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Regional sea level, Southern Oscillation and beach change, New South Wales, Australia

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Abstract

Coastal erosion is a problem of increasing concern that affects 60% of the world's sandy coastline. This erosion has been attributed to increased storminess, tectonic subsidence, eustatic sea-level rise, decreased shoreward sediment movement from the shelf, permanent longshore leakage of sediment from beach compartments, shifts in global pressure belts resulting in changes in the directional component of wave climates, and human interference. No one explanation has worldwide applicability because all factors vary in importance regionally. Evaluation of factors is complicated by a lack of accurate, continuous, long-term erosional data. Historical map evidence spanning 100-1,000 yr has been used in a few isolated areas; however, temporal resolution has not been sufficient to evaluate the effect of climatic variables. Air photographic evidence is restricted to the past 40 yr, and often suffers from insufficient ground control for accurate mapping over time. Ground surveying of beaches was rarely carried out before 1960 and is often discontinuous in time and space. I have resolved the problems of temporal and spatial continuity by studying change for the whole of Stanwell Park beach, New South Wales, Australia for the period 1895-1980 (Fig. 1). I report here that using the average high-tide wave run-up position measured accurate to ±2.5 m from oblique and vertical photographs, changes could be linked to regional sea-level variation and a globally significant climatic variable, the Southern Oscillation (SO).

Keywords

Southern Oscillation, sea level, beach erosion and accretion, Hadley cell, New South Wales, Australia

Disciplines

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

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Regional sea level, Southern Oscillation and beach change, New South Wales, Australia

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Coastal erosion is a problem of increasing concern that affects 60% of the world's sandy coastline[1]. This erosion has been attributed to increased storminess, tectonic subsidence, eustatic sea-level rise, decreased shoreward sediment movement from the shelf, permanent longshore leakage of sediment from beach compartments, shifts in global pressure belts resulting in changes in the directional component of wave climates, and human interference[2,3]. No one explanation has worldwide applicability because all factors vary in importance regionally. Evaluation of factors is complicated by a lack of accurate, continuous, long-term erosional data. Historical map evidence spanning 100–1,000 yr has been used in a few isolated areas[4–7]; however, temporal resolution has not been sufficient to evaluate the effect of climatic variables. Air photographic evidence[8] is restricted to the past 40 yr, and often suffers from insufficient ground control for accurate mapping over time. Ground surveying of beaches was rarely carried out before 1960 and is often discontinuous in time and space. I have resolved the problems of temporal and spatial continuity by studying change for the whole of Stanwell Park beach, New South Wales, Australia for the period 1895–1980 (Fig. 1). I report here that using the average high-tide wave run-up position measured accurate to ±2.5 m from oblique and vertical photographs, changes could be linked to regional sea-level variation and a globally significant climatic variable, the Southern Oscillation (SO).

Stanwell Park beach, located on the tectonically-stable South Coast of New South Wales[12], is a compartmentalized, exposed, ocean beach having no permanent longshore leakage of sediment and little human interference. The beach faces the main south-east swell which averages 10 s in period and 1.2 m in wave height[9]; however, the beach is modified to some degree by all wave directions affecting this coastline[3]. Inshore topography varies rapidly from alternating shore-tied shoals and rip channels to a single, shore-parallel bar-trough in response to storm waves which often exceed 4 m in height.

Oblique tourist photographs, dated 1895–1980, were solicited from the public using local and national newspaper advertisements, and were supplemented by photographs from historical societies, government departments, postcard companies and libraries. Vertical photographs taken by state and federal governments since 1948 were also collected. Undated photographs were sequentially ordered and dated to the nearest year using geomorphic, vegetational and accurately dated cultural changes. Shadow positions of telegraph poles and trees of known elevation were then used to calculate solar azimuth, elevation and hour angle[10]. From this information the exact time of year could be obtained with spring and autumn months being separated on the basis of vegetational differences. The record of 128 photographs averaged one every 4 yr between 1895 and 1920, one every 2 yr between 1920 and 1933, and more than 1 per yr thereafter.

A direct linear transformation method[11] requiring a minimum of six control points was used to transform the position of high-tide wave run-up from single photographs to plan maps. Single rather than stereo photographs could be used because ground surveying over time indicated that high-tide run-up was stable at 3.5 m above low tide (standard error, 0.56 m). The accuracy of the method was evaluated further by comparing plan maps of identical photographs analysed more than once, and of photographs taken at the same time from different locations or using different cameras. Total mapping error amounted to ±2.5 m. Ninety-five per cent of photographs were analysed using seven or more control points with a standard error of <1.5 m.

Fig. 1 Location map of the study area.

Table 1 Correlation of high-tide position with climatic factors between 1895 and 1980

	SO index (quarterly 1897–1974)	Sea level (monthly 1897–1980)	Hadley cell position (monthly 1941–77)	Sea-surface temperature (monthly 1967–76)
Time	$r = 0.117^{*}$ 0.013 yr^{-1} $n = 312$	$r = 0.253^{\dagger}$ 0.64 mm yr^{-1} $n = 1,020$	$r = 0.087^{\ddagger}$ 0.039° S yr^{-1} $n = 444$	NS
Mean high-tide position	$r = -0.192^{*}$ $n = 117$	$r = -0.194^{*}$ $n = 128$	NS	NS

Pearson product-moment correlation coefficients between high-tide wave run-up position and SO index, Sydney sea level, Hadley cell position on East Coast of Australia, and sea-surface temperature for 1° square 33°–34° S, 153°–154° E.

* Significant 0.05 level. † Significant 0.01 level. ‡ Significant 0.10 level. NS, not significant.

Deviations from mean high-tide position (Fig. 2) show that, apart from the 1-in-100 yr storms of 1974, the beach has undergone continuous and constant fluctuations in the magnitude of erosion and accretion since 1930 with no significant loss or gain of sediment since 1895[3]. In the 1930s and 1940s changes were superimposed on an accretional trend. Beginning in 1948 coastal recession has predominated except for the period 1970–74. Between 1895 and 1967 erosion on Stanwell Park did not always occur contemporaneously with documented erosion on adjacent beaches in the region[12]. Discrepancies can be attributed to the sporadic nature of documentation along the New South Wales coast and its bias towards the destruction of manmade structures infringing on the active coastal zone—an aspect not applicable to Stanwell Park. Since 1967 when more intense coastal research commenced in New South Wales, the Stanwell Park and regional records coincide.

The date 1948 represents the beginning of a cold phase of temperature in the Northern Hemisphere[13,14] and one of increased storminess along the US Atlantic seaboard[15]. In Australia this date is perceived as a climatic turning point. Autumn temperature[16] and rainfall[17–19] have increased with more frequent blocking at mid-latitudes, fewer anticyclones and poleward movement of westerlies[20]. Responses to these changes in New South Wales include increased flood frequency on the Hawkesbury River, higher lake levels in Lake George, and channel expansion in the Hunter Valley[21,22]. To account for the variation in coastal change, the high-tide data for Stanwell

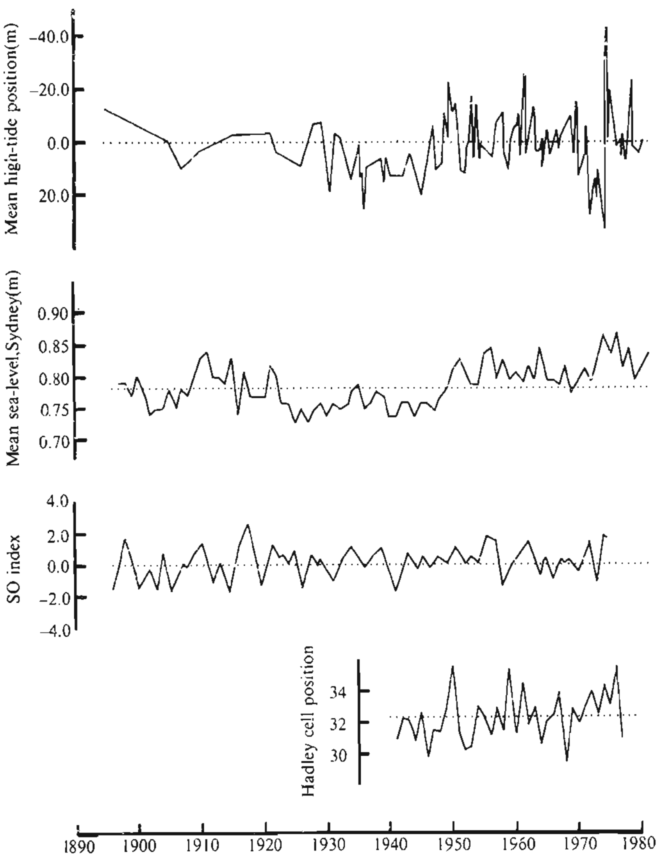

Fig. 2 Changes for various periods 1895–1980 in high-tide wave run-up position averaged for whole of Stanwell Park beach (values measure deviations from mean record), sea level at Sydney, Southern Oscillation index (values measure the normalized pressure difference between Darwin and Tahiti), and latitude of the centre of the Hadley cell along the East Coast of Australia.

Park were correlated to monthly mean sea level measured at Sydney 40 km northwards, the quarterly barometric pressure difference between Darwin and Tahiti[23], the monthly position of the centre of the Hadley high-pressure cell along the east Australian coast[24], and monthly sea-surface temperature averaged for the 1° square 33°–34° S, 153°–154° E[25] (Fig. 2, Table 1). Additionally, these meteorological and oceanographic variables were lagged and then linearly cross-correlated with and without seasonal effects (Fig. 3).

Each of these variables has direct relevance to coastal erosion. Sea-level variation has been related to erosion on beaches having equilibrium profiles and little longshore sediment movement[1,26]. In these conditions, as sea level rises, sediment moves offshore to maintain a uniform profile shape and the shoreline retreats landward. The process is known as Bruun's rule and has been invoked to account for erosion rates of 0.21 and 1.81 m per cm rise in waterlevel per yr in the Great Lakes and Chesapeake Bay respectively[27,28]. Sea-level change also affects beach water tables. Measurements taken over a tidal cycle[29,30] and over a 5-yr period at Warilla beach 30-km south of the study area[31], together with experiments in which water tables were raised artificially[32], have shown that substantial beach erosion can be initiated by rising water tables associated with rising sea level.

The Darwin – Tahiti pressure difference values, normalized here to a standard deviation of 1.0, measure the strength of a longitudinal pressure wave across the Pacific Ocean—Walker circulation. This circulation is inherently linked out of phase to sea-surface temperature in the East Pacific[33]. The phenomenon, also known as the SO, oscillates every 2–3 yr and, at times of warmest sea-surface temperature—the El Niño of Peru—has been related to a wide range of climatic events worldwide including equatorward displacement of subpolar lows and subtropical highs, below average monsoonal rainfall in India, drought in Australia and colder winter temperatures in the United States[33]. Regionally the Hadley cell positioning along the east coast of Australia controls the strength and persistence of erosive onshore winds. A southward movement has been correlated to increased rainfall in New South Wales[17]. Enhancement of east–west flow caused by southward movement of the Hadley cell beyond 40° S, coupled with increased sea-surface temperature anomalies, has been envisaged as increasing the intensity and duration of cyclogenesis (storms), especially in autumn, along the New South Wales coast[34].

Overall the SO index and regional sea level have increased (0.05 level of significance) since 1897 while the centre of the Hadley cell has shifted (0.10 level of significance) southwards by 1.4° since 1940. Sea-level rise has amounted to 0.64 mm yr^{-1} which is less than the eustatic rate of 0.95 mm yr^{-1} (ref. 35). Specifically sea level fell or was stable between 1910 and 1946 during the main accretional phase on Stanwell Park beach and rose in a step-functional manner by 5–10 cm after 1948 concomitantly with beach recession. Oscillations before 1950 are not coincident with world-scale climatically induced fluctuations in eustatic sea level[35]—a fact suggesting that regional long-term variations in meteorological variables such as barometric pressure, the incidence of storm surges or frequency of induced shelf waves are more important in controlling the Sydney sea-level curve[36,37]. Both the SO index and sea-level correlate inversely (0.05 level of significance) with beach accretion ($r = -0.192$ and -0.194 respectively). The Hadley cell position and sea temperature appear to have no such effect on beach position. Increased hemispheric easterly flow (positive SO index) also results both seasonally and over the long-term in a rise in sea level ($r > 0.138$). While Hadley cell movement is related to the SO index in that it precedes the index by 9–12 months ($r > 0.153$), it does not affect shoreline change. Seasonally southward movement of the Hadley cell increases sea-surface temperature ($r = 0.542$) and, after a three month lag, sea level ($r = 0.324$). These increases are directly attributable to an associated poleward shift in the warm East Australian current. The long-term poleward displacement of the Hadley cell produces decreased sea level—a result that does not facilitate beach recession. Isolated movement and stagnation of the Hadley cell poleward of 40° S in autumn has exacerbated erosion only for the storm periods of 1949, 1956 and 1974. This erosion may be associated with increased cyclogenesis and higher sea-surface temperatures, but the sea-temperature record, short though it may be, indicates that beach recession has followed periods of both high and low sea temperature.

Long-term coastline recession and accretion on Stanwell Park beach are linked primarily to variations in sea level produced by phenomena associated with fluctuation in the Walker circulation. Increased storminess, or factors responsible for storms are not as important, as evidenced by the fact that the magnitude and frequency of erosional events has remained constant since 1930 during both accretional and erosional phases. While sea-level fluctuations have not exceeded 12 cm, a 1-cm rise in sea level can be related significantly to a 0.5-m recession of the high-tide line. This rate is similar to those reported elsewhere[27,28] invoking Bruun's rule to account for shoreline erosion. Recession must also be aided by an associated rise in beach water tables. The fact that a hemispheric climatic variable, which can be linked to a wide range of climatic events worldwide, is also linked regionally to sea-level variation and beach recession on Stanwell Park beach, may warrant a change in emphasis to world climatic variability as a major cause of present day coastal erosion.

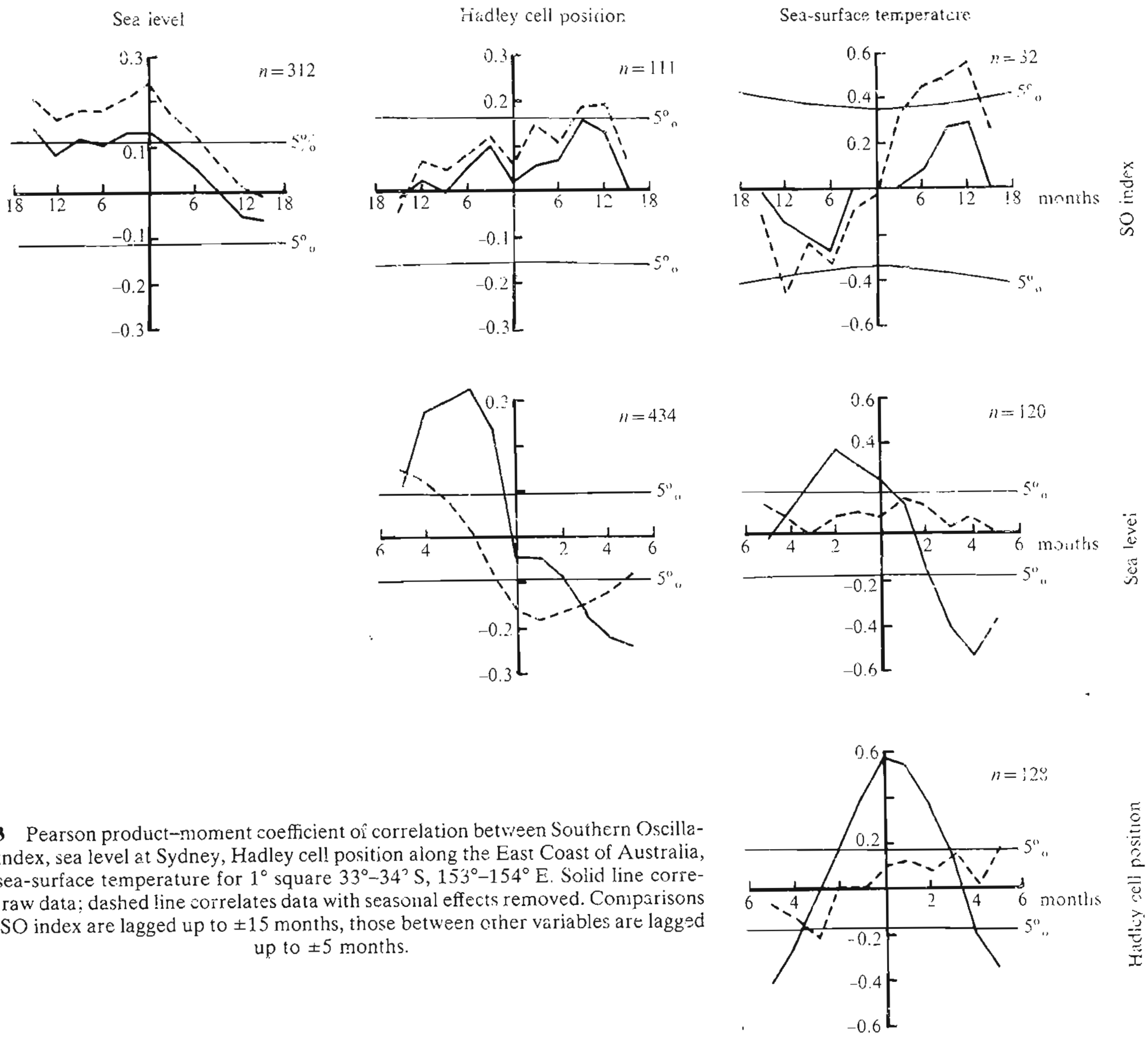

Fig. 3 Pearson product–moment coefficient of correlation between Southern Oscillation index, sea level at Sydney, Hadley cell position along the East Coast of Australia, and sea-surface temperature for 1° square 33°–34° S, 153°–154° E. Solid line correlates raw data; dashed line correlates data with seasonal effects removed. Comparisons with SO index are lagged up to ±15 months, those between other variables are lagged up to ±5 months.

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