CONTEXTUALISING THE RETURN PERIOD OF THE JUNE 2016 EAST COAST LOW: WAVES, WATER LEVELS AND EROSION

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Abstract

Domestic insurance for coastal hazards received media attention as a result of the dramatic coastal erosion affecting properties along the New South Wales coastline from the June 2016 East Coast Low. 'Actions of the sea' and 'coastal erosion' are generally not covered in domestic insurance policies, although oceanic inundation may be covered in certain situations such as joint occurrence with wind or flood related damage.

This recent storm event prompted an investigation of the Annual Recurrence Interval of such an event in terms of wave height and run-up in order to understand the ongoing risk of coastal properties to this hazard. Firstly, the nearshore waves and water levels associated with the event were hindcast in high resolution calibrated numerical models along the whole NSW coastline. The resulting wave parameters and storm tide estimates were used to calculate wave run-up levels, as well as coastal erosion potential at selected sites. A site inspection was undertaken at Narrabeen-Collaroy following the storm to identify in the vertical elevation of wave impact for validation. The results of this case study are compared back to the wider NSW analysis.

To contextualise the resulting coastal inundation and erosion against historical climatology, the nearshore impacts of a set of over 300 hindcast historical storms impacting the NSW coastline between 1970 and 2010 were subsequently calculated and the ARI of the June 2016 event approximated in terms of nearshore wave parameters, run-up levels and coastal erosion potential. The consequence of this risk assessment for domestic insurance is discussed from an industry context.

1. Introduction

Australia's domestic insurance market offers limited coverage in regards to 'actions of the sea', however, some brands may cover storm tide inundation if coincident with other damage attributable to the event (such as wind damage or rain ingress). Coastal (or oceanic) inundation is the temporary flooding of coastal land with water from the sea. It is a result of elevated oceanic water levels at the coast. Coastal water levels vary as a result of several processes operating over different spatial and temporal scales. These include: astronomical tides, storm surge, wave set-up and run-up. Coastal erosion is a distinct hazard from coastal inundation. Coastal erosion is the loss of coastal sediment in response to wave action and elevated water levels associated with energetic storm events. From an insurance perspective, it is important to distinguish between these hazards. Temporary flooding by sea water will cause different damage to a property compared to the erosion of land from beneath a structure. Coverage for coastal erosion is not available, since domestic insurance covers the structure and not the underlying land or land value.

East coast lows are low pressure cyclones occurring off the eastern coastline of Australia with the potential for rapid intensification, generating gale force winds, heavy rainfall, heavy sea and swells and some storm surge. They may form in a variety of synoptic situations, including embedded within an easterly low pressure trough, an inland trough low, a continental low, a southern Tasman low, a southern secondary low or from an ex-tropical cyclone (Shand et al. 2010). In terms of climatology, ECLs can occur throughout the year with more frequent occurrence in Autumn and Winter (http://www.bom.gov.au/nsw/sevwx/facts/ecl.shtml). They frequently develop in association with warm sea surface temperatures that form in some southward propagating eddies of the East Australian Current. For more information on ECLs, please refer to Speer et al. (2009), Browning and Goodwin (2013) and Pepler et al. (2016) and references therein.

A complex intense east coast low (ECL) system occurring from 4th to 6th June 2016 impacted southeastern Queensland, NSW, Victoria and Tasmania with severe winds, heavy rainfall and associated freshwater flooding, and high swell waves. Combined with the coincident king tide conditions, the storm resulted in significant coastal inundation and erosion.

An understanding of the relative severity of this event was required by the insurance industry, particularly in regards to its coastal inundation and erosion impact, in the context of the climatology of east coast low events impacting NSW.

This study firstly presents an overview of the event from analysis of measured datasets (Section 2), then a modelled hindcast of the event (Section 3). From the simulations and analysis, the likely nearshore coastal inundation associated with the event is calculated along the NSW coast. Further, the event is contextualised within the past climatology of NSW storm events (Section 4). A similar assessment of the coastal erosion impact of the event is also made at specific case study sites (Section 4).

2. Event Summary

The June 2016 ECL occurred as an upper atmospheric cold air mass over central Australia collided with a deep and extended easterly low pressure trough that formed along the very warm East Australia Current. The east coast low tracked southward along the NSW coastline from 4th to 6th June before impacting Victoria and Tasmania (Figure 1). The low had multiple low pressure centres, with one closer to the coast producing heavy rainfall and extreme winds, and another further offshore generating high northeasterly ocean swell that impacted the NSW coastline.

The event was characterised by heavy rainfall and strong winds along the east coast of Australia from SE Queensland to Tasmania, with in excess of 100 mm of rainfall affecting most of the east coast from SE Qld to Tasmania, and very high concentrations of rainfall in coastal pockets including the Gold Coast, NSW Northern Rivers, Sydney Basin and South Coast. Strong winds were experienced along the whole NSW coastline, with peak gusts exceeding gale force occurring along the central Hunter-Sydney-Illawarra coastline (Table 1). The peak wind direction was east-northeast to north-northeast along the NSW coastline. Low atmospheric pressures were also recorded at all coastal centres, some more typical of tropical cyclones than midlatitude systems: 993 hPa at Narrabeen, 989 hPa at Currarong Creek, Jervis Bay, and 991 hPa at Tuross Heads, South Coast (source: MHL). These contributed to the elevated ocean water levels through the inverse barometric effect.

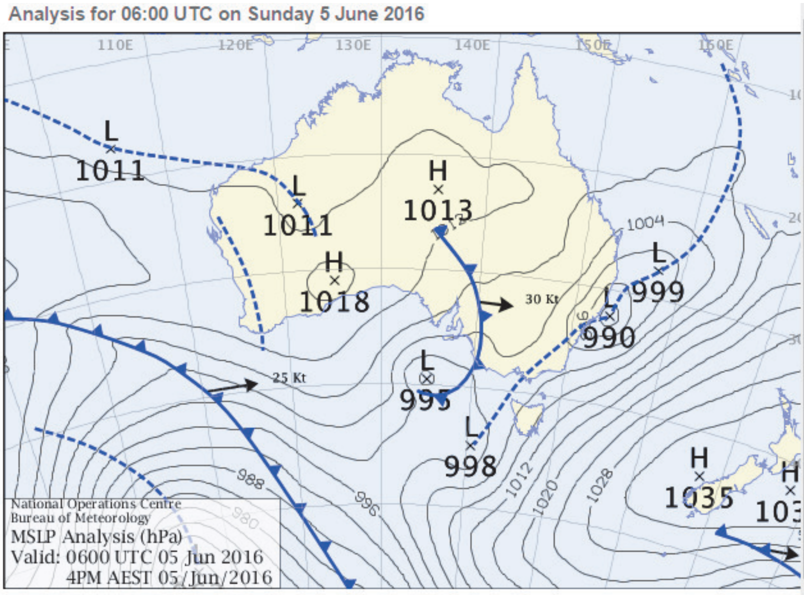


Figure 1. Synoptic chart showing the dual low pressure centres of the east coast low southward along the eastern Australian seabord, 5th June 2016 (BOM).

Table 1. Summary of weekly rainfall, daily peak winds and minimum atmospheric pressure occurring in the June 2016 East Coast Low along the NSW coastline (source: BOM).

Site	Weekly Cumulative Rainfall (mm)	Max Wind Gust (km/h) (Direction)	Mean Surface Level Pressure (hPa)
Tweed Heads	438	78 (ENE)*	996.6*
Ballina	272	91 (ENE)	996.3
Coffs Harbour	263	85 (NE)	993.7
Port Macquarie	121	78 (NNE)	991.6
Foster	217	67 (NE)	-
Newcastle (Nobbys)	138	106 (ENE)	995.5**
Sydney Airport	236	98 (NE)	996.3
Wollongong	289	102 (ENE)	997.6
Batemans Bay	265	80 (ENE)***	996.3***
Bega	298	76 (NE)	997.4

*Coolangatta station ** Norah Head station *** Moruya Airport

The June 2016 ECL event was notable for its coastal inundation and erosion impacts along the NSW coast, comparable in some locations to the design May 1974 ECL event which also occurred on a king tide. However, the impacts of the 2016 event were not as widespread, instead isolated to specific coastal locations typically facing east to northeast. While the deepwater wave heights in the June 2016 event were lower than the 1974 event, the unique aspect of the June 2016 event was the persistent wind and wave direction from the northeastern quadrant, causing high wave conditions in northerly facing bays which do not frequently experience such wave conditions. High swells and coastal water levels (including residuals) exceeding Highest Astronomical Tide (HAT) were observed from SE Qld to Eden in southern NSW as the event coincided with winter king tides.

The peak water level occurred on the high tide of the evening of the 5th June for most sites. Elevated water levels persisted for three consecutive tide cycles. The storm surge at the time of the peak ocean water level ranged from 0.17 m to 0.43 m (Table 2, Figure 2), and was 0.2 m in Sydney (the 0.68 m value for Ulladulla is discounted as this harbour is known for seiching). In context of the long term measured water level record, the tidal residuals measured in the 2016 event are not particularly exceptional, with an

ARI of <5 years at most sites, ~20 years at Batemans Bay, ~10 years at Coffs Harbour, and 7 years at Port Macquarie (MHL, 2010), In comparison, the largest recorded tidal residual on record of 0.59 m at Fort Dennison occurred during the May 1974 event (Watson 2009), producing a peak water level of 1.475 m AHD.

Table 2. Peak ocean water levels and storm surge occurring in the June 2016 East Coast Low along the NSW coastline (data source: MHL).

Site	Peak Water Level (m AHD)	Predicted Tide at Peak Water Level (m AHD)	Residual at Peak Water Level (m AHD)	Time of Peak Water Level (AEST)	Peak Tidal Residual (m)	Time of Peak Storm Surge (AEST)
Ballina	1.40	1.09	0.31	5/06/2016 20:30	0.42	5/06/2016 15:45
Yamba	1.22	1.05	0.17	5/06/2016 20:15	0.39	5/06/2016 11:30
Coffs Harbour	1.57	1.13	0.43	4/06/2016 19:15	0.48	5/06/2016 2:00
Port Macquarie	1.39	0.97	0.43	5/06/2016 20:30	0.75	5/06/2016 13:30
Crowdy Head	1.42	1.10	0.33	5/06/2016 20:00	0.56	5/06/2016 9:00
Shoal Bay	1.30	1.07	0.24	5/06/2016 21:00	0.34	5/06/2016 13:15
Sydney	1.29	1.08	0.20	5/06/2016 20:15	0.34	5/06/2016 13:45
Ulladulla	1.53	0.86	0.68	5/06/2016 20:15	0.68	5/06/2016 20:15
Batemans Bay	1.24	1.00	0.24	5/06/2016 20:30	0.56	6/06/2016 4:15
Eden	1.21	0.88	0.33	6/06/2016 21:45	0.42	6/06/2016 2:00

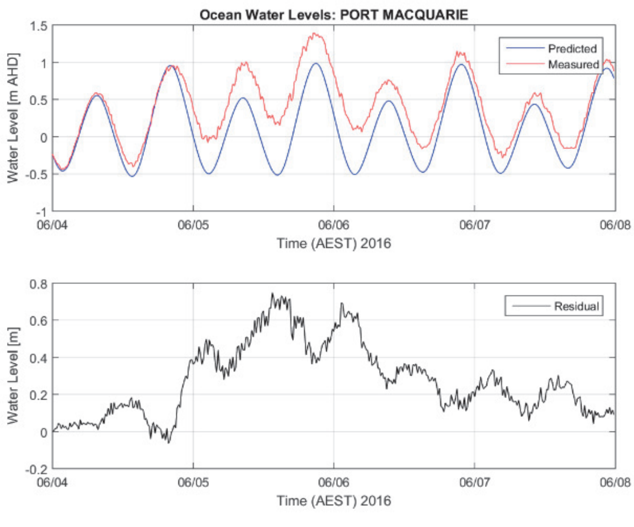


Figure 2. Measured water levels at NSW estuaries between 4th and 8th June 2016 at Port Macquarie, showing a clear storm surge signature (MHL).

The peak maximum wave heights during the June 2016 ECL event varied from 9.54 m in Byron Bay to 13.29 m at Crowdy Head (Table 3). The corresponding peak wave period ranged between 11.5 and 14.9 s. The long period waves generated over a long ocean fetch caused powerful wave impact on the beach face. The peak wave direction throughout the storm was persistently from the east to east-northeast, persisting for three to five days along the NSW coastline. The highest waves generally coincided with very high water levels, and several high tides occurred during the storm event.

In comparison with the non-directional design wave conditions for NSW derived from long term measured data published by Shand et al (2010), the event produced between a 1 and 10 year ARI wave height at all sites (excluding Eden where the buoy was adrift). The event equated to a place in the top 10 of measured events in terms of significant wave height for Coffs Harbour to Sydney (and likely Eden). However, the measured wave record does not capture a particularly stormy period in the mid-1970s. The east-to-northeasterly wave direction was unusual. The 10 year ARI northerly quadrant (0° to 90°) significant wave height was estimated by Shand et al. (2010) to be 4.3 to 4.6 m along the NSW coastline, and this event exceeded the largest ever recorded from this direction since directional measurements began in 1992. This signifies that a wave event of this magnitude from this quadrant has a long return period with implications for greater impacts at sites exposed to the northeast but not typically exposed to storm waves from the east to south.

Table 3. Measured peak wave parameters in deep water occurring in the June 2016 East Coast Low along the NSW coastline (data sources: MHL; NSW Ports).

Site	Peak Significant Wave Height (m)	Peak Maximum Wave Height (m)	Peak wave period @ peak Hs (s)	Peak Wave Direction @ peak Hs (octant)	Peak Water Level @ peak Hs (m AHD)
Byron Bay	5.04	9.54	12.93	E	2.00 (Ballina)
Coffs Harbour	6.52	10.99	11.45	ENE	2.03
Crowdy Head	6.62	13.29	12.14	E	1.87
Sydney (Long Reef)	6.52	12.01*	13.82	E	0.65
Sydney (Botany Bay)	7.20	12.90	14.80	E	0.65
Port Kembla	5.54	9.77	14.85	E	1.91**
Eden***	*8.49*	*17.67*	*16.04*	*ENE*	*Na*

* updated from preliminary **Sydney tide gauge *** buoy adrift

Coastal erosion and inundation associated with the June 2016 ECL event was reported along the whole NSW coastline. Coastal erosion was most notable in north-to-northeastward exposed beaches and bays due to the prevailing wind and wave conditions. Since the typical extreme wave climate for the NSW coastline originates from the south-to-southeast, a northeasterly storm exposes coastlines not typically exposed to such conditions. Coastal inundation of properties and council infrastructure was reported at locations including: Avoca, Narrabeen – Collaroy, Cronulla, Bundeena, Tarthra, and Pambula.

Coastal erosion during the June 2016 event was reported at locations spanning the NSW coastline, including Sandon (far north coast), Wamberal (central coast), Pearl Beach, Narrabeen – Collaroy, Kiama Harbour, and Guerilla Bay (Batemans Bay). At Kiama Harbour, the coastal foreshore walkway was destroyed (Figure 3 left). At the northward facing Guerilla Bay, erosion undermined trees that had been present for ~40 years (Figure 3 right), indicating that the coastal erosion experienced in these embayments was close to the largest on record. Notable erosion with impact upon residences occurred at Narrabeen-Collaroy on Sydney's northern beaches.

Figure 3. Beach erosion following the June 2016 ECL along the NSW coastline: Kiama Harbour (left) and Guerilla Bay (right), NSW South Coast. Photos: Mr R Burston (local resident), Mrs Penny Collings (local resident).

3. Event Hindcast

The coastal inundation and erosion potential of the June 2016 east coast low are estimated using simulated and measured data. Hindcasts of the event for waves and storm surge are discussed in Sections 3.1 and 3.2, and the subsequent coastal inundation and coastal erosion assessments are made in Sections 3.3 and 3.4.

3.1 Model Set-up

Hindcasts of the ocean waves and storm surge occurring in the June 2016 east coast low event were conducted using numerical models. Winds and atmospheric pressure fields from NOAA's Global Assimilation Data System (GDAS) were applied to the numerical models. The simulations were conducted from 12:00 3rd to 00:00 6th June 2016 UTC at 15 min time steps for waves and 5 min time steps for storm surge.

For ocean waves, the waves generated by the storm were simulated using the numerical modelling system established in WaveWatch-III v4.18 that is also used by Baird Australia to support wave forecasting and hazard assessment for the NSW government. WaveWatch-III (WW-III) is a full-spectral third-generation wind-wave model developed by the USA's National Center for Environmental Prediction (NCEP) (Tolman 2014). The model set-up and validation is described in Taylor et al. (2015) (Figure 4). For the storm surge simulation, the same local unstructured mesh was used in the hydrodynamic numerical model MIKE-21 by DHI in 2D-depth integrated mode.

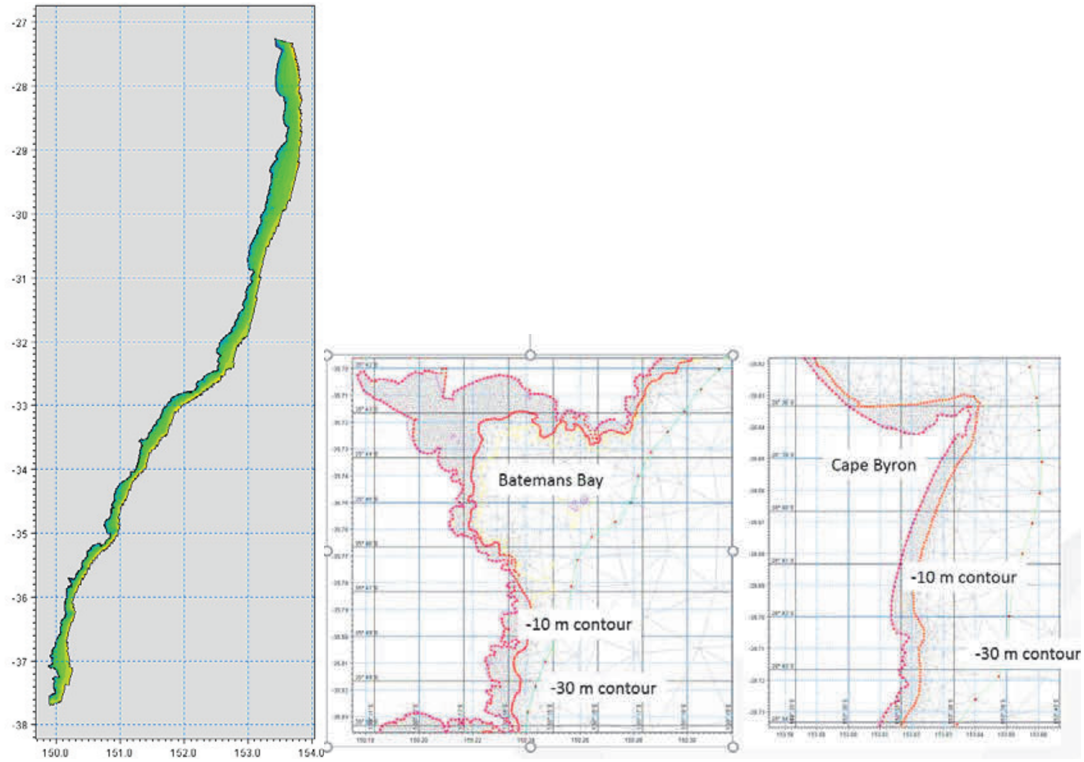


Figure 4. (left) Extents of the NSW-wide nearshore wave unstructured mesh and (right) close-up showing resolution of elements at Batemans Bay and Byron Bay.

3.2 Model Results

The WW-III model results generally compare well with the deepwater wave buoy measurements (Figure 5), with some overestimation of the peak wave height by approximately 10 % at most sites, indicating that the modelled offshore winds were likely too strong. The wave period and direction compare well between modelled and measured. Higher significant wave heights of up to 7.2 m were measured at the NSW Ports buoy off Botany Bay than the Longreef buoy operated by Manly Hydraulics Laboratory. A sample nearshore time series of wave for Collaroy in Figure 6 shows refraction to an easterly wave direction and a peak nearshore wave height of approximately 5 m. The peak wave parameters at each coastal output point are shown in Figure 7, with the peak nearshore wave height exceeding 5 m all along the NSW coastline, peaking at 8.5 m just north of Eden and around Jervis Bay on the south coast. Other areas with high wave heights include: the mid north coast, on the open coast around Port Stephens, the southern beaches of Sydney and the Illawarra and south of Batemans Bay.

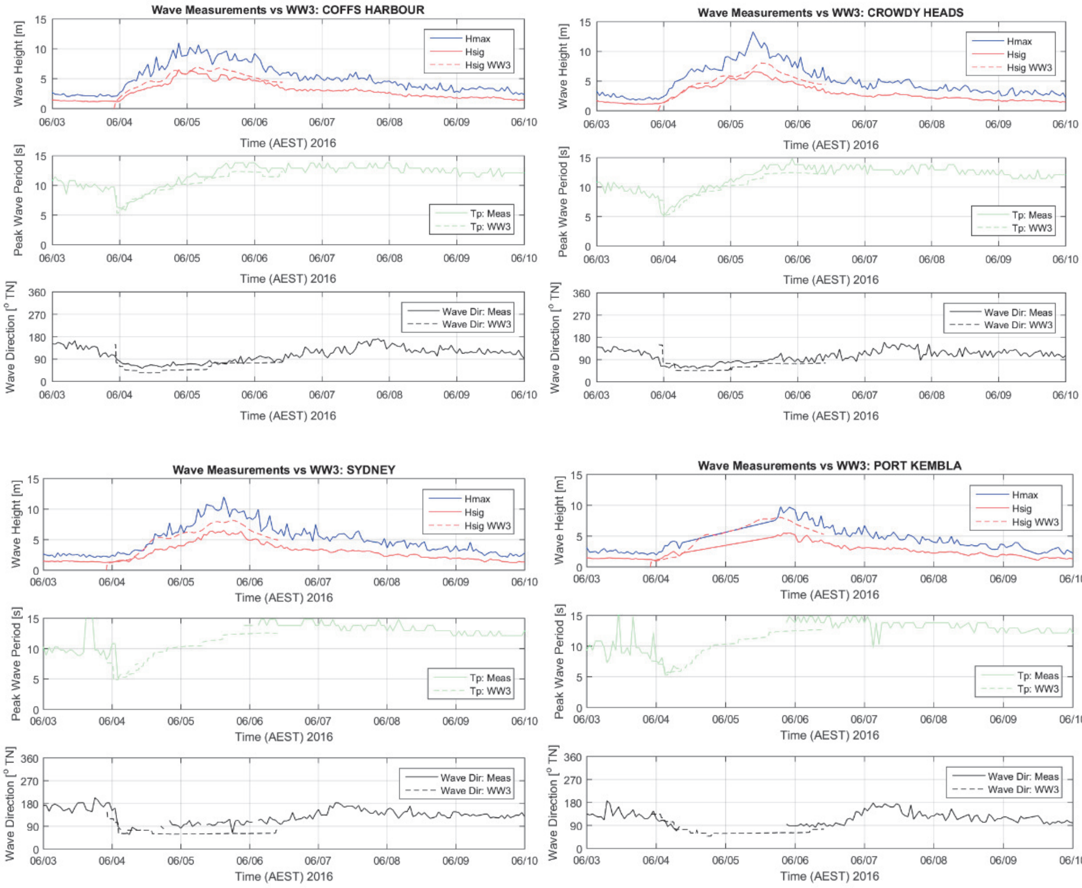


Figure 5. Modelled vs measured wave parameters at selected NSW offshore wave buoys between 4th and 9th June 2016 (measurements: MHL).

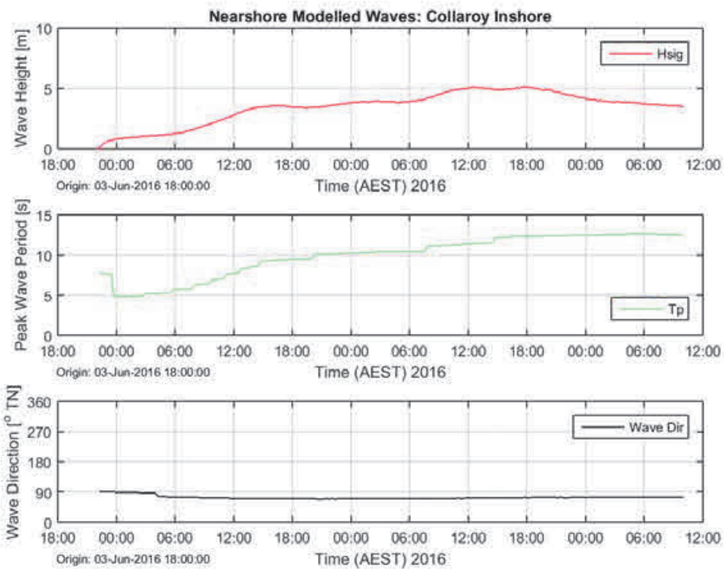


Figure 6. Nearshore modelled wave time series for Collaroy from WW3 simulation.

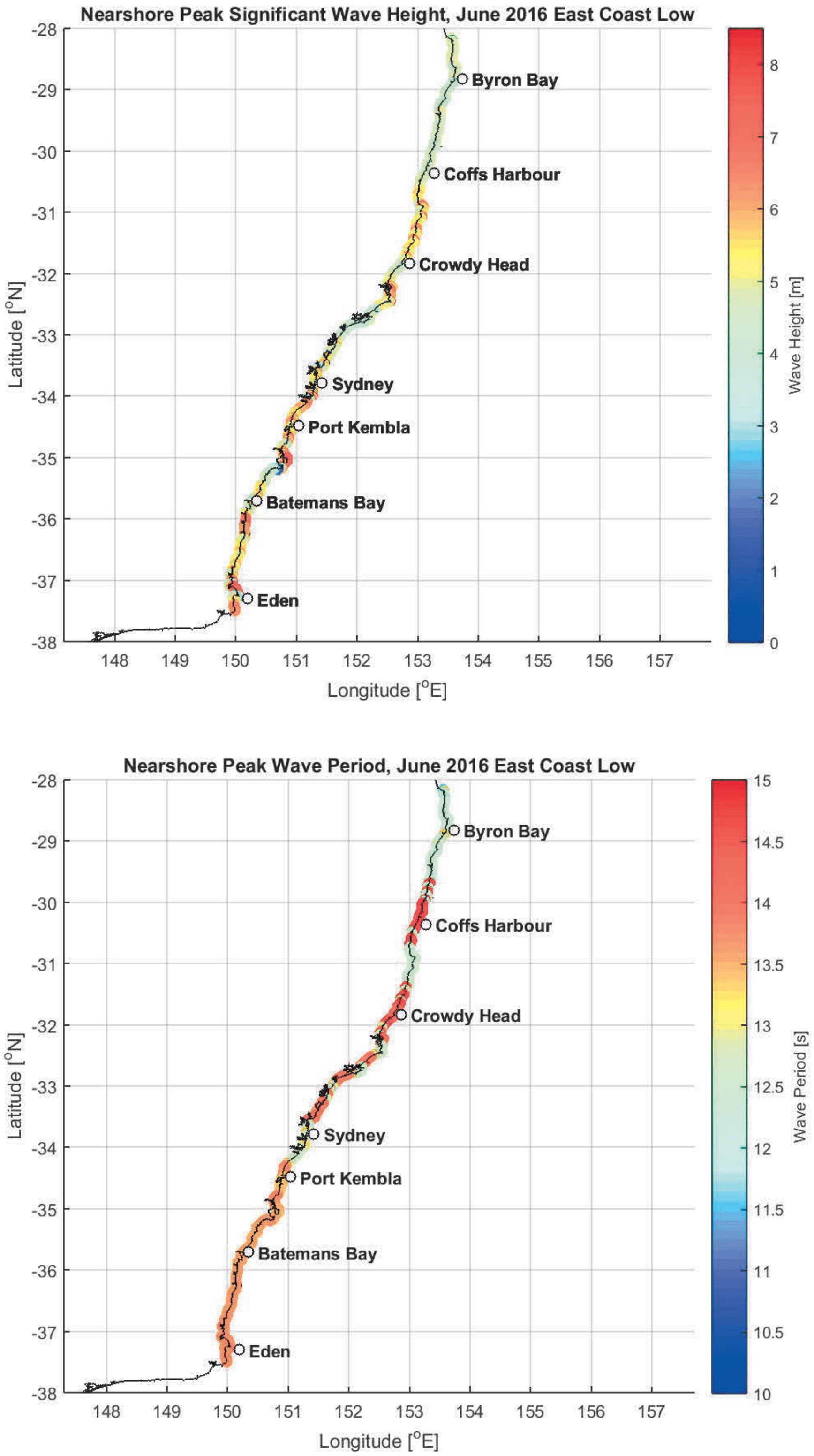


Figure 7. Modelled nearshore peak wave parameters for the June 2016 East Coast Low: (left) Significant wave height and (right) Wave period.

The results of the storm surge simulation showed good agreement with measured peak tidal residuals in the south of the state (from Sydney to Eden), but did not produce satisfactory results in comparison with measurements in the north of the state where the measured tidal residual exceeded 0.4 m from Tweed Heads to Crowdy Head (Figure 8). This poor comparison is attributed to insufficient representation of the nearshore winds by the global assimilation model (i.e., the peak of the modelled winds was positioned too far offshore). In light of the poor comparison for the modelled storm surge, the tidal residual water level measurements for seven tide gauges were interpolated to each of the coastal output points to estimate the coastal water levels for the June 2016 east coast low.

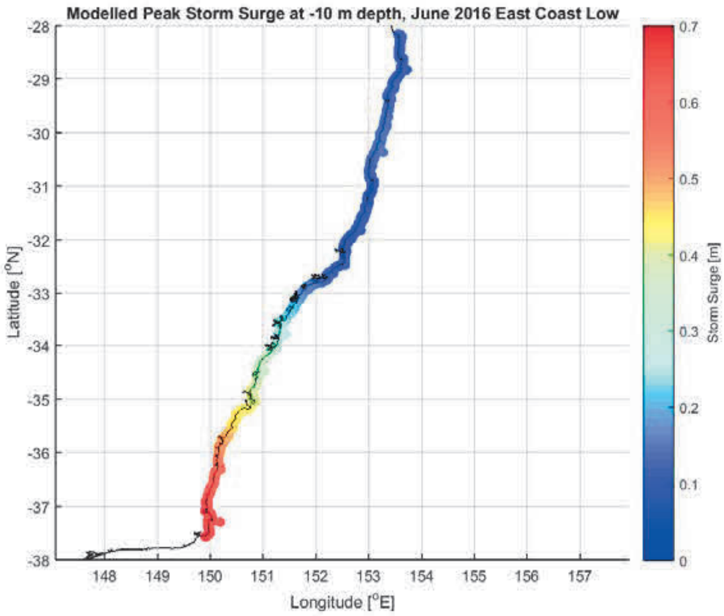


Figure 8. Modelled nearshore peak storm surge for the June 2016 East Coast Low.

3.3 Coastal Inundation Assessment

The peak coastal water level for open beach locations (i.e. those exposed to ocean wave action) along the NSW coastline during the June 2016 east coast low was computed as the sum of the predicted tide, measured tidal residual and wave run-up (as given by the empirical equations of Nielsen and Hanslow (1991)) (Figure 9). The peak coastal water level ranged from 1.9 m AHD to 5.0 m AHD along the NSW coastline, and generally ranged above 3.5 m AHD except in embayed locations or on the southern lee of headlands. The highest coastal water levels exhibited a similar spatial pattern to wave height, just north of Eden and around Jervis Bay on the south coast. On the mid north coast, on the open coast around Port Stephens, the southern beaches of Sydney and the Illawarra and south of Batemans Bay.

In comparison with field observations, Baird Australia observed wave run-up and overtopping to a level of between 5.5 and 8.0 m AHD at Collaroy in the worst-affected locations due to the June 2016 East Coast Low. This higher level is due to the variability in beach face slope: wave run-up increases significantly in elevation with increased beach slope that often occurs with a highly eroded beach. The variation in beach slope throughout the state is not available for analysis in this study. The coastal inundation levels computed here are all with respect to an average 0.1 beach slope and hence give a good relative value of exposure along the coastline. Local inundation and overtopping at any given location can vary from the computed value. The wave run-up calculations depend on the slope of the beachface, but the beachface slope is an unknown quantity in the current investigation, and it varies significantly both through time and alongshore. In this study, a value of 0.1 has been applied state-wide. This value represents the typical mean value for Narrabeen-Collaroy from long term breach profile measurements (Burston 2008). A scarping vertical slope causes higher runup, for example at Narrabeen-Collaroy actual run-up levels exceeded 6.5 m AHD.

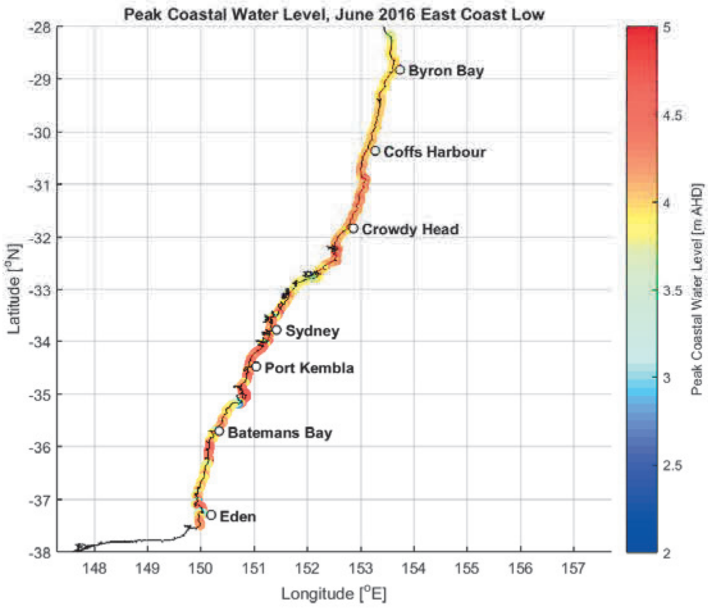


Figure 9. Estimated peak coastal water levels (run-up) (m AHD) for the June 2016 East Coast Low.

3.4 Coastal Erosion Assessment

In this study, change in shoreline position (i.e. movement of the 0 m AHD contour) is used as a proxy for coastal erosion. We investigate coastal erosion potential using an empirical formula of Davidson et al. (2013), which accounts for the nearshore wave power of the event and also the excursion of the shoreline position from its 'equilibrium' position. It uses the time series of nearshore wave conditions as input. This formulation was calibrated and validated for Narrabeen-Collaroy Beach using long term beach profile data, and has been found to well approximate coastal erosion at comparable open ocean sandy beaches (Davidson et al. 2013). For the June 2016 event, the shoreline change at Collaroy was estimated at -46 m, which accords well with reported observations. The state-wide coastal erosion assessment is presented as an 'Erosion Potential' (Figure 10). It shows variation in potential coastal erosion along the NSW coastline from -100 m to +3 m during the June 2016 east coast low event, with peak erosion potential on the open ocean beaches surrounding Jervis Bay, south of Batemans Bay, north of Eden and at Forster. These findings accord well with the field observations at Guerilla Bay and Kiama Harbour presented in Section 2. Some of the areas identified as having high erosion potential are actually rocky coastlines where wave heights are not attenuated close to shore, but such areas have limited erosion hazard.

While this erosion potential measure provides a reasonable relative estimate of the coastal erosion hazard of the event, it is not a good representation of the coastal erosion risk, as every beach will have a different tolerance for erosion depending on the availability of sand in the dune system, the buffer distance (set-back) behind the shoreline, the presence of coastal defences such as seawalls and vegetation. A future study may include reference to data on the local exposure of the coastline to erosion along the NSW coast, such as Lidar elevation data, shoreline type information, and cadastral overlays.

Assumptions made in the computation of the coastal erosion potential are:

a. Antecedent wave conditions defining the ‘equilibrium’ state of the beach are based on the average NSW wave climate (Hs = 1.6 m, Tp = 9.5 s).
b. The calibration coefficient values for the equations are based on central Narrabeen Beach.

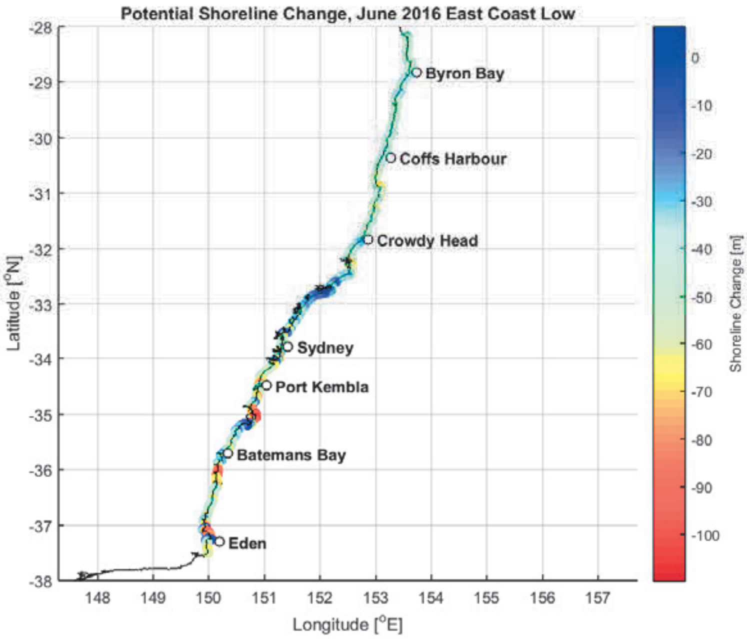


Figure 10. Estimated shoreline change potential (m) (negative = erosion, positive = accretion) for the June 2016 East Coast Low.

4. Event ARI Assessment

4.1 Approach

The coastal inundation resulting from the June 2016 east coast low event was contextualised within the climatology of storm events impacting the NSW coastline using a 46-year hindcast in WW-III using CFSR wind forcing, previously conducted over several studies for the NSW Office of Environment and Heritage (Kinsela 2014; Cardno 2012). The event set consists of 325 storms over this period.

The storm events occurring from 1970 to 2015 were selected based on generation of significant wave heights exceeding 4 m at one of the state’s offshore Waverider buoy locations. The deepwater wave results from the model simulations were transferred to the nearshore at 1 km spacing along the NSW coast (1332 points) using a parametric transfer developed for the NSW Government for such a purpose (Baird 2015).

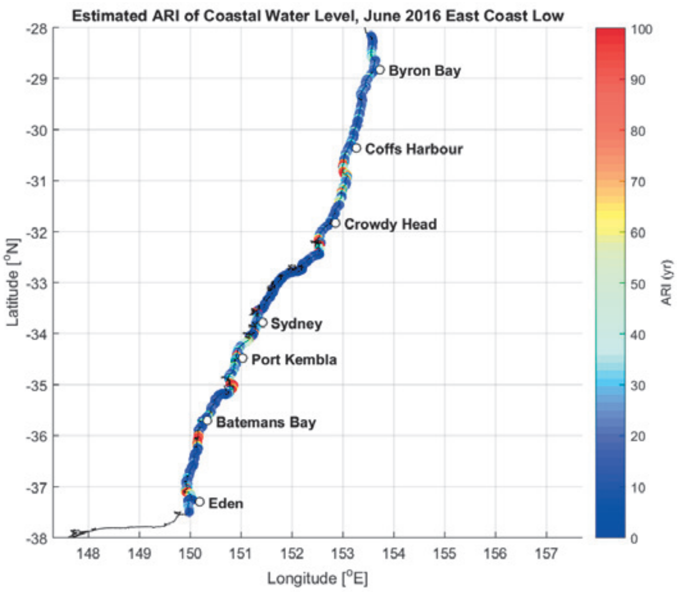
The Coastal Water Level (CWL) resulting from each storm event was calculated as the sum of the following components:

- Wave set-up and run-up were calculated using the empirical equations of Nielsen and Hanslow (1991) and an average beach slope of 0.1;
- The corresponding astronomical tide was predicted from tidal constituents for the closest port (NSW has a relatively uniform open coast tidal range of ~2 m from north to south); and
- The storm surge (tidal residual) was derived from measured water level data when available (approximately 1987 to 2005) (Burston 2008), and statistically estimated based on relationships between wave height and storm surge for storms without measured data.

Once the full event set of coastal inundation storms was compiled at the 1332 coastal output points, extreme value analysis was conducted to define the generalised extreme value curve for coastal inundation at each site. The coastal water level estimated for the June 2016 storm event (Section 3.3) were then contextualised within these curves in order to approximate the event's ARI. Further, the coastal erosion potential of the June 2016 east coast low derived in Section 3.4 was contexualised within the state-wide climatology using the same coastal erosion formulation as given in Section 3.4 applied to the 46 years of storm events. The computational expense restricted the analysis to 18 representative locations along the NSW coastline, corresponding to each of the waverider buoy sites and also the erosion 'hotspots' identified by the NSW government.

4.2 Coastal Inundation

The estimated ARI of the peak coastal water level of the June 2016 event along the NSW coastline based on the 46-year climatology is shown in Figure 11. The resulting estimate of the peak CWL ARI is quite variable along the coast: the event was particularly long return period for the Batemans Bay region. Otherwise, its ARI was only large for isolated locations, such as Forster, the Illawarra and surrounding Batemans Bay. Note that estimated ARIs greater than 200 years were capped to 200 years, and <1 year were capped to 1 year. As verification, the analysis shows that the June 2016 event produced the third largest nearshore wave height in the event set at Collaroy (after the May 1974 and June 1975 events) and the second largest Coastal Water Level after the May 1974 event, and the estimated ARI of the CWL was 56 years. This result accords with our observations and those of council engineers.



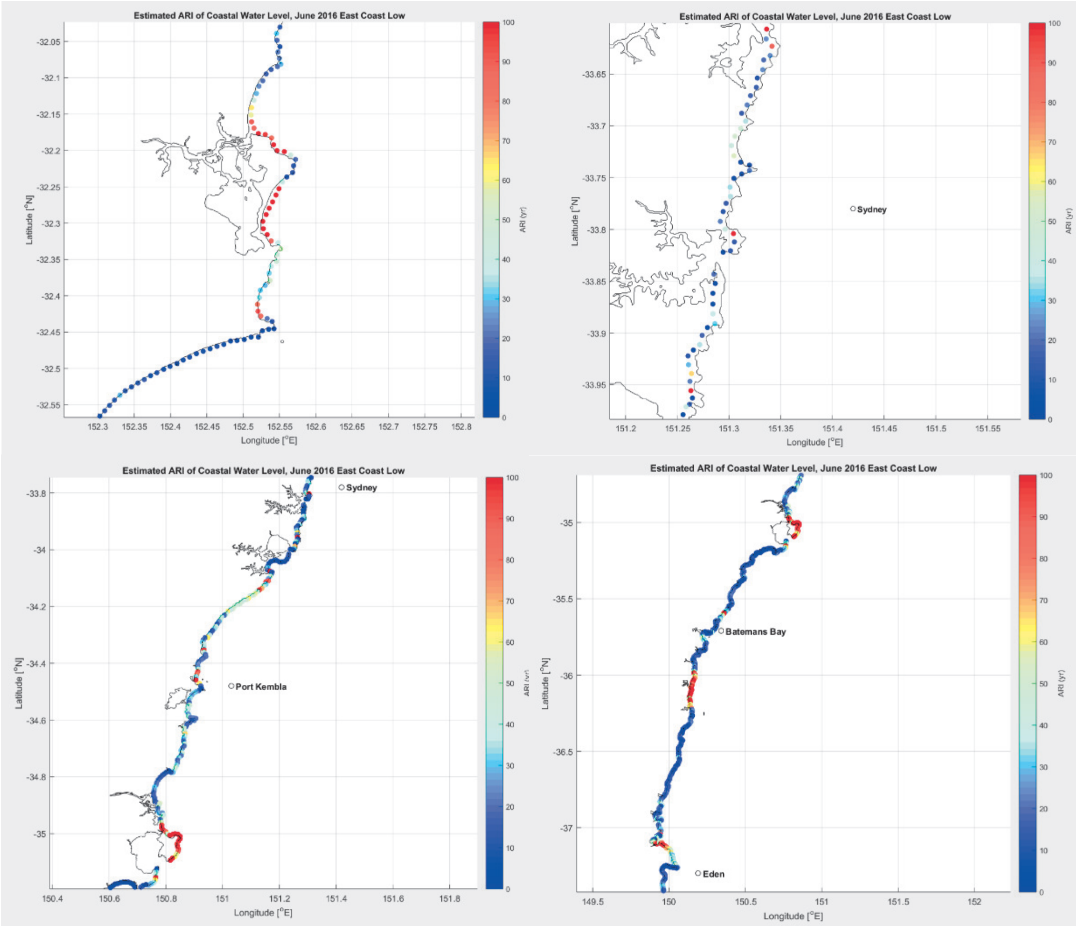


Figure 11. Estimated ARI (years) of the peak Coastal Water Level for the June 2016 East Coast Low, with close ups at Forster, Sydney, Port Kembla and Batemans Bay.

4.3 Coastal Erosion

The estimated ARI of the June 2016 event for indicative sites along the NSW coastline are shown in Figure 12. This calculation assumes impact on an open sandy beach with available reserves of sand in the beach and dune system for natural erosion to occur and no coastal protection works. The resultant ARI values between 1 and 30 years (most less than 5 years) indicate that this storm was not particularly severe in terms of coastal erosion potential at the assessed locations. The observed severe erosion at particular locations indicates the highly localised nature of coastal erosion hazard with strong dependence on wave direction.

In a validation exercise, this analysis showed the July 2016 erosion event at Collaroy was the 20th largest erosion event in terms of shoreline change potential at this site since 1970. The estimated ARI of the erosion at Collaroy is <5 years. Relative to the well documented historical record of erosion events at Collaroy, this result would appear to be an underestimation of its relative severity even though the shoreline change at Collaroy during the June 2016 erosion event was well estimated. This inconsistent result would be attributable to the fact that the erosion potential equation of Davidson et al. (2013) does not take into account elevated ocean water levels, only wave conditions. As found in Section 2, the wave conditions in the June 2016 east coast low event were <1:10 year ARI offshore, but it was the joint occurrence of the wave event with the elevated ocean water level (king tide plus storm surge) that allowed extreme erosion to take place, a situation that did not necessarily occur in all of the remaining top 20 erosion potential events identified in the hindcast. This is a limitation of the empirical equation.

Since formulating an updated formulation for erosion was beyond this scope of the study for which the analyses were completed, use of the coastal inundation ARI estimations as a proxy for coastal erosion for the June 2016 storm event was suggested as a reasonable approach. This is because coastal erosion is generated by the peak wave energy impacting above the elevated still water level, which is captured in the wave run-up formulation. Using the peak wave run-up as a proxy for erosion would not however capture the effect of storm duration on erosion potential.

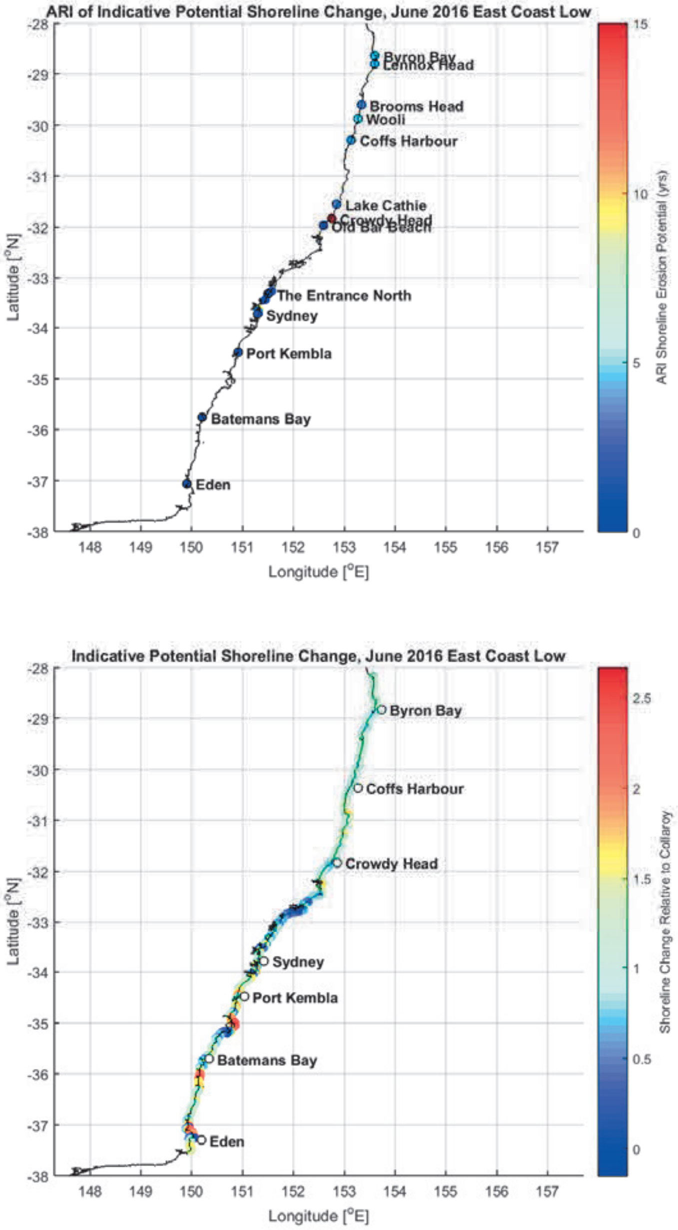


Figure 12. (upper) Estimated ARI (years) of coastal erosion and (lower) shoreline change potential relative to Collaroy for the June 2016 East Coast Low.

5. Summary

Although the June 2016 East Coast Low event produced some dramatic coastal inundation and erosion at selected locations, the analysis presented herein has demonstrated that the event was not particularly rare relative to NSW's storm climatology for most locations along the coastline. The waves impacting most locations were <10 year ARI in size, and the tidal residuals were also ~10 year ARI. The unusual northeasterly wind and wave direction of the storm exposed particular locations such as Collaroy to higher waves than usually experienced, and hence greater coastal erosion. The very localised nature of coastal inundation and erosion hazard was highlighted in this study, despite the storm having impact along the entire length of the NSW coastline. The median ARI of the coastal inundation level along the NSW coastline was ~17 years, although this ranged spatially from <1 to >200 years. High return intervals indicate uncertainty in the shape of the extreme value distribution.

Aspects of the event that could be considered rare include its spatial extent in that it impacted the whole NSW coastline from north to south with high waves and extreme water levels and it occurred on a king tide. Storms do occur in the winter perigean (king) tides more often than random as storms are more likely to occur in early winter when the East Australian Current is still maintaining warmer ocean water temperatures.

Note that a bias in the storm climatology is likely in the north of the state (north of Newcastle) as the storm events prior to 1998 were selected based on wave records only available from the centre and south of the state. We expect that this bias may result in an underestimated storm population and hence slightly overestimated ARI levels for northern NSW. Further, the far north of NSW is also exposed to tropical cyclone and ex-tropical cyclone events that may be key drivers of coastal inundation erosion hazard along this coastline.

This analysis proved valuable for the insurance industry in illustrating the coastal hazard presented by NSW's ECL climate and has prompted further studies currently underway, including a multi-hazard East Coast Low stochastic risk assessment and an Australia-wide coastal erosion risk assessment.

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