Variability at Ocean Weather Station M in the Norwegian Sea

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Abstract

Time series of temperature and salinity from Ocean Weather Station M are analysed for periodic cycles of interannual to decadal scale. Time evolutions of the spectra show various spectral peaks at all depths, but none of these cycles show persistence throughout the 50 years. In addition isopycnal surfaces and temperature and salinity values on these surfaces, are estimated and studied in terms of the relative influence of horizontal advection and vertical movement on the observed changes of water properties.

1 Introduction

The Ocean Weather Ship Station "Mike" (OWSM) at 66°N 2°E (Gammelsrød et al., 1992) is situated over the 2000 m isobath on the steep slope from the Vøring Plateau to the deep Norwegian Basin. It is monitoring the deep Norwegian Sea as well as the topographically locked subsurface front between Arctic waters and inflowing Atlantic Water (Smart, 1984). This study aims to uncover some of the time dependencies of spectral properties in the time series from OWSM, as well as study the possibility to separate vertical or cross isopycnal motion from advection.

2 Data and methods

The oceanic data sampling at OWSM is done around standard depths. The program has been running since 1948 and consists of daily casts down to 1000 m

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and weekly down into the deep, resulting in the about 10 000 profiles of salinity and temperature used in this study. The data has been interpolated to standard depths by weighted parabolic interpolation (Reiniger and Ross, 1968) and to chosen isopycnal (σ_t) surfaces by logarithmic interpolation (Fofonoff, 1962). Average profiles are shown in Figure 1. Monthly mean values were calculated from months containing more than one profile. The depths of the chosen isopycnal levels were found by linear interpolation on dense depth interpolated σ_t-profiles (Figure 2).

Wavelet transforms of the monthly data have been found using a Morlet mother wavelet (Torrence and Compo, 1997). Wavelet transformation is a method of time-frequency localization of oscillations in non-stationary records. It is similar to windowed Fourier transformation, but gives better temporal resolution due to the use of basis functions that are localized in time and of length according to their frequency (Graps, 1995). Before this spectral analysis, gaps in the time series were filled by a local variance- and trend conserving method, using information from the data neighboring the gaps.

3 Long-term trends

At all standard depths there is a weak negative overall trend in salinity. This trend is stronger in the intermediate waters (400–1200 m), where there is a pronounced salinity maximum in the early 70s preceding a clear linear decrease into a fresher than mean 90s (Figure 3b). In deep waters the salinity breaks off from the trend with an increase since 1997. This late 90s salinity increase is also seen in the shallower waters (25–300 m, Figure 3a). There is a similarity between the trends on standard depths and those on corresponding isopycnal surfaces (Figure 3c, d). The trends on isopycnal surfaces below 400 m follow the changes in isopycnal depths (Figure 2), i.e. the freshening since the 70s is accompanied by a deepening of isopycnal surfaces.

There are no significant trends of the temperature on standard depths of the upper 400 m (Figure 5a). Between 400-800 m there is a very weak overall cooling trend, with a stronger cooling during the 90s, accompanying the freshening at the same depths. Deeper than 1000 m, the overall trend is dominated by a strong warming since 1980 (Figure 5b) making the 90s significantly warmer than average (Østerhus and Gammelsrød, 1999). As the salinity and temperature are closely allied on the same isopycnal surface, their time series are nearly identical and temperature trends are the same as the salinity trends described above. Thus the abyssal warming is not present on the isopycnal surfaces, and there is a cooling trend on the shallow isopycnal surfaces (Figure 5c, d).

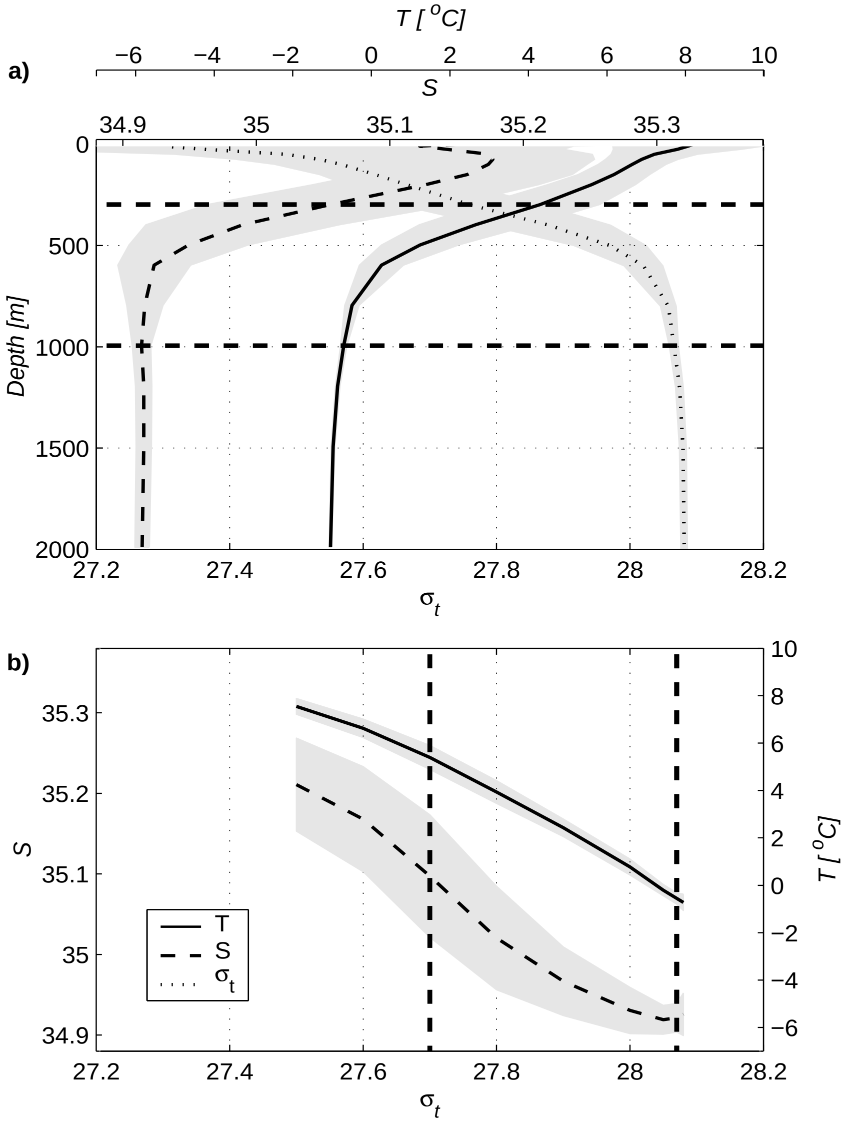

Figure 1: Average profiles from OWSM, in depth (a) and sigma-coordinates (b). Shaded regions illustrate standard deviation. Dashed thick gridlines indicate the depths and isopycnal levels analysed in this study. As can be seen these are in the pycnocline and the intermediate/deep waters respectively.

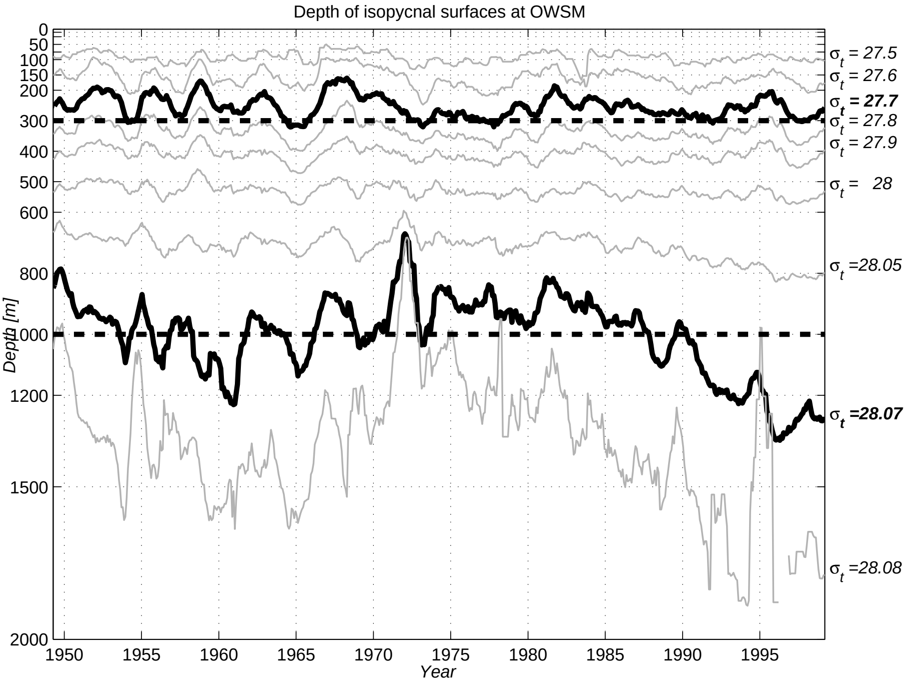

Figure 2: Time series of the depth of chosen isopycnal surfaces, smoothed by a simple 1 year wide boxcar filter. The thick lines represent the depths and isopycnal levels analysed in this study.

4 Interannual variability

Prior to 1975 there was a pronounced 10-year period oscillation in the halocline (Figure 4a). There is also a biennial periodicity in the early part of the series that weakens and seems to increase its period, possibly towards a persistent 5-year oscillation during 1980–1995. On the corresponding isopycnal surface, this oscillation is more pronounced and shifted towards longer periods (Figure 4c). More significant in this series is a decadal oscillation in the sixties, changing toward a ca. 20 year period in 1980–2000, possibly affected by edge effects in the wavelet transform, but evident in the time series (Figure 3c). In the deep waters, there are no persistent salinity oscillations present at constant depths, but sporadic energy is found at periods around 2.5, 4, and 8 years (Figure 4b). Deep isopycnal surfaces ($\sigma_t = 28.07$) are dominated by a strong localized (possibly spurious) effect of the narrow maximum in the early 70s (Figure 4d).

In temperature as in salinity, there is a biennial oscillation around 1960, but with a more transient character. Temperature series of the intermediate waters are dominated by a single 20 year oscillation (best seen in Figure 5b), but studies of time series from all levels renders this a result of a warm anomaly from above in the late 70s and the 90s abyssal warming from below. There are also transient 2 and 4 year cycles at 1000 m (Figure 6b) localized around the warm anomaly around 1975.

5 Discussion

If the changes of water properties at constant depths cannot be related to those on nearby isopycnal surfaces, the changes can be attributed to water movement perpendicular to isopycnals (usually vertical movement). If on the other hand, changes occur concurrently on isopycnal surfaces and constant depths, one can suspect they are also seeing the effects of isopycnal (horizontal) water motion. Most trends and interannual variability show similarities between properties on isopycnal surfaces and at constant depth, indicating that these changes are advected into the area. High frequency variability on the other hand, is markedly more pronounced at constant depths, and must be attributed to oscillation of the isopycnals (Figure 3a, c).

With the water structures in the pycnocline at OWSM (Figure 1), changes in depth of isopycnal levels caused by vertical motion should be in phase with both salinity and temperature variations. The overall freshening since 1970 as well as most of the interannual variability of salinity are in opposite phase with the depth of the isopycnal surfaces (Figure 2), indicating that changing isopycnal depths do not determine the changes in salinity. Temperature on the other hand, seems to be in phase with isopycnal depth, and not strongly related

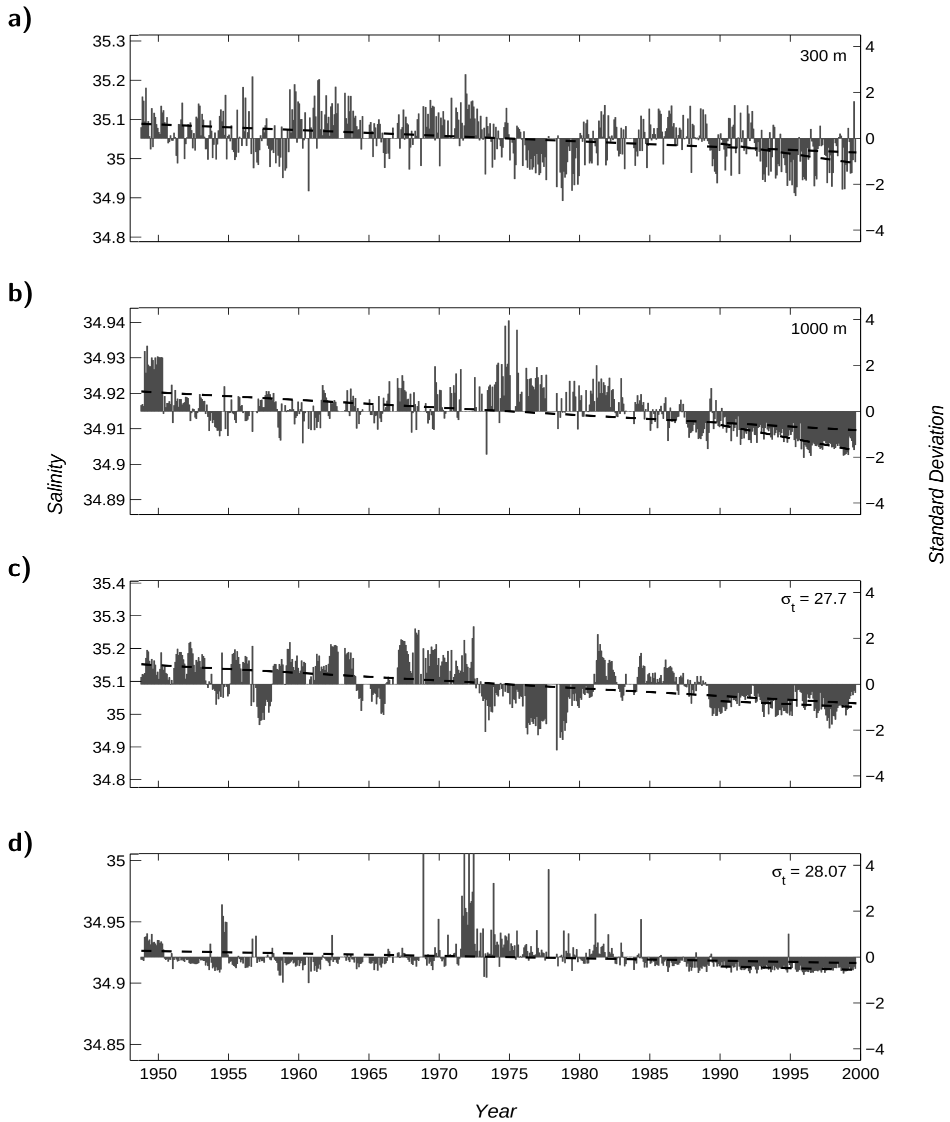

Figure 3: Time series of monthly salinity at two chosen standard depths (a,b) and at their corresponding isopycnal surfaces (c,d). Dashed lines represent linear trends.

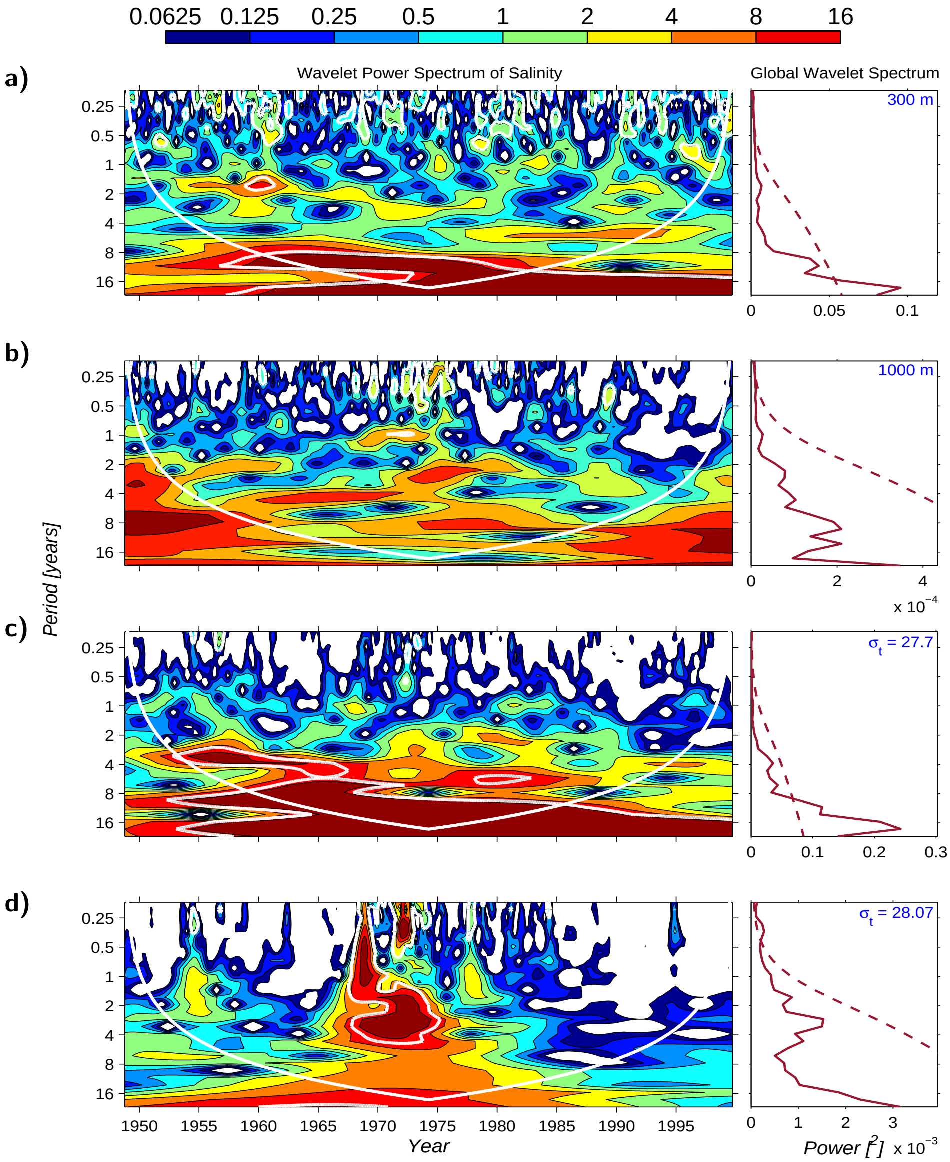

Figure 4: Wavelet Power Spectra of salinity variance at the chosen standard depths (a,b) and at their corresponding isopycnal surfaces (c,d) normalized by $1/\sigma^2$. White curves give "cones of influence" outside of which edge effects affect the result. White contours enclose regions of greater than 95% confidence for a red noise process with a lag1 coefficient of 0.72. The global wavelet spectra to the right is similar to a "regular" (Fourier) spectrum for the whole time series, and here plotted together with the mean red noise spectrum (dashed line).

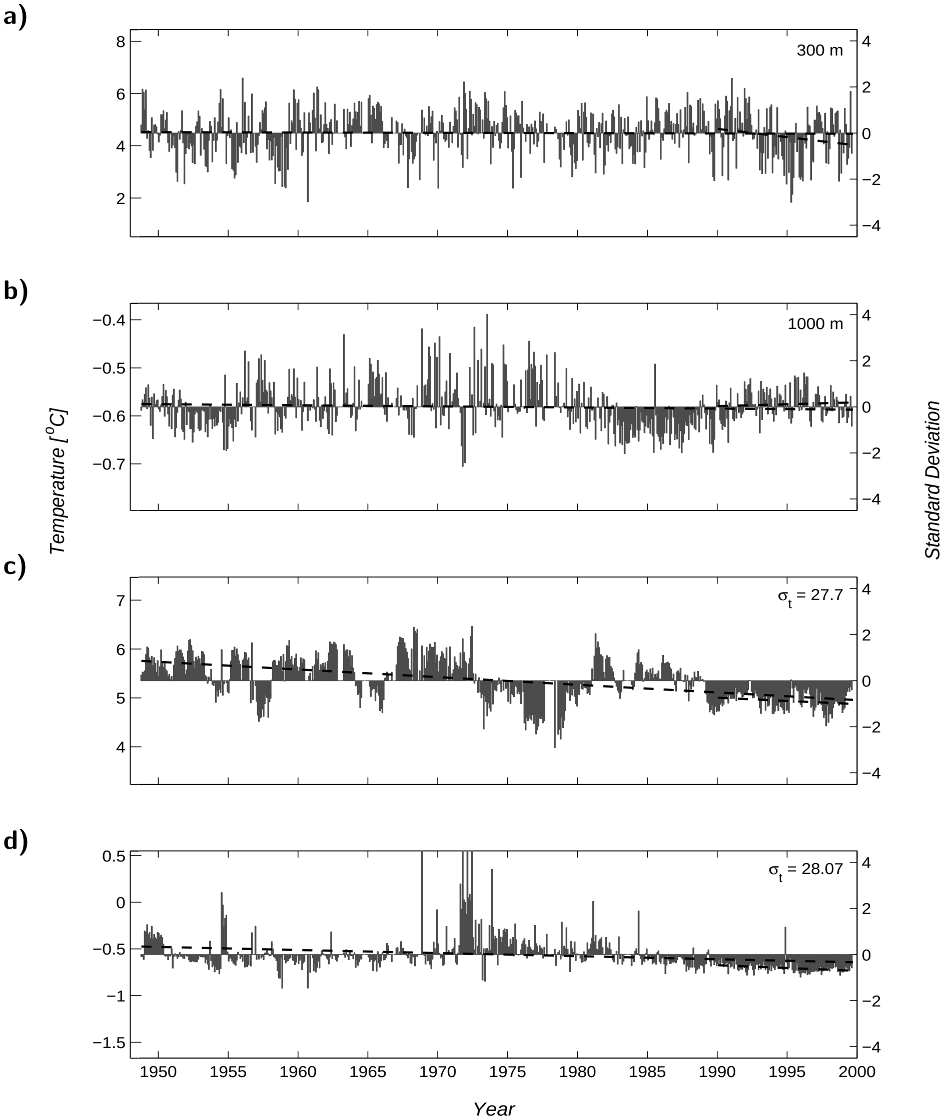

Figure 5: Time series of monthly temperature at two chosen standard depths (a,b) and at their corresponding isopycnal surfaces (c,d). Dashed lines represent linear trends.

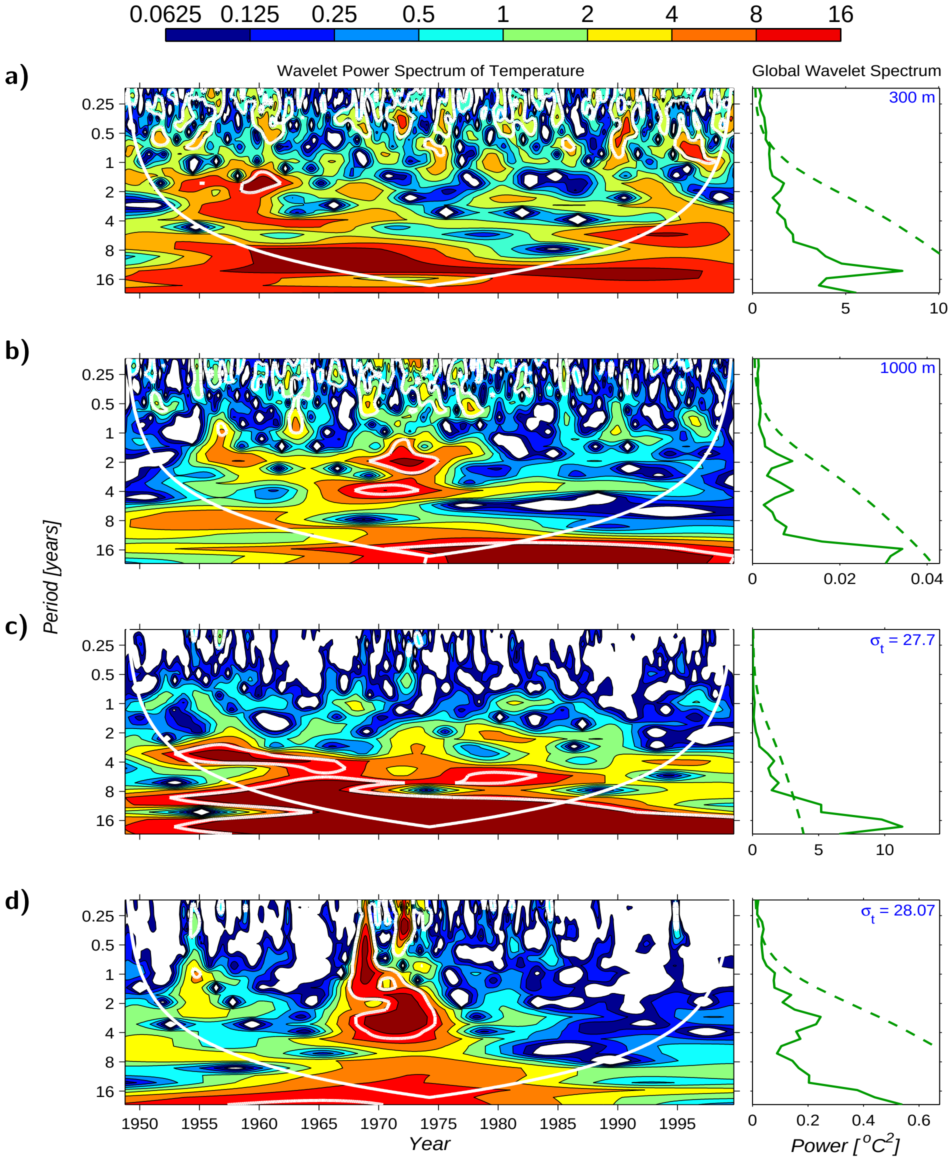

Figure 6: Wavelet Power Spectra of temperature variance at the chosen standard depths (a,b) and at their corresponding isopycnal surfaces (c,d) normalized by $1/\sigma^2$. White curves give "cones of influence" outside of which edge effects affect the result. White contours enclose regions of greater than 95% confidence for a red noise process with a lag1 coefficient of 0.72. The global wavelet spectrum to the righ is similar to a "regular" (Fourier) spectrum for the whole time series, and here plotted together with the mean red noise spectrum (dashed line).

to its counterpart on the isopycnal surface (Figures 2 and 5a, b), which is not surprising since changes in surface temperature has the strongest influence on the mixed layer depth.

6 Summary and Conclusions

Trends and interannual variability are in most cases coherent at constant depths and on isopycnal surfaces, and thus results of (isopycnal) advection into the area. High frequency variability can be attributed to oscillation of the isopycnal surfaces, and thus separated from the advection by this method. The Wavelet-analysis of interannual variability shows no clear or persistent periodicity throughout the series, but there are evidence of transient oscillations often in a bimodal structure with variability in both 2–5 year and 10–20 year bands.

Acknowledgements

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