. Towards a generalized biogeography of the Southern Ocean benthos, *Journal of Biogeography*, **36**, 162-177.

GRIFFITHS, H.J., LINSE, K. and CRAME, J.A. 2003. SOMBASE – Southern Ocean Mollusc Database: a tool for biogeographic analysis in diversity and ecology, *Organisms Diversity and Evolution,* **3**, 207–213.

GROBE, C.W., RUHLAND C.T. and DAY T.A. 1997. A new population of *Colobanthus quitensis* near Arthur Harbor, Antarctica: correlating recruitment with warmer summer temperatures, *Arctic and Alpine Research,* **29**, 217-221.

GROOTES, P.M. and STUIVER, M. 1997. Oxygen 18/16 variability in Greenland snow and ice with 10^3 to 10^5-year time resolution, *Journal of Geophysical Research,* **102**, 26455-26470.

GRZYMSKI, J.J., CARTER, B.J., DELONG, E.F., FELDMAN, R.A., GHADIRI, A. and MURRAY, A. E. 2006. Comparative genomics of DNA fragments from six antarctic marine planktonic bacteria, *Appl. Environ. Microbiol.,* **72**, 1532-1541.

GUDMUNDSSON, G.H. 2006. Fortnightly variations in the flow velocity of Rutford Ice Stream, West Antarctica, *Nature,* **444**, 1063-1064 doi:10.1038/nature05430.

GUGLIELMIN, M. 2004. Observations on permafrost ground thermal regimes from Antarctica and the Italian Alps, and their relevance to global climate change, *Global and Planetary Change,* **40**, 159-167.

GUGLIELMIN, M. 2006. Ground surface temperature (GST), active layer, and permafrost monitoring in continental Antarctica. *Permafrost and Periglacial Processes*, **17**, 133-143.

GUGLIELMIN, M. 2007, in prep. Permafrost cooling in Continental Antarctica.

GUGLIELMIN, M., BALKS, M. and PAETZOLD, R. 2003. Towards an Antarctic active layer and permafrost monitoring network. In: Phillips, M., S.M. Springman, and L. Arenson (eds.) *Proceedings of the 8th International Conference on Permaforst, Zurich, Switzerland, 21-25 July 2003*. Balkema Publishers, Lisse, 337-341.

GUGLIELMIN, M., ELLIS EVANS, C.J. and CANNONE, N. 2007 Active layer thermal regime under different vegetation conditions in permafrost areas. A case study at Signy Island (Maritime Antarctica), *Geoderma*, In Press.

GUO, Z., BROMWICH, D.H. and CASSANO, J.J. 2003. Evaluation of Polar MM5 simulations of Antarctic atmospheric circulation, *Mon. Wea. Rev.,* **131**, 384-411.

GUO, Z., BROMWICH, D.H. and HINES, K.M. 2004. Modeled Antarctic precipitation. Part II: ENSO signal over West Antarctica, *J. Climate,* **17**, 448-465.

GUTT ET AL. 2008. The Expedition ANTARKTIS-XXIII/8 of the Research Vessel “Polarstern” in 2006/2007. *Ber. Polarforsch. Meeresforsch*. **569**, 152 pp.

GUTT, J. 2000. Some “driving forces” structuring communities of the sublittoral Antarctic macrobenthos, *Antarctic Sci.,* **12** (3), 297-313.

GUTT, J. and PIEPENBURG, D. 1991. Dense aggregations of three deep-sea holothurians in the southern Weddell Sea, Antarctica, *Mar. Ecol. Prog. Ser.,* **68**, 277-285.

GUTT, J. and PIEPENBURG, D. 2003. Scale-dependent impact on diversity of Antarctic benthos caused by grounding of icebergs, *Mar. Ecol. Prog. Ser.*, **253**, 77-83

GUTT, J. and STARMANS, A. 2001. Quantification of iceberg impact and benthic recolonisation patterns in the Weddell Sea (Antarctica), *Polar Biol.,* **24**, 615-619.

GUTT, J. 2006. Coexistence of macro-zoobenthic species on the Antarctic shelf: An attempt to link ecological theory and results*, Deep-Sea Res. II,* **53**, 1009-1028.

GUTT, J. 2007. Antarctic macro-zpoobenthic communities: a review and an ecological classification, *Antarctic Sci.,* **109** (2), 165-182.

GUTT, J., GERDES, D. and KLAGES, M. 1992. Seasonality and spatial variability in the reproduction of two Antarctic holothurians (Echinodermata), *Polar Biol.,* **11**, 533-544.

GUTT, J., KOUBBI, P. and ELÉAUME, M. 2007. Mega-epibenthic diversity off Terre Adélie (Antarctica) in relation to disturbance, *Polar Biol.,* **30**, 1323-1329.

GUTT, J., SIRENKO, B.I., SMIRNOV, I.S. and ARNTZ, W.E. 2004. How many macrobenthic species might inhabit the Antarctic shelf? *Antarct. Sci.,* **16**, 11-16.

GUTT, J., STARMANS, A. and DIECKMANN, G. 1998. Phytodetritus deposited on the Antarctic shelf and upper slope: its relevance for the benthic system, *J. Mar. Syst.,* **17**, 435-444.

GUTZMANN, E., MARTÍNEZ ARBIZU, P., ROSE, A. and VEIT-KÖHLER, G. 2004. Meiofauna communities along an abyssal depth gradient in the in the Drake Passage, *Deep-Sea Res .II*, **51** (14-16), 1617-1628.

GWYNN-JONES, D., LEE, J.A., JOHANSON, U., PHOENIX, G.K., CALLAGHAN, T.V., and SONESSON, M. 1999. The response of plant functional types to enhanced UV-B radiation. *In* Rozema, J. *ed. Stratospheric Ozone Depletion: the effects of enhanced UV-B radiation on terrestrial ecosystems.* Leiden, Netherlands: Backhuys Publishers, 173–185.

HAIDVOGEL, D.B., WILKIN, J.L. and YOUNG, R.E. 1991. A semi-spectral primitive equation ocean circulation model using vertical sigma and orthogonal curvilinear horizontal coordinates, *Journal of Computational Physics*, **94**, 151–185.

HALES, B. and TAKAHASHI, T. 2007. High-resolution biogeochemical investigation of the Ross Sea, Antarctica, during the AESOPS (U.S. JGOFS) Program, *Global Biogeochemical Cycles,* **18**, GB3006, doi:10.1029/2003GB002165.

HALL, A AND VISBECK, M. 2002. Synchronous variability in the southern hemisphere atmosphere, sea ice, and ocean resulting from the annular mode, *Journal of Climate,* **15**(21), 3043-3057.

HALL, B.L. and DENTON, G.H. 2000. Extent and Chronology of the Ross Sea Ice Sheet and the Wilson Piedmont Glacier Along the Scott Coast at and Since the Last Glacial Maximum, *Geografiska Annaler Series a-Physical Geography,* **82A**, 337-363.

HALL, B.L. and DENTON, G.H. 1995. Late Quaternary lake levels in the Dry Valleys, Antarctica, *Antarctic Journal of the United States,* **30**, 52-53.

HALL, B.L. and DENTON, G.H. 2002. Holocene history of the Wilson Piedmont Glacier along the southern Scott Coast, Antarctica, *The Holocene*, **12**, 619-627.

HALL, B.L., BARONI, C. and DENTON, G.H. 2003. Holocene relative sea-level history of the southern Victoria Land coast, Antarctica, *Global and Planetary Change*, **42**, 241-263.

HALL, B.L., DENTON, G.H. and HENDY, C.H. 2000. Evidence from Taylor Valley for a Grounded Ice Sheet in the Ross Sea, Antarctica, *Geografiska Annaler*, **82A**, 275-303.

HALL, B.L., DENTON, G.H. and OVERTURF, B. 2001. Glacial Lake Wright, a high-level Antarctic lake during the LGM and early Holocene, *Antarctic Science,* **13**, 53-60.

HALL, B.L., HOELZEL, A.R., BARONI, C., DENTON, G.H., LE BOEUF, B.J., OVERTURF, B. and TOPF, A.L. 2006. Holocene Elephant Seal Distribution Implies Warmer-Than-Present Climate in the Ross Sea, *Proceedings of the National Academy of Sciences of the United States of America,* **103**, 10213-10217.

HALLBERG, R. and GNANADESIKAN, A. 2006. The role of eddies in determining the structure and response of the wind-driven Southern Hemisphere overturning: Initial results from the Modelling Eddies in the Southern Ocean project, *J. Phys. Oceanogr.*, **36**, 3312-3330.

HALLBERG, R.W. 1997. Stable split time stepping schemes for large-scale ocean modelling, *Journal of Computational Physics,* **135**, 54-6.

HAMBREY, M.J., GLASSER, N.F., MCKELVEY, B.C., SUGDEN, D.E. and FINK, D. 2007. Cenozoic Landscape Evolution of an East Antarctic Oasis (Radok Lake Area, Northern Prince Charles Mountains), and Its Implications for the Glacial and Climatic History of Antarctica, *Quaternary Science Reviews,* **26**, 598-626.

HAMILTON, G.S. 2005. Spatial patterns in mass balance of the Siple Coast and Amundsen Sea sectors, West Antarctica, *Ann. Glaciol.,* **41**, 105-106.

HAMMER, C.U., CLAUSEN, H.B. and LANGWAY, C.C.J. 1994. Electrical conductivity method (ECM) stratigraphic dating of the Byrd Station ice core, Antarctica, *Annals of Glaciology,* **20**, 115-120.

HANAWA, K AND TALLEY, L.D. 2001. Mode Waters. In: Eds. G. Siedler, J. Church and J. Gould, Ocean circulation and climate; observing and modelling the global ocean, *International Geophysics Series,* **77**, 373-386, Academic Press.

HANSEN, J., SATO, M., RUEDY, R., LO, K., LEA, D.W. and MEDINA-ELIZADE, M. 2006. Global temperature change, *Proc. Natl. Acad. Sci.,* **103**, 14288-14293.

HANSEN, J.E. 2005. A slippery slope: how much global warming constitutes "dangerous anthropogenic interference?", *Climatic Change,* **68**, 269-279.

HANSOM, J.D. and FLINT, C.P. 1989. Holocene ice fluctuations on Brabant Island, Antarctic Peninsula. Cambridge Journals Online, 165-166.

HANSOM, J.D. 1981. Storm surging in South Geogia, *British Antarctic Survey Bulletin*, **53**, 141-146.

HARDY, A. 1967. Great waters. Harper and Row, New York, 542 pp.

HARRIS, P.T. and O'BRIEN, P.E. 1996. Geomorphology and sedimentology of the continental shelf adjacent to Mac. Robertson Land, East Antarctica: a scalped shelf, *Geo-Marine Lett.,* **16**, 287-296.

HART, T.J. 1934. On the phytoplankton of the South-West Atlantic and the Bellinghausen Sea, 1929-31, *Discovery Reports,* **8**, 1-268.

HARTMANN, D.L., WALLACE, J.M., LIMPASUVAN, V., THOMPSON, D.W.J. and HOLTON, J.R. 2000. Can ozone depletion and global warming interact to produce rapid climate change?, *Proc. Natl. Acad. Sci. U.S.A.*, **97**, 1412–1417.

HARWOOD, D.M., MCMINN, A. and QUILTY, P.G. 2000. Diatom biostratigraphy and age of the Pliocene Sorsdal Formation, Vestfold Hills, East Antarctica, *Antarctic Science,* **12**, 443-462.

HAUCK, C., G. VIEIRA, S. GRUBER, J.J. BLANCO and M. RAMOS. 2007. Geophysical identification of permafrost in Livingston island, maritime Antarctica, *J. Geophys. Res*., doi:10.1029/2006JF0005444, in press.

HAUG, G.H., HUGHEN, K.A., SIGMAN, D.M., PETERSON, L.C. and RÖHL, U. 2001. Southward migration of the Intertropical Convergence Zone through the Holocene, *Science,* **293**, 1304-1308.

HAWLEY, R.L., MORRIS, E.M., CULLEN, R., NIXDORF, U., SHEPHERD, A.P. and WINGHAM, D.J. 2006. ASIRAS airborne radar resolves internal annual layers in the dry-snow zone of Greenland, *Geophys. Res. Lett.*, **33**, L04502, doi:10.1029/2005GL025147.

HEINZE, C. 2004. Simulating oceanic CaCO3 export production in the greenhouse, *Geophys. Res. Let.*, **31**, L16308, doi: 10.1029/2004GL020613.

HELD, C. and WÄGELE, J.W. 2005. Cryptic speciation in the giant Antarctic isopod *Glyptonotus antarcticus* (Isopoda: Valvifera: Chaertiliidae), *Scientia Marina,* **69**(2), 175-181.

HELD, C. 2000. Phylogeny and biogeography of serolid isopods (Crustacea, Isdopoda, Serolidae) and the use of ribosomal expension segments in molecular systematics, *Molecular Phylogenetics and Evolution,* **15**(2), 165-178.

HELLMER, H.H. 2004. Impact of Antarctic shelf basal melting on sea ice and deep ocean properties, *Geophys. Res. Lett.,* **31**, doi:10.1029/2004GL019506.

HELLMER, H.H. and S.S. JACOBS (1994) Temporal changes in shelf water of the southern Ross Sea, *Antarct. J. of the U.S.,* **29**(5), 123-124.

HELLMER, H.H., JACOBS, S.S. and JENKINS, A. 1998. Oceanic erosion of a floating Antarctic glacier in the Amundsen Sea, in: *Ocean, Ice, and Atmosphere: Interactions at the Antarctic continental margin*, S S Jacobs and R F Weiss (eds), *Antarc. Res. Ser*., **75**, 83-99.

HELMIG, D., OLTMANS, S., CARLSON, D., LAMARQUE, J.-F., JONES, A.E., LABUSCHAGNE, C., ANLAUF, K. and HAYDEN, K. 2007. A review of surface ozone in the polar regions, *Atmos. Env*., **41**, 5138-5161, doi:10.1016/j.atmosenv.2006.09.053.

HEMPEL, G. 1985. On the biology of polar seas, particularly the Southern Ocean. In: *Marine Biology of Polar Regions and Effects of Stress on Marine Organisms* (Gray JS, Christiansen ME, eds). John Wiley and Sons Ltd., Chichester, 3-33.

HENDY, C.H. 2000. Late Quaternary lakes in the McMurdo Sound region of Antarctica, *Geografiska Annaler*, **82** A, 411-432.

HENNION, F., HUISKES, A., ROBINSON, S. and CONVEY, P. (2006) Physiological traits of organisms in a changing environment, *Trends in Antarctic Terrestrial and Limnetic Ecosystems: Antarctica as a Global Indicator*, eds. Bergstrom, D.M**,** Convey, P. and Huiskes, A.H.L. Springer, Dordrecht, 129-159.

HENSE, I., TIMMERMANN, R., BECKMANN, A.and ATHMANN, U.V. 2003. Regional and interannual variability of ecosystem dynamics in the Southern Ocean, *Ocean Dynamics,* **53**, 1-10.

HEROY, D.C. and ANDERSON, J.B. 2005. Ice-sheet extent of the Antarctic Peninsula region during the Last Glacial maximum (LGM) - Insights from glacial geomorphology. *GSA Bulletin* **117**:1497-1512.

HEWITT, R.P., DEMER, D.A. and EMERY, J.H. 2003. An 8-year cycle in krill biomass density inferred from acoustic surveys conducted in the vicinity of the South Shetland Islands during the austral summers of 1991–1992 through 2001–2002, *Aquatic Living Resources,* **16**, 205-213.

HEYWOOD, K. J., NAVEIRA-GARABATO, A.C., STEVENS, D.P., AND MUENCH, R.D. 2004. On the fate of the Antarctic Slope Front and the origin of the Weddell Front, *Journal of Geophysical Research,* **109** (C06021), 1-13.

HEYWOOD, K.J. and KING, B.A. 2002. Water masses and baroclinic transports in the South Atlantic and Southern Oceans, *J. Mar. Res*., **60**(5), 639-676.

HEYWOOD, K.J., NAVEIRA GARABATO, A.C. and STEVENS, D.P. 2002. High mixing rates in the abyssal Southern Ocean, *Nature,* **415**, 1011-1014.

HEYWOOD, K.J., SPARROW, M.D., BROWN, J. AND DICKSON, R.R. 1999. Frontal structure and Antarctic Bottom Water flow through the Princess Elizabeth Trough, Antarctica, *Deep-Sea Research I*, **46**, 1181-1200.

HIBLER III, W.D. 1979. A dynamic-thermodynamic sea ice model, *Journal of Physical Oceanography*, **9**, 815–846.

HILL, D.J., HAYWOOD, A.M., HINDMARSH, R.C.A. and VALDES, P.J. (in -press) Characterising Pliocene ice-sheets: evidence from data and models. In: Williams M, Haywood A, Gregory J, Schmidt D (eds) *Deep Time Perspectives on Climate Change: Marrying biological proxies and Climate Models*, The Micropalaeontological Society and the Geological Society of London.

HILLER, A, WAND, U., KAMPF, H. and STACKEBRANDT, W. 1988. Occupation of the Antarctic continent by petrels during the past 35 000 years: inferences from a ^{14}C study of stomach oil deposits, *Polar Biology,* **9**, 69-77.

HINDMARSH, R.C.C., VAN DER WATEREN, F.M. and VERBERS, A.L.L.M. 1998. Sublimation of ice through sediments in Beacon Valley, Antarctica, *Geogr. Am,* **80A** (3-4), 209-219.

HINES K.M., BROMWICH, D.H. and MARSHALL, G.J. 2000. Artificial surface pressure trends in the NCEP–NCAR reanalysis over the Southern Ocean and *Antarctica, J. Climate*, **13**, 3940–3952.

HINES, K.M., BROMWICH, D.H., RASCH, P.J. and IACONO, M.J. 2004. Antarctic Clouds and Radiation within the NCAR Climate Models, *J. Climate*, **17**, 1198–1212.

HINKE, J.T., SALWICKA, K., TRIVELPIECE, S.G., WATTERS, G.M. and TRIVELPIECE, W.Z. 2007. Divergent responses of *Pygoscelis* penguins reveal a common environmental driver, *Oecologia*, **153**, 845-855.

HIRASAWA, N., NAKAMURA, H. and YAMANOUCHI, T. 2000. Abrupt changes in meteorological conditions observed at an inland Antarctic station in association with wintertime blocking formation, *Geophys. Res. Lett*., **27**, 1911-1914.

HIRST, A.C. 1999. The Southern Ocean response to a global warming in the CSIRO coupled ocean-atmosphere model, *Environmental Modeling and Software*, 227-241.

HIRST, A.C., GORDON, H.G. and O'FARRELL, S.P. 1996. Global warming in a coupled climate model including oceanic eddy-induced advection, *Geophys. Res. Lett*., **23**, 3361-3364.

HJÖRT, C., BJÖRCK, S., INGÓLFSSON, O. and MÖLLER, P. 1998. Holocene deglaciation and climate history of the northern Antarctic Peninsula region: a discussion of correlations between the Southern and Northern Hemispheres, *Annals of Glaciology,* **27**, 110-112.

HJÖRT, C., INGÓLFSSON, O., BENTLEY, M.J. and BJÖRCK, S. 2003. The Late Pleistocene and Holocene glacial and climate history of the Antarctic Peninsula region as documented by the land and lake sediment records - a review, *Antarctic Research Series,* **79**, 95-102.

HJÖRT, C., INGÓLFSSON, O., MÖLLER, P. and LIRIO, J.M. 1997. Holocene glacial history and sea-level changes on James Ross Island, Antarctic Peninsula, *Journal of Quaternary Science,* **12**, 259-271.

HODELL, D.A., KANFOUSH, S.L., SHEMESH, A., CROSTA, X., CHARLES, C.D. and GUILDERSON, T.P. 2001. Abrupt cooling of Antarctic surface waters and sea ice expansion in the South Atlantic sector of the Southern Ocean at 5000 cal yr B.P., *Quaternary Research,* **56**, 191-198.

HODGSON, D.A. and CONVEY, P. 2005. A 7000-year record of oribatid mite communities on a maritime-Antarctic island: responses to climate change, *Arctic Antarctic and Alpine Research,* **37**, 239-245.

HODGSON, D.A. and SMOL, J.P. 2008. High latitude palaeolimnology. *In Polar Lakes and Rivers - Arctic and Antarctic Aquatic Ecosystems*, (W. F. Vincent, and J. Laybourn-Parry, Eds.). Oxford University Press, Oxford, UK.

HODGSON, D.A., BENTLEY, M.J., ROBERTS, S.J., SMITH, J.A., SUGDEN, D.E. and DOMACK, E.W. 2006b. Examining Holocene stability of Antarctic Peninsula Ice Shelves. Eos Transactions, *American Geophysical Union,* **87**, 305-312.

HODGSON, D.A., DORAN, P.T., ROBERTS, D. and MCMINN, A. 2004a. Paleolimnological studies from the Antarctic and subantarctic islands. In: Pienitz R, Douglas MSV, Smol JP (eds) *Developments in Palaoenvironmental Research. Long-term Environmental Change in Arctic and Antarctic Lakes*, **8**, Springer, Dordrecht, 419-474.

HODGSON, D.A., MCMINN, A., KIRKUP, H., CREMER, H., GORE, D., MELLES, M., ROBERTS, D. and MONTIEL, P. 2003. Colonization, succession, and extinction of marine floras during a glacial cycle: A case study from the Windmill Islands (east Antarctica) using biomarkers, *Paleoceanography,* **18**(3), 1067, doi:1010.1029/2002PA000775.

HODGSON, D.A., NOON, P.E., VYVERMAN, W., BRYANT, C.L., GORE, D.B., APPLEBY, P., GILMOUR, M., VERLEYEN, E., SABBE, K., JONES, V.J., ELLIS-EVANS, J.C. and WOOD, P.B. 2001. Were the Larsemann Hills ice-free through the Last Glacial Maximum?, *Antarctic Science,* **13**, 440-454.

HODGSON, D.A., ROBERTS, D., MCMINN, A., VERLEYEN, E., TERRY, B., CORBETT, C. and VYVERMAN, W. 2006c. Recent rapid salinity rise in three East Antarctic lakes, *Journal of Paleolimnology,* **36**, 385-406.

HODGSON, D.A., VERLEYEN, E., SABBE, K., SQUIER, A.H., KEELY, B.J., LENG, M.J., SAUNDERS, K.M. and VYVERMAN, W. 2005. Late Quaternary climate-driven environmental change in the Larsemann Hills, East Antarctica, multi-proxy evidence from a lake sediment core, *Quaternary Research,* **64**, 83-99.

HODGSON, D.A., VERLEYEN, E., SQUIER, A.H., SABBE, K., KEELY, B.J., SAUNDERS, K.M. and VYVERMAN, W. 2006a. Interglacial environments of coastal east Antarctica: comparison of MIS 1 (Holocene) and MIS 5e (Last Interglacial) lake-sediment records, *Quaternary Science Reviews,* **25**, 179-197.

HODGSON, D.A., VYVERMAN, W., VERLEYEN, E., SABBE, K., LEAVITT, P.R., TATON, A., SQUIER, A.H. and KEELY, B.J. 2004b. Environmental factors influencing the pigment composition of *in situ* benthic microbial communities in east Antarctic lakes, *Aquatic Microbial Ecology,* **37**, 247-263.

HOFMAN, G.E., BUCKLEY, B.A., AIRAKSINEN, S., KEEN, J.E. and SOMERO, G.N. 2000 Heat-shock protein expression is absent in the Antarctic fish *Trematomus bernacchii* (family Nototheniidae), *J. Exp. Biol.,* **203**, 2331–2339.

HOFMANN, D.J., S.J. OLTMANS, J.M. HARRIS, B.J. JOHNSON, J.A. LATHROP. 1997. Ten years of ozonesonde measurements at the south pole: Implications for recovery of springtime Antarctic ozone, *J. Geophys. Res.*, **102**, 8931-8943.

HOFMANN, E.E. and KLINCK, J.M. 1998. Thermohaline variability of the waters overlying the West Antarctic Peninsula continental shelf, in: *Ocean, Ice, and Atmosphere: Interactions at the Antarctic continental margin*, S S Jacobs and R F Weiss (eds), *Antarc. Res. Ser.*, **75**, 67-81.

HOFMANN, G.E., LUND, S.G., PLACE, S.P. and WHITMER, A.C. 2005. Some like it hot, some like it cold: the heat shock response is found in New Zealand but not Antarctic notothenioid fishes, *Journal of Experimental Marine Biology and Ecology,* **316**, 79-89.

HOGG, A.M., MEREDITH, M.P., BLUNDELL, J.R. AND WILSON, C. 2008. Eddy heat flux in the Southern Ocean: Response to variable wind forcing, *Journal of Climate*, **21**(4), 608-620.

HOGG, I.D., CARY, S.C., CONVEY, P., NEWSHAM, K.K., O'DONNELL, T., ADAMS, B.J., AISLABIE, J., FRATI, F.F., STEVENS, M.I. and WALL, D.H, 2006. Biotic interactions in Antarctic terrestrial ecosystems: are they a factor? *Soil Biology and Biochemistry,* **38**, 3035-3040.

HOGG, N.G, 2001. Quantification of the deep Circulation. In: Eds. G. Siedler, J. Church and J. Gould, *Ocean circulation and climate; observing and modelling the global ocean*, *International Geophysics Series,* **77**, 259-270, Academic Press.

HOLGATE, S.J. and WOODWORTH, P.L. 2004. Evidence for enhanced coastal sea level rise during the 1990s, *Geophysical Research Letters*, **31**, L07305, doi:10.1029/2004GL019626.

HOLLAND, D.M., JACOBS, S.S. and JENKINS, A. 2003. Modelling the ocean circulation beneath the Ross Ice Shelf, *Antarctic Science*, **15** (1), 13–23 (doi: 10.1017/S0954102003001019).

HOLM-HANSEN, O., KAHRU, M., HEWES, C.D., KAWAGUCHI, S., KAMEDA, T., SUSHIN, V.A., KRASOVSKI, I., PRIDDLE, J., KORB, R., HEWITT, R.P. and MITCHELL, B.G. 2004. Temporal and spatial distribution of chlorophyll-*a* in surface waters of the Scotia Sea as determined by both shipboard measurements and satellite data, *Deep-Sea Research Part II—Topical Studies in Oceanography*, **51** (2004) (12–13), 1323–1332.

HOLT, J.W., BLANKENSHIP, D.D., MORSE, D.L., YOUNG, D.A., PETERS, M.E., KEMPF, S.D., RICHTER, T.G., VAUGHAN, D.G. and CORR, H.F.J. 2006. New boundary conditions for the West Antarctic Ice Sheet: Subglacial topography of the Thwaites and Smith glacier catchments, *Geophys. Res. Lett.*, **33**, L09502, doi:10.1029/2005GL025561.

HONRATH, R.E., LU, Y., PETERSON, M.C., DIBB, J.E., ARSENAULT, M.A., CULLEN, N.J. and STEFFEN, K., 2002. Vertical fluxes of NO_x, HONO and HNO_3 above the snowpack at Summit, Greenland, *Atmos. Environ.*, **36**, 2629-2640.

HONRATH, R.E., PETERSON, M.C., GUO, S., DIBB, J.E., SHEPSON, P.B. and CAMPBELL, B. 1999. Evidence of NO_x production within or upon ice particles in the Greenland snowpack, *Geophys. Res. Lett.*, **26**, 695-698.

HOPKINS, T.L. 1971 Zooplankton standing crop in the Pacific sector of the Antarctic. In *Biology of the Antarctic Seas IV*, (G.A. Llano, I.E. Wallen, eds.), *Antarctic Research Series,* **17**, 347-362.

HORMES, A., MÜLLER, B.J. and SCHLÜCHTER, C. 2001. The Alps with little ice: evidence for eight Holocene phases of reduced glacier extent in central Swiss Alps, *Holocene,* **11**, 255-265.

HOSKINS, B.J. and HODGES, K. 2005. A new perspective on southern hemisphere winter storm tracks, *Journal of Climate*, **18**, 4108-4129.

HOWAT, I.M., SMITH, B.E., JOUGHIN, I. and SCAMBOS, T.A. 2008. Rates of southeast Greenland ice volume loss from combined ICESat and ASTER observations, *Geophys. Res. Lett.*, **35**, L17505, doi:10.1029/2008GL034496.

HUCK, P.E., S. TILMES, G.E. BODEKER, W.J. RANDEL, A.J. MCDONALD, H. NAKAJIMA. 2007. An improved measure of ozone depletion in the Antarctic stratosphere, *J. Geophys. Res.,* **112**, D11104.

HUDSON, R.R. and COYNE, J.A. 2002. Mathematical consequences of the genealogical species concept, *Evolution,* **56**, 1557-1565.

HUGHEN, K.A., BAILLIE, M.G.L., BARD, E., BECK, J.W., BERTRAND, C.J.H., BLACKWELL, P.G., BUCK, C.E., BURR, G.S., CUTLER, K.B., DAMON, P.E., EDWARDS, R.L., FAIRBANKS, R.G., FRIEDRICH, M., GUILDERSON, T.P., KROMER, B., MCCORMAC, G., MANNING, S., RAMSEY, C.B., REIMER, P.J., REIMER, R.W., REMMELE, S., SOUTHON, J.R., STUIVER, M., TALAMO, S., TAYLOR, F.W., VAN DER PLICHT, J. and CE, W. 2004. Marine Radiocarbon Age Calibration 0-26 Cal Kyr Bp, *Radiocarbon*, **46**,1059-1108.

HUGHES, C.W. and ASH, E.R. 2001. Eddy forcing of the mean flow in the Southern Ocean, *Journal of Geophysical Research*, **106**, 2713-2722.

HUGHES, C.W., MEREDITH, M.P. and HEYWOOD, K. 1999. Wind-driven transport fluctuations through Drake Passage: a Southern mode*, Journal of Physical Oceanography*, **29**, 1971 – 1992.

HUGHES, C.W., WOODWORTH, P.L., MEREDITH, M.P., STEPANOV, V., WHITWORTH, T. and PYNE A.R. 2003. Coherence of Antarctic sea levels, Southern Hemisphere Annular Mode, and flow through Drake Passage, *Geophysical Research Letters,* **30**(9), 1464, doi:10.1029/2003GL017240.

HUGHES, G.L., RAO, S.S. and RAO, T.S. 2007. Statistical analysis and time-series models for minimum/maximum termperatures in the Antarctic Peninsula, *Proceedings of the Royal Society A*, **463,** 241-259.

HUGHES, G.O. and GRIFFITHS, R.W. 2006. A simple convective model of the global overturning circulation, including effects of entrainment into sinking regions, *Ocean Model.,* **12**, 46-79.

HUGHES, K.A. and LAWLEY, B. 2003. A novel Antarctic microbial endolithic community within gypsum crusts, *Environ. Microbiol.,* **5**, 555-565.

HUGHES, L. 2000. Biological consequences of global warming: is the signal already apparent?, *Trends Ecol. Evol.,* **15**, 56-61.

HUGHES, T.J. 1973. Is the West Antarctic ice sheet disintegrating?, *J. Geophys. Res.,* **78**(33), 7884-7910.

HUISKES, A.H.L., CONVEY, P. and BERGSTROM, D. 2006. Trends in Antarctic terrestrial and limnetic ecosystems: Antarctica as a global indicator, *Trends in Antarctic Terrestrial and Limnetic Ecosystems: Antarctica as a Global Indicator*, eds. Bergstrom, D.M**,** Convey, P. and Huiskes, A.H.L. Springer, Dordrecht, 1-13.

HUNKE, E.C. and DUKOWICZ, J.K. 1997. An Elastic–Viscous–Plastic Model for Sea Ice Dynamics, *Journal of Physical Oceanography*, **27** (9), 1849-1867.

HUNT B.P.V, PAKHOMOV, E.A. and MCQUAID, C.D. 2001. Community structure of mesozooplankton in the Antarctic Polar Frontal Zone in the vicinity of the Prince Edward Islands (Southern Ocean): Small-scale distribution patterns in relation to physical parameters, *Deep-Sea Research Part II Topical Studies Oceanography*, **49**, 3307–3325.

HUNT, B.P.V. and HOSIE, G.W. 2003. The Continuous Plankton Recorder in the Southern Ocean: a comparative analysis of zooplankton communities sampled by the CPR and vertical net hauls along 140 E, *Journal of Plankton Research*, **25**, 1561–1579.

HUNTER, J., COLEMAN, R. and PUGH, D. 2003 The sea level at Port Arthur, Tasmania, from 1841 to the present, *Geophysical Research Letters*, **30**, 1401, doi:10.1029/2002GL016813.

HURRELL, J.W. and VAN LOON, H. 1994. A Modulation of the Atmospheric Annual Cycle in the Southern Hemisphere, *Tellus,* **46A**, 325-338.

HUTTER, K. 1983. *Theoretical Glaciology,* Dordrecht: Reidel Publ. Co., 510 pp.

HUYBERS, P. and DENTON, G. 2008. Antarctic temperature at orbital timescales controlled by local summer duration, *Nature Geoscience,* **10**, 1038/ngeo311.

HUYBERS, P. and WUNSCH, C. 2005. Obliquity pacing of the late Pleistocene glacial terminations, *Nature,* **434**, 491-494.

HUYBERS, P. 2006. Early Pleistocene glacial cycles and the integrated summer insolation forcing, *Science,* **313**, 508-511.

HUYBRECHTS, P. 2002. Sea-level changes at the LGM from ice-dynamic reconstructions of the Greenland and Antarctic ice sheets during the glacial cycles, *Quaternary Science Reviews*, 21, 203-231.

HUYBRECHTS, P. 2004. Antarctica: modeling. In *Mass balance of the Cryosphere: Observations and modeling of contemporary and future changes* (J.L. Bamber and A.J. Payne, eds.), Cambridge: Cambridge University Press, 491-523.

HUYBRECHTS, P. 2009. West-side story of Antarctic ice, *Nature,* **458**, 295-296.

HUYBRECHTS, P., GREGORY, J., JANSSENS, I. and WILD, M. 2004. Modelling Antarctic and Greenland volume changes during the 20th and 21st centuries forced by GCM time slice integrations, *Glob. Planet. Change*, **42**, 83–105.

IGARASHI, A., HARADA, N. and MORIWAKI, K. 1995. Marine fossils of 30-40 ka in raised beach deposits, and late Pleistocene glacial history around Lutzow-Holm Bay, East Antarctica, *Proceedings of the NIPR Symposium on Antarctic Geosciences*, **8,** 219-229.

IGLESIAS-RODRIGUEZ, M.D., HALLORAN, P.R., RICKABY, R.E.M., HALL, I.R., COLMENERO-HIDALGO, E., GITTINS, J.R., GREEN, D.R.H., TYRRELL, T., GIBBS, S.J., VON DASSOW, P., REHM, E., ARMBRUST, E.V. and BOESSENKOOL, K.P. 2008. Phytoplankton Calcification in a High-CO_2 *World. Science,* **320**, 336–340. doi:10.1126/science.1154122.

IHB, 2002. Status of natutical charting (part A) and hydrographic surveying (part B) in Antarctica, *International Hydrographic Bureau publication* S-59. (see also previous editions of this publication with the same number.)

IIZUKA, Y., HONDOH, T. and FUJII, Y. 2008. Antarctic sea ice extent during the Holocene reconstructed from inland ice core evidence, *Journal of Geophysical Research,* **113**, D15114, doi:10.1029/2007JD009326.

INDERMÜHLE, A., MONNIN, E., STAUFFER, B., STOCKER, T.F. and WAHLEN, M. 2000. Atmospheric CO_2 concentration from 60 to 20 kyr BP from the Taylor dome ice core, Antarctica, *Geophysical Research Letters,* **27**, 735-738.

INDERMÜHLE, A., STOCKER, T.F., JOOS, F., FISCHER, H., SMITH, H.J., WAHLEN, M., DECK, B., MASTROIANNI, D., TSCHUMI, J., BLUNIER, T., MEYER, R. and STAUFFER, B. 1999. Holocene carbon-cycle dynamics based on CO2 trapped in ice at Taylor Dome, Antarctica, *Nature,* **398**, 121-126.

INGELS, J., VANHOVE, S., DE MESEL, I. and VANREUSEL, A. 2006. The biodiversity and biogeography of the free-living nematode genera *Desmodora* and *Desmodorella* (family Desmodoridae) at both sides of the Scotia Arc, *Polar Biol.,* **29** (11), 936-949.

INGÓLFSSON, Ó. 2004. Quaternary glacial and climate history of Antarctica. In: Ehlers J, Gibbard PL (eds), *Quaternary Glaciations - Extent and Chronology, Part III*, Elsevier, 3-43.

INGOLFSSON, O. and HJORT, C. 2002. Glacial history of the Antarctic Peninsula since the Last Glacial Maximum-a synthesis, *Polar Biology*, **21**, 227-234.

INGÓLFSSON, Ó., HJORT, C. and HUMLUM, O. 2003. Glacial and Climate History of the Antarctic Peninsula since the Last Glacial Maximum, *Arctic, Antarctic and Alpine Research,* **35**, 175-186.

INGÓLFSSON, Ó., HJORT, C., BERKMAN, P.A., BJÖRCK, S., COLHOUN, E.A., GOODWIN, I.D., HALL, B.L., HIRAKAWA, K., MELLES, M., MÖLLER, P. and PRENTICE, M.L. 1998. Antarctic glacial history since the last glacial maximum: an overview of the record on land, *Antarctic Science,* **10**, 326-344.

INOUE, H.Y. and ISHII, M. 2005. Variations and trends of CO2 in the surface seawater in the Southern Ocean south of Australia between 1969 and 2002, *Tellus B*, **57**, 58-69.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE. 2007. IPCC Fourth Assessment Report: the Polar Perspective (http://www.sciencepoles.org/index.php?articles/ipcc_fourth_assessment_report_the polar_perspectiveands=2andrs=homeanduid=897andlg=en).

IOC. 1997. Global Sea Level Observing System (GLOSS) implementation plan-1997. Intergovernmental Oceanographic Commission, Technical Series, No. 50, 91pp. and Annexes.

IOC. 2006. Manual on sea-level measurement and interpretation. Volume 4 - An update to 2006. (eds. Aarup, T., Merrifield, M., Perez, B., Vassie, I and Woodworth, P.). Intergovernmental Oceanographic Commission Manuals and Guides No. 14. IOC, Paris, 80 pp.

IPCC 2007. Climate Change 2007: The Physical Science Basis. Contribution of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

IPICS 2008. International Partnerships in Ice Core Sciences - white papers. In: Wolff E, Brook E (eds). http://www.pages.unibe.ch/ipics/steeringcommittee.html.

ISHIDOYA, S., SUGAWARA, S., HASHIDA, G., MORIMOTO, S. AOKI, S., NAKAZAWA, T. and YAMANOUCHI, T. 2006. Vertical profiles of the O2/N2 ratio in the stratosphere over Japan and Antarctica, *Geophys. Res. Lett.*, **33**, L13701, doi:10.1029/2006GL025886.

ISKANDARANI, M., HAIDVOGEL, D.B. and LEVIN, J.C. 2003. A three-dimensional spectral element model for the solution of the hydrostatic primitive equations, *Journal of Computational Physics,* **186**, 397–425.

IVCHENKO, V., WELLS, N. and GREZIO, A. 2004. What controls the transport of the Antarctic Circumpolar Current in ocean general circulation models?, *Geophys. Res. Abs*, **6**, 01847.

IVCHENKO, V.O., ZALESNY, V.B. and DRINKWATER, M.R. 2004. Can the Equatorial Ocean quickly responds to Antarctic sea ice-salinity anomalies?, *Geophys. Res. Lett.*, **31**(15), doi: 10.1029/2004GL020472.

IVINS, E.R. and JAMES, T.S. 2005. Antarctic glacial isostatic adjustment: a new assessment, *Antarctic Science,* **17**, 541-553.

JABAUD-JAN, A, METZL, N., BRUNET, C., POISSON, A. AND SCHAUER, B. 2004. Interannual varaibility of the carbon dioxide system in the southern Indian Ocean (20˚-60˚S): the impact of a warm anomaly in the austral summer 1998, *Global Biogeochemical Cycles*, **18**, GB1042,1010.1029/2002GB002017.

JACKA, T.H. and BUDD, W.F. 1991. Detection of temperature and sea ice extent changes in the Antarctic and Southern Ocean. Weller, G., Wilson, C. L., and Severin, B. A. *Proceedings of the International Conference on the Role of the Polar Regions in Global Change. June 11-15, 1990, University of Alaska Fairbanks*, 63-70. Fairbanks, AK, University of Alaska, Geophysical Institute.

JACKA, T.H. and BUDD, W.F. 1998. Detection of temperature and sea-ice-extent changes in the Antarctic and Southern Ocean, 1949-96, *Annals of Glaciology,* **27**, 553-559.

JACOB, U. 2006. Trophic dynamics of Antarctic shelf ecosystems – food webs and energy flow budgets, PhD thesis, AWI Bremen University.

JACOBS, G.A. and MITCHELL, J.L. 1996. Ocean circulation variations associated with the Antarctic Circumpolar Wave, *Geophys.. Res. Let.,* **23**, 2947-2950.

JACOBS, S.S. and COMISO, J.C. 1993. A recent sea-ice retreat west of the Antarctic Peninsula, *Geophys. Res. Lett.*, **20**, 1171-1174.

JACOBS, S.S. and COMISO, J.C. 1997. Climate variability in the Amundsen and Bellingshausen Seas, *Journal of Climate*, **10**(4), 697-709.

JACOBS, S.S. and GIULIVI, C.F. 1998. Interannual ocean and sea ice variability in the Ross Sea, *Antarct. Res. Ser.,* **75**, 135-150.

JACOBS, S.S. AND GIULIVI, C.F. 1999. Thermohaline Data and Ocean Circulation on the Ross Sea Continental Shelf. In: Eds G. Spezie and G.M.R. Manzella, *Oceanography of the Ross Sea Antarctica*, Springer-Verlag Italia, Milano, 3-16.

JACOBS, S.S. 1985. Oceanographic evidence for land ice/ocean interactions in the Southern ocean. In: *Glaciers, Ice Sheets and Sea Level: Effect of a CO_2-Induced Climatic Change*, *Report of a Workshop, Seattle, 13-15 Sep 1984*, DOE/ER/60235-1, 116-128.

JACOBS, S.S. 2006. Observations of change in the Southern Ocean, *Phil. Trans. Roy. Soc. A,* **364**, 1657-1681.

JACOBS, S.S., GIULIVI, C.F. and MELE, P.A. 2002. Freshening of the Ross Sea during the late 20th century. *Science,* **297**(5580), 386-389, doi:10.1126/science.1069574.

JACOBS, S.S., HELLMER, H.H. and JENKINS, A. 1996. Antarctic ice sheet melting in the southeast Pacific, *Geophysical Research Letters*, **23**(9), 23(9), 957-960.

JACOBS, S.S., MACAYEAL, D.R. and ARDAI, J.L., JR., 1986. The recent advance of the Ross Ice Shelf, Antarctica, *Journal of Glaciology,* **32**(112), 464-474.

JACOBSON, H.P. and RAYMOND, C.F. 1998. Thermal effects on the location of ice stream shear margins, *Journal of Geophysical Research,* **103**, 12,111-12,122.

JAMIESON, S.R. and SUGDEN, D.E. 2008. LANDSCAPE EVOLUTION OF ANTARCTICA. IN: COOPER AK, BARRETT P, STAGG H, STOREY B, STUMP E, WISE W (eds) *Antarctica: A Keystone in a Changing World. Proceedings of the 10th International Symposium on Antarctic Earth Sciences, Santa Barbara, California, August 26 to September 1, 2007*. Polar Research Board, National Research Council, U.S. Geological Survey

JANECH, M.G., KRELL, A., MOCK, T., KANG, J.S. and RAYMOND, J.A. 2006. Ice-binding proteins from sea ice diatoms (Bacillariophyceae), *Journal of Phycology,* **42**, 410-416.

JANSEN, E.J., OVERPECK, K.R., BRIFFA, J-C., DUPLESSY, F., JOOS, V., MASSON-DELMOTTE, D., OLAGO, B., OTTO-BLIESNER, W.R., PELTIER, S., RAHMSTORF, R., RAMESH, D., RAYNAUD, D., RIND, O., SOLOMINA, R., VILLALBA, R. and ZHANG, D. 2007. Palaeoclimate. In: Solomon SD, Qin M, Manning Z, Chen M, Marquis KB, Averyt M, Tignor, Miller HL (eds) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 433-497.

JENKINS, A., HOLLAND, D.M., NICHOLLS, K.W., SCHRÖDER, M. and ØSTERHUS, S. 2004. Seasonal ventilation of the cavity beneath Filchner-Ronne Ice Shelf simulated with an isopycnic coordinate ocean model, *J. Geophys. Res.*, **109**, C01024, doi:10.1029/2001JC001086.

JENKINS, A., VAUGHAN, D.G., JACOBS, S.S., HELLMER, H.H. and KEYS, J.R. 1997. Glaciological and oceanographic evidence of high melt rates beneath Pine Island Glacier, West Antarctica, *Journal of Glaciology,* **43**(143), 114-121.

JENKINS, A., CORR, H.F.J., NICHOLLS, K.W., STEWART, C.L., DOAKE, C.S.M. and CHRISTOPHER S.M. 2006. Interactions between ice and ocean observed with phase-sensitive radar near an Antarctic ice-shelf grounding line, *J. Glaciol.,* **52** (178), 325-346.

JENOUVRIER, S., BARBRAUD, C. and WEIMERSKIRCH, H. 2003. Effects of climate variability on the temporal population dynamics of southern fulmars, *J. Animal Ecol.,* **72**, 576–587.

JENOUVRIER, S., BARBRAUD, C., and WEIMERSKIRCH, H. 2005b. Long-term contrasted responses to climate of two antarctic seabird species, *Ecol.,* **86**, 2889–2903.

JENOUVRIER, S., CASWELL, H., BARBRAUD, C., HOLLAND, M., STRŒVE, J. and WEIMERSKIRCH, H. 2009. Demographic models and IPCC climate projections predict the decline of an emperor penguin population, *Proc. Natl. Acad. Sci. U.S.A*., January 26, doi 10.1073/pnas.0806638106.

JENOUVRIER, S., WEIMERSKIRCH, H., BARBRAUD, C., PARK, Y.H. and CAZELLES B. 2005a. Evidence of a shift in the cyclicity of Antarctic seabird dynamics linked to climate, *Proceeding of the Royal Society B*, **272**, 887-895.

JENSSEN, D. 1977. A three-dimensional polar ice sheet model, *Journal of Glaciology,* **18**, 373-389.

JEVREJEVA, S., GRINSTED, A., MOORE J.C. and HOLGATE, S. 2006. Nonlinear trends and multi-year cycle in sea level records, *Journal of Geophysical Research*, **111**, 2005JC003229.

JEZEK, K. C. 2008. The RADARSAT-1 Antarctic Mapping Project. BPRC Report No. 22, Byrd Polar Research Center, The Ohio State University, Columbus, Ohio, 64 p.

JIN, Y. and DEVRIES, A.L. 2006. Antifreeze glycoprotein levels in Antarctic notothenioid fishes inhabiting different thermal environments and the effect of warm acclimation, *Comparative Biochemistry and Physiology Part B: Biochemistry and Molecular Biology,* **144**, 290-300.

JOHN, U.P., POLOTNIANKA, R.M., SIVAKUMARAN, K.A., CHEW, O., MACKIN, L., KUIPER, M.J., TALBOT, J.P., NUGENT, G.D., MAUTORD, J., SCHRAUF, G.E. and SPANGENBERG, G.C. 2009. Ice recrystallization inhibition proteins (IRIPs) and freeze tolerance in the cryophilic Antarctic hair grass *Deschampsia antarctica* E. Desv, *Plant Cell and Environment,* **32**, 336-348.

JOHNSEN, K-P., MIAO, J. and KIDDER, S.Q. 2004. Comparison of atmospheric water vapour overarctica derived from CHAMP/GPS and AMSU-B data, *Physics and Chemistry of the Earth*, **29**, 251–255.

JOHNSON, G.C. AND DONEY, S.C. 2006. Recent western South Atlantic bottom water warming, *Geophysical research Letters*, **33**, L14614, doi:10.1029/2006GL026769.

JOHNSON, G.C., MECKING, S., SLOYAN, B.M. AND WIJFFELS, S.E. 2007. Recent Bottom Water Warming in the Pacific Ocean, *Journal of Climate*, 5365-5375, doi:10.1175/2007JCLI1879.1.

JOHNSTON, I.A. 2003. Muscle metabolism and growth in Antarctic fishes (suborder Notothenioidei): evolution in a cold environment, *Comparative Biochemistry and Physiology Part B: Biochemistry and Molecular Biology,* **136**, 701-713.

JOHNSTON, I.A., CALVO, J., GUDERLEY, H., FERNANDEZ, D. and PALMER, L. 1998. Latitudinal variation in the abundance and oxidative capacities of muscle mitochondria in perciform fishes, *J. Exp. Biol.,* **201**, 1-12.

JOHST, K., GUTT, J., WISSEL, C. and GRIMM, V. 2006. Diversity and disturbances in the Antarctic megabenthos: feasible versus theoretical disturbance ranges, *Ecosystems,* **9**, 1145-1155.

JONES, A.E., ANDERSON, P.S., WOLFF, E.W., TURNER, J., RANKIN, A.M. and COLWELL, S.R. 2006. A role for newly-forming sea ice in springtime polar tropospheric ozone loss? Observational evidence from Halley station, Antarctica, *J. Geophys. Res*., **111**, D08306, doi:10.1029/2005JD006566.

JONES, A.E., WELLER, R., ANDERSON, P.S., JACOBI, H.-W., WOLFF, E.W., SCHREMS, O. and MILLER, H. 2001. Measurements of NO_x emissions from the Antarctic snowpack, *Geophys. Res. Lett*., **28**, 1499-1502.

JONES, A.E., WELLER, R., WOLFF, E.W. and JACOBI, H-W. 2000. Speciation and rate of photochemical NO and NO_2 production in Antarctic snow, *Geophys. Res. Lett.*, **27**, 345-348.

JONES, D.A. and SIMMONDS, I. 1993. A climatology of Southern Hemisphere extratropical cyclones, *Climate Dynamics*, **9**, 131-145.

JONES, J.M. and WIDMANN, M. 2003. Instrument- and tree-ring-based estimates for the Antarctic Oscillation, *J. Clim*., **16**(21), 3511-3524.

JONES, P.D. 1995. Recent variations in mean temperature and the diurnal temperature range in the Antarctic, *Geophysics Research Letters,* **22** [11], 1345-1348.

JONES, V.J., HODGSON, D.A. and CHEPSTOW-LUSTY, A. 2000. Palaeolimnological evidence for marked Holocene environmental changes on Signy Island, Antarctica, *The Holocene,* **10**, 43-60.

JOSEPH, R. and NIGAM, S. 2006. ENSO evolution and teleconnections in IPCC's twentieth-century climate simulations: Realistic representation?, *J. Climate*, **19**, 4360-4377.

JOUGHIN, I, DAS, S.B., KING, M.A. ET AL. 2008. Seasonal speedup along the western flank of the Greenland Ice Sheet, *Science*, **320**, No. 5877, 781-783.

JOUGHIN, I. and TULACZYK, S. 2002. Positive mass balance of the Ross Ice Streams, West Antarctica, *Science*, **295** (Jan 18), No. 5554, 476-480.

JOUGHIN, I., GRAY, L., BINDSCHADLER, R., PRICE, S., MORSE, D., HULBE, C., MATTAR, K. and WERNER, C. 1999. Tributaries of West Antarctic ice streams revealed by Radarsat interferometry, *Science,* **286**, 283–286, (doi:10.1126/science.286.5438.283).

JOUGHIN, I., RIGNOT, E., ROSANOVA, C., LUCCHITTA, B. and BOHLANDER, J. 2003. Timing of recent accelerations of Pine Island Glacier, Antarctica. *Geophysical Research Letters*, **30**(13), doi:10.1029/2003GL017609.

JOUGHIN, I., TULACZYK, S., BINDSCHADLER, R.A. and PRICE, S.F. 2002. Changes in west Antarctic ice stream velocities, *Journal of Geophysical Research*, **107**, No. B11, 2289, doi:10.1029/2001/JB001029.

JOUZEL, J., MASSON-DELMOTTE, V., CATTANI, O., DREYFUS, G., FALOURD, S., HOFFMANN, G., MINSTER, B., NOUET, J., BARNOLA, J.M., CHAPPELLAZ, J., FISCHER, H., GALLET, J.C., JOHNSEN, S., LEUENBERGER, M., LOULERGUE, L., LUETHI, D., OERTER, H., PARRENIN, F., RAISBECK, G., RAYNAUD, D., SCHILT, A., SCHWANDER, J., SELMO, E., SOUCHEZ, R., SPAHNI, R., STAUFFER, B., STEFFENSEN, J.P., STENNI, B.S., TISON, J.L., WERNER, M. and WOLFF, E. 2007. Orbital and millenial Antarctic climate variability over the past 800,000 years, *Science,* **317**, 793-796.

JOUZEL, J., VAIKMAE, R., PETIT, J.R., MARTIN, M., DUCLOS, Y, STIÉVENARD, M., LORIUS, C., TOOTS, M., BURCKLE, L.H., BARKOV, N.I., KOTLYAKOV, V.M. 1995. The two-step shape and timing of the last deglaciation in Antarctica, *Climate Dynamics,* **11**, 151-161.

JOUZEL, J., VIMEUX, F., CAILLON, N., DELAYGUE, G., HOFFMANN, G., MASSON-DELMOTTE, V. and PARRENIN, F. 2003. Magnitude of the Isotope/Temperature scaling for interpretation of central Antarctic ice cores, *J. Geophys. Res*., **108**,1029-1046.

JUSTWAN, A. and KOÇA, N. 2008. A diatom based transfer function for reconstructing sea ice concentrations in the North Atlantic, *Marine Micropaleontology,* **66**, 264-278.

KALNAY, E. and COAUTHORS. 1996. The NCEP/NCAR 40-year reanalysis project, *Bull. Amer. Meteor. Soc*., **77**, 437-471.

KAMB, B. 2001. Basal zone of the West Antarctic ice streams and its role in lubrication of their rapid motion, in The West Antarctic Ice Sheet: Behavior and Environment, *AGU Antarct. Res. Ser*., **77**, edited by R. B. Alley and R. A. Bindschadler, 157– 201, AGU, Washington, D.C.

KAMEDA, T., MOTOYAMA, H., FUJITA, S. and TAKAHASHI, S. 2008. Temporal and spatial variability of surface mass balance at Dome Fuji, East Antarctica, by the stake method from 1995 to 2006, *Journal of Glaciology*, **54**(184), 107–116.

KAMIYAMA, K., AGETA, Y. and FUJII, Y. 1989. Atmospheric and depositional environments traced from unique chemical compositions of the snow over an inland high plateau, Antarcitca, *J. Geophys. Res*., **94**, D15, 18515–18519.

KAROLY, D.J. 1989. Southern Hemisphere circulation features associated with El Niño-Southern Oscillation events, *Journal of Climate,* **2**, 1239-1252.

KASPARI, S., MAYEWSKI, P.A., DIXON, D., SNEED, S.B. and HANDLEY, M.J. 2005. Sources and transport pathways for marine aerosol species into West Antarctica, *Annals of Glaciology,* **42**, 1-9.

KATO, S., LOEB, N.G., MINNIS, P., FRANCIS, J.A., CHARLOCK, T.P., RUTAN, D.A., CLOTHIAUX, E.E. and SUN-MACK, S. 2006. Seasonal and interannual variations of top-of-atmosphere irradiance and cloud cover over polar regions derived from the CERES data set, *Geophys. Res. Lett*., **33**, L19804, doi: 10.1029/2006GL026685.

KAWAMURA, K., PARRENIN, F., LISIECKI, L., UEMURA, R., VIMEUX, F., SEVERINGHAUS, J.P., HUTTERLI, M.A., NAKAZAWA, T., AOKI, S.,

JOUZEL, J., RAYMO, M.E., MATSUMOTO, K., NAKATA, H., MOTOYAMA, H., FUJITA, S., GOTO-AZUMA, K., FUJII, Y. and WATANABE, O. 2007. Northern Hemisphere forcing of climatic cycles in Antarctica over the past 360,000 years, *Nature,* **448**, 912-916.

KEJNA, M. and LASKA, K. 1999. Spatial differentiation of ground temperature in the region of Arctowski Station, King George Island, Antarctica in 1996, *Polish Polar Research*, **20**(3), 221-241.

KENNETT, J.P. and HODELL, D.A. 1993. Evidence for Relative Climatic Stability of Antarctica during the Early Pliocene: A Marine Perspective, *Geografiska Annaler. Series A, Physical Geography,* **75**, 205-220.

KENNETT, J.P. 1977. Cenozoic evolution of the Antarctic glaciation, the circum-Antarctic ocean and their impact on global paleoceanography, *J. Geophys. Res.,* **82**, 3843-3876.

KENNETT, J.P. 1978. The development of planktonic biostratigraphy in the Southern Ocean during the Cenozoic, *Marine Micropaleontology,* **3**, 301-345.

KENNETT, J.P. 1982. Marine Geology. Prentice Hall,, Englewood Cliffs, 813 pp.

KENNICUTT, M.C., MCDONALD, S.J, SERICANO, J.L., BOOTHE, P., OLIVER, J., SAFE, F., PRESLEY, B.J., LIU, H., WOLFE, D., WADE, T.L., CROCKETT, A., BOCKUS, D. 1995. Human contamination of the marine environment: Arthur Harbor and McMurdo Sound, Antarctica, *Environ. Sci. Technol.,* **29**, 1279-1287.

KEY, R.M., KOZYR, A., SABINEC, L., LEE, K., WANNINKHOF, R., BULLISTER, J., FEELY, R.A., MILLERO, F., MORDY, C. and PENG, T-H. 2004. A global ocean carbon climatology: results from GLODAP, *Global Biogeochemical Cycles,* **18**, GB4031

KEYS, H., JACOBS, S. and BARNETT, D. 1990. The calving and drift of iceberg B-9 in the Ross Sea, Antarctica, *Antarctic Science,* **2**(3), 243-257.

KHAZENDAR, A., RIGNOT, E. and LAROUR, E. 2007. Larsen B Ice Shelf rheology preceeding its disintegration inferred by a control method, *Geophysical Research Letters,* **34,** L19503, doi:10.1029/2007GL030980.

KIERNAN, K. and MCCONNELL, A. 1999. Geomorphology of the sub- Antarctic Australian territory of Heard Island–McDonald Island, *Australian Geographer,* **30**, 159–195.

KIERNAN, K. and MCCONNELL, A. 2002. Glacier retreat and melt-lake expansion at Stephenson Glacier, Heard Island World Heritage Area*, Polar Record*, **38**, 297-308.

KIM, K., JEZEK, K.C. and LIU, H. 2007. Orthorectifield image mosaic of Antarctica from 1963 Argon satellite photography: image processing and glaciological applications, *International Journal of Remote Sensing*, **28**(23), 5357-5373, doi: 10.1080/01431160601105850.

KING, J.C. 1994. Recent climate variability in the vicinity of the Antarctic Peninsula, *Int. J. Climat.,* **14**, 357-369.

KING, J.C. and COMISO, J.C. 2003. The spatial coherence of interannual temperature variations in the Antarctic Peninsula, *Geophysics Research Letters,* **30,** [2 10.1029/2002GL015580].

KING, J.C. and HARANGOZO, S.A. 1998. Climate change in the western Antarctic Peninsula since 1945: observations and possible causes, *Annals of Glaciology,* **27**, 571-575.

KING, J.C. and TURNER, J. 1997. Antarctic meteorology and climatology, Cambridge University Press, Cambridge, UK, 409 pp.

KING, J.C. 1994. Recent variability in the Antarctic Peninsula, *International Journal of Climatology,* **14**(4), 357-369.

KING, J.C. 2003. Antarctic Peninsula climate variability and its causes as revealed by analysis of instrumental records, *Antarctic Peninsula Climate Variability: Historical and Paleoenvironmental Perspectives. Antarctic Research Series,* **79**, edited by E. Domack, et al., pp. 17-30, AGU, Washington, DC.

KING, M.A. 2004. Rigorous GPS data-processing strategies for glaciological. Applications, *J. Glaciol.,* **50**, 601–607.

KING, M.A., COLEMAN, R., MORGAN, P.J. and HURD, R.S. 2007. Velocity change of the Amery Ice Shelf, East Antarctica, during the period 1968-1999, *J. Geophys. Res.*, **112**, F01013, doi:10.1029/2006JF000609.

KIRKUP, H., MELLES, M. and GORE, D.B. 2002. Late Quaternary environment of Southern Windmill Islands, East Antarctica, *Antarctic Science,* **14**, 385-394.

KISTLER, R. and COAUTHORS. 1985. The NCEP/NCAR 50-year reanalysis project, *Bull. Amer. Meteor. Soc*., **82**, 247-267.

KLAAS, C. and ARCHER, D.E. 2002. Association of sinking organic matter with various types of mineral ballast in the deep sea: Implications for the rain ratio, *Global Biogeochemical Cycles*, **16**, doi:10.1029/2001GB001765.

KLATT, O., BOEBEL, O. and FAHRBACH, E. 2007. A profiling float's sense of ice, *J. Atmos. Oceanic Technol*., **24**, 1301-1308.

KLATT, O., FAHRBACH, E., HOPPEMA, M. and ROHARDT, G. 2005. The transport of the Weddell Gyre across the Prime Meridian, *Deep-Sea Research II,* **52**, 513-528.

KNAPP, A.K. ET AL. 1999. The keystone role of bison in North American tallgrass prarie, *Bioscience,* **49**, 39–50.

KNORR, G. and LOHMANN, G. 2003. Southern Ocean origin for the resumption of Atlantic thermohaline circulation during deglaciation, *Nature,* **424**, 532-536.

KOCK, K.-H. 1992. Antarctic Fish and Fisheries. Cambridge University Press, Cambridge and New York, 359 pp.

KOCK, K.-H. 2007. Antarctic Marine Living Resources – exploitation and its management in the Southern Ocean, *Antarctic Science,* **19**, 231–238.

KÖHLER, P. and FISCHER, H. 2006. Simulating low frequency changes in atmospheric CO_2 during the last 740 000 years, *Climate of the Past,* **2**,57-78.

KÖHLER, P., FISCHER, H., MUNHOVEN, G. and ZEEBE, R.E. 2005. Quantitative interpretation of atmospheric carbon records over the last glacial termination, *Glob. Biogeochem. Cycles,* **19**, Art. No. GB4020.

KOIDE, M., GOLDBERG, E.D., HERRON, M.M. and LANGWAY, C.C. 1979. Deposition history of artificial radionuclides in the Ross Ice Shelf, Antarctica, *Earth Planet Sci. Lett.,* **44**, 205-223.

KREHER, K., JOHNSTON, P.V., WOOD, S.W., NARDI, B. and PLATT, U. 1997. Ground-based measurements of tropospheric and stratospheric BrO at Arrival Heights, Antarctica. *Geophys. Res. Lett*., **24**(23), 3021 – 3024.

KREUTZ, K.J., MAYEWSKI, P.A., MEEKER, L.D., TWICKLER, M.S. and WHITLOW, S.I. 2000b. The effect of spatial and temporal accumulation rate variability in West Antarctica on soluble ion deposition, *Geophysical Research Letters,* **27**, 2517.

KREUTZ, K.J., MAYEWSKI, P.A., PITTALWALA, I.I., MEEKER, L.D., TWICKLER M.S. and WHITLOW, S.I. 2000a. Sea-level pressure variability in the Amundsen Sea region inferred from a West Antarctic glaciochemical record, *Journal of Geophysical Research*, **105** (D3), 4047-4059.

KRINNER, G., GENTHON, C. LI, Z.-X. and LE VAN, P. 1997. Studies of the Antarctic climate with a stretched grid GCM, *J. Geophys. Res.,* **102**, 13731-13745.

KRINNER, G., GUICHERD, G., OX, K., GENTHON, C. and MAGAND, O. 2008. Simulations of Antarctic climate and surface mass balance change from 1981-2000 to 2081-2100, *Journal of Climate*, **21**, 936-962, DOI: 10.1175/2007/JCLI960.1.

KRINNER, G., MAGAND, O., SIMMONDS, I., GENTHON, C. and DUFRESNE J.L. 2007. Simulated Antarctic precipitation and surface mass balance at the end of the twentieth and twenty-first centuries, *Clim. Dyn.*, **28**, 215-230.

KUHN, M., KUNDLA, L.S. and STRESCHEIN, L.A. 1977. The radiation budget at Plateau Station, Antarctica, *Am. Geophys. Union*, 41-73 (Antarctic Res. Ser., 25).

KULBE, T., MELLES, M., VERKULICH, S.R. and PUSHINA, Z.V. 2001. East Antarctic climate and environmental variability over the last 9400 years inferred from marine sediments of the Bunger Oasis, *Arctic Antarctic and Alpine Research,* **33**, 223-230.

KUNZE, E., FIRING, E., HUMMON, J.M., CHERESKIN, T.K. and THURNHERR, A.M. 2006. Global abyssal mixing inferred from lowered ADCP shear and CTD strain profiles, *J. Phys. Oceanogr.,* **36**, 1553-1576.

KURBATOV, A.V., ZIELINSKI, G.A., DUNBAR, N.W., MAYEWSKI, P.A., MEYERSON, E.A., SNEED, S.B. and TAYLOR, K.C. 2006. A 12,000 year record of explosive volcanism in the Siple Dome Ice Core, West Antarctica, *Journal of Geophysical Research,* **111**, D12307, doi:10.1029/2005JD006072.

KWOK, R. and COMISO, J.C. 2002. Southern ocean climate and sea ice anomalies associated with the Southern Oscillation, *J. Climate*, **15**, 487–501.

L'HEUREUX, M.L. and THOMPSON, D.W.J. 2006. Observed relationships between the El-Niño/Southern Oscillation and the extratropical zonal mean circulation, *J. Climate*, **19**, 276–287.

LACHLAN-COPE, T.A. and CONNOLLEY, W.M. 2006. Teleconnections between the tropical Pacific and the Amundsen-Bellingshausen Sea: role of the El Niño/Southern Oscillation, *Journal of Geophysical Research,* **111** [D23], doi:10.1029/2005JD006386.

LACHLAN-COPE, T.A. 1992. The use of a simultaneous physical retrieval scheme for satellite derived atmospheric temperaturesL Weddell Sea, Antarctica, *International Journal of Remote Sensing*, **13**, 141–154.

LACIS, A.A., WEUBBLES, D.J. and LOGAN, J.A. 1990. Radiative forcing of climate change by changes in the vertical distribution of ozone, *J. Geophys. Res.*, **95**, 9971-9981.

LAMBECK, K. and CHAPPELL, J. 2001. Sea level change through the last glacial cycle, *Science,* **292**, 679-686.

LANG, O., RABUS, B. and DECH, S. 2004. Velocity map of the Thwaites Glacier catchment, West Antarctica, *Journal of Glaciology*, **50**(168), 46--56.

LANGDON, C. and ATKINSON, M.J. 2005. Effect of elevated pCO_2 on photosynthesis and calcification of corals and interactions with seasonal change in temperature/irradiance and nutrient enrichment, *Journal of Geophysical Research-Oceans*, **110**, C09S07, doi:10.1029/2004JC002576.

LANNIG, G., BOCK, C., SARTORIS, F.J. and PÖRTNER, H.O. 2004. Oxygen limitation of thermal tolerance in cod, *Gadus morhua* L. studied by non-invasive NMR techniques and on-line venous oxygen monitoring, *Amer. J. Physiol.,* **287**, R902–R910.

LANNIG, G., STORCH, D. and PÖRTNER, H.O. 2005. Aerobic mitochondrial capacities in Antarctic and temperate eelpout (Zoarcidae) subjected to warm versus cold acclimation, *Polar Biol.,* **28**, 575-584. DOI: 10.1007/s00300-005-0730-9.

LARGE, W.G. and NURSER, A.J.G. 1998. Ocean Surface Water Mass Transformations, 317-336 in: Eds: Siedler, G., Church, J. and Gould, J., *Ocean Circulation and Climate*. Academic Press, San Diego, 715 pp.

LARGE, W.G., WILLIAMS, J.C. and DONEY, S.C. 1994. Oceanic vertical mixing: a review and a model with nonlocal boundary layer parameterization, *Reviews of Geophysics*, **32**, 363-403.

LAW, R.M., MATEAR, R.J. and FRANCEY, R.J. 2008. Comment on "Saturation of the Southern Ocean CO2 Sink Due to Recent Climate Change", *Science*, **359**, 570, *doi: 10.1126/science.1136188.*

LAWS, R. 1977a. Seals and whales of the Southern Ocean, *Phil. Trans Royal Soc. London*. B279, 81-96.

LAWS, R.M. 1977b. The significance of vertebrates in the Antarctic marine ecosystem. In: *Adaptations within Antarctic Ecosystem* (ed. G.A. Llano). Gulf Publishing Company, Houston, 411–438.

LAWVER, L.A. and GAHAGAN, L.M. 2003. Evolution of Cenozoic seaways in the circum-Antarctic region, *Palaeogeography, Palaeoclimatology, Palaeoecology*, **198**, 11-37.

LAZZARA, M.A., JEZEK, K.C., SCAMBOS, T.A., MACAYEAL, D.R. and VAN DER VEEN, C.J. 1999. On the recent calving of icebergs from the Ross Ice Shelf, *Polar Geography*, **23**(3), 201-212.

LE QUERE, C., RODENBECK, C., BUITENHUIS, E.T., CONWAY, T.J., LANGENFELDS, R., GOMEZ, A., LABUSCHAGNE, C., RAMONET, M., NAKAZAWA, T., METZL, N., GILLETT, N. AND HEIMANN, M. 2007.

Saturation of the Southern Ocean CO_2 Sink Due to Recent Climate Change, *Science 10.1126/science.1136188*, **316**, 1735-1738.

LEAPER, R., BANNISTER, J.L., BRANCH, T.A., CLAPHAM, P., DONOVAN, G., and REILLY, S. and ZERBINI, A.N. 2008. A review of abundance, trends and foraging parameters of baleen whales in the Southern Hemisphere. Paper SC/60/EM3 presented to the IWC Scientific Committee, June 2008 (in press) 51pp.

LEAPER, R., COOKE, J., TRATHAN, P.N., REID, K., ROWNTREE, V. and PAYNE, R. 2006. Global climate drives southern right whale (*Eubalaena australis*) population dynamics, *Biology Letters*, **2**, 289–292.

LEDLEY, T.S. and HUANG, Z. 1997. A Possible ENSO Signal in the Ross Sea, *Geophysical Research Letters*, **24**, 3253-3256.

LEDUC, R.G., ROBERSTON, K.M. and PITMAN, R.L. 2008. Mitochondrial sequence divergence among Antarctic killer whale ecotypes is consistent with multiple species, *Biology Letters,* **4**, 426-429.

LEE J.E. and CHOWN S.L. 2007. Mytilus on the move: transport of an invasive bivalve to the Antarctic, *Mar. Ecol Progr. Ser.*, **339**, 307–310.

LEE, A.M., ROSCOE, H.K., JONES, A.E., HAYNES, P.H., SHUCKBURGH, E.F., MORREY, M.J. and PUMPHREY, H.C. 2001. The impact of the mixing properties within the Antarctic stratospheric vortex on ozone loss in spring, *J. Geophys. Res.,* **106**, 3203-3211.

LEE, H.J., GERDES, D., VANHOVE, S. and VINCX, M. 2001a. Meiofauna response to iceberg disturbance on the Antarctic continental shelf at Kapp Norvegia (Weddell Sea), *Polar Biol*., **24** (12), 926-933.

LEE, H.J., VANHOVE, S., PECK, L.S. andVINCX, M. 2001b. Recolonisation of meiofauna after catastrophic iceberg scouring in shallow Antarctic sediments, *Polar Biol*., **24** (12), 918-925.

LEFEBRE, W. AND GOOSSE, H. 2008. Analysis of the projected regional sea-ice changes in the Southern Ocean during the twenty-first century, *Climate Dynamics,* **30**, 59-76, DOI 10.1007/s00382-007-0273-6.

LEFEBVRE, W., GOOSSE, H., TIMMERMANN, R. and FICHEFET, T. 2004. Influence of the Southern Annular Mode on the sea ice-ocean system, *J. Geophys. Res.*, **109**, C09005, doi:10.1029/2004JC002403.

LEGG, S., HALLBERG, R.R. and GIRTON, J.B. 2006. Comparison of entrainment in overflows simulated by z-coordinate, isopycnal and non-hydrostatic models, *Ocean Modelling*, **11** (1-2), 69-79.

LEGRAND, M. and MAYEWSKI, P. 1997. Glaciochemistry of polar ice cores: a review, *Rev. of Geophys*., **35** (3), 219-243.

LEGRESY, B. and REMY, F. 1997. Altimetric observations of surface characteristics of the Antarctic ice sheet, *J. Glaciol*., **43**(144), 265–275.

LEMKE, P., REN, J., ALLEY, R., ALLISON, I., CARRASCO, J., FLATO, G., FUJII, Y., KASER, G., MOTE, P., THOMAS, R. and ZHANG, T. 2007. Observations: change in snow, ice and frozen ground. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, 337-384 (Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL, Eds), Cambridge University Press, Cambridge, UK.

LENIHAN, H.S. and OLIVER, J.S. 1995. Anthropogenic and natural disturbance to main benthic communities in Antarctica, *Ecol. Appl.* **5**, 311-326.

LENIHAN, H.S., OLIVER, J.S., OAKDEN, J.M. and STEPHENSON, M.D. 1990. Intense and localized benthic marine pollution around McMurdo Station, Antarctica, *Mar. Pollut. Bull.* **21**, 422-430 .

LENTON, A. and MATEAR, R.J. 2007. The role of the Southern Annular Mode (SAM) in Southern Ocean CO2 uptake, *Global Biogeochemical Cycles*, **21**, doi: 10:1029/2006GB002714.

LENTON, A., BOPP, L. and MATEAR R.J. 2009. Strategies for high-latitude northern hemisphere CO_2 sampling now and in the future, *Deep Sea Research II*, doi:10.1016/j.dsr2.2008.12.008.

LENTON, A., MATEAR, R.J. and TILBROOK, B. 2006. Design of an observational strategy for quantifying the Southern Ocean uptake of CO2, *Global Biogeochemical Cycles*, GB0410, doi:10.1029/2005GB002650 .

LENTON, A., METZL, N., AUMONT, O., LO MONACO, C. and RODGERS, K. 2006. Simulating the Ocean Carbon Cycle: A focus on the Southern Ocean. Presented at Second CARBOOCEAN Annual Meeting, 4-8 Dec 2006, Maspalomas, Spain.

LEVANON, N., JULIAN, P.R. and SUOMI, V.E. 1977. Antarctic topography from balloons, *Nature*, **268**, 514-516, doi:10.1038/268514a0.

LEVENTER, A., DOMACK, E., BARKOUKIS, A., MCANDREWS, B. and MURRAY, J. 2002. Laminations from the Palmer Deep: A diatom-based interpretation, *Paleoceanography,* **17**, 8002.

LEVITUS, S., ANTANOV, J.I., BOYER, T.P. and STEPHENS, C. 2000. Warming of the world ocean, *Science*, **287** (5461), 2225-2229.

LEVITUS, S., ANTONOV, J. and BOYER, T. 2005. Warming of the world ocean, *Geophysical Res. Letters*, **32**, L02604, doi:10.1029/2004GL021592.

LEWIS, A.R., MARCHANT, D.R., ASHWORTH, A.C., HEDENAS, L., HEMMING, S.R., JOHNSON, J.V., LENG, M.J., MACHLUS, M.L., NEWTON, A.E. and RAINE, J.I. 2008. Mid-Miocene cooling and the extinction of tundra in continental Antarctica, *Proceedings of the National Academy of Sciences*, **105**, 10676-10680.

LEWIS, A.R., MARCHANT, D.R., ASHWORTH, A.C., HEMMING, S.R. and MACHLUS, M.L. 2007. Major middle Miocene global climate change: Evidence from East Antarctica and the Transantarctic Mountains, *GSA Bulletin,* **119**, 1449-1461.

LEWIS, P.N., BERGSTROM, D.M. and WHINAM, J. 2006. Barging in: A Temperate Marine Community Travels to the Subantarctic, *Biological Invasions,* **8**, 787-795.

LEWIS, P.N., HEWITT, C.L., RIDDLE, M. and MCMINN, A. 2003. Marine introductions in the Southern Ocean: an unrecognised hazard to biodiversity, *Marine Pollution Bulletin,* **46**, 213-223.

LI, J., ZWALLY, H.J. and COMISO, J.C. 2007. Ice-sheet elevation changes caused by variations of the firn compaction rate induced by satellite-observed temperature variations (1982–2003), *Ann. Glaciol.,* **46**, 8-13.

LI, Z.X., 2000. Influence of Tropical Pacific El Nino on the SST of the Southern Ocean through atmospheric bridge, *Geophysical Research Letters,* **27** (21), 3505-3508.

LICHT, K.J., DUNBAR, N.W., ANDREWS, J.T. and JENNINGS, A.E. 1999. Distinguishing subglacial till and glacial marine diamictons in the western Ross Sea, Antarctica: implications for last glacial maximum grounding line, *Geological Society of America Bulletin,* **111**, 91-103.

LICHT, K.J., JENNINGS, A.E., ANDREWS, J.T. and WILLIAMS, K.M. 1996. Chronology of late Wisconsin ice retreat from the western Ross Sea, Antarctica, *Geology,* **24**, 223-226.

LILJEQUIST, G.H. 1956. Energy exchange of an antarctic snow-field: A. Short-wave radiation; B. Long-wave radiation and radiation balance. Norweigian-British-Swedish Antarctic Expedition 1949-1952, *Scientific Results*, **2**, Part 1, Norsk Polarinstitut, Oslo, 1-184.

LIMPASUVAN, V. and HARTMANN, D.L. 2000. Wave-maintained annular modes of climate variability, *Journal of Climate*, **13**, 4414-4429.

LINSE, K., COPE, T., LÖRZ, A.-N. and SANDS C.J. 2007. Is the Scotia Sea a center of Antarctic marine diversification? Some evidence of cryptic speciation in the circum-Antarctic bivalve *Lissarca notorcadensis* (Arcoidea: Philobryidae), *Polar Biol.*, **30**, 1059-1068.

LINSE, K., GRIFFITHS, H.J., BARNES, D.K.A. and CLARKE, A. 2006. Biodiversity and biogeography of Antarctic and Sub-Antarctic Mollusca, *Deep-Sea Research II*, **53**, 985-1008.

LISIECKI, L.E. and RAYMO, M.E. 2005. A Pliocene-Pleistocene stack of 57 globally distributed benthic d18O records, *Paleoceanography,* **20**, PA1003, doi:1010.1029/2004PA001071.

LIU, H., WANG, L. and JEZEK, K.C. 2006. Spatiotemporal variations of snowmelt in Antarctica derived from satellite scanning multichannel microwave radiometer and Special Sensor Microwave Imager data (1978–2004), *J. Geophys. Res.,* **111**(F1), F01003. (10.1029/2005JF000318.)

LIU, J., CURRY, J.A. and MARTINSON, D.G. 2004. Interpretation of recent Antarctic sea ice variability, *Geophys. Res. Lett.*, **31**, L02205, doi:10.1029/2003GL018732.

LIU, J.P., YUAN, X.J., RIND, D. and MARTINSON, D.G. 2002. Mechanism study of the ENSO and southern high latitude climate teleconnections, *Geophysical Research Letters,* **29**, 1679.

LIU, X., SUN, L., XIE, Z., YIN, X., ZHU, R. and WANG, Y. 2007. A preliminary record of the historical seabird population in the Larsemann Hills, East Antarctica, from geochemical analyses of Mochou Lake sediments, *Boreas,* **36**, 182-197.

LIU, X.D., SUN, L., XIE, Z., YIN, X. and WANG, Y. 2005. A 1300-Year Record of Penguin Populations at Ardley Island in the Antarctic, as Deduced From the Geochemical Data in the Ornithogenic Lake Sediments, *Arctic Antarctic and Alpine Research,* **37**, 490-498.

LIU, X-D., LI, H-C., SUN, L-G., YIN, X-B., ZHAO, S-P. and WANG, Y-H. 2006. δ13C and δ15N in the ornithogenic sediments from the Antarctic maritime as palaeoecological proxies during the past 2000 yr, *Earth and Planetary Science Letters,* **243**, 424-438.

LIVERMORE, R., NANKIVELL, A., EAGLES, G. and MORRIS, P. 2004. Paleogene opening of Drake Passage, *Earth and Planetary Science Letters,* **236**, 459 – 470.

LIZOTTE, M.P. 2001. The contributions of sea ice algae to. Antarctic marine primary production, *Am. Zool.,* **41**, 57–73.

LO MONACO, C., METZL, N., POISSON, A., BRUNET, C. and SCHAUER, B. 2005. Anthropogenic CO_2 in the Southern Ocean: Distribution and inventory at the Indian-Atlantic boundary (WOCE line I6), *Journal of Geophysical Research*, **110**, 18.

LOCARNINI, R.A. 1994. Water masses and circulation in the Ross Gyre and environments. PhD thesis, Texas AandM University college Station.

LOEB, V., SIEGEL, V. HOLM-HANSEN, O., HEWITT, R., FRASER, W., TRIVELPIECE, W. and TRIVELPIECE, S. 1997. Effects of sea-ice extent and krill or salp dominance on the Antarctic food web, *Nature,* **387**, 897-900.

LONG, D.G. and DRINKWATER, M.R. 1999. Cryosphere applications of NSCAT data, *IEEE Trans. Geosci. Remote Sens.,* **37**(3), 1671–1684.

LONG, D.G., DRINKWATER, M.R., HOLT, B., SAATCHI, S. and BERTOIA, C. 2001. Global ice and land climate studies using scatterometer image data, *EOS, Transactions of the American Geophysical Union,* **82,** 503 (see also *http://www.agu.org/eos_elec/010126e.html*).

LOOTS, C., KOUBBI, P. and DUHAMEL, G. 2007. Habitat modelling of *Electrona antarctica* (Myctophidae, Pisces) in Kerguelen by generalized additive models and geographic information systems, *Polar Biol.*, **30**, 951-959.

LORIUS, C., MERLIVAT, L., JOUZEL, J. and POURCHET, M. 1979. A 30,000-yr isotope climatic record from Antarctic ice, *Nature,* **280**, 644-648.

LÖRZ A.-N., MAAS E.W., LINSE K. and FENWICK G.D. 2007. *Epimeria schiaparelli* sp nov., an epimeriid amphipod from the Ross Sea with a molecular characterization, *Zootaxa,* **1420**, 23-37.

LOULERGUE, L., PARRENIN, F., BLUNIER, T., BARNOLA, J.M., SPAHNI, R., SCHILT, A., RAISBECK, G. and CHAPPELLAZ, J. 2007. New constraints on the gas age-ice age difference along the EPICA ice cores, 0-50 kyr, *Climate of the Past,* **3**, 527-540.

LOULERGUE, L., SCHILT, A., SPAHNI, R., MASSON-DELMOTTE, V., BLUNIER, T., LEMIEUX, B., BARNOLA, J.M., RAYNAUD, D., STOCKER, T. and CHAPPELAZ, J. (Submitted). Orbital and millenial-scale features of atmospheric CH_4 over the last 800 000 years, *Nature.*

LOVENDUSKI, N., GRUBER, N., DONEY, S.C. and LIMA, I.D. 2007. Enhanced CO2 outagssing in the Southern Ocean from a positive phase of the Southern Annular Mode, *Global Biogeochemical Cycles*, **21**, GB2026, doi:10.1029/2006GB002900.

LOWE, A.L. and ANDERSON, J.B. 2002. Late Quaternary advance and retreat of the West Antarctic Ice Sheet in Pine Island Bay, Antarctica, *Quaternary Science Reviews,* **21**, 1879-1897.

LOWE, C.J. and DAVISON, W. 2005. Plasma osmolarity, glucose concentration and erythrocyte responses of two Antarctic nototheniid fishes to acute and chronic thermal change, *J. Fish Biol.,* **67**(3), 752-766.

LOWE, J.A., GREGORY, J.M. and FLATHER, R.A. 2001. Changes in the occurrence of storm surges around the United Kingdom under a future climate scenario using a dynamic storm surge model driven by the Hadley Centre climate models, *Climate Dynamics*, **18**, no. 3/4, 179-188.

LOWE, J.A., GREGORY, J.M., RIDLEY, J., HUYBRECHTS, P., NICHOLLS, R.J. and COLLINS, M. 2006. The role of sea-level rise and the Greenland ice sheet in dangerous climate change: Implications for the stabilisation of climate. *In Avoiding Dangerous Climate Change*, Schellnhuber, H.J., Cramer, W., Nakicenovic, N., Wigley, T. and Yohe, G. (eds). Cambridge University Press.

LUCHITTA, B.K. and ROSANOVA, C.E. 1998. Retreat of northern margins of George VI and Wilkins ice shelves, Antarctic Peninsula, *Ann. Glaciol*., **27**, 41.

LUD, D., MOERDIJK, T.C.W., VAN DE POLL, W.H., BUMA, A.G.J., and HUISKES, A.H.L. 2002. DNA damage and photosynthesis in Antarctic and Arctic *Sanionia uncinata* (Hedw.) Loeske under ambient and enhanced levels of UV-B radiation, *Plant Cell and Environment,* **25**, 1579-1589.

LUMPKIN, R AND SPEER, K. 2007. Global ocean meridional overturning, *Journal of Physical Oceanography,* **37**, 2550-2562.

LÜTHI, D., LE FLOCH, M., BEREITER, B., BLUNIER, T., BARNOLA, J-M., SIEGENTHALER, U., RAYNAUD, D., JOUZEL, J., FISCHER, H., KAWAMURA, K. and STOCKER, T.F. 2008. High-resolution carbon dioxide concentration record 650,000-800,000 years before present, *Nature,* **453**, 379-382.

LYNCH, A., UOTILA, P. and CASSANO, J.J. 2006. Changes in synoptic weather patterns in the polar regions in the twentieth and twenty-first centuries, Part 2: Antarctic, *Int. J. Climatol.*, **26**, 1181–1199.

LYONS, W.B., LAYBOURN-PARRY, J., WELCH, K.A. and PRISCU, J.C. 2006. Antarctic lake systems and climate change. In: *Trends in Antarctic Terrestrial and Limnetic Ecosystems: Antarctica as a Global Indicator*, eds. Bergstrom, D.M, Convey, P. and Huiskes, A.H.L. Springer, Dordrecht, 273-295.

LYONS, W.B., TYLER, S.W., WHARTON, R.A., MCKNIGHT, D.M. and VAUGHAN, B.H. 1998. A late Holocene desiccation of Lake Hoare and Lake Fryxell, McMurdo Dry Valleys, Antarctica, *Antarctic Science,* **10**, 247-256.

LYTHE, M.B., VAUGHAN, D.G. and BEDMAP CONSORTIUM, 2001. BEDMAP: A new ice thickness and subglacial topographic model of Antarctica, *Journal of Geophysical Research*, **106** , No. B6 , 11,335-11,3351.

LYTHE, M.B., VAUGHAN, D.G. and THE BEDMAP CONSORTIUM. 2000. BEDMAP - bed topography of the Antarctic. 1:10,000,000 scale map. BAS (Misc) 9. Cambridge, British Antarctic Survey.

MAASCH, K., MAYEWSKI, P.A., ROHLING, E., STAGER, C., KARLÉN, W., MEEKER, L.D. and MEYERSON, E. 2005. Climate of the past 2000 years, *Geografiska Annaler,* **87A** (1), 7-15.

MACAYEAL, D.R. 1989. Large-scale ice flow over a viscous basal sediment: Theory and application to Ice Stream B, Antarctica, *Journal of Geophysical Research,* **94**(B4), 4071-4087.

MACAYEAL, D.R., SCAMBOS, T.A., HULBE, C.L. and FAHNESTOCK, M.A., 2003. Catastrophic Ice-Shelf Break-Up by an Ice-Shelf-Fragment-Capsize Mechanism, *J. Glaciol.*, **49**(164) 22-36.

MACKINTOSH, A., WHITE, D., FINK, D., GORE, D.B., PICKARD, J. and FANNING, P.C. 2007. Exposure ages from mountain dipsticks in Mac. Robertson Land, East Antarctica, indicate little change in ice-sheet thickness since the Last Glacial Maximum, *Geology,* **35**, 551-554.

MACKINTOSH, N.A. and HERMAN, H.F.P. 1940. Distribution of the pack-ice in the Southern Ocean, *Discovery Report*s, **19**, 285-296.

MACKINTOSH, N.A. 1972. Life cycle of Antarctic krill in relation to ice and water conditions, *Discovery Reports*, **36**, 1-94.

MADDEN, R.A. and JULIAN, P.R. 1994. Observations of the 40-50 day tropical oscillation - A review, *Monthly Weather Review,* **122***,* 814-837.

MADEC, G. 2008. "NEMO ocean engine". Note du Pole de modélisation, Institut Pierre-Simon Laplace (IPSL), France, No **27** ISSN No 1288-1619.

MADEC, G., DELECLUSE, P., IMBARD, M. AND LÉVY, C. 1998. OPA8.1 Ocean general circulation model reference manual. Notes de l'IPSL, Université P. et M. Curie, B102 T15-E5, 4 place Jussieu, Paris cedex 5, N°11, 91p.

MAE, S. and YOSHIDA, M. 1987. Airborne radio echo-sounding in Shirase Glacier drainage basin, Antarctica, *Ann. Glaciol*., **9**, 160–165.

MAGAND O., GENTHON, C., FILY, M., KRINNER, G., PICARD, G., FREZZOTTI, M. and EKAYKIN, A.A. 2007. An up-to-date quality-controlled surface mass balance data set for the 90°–180°E Antarctica sector and 1950–2005 period, *J. Geophys. Res*., **112**, D12106, doi:10.1029/2006JD007691.

MAGAND, O., FREZZOTTI, M., POURCHET, M., STENNI, B., GENONI, L. and FILY, M. 2004. Climate variability along latitudinal and longitudinal transects in East Antarctica, *Annals of Glaciology,* **39**, 351-358.

MAHADEVAN, A., LEVY, M and MEMERY, L. 2004. Mesoscale variability of sea surface pCO_2: What does it respond to?, *Global Biogeochemical Cycles*, **18** (1), GB1017/10.1029/2003GB002102.

MAHAFFY, M.W. 1976. A three-dimensional numerical model of ice sheets: tests on the Barnes Ice Cap, Northwest Territories, *Journal of Geophysical Research,* **81**, 1059-1066.

MAHON A.R., ARANGO C.P. and HALANYCH K.M. 2008. Genetic diversity of *Nymphon* (Arthropoda: Pycnodonida: Nymphonidae) along the Antarctic Peninsula with a focus on Nymphon austral Hodgson 1902, *Mar. Biol.*, **155**, 315-323.

MAKINSON, K. 2002. Modeling tidal current profiles and vertical mixing beneath Filchner-Ronne Ice Shelf, Antarctica, *J. Phys. Oceanogr.,* **32**, 202-215.

MAKINSON, K., SCHRÖDER, M. and OSTERHUS, S. 2006. Effect of critical latitude and seasonal stratification on tidal current profiles along Ronne Ice Front, Antarctica, *J. Geophys. Res.,* **111**, doi:10.1029/2005JC003062.

MALTRUD, M.E. and MCCLEAN, J.L. 2005. An eddy resolving global 1/10 degrees ocean simulation, *Ocean Modelling*, **8**(1-2), 31-54.

MANABE S., STOUFFER, R.J., SPELMAN, M.J. and BRYAN, K. 1991. Transient responses of a coupled atmosphere-ocean model to gradual changes of atmospheric CO_2. I. Annual mean response, *J. Clim.*, **4**, 785-818.

MANABE, S. and STOUFFER, R.J. 1993. Century-scale effects of increased atmospheric CO2 on the ocean-atmosphere system, *Nature,* **364**, 215-218.

MANN, M. E. and JONES, P.D. 2003. Global surface temperatures over the past two millennia, *Geophysical Research Letters*, **30**, doi: 10.129/2003GL017814.

MANZINI, E., STEIL, B., BRÜHL, C., GIORGETTA, M.A. and KRÜGER, K. 2003. A new interactive chemistry-climate model: 2. Sensitivity of the middle atmosphere to ozone depletion and increase in greenhouse gases and implications for recent stratospheric cooling, *J. Geophys. Res.*, **108**, 4429.

MARCHANT, D.R., LEWIS, A., PHILLIPS, W.M., SOUCHEZ, R., DENTON, G.H., SUGDEN, D.E. and LANDIS, P. 2002. Formation of patterned ground and sublimation till over Miocene glacier ice in Beacon Valley, southern Victoria Land, *Geological Society of America Bulletin,* **114**, 718-730.

MARK, F.C., BOCK, C. and PÖRTNER, H.O. 2002. Oxygen limited thermal tolerance in Antarctic fish investigated by magnetic resonance imaging (MRI) and spectroscopy (^{31}P-MRS), *Amer. J. Physiol.,* **283**, R1254-R1262.

MARKUS, T., KOTTMEIER C. AND FAHRBACH, E. 1998. Ice formation in coastal polynyas in the Weddell Sea and their impact on oceanic salinity, in *Antarctic Sea Ice: Physical Processes, Interactions and Variability*, edited by M. O. Jeffries, 273-292, AGU, Washington D.C.

MARSHALL, A., LYNCH, A.H. and GÖRGEN, K. 2007. A model intercomparison study of the Australian summer monsoon. Part II: Variability at intraseasonal and interannual timescales, *Aust. Met. Mag.* (in review).

MARSHALL, D. P. and NAVEIRA GARABATO A. C. 2007. A conjecture on the role of bottom-enhanced diapycnal mixing in the parameterization of geostrophic eddies, *J. Phys. Oceanogr.*, in press.

MARSHALL, D.J. and COETZEE, L. 2000. Historical biogeography and ecology of a continental Antarctic mite genus, Maudheimia (Acari, Oribatida): evidence for a Gondwanan origin and Pliocene-Pleistocene speciation, *Zoological Journal of the Linnean Society,* **129**, 111-128.

MARSHALL, D.J. and CONVEY, P. 2004. Latitudinal variation in habitat specificity of ameronothroid mites, *Experimental and Applied Acarology,* **34**, 21-35.

MARSHALL, G. J. 2003. Trends in the Southern Annular Mode from Observations and Reanalyses, *Journal of Climate*, **16**, 4134-4143.

MARSHALL, G. J., ORR, A., VAN LIPZIG, N.P.M. and KING, J.C. 2006. The impact of a changing Southern Hemisphere Annular Mode on Antarctic Peninsula summer temperatures, *Journal of Climate,* **19** [20], 5388-5404.

MARSHALL, G.J. and CONNOLLEY, W.M. 2006. The effect of changing Southern Hemisphere winter sea surface temperatures on Southern Annular Mode strength, *Geophysical Research Letters*, **33** (17), 4, pp. doi 10.1029/2006GL026627.

MARSHALL, G.J. and TURNER, J. 1997b. Katabatic wind propagation over the western Ross Sea observed using ERS-1 scatterometer data, *Antarctic Science,* **9,** 221–226.

MARSHALL, G.J. and TURNER, J. 1997a. Surface wind fields of Antarctic mesocyclones derived from ERS-1 scatterometer data, *Journal of Geophysical Research,* **102,** 13907–13921.

MARSHALL, G.J. and TURNER, J. 1999. Synoptic-scale weather systems observed during the FROST project via scatterometer winds, *Weather and Forecasting,* **14,** 867–877.

MARSHALL, G.J. 2002. Analysis of recent circulation and thermal advection in the northern Antarctic Peninsula, *Int. J. Climatol.*, **22**,1557– 1567.

MARSHALL, G.J. 2007. Half-century seasonal relationships between the Southern Annular Mode and Antarctic temperatures, *Int. J. Climatol.*, **27**, 373-383.

MASLEN, N.R. and CONVEY, P. 2006. Nematode diversity and distribution in the southern maritime Antarctic – clues to history?, *Soil Biology and Biochemistry,* **38**, 3141-3151.

MASLENNIKOV, V.V. 1987. Secondary frontal discontinuities in the western part of the Antarctic Pacific sector (in Russian), *Biological oceanographic investigations in the Pacific sector of Antarctica,* VNIRO, Moscow, 32-41.

MASLIN, M., SEIDOV, D. and LOWE, J. 2001. Synthesis of the nature and causes of rapid climate transitions during the Quaternary, *Geophysical monograph,* **126**, 9-52.

MASSÉ, G., ROWLAND, S., SICRE, M-A., JACOB, J., JANSEN, E. and BELT, S. 2008. Abrupt climate changes for Iceland during the last millennium: Evidence from high resolution sea ice reconstructions, *Earth and Planetary Science Letters,* **269**, 564-568.

MASSOM, R.A., POOK, M.J., COMISO J.C., ADAMS, N., TURNER, J., LACHLAN-COPE, T. and GIBSON, T.T. 2004. Precipitation over the interior East Antarctic Ice Sheet related to midlatitude blocking-high activity*, J. Climate*, **17**, 1914–1928.

MASSON, V., VIMEUX, F., JOUZEL, J., MORGAN, V., DELMOTTE, M., CIAIS, P., HAMMER, C., JOHNSEN, S., LIPENKOV, V.Y., MOSLEY-THOMPSON, E., PETIT, J.R., STEIG, E.J., STIEVENARD, M. and VAIKMAE, R. 2000. Holocene climate variability in Antarctica based on 11 ice-core isotope records, *Quaternary Research,* **54**, 348-358.

MASSON-DELMOTTE, V., HOU, S., EKAYKIN, A., JOUZEL, J., ARISTARAIN, A., BERNARDO, R.T., BROMWHICH, D., CATTANI, O., DELMOTTE, M., FALOURD, S., FREZZOTTI, M., GALLÉE, H., GENONI, L., ISAKSSON, E., LANDAIS, A., HELSEN, M., HOFFMANN, G., LOPEZ, J., MORGAN, V., MOTOYAMA, H., NOONE, D., OERTER, H., PETIT, J.R., ROYER, A., UEMURA, R., SCHMIDT, G.A., SCHLOSSER, E., SIMÕES, J.C., STEIG, E., STENNI, B., STIEVENARD, M., BROEKE, M.V.D., WAL, R.V.D., BERG, W-J.V.D., VIMEUX, F. and WHITE, J.W.C. 2008. A review of Antarctic surface snow isotopic composition : observations, atmospheric circulation and isotopic modelling, *J. Climate,* **21**, 3359-3387.

MASSON-DELMOTTE, V., JOUZEL, J., LANDAIS, A., STIEVENARD, M., JOHNSEN, S.J., WHITE, J.W.C., WERNER, M., SVEINBJORNSDOTTIR, A. and FUHRER, K. 2005. GRIP Deuterium Excess Reveals Rapid and Orbital-Scale Changes in Greenland Moisture Origin, *Science,* **309**, 118 – 121.

MASSON-DELMOTTE, V., KAGEYAMA, M., BRACONNOT, P., CHARBIT, S., KRINNER, G., RITZ, C., GUILYARDI, E., JOUZEL, J., ABE-OUCHI, A., CRUCIFIX, M., GLADSTONE, R.M., HEWITT, C.D., KITOH, A., LEGRANDE, A., MARTI, O., MERKEL, U., MOTOI, T., OHGAITO, R., OTTO-BLIESNER, B., PELTIER, W.R., ROSS, I., VALDES, P.J., VETTORETTI, G., WEBER, S.L. and WOLK, F. 2006. Past and future polar amplification of climate change: climate model intercomparisons and ice-core constraints, *Climate Dynamics,* **26**, 513-529

MASSON-DELMOTTE, V., STENNI, B. and JOUZEL, J. 2004. Common millennial-scale variability of Antarctic and Southern Ocean temperatures during the past 5000 years reconstructed from the EPICA Dome C ice core, *The Holocene,* **14**, 145-151.

MATALONI, G. and TELL G. 2002. Microalgal communities from ornithogenic soils at Cierva Point, Antarctic Peninsula, *Polar Biol.*, **25**, 488-491.

MATEAR, R.J. and HIRST, A.C. 1999. Climate change feedback on the future oceanic CO_2 uptake, *Tellus*, **51B**, 722-733.

MATEAR, R.J. and LENTON, A. 2008. Impact of Historical Climate Change on the Southern Ocean Carbon Cycle, *Journal of Climate*, **21**, 5820-5834, doi: 10.1175/2008JCLI2194.1.

MATSUMOTO, G.I., KOMORI, K., ENOMOTO, A., IMURA, S., TAKEMURA, T., OHYAMA, Y. and KANDA, H. 2006. Environmental changes in Syowa Station area of Antarctica during the last 2300 years inferred from organic components in lake sediment cores, *Polar Biosciences,* **19**, 52-61.

MATSUOKA, N., MORIWAKI, K., IWATA, S. and HIRAKAWA, K. 1990. Ground temperature regimes and their relation to periglacial processes in the S/,or Rondane Mountains, East Antarctica. In: *Proceedings of the NIPR Symposium on Antarctic Geosciences*, **4**, 55-66.

MATTHEWS, A.J. and MEREDITH, M.P. 2004. Variability of Antarctic circumpolar transport and the Southern Annular Mode associated with the Madden-Julian

Oscillation, *Geophysical Research Letters*, **31**(24), L24312, 10.1029/2004GL021666.

MATTHEWS, H.D. and CALDEIRA, K. 2008. Stabilizing climate requires near-zero emissions, *Geophysical Research Letters*, **35**, L04705, doi:10.1029/2007GL032388.

MÄUSBACHER, R., MÜLLER, J. and SCHMIDT, R. 1989. Evolution of postglacial sedimentation in Antarctic Lakes (King-George-Island), *Zeitschrift Fur Geomorphologie,* **33**, 219-234.

MAYEWSKI, P. A., MEEKER, L. D., TWICKLER, M. S., WHITLOW, S. I., YANG, Q., LYONS, W. B., and PRENTICE, M., 1997b, Major features and forcing of high latitude northern hemisphere atmospheric circulation over the last 110 000 years, *J. Geophys. Res.*, **102**(C12), 26 345–26 366.

MAYEWSKI, P.A. and MAASCH, K. 2006. Recent warming inconsistent with natural association between temperature and atmospheric circulation over the last 2000 years. Climate of the Past (Discussions) http://www.copernicus.org/EGU/cp/cpd/2/327/cpd-2-327.htm.

MAYEWSKI, P.A. ET AL. 2006. The International Trans-Antarctic Scientific Expedition (ITASE): An overview, *Annals of Glaciology,* **41**, 180-185.

MAYEWSKI, P.A., DENTON, G.H. and HUGHES, T. 1981. Late Wisconsin ice margins of North America, In *The Last Great Ice Sheets*, ed. G. Denton and T. Hughes, 67-178.

MAYEWSKI, P.A., MAASCH, K., YAN, Y., KANG, S., MEYERSON, E., SNEED, S., KASPARI, S., DIXON, D., MORGAN, V., VAN OMMEN, T. and CURRAN, M. 2005b. Solar forcing of the polar atmosphere, *Annals of Glaciology,* **41**, 147-154.

MAYEWSKI, P.A., MAASCH, K.A., WHITE, J.W.C., MEYERSON, E., GOODWIN, I., MORGAN, V.I., VAN OMMEN, T., CURRAN, M.A.J., SOUNEY, J. and KREUTZ, K. 2004b. A 700 year record of Southern Hemisphere extra-tropical climate variability, *Annals of Glaciology,* **39**, 127-132.

MAYEWSKI, P.A., MEREDITH, M.P., SUMMERHAYES, C.P., TURNER, J., WORBY, A.P., BARRETT, P.J., CASASSA, G., BERTLER, N.A.N., BRACEGIRDLE, T.J., NAVEIRA-GARABATO, A.C., BROMWICH, D.H., CAMPBELL, H., HAMILTON, G.H., LYONS, W.B., MAASCH, K.A., AOKI, S., and XIAO, C. 2009. State of the Antarctic and Southern Ocean Climate System (SASOCS), *Reviews of Geophysics* , **47**, RG1003, doi:10.1029/2007RG000231.

MAYEWSKI, P.A., ROHLING, E., STAGER, C., KARLÉN, K., MAASCH, K., MEEKER, L.D., MEYERSON, E., GASSE, F., VAN KREVELD, S., HOLMGREN, K., LEE-THORP, J., ROSQVIST, G., RACK, F., STAUBWASSER, M., and SCHNEIDER, R., 2004a, Holocene climate variability, Quaternary Research, *Quaternary Research* **62**, 243-255.

MAYEWSKI, P.A., FREZZOTTI, M., BERTLER, N., VAN OMMEN, T., HAMILTON, G., JACKA, T.H., WELCH, B., FREY, M., DAHE, Q., JIAWEN, R., SIMÖES, J., FILY, M., OERTER, H., NISHIO, F., ISAKSSON, E., MULVANEY, R., HOLMUND, P., LIPENKOV, V. and GOODWIN, I. 2005a.

The International Trans-Antarctic Scientific Expedition (ITASE): an overview, *Ann. Glaciol.*, **41**(1), 180-185.

MCCARRON, J.J. and LARTER, R.D. 1998. Late Cretaceous to Early Tertiary Subduction History of the Antarctic Peninsula, *J. Geol. Soc. Lond.*, **155**, 255-268.

MCCARTNEY, M.S. and DONOHUE, K.A. 2007. A deep cyclonic gyre in the Australian-Antarctic Basin, *Progress in Oceanography*, **75**, 675-750.

MCCARTNEY, M.S. 1977. Subantarctic Mode Waters. In: Angel, M. (ed) *A voyage of discovery,* Pergamon, New York, 103-119.

MCCARTNEY, M.S. 1982. The subtropical circulation of Mode Waters, *Journal of Marine Research,* **40** (suppl), 427-464.

MCCONNELL, J.C., HENDERSON, G.S., BARRIE, L., BOTTENHEIM, J., NIKI, H., LANGFORD, C.H. and TEMPLETON, E.M.J. 1992. Photochemical bromine production implicated in Arctic boundary-layer ozone depletion, *Nature*, **355**, 150-152.

MCCORMAC, F., HOGG, A., BLACKWELL, P., BUCK, C., HIGHAM, T. and REIMER, P. 2004. Shcal04 Southern Hemisphere Calibration 0-11.0 Cal Kyr Bp, *Radiocarbon,* **46**, 1087-1092.

MCGRAW, J.B. and DAY, T.A. 1997. Size and characteristics of a natural seed bank in Antarctica, *Arctic and Alpine Research,* **29**, 213-216.

MCINNES, K.L., WALSH, K.J.E., HUBBERT. G.D. and BEER, T. 2003. Impact of Sea-Level Rise and Storm Surges on a Coastal Community, *Natural Hazards*, **30** Number 2, October 2003, 187-207(21).

MCKAY, C.P., MELLON, M.T., FRIEDMANN, E.I. 1998. Soil temperatures and stability of ice-cemented ground in the McMurdo Dry Valleys, Antarctica, *Antarctic Science*, **10**(1), 31-38.

MCKAY, R.M., BARRETT, P.J., HANNAH, M.H. and HARPER, M.A. 2008. Atmospheric transport and concentration of diatoms in surficial and glacial sediments of the Allan Hills, Transantarctic Mountains. Palaeogeography, *Palaeoclimatology, Palaeoecology,* **260**, 168-183.

MCMINN, A. 2000. Late Holocene increase in sea ice extent in fjords of the Vestfold Hills, eastern Antarctica, *Antarctic Science,* **12**, 80-88.

MCMULLEN, K., DOMACK, E.W., LEVENTER, A., DUNBAR, R.B. and BRACHFELD, S. 2006. Glacial morphology and sediment formation in the Mertz Trough, East Antarctica, *Palaeogeography, Palaeoclimatology, Palaeoecology,* **231**, 169- 180.

MCNEIL, B.I., METZL, N., KEY, R.M., MATEAR R.J. and CORVIERE, A. 2007., An empirical estimate of the Southern Ocean air-sea CO2 flux, *Global Biogeochemical Cycles*, **21***(3), GB03011, doi:10.1029/2007GB002991*

MCPHEE, M.G., MORISON, J.H. AND NILSEN, F. 2008. Revisiting heat and salt exchange at the ice-ocean interface: Ocean flux and modelling considerations, *Journal of Geophysical Research*, **113**, C06014, doi: 10.1029/2007JC004383.

MEEHL, G.A., T.F. STOCKER, W.D. COLLINS, P. FRIEDLINGSTEIN, A.T. GAYE, J.M. GREGORY, A. KITOH, R. KNUTTI, J.M. MURPHY, A. NODA,

S.C.B. RAPER, I.G. WATTERSON, A.J. WEAVER, and Z.-C. ZHAO, 2007: Global Climate Projections. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 749-845.

MEEKER, L.D. and MAYEWSKI, P.A. 2002. A 1400-year high-resolution record of atmospheric circulation over the North Atlantic and Asia, *The Holocene,* **12**, 257-266.

MELICK, D.R. and SEPPELT, R.D. 1992. Loss of soluble carbohydrates and changes in freezing point of Antarctic bryophytes after leaching and repeated freeze-thaw cycles, *Antarctic Science,* **4**, 399-404.

MELLES, M., KULBE, T., VERKULICH, S.R., PUSHINA, Z.V. and HUBBERTEN, H-W. 1997. Late Pleistocene and Holocene environmental history of Bunger Hills, East Antarctica, as revealed by fresh-water and epishelf lake sediments. In: Ricci CA (ed) *The Antarctic Region: Geological Evolution and Processes. Proceedings of the VII International Symposium on Antarctic Earth Sciences, Siena, 1995*. Terra Antarctica, Sienna, 809-820.

MELLOR, G.L. and YAMADA, T. 1982. Development of a turbulent closure model for geophysical fluid problems, *Geophysics and Space Physics*, **20**, 851-875.

MELLOR, G.L. 2003. Users guide for a three-dimensional, primitive equation, numerical ocean model (June 2003 version), 53 pp., Prog. in Atmos. and Ocean. Sci, Princeton University.

MERCER, J.H. 1968. Antarctic ice and Sangamon sea level, *IASH publ.* **79**, 217-225.

MERCER, J.H. 1978. West Antarctic ice sheet and CO2 greenhouse effect: a threat of disaster, *Nature,* **271**, 321-325.

MEREDITH, M.P. and HOGG, A.M. 2006. Circumpolar response of Southern Ocean eddy activity to a change in the Southern Annular Mode, *Geophys. Res. Letters*, **33**, doi: 10.1029/2006GL026499.

MEREDITH, M.P. and HUGHES, C.W. 2005. On the sampling timescale required to reliably monitor interannual variability in the Antarctic circumpolar transport, *Geophysical Research Letters*, **32**(3), L03609, 10.1029/2004GL022086.

MEREDITH, M.P. and KING, J.C. 2005. Rapid climate change in the ocean west of the Antarctic Peninsula during the second half of the 20^{th} century, *Geophys. Res. Lett.,* **32**, L19604. (doi: 10.1029/2005GL024042)

MEREDITH, M.P., LOCARNINI, R.A., VAN SCOY, K.A., WATSON, A.J., HEYWOOD, K.J. and KING, B.A. 2000. On the sources of Weddell Gyre Antarctic Bottom Water, *J. Geophys. Res*., **105**, 1093-1104.

MEREDITH, M.P., MURPHY, E.J. HAWKER, E.J., KING, J.C. and WALLACE, M.I. 2007. On the interannual variability of ocean temperatures around South Georgia, Southern Ocean: forcing by El Niño/Southern Oscillation and the Southern Annular Mode, *Deep-Sea Research II,* in press.

MEREDITH, M.P., RENFREW, I.A., CLARKE, A., KING, J.C. and BRANDON, M.A. 2004. Impact of the 1997/98 ENSO on upper ocean characteristics in

Marguerite Bay, western Antarctic Peninsula, *Journal of Geophysical Research Oceans*, **109**, C09013.

MEREDITH, M.P., WOODWORTH, P.L., HUGHES, C.W. and STEPANOV, V. 2004. Changes in the ocean transport through Drake Passage during the 1980s and 1990s, forced by changes in the Southern Annular Mode, *Geophysical Research Letters*, **31**(21), L21305, 10.1029/2004GL021169.

METZL, N. 2009. Decadal Increase of ocean carbon dioxide in the Southwest Indian Ocean Surface Waters (1991-2007), *Deep Sea Research II*, doi:10.1016/j.dsr2.2008.12.007.

METZL, N., BRUNET, C., JABAUD-JAN, A., POISSON, A. and SCHAUER, B. 2006. Summer and Winter Air-Sea CO_2 Fluxes in the Southern Ocean, *Deep-Sea Research II*, **53**.

METZL, N., TILBROOK, B. and POISSON, A. 1999. The annual fCO2 cycle and the air-sea CO2 flux in the sub-Antarctic Ocean, *Tellus*, **51B**, 849-861.

MEURK, C.D., FOGGO, M.N. and WILSON, J.B. 1994a. The vegetation of subantarctic Campbell Island, *New Zealand Journal of Ecology,* **18,** 123–168.

MEURK, C.D., FOGGO, M.N., THOMPSON, B.M., BATHURST, E.T.J., and CROMPTON, M.B. 1994b. Ion–rich precipitation and vegetation patterns on subantarctic Campbell Island, *Arctic and Alpine Research,* **26**, 281–289.

MEYERS, G., BAILEY, R.J. and WORBY, A.P. 1995. Geostrophic transport of Indonesian Throughflow, *Deep-Sea Res*., I, **42**, 1163-1174.

MEYERSON, E.A., MAYEWSKI, P.A., WHITLOW, S.I., MEEKER, L.D., KREUTZ, K.J. and TWICKLER, M.S. 2002. The extratropical expression of ENSO recorded in a South Pole glaciochemical time series, *Annals of Glaciology,* **35**, 430-436.

MICHAUD, L., CELLO, F.D., BRILLI, M., FANI, R., GUIDICE, A.L. and BRUNI, V. 2004. Biodiversity of cultivable psychrotrophic marine bacteria isolated from Terra Nova Bay (Ross Sea, Antarctica), *FEMS Microbiol. Lett.,* **230**, 63-71.

MIDDLETON, A.J., BROWN, A.M., DAVIES, P.L. and WALKER, V.K. 2009. Identification of the ice-binding face of a plant antifreeze protein, *FEBS letters,* **583**, 815-819.

MIGNONE, B.K., GNANADESKIKAN, A., SARMEINTO, J.L. and SLATER, R.D. 2006. Central role of the Southern Hemisphere winds and eddies in modulating the oceanic uptake of anthropogenic carbon, *Geophysical Research Letters*, **33**, doi:10.0129/2005GL024464.

MILLER, K.G., WRIGHT, J.D., KATZ, M.E., BROWNING, J.V., CRAMER, B.S., WADE, B.S. and MIZINTSEVA, S.F. 2008. A View of Antarctic Ice-Sheet Evolution from Sea-Level and Deep-Sea Isotope Changes During the Late Cretaceous-Cenozoic. In: Cooper AK, Barrett P, Stagg H, Storey B, Stump E, Wise W (eds) *Antarctica: A Keystone in a Changing World. Proceedings of the 10th International Symposium on Antarctic Earth Sciences, Santa Barbara, California, August 26 to September 1, 2007*. Polar Research Board, National Research Council, U.S. Geological Survey.

MILLER, R.L., SCHMIDT, G.A. and SHINDELL, D.T. 2006. Forced annular variations in the 20th century Intergovernmental Panel on Climate Change Fourth Assessment Report models, *J. Geophys. Res.*, **111,** doi:10.1029/2005JD006323.

MILNE, G.A. 2009. Using models to inform the field community: Far-field sea level data applications, *PAGES News,* **17,** No 2 June 2009, 56-57.

MILNE, G.A., GEHRELS, W.R., HUGHES, C.W. and TAMISIEA, M.E. 2009. Identifying the causes of sea-level change, *Nature Geoscience*, advance online publication, doi: **10**.1038/ngeo544.

MINCKS, S.L., SMITH, C.R. and DEMASTER, D.J. 2005. Persistence of labile organic matter and microbioal biomass in Antarctic shelf sediments: evidence of a sediment 'food bank', *Mar. Ecol. Prog. Ser.,* **300**, 3-19.

MITCHELL, A.D., MEURK, C.D. and WAGSTAFF, S.J. 1999. Evolution of *Stilbocarpa,* a megaherb from New Zealand's sub–antarctic islands, *New Zealand Journal of Botany,* **37**, 205–211.

MIURA, H., MAEMOKU, H., IGARISHI, A. and MORIWAKI, K. 1998. Late Quaternary raised beach deposits and radiocarbon dates of marine fossils around Lützow-Holm Bay, Special map series of National Institute of Polar Research, 6, Tokyo.

MO, K.C. and HIGGINS, R.W. 1998. The Pacific-South America modes and tropical convection during the Southern Hemisphere winter, *Mon. Weather Rev*., **126**, 1581-1596.

MOBERG, A., SONECHIDEN, D.M., HOLMGREN, K., DATSENKO, M.N. and KARL EN, W. 2005. Highly variable Northern Hemisphere temperatures reconstructed from low- and high-resolution proxy data, *Nature*, **433**, 613–17.

MOENS, T. and VINCX, M. 2000b. Temperature, salinity and food thresholds in two brackish-water bacterivorous nematode species: assessing niches from food absorption and respiration experiments, *Journal of Experimental Marine Biology and Ecology,* **243**, 137-154.

MOENS, T. and VINCX, M. 2000a. Temperature and salinity constraints on the life cycle of two brackish-water nematode species, *Journal of Experimental Marine Biology and Ecology,* **243**, 115 – 135.

MOENS, T., VANHOVE, S., DE MESEL, I., KELEMEN, B., JANSSENS, T., DEWICKE, A. and VANREUSEL, A. 2007. Carbon sources of Antarctic nematodes as revealed by natural carbon isotope ratios and a pulse-chase experiment, *Polar Biol*., **31** (1), 1-13.

MOLEMAKER, J., MCWILLIAMS, J.C. and YAVNEH, I. 2005. Baroclinic instability and loss of balance, *J. Phys. Oceanogr.* **35**, 1505-1517.

MOLINE, M.A. and PREZELIN, B.B. 1996. Palmer LTER 1991-1994: Long-term monitoring and analyses of physical factors regulating variability in coastal Antarctic phytoplankton biomass, in situ productivity and taxonomic composition over subseasonal, seasonal and interannual time scales phytoplankton dynamics, *Mar. Ecol. Prog. Ser.,* **145**, 143-160.

MOLINE, M.A., CLAUSTRE, H., FRAZER, T.K., GRZYMSKI, J., SCHOFIELD, O.M. and VERNET, M. 2000. Changes in phytoplankton assemblages along the

Antarctic Peninsula and potential implications for the Antarctic food web. In: *Antarctic Ecosystems: Models for Wider Ecological Understanding*. W. Davidson, C. Howard-Williams, P. Broady (eds), 263-271.

MONAGHAN, A.J. and BROMWICH, D.H. 2008. Advances in describing recent Antarctic climate variability, *Bull. Amer. Meteorol. Soc.*, **89**, 1295-1306.

MONAGHAN, A.J., BROMWICH, D.H. and WANG, S-H. 2006a. Recent trends in Antarctic snow accumulation from Polar MM5, *Philosophical Trans. Royal. Soc. A*, **364**, 1683-1708.

MONAGHAN, A.J., BROMWICH, D.H., CHAPMAN, W. and COMISO, J.C. 2008. Recent variability and trends of Antarctic near-surface temperature, *J. Geophys. Res.*, **113**D04105, doi:10.1029/2007JD009094.

MONAGHAN, A.J., BROMWICH, D.H., FOGT, R.L., WANG, S.H., MAYEWSKI, P.A., DIXON, D.A., EKAYKIN, A., FREZZOTTI, M., GOODWIN, I., ISAKSSON, E., KASPARI, S.D., MORGAN, V.I., OERTER, H., VAN OMMEN, T.D., VAN DER VEEN, C.J. and WEN, J.H. 2006a. Insignificant change in Antarctic snowfall since the International Geophysical Year, *Science,* **313**, 827-831.

MONNIN, E., INDERMUHLE, A., DALLENBACH, A., FLUCKIGER, J., STAUFFER, B., STOCKER, T.F., RAYNAUD, D. and BARNOLA, J-M. 2001. Atmospheric CO2 Concentrations over the Last Glacial Termination, *Science,* **291**, 112-114.

MONTES-HUGO, M., DONEY, S.C., DUCKLOW, H.W., FRASER, W., MARTINSON, D., STAMMERJOHN, S.E. and SCHOFIELD, O. 2009. Recent Changes in Phytoplankton Communities Associated with Rapid Regional Climate Change Along the Western Antarctic Peninsula, *Science,* **323** (5920), 1470-1473.

MONTONE, R.C., TANIGUCHI, S. and WEBER, R.R. 2003. PCBs in the atmosphere of King George Island, Antarctica, *The Science of the Total Environment,* **308**, 167-173.

MOORE, J.K., ABBOTT, M.R. and RICHMAN, J.G. 1999. Location and dynamics of the Antarctic Polar Front from satellite sea surface temperature data, *Journal of Geophysical Research,* **104**, 3059-3073.

MORALES MAQUEDA, M.A., WILLMOTT, A.J. and BIGGS, N.R.T. 2004. Polynya dynamics: A review of observations and modelling, *Rev. Geophys.,* **42**, doi:10.1029/2002RG000116.

MORGAN, V., DELMOTTE, M., VAN OMMEN, T., JOUZEL, J., CHAPPELLAZ, J., WOON, S., MASSON-DELMOTTE, V. and RAYNAUD, D. 2002. Relative Timing of Deglacial Climate Events in Antarctica and Greenland, *Science,* **297**, 1862-1864.

MORGAN, V.I. and VAN OMMEN, T.D. 1997. Seasonality in late-Holocene climate from ice core records, *The Holocene*, **7**, 351-354.

MORIMOTO, S., NAKAZAWA, T., AOKI, S., HASHIDA, G. and YAMANOUCHI, T. 2003. Concentration variations of atmospheric CO2 observed at Syowa Station, Antarctica from 1984 to 2000, *Tellus*, **55B**, 170-177.

MORLEY, S.A., PECK, L.S., MILLER, A.J. and PÖRTNER, H.O. 2007. Hypoxia tolerance associated with activity reduction is a key adaptation for *Laternula elliptica* seasonal energetics, *Oecologia,* **153**, 29–36.

MORRIS, E.M. and MULVANEY, R. 2004. Recent variations in surface mass balance of the Antarctic Peninsula Ice Sheet, *J. Glaciol.,* **50***,* 257-267.

MORRIS, E.M. and VAUGHAN. D.G. 2003. Spatial and temporal variation of surface temperature on the Antarctic Peninsula and the limit of viability of ice shelves, In *Antarctic Peninsula Climate Variability: Historical and Paleoenvironmental Perspectives. Antarctic Research Series,* **79**, edited by E. Domack, et al., 61-68, AGU, Washington, DC.

MORRIS, W.F. and DOAK, D.F. 2004. Buffering of life histories against environmental stochasticity: accounting for a spurious correlation between the variabilities of vital rates and their contributions to fitness, *American Naturalist*, **163**, 579-590.

MORROW, R., CHURCH, J., COLEMAN, R., CHELTON, D. and WHITE, N. 1992. Eddy momentum flux and its contribution to the Southern Ocean momentum balance, *Nature*, **357**, 482–484.

MOSLEY-THOMPSON, E., J. F. PASKIEVITCH, A. J. GOW, L. G. THOMPSON, 1999: Late 20th century increase in South Pole snow accumulation, *J. Geophys. Res.,* **104**(D4), 3877-3886, 10.1029/1998JD200092.

MOSOLA, A.B. and ANDERSON, J.B. 2006. Expansion and rapid retreat of the West Antarctic Ice Sheet in Eastern Ross Sea: possible consequence of over extended ice streams?, *Quaternary Science Reviews,* **25**, 2177-2196.

MOTOYAMA, H. 2007. The second deep ice coring project at Dome Fuji, Antarctica, *Scientific Drilling,* **5**, 41-43.

MÜLLER, R., LÄPPLE, T., BARTSCH, I. and WIENCKE, C. Submitted. Impact of global climate change on the distribution of seaweeds in polar waters. *Bot. Mar.*

MUNILLA, T. and SOLER-MEMBRIVES, A. 2008. Check-list of the pycnogonids from Antarctic and sub-Antarctic waters: zoogeographic implications, *Antarctic Science*, doi:10.1017/S095410200800151X.

MURPHY, B.F. and SIMMONDS, I. 1993. An analysis of strong wind events simulated in a GCM near Casey in the Antarctic, *Monthly Weather Review*, **121**, 522-534.

MURPHY, E.J., TRATHAN, P.N., WATKINS, J.L., REID, K., MEREDITH, M.P., FORCADA, J., THORPE, S.E., JONSTON, N.M. and ROTHERY, P. 2007. Climatically driven fluctuations in Southern Ocean ecosystems, *Proceedings of the Royal Society B*, doi:10.1098/rspb.2007.1180.

MURPHY, E.J., WATKINS, J.L., REID, K., TRATHAN, P.N., EVERSON, I., CROXALL, J.P., PRIDDLE, J., BRANDON, M.A., BRIERLEY, A.S. and HOFMANN, E. 1998. Interannual variability of the South Georgia marine ecosystem: biological and physical sources of variation in the abundance of krill, *Fisheries Oceanography*, **7**, 381-390.

MURPHY, E.J., WATKINS, J.L., TRATHAN, P.N., REID, K., MEREDITH, M.P., THORPE, S.E., JOHNSTON, N.M., CLARKE, A., TARLING, G.A., COLLINS,

M.A., FORCADA, J., SHREEVE, R.S., ATKINSON, A., KORB, R., WHITEHOUSE, M.J., WARD, P., RODHOUSE, P.G., ENDERLEIN, P., HIRST, A.G., MARTIN, A.R., HILL, S.L., STANILAND, I.J., POND, D.W., BRIGGS, D.R., CUNNINGHAM, N.J. and FLEMING, A.H. 2006. Spatial and temporal operation of the Scotia Sea ecosystem: a review of large-scale links in a krill centred food web, *Philosophical Transactions of the Royal Society B: Biological Sciences*, **362**, (1477), DOI: 10.1098/rstb.2006.1957.

MURRAY, A.E. and, GRZYMSKI, J J. 2007. Diversity and genomics of Antarctic marine micro-organisms, *Philosophical Transactions of the Royal Society B-Biological Sciences,* **362**, 2259-2271.

MURRAY, A.E., PRESTON, C.M., MASSANA, R., TAYLOR, L.T., BLAKIS, A., WU, K. and DELONG, E.F. 1998. Seasonal and spatial variability of bacterial and archaeal assemblages in the coastal waters off Anvers Island, Antarctica, *Appl. Environ. Microbiol.,* **64**, 2585-2595.

NAISH, T., POWELL, R., LEVY, R., WILSON, G., SCHERER, R., TALARICO, F., KRISSEK, L., NIESSEN, F., POMPILIO, M., WILSON, T., CARTER, L., DECONTO, R., HUYBERS, P., MCKAY, R., POLLARD, D., ROSS, J., WINTER, D., BARRETT, P., BROWNE, G., CODY, R., COWAN, E., CRAMPTON, J., DUNBAR, G., DUNBAR, N., FLORINDO, F., GEBHARDT, C., GRAHAM, I., HANNAH, M., HANSARAJ, D., HARWOOD, D., HELLING, D., HENRYS, S., HINNOV, L., KUHN, G., KYLE, P., LÄUFER, A., MAFFIOLI, P., MAGENS, D., MANDERNACK, K., MCINTOSH, W., MILLAN, C., MORIN, R., OHNEISER, C., PAULSEN, T., PERSICO, D., RAINE, I., REED, J., RIESSELMAN, C., SAGNOTTI, L., SCHMITT, D., SJUNNESKOG, C., STRONG, P., TAVIANI, M., VOGEL, S., WILCH, T. and WILLIAMS, T. 2009. Obliquity-paced Pliocene West Antarctic ice sheet oscillations, *Nature,* **458**, 322-328.

NAISH, T.R., CARTER, L., WOLFF, E. and POWEL, R.D. 2008a. Chapter 11 - Late Pliocene-Pleistocene Antarctic climate variability at orbital and suborbital scale: Ice sheet, ocean and atmospheric interactions. In: Florindo F, Siegert M (eds) *Antarctic Climate Evolution*, Developments in Earth and Environmental Science, **8**, Elsevier, Amsterdam.

NAISH, T.R., POWELL, R.D., BARRETT, P.J., LEVY, R.H., HENRYS, S., WILSON, G.S., KRISSEK, L.A., NIESSEN, F., POMPILIO, M., SCHERER, R. and TALARICO, F. 2008b. Late Neogene climate history of the Ross Embayment from the AND-1B drill core: culmination of three decades of Antarctic margin drilling. In: Cooper AK, Barrett PJ, Stagg H, Storey B, Stump E, Wise W (eds) *Antarctica: A Keystone in a Changing World. Proceedings of the 10th International Symposium on Antarctic Earth Sciences*. The National Academies Press, Washington, DC, 71-82.

NAISH, T.R., POWELL, R.D., HENRYS, S., WILSON, G.S., KRISSEK, L.A., NIESSEN, F., POMPILIO, M., SCHERER, R., TALARICO, F., LEVY, R.H. and PYNE, A. 2007. New insights into Late Neogene (13-0Ma) climate history of Antarctica: Initial results from the ANDRILL McMurdo Ice Shelf (MIS) Project (AND-1B). In: A.K. Cooper, C.R. Raymond, al e (eds) *A Keystone in a Changing World - Online Proceedings of the 10th ISAES,* USGS Open-File Report 2007, 1-11.

NAISH, T.R., WILSON, G.S., DUNBAR, G.B. and BARRETT, P.J. 2008c. Constraining the amplitude of Late Oligocene bathymetric changes in Western Ross Sea during orbitally-influenced oscillations in the East Antarctic Ice Sheet: (2) Implications for global glacio-eustasy, *Palaeogeography, Palaeoclimatology, Palaeoecology,* in press.

NAISH, T.R., WOOLFE, K.J., BARRETT, P.J., WILSON, G.S., ATKINS, C., BOHATY, S.M., BUCKER, C.J., CLAPS, M., DAVEY, F.J., DUNBAR, G.B., DUNN, A.G., FIELDING, C.R., FLORINDO, F., HANNAH, M.J., HARWOOD, D.M., HENRYS, S.A., KRISSEK, L.A., LAVELLE, M., VAN DER MEER, J., MCINTOSH, W.C., NIESSEN, F., PASSCHIER, S., POWELL, R.D., ROBERTS, A.P., SAGNOTTI, L., SCHERER, R.P., STRONG, C.P., TALARICO, F., VEROSUB, K.L., VILLA, G., WATKINS, D.K., WEBB, P-N. and WONIK, T. 2001. Orbitally induced oscillations in the East Antarctic ice sheet at the Oligocene/Miocene boundary, *Nature,* **413**, 719-723.

NAKADA, M. and LAMBECK, K. 1988. The melting history of the Late Pleistocene Antarctic ice-sheet, *Nature,* **333**, 36-40.

NAKADA, M., KIMURA, R., OKUNO, J., MORIWAKI, K., MIURA, H. and MAEMOKU, H. 2000. Late Pleistocene and Holocene melting history of the Antarctic ice sheet derived from sea-level variations, *Marine Geology,* **167**, 85-103.

NAKAMURA K., DOI, K. and SHIBUYA, K. 2007. Estimation of seasonal changes in the flow of Shirase Glacier using JERS-1/SAR image correlation, *Polar Sci.*, **1**(2-4), 73-84.

NAKAOKA, S., NAKAZAWA, T., YOSHIKAWA-INOUE, H., AOKI, S., HASHIDA, G., TILBROOK, B., ISHII, M., YAMANOUCHI, T., ODATE, T. and FUKUCHI, M. 2008. Summertime variations of oceanic pCO2 and air-sea CO_2 flux in the eastern Indian sector of the Southern Ocean, Submitted to GRL.

NAKICENOVIC, N., ALCAMO, J., DAVIS, G., DE VRIES, B., FENHANN, J., GAFFIN, S., GREGORY, K., YONG JUNG, T., KRAM, T., LEBRE, L.A., ROVERE, E., MICHAELIS, E., MORI, S., MORITA, T., PEPPER, W., PITCHER, H., PRICE, L., RIAHI, K., ROEHRL, A., ROGNER, H-H., SCHLESINGER, A.M., SHUKLA, P., SMITH, S., SWART, R., VAN ROOIJEN, S., VICTOR, N. AND, ZHOU DADI, L. 2000. Special Report on Emissions Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, U.K., 599 pp. Available online at: http://www.grida.no/climate/ipcc/emission/index.htm).

NARUSE, R. 1979. Thinning of the ice sheet in Mizuho Plateau, East Antarctica, *J. Glaciol.*, **24**, 45–52.

NAUD, C., MULLER, J.-P. and DE VALK, P. 2005. On the use of ICESAT-GLAS measurements for MODIS and SEVIRI cloud-top height accuracy assessment, *Geophys. Res. Lett.*, **32**, No. 19, L19815, 10.1029/2005GL023275, 13 October 2005

NAVEIRA GARABATO, A.C., MCDONAGH, E.L., STEVENS, D.P., HEYWOOD, K.J. and SANDERS, R.J. 2002. On the export of Antarctic Bottom Water from the Weddell Sea, *Deep-Sea Res. II,* **49**, 4715-4742.

NAVEIRA GARABATO, A.C., POLZIN, K.L., KING, B.A., HEYWOOD, K.J. and VISBECK, M. 2004. Widespread intense turbulent mixing in the Southern Ocean, *Science,* **303**, 210-213.

NAVEIRA GARABATO, A.C., STEVENS, D.P., WATSON, A.J. and ROETHER, W. 2007. Short-circuiting of the overturning circulation in the Antarctic Circumpolar Current, *Nature,* **447**, 194-197.

NEAR, T. 2004. Estimating divergence times of notothenioid fishes using a fossil-calibrated molecular clock, *Antarctic Sci.,* **16**, 37-44.

NEAR, T.J. and CHENG, C-H.C. 2008. Phylogenetics of notothenioid fishes (Teleostei: Acanthomorpha): Inferences from mitochondrial and nuclear gene sequences, *Mol. Phylogenet. Evol.,* **47**, 832-840.

NEAR, T.J., PARKER. S.W. and DETRICH, III H.W. 2006. A Genomic fossil reveals key steps in hemoglobin loss by the Antarctic icefishes, *Mol. Biol. Evol.,* **23**, 2008-2016

NEAR, T.J., PESAVENTO, J.J. and CHENG, C-H.C. 2003. Mitochondrial DNA, morphology and the phylogenetic relationships of Antarctic icefishes (Notothenioidei: Channichthyidae), *Mol. Phylogenet. Evol.,* **28**, 87–98.

NEAR, T.J., PESAVENTO, J.J. and CHENG, C-H.C. 2004. Phylogenetic investigations of Antarctic notothenioid fishes (Perciformes: Notothenioidei) using complete gene sequences of the mitochondrial encoded 16S rRNA, *Mol. Phylogenet. Evol.,* **32**, 881-891.

NEGRISOLO, E., BARGELLONI, L., PATARNELLO, T., OZOUF-COSTAZ, C., PISANO, E., DI PRISCO, G. and VERDE, C. 2008. Comparative and evolutionary genomics of globin genes in Fish, *Methods Enzymol.,* **436**, 511-538.

NELSON, A.E., SMELLIE, J.L., WILLIAMS, M. and MORETON, S. 2008. Age, geographical distribution and taphonomy of an unusual occurrence of mummified crabeater seals on James Ross Island, Antarctic Peninsula, *Antarctic Science,* **20**, 485-493.

NELSON, F.E., OUTCALT, S.I., BROWN, J., SHIKLOMANOV, N.I. and HINKEL, K.M. 1998. Spatial temporal attributes of the active-layer thickness record, Barrow, Alaska, USA. In: Lewkowicz, AG., Allard M. (eds.) *Permafrost, Seventh International Conference, June 23-27, 1998, Proceedings.*, Université Laval , Nordicana 57**,** 797-802.

NEWMAN, P.A., NASH, E.R., KAWA, S.R., MONTZKA, S.A. and SCHAUFFLER, S.M. 2006. When will the Antarctic ozone hole recover?, *Geophys. Res. Lett.*, **33**, L12814.

NEWSHAM, K.K. 2003. UV-B radiation arising from stratospheric ozone depletion influences the pigmentation of the moss *Andreaea regularis*, *Oecologia,* **135**, 327-331.

NEWSHAM, K.K. and ROBINSON, S.A. 2009. Responses of plants in polar regions to UV-B exposure: a meta-analysis, *Global Change Biology,* **15**, DOI: 10.1111/j.1365-2486.2009.01944.x.

NEWSHAM, K.K., GEISSLER, P., NICOLSON, M., PEAT, H.J., and LEWIS SMITH, R.I. 2005. Sequential reduction of UV-B radiation in the field alters the pigmentation of an Antarctic leafy liverwort, *Environmental and Experimental Botany,* **54**(1), 22-32.

NEWSHAM, K.K., HODGSON, D.A., MURRAY, A.W.A., PEAT, H.J., and LEWIS SMITH, R.I. 2002. Response of two Antarctic bryophytes to stratospheric ozone depletion, *Global Change Biology,* **8**, 972-983.

NICHOL, S.A. and, ALLISON, I. 1997. The frozen skin of the Southern Ocean, *American Scientist,* **85**, 426-439

NICHOLLS, K.W. and JENKINS, A. 1993, Temperature and salinity beneath Ronne Ice Shelf, Antarctica, *J. Geophys. Res.,* **98,** 22,553–22,568.

NICHOLLS, K.W., MAKINSON, K. and OSTERHUS, S. 2004. Circulation and water masses beneath the northern Ronne Ice Shelf, Antarctica, *J. Geophys. Res.,* **109**, doi:10.1029/2004JC002302.

NICHOLLS, K.W., OSTERHUS, S., MAKINSON, K., GAMMELSROD, T. AND FAHRBACH, E. 2009. Ice-ocean processes over the continental shelf of the southern Weddell Sea, Antarctica: A review, *Reviews of Geophysics*, doi:10.1029/2007RG000250, in press.

NICHOLS, R.L. and BALL, D.G. 1964. Soil temperatures, Marble point, McMurdo Sound, Antarctica, *Journal of Glaciology*, **5**, 357-359.

NICOL, S., CROXALL, J., TRATHAN, P., GALES, N. and MURPHY, E. 2007. Paradigm misplaced ? Antarctic marine ecosystems are affected by climate change as well as biological processes and harvesting, *Antarctic Sci.,* **19**, 291-295 .

NICOL, S., WORBY, A. and LEAPER, R. 2008. Changes in the sea-ice ecosystem: potential effects on krill and baleen whales, *Marine and Freshwater Research,* **59**, 361-382.

NIELSEN, S.H.H., KOC, N. and CROSTA, X. 2004. Holocene climate in the Atlantic sector of the Southern Ocean: controlled by insolation or oceanic circulation?, *Geology,* **32**, 317-320.

NIKOLAIEV, V.I., KOTLYAKOV, V.M. and SMIRNOV, K.E. 1988. Isotopic studies of the ice core from the Komsomolskaia station, Antarctica. *Data of Glaciological Studies of the USSR Academy of Sciences*, **63**, 97-102.

NISHIO, F., FURUKAWA, T., HASHIDA, G., IGARASHI, M., KAMEDA, T., KOHNO, M., MOTOYAMA, H., NAOKI, K., SATOW, K., SUZUKI, K., TAKATA, M., TOYAMA, Y., YAMADA, T. and WATANABE, O. 2002. Annual-layer determinations and 167 year records of past climate of H72 ice core in east Dronning Maud Land, Antarcitaca, *Ann. Glacio*., **35**, 471-479.

NITSCHE, F.O., JACOBS, S.S., LARTER, R.D. and GOHL, K. 2007. Bathymetry of the Amundsen Sea continental shelf: Implications for geology, oceanography, and glaciology, *Geochem. Geophys. Geosyst*., **8**, Q10009, doi:10.1029/2007GC001694.

NOONE, D. and SIMMONDS, I. 2002. Annular variations in moisture transport mechanisms and the abundance of delta18O in Antarctic snow, *J. Geophys. Res.*, **107**, 4742, doi:10.1029/2002JD002262.

NORTHGRIP-COMMUNITY-MEMBERS 2004. High resolution climate record of the northern hemisphere reaching into last interglacial period, *Nature,* **431**, 147-151.

NOWLIN, W.D. and KLINCK, J.M. 1986. The physics of the Antarctic Circumpolar Current, *Reviews of Geophysics,* **24**, 469-491.

NRIAGU, J.O. and PACYNA, J.M. 1988. Quantitative assessment of worldwide contamination of air, water and soils by trace metals, *Nature,* **333**, 134-139.

NRIAGU, J.O., 1989. A global assessment of natural sources of atmospheric trace metals, *Nature,* **338**, 47-49.

NÚÑEZ-RIBONI, I AND FAHRBACHM, E. 2009. Seasonal variability of the Antarctic Coastal Current and its driving mechanisms in the Weddell Sea, *Deep-Sea Research* I, in press.

NYE, J.F. 1957. The distribution of stress and velocity in glaciers and ice sheets, *Proceedings of the Royal Society of London Series A,* **275**, 87-112.

Ó COFAIGH, C., DOWDESWELL, J.A., ALLEN, C.S., HIEMSTRA, J.F., PUDSEY, C.J., EVANS, J. and EVANS, D.J.A. 2005. Flow dynamics and till genesis associated with a marine-based Antarctic palaeo-ice stream, *Quaternary Science Reviews,* **24**, 709-740.

Ó COFAIGH, C., PUDSEY, C.J., DOWDESWELL, J.A. and MORRIS, P. 2002. Evolution of subglacial bedforms along a paleo-ice stream, Antarctic Peninsula continental shelf, *Geophysical Research Letters,* **29**, 1199.

O'BRIEN, P.E. and HARRIS, P.T. 1996. Patterns of glacial erosion and deposition in Prydz Bay and the past behavior of the Lambert Glacier, *Papers and Proceedings of the Royal Society of Tasmania*, **130**, 79-85.

O'BRIEN, P.E. and LEITCHENKOGV, G. 1997. Deglaciation of Prydz Bay, East Antarctica based on echo sounder and topographic features, *Antarctic Research Series,* **71**, 109-126.

O'BRIEN, P.E. 1994. Morphology and late glacial history of Prydz Bay, Antarctica, based on echo sounder data, *Terra Antarctica,* **1**, 403-405.

OECHEL, W.C., VOURLITIS, G.L., HASTINGS, S.J., ZULUETA, R.C., HINZMAN, L. and KANE, D. 2000. Acclimation of ecosystem CO_2 exchange in the Alaskan Arctic in response to decadal climate warming, *Nature,* **406**, 978–981.

OERLEMANS, J. 1982a. A model of the Antarctic Ice Sheet, *Nature,* **297**, 550-553.

OERLEMANS, J. 1982b. Response of the Antarctic Ice Sheet to a climatic warming: a model study, *Journal of Climatology,* **2**, 1-11.

OERTER, H., GRAF, W., WILHELMS, F., MINIKIN, A. and MILLER, H. 1999. Accumulation studies on Amundsenisen, Dronning Maud Land, Antarctica, by means of tritium, dielectric profiling and stable-isotope measurements: first results from the 1995-96 and 1996-97 field seasons, *Ann. Glaciol.*, **29**, 1-9.

OHMURA, A., GILGEN, H., HEGNER, H., MULLER, G., WILD, M., DUTTON, E., FORGAN, B., FROHLICH, C., PHILIPONA, R., HEIMO, A., KONIG-LANGO, G., MCARTHUR, B., PINKER, R., WHITLOCK, C.H. and DEHNE, K. 1998. Baseline Surface Radiation Network (BSRN/WCRP): New precision radiometery for climate research, *Bull. Am. Meteorol. Soc.*, **10**, 2115-2136.

OHMURA, A., WILD, M.A. and BENGTSSON, L. 1996. A possible change in mass balance of Greenland and Antarctic ice sheets in the coming century, *J. Climate,* **9**, 2124-2135.

OKE, T.R. 1987. Boundary layer of climate, Mehuen and C Ed., London.

OKUNO, J., MIURA, H. and MAEMOKU, H. 2007. The possibility of the rapid melting of ice sheet in Holocene around the Lutzow-Holm Bay, Antarctica, *Geophysical Research Abstracts,* **7**.

OLBERS, D. AND HELLMER, H. 2009. A box model of circulation and melting in ice shelf caverns, *Ocean Dynamics*, submitted.

OLBERS, D., BOROWSKI, D., VÖLKER, C. and WOLFF, J.-O. 2004. The dynamical balance, transport and circulation of the Antarctic Circumpolar Current, *Antarct. Sci.,* **16**, 439–470.

OREJAS, C., GILI, J-M. and ARNTZ, W. 2003. Role of small-plankton communities in the diet of two Antarctic octocorals (*Primnoisis antarctica* and *Primnoella* sp.), *Mar. Ecol. Prog. Ser.,* **250**, 105-116.

ORR, A., CRESSWELL, D., MARSHALL, G.J., HUNT, J.C.R., SOMMERIA, J., WANG, C.G. and LIGHT, M. 2004. A 'low-level' explanation for the recent large warming trend over the western Antarctic Peninsula involving blocked winds and changes in zonal circulation, *Geophys. Res. Lett.*, **31**, L06204, doi:10.1029/2003GL019160.

ORR, J.C., FABRY, V.J., AUMONT, O., BOPP, L., DONEY, S.C., FEELY, R A., GNANADESIKAN, A., GRUBER, N., ISHIDA, A., JOOS, F., KEY, R.M., LINDSAY, K., MAIER-REIMER, E., MATEAR, R., MONFRAY, P., MOUCHET, A., NAJJAR, R.G., PLATTNER, G.K., RODGERS, K.B., SABINE, C.L., SARMIENTO, J.L., SCHLITZER, R., SLATER, R.D., TOTTERDELL, I.J., WEIRIG, M.F., YAMANAKA, Y. AND YOOL, A. 2005. Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms, *Nature*, **437**, 681-686.

ORSI, A.H., JOHNSON, G.C. and BULLISTER, J.B. 1999. Circulation, mixing and production of Antarctic Bottom Water, *Prog. Oceanog.*, **43**, 55-109.

ORSI, A.H., WHITWORTH III, T.W. and NOWLIN JR.,W.D. 1995. On the meridional extent and fronts of the Antarctic Circumpolar Current, *Deep-Sea Res.*, **42**, 641-673.

PACANOWSKI, R.C. and PHILANDER, S.G.H. 1981. Paramerization of vertical mixing in numerical models of tropical oceans, *Journal of Physical Oceanography*, **11**, 1443-1451.

PADMAN, L. and FRICKER, H.A. 2005. Tides on the Ross Ice Shelf observed with ICESat, *Geophysical Research Letters*, **32**, No. 14, Art. No. L14503, July 29, 2005.

PAGANI, M., ZACHOS, J.C., FREEMAN, K.H., TIPPLE, B. and BOHATY, S. 2005. Marked Decline in Atmospheric Carbon Dioxide Concentrations During the Paleogene, *Science,* **309**, 600-603.

PAGE, T.J. and LINSE, K. 2002. More evidence of speciation and dispersal across the Antarctic Polar Front through molecular systematics of Southern Ocean *Limatula* (Bivalvia: Limidae), *Polar Biol.*, **25**, 818-826.

PAPETTI, C., LIÒ, P., RÜBER, L., PATARNELLO, T. and ZARDOYA, R. 2007. Antarctic fish mitochondrial genomes lack *ND6* gene, *J. Mol. Evol.,* **65**, 519-528.

PARK, M., RANDEL, W.J., KINNISON, D.E., GARCIA, R.R. and CHOI, W. 2004. Seasonal variation of methane, water vapor, and nitrogen oxides near the tropopause: Satellite observations and model simulations, *J. Geophys. Res.*, **109**, D03302.

PARK, Y., ROQUET, F. and VIVIER, F. 2004. Quasi-stationary ENSO wave signals versus the Antarctic Circumpolar Wave scenario, *Geophys. Res. Lett.*, **31**, L09315, doi:10.1029/2004GL019806.

PARKINSON, C.L. 2004. Southern Ocean sea ice and its wider linkages: insights revealed from models and observations, *Antarctic Science*, **16**, 387–400.

PARKINSON, C.L., VINNIKOV, K.Y. and CAVALIERI, D.J. 2006. Evaluation of the simulation of the annual cycle of Arctic and Antarctic sea ice coverages by 11 major global climate models, *J. Geophys. Res.*, **111**, doi:10.1029/2005JC003408.

PARMESAN, C. and YOHE, G. 2003. A globally coherent fingerprint of climate change impacts across natural systems, *Nature,* **421**, 37-42.

PARNIKOZA, I., CONVEY, P., DYKYY, I., TRAKHIMETS, V., MILINEVSKY, G., TYSCHENKO, O., INOZEMTSEVA, D. and KOZERETSKA, I. Current status of the Antarctic herb tundra formation in the central Argentine Islands, *Global Change Biology* (in review).

PATARNELLO, T., MARCATOA, S., ZANEA, L., VAROTTOA, V. and BARGELLONIA, L. 2003. Phylogeography of the Chionodraco genus (Perciformes, Channichthydae) in the Southern Ocean, *Molecular Phylogenetics and Evolution,* **28**, 420-429.

PAWLOWSKI, J., FAHRNI, J.F., BRYKCZYNSKA, U., HABURA, A. and BOWSER S.S. 2002. Molecular data reveal high taxonomic diversity of allogromiid Foraminifera in Explorers Cove (McMurdo Sound, Antarctica), *Polar Biol.*, **25**(2), 96-105.

PAYNE, A.J. 1998. Dynamics of the Siple Coast ice streams, West Antarctica: results from a thermomechanical ice sheet model, *Geophysical Research Letters,* **25**, 3173-3176.

PAYNE, A.J., HOLLAND, P.R., SHEPHERD, A.P., RUTT, I.C., JENKINS, A. and JOUGHIN, I. 2007. Numerical modeling of ocean-ice interactions under Pine Island Bay's ice shelf, *J. Geophys. Res*., **112**, doi:10.1029/2006JC003733.

PAYNE, A.J., SAMMONDS, P. and HUNT, J.C.R. 2006, Evolution of the Antarctic ice sheet: new understanding and new challenges, *Philosophical Transactions of the Royal Society A,* **364**, 1844.

PAYNE, A.J., VIELI, A., SHEPHERD, A.P., WINGHAM, D.J. and RIGNOT, E. 2004. Recent dramatic thinning of largest West Antarctic ice stream triggered by oceans, *Geophysical Research Letters,* **31**, L23401, doi: 10.1029/2004GL02184.

PEARCE, D. 2008. Biodiversity of the bacterioplanbkton in the surface waters around Southern Thule in the Southern Ocean, *Antarct. Sci*., **20**, 291-300.

PEARSON, P.N. and PALMER, M.R. 2000. Atmospheric carbon dioxide concentrations over the past 60 million years, *Nature,* **406**, 695-699.

PEAT, H.J., CLARKE, A. and CONVEY, P. 2007 Diversity and biogeography of the Antarctic flora, *Journal of Biogeography,* **34**, 132-146.

PECK, L.S. and CONWAY, L.Z. 2000. The myth of metabolic cold adaptation: oxygen consumption in stenothermal Antarctic bivalves. In Harper E, Tatlor JD, Crame JA (eds). *Evolutionary biology of the bivalvia*, **177**. Geol Soc Special Publications, London, 441-450.

PECK, L.S. 1989. Temperature and basal metabolism in two Antarctic marine herbivores, *J. Exp. Mar. Biol. Ecol.,* **127**, 1-12.

PECK, L.S. 2002. Ecophysiology of Antarctic marine ectotherms: limits to life, *Polar Biology,* **25**, 31-40.

PECK, L.S. 2005. Prospects for survival in the Southern Ocean: vulnerability of benthic species to temperature change, *Antarctic Sci.,* **17**, 497-507.

PECK, L.S., BROCKINGTON, S., VANHOVE, S. and BEGHYN, M. 1999. Community recovery following catastrophic iceberg impacts in a soft-sediment shallow-water site at Signy Island, Antarctica, *Mar. Ecol. Prog. Ser.,* **186**, 1-8.

PECK, L.S., CONVEY, P. and BARNES, D.K.A. 2006. Environmental constraints on life histories in Antarctic ecosystems: tempos, timings and predictability, *Biol. Rev.,* **81**, 75-109.

PECK, L.S., MORLEY, S.A., PÖRTNER, H.O. and CLARK, M.S. 2007. Small increases in temperature and reductions in oxygen availability limit burrowing capacity in the Antarctic clam Laternula elliptica, *Oecologia,* **154**, 479-484.

PECK, L.S., MORLEY, S.A., PÖRTNER, H.O. and CLARK, M.S. 2007. Thermal limits of burrowing capacity are linked to oxygen availability and size in the Antarctic clam *Laternula elliptica*. Oecologia. Published on line DOI 10.1007/s00442-007-0858-0.

PECK, L.S., PÖRTNER, H.O. and HARDEWIG, I. 2002. Metabolic demand, oxygen supply, and critical temperatures in the Antarctic bivalve *Laternula elliptica*, *Physiol. Biochem. Zool.,* **75**, 123-133.

PECK, L.S., WEBB, K. and BAILEY, D. 2004. Extreme sensitivity of biological function to temperature in Antarctic marine species, *Functional Ecology,* **18**, 625-630.

PECK, L.S., WEBB, K.E., MILLER, A., CLARK, M.S. and HILL, T. (in press). Temperature limits to activity, feeding and metabolism in the Antarctic starfish *Odontaster validus*, Mar. Ecol. Prog. Ser.

PEINERT, R., BODUNGEN, B. and VON SMETACEK, V.S. 1989. Food web structure and loss rate. In *Productivity in the ocean: present and past* (Eds: Berger WH, Smetacek VS, Wefer G) Wiley-Interscience, Chichester, 35-48.

PELTIER, W.R. 2002. Comments on the paper of Yokoyama et al. (2000), entitled Timing of the Last Glacial Maximum from observed sea level minima, *Quaternary Science Reviews,* **21**, 409-414.

PELTIER, W.R. 2005. On the hemispheric origins of meltwater pulse 1a, *Quaternary Science Reviews,* **24**, 1655-1671.

PENDUFF, T., LE SOMMER, J., BARNIER, B., TREGUIER, A.-M., MOLINES, J.-M., and MADEC, G., 2007: Influence of numerical schemes on current-topography interactions in 1/4° global ocean simulations, *Ocean Science*, **3**, 509-524.

PEREIRA, A.F., BECKMANN, A. and HELLMER, H.H. 2002. Tidal mixing in the southern Weddell Sea: Results from a three-dimensional model, *J. Phys. Oceanogr.,* **32**, 2151-2170.

PEREIRA, E.B., EVANGELISTA, H., PEREIRA, K.C.D., CAVALCANTI, I.F.A. and SETZER, A.W. 2006. Apportionment of black carbon in the South Shetland Islands, Antarctic Peninsula, *J. Geophys. Res*., **111**, D03303, doi: 10.1029/2005JD006086.

PERLWITZ, J., PAWSON, S., FOGT, R.L., NIELSEN, J.E. and NEFF, W.D. 2008. Impact of stratospheric ozone hole recovery on Antarctic climate, *Geophysical Research Letters*, **35**, L08714, doi:10.1029/2008GL033317.

PETERS, A.F. and BREEMAN, A.M. 1992. Temperature responses of disjunct temperate brown algae indicate long-distance dispersal of microthalli across the tropics, *J. Phycol*., **28**, 428-438.

PETERSON, R.G. and WHITE, W.B. 1998. Slow oceanic teleconnections linking the Antarctic Circumpolar Wave with tropical ENSO, *Journal of Geophysical Research,* **103**, 24573-24583.

PETIT, J.R., BASILE, I., LERUYUET, A., RAYNAUD, D., LORIUS, C., JOUZEL, J., STIEVENARD, M., LIPENKOV, V.Y., BARKOV, N.I., KUDRYASHOV, B.B., DAVIS, M., SALTZMAN, E. and KOTLYAKOV, V. 1997. Four climatic cycles in Vostok ice core, *Nature,* **387**, 359.

PETIT, J.R., JOUZEL, J., RAYNAUD, D., BARKOV, N.I., BARNOLA, J.M., BASILE, I., BENDER, M., CHAPPELLAZ, J., DAVIS, J., DELAYGUE, G., DELMOTTE, M., KOTYAKOV, V.M., LEGRAND, M., LIPENKOV, V.Y., LORIUS, C., PÉPIN, L., RITZ, C., SALTZMAN, E. and STIEVENARD, M. 1999. Climate and Atmospheric History of the Past 420000 years from the Vostok Ice Core, Antarctica, *Nature,* **399**, 429-436.

PETOUKHOV, V., CLAUSSEN, M., BERGER, A., CRUCIFIX, M. EBY, M., ELISEEV, A., FICHEFET, T., GANOPOLSKI, A., GOOSSE, H., KAMENKOVICH, I. MOKHOV, I., MONTOYA, M., MYSAK, L.A., SOKOLOV, A., STONE, P., WANG, Z. and WEAVER, A.J. 2005. EMIC Inter-comparison Project (EMIP-CO2): Comparative analysis of EMIC simulations of climate, and of equilibrium and transient responses to atmospheric CO_2 doubling, *Climate Dynamics,* **25,** 363-385.

PEYLIN, P., ET AL. 2005. Multiple constrains on regional CO_2 flux variations over land and oceans, *Global Biogeochemical Cycles*, **19**, doi:10.1029/2003GB002214.

PFEFFER, W.T, HARPER, J.T. and O'NEILL, S. 2008. Kinematic Constraints on Glacier Contributions to 21st-Century Sea-Level Rise, *Science,* **321**, 1340-3.

PHILLIPS, H.E. and RINTOUL, S.R. 2000. Eddy variability and energetics from direct current measurements in the Antarctic Circumpolar Current south of Australia, *Journal of Physical Oceanography*, **30**, 3050-3076.

PICKARD, J., ADAMSON, D.A., HARWOOD, D.M., MILLER, G.H., QUILTY, P.G., DELL, R.K. 1986. Early Pliocene marine sediments in the Vestfold Hills, East Antarctica: implications for coastline, ice sheet and climate, *South African Journal of Science,* **82**, 520-521.

PISANO, E., COCCA, E., MAZZEI, F., GHIGLIOTTI, L., DI PRISCO, G., DETRICH, H.W. III and OZOUF-COSTAZ, C. 2003 Mapping of alpha- and beta-globin on Antarctic fish chromosomes by fluorescence in situ hybridisation, *Chromosome Res.,* **11**, 633-640.

PISANO, E., OZOUF-COSTAZ, C. and PRIRODINA, V. 1998. Chromosome diversification in Antarctic fish (Notothenioidei). In: di Prisco G, Pisano E and Clarke A (Eds) *Fishes of Antarctica. A Biological Overview,* 275-285, Springer, Milano.

PITARI, G., MANCINI, E., RIZI, V. and SHINDELL, D.T. 2002. Impact of future climate change and emission changes on stratospheric aerosols and ozone, *J. Atmos. Sci.*, **59**, 414-440.

PLANCHON, F.A.M., BOUTRON, C.F., BARBANTE, C., COZZI, V., GASPARI, V., WOLFF, E.W., FERRARI, C.P., CESCON, P. 2002. Changes in heavy metals in Antarctic snow from Coats Land since the mid-19th to the late-20th century, *Earth and Planetary Science Letters*, **200**, 207-222.

PLATTNER, G.K., JOOS, F., STOCKER, T.F. AND MARCHAL, O. 2001. Feedback Mechanisms and sensitivities of ocean carbon uptake under global warming, *Tellus B*, **53**, 564-592.

PODRABSKY, J.E. and SOMERO, G.N. 2006. Inducible heat tolerance in Antarctic notothenioid fishes, *Polar Biology,* **30**, 39-43, DOI 10.1007/s00300-00006-00157-y.

PODRABSKY, J.E. 2009. Gene duplication underlies cold adaption in Antarctic fish, *J. Exp. Biol*., **212**, doi: 10.1242/jeb.021493.

POLLARD, D. and DECONTO, R. 2009. Modelling West Antarctic ice sheet growth and collapse through the past five million years, *Nature,* **458**, 329-332.

POLZIN, K.L. 2007. How Rossby Waves Break. Results from POLYMODE and the end of the enstrophy cascade, *J. Phys. Oceanogr.*, in press.

POOK, M. and GIBSON, T. 1999. Atmospheric blocking and storm tracks during SOP-1 of the FROST Project, *Aust. Meteorol. Mag., Special Edition*, 51-60.

POPOVA, E.E., COWARD, A.C., NURSER, G.A., DE CUEVAS, B., FASHAM, M.J.R. and ANDERSON, T.R. 2006. Mechanisms controlling primary and new production in a global ecosystem model – Part I: Validation of the biological simulation, *Ocean Science*, **2**, 249-266.

PÖRTNER, H., PECK, L., ZIELINSKI, S. and CONWAY, L. 1999a. Temperature and metabolism in the highly stenothermal bivalve mollusc Limopsis marionensis from the Weddell Sea, Antarctica, *Polar Biology,* **22**, 17-30.

PÖRTNER, H.O. and FARREL, A.P. 2008. *Pysiology and Climate Change. Science,* **322**, 690-692.

PÖRTNER, H.O. and KNUST, R. 2007. Climate change affects marine fishes through the oxygen limitation of thermal tolerance, *Science,* **315**, 95 – 97.

PÖRTNER, H.O. 2001. Climate change and temperature-dependent biogeography: oxygen limitation of thermal tolerance in animals, *Naturwiss,* **88**, 137-146.

PÖRTNER, H.O. 2002. Climate variations and the physiological basis of temperature dependent biogeography: systemic to molecular hierarchy of thermal tolerance in animals, *Comp. Biochem. Physiol. A,* **132**, 739-761.

PÖRTNER, H.O., BERDAL, B., BLUS, R., BRIX, O., COLOSIMO, A., DE WACHTER, B., GIULIANI, A., JOHANSEN, T., FISCHER, T., KNUST, R., NAEVDAL, G., NEDENES, A., NYHAMMER, G., SARTORIS, F.J., SERENDERO, I., SIRABELLA, P., THORKILDSEN, S. and ZAKHARTSEV, M. 2001. Climate effects on growth performance, fecundity and recruitment in marine fish: developing a hypothesis for cause and effect relationships in Atlantic cod (*Gadus morhua*) and common eelpout (*Zoarces viviparus*), *Continental Shelf Res.,* **21**, 1975-1997.

PÖRTNER, H.O., HARDEWIG, I., SARTORIUS, F.J. and VAN DIJK, P.L.M. 1998. Energetic aspects of cold adaptation: critical temperatures in metabolic, ionic and acid-base regulation? In Pörtner HO, Playle R (eds) *Cold Ocean Physiology*, Cambridge University Press, Cambridge, 88-120.

PÖRTNER, H.O., MARK, F.C. and BOCK, C. 2004. Oxygen limited thermal tolerance in fish? Answers obtained by Nuclear Magnetic Resonance techniques, *Resp. Physiol. Neurobiol.,* **141**, 243–260.

PÖRTNER, H.O., PECK, L., ZIELINSKI, S. and CONWAY, L.Z. 1999b. Intracellular pH and energy metabolism in the highly stenothermal Antarctic bivalve Limopsis marionensis as a function of ambient temperature, *Polar Biology,* **22**, 17-30.

PÖRTNER, H.O., PECK, L.S. and HIRSE, T. 2006. Hyperoxia alleviates thermal stress in the Antarctic bivalve, *Laternula elliptica*: evidence for oxygen limited thermal tolerance, *Polar Biol.,* **29**, 688-693 .

PÖRTNER, H.O., PECK, L.S. and SOMERO, G.N. 2007. Thermal limits and adaptation: an integrative view (Antarctic Ecology: From Genes to Ecosystems), *Phil. Trans. R. Soc. B,* **362**, 2233–2258.

PÖRTNER, H.O., VAN DIJK, P.L.M., HARDEWIG, I. and SOMMER, A. 2000. Levels of metabolic cold adaptation: tradeoffs in eurythermal and stenothermal ectotherms. In: Davison W, Williams CW (Eds) *Antarctic Ecosystems: Models for a Wider Understanding*, Caxton Press, Christchurch, New Zealand, 109-122.

POST, L.A., HEMER, M.A., O'BRIEN, P.E., ROBERTS, D. and CRAVEN, M. 2007. History of benthic colonization beneath the Amery Ice Shelf, East Antarctica, *Mar. Ecol. Prog. Ser.,* **344**, 29-37.

POTTHOFF, M., JOHST, K. and GUTT, J. 2006. How to survive as a pioneer species in the Antarctic benthos: minimum dispersal distance as a function of lifetime and disturbance, *Polar Biol.*, **29**, 543-551.

POULIN, E., PALMA, A.T. and FERAL, J.-P. 2002. Evolutionary versus ecological success in Antarctic benthic invertebrates, *Trends Ecol. Evol.,* **17**, 218-222.

POWELL, D.K., TYLER, P.A. and PECK, L.S. 2001. Effect of sperm concentration and sperm ageing on fertilization success in the Antarctic soft-shelled clam

Laternula elliptica and the Antarctic limpet *Nacella concinna*, *Mar. Ecol. Prog. Ser.,* **215**, 191-200.

PREBBLE, J.G., HANNAH, M.J. and BARRETT, P.J. 2006. Changing Oligocene climate recorded by palynomorphs from two glacio-eustatic sedimentary cycles, Cape Roberts Project, Victoria Land Basin, Antarctica, *Palaeogeography, Palaeoclimatology, Palaeoecology,* **231**, 58-70.

PRESTI, M., DE SANTIS, L., BRANCOLINI, G. and HARRIS, P.T. 2005. Continental shelf record of the East Antarctic Ice Sheet evolution: Seismo-stratigraphic evidence from the George V Basin, *Quaternary Science Reviews,* **24**, 1223-1241.

PRICE, J.F., WELLER, R.A. and OINKEL, R. 1986. Duirnal cycling: Observations and models of the upper ocean response to diurnal heating, cooling and wind mixing, *Journal of Geophysical Research*, **91**, 8411-8427.

PRISCU, J.C., FRITSEN, C.H., ADAMS, E.E., GIOVANNONI, S.J., PAERL, H.W., MCKAY, C.P., DORAN, P.T., GORDON, D.A., LANOIL, B.D. and PINCKNEY, J.L. 1998. Perennial Antarctic lake ice: an oasis for life in a polar desert, *Science,* **280**, 2095-2098.

PRITCHARD, H.D. and VAUGHAN, D.G. 2007. Widespread acceleration of tidewater glaciers on the Antarctic Peninsula, *J. Geophys. Res.*, **112**, F03S29, doi:10.1029/2006JF000597.

PRITCHARD, H.D., ARTHERN, R. J. and VAUGHAN, D. G. (in submission). A detailed new view of ice sheet change.

PROPOSITO, M., PROPOSITO, M., BECAGLI, S., CASTELLANO, E., FLORA, O., GRAGNANI, R., STENNI, B., TRAVERSI, R., UDISTI, R. and FREZZOTTI, M. 2002. Chemical and isotopic snow variability along the 1998 ITASE traverse from Terra Nova Bay to Dome C (East-Antarctica), *Ann. Glaciol.*, **35**, 187-194.

PUDSEY, C.J. and EVANS, J. 2001. First survey of Antarctic sub-ice shelf sediments reveals mid-Holocene ice shelf retreat, *Geology,* **29**, 787-790

PUGH, P.J.A. and CONVEY, P. 2008. Surviving out in the cold: Antarctic endemic invertebrates and their refugia, *Journal of Biogeography,* **35**, 2176-2186.

PUGH, P.J.A. and SCOTT, B. 2002. Biodiversity and biogeography of non-marine Mollusca on the islands of the southern Ocean, *Journal of Natural History,* **36**, 927-952.

PUGH, P.J.A. 1993. A synonymic catalogue of the Acari from Antarctica, the sub-Antarctic Islands and the Southern Ocean, *Journal of Natural History,* **27**, 323-421.

PUGH, P.J.A., DARTNALL, H.J.G. and MCINNES, S.J. 2002. The non-marine crustacea of Antarctica and the islands of the Southern Ocean: biodiversity and biogeography. *Journal of Natural History* **36**:1047-1103.

QIN, D., MAYEWSKI, P.A., LYONS, W.B., SUN, J. and HOU, S. 1999. Lead pollution in Antarctic surface snow revealed along the route of the International Trans-Antarctic Expedition (ITAE), *Ann. Glaciol.*, **29**, 94-98.

QUAYLE, W., CONVEY, P., PECK, L., ELLIS-EVANS, J., BUTLER, H. and PEAT, H. 2004. Ecological responses of maritime Antarctic lakes to regional climate change. In: Domack E, Leventer A, Burnett A, Convey P, Kirby M, Bindschadler R (eds) American Geophysical Union: Monograph Antarctic Peninsula Climate Variability: A Historical and Paleoenvironmental Perspective, *Antarctic Research Series*; **79**, 159-170.

QUAYLE, W.C., PECK, L.S., PEAT, H., ELLIS-EVANS, J.C. and HARRIGAN, P.R. 2002. Extreme responses to climate change in Antarctic lakes, *Science,* **295**, 645-645.

QUESADA, A., VINCENT, W.F., KAUP, E., HOBBIE, J.E., LAURION, I., PIENITZ, R., LÓPEZ-MARTÍNEZ, J. and DURÁN, J.J. 2006. In: *Trends in Antarctic Terrestrial and Limnetic Ecosystems: Antarctica as a Global Indicator*, Eds. Bergstrom, D.M, Convey, P. and Huiskes, A.H.L. Springer, Dordrecht, 221-252.

QUETIN, L.B. and ROSS, R.M. 2003. Episodic recruitment in Antarctic krill *Euphausia superba* in the Palmer LTER study region, *Marine Ecology Progress Series*, **259**, 185–200.

QUINN, W.H. and NEAL, V.T. 1992. The historical record of El Nino events, In *Climate Since A.D. 1500*, Eds. R.S. Bradley and P.D. Jones, Routledge, London, 623-648.

QUINN, W.H., NEAL, V.T. and ANTUNEZ DE MAYOLO, S.E. 1987. El Nino occurrences over the past four and a half centuries, *J. Geophys. Res*., **92**, C13, 14449-14461.

RAHMSTORF, S., CAZENAVE, A., CHURCH, J.A., HANSEN, J.E., KEELING, R., PARKER, D.E. and SOMERVILLE, R.C.J. 2007. Recent climate observations compared to projections, *Science*, **316**, 709, doi:10.1126/science.1136843.

RÄISÄNEN, J. 2007. How reliable are climate models? *Tellus*, **59A,** 2-29.

RAISBECK, G.M., YIOU, F., JOUZEL, J. and PETIT, J.R. 1990. 10Be and 2H in polar ice cores as a probe of the solar variability's influence on climate, *Philosophical Transactions of the Royal Society London A*, **330** (1615), 463– 470.

RAMILLIEN, G., LOMBARD, A., CAZENAVE, A., IVINS, E.R., LLUBES, M., REMY, F. and BIANCALE, R. 2006. Interannual variations of the mass balance of the Antarctica and Greenland ice sheets from GRACE, *Global and Planetary Change,* **53,** 198–208.

RAMOS, M. and VIEIRA, G. 2003. Active layer and permafrost monitoring in Livingston Island, Antarctic. First results from 2000 to 2001. In: Phillips, M., S.M. Springman, and L. Arenson (eds.) *Proceedings of the 8th International Conference on Permaforst, Zurich, Switzerland, 21-25 July 2003*. Balkema Publishers, Lisse, 929-933.

RANDALL, D.A., WOOD, R.A., BONY, S., COLMAN, R., FICHEFET, T., FYFE, J., KATTSOV, V., PITMAN, A., SHUKLA, J., SRINIVASAN, J., STOUFFER, R.J., SUMI, A. and TAYLOR, K.E. 2007. Climate Models and Their Evaluation. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

RANKIN, A.M., WOLFF, E.W. andMARTIN, S. 2002. Frost flowers: Implications for tropospheric chemistry and ice core interpretation, *J. Geophys. Res*., **107**, 4683, doi:10.1029/2002JD002492.

RAPER, S.C., WIGLEY, T.M., JONES, P.D. and SALINGER, M. J. 1984. Variations in surface air temperatures: Part 3. The Antarctic, 1957-1982, *Monthly Weather Review,* **112**, 1341-1353.

RAPHAEL, M.N. and HOLLAND, M.M. 2006. Twentieth century simulation of the Southern Hemisphere climate in coupled models. Part 1: Large scale circulation variability, *Clim. Dyn.*, **26**, 217–228, doi:10.1007/s00382-005-0082-8.

RAPHAEL, M.N. 2003. Impact of observed sea-ice concentration on the Southern Hemisphere extratropical atmospheric circulation in summer, *J. Geophys. Res*., **108**, No. D22, 4687 10.1029/2002JD003308.

RASCHKE, E., VONDER HAAR, T.H., BANDEEN, W.R. and PASTERNAK, M. 1973. The annual radiation balance of the earth-atmosphere system during 1969-1970 from Nimbus 3 measurements, *J. Armos. Sci.,* **30,** 341-364.

RASMUSSEN, S.O., ANDERSEN, K.K., SVENSSON, A.M., STEFFENSEN, J.P., VINTHER, B.M., CLAUSEN, H.B., SIGGAARD-ANDERSEN, M.-L., JOHNSEN, S.J., LARSEN, L.B., DAHL-JENSEN, D., BIGLER, M., RÖTHLISBERGER, R., FISCHER, H., GOTO-AZUMA, K., HANSSON, M.E. and, RUTH, U. 2006. A new Greenland ice core chronology for the last glacial termination, *Journal of Geophysical Research,* **111** , D06102.

RAU, F. and BRAUN, M. 2002. The regional distribution of the dry-snow zone on the Antarctic Peninsula north of 70° S, *Annals of Glaciology,* **34**, 95-100.

RAUPACH, M., ET AL. 2007, Global and regional drivers of accelerating CO_2 emissions, *Proc. Nat. Acad. Sci*., **104**, no. 24 10288-10293.

RAUPACH, M.J. and WÄGELE, J.W. 2006. Distinguishing cryptic species in Antarctic Asellota (Crustacea: Isopoda) - a preliminary study of mitochondrial DNA in *Acanthaspidia drygalskii*, *Antarct. Sci*., **18**, 191-198.

RAUPACH, M.J., HELD, C. and WÄGELE, J.W. 2004. Multiple colonization of the deep sea by the Asellota (Crustacea: Peracarida: Isopoda), *Deep-Sea Research II,* **51**, 1787-1795.

RAVELO, A.C., ANDREASEN, D.H., LYLE, M., OLIVAREZ LYLE, A. and WARA, M.W. 2004. Regional climate shifts caused by gradual global cooling in the Pliocene epoch, *Nature,* **429**, 263-267.

RAYMO, M.E. 1997. The timing of major climate terminations, *Paleoceanography,* **12**, 577-585.

RAYMO, M.E., GRANT, B., HOROWITZ, M. and RAU, G.H. 1996. Mid-Pliocene warmth: stronger greenhouse and stronger conveyor, *Marine Micropaleontology,* **27**, 313-326.

RAYMOND, C. 1996. Shear margins in glaciers and ice sheets, *Journal of Glaciology,* **42**, 90-102.

RAYMOND, C.F., ECHELMEYER, K.A., WHILLANS, I.M. and DOAKE, C.S.M. 2001. Ice stream shear margins. In: *The West Antarctic Ice Sheet: Behavior and* *environment* (R.B. Alley and R.A. Bindschadler, eds.). Washington DC: American Geophysical Union*, Antarctic Research Series,* **77**, 137-155.

RAYNAUD, D., BLUNIER, T., ONO, Y. and DELMAS, R.J. 2003. The Late Quaternary History of Atmospheric Trace Gases and Aerosols: Interactions Between Climate and Biogeochemical Cycles. In: Alverson K, Bradley R, Pedersen T (eds), *Paleoclimate, Global Change and the Future*, Springer-Verlag, 13-35.

READ, K.A. LEWIS, A.C., BAUGUITTE, S., RANKIN, A.M., SALMON, R.A., WOLFF, E.W., SAIZ-LOPEZ, A., BLOSS, W.J., HEARD, D.E., LEE, J.D. and PLANE, J.M.C. 2008. DMS and MSA measurements in the Antarctic Boundary Layer: impact of BrO on MSA production, *Atmos. Chem. Phys*., **8**, 2985-2997.

REID, J.L. 1986. On the total geostrophic circulation of the South Pacific Ocean: flow patterns, tracers and transports, *Progress in Oceanography,* **16**, 1-61.

REIMER, P.J., BAILLIE, M.G.L., BARD, E., BAYLISS, A., BECK, J.W., BERTRAND, C.J.H., BLACKWELL, P.G., BUCK, C.E., BURR, G.S., CUTLER, K.B., DAMON, P.E., EDWARDS, R.L., FAIRBANKS, R.G., FRIEDRICH, M., GUILDERSON, T.P., HOGG, A.G., HUGHEN, K.A., KROMER, B., MCCORMAC G, MANNING S, RAMSEY CB, REIMER RW, REMMELE, S., SOUTHON, J.R., STUIVER, M., TALAMO, S., TAYLOR, F.W., VAN DER PLICHT, J. and WEYHENMEYER, C.E. 2004. Intcal04 Terrestrial Radiocarbon Age Calibration, 0-26 Cal Kyr Bp, *Radiocarbon*, **46**, 1029-1058.

RENFREW, I.A., KING, J.C. and MARKUS, T. 2002. Coastal polynyas in the southern Weddell Sea: Variability of the surface energy budget, *J. Geophys. Res.,* **107**, doi:10.1029/2000JC000720.

RENSSEN, H., GOOSSE, H., FICHEFET, T., MASSON-DELMOTTE, V. and KOC, N. 2005a. Holocene climate evolution in the high-latitude Southern Hemisphere simulated by a coupled atmosphere-sea ice-ocean-vegetation model, *The Holocene,* **15**, 951-964.

RENWICK, J.A. and REVELL, M.J. 1999. Blocking over the South Pacific and RossbyWave propagation, *Mon.Wea. Rev*., **127**, 2233– 2247.

RETZLAFF, R. and BENTLEY, C.R. 1993. Timing of stagnation of Ice Stream C, West Antarctica, from short-pulse radar studies of buried surface crevasses, *Journal of Glaciology,* **39**, No. 133, 553-561.

REVELLE, R. and SUESS, H.E. 1957. Carbon dioxide exchange between atmosphere and ocean and the question of an increase of atmospheric CO_2 during the past decades, *Tellus*, **9**, 18-27.

RIBIC C.A. and AINLEY, D.G. 1988. Constancy of seabird species assemblages: an exploratory look, *Biol. Oceanogr*., **6**, 175-202.

RICHARDSON, A.J. and SCHOEMAN, D.S. 2004. Climate impact on ecosystems in the northeast Atlantic, *Science,* **305**, 1609-1612.

RICHARDSON, C. and HOLMLUND, P. 1999. Regional and local variability in shallow snow layer depth from a 500 km continuous radar traverse on the polar plateau, central Dronning Maud Land, East Antarctica, *Annals of Glaciology,* **29**, 10-16.

RICHARDSON, G., WADLEY, M.R., HEYWOOD, K.J., STEVENS, D.P. AND

BANKS, H.T. 2005. Short-term climate response to a freshwater pulse in the Southern Ocean, *Geophysical Research Letters*, **32**, L03702, doi:10.1029/2004GL021586.

RICHARDSON-NASLUND, C. 2004. Spatial characteristics of snow accumulation in Dronning Maud Land, Antarctica, *Global and Planetary Change*, **42** (1 4), 31-43.

RIDDLE, M.J., CRAVEN, M., GOLDSWORTHY, P.M. and CARSEY, F. 2007. A diverse benthic assemblage 100 km from open water under the Amery Ice Shelf, Antarctic, *Palaeoceanography,* **22**, PA1204; DIO: 10.1029/2006PA001327.

RIDGWAY, K.R. AND DUNN, J.R. 2007. Observational evidence for a Southern Hemisphere oceanic supergyre, *Geophysical Research Letters*, **34**, L13612, doi:10.1029/2007GL030392.

RIDLEY, J. 1993. Surface melting on Antarctic peninsula ice shelves detected by passive microwave sensors, *Geophys. Res. Lett.,* **20**(23), 2639–2642.

RIEBESELL, U., ET AL. 2000. Reduced calcification of marine plankton in response to increased atmospheric CO_2, *Nature*, **407**, 364-367.

RIESENFELD, C.S., MURRAY, A.E. and BAKER, B.J. 2008. Characterization of the microbial community and polyketide biosynthetic potential in the Palmerolide-producing tunicate, *Synoicum adareanum*., *J. Nat. Prod.,* **71**, 1812-1818.

RIGNOT, E. 2008. Changes in West Antarctic ice stream dynamics observed with ALOS PALSAR data, *Geophysical Research Letters*, **35**, L12505, doi:10.1029/2008GL033365.

RIGNOT, E. and JACOBS, S.S. 2002. Rapid bottom melting widespread near Antarctic ice sheet grounding lines, *Science,* **296**, 2020-2023.

RIGNOT, E. and THOMAS, R.H. 2002. Mass balance of polar ice sheets, *Science*, **297** (5586), 1502-1506 AUG 30 2002.

RIGNOT, E. 1998a. Radar Interferometry Detection of Hinge Line Migration on. Rutford Ice Stream and Carkon Inlet, Antarctica, *Annals of Glaciology*, **27**, 25-32.

RIGNOT, E. 1998b. Fast recession of a West Antarctic Glacier, *Science,* **281**, 549–551, (doi:10.1126/science.281.5376.549).

RIGNOT, E. 2006. Changes in ice dynamics and mass balance of the Antarctic ice sheet, *Phil. Trans. R. Soc. A,* **364**, 1637-1655; doi:10.1098/rsta.2006.1793

RIGNOT, E. and KANAGARATNAM, P. 2006. Changes in the Velocity Structure of the Greenland Ice Sheet, *Science,* **311**, no. 5763, 986 – 990.

RIGNOT, E., BAMBER, J.L., VAN DEN BROEKE, M.R., DAVIS, C., YONGHONG, L., VAN DEBERG, W.J. and VAN MEIJGAARD, E. 2008. Recent Antarctic ice mass loss from radar interferometry and regional climate modeling, *Nature Geoscience*, 13 January 2008; doi:10.1038/ngeo102.

RIGNOT, E., CASASSA, G., GOGINENI, P., KANAGARATNAM, P., KRABILL, W., PRITCHARD, H., RIVERA, A., THOMAS, R., TURNER, J. and VAUGHAN, D.G. 2005. Recent ice loss from the Fleming and other glaciers,Wordie Bay, West Antarctic Peninsula, *Geophys. Res. Let.*, **32**, doi:10.1029/2004GL021947.

RIGNOT, E., CASASSA, G., GOGINENI, P., KRABILL, W., RIVERA, A. and THOMAS, R. 2004a. Accelerated ice discharge from the Antarctic Peninsula following the collapse of Larsen B ice shelf, *Geophys. Res. Let.*, **31**, doi:10.1029/2004GL020679.

RIGNOT, E., THOMAS, R., KANAGARATNAM, P., CASASSA, G., FREDERICK, E., GOGINENI, P., KRABILL, W., RIVERA, A., RUSSELL, R., SONNTAG, J., SWIFT, R. and YUNGEL, J. 2004b. Improved estimate of the mass balance of glaciers draining into the Amundsen Sea of West Antarctica from CECS/NASA 2002 campaign, *Annals of Glaciology*, **39**, 231-237.

RIGNOT, E.J., and JACOBS, S.S. 2002. Rapid Bottom Melting Widespread near Antarctic Ice Sheet Grounding Lines, *Science,* **296**, 2020-2023.

RINTOUL, S.R. and SOKOLOV, S. 2001. Baroclinic transport variability of the Antarctic Circumpolar Current south of Australia (WOCE repeat section SR3), *Journal of Geophysical Research*, **106**, 2795-2814.

RINTOUL, S.R. 1998. On the origin and influence of Adelie Land Bottom Water. In: *Ocean, Ice and Atmosphere: Interactions at the Antarctic Continental Margin*, S. Jacobs and R. Weiss (eds.), *Antarctic Research Series*, **75**, 151-171, American Geophysical Union, Washington.

RINTOUL, S.R., HUGHES, C.W. and OLBERS, D. 2001. The Antarctic Circumpolar Current system. In: Eds. G. Siedler, J. Church and J. Gould, *Ocean circulation and climate; observing and modelling the global ocean. International Geophysics Series,* **77**, 271-302, Academic Press.

RINTOUL, S.R., SOKOLOV, S. and CHURCH, J. 2002. A six year record of baroclinic transport variability of the Antarctic Circumpolar Current at 140°E, derived from XBT and altimeter measurements, *Journal of Geophysical Research – Oceans*, **107** (C10): art.no. 3155.

RINTOUL., S.R. 2007. Rapid freshening of Antarctic Bottom Water formed in the Indian and Pacific Oceans, *Geophys. Res. Lett.*, **34**, L06606, doi:10.1029/2006GL028550.

RISEBROUGH, R.W., DE LAPPE, B.W. and YOUNGHANS-HAUG, C. 1990. PCB and PCT contamination in Winter Quarters Bay, Antarctica, *Mar. Pollut. Bull.,* **21**, 523-529.

RIST, M.A., SAMMONDS, P.R., OERTER, H. and DOAKE, C.S.M. 2002. Fracture of Antarctic shelf ice, *J. Geophys. Res.*, **107**(B1), 10.1029/2000JB000058.

ROBERTS, D. and MCMINN, A. 1996. Palaeosalinity reconstruction from saline lake diatom assemblages in the Vestfold Hills, Antarctica. In: Lyons WB, Howard-Williams C, Hawes I (eds) *Ecosystem Processes in Antarctic Ice-Free Landscapes: Polar Desert Ecosystems Conference Proceedings, Christchurch, New Zealand*, 207-220,

ROBERTS, D. and MCMINN, A. 1999a. A diatom-based palaeosalinity history of Ace Lake, Vestfold Hills, Antarctica, *The Holocene,* **9**, 401-408.

ROBERTS, D. and MCMINN, A. 1999b. Palaeohydrological modelling of Ace Lake, Vestfold Hills, Antarctica, *The Holocene,* **9**, 515-520.

ROBERTS, D., MCMINN, A., CREMER, H., GORE, D. and MELLES, M. 2004. The Holocene evolution and palaeosalinity history of Beall Lake, Windmill Islands

(East Antarctica) using an expanded diatom-based weighted averaging model, *Palaeogeography Palaeoclimatology Palaeoecology,* **208**, 121-140.

ROBERTS, D., VAN OMMEN, T.D., MCMINN, A., MORGAN, V. and ROBERTS, J.L. 2001. Late Holocene East Antarctic climatic trends from ice core and lake sediment proxies, *The Holocene,* **11**, 117-120.

ROBERTS, S.J., HODGSON, D.A., BENTLEY, M.J., SMITH, J.A., MILLAR, I., OLIVE, V. and SUGDEN, D.E. 2008. The Holocene history of George VI Ice Shelf, Antarctic Peninsula from clast-provenance analysis of epishelf lake sediments, *Palaeogeography Palaeoclimatology Palaeoecology,* **259**, 258-283.

ROBERTSON, E.I. and MACDONALD, W.J.P. 1962. Electrical resistivity and ground temperature at Scott Base, Antarctica, *New Zealand Journal of Geology and Geophysics*, **5**(5), 797-809.

ROBERTSON, R. 2001. Internal tides and baroclinicity in the southern Weddell Sea: Part II: Effects of the critical latitude and stratification, *J. Geophys. Res.,* **106**, 27017-27034.

ROBERTSON, R., BECKMANN, A. and HELLMER, H. 2003. M_2 tidal dynamics in the Ross Sea, *Antarct. Sci.,* **15**, 41-46.

ROBERTSON, R., VISBECK, M., GORDON, A.L. and FAHRBACH, E. 2002. Long-term temperature trends in the Deep Waters of the Weddell Sea, *Deep-Sea Research II*, **49**(21), 4791-4806.

ROBIN, G. DE Q., SWITHINBANK, C.W.M. and SMITH, B.M.E. 1970. Radio echo exploration of the Antarctic ice sheet, *Int. Assoc. Sci. Hydrol. Publ.,* **86**, 97-115.

ROBINSON, S.A., TURNBULL, J.D. and LOVELOCK, C.E. 2005. Impact of changes in natural UV radiation on pigment composition, surface reflectance and photosynthetic function of the Antarctic moss, *Grimmia antarctici*, *Global Change Biology,* **11**, 476-489.

ROBINSON, S.A., WASLEY, J. and TOBIN, A.K. 2003. Living on the edge - plants and global change in continental and maritime Antarctica, *Global Change Biology* **9**, 1-37.

ROCK, J., COSTA, F.O., WALKER, D.I., NORTH, A.W., HUTCHINSON, W.F. and CARVALHO, G.R. 2008. DNA barcodes of fish of the Antarctic Scotia Sea indicate priority groups for taxonomic and systematics focus, *Antarct. Sci*., **20**, 253-262.

RODRIGUEZ-TRELLES, F. and RODRIGUEZ, M.A. 1998. Rapid micro-evolution and loss of chromosomal diversity in *Drosophila* in response to climate warming, *Evol. Ecol.,* **12**, 829-838.

ROGERS, A.D. 2007. Evolution and biodiversity of Antarctic organisms: a molecular perspective, *Philosophical Transactions of the Royal Society of London, Series B, Biological Sciences,* **362**, 2191-2214.

ROGERS, J.C. and VAN LOON, H. 1982. Spatial Variability of Sea Level Pressure and 500 mb Height Anomalies over the Southern Hemisphere, *Mon. Wea. Rev.*, **110**, 1375-1392.

ROLEDA, M.Y., ZACHER, K., WULFF, A., HANELT, D. and WIENCKE, C. 2008.

Susceptibility of spores of different ploidy levels from Antarctic *Gigartina skottsbergii* (Gigartinales, Rhodophyta) to ultraviolet radiation, *Phycologia,* **47**, 361-370.

ROMANOVSKY, V.E. and OSTERKAMP T.E. 1995. Interannual variations of the thermal regime of the active layer and near surface permafrost in northern Alaska, *Permafrost and Periglacial Processes*, **6**, 313-335.

ROMANOVSKY, V.E., BURGESS, M., SMITH, S., YOSHIKAWA, K. and BROWN, J. 2002. Permafrost temperature records: indicators of climate change, *EOS Transactions,* **83**, 589-594.

RØNNING, O.I. 1996. *The flora of Svalbard*. Norsk Polarinstitut, Oslo: 184 pp.

ROOT, T.L., PRICE, J.T., HALL, K.R., SCHNEIDER, S.H., ROSENZWEIG, C. and POUNDS, J.A. 2003. Fingerprints of global warming on wild animals and plants, *Nature,* **421**, 57-60.

ROSCOE, H.K., KREHER, K. and FRIEB, U. 2001. Ozone loss episodes in the free Antarctic troposphere, suggesting a possible climate feedback, *Geophys. Res. Letts*., **28**, 2911-2914.

ROSENHEIM, J.A. and TABASHNIK, B.E. 1991. Influence of generation time on the rate of response to selection, *American Naturalist,* **137**, 527-541.

ROSS, R.M., QUETIN, L.B. and LASCARA, C. 1996. Distribution of Antarctic krill and dominant zooplankton west of the Antarctic Peninsula. In: *Foundations for Ecological Research West of the Antarctic Peninsula,* (Eds. R.M. Ross, E.E. Hofmann and L.B. Quetin), American Geophysical Union, Washington, D.C. *Antarctic Research Series,* **70**, 199–217

ROSS, R.M., QUETIN, L.B., MARTINSON, D.G., IANNUZZI, R.A., STAMMERJOHN, S.E. and SMITH, R.C. 2008. Palmer LTER: Patterns of distribution of five dominant zooplankton species in the epipelagic zone west of the Antarctic Peninsula, 1993–2004, *Deep-Sea Res. II*, **55**, 2086-2105.

ROTSCHKY, G., EISEN, O., WILHELMS, F., NIXDORF, U. and OERTER, H. 2004. Spatial distribution of surface mass balance on Amundsenisen plateau, Antarctica, derived from ice-penetrating radar studies, *Annals of Glaciology,* **39**, 265-270.

ROTSCHKY, G., RACK, W., DIERKING, W. and OERTER, H. 2006. Retrieving Snowpack Properties and Accumulation Estimates from a Combination of SAR and Scatterometer Measurements, *IEEE Transactions on Geoscience and Remote Sensing*, **44**(4), 943-956., doi:10.1109/TGRS.2005.862524.

ROTT, H., RACK, W., NAGLER, T. and SKVARCA, P. 1998. Climatically induced retreat and collapse of northern Larsen Ice Shelf, Antarctic Peninsula, *Annals of Glaciology,* **27**, 86-92.

ROTT, H., RACK, W., SKVARCA, P. and DE ANGELIS, H. 2002. Northern Larsen Ice Shelf, Antarctica: further retreat after collapse, *Annals of Glaciology,* **34**, 277-282.

ROTT, H., SKVARCA, P. and NAGLER. T. 1996. Rapid collapse of Northern Larsen Ice Shelf, Antarctica, *Science*, **271**, 788-792.

ROUAULT, M., MELICE, J.L., REASON, C.J.C. and LUTJEHARMS, J.R.E. 2005. Climate variability at Marion Island, Southern Ocean, since 1960, *J. Geophy. Res. – Oceans*, 110, C05007, doi:10.1029/2004JC002492.

ROWLEY, R.J, KOSTELNICK, J.C., BRAATEN, D., LI, X. and MEISEL, J. 2007. Risk of rising sea level to population and land area, *EOS Transactions*, **88**, 105, 107.

ROYER, D.L. 2006. CO2-forced climate thresholds during the Phanerozoic, *Geochim. Cosmochim. Acta,* **70***,* 5665-5675.

ROZANOV, E., SCHRANER, M., SCHNADT, C., EGOROVA, T., WILD, M., OHMURA, A., ZUBOV, V. and SCHMUTZ, W. 2005. Assessment of the ozone and temperature variability during 1979-1993 with the chemistry-climate model SOCOL, *Adv. Space Res.*, **35**, 1375-1384.

RUHLAND, C.T. and DAY, T.A. 2000. Effects of ultraviolet-B radiation on leaf elongation, production and phenylpropanoid concentrations of *Deschampsia antarctica* and *Colobanthus quitensis* in Antarctica, *Physiologia Plantarum,* **109**, 244-251.

RUSSELL, J.L., DIXON, K.W., GNANADESIKAN, A., STOUFFER, R.J. and TOGGWEILER, J.R. 2006b. The Southern hemisphere westerlies in a warming world: propping open the door to the deep ocean, *J. Clim*., **19,** 6382–6390.

RUSSELL, J.L., STOUFFER. R.J. and DIXON, K.W. 2006a. Intercomparison of the Southern Ocean circulation in IPCC coupled model controm simulations, *J. Clim.,* **19,** 4560-4575.

RUUD, J.T. 1954. Vertebrates without erythrocytes and blood pigment, *Nature,* **173**, 848-850

SABBE, K., HODGSON, D.A., VERLEYEN, E., TATON, A., WILMOTTE, A., VANHOUTTE, K. and VYVERMAN, W. 2004. Salinity, depth and the structure of and composition of microbial mats in continental Antarctic lakes, *Freshwater Biol.,* **49**, 296-319.

SABINE, C.L., ET AL. 2004. The Oceanic Sink for Anthropogenic CO_2, *Science*, **305**, 367-371.

SACHS, O. 2008. Benthic organic carbon fluxes in the Southern Ocean: regional differences and links to surface primary production and carbon export, *Ber. Polarforsch. Meeresforsch*., **578**, 1-143.

SAIZ-LOPEZ, A., MAHAJAN, A.S., SALMON, R.A., BAUGUITTE, S.J.-B., JONES, A.E., ROSCOE, H.K. and PLANE, J.M.C. 2007. Boundary layer halogens in coastal Antarctica, *Science,* **317**, 348-351, DOI: 10.1126/science.1141408.

SALLÉE, J.-B., WIENDERS, N., SPEER, K. AND MORROW, R. 2006. Formation of subantarctic mode water in the southeastern Indian Ocean, *Ocean Dynamics,* **56**, 525–542, DOI 10.1007/s10236-005-0054-x.

SANDS, C.J., CONVEY, P., LINSE, K. and MCINNES, S.J. 2008. Assessing meiofaunal variation among individuals: an example using Tardigrada, *BMC Ecology,* **8**, 7.

SANDVIK, A., BIRYULINA, M., KVAMSTO, N.G., STAMNES, J.J. and STAMNES, K. 2007. Observed and simulated microphysical composition of arctic clouds: Data properties and model validation, *J. Geophys. Res.,* **112,** Art. No. D05205.

SANDWELL, D.T. and SMITH, W.H.F. 1997. Marine gravity anomaly from Geosat and ERS-1 satellite altimetry, *J. Geophys. Res*., **102**, 10,039-10,054.

SARMIENTO, J.L., Gruber, N., Brzezinski, M.A. and Dunne, J.P. 2004a. High-latitude Controls of Thermocline Nutrients and Low Latitude Biological Productivity, *Nature*, **427**, 56-60.

SARMIENTO, J.L., SLATER, R., BARBER, R.T., BOPP, L., DONEY, S.C., HIRST, A.C., KLEYPAS, J., MATEAR, R.J., MIKLOLAJEWICZ, U., MONFRAY, P., SOLDATOV, V., SPALL, S.A. AND STOUFFER, R, 2004B. Response of Ocean Ecosystems to Climate Warming, *Global Biogeochemical Cycles*, **18**, doi:10.1029/2003GB002134.

SARMIETO, J.L., HUGHES, T.M.C., STOUFFER, R.J. and MANABE, S. 1998. Simulated response of the ocean carbon cycle to an anthropogenic climate warming, *Nature,* **393**, 245-249.

SAUNDERS, R.A., BRIERLEY, A.S., WATKINS, J.L., REIS, K., MURPHY, E.J., ENDERLEIN, P. and BONE, D.G. 2007. Intra-Annual variability in the density of Antarctic krill (Euphausia superba) at South Georgia, 2002-2005: within-year variation provides a new framework for interpreting previous 'annual' estimates of krill densitiy, *CCAMLR Science,* **14**, 27-41.

SAWAGAKI, T. 1995. Ground temperature regimes and frost heave activity in the vicinity of Syowa Station, East Antarctica. In: *Proceedings of the NIPR symposium on Antarctic geosciences*, **8**, 239-249.

SCAMBOS, T., HUBLE, M., FAHNESTOCK, M. and BOHLANDER, J. 2000. The link between climate warming and break-up of ice shelves in the Antarctic Peninsula, *Journal of Glaciology*, **46**, 516-530.

SCAMBOS, T.A., BOHLANDER, J., SHUMAN, C. and SKVARCA, P. 2004. Glacier acceleration and thinner after ice shelf collapse in the Larsen B embayment, Antarctica, *Geophys. Res. Lett.,* **31**, doi:10.1029/2004GL020670.

SCAMBOS, T.A., DUTKIEWICZ, M.J., WILSON, J.C. and BINDSCHADLER, R.A. 1992. Application of image cross-correlation to the measurement of glacier velocity using satellite image data, *Remote Sensing of Environment*, **42**, 177-186.

SCAMBOS, T.A., HULBE, C. and FAHNESTOCK, M. 2003. Climate-induced ice shelf disintegration in the Antarcitc Peninsula. In: *Antarctic Peninsula Climate Variability; Historical and Paleoenvironmental Perspectives* (E. Domack, A. Burnett, A. Leventer, P. Conley, M. Kirby, and R. Bindschadler, editors), *Antarctic Research Series*, **79**, 79-92.

SCHER, H.D. and MARTIN, E.E. 2006. Timing and Climatic Consequences of the Opening of Drake Passage, *Science,* **312**, 428-430.

SCHEWE, I. and SOLTWEDEL, T. 2003. Benthic response to ice-edge-induced particle flux in the Arctic Ocean, *Polar Biol.,* **26**, 610-620.

SCHMIDT, R., MÄUSBACHER, R. and MULLER, J. 1990. Holocene diatom flora and stratigraphy from sediment cores of two Antarctic lakes (King George Island), *Journal of Paleolimnology,* **3**, 55-74.

SCHMITZ, W. J. 1995. On the Interbasin-scale Thermohaline Circulation, *Reviews of Geophysics,* **33**, 2, American Geophysical Union, 151-173.

SCHNACK-SCHIEL, S.B., HAGEN, W. and MIZDALSKI, E. 1998. Seasonal carbon dynamics of Antarctic copepods in the Weddell Sea, *Journal of Marine Systems,* **17**, 305-311.

SCHNACK-SCHIEL, S.B., MICHELS, J., MIZDALSKI, E., SCHODLOK, M. and SCHRÖDER, M. 2008. Composition and community structure of zooplankton in the sea ice covered western Weddell Sea in spring 2004 – with emphasis on calanoid copepods, *Deep-Sea Research II,* **55**, 1040-1055.

SCHNEIDER, D.P. and STEIG, E.J. 2008. Ice cores record significant 1940s Antarctic warmth related to tropical climate variability, *Proceedings of the National Academy of Sciences of the United States of America,* **105**(34), 12154-12158.

SCHNEIDER, D.P., STEIG, E.J. and COMISO, J.C. 2004. Recent climate variability in Antarctica from satellite-derived temperature data, *J. Climate*, **17**, 1569-1583.

SCHNEIDER, D.P., STEIG, E.J., VAN OMMEN, T.D., DIXON, D.A., MAYEWSKI, P.A., JONES, J.M. and BITZ, C.M. 2006. Antarctic temperatures over the past two centuries from ice cores, *Geophysics Research Letters,* **33**, L16707, doi:10.1029/2006GL027057.

SCHOOF, C. 2007. Marine ice sheet dynamics. Part I: The case of rapid sliding, *J. Fluid. Mech.*, **573**, 27-55.

SCHROEDER, M. and FAHRBACH, E. 1999. On the structure and transport of the eastern Weddell Gyre, *Deep Sea Research*, **46**, 501-527.

SCHROEDER, W.H., ANLAUF, K.G., BARRIE, L.A., LU, J.Y., STEFFEN, A., SCHNEEBERGER, D.R. and BERG, T. 1998. Arctic springtime depletion of mercury, *Nature,* **394**, 331-332.

SCHULZ, K.G. and ZEEBE, R.E. 2006. Pleistocene glacial terminations triggered by synchronous changes in Southern and Northern Hemisphere insolation : the insolation canon hypothesis, *Earth and Planetary Science Letters,* **249**, 326-336.

SCHUTZ, B.E., ZWALLY, H.J., SHUMAN, C.A., HANCOCK, D. and DIMARZIO, J.P. 2005. Overview of the ICESat Mission, *Geophys. Res. Lett.*, **32**, L21S01, doi:10.1029/2005GL024009.

SCHWERDTFEGER, W. 1970. The climate of the Antarctic, *World Survey of Climatology*, Chapter 4, 253-355.

SCOTT, R.B. and WANG, F. 2005. Direct evidence of an oceanic inverse kinetic energy cascade from satellite altimetry, *J. Phys. Oceanogr.,* **35**, 1650-1666.

SEBASTIAN, S., RAES, M., DE MESEL, I. and VANREUSEL, A. 2007. Comparison of the nematode fauna from the Weddell Sea Abyssal Plain with two North Atlantic abyssal sites, *Deep-Sea Res. II*, **54**, 1727-1736.

SEDDIK, H., GREVE, R., LUCA, P., ILKA, H. and OLIVIER, G. 2008. Application of a continuum-mechanical model for the flow of anisotropic polar ice to the EDML core, Antarctica, *J. Glaciol*., **54**(187), 631-642.

SEEBACHER, F., DAVISON, W., LOWE, C.J. and FRANKLIN, C.E. 2005. A falsification of the thermal specialization paradigm: compensation for elevated temperatures in Antarctic fish, *Biol. Lett.,* **2**, 151-154.

SEILER, J. and GUTT, J. 2007. Can dead sponges still talk?, *Antarctic Sci.,* **19** (3), 337-338.

SEMTNER, A. 1976. A model for the thermodynamic growth of sea ice in numerical investigations of climate, *Journal of Physical Oceanography*, **6** (3), 379–389.

SEMTNER, A.J. 1974. An oceanic general circulation model with bottom topography, Technical Report No. 9, Dept. of Meteorology, UCLA, Los Angeles, CA 90095, USA.

SEN GUPTA, A. and ENGLAND, M.H. 2007. Coupled ocean-atmosphere feedback in the Southern Annular Mode, *J. Climate*, **20**, 3677-3692.

SEVERI, M., BECAGLI, S., CASTELLANO, E., MORGANTI, A., TRAVERSI, R., UDISTI, R., RUTH, U., FISCHER, H., HUYBRECHTS, P., WOLFF, E., PARRENIN, F., KAUFMANN, P., LAMBERT, F. and STEFFENSEN, J.P. 2007. Synchronisation of the EDML and EDC ice cores for the last 52 kyr by volcanic signature matching, *Climate of the Past,* **3**, 367-374.

SEVERINGHAUS, J.P. and BATTLE, M. 2006. Fractionation of gases in polar ice during bubble close-off, new constraints from firn air Ne, Kr, and Xe observations, *Earth and Planetary Science Letters,* **244**, 474-500.

SEXTON, D.M.H. 2001. The effect of stratospheric ozone depletion on the phase of the Antarctic Oscillation, *Geophys. Res. Lett.*, **28**, 3697–3700.

SHABTAIE, S. and BENTLEY, C.R. 1987. West Antarctic ice streams draining into the Ross ice shelf: configuration and mass balance, *J. Geophys. Res.,* **92**, 1311–1336.

SHACKLETON, N.J. and KENNETT, J.P. 1975. Paleotemperature history of the Cenozoic and the initiation of Antarctic glaciation: oxygen and carbon isotope analysis in DSDP sites 277, 279 and 281. In: Kennett JP, Houtz RE (eds) *Initial Reports of the Deep Sea Drilling Project*, **29**. Washington (U.S. Government Printing Office), 743-755.

SHACKLETON, N.J., BACKMAN, J., ZIMMERMAN, H., KENT, D.V., HALL, M.A., ROBERTS, D.G., SCHNITKER, D., BALDAUF, J.G., DESPRAIRIES, A., HOMRIGHAUSEN, R., HUDDLESTUN, P., KEENE, J.B., KALTENBACK, A.J., KRUMSIEK, K.A.O., MORTON, A.C., MURRAY, J.W. and WESTBERG-SMITH, J. 1984. Oxygen isotope calibration of the onset of ice-rafting and history of glaciation in the North Atlantic region, *Nature,* **307**, 620-623.

SHAW, G.E. 1988. Antarctic aerosol: a review, *Rev. Geophys.,* **26**, 89-112.

SHAW, J.D. 2005. *Reproductive Ecology of Vascular Plants on Subantarctic Macquarie Island*. PhD Thesis, University of Tasmania, Hobart.

SHAW, J.D., BERGSTROM, D.M. and HOVENDEN, M. 2005. The impact of feral rats (*Rattus rattus*) on populations of subantarctic megaherb (*Pleurophyllum hookeri*), *Austral. Ecology,* **30**, 118-125.

SHCHEPETKIN, A.F. and MCWILLIAMS, J.C. 2003. A method for computing horizontal pressure-gradient force in an oceanic model with a nonaligned vertical coordinate, *Journal of Geophysical Research*, **108** (c3), 3090, doi:10.1029/2001JC001047.

SHEPHERD, A. and WINGHAM, D. 2007. Recent sea-level contributions of the Antarctic and Greenland ice sheets, *Science,* **315** (5818), 1529-1532.

SHEPHERD, A., WINGHAM, D. and RIGNOT, E. 2004. Warm ocean is eroding West Antarctic ice sheet, *Geophys. Res. Lett.*, **31**, L23402, doi:10.1029/2004GL021106.

SHEPHERD, A., WINGHAM, D.J., MANSLEY, J.A.D. and CORR, H.F.J. 2001. Inland thinning of Pine Island Glacier, West Antarctica, *Science,* **291**, 862–864, (doi:10.1126/science.291.5505.862).

SHEPHERD, A.P., WINGHAM, D.J. and MANSLEY, J.A.D. 2002. Inland thinning of the Amundsen Sea sector, West Antarctica, *Geophys. Res. Lett.*, **29**, 1364, doi:10.1029/2001GL014183.

SHEPHERD, L.D., MILLAR, C.D., BALLARD, G., AINLEY, D.G., WILSON, P.R., HAYNES, G.D., BARONI, C., LAMBERT, D.M. 2005. Microevolution and mega-icebergs in the Antarctic, *Proc. Natl. Acad. Sci.,* **102**, 16717-16722

SHERJAL, I. and FILY, M. 1994. Temporal variations of microwave brightness temperatures over Antarctica, *Ann. Glaciol.,* **20**, 19–25.

SHEVENELL, A.E., DOMACK, E.W. and KERNAN, G. 1996. Record of Holocene paleoclimate change along the Antarctic Peninsula: Evidence from glacial marine sediments, Lallemand Fjord, *Papers and Proceedings of the Royal Society of Tasmania,* **130**, 55-64.

SHI, G.R. and GRUNT, T.A. 2000. Permian Gondwana-Boreal antitropicality with special reference to brachiopod faunas, *Palaeogeography, Palaeoclimatology, Palaeoecology,* **155**, 239-263.

SHIBATA, K., DEUSHI, M., SEKIYAMA, T.T. and YOSHIMURA, H. 2005. Development of an MRI chemical transport model for the study of stratospheric chemistry, *Pap. Meteorol. Geophys.*, **55***,* 75-119.

SHINDELL, D.T. and SCHMIDT, G.A. 2004. Southern hemisphere climate response to ozone changes and greenhouse gas increases, *Geophys. Res. Lett.*, **31**, L18209, doi:10.1029/2004GL020724.

SHIPP, S., ANDERSON, J.B. and DOMACK, E.W. 1999. Seismic signature of the Late Pleistocene fluctuation of the West Antarctic Ice Sheet system in Ross Sea: a new perspective, Part I, *Ecolological Society of America Bulletin,* **111**, 1486-1516.

SHRAVAGE, B.V., DAYANANDO, K.M., PATOLE, M.S. and SHOUCHE, Y.S. 2007. Molecular microbial diversity of a soil sample and detection of ammonia oxidizers from Cape Evan, McMurdo Dry Valley, Anatarctica, *Microbiol. Res.*, **162**, 15-25.

SHULMEISTER, J., GOODWIN, I., RENWICK, J., HARLE, K., ARMAND, L., MCGLONE, M. S., COOK, E., DODSON, J., HESSE, P. P.,MAYEWSKI. P.A. and CURRAN, M. 2004. The Southern Hemisphere Westerlies in the Australasian sector: A synthesis, *Quaternary International,* **118-119**, 23-53.

SIEGEL, V. 2005. Distribution and population dynamics of Euphausia superba: summary of recent findings, *Pol. Biol*., **29**, 1-22, doi:10.1007/s00300-005-0058-5.

SIEGENTHALER, U., MONNIN, K., KAWAMURA, R., SPAHNI, J., SCHWANDER, B., STAUFFER, T.F., STOCKER, J-M., BARNOLA, H. and FISCHER, H. 2005a. Supporting evidence from the EPICA Dronning Maud Land ice core for atmospheric CO2 changes during the past millennium, *Tellus B,* **57**, 51-57.

SIEGENTHALER, U., STOCKER, T.F., MONNIN, E., LUTHI, D., SCHWANDER, J., STAUFFER, B., RAYNAUD, D., BARNOLA, J-M., FISCHER, H., MASSON-DELMOTTE, V. and JOUZEL, J. 2005b. Stable Carbon Cycle-Climate Relationship During the Late Pleistocene, *Science,* **310**, 1313-1317.

SIEGERT MJ, BARRETT P, DECONTO R, DUNBAR R, COFAIGH CO, PASSCHIER S, NAISH T. R. 2008. Recent Advances in Understanding Antarctic Climate Evolution, *Antarctic Sci.,* 1, 1-13.

SIEGERT, M.J., POKAR, M., DOWDESWELL, J.A. and BENHAM, T. 2005a. Radio-echo layering in West Antarctica: a spreadsheet dataset, *Earth Surf. Process. Landforms,* **30**, 1583–1591.

SIEGERT, M.J., CARTER, S. TABACCO, I. and POPOV, S. 2005b. A revised inventory of Antarctic subglacial lakes, *Antarctic Science,* **17**, 453–460.

SIMMONDS, I. and KEAY, K. 2000. Variability of Southern Hemisphere extratropical cyclone behaviour, 1958–97, *J. Climate*, **13**(3), 550–561.

SIMMONDS, I.H., KEAY, K. and LIM, E. 2003. Synoptic Activity in the Seas around Antarctica, *Monthly Weather Review*, **131**, 272-288.

SIMMONS, H., HALLBERG, R. and ARBIC, B. 2004. Internal wave generation in a global baroclinic tide model, *Deep-Sea Res. II,* **51**, 3043-3068.

SIMPSON, W.R., VON GLASOW, R., RIEDEL, K., ANDERSON, P. ARIYA, P., BOTTENHEIM, J., BURROWS, J., CARPENTER, L.J., FRIEß, U., GOODSITE, M.E., HEARD, D., HUTTERLI, H., JACOBI, H.-W., KALESCHKE, L., NEFF, B., PLANE, J., PLATT, U., RICHTER, A., ROSCOE, H., SANDER, R., SHEPSON, P., SODEAU, J., STEFFEN, A., WAGNER, T. and WOLFF, E. 2007. Halogens and their role in polar boundary-layer ozone depletion, *Atmos. Chem. Phys.*, **7**, 4375-4418.

SINCLAIR, B.J. and CHOWN, S.L. 2005. Deleterious effects of repeated cold exposure in a freeze-tolerant sub-Antarctic caterpillar, *Journal of Experimental Biology,* **208**, 869-879.

SINCLAIR, B.J. 2001. Field ecology of freeze tolerance: interannual variation in cooling rates, freeze-thaw and thermal stress in the microhabitat of the alpine cockroach *Celatoblatta quinquemaculata*, *Oikos,* **93**, 286-293.

SINCLAIR, M.R. 1996. A climatology of anticyclones and blocking for the Southern Hemisphere, *Mon. Wea. Rev*., **124**, 245-263.

SINCLAIR, M.R., RENWICK, J.A. and KIDSON, J.W. 1997. Low-frequency variability of Southern Hemisphere sea level pressure and weather system activity, *Mon. Weather Rev.*, **125**, 2531–2543.

SINHA, B. and RICHARDS, K.J. 1999. Jet structure and scaling in Southern Ocean models, *J. Phys. Oceanogr*., **29**, 1143-1155.

SJUNNESKOG, C. and TAYLOR, F. 2002. Postglacial marine diatom record of the Palmer Deep, Antarctic Peninsula (ODP Leg 178, Site 1098) 1. Total diatom abundance, *Paleoceanography,* **17**, art. no. 8003.

SKVARCA, P. 1993. Fast recession of the northern Larsen Ice Shelf monitored by space images, *Annals of Glaciology*, **17**, 317-321.

SKVARCA, P. 1994. Changes and surface features of the Larsen Ice Shelf, Antarctica, derived from Landsat and Kosmos mosaics, *Ann. Glaciol.,* **20**, 6.

SKVARCA, P., RACK, W., ROTT, H., IBARZÁBAL, T. and DONÁNGELO, Y. 1998. Evidence of recent climatic warming on the eastern Antarctic Peninsula, *Annals of Glaciology,* **27**, 628-635.

SLABBER, S. and CHOWN, S.L. 2002. The first record of a terrestrial crustacean, *Porcellio scaber* (Isopoda, Porcellionidae), from sub-Antarctic Marion Island, *Polar Biology,* **25,** 855-858.

SLABBER, S. 2005. Physiological plasticity in arthropods from Marion Island: indigenous and alien species. PhD Thesis, Stellenbosch University, South Africa.

SLOYAN, B.M. 2005. Spatial variability of mixing in the Southern Ocean, *Geophys. Res. Lett.,* **32**, doi:10.1029/2005GL023568.

SMALE, D.A., BARNES, D.K.A. and FRASER, K.P.P. 2007. The influence of depth, site exposure and season on the intensity of iceberg scouring in nearshore Antarctic waters, *Polar Biol.,* **30**, 769-779.

SMEDSRUD, L.H. 2005. Warming of the deep water in the Weddell Sea along the Greenwich Meridian: 1997-2001, *Deep-Sea Research I*, **52**(2), 241-258.

SMETACEK. V. and NICOL, S. 2005. Polar ocean ecosystems in a changing world, *Nature,* **437**, 362-368.

SMETHIE, W.M. and JACOBS, S.S. 2005. Circulation and melting under the Ross Ice Shelf: Estimates from evolving CFC, salinity and temperature fields in the Ross Sea, *Deep-Sea Res*. I, **52**, 959-978.

SMITH, A.M. 2007b. Subglacial Bed Properties from Normal-Incidence Seismic Reflection Data, *J. Env. and Eng. Geophys.*, **12**, 3-13.

SMITH, A.M., MURRAY, T., NICHOLLS, K.W., MAKINSON, K., AÐALGEIRSDÓTTIR, G., BEHAR, A.E. and VAUGHAN, D.G. 2007a. Rapid erosion, drumlin formation, and changing hydrology beneath an Antarctic ice stream, *Geology,* **35**, 127-130.

SMITH, A.M., VAUGHAN, D.G., DOAKE, C.S.M., ET AL. 1998. Surface lowering of the ice ramp at Rothera Point, Antarctic Peninsula, in response to regional climate change, *Ann. Glaciol.,* **27**, 113-118.

SMITH, C.R., MINKS, S. and DEMASTER, D.J. 2006. A síntesis of bentho-pelagic coupling on the Antarctic shelf: Food banks, ecosystem inertia and global climate change, *Deep-Sea Res. II,* **53**, 875-894.

SMITH, I. N., MCINTOSH, P., ANSELL, T. J., REASON, C.J. C. and MCINNES, K. 2000. Southwest Western Australian winter rainfall and its association with Indian Ocean climate variability, *International Journal of Climatology,* **20**, 1913-1930.

SMITH, J., VANCE, D., KEMPA, R.A., ARCHER, C., TOMSA, P., KINGA, M. and ZÁRATE, M. 2003. Isotopic constraints on the source of Argentinian loess-with implications for atmospheric circulation and the provenance of Antarctic dust during recent glacial maxima, *Earth and Planetary Science Letters,* **212**, 181-196.

SMITH, J.A., BENTLEY, M.J., HODGSON, D.A., ROBERTS, S.J., LENG, M.J., LLOYD, J.M., BARRETT, M.J., BRYANT, C. and SUGDEN, D.E. 2007. Oceanic and atmospheric forcing of early Holocene ice shelf retreat, George VI Ice Shelf, Antarctica Peninsula, *Quaternary Science Reviews,* **26**, 500-516.

SMITH, M.C., BOWMAN, J.P., SCOTT, F.J. and LINE, M.A. 2000. Sublithic bacteria associated with Antarctic quartz stones, *Antarct. Sci*., **12**, 177-184.

SMITH, N.R., DONG, Z. KERRY, K.R. and WRIGHT, S. 1984. Water masses and circulation in the region of PrydzBay, *Antarctica, Deep-sea Research*, **31**, 1121-1147.

SMITH, P.J., STEINKE, D., MCVEAGH, S.M., STEWART, A.L., STRUTHERS, C.D. and ROBERTS, C.D. 2008. Molecular analysis of Southern Ocean skates (*Bathyraja*) reaveals a new species of Antarctic skate, *Journal of Fish Biology,* **73**, 1170-1182.

SMITH, R.I.L. 1984. Terrestrial plant biology of the sub-Antarctic and Antarctic. In: Laws, R.M. (ed.), *Antarctic Ecology*, **1**, Academic Press, London, 61-162.

SMITH, R.I.L. 1994. Vascular plants as bioindicators of regional warming in Antarctica, *Oecologia*, **99**, 322-328.

SMITH, V.R. and STEENKAMP, M. 1990. Climatic change and its ecological implications at a sub-Antarctic island, *Oecologia,* **85**, 14-24.

SMITH, V.R. 2002. Climate change in the sub-Antarctic: An illustration from Marion Island, *Climate Change,* **52**, 345-357.

SMITH, W. and ASPER, V.A. 2007. New Ways to Collect Data in the Antarctic, *EOS, Transactions American Geophysical Union*, **88**, no. 48, 525.

SMITH, W.O. and COMISO, J.C. 2008. Influence of sea ice on primary production in the Southern Ocean: A satellite perspective**,** *J. Geophys. Res.,* **113***,* C05S93, doi:10.1029/2007JC004251 .

SMITH, W.O. and NELSON, D.M. 1986. Importance of ice edge phytoplankton production in the Southern Ocean, *BioScience,* **36**, 251–257.

SNELL, K.R.S., KOKUBUN, T., GRIFFITHS, H., CONVEY, P., HODGSON, D.A. and NEWSHAM, K.K. 2009. Quantifying the metabolic cost to an Antarctic liverwort of responding to an abrupt increase in UV-B radiation exposure, *Global Change Biology,* **15**, DOI: 10.1111/j.1365-2486.2009.01929.x.

SOKOLOV, S. and RINTOUL, S.R. 2007. Multiple jets of the Antarctic Circumpolar Current south of Australia, *Journal of Physical Oceanography*, **37**, 1394-1412.

SOKOLOV, S. and RINTOUL, S.R. 2002. The structure of Southern Ocean fronts at 140E, *Journal of Marine Systems*, **37**, 151-184.

SOKOLOV, S. and RINTOUL, S.R. 2003. The subsurface structure of interannual temperature anomalies in the Australian sector of the Southern Ocean, *Journal of Geophysical Research*, **108** (C9): Art. No. 3285.

SOLOMON, S., PLATTNER, G.-K., KNUTTI, R. and FRIEDLINGSTEIN, P. 2009. Irreversible climate change due to carbon dioxide emissions. *Proceedings of the National Academy of Sciences,* **106**, 1704-9.

SOMERO, G.N. and DE VRIES, A.L. 1967. Temperature tolerance of some Antarctic fishes, *Science,* **156**, 257-258.

SOMERO, G.N. 2005. Linking biogeography to physiology: evolutionary and acclamatory adjustments of thermal limits, *Front. Zool*., **2**, 1, DOI: 10.1186/1742-9994-2-1.

SOMERO, G.N., DAHLHOFF, E. and LIN, J.J. 1996. Stenotherms and eurytherms: mechanisms establishing thermal optima and tolerance ranges. In: Johnston IA, Bennett AF (Eds) *Animals and Temperature: Phenotypic and Evolutionary Adaptation*. Cambridge University Press, Cambridge, 53-57.

SOMERO, G.N., FIELDS, P.A., HOFMANN, G.E., WEINSTEIN, R.B. and KAWALL, H. 1998. Cold adaptation and stenothermy in Antarctic notothenioid fishes: what has been gained and what has been lost. In: di Prisco G, Pisano E, Clarke A, (Eds), *Fishes of Antarctica: a Biological Overview*. Springer, Milano, 97-109.

SONE, T., STRELIN, J. and MORI, J. 2001 Thermal characteristics of permafrost in Seymour Island and James Ross Island, Antarctic Peninsula. *In: 1st European Permafrost Conference, Rome 26-28 March, 2001– Abstracts*, 100.

SONG, Y.T. and HAIDVOGEL, D. 1994. A semi-implicit ocean circulation model using a generalized topography following coordinate system, *Journal of Computational Physics*, **115**, 228–248.

SOO, R.M., WOOD, S.A., GRZYMSKI, J.J., MCDONALD, I.R. and CARY, S.C. 2009. Microbial biodiversity of thermophilic communities in hot mineral soils of TramwayRidge, Mount Erebus, Antarctica, *Environm. Microbiol*., **11**, 715-728.

SOUNEY, J., MAYEWSKI, P.A., GOODWIN, I., MORGAN, V. and VAN OMMEN, T. 2002a. A 700-year record of atmospheric circulation developed from the Law Dome ice core, East Antarctica, *J. Geophys. Res.,* **107** (D22), 46084616.

SOUNEY, J., MAYEWSKI, P.A., GOODWIN, I., MORGAN, V. and VAN OMMEN, T. 2002b. A late Holocene climate record from Law Dome, East Antarctica, *J. Geophys. Res*., **107** (D22), 4608, 1-9.

SPAHNI, R., CHAPPELLAZ, J., STOCKER, T.F., LOULERGUE, L., HAUSAMMANN, G., KAWAMURA, K., FLUCKIGER, J., SCHWANDER, J., RAYNAUD, D., MASSON-DELMOTTE, V. and JOUZEL, J. 2005. Atmospheric Methane and Nitrous Oxide of the Late Pleistocene from Antarctic Ice Cores, *Science,* **310**, 1317-1321.

SPARROW, M. 2007. The Southern Ocean Observing System, *CLIVAR Exchanges*, **12**, No.4 Oct. 2007.

SPEICH, S., BLANKE, B. and CAI, W.J. 2007. Atlantic meridional overturning circulation and the Southern Hemisphere supergyre, *Geophys. Res. Let*., **34**, L23614.

SPEICH, S., BLANKE, B., DE VRIES, P., ET AL. 2002. Tasman leakage: A new route in the global ocean conveyor belt, *Geophys. Res. Lett*., **29**, 1416.

SPENCER, R. and VASSIE, J.M. 1997. The evolution of deep ocean pressure measurements in the U.K, *Progress in Oceanography*, **40**, 423-435.

SPIKES, V.B., HAMILTON, G.S., ARCONE, S.A., KASPARI, S. and MAYEWSKI, P.A. 2004. Variability in accumulation rates from GPR profiling on the West Antarctic Plateau, *Ann. Glaciol.,* **39**, 238-244.

STAGER, J.C. and MAYEWSKI, P.A. 1997. Abrupt mid-Holocene climatic transitions registered at the equator and the poles, *Science,* **276**, 1834-1836.

STAM, W.T., BEINTEMA, J.J., D'AVINO, R., TAMBURRINI, M., COCCA, E. and DI PRISCO, G. 1998. Evolutionary studies on teleost hemoglobin sequences. In: di Prisco G, Pisano E and Clarke A (Eds) *Fishes of Antarctica. A Biological Overview,* 355-359. Springer, Milano.

STAM, W.T., BEINTEMA, J.J., D'AVINO, R., TAMBURRINI, M. and DI PRISCO, G. 1997. Molecular evolution of Antarctic fishes (Notothenioidei), *J. Mol. Evol.,* **45**, 437-445.

STARK, J.S., SNAPE, I. and RIDDLE, M.J. 2003. The effects of petroleum hydrocarbon and heavy metal contamination of marine sediments on recruitment on Antarctic soft-bottom assemblages: a field experimental investigation, *J. Exp. Mar. Biol. Ecol.,* **283**, 21-50 .

STARK, J.S., SNAPE, I. and RIDDLE, M.J. 2006. Abandoned Antarctic waste disposal sites: monitoring remediation outcomes and limitations at Casey Station, *Ecol. Manage. Res*t., **7**, 21-31 .

STEARNS, L.A., SMITH, B.E. and HAMILTON, G.S. 2008. Increased flow speed on a large East Antarctic outlet glacier caused by subglacial floods, *Nature Geoscience,* **1**, 827-831.

STEHLI F.G. and WELLS J.W. 1971. Diversity and age patterns in hermatypic corals, *Syst. Zool*., **20**, 115-126.

STEIG, E.J., BROOK, E.J., WHITE, J.W.C., SUCHER, C.M., BENDER, M.L., LEHMAN, S.J., MORSE, D.L., WADDINGTON, E.D. and CLOW, G.D. 1998. Synchronous climate changes in Antarctica and the North Atlantic, *Science,* **282**, 92-95.

STEIG, E.J., MAYEWSKI, P.A., DIXON, D.A., KASPARI, S.D., FREY, M.M., SCHNEIDER, D.P., ARCONE, S.A., HAMILTON, G.S., SPIKES, V.B., ALBERT, M., MEESE, D., GOW, A.J., SHUMAN, C.A., WHITE, J.W.C., SNEED, S., FLAHERTY, J. and WUMKES, M. 2005. High-resolution ice cores from US-ITASE (West Antarctica): Development and validation of chronologies and determination of precision and accuracy, *Annals of Glaciology*, **41**, 77–84.

STEIG, E.J., MORSE, D.L., WADDINGTON, E.D., STUIVER, M., GROOTES, P.M., MAYEWSKI, P.A., TWICKLER, M.S. and WHITLOW, S.I. 2000. Wisconsinan and Holocene climate history from an ice core at Taylor Dome, western Ross Embayment, Antarctica, *Geografiska Annaler Series a-Physical Geography,* **82A**, 213-235.

STEIG, E.J., SCHNEIDER, D.P., RUTHERFORD, S.D., MANN, M.E., COMISO, J. C. and SHINDELL, D.T. 2009. Warming of the Antarctic ice-sheet surface since the 1957 International Geophysical Year, *Nature,* **457**, 459-462.

STEINHAGE, D., NIXDORF, U., MEYER, U. and MILLER, H. 1999. New maps of the ice thickness and subglacial topography in Dronning Maud Land, Antarctica, determined by means of airborne radio echo sounding, *Ann. Glaciol.,* **29**, 267-272.

STENNI, B., MASSON-DELMOTTE, V., JOHNSEN, S., JOUZEL, J., LONGINELLI, A., MONNIN, E., ROTHLISBERGER, R. and SELMO, E. 2001. An Oceanic Cold Reversal During the Last Deglaciation, *Science,* **293**, 2074-2077.

STEPHENS, B.B. and KEELING, R.F. 2000. The influence of Antarctic sea ice on glacial-interglacial CO_2 variations, *Nature,* **404**, 171-174.

STEVENS, M.I. and HOGG, I.D. 2003. Long-term isolation and recent range expansion revealed for the endemic springtail Gomphiocephalus hodgsoni from southern Victoria Land, Antarctica, *Molecular Ecology,* **12**, 2357-2369.

STEVENS, M.I. and HOGG, I.D. 2006. The molecular ecology of Antarctic terrestrial and limnetic invertebrates and microbes. In: Bergstrom DM, Convey P, Huiskes AHL (eds) *Trends in Antarctic Terrestrial and Limnetic Ecosystems: Antarctica as a global indicator*. Springer, Dordrecht, 177-192.

STEVENS, M.I., GREENSLADE, P., HOGG, I.D. and SUNNUCKS, P. 2006. Southern hemisphere springtails: could any have survived glaciation of Antarctica?, *Mol. Biol. Evol*., **23**, 874-882.

STICKLEY, C.E., BRINKHUIS, H., SCHELLENBERG, S.A., SLUIJS, A., RÖHL, U., FULLER, M., GRAUERT, M., HUBER, M., WARNAAR, J. and WILLIAMS, G.L. 2004. Timing and nature of the deepening of the Tasmanian Gateway, *Paleoceanography,* **19**, PA4027, doi:4010.1029/2004PA001022.

STILWELL, J.D. and ZINSMEISTER, W.J. 1992. Molluscan systematics and biostratigraphy: Lower Tertiary La Meseta Formation, Seymour Island, Antarctic Peninsula, *Antarctic Research Series,* **55**, 152 pp.

STOCKER, T.F. and WRIGHT, D.G. 1991. Rapid transitions of the ocean's deep circulation induced by changes in surface water fluxes, *Nature,* **351**, 729-732.

STOCKTON, W.L. 1984. The biology and ecology of the epifaunal scallop *Adamussium colbecki* on the west side of McMurdo Sound, Antarctica, *Mar. Biol.,* **78**, 171-178.

STOCKWELL, C.A., HENDRY, A. and KINNISON, M.T. 2003. Contemporary evolution meets conservation biology, *Trends Ecol. Evol.,* **18**, 94-101.

STOKES, C.R., CLARK, C.D., LIAN, O.B. and TULACZYK, S. 2007. Ice stream sticky spots: A review of their identification and influence beneath contemporary and palaeo-ice streams, *Earth-Science Reviews,* **81**, 217–249.

STRATTON, R.A. and POPE, V.D. 2004. Modelling the climatology of storm tracks - Sensitivity to resolution. In: *The Second Phase of the Atmospheric Model Intercomparison Project (AMIP2)* [Gleckler, P. (ed.)]. Proceedings of the WCRP/WGNE Workshop, Toulouse, 207-210.

STRUGNELL, J.M., ROGERS, A.D., PRODÖHL, P.A., COLLINS, M.A. and ALLCOCK, A.L. 2008. The thermohaline expressway: the Southern ocean as a centre of origin for deep-sea octopuses, *Cladistics,* **24**, 853-860.

STRUTHERS, H., KREHER, K., AUSTIN, J., SCHOFIELD, R., BODEKER, G.E., JOHNSTON, P.V., SHIONA, H. and THOMAS, A. 2004. Past and future simulations of NO2 from a coupled chemistry-climate model in comparison with observations, *Atmos. Chem. Phys.*, **4**, 2227-2239.

STUIVER, M. and BRAZIUNAS, T.F. 1993. Sun, ocean, climate, and atmospheric CO_2: an evaluation of causal and spectral relationships, *Holocene,* **3**(4), 289-305.

STUIVER, M., DENTON, G.H., HUGHES, T.J. and FASTOOK, J.L. 1981. History of the marine ice sheet in West Antarctica during the last glaciation: a working hypothesis. In: Denton GH, Hughes TJ (eds) *The Last Great Ice Sheets*. Wiley-Inter-science, New York, 319-436.

STUIVER, M., REIMER, P.J. and BRAZIUNAS, T.F. 1998. High precision radiocarbon age calibration for terrestrial and marine samples, *Radiocarbon,* **40**, 1127-1151.

SUGDEN, D.E., MARCHANT, D.R. and DENTON, G.H. 1993. The case for a stable East Antarctic Ice Sheet: a special volume arising from the Vega Symposium, 26 April 1993 Stockholm, *Geografiska Annaler,* **75A**, No. 4.

SUGDEN, D.E., MARCHANT, D.R., POTTER, N., SOUCHEZ, R.A., DENTON, G.H., SWISHER, C.C. and TISON, J.-L. 1995. Preservation of Miocene glacier ice in East Antarctica, *Nature,* **376**, 412-414.

SUMMERFIELD, M.A., STUART, F.M., COCKBURN, H.A.P., SUGDEN, D.E., DENTON, G.H., DUNAI, T. and MARCHART, D. R. 1999. Long-term rates of denudation in the Dry Valleys, Transantarctic Mountains, southern Victoria Land, Antarctica, based on in-situ-produced cosmogenic 21Ne, *Geomorphology,* **27**, 113-129.

SUMMERHAYES, C., DICKSON, B., MEREDITH, M., DEXTER P. and ALVERSON, K. 2007. Observing the Polar Oceans during the International Polar Year and Beyond, *WMO Bulletin,* **56** (4), 270-2893.

SUN, L.G., XIE, Z.Q. and ZHAO, J.L. 2000. A 3,000-year record of penguin populations, *Nature,* **407**, 858.

SURDYK, S. and FILY, M. 1994. Results of a stratified snow emissivity model based on the wave approach: application to the Antarctic ice sheet, *J. Geophys. Res.,* **100**(C5), 8837–8848.

SUWA, M. and BENDER, M.L. 2008. Chronology of the Vostok ice core constrained by O2/N2 ratios of occluded air, and its implication for the Vostok climate records, *Quaternary Science Reviews,* **27**, 1093-1106.

SWINGEDOUW D., FICHEFET, T., HUYBRECHTS, P., GOOSSE, H., DRIESSCHAERT, E. and LOUTRE, M.F. 2008. Antarctic ice-sheet melting provides negative feedbacks on future climate warming, *Geophysical Research Letters,* **35**, L17705, doi:10.1029/2008GL034410.

SYVITSKI, J.P.M., FARROW, G.E., ATKINSON, R.J.A., MOORE, P.G. and ANDREWS, J.T. 1989. Baffin Island macrobenthos: bottom communities and environmental significance, *Arctic,* **42**, 232-247.

TAKAHASHI, S. and KAMEDA, T. 2007. Snow density for measuring surface mass balance using the stake method, *Journal of Glaciology*, **53**(183), 677–680.

TAKAHASHI, T., SUTHERLAND, S.C., WANNINKHOF, R., SWEENEY, C., FEELY, R.A., CHIPMAN, D.W., HALES, B., FRIEDERICH, G., CHAVEZ, F.,

SABINE, C., WATSON, W., BAKKER, D.C.E., SCHUSTER, U., METZL, N., YOSHIKAWA-INOUE, H., MASAO ISHII, M., MIDORIKAWA, T., NOJIRI, Y., KORTZINGER, A., STEINHOFF, T., HOPPEMA, M., OLAFSSON, J., THORARINN, S.., ARNARSON, T.S., TILBROOK, B., JOHANNESSEN, T., OLSEN, A., BELLERBY, R., WONG, C.S., DELILLE, B., BATES, N.R. AND DE BAAR, H.J.W. 2009. Climatological mean surface PCO2 and net CO_2 flux over the global oceans, *Deep Sea Research*, doi:10.1016/dsr2.2008.12.009.

TAKAHASHI, T., AGETA, Y, FUJII, Y. and WATANABE, O. 1994. Surface mass balance in east Dronning Maud Land, Antarctica, observed by Japanese Antarctic Research Expeditions, *Ann. Glaciol,* **20**, 242–248.

TAKAHASHI, T., OLAFSSON, J., GODDARD, J.G., CHIPMAN, D.W. AND SUTHERLAND, S.C. 1993. Seasonal variation of CO_2 and nutrients in the high-latitude surfcae oceans: a comparative study, *Global Biogeochemical Cycles*, **7**, 843-878.

TAMURA, T., OHSHIMA, K.I. and NIHASHI, S. 2008. Mapping of sea ice production for Antarctic coastal polynyas, *Geophys. Res. Lett*., **35**, L07606, doi:10.1029/2007GL032903.

TATON, A., GRUBISIC, S., BALHASART, P., HODGSON, D.A., LAYBOURN-PARRY, J. and WILMOTTE, A. 2006. Biogeographical distribution and ecological ranges of benthic cyanobacteria in East Antarctic lakes, *FEMS Microbiol. Ecol.,* **57**, 272-289.

TATON, A., GRUBISIC, S., BRAMBILLA, E., DE WIT, R. and WILMOTTE, A. 2003. Cyanobacterial diversity in natural and artificial microbial mats of Lake Fryxell (McMurdo Dry Valleys, Antarctica): a morphological and molecular approach, *Appl. Environm. Microbiol*., **69**, 5157-5169.

TAVARES, M. and MELO, M.E.S. 2004. Discovery of the first known benthic invasive species in the Southern Ocean: the North Atlantic spider crab Hyas araneus found in the Antarctic Peninsula, *Antarct. Sci*., **16**, 129-131.

TAYLOR, F, WHITEHEAD, J.M. and DOMACK, E. 2001. Holocene paleoclimate change in the Antarctic Peninsula: evidence from the diatom, sedimentary and geochemical record, *Marine Micropaleontology,* **41**, 25-43.

TEARLE, P.V. 1987. Cryptogamic carbohydrate release and microbial response during spring freeze-thaw cycles in Antarctic fellfield fines, *Soil Biology and Biochemistry,* **19**, 381-390.

TEBALDI, C., HAYHOE, K., ARBLASTER, J.M. and MEEHL, G.A. 2006. going to the extremes: An intercomparison of model-simulated historicak and future changes in extreme events, *Climate Change*, **79**, 185-211.

TEBALDI, C., SMITH, R.L., NYCHKA, D. and MEARNS, L.O. 2004. Quantifying Uncertainty in Projections of Regional Climate Change: A Bayesian Approach to the Analysis of Multimodel Ensembles, *J. Clim*, **18,** 1524-1540.

TEDESCO, M. 2008. Updated 2008 surface snowmelt trends in Antarctica, *Eos. Trans*., **89** (13).

TEIXIDÓ, N., GARRABOU, J., GUTT, J. and ARNTZ, W.E. 2004. Recovery in Antarctic benthos after iceberg disturbance: trends in benthic composition, abundance and growth forms, *Mar. Ecol. Prog. Ser.,* **278**, 1-16.

THATJE, S., and FUENTES, V. 2003. First record of anomuran and brachyuran larvae (Crustacea: Decapoda) from Antarctic waters, *Polar Biology,* **26**, 279-282.

THOMA, M., JENKINS, A., HOLLAND, D. and JACOBS, S. 2008. Modelling Circumpolar Deep Water intrusions on the Amundsen Sea continental shelf, Antarctica, *Geophys. Res. Lett.,* **35**, L18602. doi:10.1029/2008GL034939.

THOMAS, C.D., BODSWORTH, E.J., WILSON, R.J., SIMMONS, A.D., DAVIES, Z.G., MUSCHE, M. and CONRADT, L. 2001. Ecological and evolutionary processes at expanding range margins, *Nature,* **411**, 577-581.

THOMAS, C.D., CAMERON, A., GREEN, R.E., BAKKENES, M., BEAUMONT, L.J., COLLINGHAM, Y.C., ERASMUS, B.F., DE SIQUEIRA, M.F., GRAINGER, A., HANNAH, L., HUGHES, L., HUNTLEY, B., VAN JAARSVELD, A.S., MIDGLEY, G.F., MILES, L., ORTEGA-HUERTA, M.A., PETERSON, A.T., PHILLIPS, O.L. and WILLIAMS, S.E. 2004. Extinction risk from climate change, *Nature,* **427**, 145-148.

THOMAS, D.N. and DIECKMANN, G.S. 2002. Antarctic sea ice-a habitat for extremophiles, *Science,* **295**, 641-644.

THOMAS, D.N. and WIENCKE, C. 1991. Photosynthesis, dark respiration and light independent carbon fixation of endemic Antarctic macroalgae, *Polar Biol*., **11**, 329-337.

THOMAS, R.H. 1973. The creep of ice shelves: Theory, *Journal of Glaciology*, **12** (64), 45-53.

THOMAS, R.H., RIGNOT, E.J., CASASSA, G., KANAGARATNAM, P., ACUÑA, C., AKINS, T.L., BRECHER, H., FREDERICK, E.B., GOGINENI, S.P., KRABILL, W.B., MANIZADE, S., RAMAMOORTHY, H., RIVERA, A., RUSSELL, R., SONNTAG, J., SWIFT, R., YUNGEL, J., and ZWALLY, H.J. 2004a. Accelerated Sea-Level rise from West Antarctica. *Science,* **306**, 255-258.

THOMAS, R.H., RIGNOT, E., KANAGARATNAM, P., KRABILL, W. and CASASSA, G. 2004b, Force perturbation analysis of Pine Island Glacier suggests cause for recent acceleration, *Ann. Glaciol.,* **39**, 133-138.

THOMPSON, A.F. and HEYWOOD, K.J. 2008. Frontal structure and transport in the northwestern Weddell Sea, *Deep-Sea Research I*, **55**, 1229-1251.

THOMPSON, D. and SOLOMON, S. 2002. Interpretation of recent southern hemisphere climate change, *Science*, **296**(5569), 895-899.

THOMPSON, D.W.J. and WALLACE, J.M. 2000. Annular modes in extratropical circulation, Part 1: Month-to-month variability, *J. Climate*, **13**, 1000–1016.

THOMPSON, D.W.J. and WALLACE, J.M. 2001. Regional climate impacts of the northern hemisphere annular mode, *Science,* **293**, 85-89.

THOMPSON, D.W.J., WALLACE, J.M. and HEGERL, G.C. 2000. Annular modes in the extratropical circulation: Part II: Trends, *J. Climate*, **13**, 1018-1036.

THOMPSON, W.G. and GOLDSTEIN, S.L. 2005. Open-system coral ages reveal persistent suborbital sea-level cycles, *Science,* **308**, 401-404.

THOMSON, D.C., BROMLEY, A.M., CRAIG, R.M.F. 1971a. Ground temperatures in an Antarctic dry valley, *New Zealand Journal of Geology and Geophysics*, **14**, 477-483.

THORN, V.C., FRANCIS, J.E., RIDING, J.B., RAISWELL, R.W., PIRRIE, D., HAYWOOD, A.M., CRAME, J.A. and MARSHALL, J.M. 2007. Terminal Cretaceous climate change and biotic response in Antarctica In: *Online Proceedings of the 10th ISAES X*, USGS Open-File Report 2007-1047, Extended Abstract 096, 4 p.

THRUSH, S., DAYTON, P., CATTANEO-VIETTI, R., CHIANTORE, M., CUMMINGS, V., ANDREW, N., HAWES, I., KIM, S., KVITEL, R. and SCHWARZ, A-M. 2006. Broad-scale factors influencing the biodiversity of coastal benthic communities of the Ross Sea, *Deep-Sea Res II,* **53**, 959-971.

THURNHERR, A.M. and SPEER, K.G. 2003. Boundary mixing and topographic blocking on the Mid-Atlantic Ridge in the South Atlantic, *J. Phys. Oceanogr.,* **33**, 848-862.

TIAN, W. and CHIPPERFIELD, M.P. 2005. A new coupled chemistry-climate model for the stratosphere: The importance of coupling for future O3-climate predictions, *Quart. J. Roy. Meteorol. Soc.*, **131**, 281-303.

TIMMERMANN, R., HELLMER, H.H. and BECKMANN, A. 2002. Simulations of ice-ocean dynamics in the Weddell Sea 2. Interannual variability 1985-1993, *J. Geophys. Res.*, **107**(C3), 3025, doi:10.1029/2000JC000742.

TIN, T., FLEMING, Z., HUGHES, K.A., AINLEY, D., CONVEY, P., MORENO, C., PFEIFFER, S., SCOTT, J., and SNAPE, I. 2009. Impacts of local human activities on the Antarctic environment: a review, *Antarctic Science*. (in press),

TOGGWEILER, J.R.,RUSSELL, J.L. and CARSON, S.R. 2006. Midlatitude westerlies, atmospheric CO_2, and climate change during the ice ages, *Palaeoceanography,* **21,** PA2005, doi:10.1029/2005PA001154.

TOMASI, C. and 30 COLLABORATORS. 2007. Aerosols on polar regions: An historical overview on the basis of optical depth and in-situ observations, *J. Geophys. Res.*, **112**, D16205, doi: 10.1029/2007JD008432.

TOMCZAK, M. 2007. Variability of Antarctic intermediate Water properties in the South Pacific Ocean, *Ocean Science,* **3**, 363-377.

TOPPING, J.N., HEYWOOD, J.L., WARD, P. and ZUBKOV, M.V. 2006. Bacterioplankton composition in the Scotia Sea, Antarctica, during the austral summer of 2003, *Aquat. Microbial Ecol.*, **45**, 229-235.

TORINESI, O., FILY, M. and GENTHON, C. 2003. Variability and trends of summer melt period of Antarctic ice margins since 1980 from microwave sensors, *J. Climate,* **16**(7), 1047–1060.

TOVAR-SANCHEZ, A., DUARTE, C.M., HERNANDEZ-LEON, S. and SANUDO-WILHELMY, S.A. 2007. Krill as a central node for iron cycling in the Southern Ocean, *Geophys. Res. Lett.*, **34**, (L11601, doi:10.1029/2006GL029096).

TOWN, M. S., WALDEN, V.P. and WARREN, S.G. 2007. Cloud cover over the South Pole from visual observations, satellite retrievals, and surface-based infrared measurements, *J. Climate*, **20**, 544-559.

TRATHAN, P.N. and MURPHY, E.J. 2002. Sea surface temperature anomalies near South Georgia: relationships with the Pacific El Nino regions, *Journal of Geophysical Research - Oceans*, **108**, 8075.

TRATHAN, P.N., FORCADA, J. and MURPHY, E.J. 2007. Environmental forcing and Southern Ocean marine predator populations: effects of climate change and variability, *Philosophical Transactions of the Royal Society B*, **362**, 2351–2365.

TRATHAN, P.N., MURPHY, E.J., FORCADA, J., CROXALL, J.P., REID, K. and THORPE, S.E. 2006. Physical forcing in the southwest Atlantic: ecosystem control. In Top *predators in marine ecosystems: their role inmonitoring andmanagement* (eds I L Boyd, S Wanless and C J Camphuysen), 28–45. Cambridge, UK: Cambridge University Press.

TRENBERTH, K.E. AND CARON, J.M. 2001. Estimates of meridional atmosphere and ocean heat transports, *Journal of Climate*, **13**, 4358-4365.

TRENBERTH, K.E. ET AL. 2007. Observations: Surface and Atmospheric Change. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,. In: D.Q. S. Solomon, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (Editor), *Climate Change 2007: The Physical Science Basis*. Cambridge University Press,, Cambridge, U.K., and New York, U.S.A.

TRESHNIKOV, A.F. 1964. Surface water circulation in the Antarctic Ocean, *Information Bulletin of the Soviet Antarctic Expedition,* **5**, 81-83 (English translation)

TRESSLER, W.L. and OMMUNDSEN, A.M. 1963. Oceanographic studies in McMurdo Sound, Antarctica, IG Bull. 67, *Trans. Am. Geophys. Un.* **44**(1), 217-225.

TRIPATI, A., BACKMAN, J., ELDERFIELD, H. and FERRETTI, P. 2005. Eocene bipolar glaciation associated with global carbon cycle changes, *Nature,* **436**, 341-346.

TROEDSON, A.L. and SMELLIE, J.L. 2002. The Polonez Cove formation of King George Island, Antarctica: stratigraphy, facies and implications for mid-Cenozoic cryosphere development, *Sedimentology,* **49**, 277-301.

TRUFFER M. and FAHNESTOCK, M. 2007. Rethinking Ice Sheet Time Scales, *Science,* **315**, 1508.

TURNBULL, J.D. and ROBINSON, S.A. 2008. Accumulation of DNA damage in Antarctic mosses: correlations with ultraviolet-B radiation, temperature and turf water content vary among species, *Global Change Biology,* **14**, in press.

TURNER, J. 2004. The El Niño-Southern Oscillation and Antarctica, *International Journal of climatology*, **24**, 1-31.

TURNER, J., LACHLAN-COPE, T.A., COLWELL, S.R., MARSHALL, G.J. and CONNOLLEY, W.M. 2006. Significant warming of the Antarctic winter troposphere, *Science*, **311,** 1914-1917.

TURNER, J., COLWELL, S. R., MARSHALL, G. J., LACHLAN-COPE, T. A., CARLETON, A. M., JONES, P. D., LAGUN, V., REID, P. A. and IAGOVKINA,

S. 2004. The SCAR READER project: Towards a high-quality database of mean Antarctic meteorological observations, *Journal of Climate,* **17**, 2890-2898.

TURNER, J., COLWELL, S.R., MARSHALL, G.J., LACHLAN-COPE, T.A., CARLETON, A.M., JONES, P.D., LAGUN, V., REID, P.A. and IAGOVKINA, S. 2005a. Antarctic climate change during the last 50 years, *International Journal of Climatology,* **25**, 279-294.

TURNER, J., COMISO, J.C., MARSHALL, G.J., LACHLAN-COPE, T.A., BRACEGIRDLE, T., MAKSYM, T., MEREDITH, M.P., WANG, Z. and ORR, A. 2009. Non-annular atmospheric circulation change induced by stratospheric ozone depletion and its role in the recent increase of Antarctic sea ice extent, *Geophys. Res. Lett.*, **36,** L08502, doi:10.1029/2009GL037524.

TURNER, J., CONNOLLEY, W.M., LEONARD, S., MARSHALL, G.J. and VAUGHAN, D.G. 1999. Spatial and temporal variability of net snow accumulation over the Antarctic from ECMWF re-analysis project data, *Int. J. Climatol.*, **19**, 697-724.

TURNER, J., LACHLAN-COPE, T.A., COLWELL, S. and MARSHALL, G.J. 2005b. A positive trend in western Antarctic Peninsula precipitation over the last 50 years reflecting regional and Antarctic-wide atmospheric circulation changes, *Ann. Glaciol.*, **41**, 85-91.

TURNER, J., LEONARD, S., LACHLAN-COPE, T., and MARSHALL, G.J. 1998. Understanding Antarctic Peninsula precipitation distribution and variability using a numerical weather prediction model, *Ann. Glaciol.*, **27**, 591–596.

TURNER, J., OVERLAND, J.E. and WALSH, J.E. 2007. An Arctic and Antarctic perspective on recent climate change, *Intern. J. Climatol.,* **27**, 277-293.

UNEP 2002. Regionally based assessment of persistent toxic substances – Antarctica regional report. United Nations Environmental Programmme, Chemicals, Geneva.

UOTILA P., LYNCH, A.H., CASSANO, J.J. and CULLATHER, R.I. 2007. Changes in Antarctic net precipitation in the 21st century based on Intergovernmental Panel on Climate Change (IPCC) model scenarios, *J. Geophys. Res.*, **112**, D10107, doi:10.1029/2006JD007482.

URBINI, S., GANDOLFI, S. and VITTUARI, L. 2001. GPR and GPS data integration: examples of application in Antarctica, *Annali di Geofisca,* **44** (4), 687-702.

VALLELONGA, P., VAN DE VELDE, K., CANDELONE, J.-P., MORGAN, V.I., BOUTRON, C.F. and ROSMAN, K.J.R. 2002. The lead pollution history of Law Dome, Antarctica, from isotopic measurements on ice cores: 1500 AD to 1989 AD, *Earth and Planetary Science Letters,* **203**, 291-306.

VAN DE BERG, W.J., VAN DEN BROEKE, M.R., REIJMER, C.H. and VAN MEIJGAARD, E. 2005. Characteristics of the Antarctic surface mass balance (1958-2002) using a regional atmospheric climate model, *Ann. Glaciol.*, **41**, 97–104.

VAN DE BERG, W.J., VAN DEN BROEKE, M.R., REIJMER, C.H. and VAN MEIJGAARD, E. 2006. Reassessment of the Antarctic surface mass balance using calibrated output of a regional atmospheric climate model, *J. Geophys. Res*., **111**, D11104, doi:10.10292005JD006495.

VAN DE VELDE, K., VALLELONGA, P., CANDELONE, J.-P., ROSMAN, K.J.R., GASPARI, V., COZZI, G., BARBANTE, C., UDISTI, R., CESCON, P. and BOUTRON, C.F. 2005. Pb isotope record over one century in snow from Victoria Land, Antarctica, *Earth and Planetary Science Letters,* **232**, 95-108.

VAN DEN BROEKE, M. 2005. Strong surface melting preceded collapse of Antarctic Peninsula ice shelf, Geophysical Research Letters, **32**, L12815, doi:10.1029/2005GL023247.

VAN DEN BROEKE, M.R. and VAN LIPZIG, N.P.M. 2004. Changes in Antarctic temperature, wind and precipitation in response to the Antarctic Oscillation, *Ann. Glaciol.,* **39**, 199-126.

VAN DEN BROEKE, M.R., VAN DE BERG, W.J. and VAN MEIJGAARD, E. 2006. Snowfall in coastal West Antarctica much greater than previously assumed, *Geophys. Res. Letts.,* **33**, L02505, doi:10.1029/2005GL025239.

VAN DER VEEN, C.J. and ISMASS. 2007. A need for more realistic ice-sheet models, *SCAR Report* No. **30,** 27 pp.

VAN DER VEEN, C.J. and PAYNE, A.J. 2003. Modelling land-ice dynamics. In: *Mass Balance of the Cryosphere: observations and modelling of contemporary and future changes (eds. J.L. Bamber and A.J. Payne).* Cambridge: Cambridge University Press, 169-225.

VAN DER VEEN, C.J. 1999a. *Fundamentals of Glacier Dynamics.* Rotterdam: A.A. Balkema, 462 pp.

VAN DER VEEN, C.J. 1999b. Evaluating the performance of cryospheric models, *Polar Geography,* **23,** 83-96.

VAN DER VEEN, C.J., JEZEK, K.C. and STEARNS, L. 2007. Shear measurements across the northern margin of Whillans Ice Stream, *Journal of Glaciology,* **53**, 17-29.

VAN DIJK, P.L.M., TESCH, C., HARDEWIG, I. and PÖRTNER, H.O. 1999. Physiological disturbances at critically high temperatures: a comparison between stenothermal Antarctic and eurythermal temperate eelpouts (Zoarcidae), *J. Exp. Biol.,* **202**, 3611-3621 .

VAN LIPZIG, N.P.M., KING, J.C., LACHLAN-COPE, T.A. and VAN DEN BROEKE, M.R. 2004a. Precipitation, Sublimation and Snow Drift in the Antarctic Peninsula Region from a Regional Atmospheric Model, *Journal of Geophysical Research,* **109**, doi 10.1029/2004JD004701.

VAN LIPZIG, N.P.M., MARSHALL, G.J., ORR, A. and KING, J.C. 2006. The relation between the Southern Hemisphere Annular Mode and Antarctic Peninsula summer temperatures: Analysis of a high-resolution model climatology, *J. Clim.,* **21**(8): 1649.

VAN LIPZIG, N.P.M., TURNER, J., COLWELL, S.R. and. VAN DEN BROEKE, M.R. 2004b. The near-surface wind field over the Antarctic continent, *International Journal of Climatology*, **24,** 1973-1982.

VAN LIPZIG, N.P.M., VAN MEIJGAARD, E. and OERLEMANS, J. 2002. The spatial and temporal variability of the surface mass balance in Antarctica: results from a regional atmospheric climate model, *Int. J. Climatol.,* **22**, 1197-1217.

VAN LOON, H. 1967. The half yearly oscillations in middle and high southern latitudes and the coreless winter, *J. Atmos. Sci.*, **24**, 472-486.

VAN OEVELEN, D., MOODLEY, L., SOETAERT, K., MIDDELBURG, J.J. 2006. The trophic significance of bacterial carbon in a marine intertidal sediment: Results of an in situ stable isotope labeling study, *Limnology and Oceanography,* **51**, 2349-2359.

VAN OLDENBORGH, G.J., PHILIP, S.Y. and COLLINS, M. 2005. El Nino in a changing climate: a multi-model study, *Ocean Sci.*, **1**, 81–95.

VAN OMMEN, T.D. and MORGAN, V.I. 1996. Peroxide concentrations in the Dome Summit South ice core, Law Dome, Antarctica, *J. Geophys. Res*., **101** (D10) 15,147-15,152.

VAN TRAPPEN, S., MERGAERT, J. and SWINGS, J. 2004. *Loktanella salsilacus* gen. nov., sp nov., *Loktanella fryxellensis* sp nov and *Loktanella vestfoldensis* sp nov., new members of the Rhodobacter group, isolated from microbial mats in Antarctic lakes, *Int. J. Syst. Evol. Microbiol.,* **54**, 1263-1269.

VAN TRAPPEN, S., MERGAERT, J., VAN EYGEN, S., DAWYNDT, P., CNOCKAERT, M.C. and SWINGS, J. 2002. Diversity of 746 heterotrophic bacteria isolated from microbial mats from ten Antarctic lakes, *Syst. Appl. Microbiol.,* **25**, 603-610.

VAN TRAPPEN, S., VANDECANDELAERE, I., MERGAERT, J. and SWINGS, J. 2005. *Flavobacterium fryxellicola* sp. nov. and *Flavobacterium psychrolimnae* sp. nov., novel psychrophilic bacteria isolated from microbial mats in Antarctic lakes, *Int. J. Syst. Evol. Microbiol*., **55**, 769-772.

VAN VUUREN, B.J., MORTIMER, E., STEVENS, M.I., MARSHALL, D.J., CONVEY, P., DANIELS, S.R. and CHOWN, S.L. 2007. Molecular data can help to unveil biogeographic complexities since the Miocene: lessons from ameronothroid mites and isotomid springtails – Online Proceedings of the 10th ISAES (http://pubs.usgs.gov/of/2007/1047/).

VANHOVE, S., ARNTZ, W. and VINCX, M. 1999. Comparative study of the nematode communities on the southeastern Weddell Sea shelf and slope (Antarctica), *Mar. Ecol. Prog. Ser*., **181**, 237-256

VANHOVE, S., BEGHYN, M., VAN GANSBEKE, D., BULLOUGH, L.W. and VINCX, M. 2000. A seasonally varying biotope at Signy Island, Antarctic: implications for meiofaunal structure, *Mar. Ecol. Prog. Ser*., **202**, 13-25.

VAUGHAN D.G., BAMBER, J.L., GIOVINETTO, M.B., RUSSELL, J. and COOPER, A.P.R. 1999. Reassessment of net surface mass balance in Antarctica, *Journal of Climate*, **12**, No. 4, 933-946.

VAUGHAN, D.G. and DOAKE, C.S.M. 1996. Recent atmospheric warming and retreat of ice shelves on the Antarctic Peninsula, *Nature,* **379**, 328-330.

VAUGHAN, D.G. 1993. Implications of the break-up of the Wordie Ice Shelf, Antarctica for sea level rise, *Antarctic Science,* **5**(4), 403-408.

VAUGHAN, D.G. 1995, Tidal Flexure at Ice Sheet Margins, *Journal of Geophysical Research*, **100** (B4), 6213-6224.

VAUGHAN, D.G. 2006. Recent trends in melting conditions on the Antarctic Peninsula and their implications for ice-sheet mass balance, *Arctic, Antarctic and Alpine Research*, **38**, 147-152.

VAUGHAN, D.G., CORR, H.F.J., FERRACCIOLI, F., FREARSON, N., O'HARE, A., MACH, D., HOLT, J.W., BLANKENSHIP, D.D., MORSE, D.L. and YOUNG, D.A. 2006. New boundary conditions for the West Antarctic ice sheet: Subglacial topography beneath Pine Island Glacier, *Geophys. Res. Lett.*, **33**, L09501, doi:10.1029/2005GL025588.

VAUGHAN, D.G., HOLT, J.W., BLANKENSHIP, D.D. 2007. West Antarctic links to sea level estimation, *EOS Transactions*, **88**(46), 485-486.

VAUGHAN, D.G., MANTRIPP, D.R., SIEVERS, J. and DOAKE, C.S.M. 1993. A synthesis of remote sensing data on Wilkins Ice Shelf, Antarctica, *Annals of Glaciology,* **17**, 211-218.

VAUGHAN, D.G., MARSHALL, G., CONNOLLEY, W.M., PARKINSON, C., MULVANEY, R., HODGSON, D.A., KING, J.C., PUDSEY, C.J., TURNER, J. and WOLFF, E. 2003. Recent rapid regional climate warming on the Antarctic Peninsula, *Climatic Change,* **60**, 243-274.

VAZQUEZ, ET AL. 1998. NOAA/NASA AVHRR Oceans Pathfinder Sea Surface Temperature Data Set User's Reference Manual Version 4.0, 10 April 1998, JPL Publication D-14070.

VÁZQUEZ-RODRÍGUEZ, M., ET AL. 2008. Anthropogenic carbon distributions in the Atlantic ocean: data-based estimates from the Arctic to the Antarctic, *Biogeosciences Discussion*, **5**, 1421-1443.

VELICOGNA, I. and WAHR, J. 2002. A method for separating Antarctic postglacial rebound and ice mass balance using future ICESat Geoscience Laser Altimeter System, Gravity Recovery and Climate Experiment, and GPS satellite data, *J. Geophys. Res*., **107**, 10.1029/2001JB000708.

VELICOGNA, I. and WAHR, J. 2006, Measurements of Time-Variable Gravity Show Mass Loss in Antarctica, *Science,* **311,** (5768), 1754 DOI:10.1126/science.1123785.

VENEGAS, S.A. and DRINKWATER, M.R. 2001. Sea ice, atmosphere and upper ocean variability in the Weddell Sea, Antarctica, *Journal of Geophysical Research*, **106**(C8), 16,747–16,766.

VENEGAS, S.A. 2003. The Antarctic Circumpolar Wave: a combinationof two signals?, *Journal of Climate*, **16**, 2509-2525.

VERDE, C., BALESTRIERI, M., DE PASCALE, D., PAGNOZZI, D., LECOINTRE, G. and DI PRISCO, G. 2006a. The oxygen-transport system in three species of the boreal fish family Gadidae. Molecular phylogeny of haemoglobin, *J. Biol. Chem.,* **281**, 22073-22084.

VERDE, C., BERENBRINK, M. and DI PRISCO, G. 2008a. Evolutionary physiology of oxygen secretion in the eye of fishes of the suborder Notothenioidei. In *Dioxygen*

Binding and Sensing Proteins, Protein Reviews Series (Eds. Bolognesi M, di Prisco G, Verde C). Springer.

VERDE, C., CARRATORE, V., RICCIO, A., TAMBURRINI, M., PARISI, E. and DI PRISCO, G. 2002. The functionally distinct hemoglobins of the Arctic spotted wolffish *Anarhichas minor*, *J. Biol. Chem.,* **277**, 36312–36320.

VERDE, C., GIORDANO, D. and DI PRISCO, G. 2006b. Molecular evolution of haemoglobins of polar fishes, *Rev. Envir. Sci. Biotech.,* **5**, 297-308.

VERDE, C., GIORDANO, D. and DI PRISCO, G. 2008b. The adaptation of polar fishes to climatic changes: structure, function and phylogeny of haemoglobin, *IUBMB Life,* **60**, 29-40.

VERDE, C., GIORDANO, D., RUSSO, R., RICCIO, A., VERGARA, A., MAZZARELLA, L. and DI PRISCO, G. 2009. Hemoproteins in the cold, *Marine Genomics*, in press.

VERDE, C., LECOINTRE, G. and DI PRISCO, G. 2007. The phylogeny of polar fishes and the structure, function and molecular evolution of haemoglobin, *Polar Biol.,* **30**, 523-539.

VERDE, C., PARISI, E. and DI PRISCO, G. 2006c. The evolution of thermal adaptation in polar fish, *Gene.,* **385**, 137-145.

VERDE, C., PATARNELLO, T., ZANE, L., GIORDANO, D., PÖRTNER, H-O. and DI PRISCO, G. 2009. Molecular adaptations in polar fish – an integrative and evolutionary view, *Biol. Rev.* (invited review, submitted).

VERDE, C., VERGARA, A., MAZZARELLA, L. and DI PRISCO, G. 2008c. The hemoglobins of fishes living at polar latitudes - Current knowledge on structural adaptations in a changing environment, *Curr. Prot. Peptide. Sci.,* **9**, 578-590.

VERDY, A., DUTKIEWICZ, S., FOLLOWS, M., MARSHALL, J. AND CZAJA, A. 2007. Carbon dioxide and oxygen fluxes in the Southern Ocean: mechanisms of interannual variability, *Global Biogeochemical Cycles*, *GB2020*.

VERKULICH, S.R. and HILLER, A. 1994. Holocene Deglaciation of the Bunger Hills Revealed by C-14 Measurements on Stomach Oil Deposits in Snow Petrel Colonies, *Antarctic Science,* **6**, 395-399.

VERKULICH, S.R., MELLES, M., PUSHINA, Z.V. and HUBBERTEN, H-W. 2002. Holocene Environmental changes and development of Figurnoye Lake in the southern Bunger Hills, East Antarctica, *Journal of Paleolimnology,* **28**, 253-267.

VERLEYEN, E., HODGSON, D.A., MILNE, G.A., SABBE, K. and VYVERMAN, W. 2005. Relative sea level history from the Lambert Glacier region (East Antarctica) and its relation to deglaciation and Holocene glacier re-advance, *Quaternary Research,* **63**, 45-52.

VERLEYEN, E., HODGSON, D.A., SABBE, K. and VYVERMAN, W. 2004b. Late Quaternary deglaciation and climate history of the Larsemann Hills (East Antarctica), *Journal of Quaternary Science,* **19**, 361-375.

VERLEYEN, E., HODGSON, D.A., SABBE, K., VANHOUTTE, K. and VYVERMAN, W. 2004a. Coastal oceanographic conditions in the Prydz Bay region (East Antarctica) during the Holocene recorded in an isolation basin, *The Holocene,* **14**, 246-257.

VERLEYEN, E., VYVERMAN, W., STERKEN, M., HODGSON, D.A., DE WEVER, A., JUGGINS, S., VAN DE VIJVER, B., JONES, V.J., VANORMELINGEN, P., ROBERTS, D., FLOWER, R., KILROY, C., SOUFFREAU, C. and SABBE, K. 2009. The importance of dispersal related and local factors in shaping the taxonomic structure of diatom metacommunities, *Oikos,* 118, 1239-1249.

VERMEEREN, H., VANREUSEL, A. and VANHOVE, S. 2004. Species distribution within the free-living marine nematode genus *Dichromadora* in the Weddell Sea and adjacent areas, *Deep-Sea Res. II*, **51** (14-16), 1643-1664.

VETTER, R.A.H. and BUCHHOLZ, F. 1998. Kinetics of enzymes in cold stenothermal invertebrates. In: Pörtner H. O., Playle RC (eds) *Cold Ocean Physiology*. *Society for Experimental Biology Seminar Series,* **66**, 190-211.

VIELI, A. and PAYNE, A.J. 2005. Assessing the ability of numerical ice sheet models to simulate grounding line migration, *Journal of Geophysical Research,* **110**, F01003, doi: 10.1029/2004JF000202.

VIELI, A., JANIA, J. and KOLONDRA, L. 2002. The retreat of a tidewater glacier: observations and model calculations on Hansbreen, Spitsbergen, *J. Glaciol.*, **48**, 592-600.

VIELI, A., PAYNE, A.J., SHEPHERD, A. and DU, Z. 2007. Causes of pre-collapse o fthe Larsen B ice shelf: numerical modeling and assimilation of satellite observations, *Earth and Planetary Science Letters,* **259**, 297-306, doi:10.1016/j.epsl.2007.04.50.

VIMEUX, F., CUFFEY, K. and JOUZEL, J. 2002. New insights into Southern Hemisphere temperature changes from Vostok ice cores using deuterium excess correction over the last 420, 000 years, *Earth Planet. Sci. Lett*., **2O3**, 829-843.

VOGEL, S.W., TULACZYK, S., KAMB, B., ENGELHARDT, H., CARSEY, F., BEHAR, A., LANE, A. and JOUGHIN, I. 2005. Subglacial Conditions During And After Stoppage of an Antarctic Ice Stream: Is Reactivation Imminent, *Geophys. Res. Lett.,* **32** (14), L14502, doi:10.1029/2005GL022563.

VOLK, T. and HOFFERT, M.I. 1985. Ocean Carbon Pumps: Analysis of relative strenghts and efficencies in ocean-driven atmospheric CO2 changes, *Geophys. Monogr*., **32**, 99–110.

VON GLASOW, R., SANDER, R., BOTT, A. and CRUTZEN, P.J. 2002. Modelling halogen chemistry in the marine boundary layer. 2. Interactions with sulfur and cloud-covered MBL, *J. Geophys. Res.*, **107**, 4323.

VORONINA, N.M. 1966. Distribution of the zooplankton biomass in the Southern Ocean, *Oceanology,* **6**, 836-846.

VYVERMAN, W., VERLEYEN, E., SABBE, K., VANHOUTTE, K., STERKEN, M., HODGSON, D.A., MANN, D.G., JUGGINS, S., VAN DE VIJVER, B., JONES, V.J., FLOWER, R., ROBERTS, D., CHEPURNOV, V.A., KILROY, C., VANORMELINGEN, P. and DE WEVER, A. 2007. Historical processes constrain patterns in global diatom diversity, *Ecology,* **88**, 1924-1931.

WAELBROECK, C., LABEYRIE, L., MICHEL, E., DUPLESSY, J.C., MCMANUS, J.F., LAMBECK, K., BALBON, E. and LABRACHERIE, M. 2002. Sea level and deep water temperature changes derived from bentic foraminifera isotopic records, *Quat. Sci. Rev.,* **21**, 295-305.

WAGNER, B., CREMER, H., HULTZSCH, N., GORE, D.B. and MELLES, M. 2004. Late Pleistocene and Holocene history of Lake Terrasovoje, Amery Oasis, East Antarctica, and its climatic and environmental implications, *Journal of Paleolimnology,* **32**, 321-339.

WAGNER, B., HULTZSCH, N., MELLES, M. and GORE, D.B. 2007. Indications of Holocene sea-level rise in Beaver Lake, East Antarctica, *Cambridge Journals Online*, 125-128.

WAGNER, B., MELLES, M., DORAN, P.T., KENIG, F., FORMAN, S.L., PIERAU, R. and ALLAN, P. 2006. Glacial and postglacial sedimentation in the Fryxell basin, Taylor Valley, southern Victoria Land, Antarctica, *Palaeography, Palaeoclimatology, Palaeoecology,* **241**, 320-337.

WAKABAYASHI, H. and NISHIO, F. 2004. Glacier flow estimation by SAR image correlation, *Proc. IGARSS*, **2**, 1136-1139.

WALKER, D.P., BRANDON. M.A., JENKINS, A., ALLEN, J.T., DOWDESWELL, J.A. and EVANS, J. 2007. Oceanic heat transport onto the Amundsen Sea shelf through a submarine glacial trough, *Geophys. Res. Lett.*, **34**, doi:10.1029/2006GL028154.

WALKER, R. and HOLLAND, D.M. 2007. A two-dimensional coupled model for ice shelf - ocean interaction, *Ocean Modelling*, **17**, 123-139.

WALKER, R.T., DUPONT, T.K., PARIZEK, B.R. and ALLEY, R.B. 2008. Effects of basal-melting distribution on the retreat of ice-shelf grounding lines, *Geophys. Res. Lett*., **35**, L17503, doi:10.1029/2008GL034947.

WALLACE, D.W.R. 2001. Introduction to special section: Ocean measurements and models of carbon sources and sinks, *Global Biogeochemical Cycles*, **15**, 3-10.

WALTHER, G-R., POST, E., CONVEY, P., MENZEL, A., PARMESAN, C., BEEBEE, T.J.C, FROMENTIN, J-M., HOEGH-GULDBERG, O. and BAIRLEIN, F. 2002. Ecological responses to recent climate change, *Nature,* **416**, 389-395.

WALTON, D.W.H. 1977. Radiation and soil temperatures 1972-74: Signy Island Terrestrial Reference Site, *British Antarctic Survey Data*, 1, 49 pp.

WANG, F.M. 2007. Investigating ENSO sensitivity to mean climate in an intermediate model using a novel statistical technique, *Geophys. Res. Lett.*, **34**, L07705.

WANG, X., DEVRIES, A.L. and CHENG, C-H.C. 1995. Antifreeze peptide heterogeneity in an antarctic eel pout includes an unusually large major variant comprised of two 7 kDa type III AFPs linked in tandem, *Biochimica et Biophysica Acta - Protein Structure and Molecular Enzymology,* **1247**, 163-172.

WANG, X.L., SWAIL, V.R. and ZWIERS, F.W. 2006. Climatology and changes of extratropical storm tracks and cyclone activity: Comparison of ERA-40 with NCEP/NCAR Reanalysis for 1958–2001, *J. Climate*, **19**, 3145−3166.

WANG, Z. AND MEREDITH, M.P. 2009. On the predicted intensification of the Southern Ocean subpolar gyres in a warming climate, *Journal of Climate,* submitted.

WANG, Z. and MEREDITH, M.P. 2008. Density-driven Southern Hemisphere subpolar gyres in coupled climate models, *Geophysical Research Letters,* **35**(14) 5, pp. 10.1029/2008GL034344.

WANIA, F. and MACKAY, D. 1993. Global fractionation and cold condensation of volatile organochlorine compounds in polar regions, *Ambio,* **22**, 10-18.

WANNINKHOF, R. 1992. Relationship between wind speed and gas exchange over the ocean, *Journal of Geophysical Research*, **97**, 7373-7382.

WARD, C.G. 1995. Mapping ice front changes of Müller Ice Shelf, Antarctic Peninsula, *Antarct. Science,* **7***,* 197.

WARDLE, P. 1991. *Vegetation of New Zealand.* Cambridge University Press, Cambridge: 672 pp.

WASLEY, J., ROBINSON, S.A., LOVELOCK, C.E. and POPP, M. 2006. Some like it wet – an endemic Antarctic bryophyte likely to be threatened under climate change induced drying, *Functional Plant Biology,* **33**, 443–455.

WATANABE, O., JOUZEL, J., JOHNSEN, S., PARRENIN, F., SHOJI, H. and YOSHIDA, N. 2003. Homogeneous climate variability across East Antarctica over the past three glacial cycles, *Nature,* **422**, 509-512.

WATSON, A.J. and ORR, J.C. 2003. Carbon Dioxide Fluxes in the Global Ocean, in *Ocean Biogeochemistry: The Role of the Ocean carbon Cycle in Global Change*, edited by M. J. R. Fasham, Springer, Heidelberg.

WAUGH, D.W., HALL, T.M., MCNEIL, B. AND KEY, R. 2006. Anthropogenic CO_2 in the oceans estimated using transit-time distributions, *Tellus B*, **58,** 376–389.

WEAVER, A.J., SAENKO, O.A., CLARK, P.U. and MITROVICA, J.X. 2003. Meltwater Pulse 1A from Antarctica as a trigger of the Bølling-Allerød warm interval, *Science,* **299**, 1709-1713.

WEBB, D.J. and DE CUEVAS, B.A. 2007. On the fast response of the Southern Ocean to changes in the zonal wind, *Ocean Science*, **3**, 417-427.

WEBB, D.J. and.DE CUEVAS, B.A. 2006. On the fast response of the Southern Ocean to changes in the zonal wind, *Ocean Science Discussions*, **3**(3), 471-501.

WEBB, K.E., BARNES, D.K.A., CLARK, M.S. and BOWDEN, D.A. 2006. DNA barcoding: a molecular tool to identify Antarctic marine larvae, *Deep-Sea Res. II,,* **53** (8-10), 1053-1060.

WEBER, K. and GOERKE, H. 2003. Persistent organic pollutants (POPs) in Antarctic fish: levels, patterns, changes, *Chemosphere,* **53**, 667-378.

WEBSTER, J., HAWES, I., DOWNES, M., TIMPELEY, M. and HOWARD-WILLIAMS, C. 1996. Evidence for regional climate change in the recent evolution of a high latitude pro-glacial lake, *Antarctic Science,* **8**, 49–59.

WEBSTER, J., WEBSTER, K., NELSON, P. and WATERHOUSE, E. 2003. The behaviour of residual contaminants at a former station site, Antarctica, *Environ. Pollut.,* **123**,163-179.

WEBSTER, N.S. and BOURNE, D. 2007. Bacterial community structure associated with the Antarctic soft coral, *Alcyonium antarcticum*, *Fems. Microbiol. Ecol.*, **59**, 81-94.

WEBSTER, N.S., NEGRI, A.P., MUNRO, M. and BATTERSHILL, C.N. 2004. Diverse microbial communities inhabit Antarctic sponges, *Environ. Microbiol.,* **6**, 288-300.

WEERTMAN, J. 1974. Stability of the junction of an ice sheet and an ice shelf, *J. Glaciol.,* **13**, 3–11.

WEERTMAN, J., 1973, Can a water-filled crevasse reach the bottom surface of a glacier?, *International Association of Scientific Hydrology Publication,* **95**, 139-145.

WEI, W. and WISE, S.W. 1992. Eocene-Oligocene calcareous nannofossil magnetobiochronology of the Southern Ocean, *Newsl. Stratigr*., **26**, 119-132.

WEI, W. 2004. Opening of the Australia-Antarctica Gateway as dated by nannofossils, *Marine Micropaleontology,* **52**, 133-152.

WEIMERSKIRSCH, H., INCHAUSTI, P., GUINET, C. and BARBRAUD, C. 2003. Trends in bird and seal populations as indicators of a system shift in the Southern Ocean, *Antarctic Science*, **15**, 249–256.

WEISSE, R., MIKOLAJEWICZ, U., STERL, A. and DRIJFHOUT, S.S. 1999. Stochastically forced variability in the Antarctic Circumpolar Current, *J. Geophys. Res*., **104**(C5), 11,049–11,064.

WEISSENBERGER, J. and GROSSMANN, S. 1998. Experimental formation of sea ice: importance of water circulation and wave action for incorporation of phytoplankton and bacteria., *Polar Biol.*, **20**, 178-188.

WELCH, B.C. and JACOBEL, R.W. 2003. Analysis of deep-penetrating radar surveys of West Antarctica, US-ITASE 2001, *Geophysical Research Letters,* **30**(8, 1444), 10:1029/2003GL017210.

WELCH, K.A., MAYEWSKI, P.A. and WHITLOW, S.I. 1993. Methanesulphonic acid in coastal Antarctic snow related to sea-ice extent, *Geophysical Research Letters,* **20**, 443-446.

WELLNER, J.S., HEROY, D.C. and ANDERSON, J.B. 2006. The death mask of the antarctic ice sheet: Comparison of glacial geomorphic features across the continental shelf, *Geomorphology,* **75**, 157-171.

WELLS, R.M.G. 1990. Hemoglobin physiology in vertebrate animals: a cautionary approach to adaptationist thinking. In: Bartilie RG (ed) *Advances in comparative and environmental physiology*. Springer, Berlin, 143- 161.

WENDT, A., G. CASASSA, A. RIVERA, and J. WENDT (2009). Reassessment of ice mass balance at Horseshoe Valley, Antarctica. Antarctic Science. doi:10.1017/S0954102009002053.

WENDT, J., A. RIVERA, F. BOWN, A. WENDT, R. ZAMORA, G. CASASSA AND C. BRAVO (In Press) Recent ice elevation changes of Fleming Glacier in response to the removal of Wordie ice shelf, Antarctic Peninsula. Annals of Glaciology.

WERNER, M., HEIMANN, M. and HOFFMANN, G. 2001. Isotopic composition and origin of polar precipitation in present and glacial climate simulations, *Tellus,* **53B**, 53-71.

WESSEL, S., AOKI, S., WINKLER, P., WELLER, R., HERBER, A., GERNANDT, H. and SCHREMS, O. 1998. Tropospheric ozone depletion in polar regions: A comparison of observations in the Arctic and Antarctic, *Tellus*, **50B**, 34-50.

WEYKAM, G., GÓMEZ, I., WIENCKE, C., IKEN, K. and KLÖSER, H. 1996. Photosynthetic characteristics and C:N ratios of macroalgae from King George Island (Antarctica), *Journal of Experimental Marine Biology and Ecology,* **204**, 1-22.

WHINAM, J., CHILCOTT, N. and BERGSTROM, D.M. 2005. Subantarctic hitchhikers: expeditioners as vectors for the introduction of alien organisms, *Biological Conservation,* **121**, 207-219.

WHITE, M.G. 1984. Marine benthos. In: Laws, R.M. (ed.) *Antarctic Ecology*. Vol. **2**. Academic Press, London, 421-461.

WHITE, W.B., CHEN, S.C., ALLAN, R.J. and STONE, R.C. 2002. Positive feedbacks between the Antarctic Circumpolar Wave and the global El Nino-Southern Oscillation Wave, *Journal of Geophysical Research Oceans,* **107**, 3165..

WHITE, W.B., GLOERSEN, P. and SIMMONDS, I. 2004. Tropospheric response in the Antarctic circumpolar wave along the sea ice edge around Antarctica, *J. Clim*., **17** (14), 2765–2779.

WHITEHEAD, J.M., WOTHERSPOON, S. and BOHATY, S.M. 2005. Minimal Antarctic sea ice during the Pliocene, *Geology,* **33**, 137-140.

WHITEHOUSE, M.J., MEREDITH, M.P., ROTHERY, P., ATKINSON, A., WARD, P. and KORB, R.E. 2008. Rapid warming of the ocean at South Georgia, Southern Ocean during the 20th Century: forcings, characteristics and implications for lower trophic levels, *Deep-Sea Research I,* **55**, 1218-1228.

WHITWORTH, T. and PETERSON, R.G. 1985. Volume transport of the Antarctic Circumpolar Current from bottom pressure measurements, *Journal of Physical Oceanography*, **15**, 810-816.

WHITWORTH, T., III 2002. Two modes of bottom water in the Australian-Antarctic Basin, *Geophys. Res. Lett.,* **29**(5)*,* 1073, doi:10.1029/2001GL014282.

WHITWORTH, T., ORSI, A.H., KIM, S.J., NOWLIN, W.D. and LOCARNINI, R.A. 1998. Water masses and mixing near the Antarctic Slope Front, *Antarct. Res. Ser.,* **75**, 1-27.

WIENCKE, C. and CLAYTON, M.N. 2002. Antarctic Seaweeds, (Synopses of the Antarctic Benthos. Ed.: *J. W. Wägele and J. Sieg* ; Vol. **9**), Ruggell : Gantner ; Königstein : Koeltz Scientific Books., 239 pp.

WIENCKE, C. and FISCHER, G. 1990. Growth and stable carbon isotope composition of cold-water macroalgae in relation to light and temperature, *Mar. Ecol. Prog. Ser*., **65**, 283-292.

WIENCKE, C. and TOM DIECK, I. 1989. Temperature requirements for growth and temperature tolerance of macroalgae endemic to the Antarctic region, *Mar. Ecol. Prog. Se*r., **54**, 189-197.

WIENCKE, C. and TOM DIECK, I. 1990. Temperature requirements for growth and survival of macroalgae from Antarctica and southern Chile, *Mar. Ecol. Prog. Ser*., **59**, 157-170.

WIENCKE, C. 1990. Seasonality of brown macroalgae from Antarctica - a long-term culture study under fluctuating Antarctic daylengths, *Polar Biol.*, **10**, 589-600.

WIENCKE, C. 1996. Recent advances in the investigation of Antarctic macroalgae, *Polar Biol,* **16**, 231-240.

WIENCKE, C., BARTSCH, I., BISCHOFF, B., PETERS, A.F. and BREEMAN, A.M. 1994. Temperature requirements and biogeography of Antarctic, Arctic and amphiequatorial seaweeds, *Botanica Marina.,* **37**, 247-259.

WIENCKE, C., CLAYTON, M. N., GÓMEZ, I., IKEN, K., LÜDER, U. H., AMSLER, C. D., KARSTEN, U., HANELT, D., BISCHOF, K. and DUNTON, K. 2007. Life strategy, ecophysiology and ecology of seaweeds in polar waters, *Reviews in Environmental Science and Biotechnology,* **6**(1/3), 95-126.

WIENCKE, C., RAHMEL, J., KARSTEN, U., WEYKAM, G. and KIRST, G.O. 1993. Photosynthesis of marine macroalgae from Antarctica Light and temperature requirements, *Botanica Acta,* **106**, 78-87.

WILD, M., CALANCA, P., SCHERRER, S.C. and OHMURA, A. 2003. Effects of polar ice sheets on global sea level in high-resolution greenhouse scenarios, *J. Geophys. Res.*, **108**, 4165, doi:10.1029/2002JD002451.

WILLEBRAND, J., BARNIER, B., BOENING, C., DIETERICH, C., KILLWORTH, P, LE PROVOST, C., JIA. Y., MOLINES, J. and NEW, A.L. 2001. Circulation characteristics in three eddy-permitting models of the North Atlantic, *Progress in Oceanography,* **48**, 123–161.

WILLIS, J. 2007. Could whales have maintained a high abundance of krill?, *Evol. Ecol. Res.,* **9**, 651-662.

WILLIS, J.K., ROEMMICH, D. and CORNUELLE, B. 2004. Interannual variability in upper ocean heat content, temperature, and thermosteric expansion on global scales, *J. Geophys. Res.,* **109**, doi:10.1029/2003JC002260.

WILSON, N.G., HUNTER, R.L., LOCKHART, S.J. and HALANYCH, K.M. 2007. Multiple lineages and an absence of panmixia in the 'circumpolar' crinoid *Promachocrinus kerguelensis* in the Atlantic sector of Antarctica, *Mar. Biol.*, **152**, 895-904.

WILSON, P.R., AINLEY, D.G., NUR, N., JACOBS, S.S., BARTON, K.J., BALLARD, G. and COMISO, J.C. 2001. Adélie penguin population change in the pacific sector of Antarctica: relation to sea-ice extent and the Antarctic Circumpolar Current, *Marine Ecology Progress Series*, **213**, 301-309.

WILSON, T. 2007. Post-Gondwana and active tectonics, in TransAntarctic Mountains TRANsition Zone (TAM TRANZ Project). In: Elliot DH, Lyons WB, Everett LR (eds) *Multidisciplinary Research in the Central and Southern Transantarctic Mountains.* Miscellaneous Series 430, Byrd Polar Research Center, The Ohio State University, Columbus, OH., 99 pp

WINGHAM, D.J., RIDOUT, A.L., SCHARROO, R., ARTHERN, R.J. and SCHUM, C.K. 1998, Antarctic elevation change from 1990 to 1996, *Science,* **282**, 456–458, (doi:10.1126/science.282.5388.456).

WINGHAM, D.J., SHEPHERD, A., MUIR, A. and MARSHALL, G.J. 2006a. Mass balance of the Antarctic ice sheet, *Philosophical Transactions of the Royal Society*

A: Mathematical, Physical and Engineering Sciences, DOI: 10.1098/rsta.2006.1792.

WINGHAM, D.J., SIEGERT, M.J., SHEPHERD, A. and MUIR, A.S. 2006b. Rapid discharge connects Antarctic subglacial lakes, *Nature*, **440**, pp. 1033-1036 , doi:10.1038/nature04660.

WMO, 2002. Scientific Assessment of Ozone Depletion, *World Meteorological Organisation Global Ozone Research and Monitoring Project - Report No. 47.*

WÓJCIK, G. 1989. Temperature of active layer at Bunger Oasis in Antarctica in summer 1978-79, *In* K. Senneset (ed.): *5th International Conference onPermafrost*, 1. Tapir, Trondheim, 505-510.

WOLFF, E.W. and CACHIER, H. 1998. Concentrations and seasonal cycle of black carbon in aerosol at a coastal Antarctic station, *J. Geophys. Res.*, **103**(D9), 11033-11042, 10.1029/97JD01363.

WOLFF, E.W. and SUTTIE, E.D., 1994. Antarctic snow record of Southern Hemisphere lead pollution, *Geophysical Research Letters,* **21**, 781-784.

WOLFF, E.W., FISCHER, H., FUNDEL, F., RUTH, U., TWARLOH, B., LITTOT, G.C., MULVANEY, R., RÖTHLISBERGER, R., DE ANGELIS, M., BOUTRON, C.F., HANSSON, M., JONSELL, U., HUTTERLI, M.A,, LAMBERT, F., KAUFMANN, P., STAUFFER, B., STOCKER, T.F., STEFFENSEN, J.P., BIGLER, M., SIGGAARD-ANDERSEN, M.L., UDISTI, R., BECAGLI, S., CASTELLANO, E., SEVERI, M., WAGENBACH, D., BARBANTE, C., GABRIELLI, P. and GASPARI, V. 2006. Southern Ocean sea-ice extent, productivity and iron flux over the past eight glacial cycles, *Nature,* **440**, 491-496 (doi:10.1038/nature04614).

WOLFF, E.W., RANKIN, A.M. and ROTHLISBERGER, R. 2003. An ice core indicator of Antarctic sea ice production?, *Geophysical Research Letters,* **30**, 2158. (10.1029/2003GL018454.)

WOLFF, E.W., SUTTIE, E.D. and PEEL, D.A. 1999. Antarctic snow record of cadmium, copper and zinc content during the twentieth century, *Atmospheric Environment,* **33**, 1535-1541.

WONG, A.P.S., BINDOFF, N.L. AND CHURCH, J.A. 1999. Large-scale freshening of intermediate waters in the Pacific and Indian oceans, *Nature*, **400**, 86743), 440-443.

WOODWORTH, P.L. and PLAYER, R. 2003. The Permanent Service for Mean Sea Level: an update to the 21st century, *Journal of Coastal Research*, **19**, 287-295.

WOODWORTH, P.L., AARUP, T., MERRIFIELD, M., MITCHUM, G.T. and LE PROVOST, C. 2003. Measuring progress of the Global Sea Level Observing System, *EOS*, *Transactions of the American Geophysical Union,* **84**(50), 16 December 2003, 565, 10.1029/2003EO500009.

WOODWORTH, P.L., GREGORY, J.M. and NICHOLLS, R.J. 2004. Long term sea level changes and their impacts, 715-753 (chapter 18) in *The Sea*, **13**, edited by A.R. Robinson and K.H. Brink. Harvard University Press.

WOODWORTH, P.L., HUGHES, C.W., BLACKMAN, D.L., STEPANOV, V.N., HOLGATE, S.J., FODEN, P.R., PUGH, J.P., MACK, S., HARGREAVES, G.W., MEREDITH, M.P., MILINEVSKY, G. and FIERRO CONTRERAS, J.J. 2006. Antarctic peninsula sea levels: a real time system for monitoring Drake Passage transport, *Antarctic Science*, **18**(3), 429-436.

WOODWORTH, P.L., LE PROVOST, C., RICKARDS, L.J., MITCHUM, G.T. and MERRIFIELD, M. 2002. A review of sea-level research from tide gauges during the World Ocean Circulation Experiment, *Oceanography and Marine Biology: An Annual Review*, **40**, 1-35.

WOODWORTH, P.L., PUGH, D.T., MEREDITH, M.P. and BLACKMAN, D.L. 2005. Sea level changes at Port Stanley, Falkland Islands, *Journal of Geophysical Research*, **110**, C06013, doi:10.1029/2004JC002648.

WOODWORTH, P.L., VASSIE, J.M., HUGHES, C.W. and MEREDITH, M.P. 1996. A test of the ability of TOPEX/POSEIDON to monitor flows through the Drake Passage, *Journal of Geophysical Research*, **101**(C5), 11935-11947.

WORBY, A. P. AND ALLISON, I. 1999. A ship-based technique for observing Antarctic sea ice. Part I: Observational Techniques and Results, *Antarctic CRC Research Report*, **14**, 1-23.

WORBY, A.P**.** and COMISO, J.C. 2004. Studies of the Antarctic sea ice edge and ice extent from satellite and ship observations, *Remote Sensing of Environment,* **92**, 98-111; [Ref: 11519]; AAS Project 189.

WORLD METEOROLOGICAL ORGANIZATION, Scientific Assessment of Ozone Depletion: 2002, *Global Ozone Research and Monitoring Project–Report No. 47*, Geneva, Switzerland (2003).

WORLD METEOROLOGICAL ORGANIZATION, Scientific Assessment of Ozone Depletion: 2006, *Global Ozone Research and Monitoring Project–Report No. 50*, Geneva, Switzerland (2006).

WUNSCH, C. and FERRARI, R. 2004. Vertical mixing, energy, and the general circulation of the oceans, *Ann. Rev. Fluid Mech.,* **36**, 281-314.

WUNSCH, C. 1998. The work done by the wind on the oceanic general circulation, *J. Phys. Oceanogr,* **28**, 2332–2340.

WÜST, G. 1935. The Stratosphere of the Atlantic Ocean. *Scientific Results of the German Atlantic Expedition of the Research Vessel "Meteor" 1925 – 1927* (English translation, E.J. Emery (ed.), Amerind, new Delhi, 1978), **6**, 109-288.

XIE, P.P. and ARKIN, P.A. 1998. Global monthly precipitation estimates from satellite-observed outgoing longwave radiation, *J. Climate,* **11**, 137-164.

XIONG, F. and DAY, T. 2001. Effect of solar ultraviolet-B radiation during springtime ozone depletion on photosynthesis and biomass production of Antarctic vascular plants, *Plant Physiol.,* **125**, 738-751.

YAMAGUCHI, K. and NODA, A. 2006. Global Warming Patterns over the North Pacific: ENSO versus AO, *J. Meteor. Soc. Japan*, **84**, 221-241.

YAMANOKUCHI, T., DOI, K. and SHIBUYA, K. 2005. Validation of grounding line of the East Antarctic Ice Sheet derived by ERS-1/2 interferometric SAR data, *Polar Geoscience*, **18**, 1-14.

YAMANOUCHI, T. and CHARLOCK, T.P. 1997. Effects of clouds, ice sheet and sea ice on the earth radiation budget in the Antarctic, *J. Geophys. Res.*, **102**, 6953-6970.

YAMANOUCHI, T. and KAWAGUCHI, S. 1984. Longwave radiation balance under a strong surface inversion in the katabatic wind zone, Antarctica. *J. Geohys. Res.*, **89**, 11771-11778.

YAMANOUCHI, T. and KAWAGUCHI, S. 1992. Cloud distribution in the Antarctic from a VHRR data and radiation measurements at the surface, *International Journal of Remote Sensing*, **13**, 111–127.

YAMANOUCHI, T. 1983. Variation of incident solar flux and snow albedo on the solar zenith angle and cloud cover, at Mizuho Station, Antarctica. *J. Meteor. Soc. Jpn*, **61**, 879-893.

YAMAONUCHI, T. and SHUDOU, Y. 2007. Trends in cloud amount and radiative fluxes at Syowa Station, Antarctica, *Polar Science*, **1**, 17-23.

YAMASHITA, N., KANNAN, K., TANIYASU, S., HORII, Y., PETRICK, G. and, GAMO, T. 2005. A global survey of perfluorinated acids in oceans, *Mar. Pollut. Bull.,* **51**, 658-668.

YAN, Y., MAYEWSKI, P.A., KANG, S. and MEYERSON, E. 2005. An ice core proxy for Antarctic circumpolar wind intensity, *Annals of Glaciology,* **41**, 121-130.

YANG, E.-S., CUNNOLD, D.M., SALAWITCH, R.J., MCCORMICK, M.P., RUSSELL III, J., ZAWODNY, J.M., OLTMANS, S., and NEWCHURCH, M.J. 2006. Attribution of recovery in lower-stratospheric ozone, *J. Geophys. Res.*, **111**, D17309, doi:10.1029/2005JD006371.

YAO, T., PETIT, J.R., JOUZEL, J., LORIUS, C. and DUVAL, P. 1990. Climatic record from an ice margin area in East Antarctica, *Annals of Glaciology,* **14**, 323-327.

YEH, S.-W. and KIRTMAN, B.P. 2007. ENSO amplitude changes due to climate change projections in different coupled models, *J. Climate*, **20**, 203-217.

YIN, J. H. 2005. A consistent poleward shift of the storm tracks in simulations of 21st century climate, *Geophysical Research Letters*, **32,** L18701.

YOKOYAMA, Y., LAMBECK, K., DE DECKKER, P., JOHNSTON, P. and, FIFIELD, I.K. 2001. Timing of the Last Glacial Maximum from observed sea-level minima, *Nature,* **412**, 99-119.

YOON, H.I., PARK, B.K., KIM, Y. and KIM, D. 2000. Glaciomarine Sedimentation and Its Paleoceanographic Implications Along the Fjord Margins in the South Shetland Islands, Antarctica During the Last 6000 Years, *Palaeogeography Palaeoclimatology Palaeoecology,* **157**, 189-211.

YUAN, X.J. and MARTINSON, D.G. 2000. Antarctic sea ice extent variability and its global connectivity, *Journal of Climate*, **13**(10): 1697-1717.

YUAN, X.J. and MARTINSON, D.G. 2001. The Antarctic Dipole and its predictability, *Geophysical Research Letters*, **28**(18), 3609-3612.

YUAN, X.J. 2004. ENSO-related impacts on Antarctic sea ice: a synthesis of phenomenon and mechanisms, *Antarctic Science*, **16**(4), 415-425.

ZACHER, K., ROLEDA, M.Y., WULFF, A., HANELT, D. and WIENCKE, C. In press. Responses of Antarctic *Iridaea cordata* (Rhodophyta) tetraspores exposed to ultraviolet radiation, *Phycological Research.*

ZACHER, K., WULFF, A., MOLIS, M., HANELT, D. and WIENCKE, C. 2007. Ultraviolet radiation radiation and consumer effects on a field-grown intertidal macroalgal assemblage in Antarctica, *Global Change Biology,* **13**(6), 1201-1215.

ZACHOS, J., PAGANI, M., SLOAN, L., THOMAS, E. and BILLUPS, K. 2001 Trends, Rhythms, and Aberrations in Global Climate 65 Ma to Present, *Science,* **292**, 686 – 693.

ZACHOS, J.C., DICKENS, G.R. and ZEEBE, R.E. 2008. An early Cenozoic perspective on greenhouse warming and carbon-cycle dynamics, *Nature,* **451**, 279-283.

ZACHOS, J.C., ROHL, U., SCHELLENBERG, S.A., SLUIJS, A., HODELL, D.A., KELLY, D.C., THOMAS, E., NICOLO, M., RAFFI, I., LOURENS, L.J., MCCARREN, H. and KROON, D. 2005. Rapid Acidification of the Ocean During the Paleocene-Eocene Thermal Maximum, *Science,* **308**, 1611-1615.

ZACHOS, J.C., WARA, M.W., BOHATY, S., DELANEY, M.L., PETRIZZO, M.R., BRILL, A., BRALOWER, T.J. and PREMOLI-SILVA, I. 2003. A Transient Rise in Tropical Sea Surface Temperature During the Paleocene-Eocene Thermal Maximum, *Science,* **302**, 1551-1554.

ZAKHARTSEV, M.V., DE WACHTER, B., SARTORIS, F.J., PÖRTNER, H.O. and BLUST, R. 2003. Thermal physiology of the common eelpout (*Zoarces viviparus*), *J. Comp. Physiol. B,* **173**, 365-378.

ZANE, L., MARCATO, S., BARGELLONI, L., BORTOLOTTO, E., PAPETTI, C., SIMONATO, M., VAROTTO, V. and PATARNELLO, T. 2006. Demographic history and population structure of the Antarctic silverfish Pleuragramma antarcticum, *Molecular Ecology,* **15**, 4499 – 4511.

ZENK, W. AND MOROZOV, E. 2007. Decadal warming of the coldest Antarctic Bottom Water flowing through the Vema Channel, *Geophysical Research Letters*, **34,** L14607, doi:10.1029/2007/GLR030340

ZHANG, T., and STAMMES, K. 1998. Impact of climatic factors on the active layer and permafrost at Barrow, Alaska, *Permafrost and Periglacial Processes*, **9**, 1, 229-246.

ZHAO, Y., RATNAYAKE-LECAMWASAM, M., PARKER, S.K., COCCA, E., CAMARDELLA, L., DI PRISCO, G. and DETRICH III, H.W. 1998. The major adult α-globin gene of Antarctic teleosts and its remnants in the hemoglobinless icefishes. Calibration of the mutational clock for nuclear genes, *J. Biol. Chem.,* **273**, 14745-14752.

ZICKFELD, K., FYFE, J.C., EBY, M. and WEAVER, A.J. 2008. Comment on "Saturation of the Southern Ocean CO2 Sink due to Recent Climate Change", *Nature*, **570b**.

ZICKFELD, K., FYFE, J.C., SAENKO, O.A., EBY, M. and WEAVER, A.J. 2007. Response of the global carbon cycle to human-induced changes in Southern

Hemisphere winds, *Geophysical Research Letters*, **34**, L12712 doi:10.1029/2006GL028797

ZIELINSKI, G.A., MAYEWSKI, P.A., MEEKER, L.D., WHITLOW, S.I., TWICKLER, M.S., MORRISON, M.C., MEESE, D., ALLEY, R. and GOW. A.J. 1994. Record of volcanism since 7000 BC from the GISP2 Greenland ice core and implications for the volcano-climate system, *Science,* **264**, 948-952.

ZIMOV, S.A., CHUPRYNIN, V.I., ORESHKO, A.P., CHAPIN III, F.S., REYNOLDS, J.F. and CHAPIN, M.C. 1995. Steppe-tundra transition: A herbivore driven biome shift at the end of the Pleistocene, *Am. Nat.,* **146**, 765-794.

ZINSMEISTER, W.J. 1982. Upper Cretaceous-Lower Tertiary stratigraphy of Seymour Island, *Antarctica Journal of the Geological Society of London,* **139**, 779-786.

ZWALLY, H.J, COMISO, J.C., PARKINSON, C.L., CAVALIERI, D.J. and GLOERSEN, P. 2002a. Variability of Antarctic sea ice 1979-1998, *Journal of Geophysical Research,* **10,** 3041, doi: 3010.1029/2000JC000733.

ZWALLY, H.J. and FIEGLES, S. 1994. Extent and duration of Antarctic surface melting, *J. Glaciol.,* **40**(136), 463–476.

ZWALLY, H.J. and GLOERSEN. P. 1977. Passive-microwave images of the polar regions and research applications, *Polar Records,* **18**, 431-450.

ZWALLY, H.J., PARKINSON, C.L. and COMISO, J.C. 1983. Variability of Antarctic Sea Ice: and Changes in Carbon Dioxide, *Science* 3 June 1983, **220**. no. 4601, 1005 – 1012.

ZWALLY, H.J., ABDALATI, W., HERRING, T., LARSON, K., SABA, J. and STEFFEN, K. 2002b. Surface melt-induced acceleration of Greenland ice-sheet flow, *Science*, **297,** No. 5579, 218-222.

ZWALLY, H.J., GIOVINETTO, M., LI, J., CORNEJO, H., BECKLEY, M., BRENNER, A., SABA, J. and YI, D. 2005. Mass changes of the Greenland and Antarctic ice sheets and shelves and contributions to sea-level rise: 1992-2002, *Journal of Glaciology,* **51**(175), 509-527.

ZWARTZ, D., BIRD, M., STONE, J. and LAMBECK, K. 1998. Holocene sea-level change and ice-sheet history in the Vestfold Hills, East Antarctica, *Earth and Planetary Science Letters,* **155**, 131-145.