



Variability and trends in the Australian wave climate and consequent coastal vulnerability.

M. A. Hemer¹, K. McInnes¹, J. A. Church¹, J. O'Grady¹, & J. R. Hunter².
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² Antarctic Climate and Ecosystems Co-operative Research Centre

Final Report for Department of Climate Change
Surface Ocean Wave Variability Project

EXECUTIVE SUMMARY

Changing wind systems projected to occur with climate change will have the effect of altering the surface ocean wave energy felt on Australia's coasts. These changes must be quantified in order to assess the ocean wave resources available for renewable wave energy generation, and to enable coastal managers and researchers to determine how any changes will impact on Australia's coastal infrastructure and environment.

The Department of Climate Change and CSIRO Wealth from Oceans National Research Flagship funded this study to describe Australia's ocean wave climate and identify the trends and year-to-year changes in Australia's offshore wave climate, including an estimate of the range of the extremes.

Possible impacts of changing ocean waves in the coastal zone are:

- coastal inundation during severe storm events through the combined effects of sea-level rise, storm surge, and ocean waves.
- chronic coastal erosion brought about by large wave events, or changes in wave direction shifting coastal sand and sediment
- sea-bed disturbance impacting sub-tidal habitats.

The study has the effects of increasing our understanding of the potential impacts of these processes. Additionally, the study has quantified the wave power in Australian waters available for electricity generation, which has the potential to reduce emissions and reduce any negative impacts of climate change.

The study had four objectives:

- 1- Describe the mean wave conditions in the Australian region, (including season-to-season changes, and estimates of the extreme waves) by combining satellite, model and moored instrument data.
- 2 - To identify historical changes in the offshore wave climate, and in the intensity and frequency of extreme wave events, in the Australian region.
- 3 - To estimate historical changes in the intensity of waves reaching the coastline using regional wave models for selected regions.
- 4 - To develop new models to simulate the combined effects of surface waves and storm surges and test these simulations along the eastern Victorian coast.

Historical changes in Australia's offshore ocean wave climate have been identified using available wave data in the region. Wave data is sourced from the network of Australian wave-rider buoys managed by State marine authorities, the Bureau of Meteorology, and industry, global and regional ocean wave models and satellite altimeter data.

This report assesses the year-to-year changes and trends of the offshore mean wave climate but due to a limited availability of waverider buoy data, wave climate in the Southern Hemisphere is best described using ocean-observing satellite sensors that measure wave height across hundreds of kilometres and global ocean wave models.

The satellite data span the period 1985 to present, with the exception of a two year gap in 1989-1991. Interannual variability and trends in the significant wave height are determined from the satellite altimeter record (1991 - present).

Analysis of this data shows significant wave heights in the Southern Ocean correlating closely with a regional atmospheric climate feature known as the Southern Annular Mode, particularly during the southern hemisphere autumn and winter months. There is also a correlation between altimeter-derived significant wave heights and the Southern Oscillation Index linked to El Niño and La Niña patterns in the Pacific basin. This is consistent with several previous studies.

Significant wave height, wave period and wave direction data are used to describe the waves, using archives from global wave models, in this case for the period 1980-2001. The study has identified linkages between the year-to-year changes of these variables and atmospheric climate drivers.. The dominant mode of variability during autumn and winter months is strongly correlated with the Southern Annular Mode. Similarly, wave direction along the southern and western coasts of Australia is observed to shift from westerly to southerly with the intensification of the Southern Ocean storm belt associated with the Southern Annular Mode. Along Australia's eastern coast, a similar rotation of wave direction is observed during El-Niño events, such that wave direction shifts from easterly to southerly.

Analysis of trends and variability in extreme wave events can be carried out using a variety of procedures. For this study, the variability of extremes is separated into temperate and tropical Australia.

This analysis concentrates on the variability of extreme wave events in temperate Australia. The Cape Sorell wave-rider buoy site, 10 kilometres west of Macquarie Harbour on Tasmania's west coast, was chosen as an indicator location for the variability of large wave events on Australia's southern margin.

Large waves were identified in the 20-year wave-rider buoy record and weather pressure types associated with these events were analysed using sea-level pressure records. The occurrence of these synoptic patterns over the full 45-50-year review were tallied as an indicator of the trends and changes in the occurrence of large wave events.

A significant percentage of wave events observed at Cape Sorell can be tracked between wave records along the full length of Australia's southern coastline. The positive trend in the frequency of observed weather events which lead to large wave events is therefore expected to apply to the whole southern margin.

The extreme wave climate of northern Australia is dominated by the occurrence of tropical cyclones. An increase in El-Niño years over the past two decades has effectively reduced the number of tropical cyclones influencing the north-east Australian coast. A recent study on cyclones on the north-west Australian shelf indicates that variability in the Southern Annular Mode explains part of the variability in cyclones forming off Western Australia, with a positive Southern Annular Mode anomaly producing favourable sea-surface temperature conditions for cyclone genesis and development in the region. The positive trend in the Southern Annular Mode over recent decades is a potential source of an increase in the number of cyclones in Western Australia over the same period.

Having establishing an understanding of the year-year changes and trends in the wave climate offshore, it is important to understand how this might impact on Australia's coastal zone. Effects of the offshore wave variability have not been previously documented in the coastal zone although this is not surprising given the scarcity of long-term shoreline monitoring programs in Australia.

As surface ocean waves propagate from the deep water zone towards the coast, they undergo a range of transformations (shoaling, refraction, diffraction, blocking by land, frictional losses and scouring at the sea-bed, depth-induced breaking etc).

As a consequence, the impact of a changing offshore wave climate is not always experienced at the coast. Some sections of coast may be more sensitive to changes in the offshore wave climate than others. This report demonstrates a capacity to identify coastal locations which are most susceptible to wave climate change.

The method is demonstrated in detail on a wave-dominated coastline at the southern tip of Yorke Peninsula, South Australia. It is demonstrated the coastal sections dominated by large waves are the most susceptible to wave climate change. This work has outlined how it would be possible to automate the procedure for the full length of the Australian coastline and identify regions most susceptible to wave damage.

The method will provide an additional data layer of value in all coastal vulnerability assessments. Such a layer would be of most use when overlaid with a geomorphological dataset, such as the nationally-consistent coastal GIS map, SMARTLINE mapping landforms, and soils and sediment types. The method is demonstrated for a considerable portion of the Australian coast (the full southern Australian margin), but further research is required in assessing the accuracy of the model for the larger domain.

Project Outcomes

Generated a climatology of offshore wave conditions (including estimates of the seasonal variability and extremes) in the Australian region by combining satellite altimeter, global wave model and wave-rider buoy data.

- The surface ocean wave climatology was developed from all available data, describing wave parameters significant wave height, mean wave period, and mean wave direction, and was presented in an accompanying report (*Hemer et al.*, 2007). The wave climatology developed as part of the project provided an intercomparison between available datasets, and shows a strong seasonal signal.
- Strongest seasonal variability of wave direction is observed in the tropical latitudes in response to the trade winds– monsoon season wind reversal.
- Wave directions in the Tasman Sea exhibit large amounts of seasonal variability, with a greater southerly component experienced during the Australian winter.
- Extreme wave conditions are greatest south of the Australian continent, associated with the passage of extra-tropical storms along Australia’s southern margin.

Identified historical changes in the offshore wave climate, and in the intensity and frequency of extreme wave events, in the Australian region.

- The principal mode of wave power variability is significantly correlated with the Southern Annular Mode Index. Positive Southern Annular Mode values are associated with increased wave heights and a southerly shift of the wave direction in the Southern Ocean.
- The relationship to the positive trending Mode appears to have led to trends in the wave climate along Australia’s southern margin, via increased frequency of large wave events of approximately four large wave events a year, increased wave heights, and anticlockwise rotation of wave direction in response to a southern shift in storm position.

- Variability of wave power in the Tasman and Coral Seas is significantly correlated with the Southern Oscillation Index. El-Niño events (negative SOI anomaly) are associated with a southerly shift of wave direction along Australia's eastern margin.
- Variability of wave power in Northern Australia is potentially related to variability in the length and strength of the Monsoon season.

To estimate historical changes in the intensity of waves reaching the near-shore environment using regional wave models for selected regions.

- Directional changes of the waves in the western Pacific Ocean has previously been shown to be of importance to sand transport along the south-eastern Australian margin via beach rotation processes.
- The directional variability of the wave energy flux of the Southern Ocean associated with the Southern Annular Mode is expected to be of importance to the wave-driven currents responsible for the transport of sand along coastal margins in the Southern Hemisphere, in particular those on the Southern and Western coastal margins of the Australian continent.
- However scarcity of available long-term shoreline monitoring sites or near-shore directional wave data in the affected regions has limited the analyses available to determine historical changes in the near-shore wave climate.
- To counteract the limited available shoreline data, a method has been devised to identify sections of Australia's coast which are best suited for observing wave climate change.
- Susceptible coasts to wave climate change are identified as those stretches of coast where cross-continental shelf wave transformations fail to dampen the variability observed in the offshore wave climate.
- The method is demonstrated in detail for a section of South Australian coast, and is applied in less detail for approximately one-half of Australia's coastline to demonstrate how the method can be applied over a large scale. This 'susceptibility-to-wave-climate change index' has the potential to be a valuable tool for future coastal vulnerability assessments.

To include a parameterisation of surface waves in storm surge models and test this parameterisation along the eastern Victorian coast.

- An analysis of available data along the eastern Victorian coast revealed that high wave events occurred under all wind directions where as storm surge occurred mainly under the influence of predominantly westerly winds with easterly winds often causing decreases in local sea level.
- Simulation of combined storm surge and surface ocean wave setup requires greater computing resources to simulate a larger range of meteorological events.

Recommendations

While this project has made considerable progress in understanding variability of the Australian surface ocean wave climate in the context of broader climate variability, impacts of a changing wave climate on the coastal zone remain poorly understood.

Key recommendations for further research include:

1. Downscaling of Australian wave climatology to include greater detail at a national scale. A fine resolution climatology will have applications to coastal vulnerability assessments, coastal engineering problems, and renewable ocean wave energy resource assessments.
2. Projections of climate-change driven variations in the offshore wave climate on a national scale, and determine the potential coastal response to these projections.
3. Further site specific analyses of historical wave data are required, particularly of extreme events, ideally after vulnerable sections of coast have been identified.
4. A network of long-term coastal observation sites should be established to enable future research identifying coastal response to climate variability and change.
5. Further research is required to test the wave and hydrodynamic models where detailed coastal data is available for validation and under a greater range of meteorological conditions.
6. A high resolution reanalysis model for Australia is needed to evaluate coastal extreme sea levels over a longer period.