Continental Shelf Research 98 (2015) 36–53

Contents lists available at ScienceDirect

Continental Shelf Research

journal homepage: www.elsevier.com/locate/csr

Research papers

Directional wave climate and power variability along the Southeast Australian shelf

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ARTICLE INFO

Article history:
Received 20 September 2014
Received in revised form
24 February 2015
Accepted 24 February 2015
Available online 5 March 2015

Keywords:
Wave climate
Wave power
Cluster analysis
Sub-tropical ridge
Southeast Australia
Tasman Sea

ABSTRACT

Variability in the modal wave climate is a key process driving large-scale coastal behaviour on moderate- to high-energy sandy coastlines, and is strongly related to variability in synoptic climate drivers. On sub-tropical coasts, shifts in the sub-tropical ridge (STR) modulate the seasonal occurrence of different wave types. However, in semi-enclosed seas, isolating directional wave climates and synoptic drivers is hindered by a complex mixed sea-swell environment. Here we present a directional wave climate typology for the Tasman Sea based on a combined statistical-synoptic approach using mid-shelf wave buoy observations along the Southeast Australian Shelf (SEAS). Five synoptic-scale wave climates exist during winter, and six during summer. These can be clustered into easterly (Tradewind), south-easterly (Tasman Sea) and southerly (Southern Ocean) wave types, each with distinct wave power signatures. We show that a southerly shift in the STR and trade-wind zone, consistent with an observed poleward expansion of the tropics, forces an increase in the total wave energy flux in winter for the central New South Wales shelf of 1.9 GJ m^{-1} wave-crest-length for 1° southerly shift in the STR, and a reduction of similar magnitude (approximately 1.8 GJ m^{-1}) during summer. In both seasons there is an anti-clockwise rotation of wave power towards the east and south-east at the expense of southerly waves. Reduced obliquity of constructive wave power would promote a general disruption to northward alongshore sediment transport, with the cross-shore component becoming increasingly prevalent. Results are of global relevance to sub-tropical east coasts where the modal wave climate is influenced by the position of the zonal STR.

1. Introduction

Wave climate change, rather than sea-level rise, is presently expected to be the dominant process impacting shoreline change on moderate- to high-energy sandy coastlines in the coming decades (Slott et al., 2006; Coelho et al., 2009; Hemer et al., 2012). It has long been realised that variations in the deep-water ocean wave field directly modulate the power that forces the evolution of coastal morphology (e.g. Johnson, 1919). However, there remains a stronger research focus on sea-level rise (Nicholls et al., 2007) than studies on wave climate change globally, leading to only low confidence in projected changes (Hemer et al., 2013; Church et al., 2013).

Definition of wave climate and directional wave power is a key component in the fields of marine renewables (Hughes and Heap, 2010), shipping (Semedo et al., 2011), coastal and ocean engineering (Callaghan et al., 2008), marine ecology (Storlazzi et al., 2005) and coastal management (Nicholls et al., 2013). A wave climate can be defined simply as the long-term (a decade or more) statistical characteristics of the waves at any one location (Holthuijsen, 2007). Often, the bulk wave climate (seasonal to centennial) is composed of a number of wave types, originating from a range of synoptic weather systems that produce distinct surface wind-wave signatures.

The bulk wave climate will therefore comprise a mixture of wave types and distributions. Often it is desirable to decompose the wave climate into component groups – a process known as wave climate typing. For example, statistical or dynamical down-scaling of long-term offshore wave information is frequently required for coastal process or maritime engineering studies. The computational inefficiency of down-scaling all available data requires that a small number of representative sea states are determined, which are later propagated to shallow water (Camus et al., 2011a).

Wave climate typing can be approached either synoptically or statistically. Basic synoptic typing of wave climates was first proposed by Munk and Traylor (1947). This has since evolved towards

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http://dx.doi.org/10.1016/j.csr.2015.02.007
0278-4343/

the identification of dominant patterns of synoptic-scale weather systems based on large-scale synoptic evolution and atmospheric pressure gradients (Browning and Goodwin, 2013; Goodwin et al., submitted), or using Empirical Orthogonal Functions (EOF) of mean sea level pressure (MSLP) fields (Speer et al., 2009; Hemer et al., 2008).

A limitation of EOF analysis applied to climate data, is that it is often difficult to attribute specific synoptic conditions or mechanisms to the orthogonal datasets. Even in cases where EOFs adequately explain weather pattern variance, multiple synoptic types will not necessarily produce statistically dissimilar wave climates, but rather characterise the different synoptic evolution of wave generation. Moreover, EOF analyses will typically discard a large portion of the original dataset not described by the primary EOFs.

An alternative approach is statistical typing of parametric wave data. This involves the decomposition of a continuous wave timeseries without explicitly linking the wave types to their synoptic generation source. A major advantage of statistical typing is that 100% of the variance in the geophysical dataset is used. The most common approach is to define the empirical joint probability density function (PDF) of wave height and period for a given directional bin, and to visualise the results using two-dimensional histograms (Holthuijsen, 2007). The draw-back to this method is the subjectivity with which the position and width of directional bins are chosen. Unsuitable directional bins may split a wave climate in two, or merge adjacent wave climates. In addition, transient wave generation often results in the tails of the distribution being mixed with those of their neighbours.

An alternative statistical approach is to use clustering algorithms to obtain a wave typology. Clustering aims to group multivariate wave data into n number of classes ('wave climates') in an optimised manner such that dissimilarity between cluster groups is maximised. Cluster models such as K-means, Partitioning Around Medoids (PAM), Self-Organised Mapping (SOM) and Maximum Dissimilarity are currently the principle algorithms used to characterise wave climates for coastal engineering applications (Hamilton, 2010; Camus et al., 2011a, 2011b; Guanche et al., 2013). Alternatively, Camus et al. (2014) have shown that clustering of hindcast MSLP fields (rather than direct clustering of a wave timeseries) can yield accurate wave climate types, by relating the clusters to sea states based on linear regressions built between MSLP and dynamical ocean wave hindcasts.

The principle disadvantage of wave cluster analysis is that the optimal number of wave clusters, k, is unknown. For open coast examples, where there is a clear distinction between far-field swells and localised wind-sea, clustering is often visually discernible from plotting. In these cases k can be estimated and fitted to a cluster model of choice. Western Australia (Masselink and Pattiaratchi, 2001), Southern California (Storlazzi and Wingfield, 2005) and the Iberian Peninsula (Camus et al., 2011b; Guanche et al., 2013) are all global open coast examples where the number of wave climates have been visually determined for conceptual or statistical description.

In semi-enclosed sea environments the distinction between wave climates is not so clear. The complexity of discerning between fetch-limited sea and swell in these environments has been acknowledged by authors in the North Sea (Boukhanovsky et al., 2007), Gulf of Mexico (Wang and Hwang, 2001), and Mediterranean Sea (Alomar et al., 2014).

The Tasman Sea is open to the north and south, borders the east coast of Australia, and is partially blocked from the Southwest Pacific Ocean by the New Zealand landmass (Fig. 1). It extends from the mid latitudes to where it meets the Coral Sea in the north, at approximately 30°S (IHO, 1953). Waves propagating in water depths exceeding 5000 m in the Tasman Sea rapidly shoal to

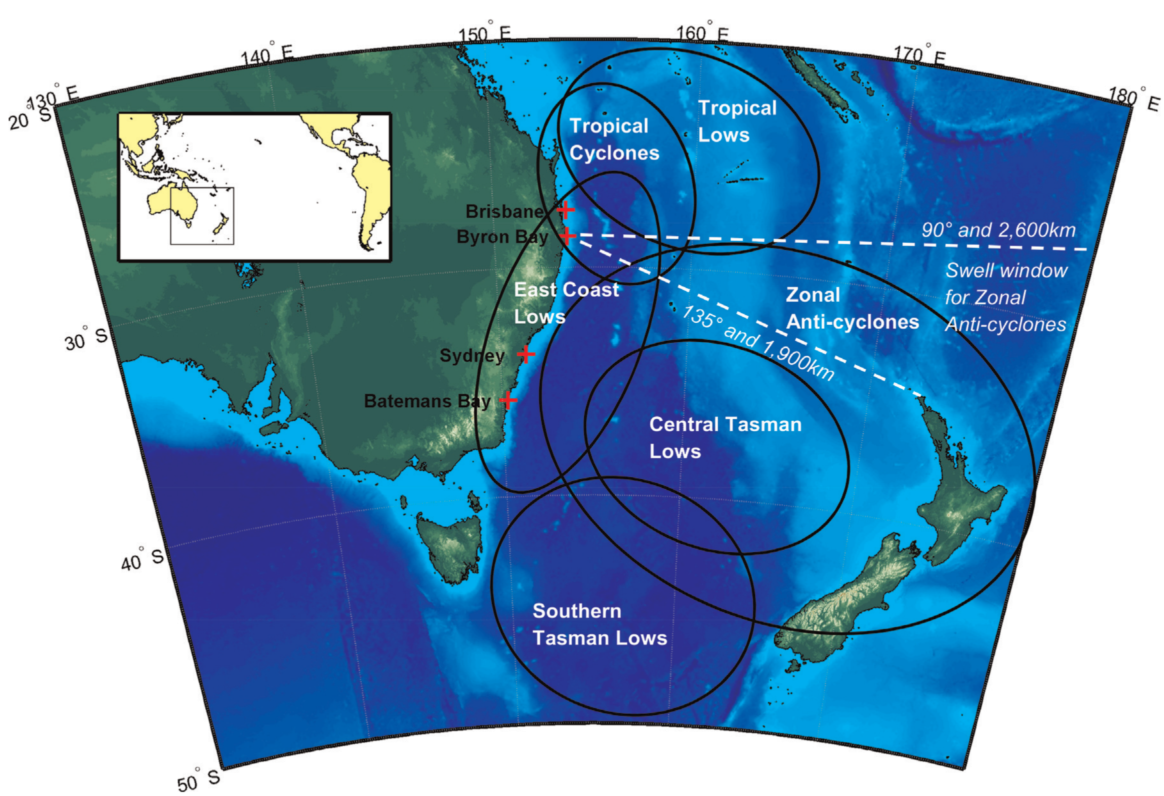

Fig. 1. Approximate area of influence of wave-producing meteorological types in the Tasman and Coral Seas, based on work by Short and Trenaman (1992) and Shand et al. (2011a). Also shown is the potential swell window for zonal anti-cyclones outside the Tasman Sea. Inset shows position of study area in relation to Pacific Basin. ETOPO01 imagery courtesy of NOAA (Amante and Eakins, 2009).