briefing note
423
July 2020

How many storms make a big storm?

Thomas Mortlock and Stuart Browning

The past few weeks have not been pleasant for beachfront property owners at Terrigal-Wamberal (see Figure 1), and worrisome for those with a sea view at other erosion "hot-spots" on the east coast, such as Collaroy-Narrabeen and Belongil. Beyond the difficult questions around coastal development and defence that this has raised (again), the passage of two East Coast Low (ECL) storms in quick succession, with a series of low pressure cells still lurking in the Tasman Sea, has highlighted another important issue for coastal hazard assessment. That is, of storm clustering, the resulting cumulative risk, and how we should be doing more to incorporate this additional dimension into the assessment of coastal risk.

Figure 1. Erosion at Wamberal, on the NSW Central Coast, July 2020. Source: Daily Telegraph, 28 July 2020.

What happened in July?

In a period of less than three weeks – from the week beginning 13 July to week ending 31 July – two successive ECL storms impacted the southeast coast of Australia bringing heavy rain, large waves and dangerous surf conditions to many areas including much of the Illawarra, Sydney and Central Coast regions.

The first (week beginning 13 July) was a typical wintertime ECL, with an extra-tropical origin in the South Tasman Sea progressing northwards up the coast (Figure 2, left panel). The peak-storm hourly significant wave height (the highest third of all waves measured in an hour, and a common measure of storm intensity) was 6.9 m at the Sydney wave buoy (located approximately 10 km offshore of Narrabeen), while the maximum single wave recorded during the storm was 11.6 m (on Wednesday 15 July). The wave direction was from the south-south-east for much of the storm, until Friday 17 July when the direction swung round to the south-east. The storm wave height had a return period of about 4 years.

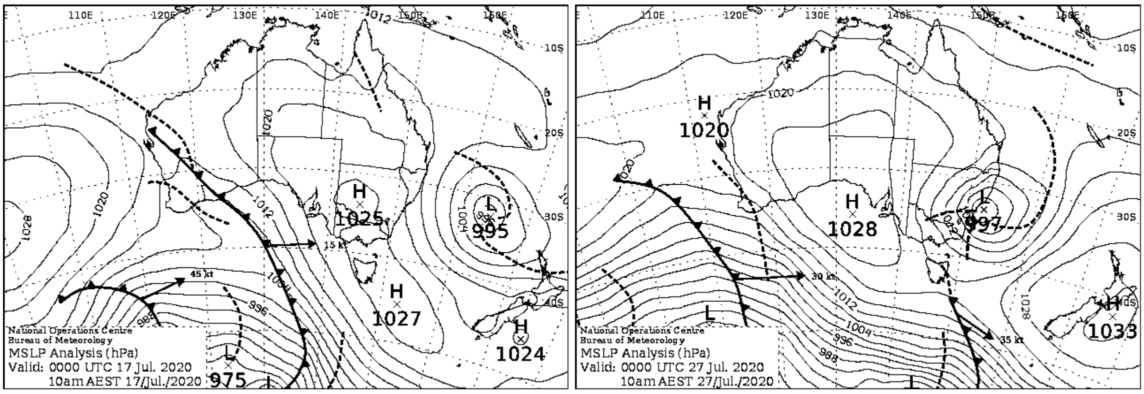

Figure 2. Left panel: synoptic chart for the first ECL on 17 July 2020 at 10 AM as the wave direction becomes southeast to easterly. ECL is moving in a northward direction. Right panel: synoptic setup for the second ECL exactly ten days later with wave directions from the northeast to east. ECL is moving in a southward direction. Source: Bureau of Meteorology Weather Map Archive (2020).

The genesis and track of the second ECL (week beginning 27 July) is less usual during winter, with a tropical origin in the Coral Sea progressing southwards down the coast (Figure 2, right panel). The peak-storm hourly significant wave height was 4.0 m at Sydney and the maximum single wave height recorded was 7.6 m – much smaller than the preceding ECL. This time, the wave direction was from the north-east for much of the storm, before eventually becoming bi-directional, with one mode from the north-east and a second from the south-south-east. As the storm decayed, the south-south-east mode became more prevalent. The storm wave height of the second event had a return period of less than 1 year, but the direction made it more significant (as was the case during the infamous June 2016 ECL, see Mortlock et al., 2017a).

Both storms led to significant erosion at some locations along the east coast, with perhaps the worst area affected being Wamberal, on the NSW Central Coast. The Terrigal-Wamberal embayment is oriented south-east (unlike most other coastal compartments in NSW which face east) making it more exposed to waves from the south-east and anticlockwise thereof. The south-easterly wave direction of the first ECL on Friday 17 July, combined with the morning high tide, is likely to have done most of the damage. The north-easterly direction of the second ECL, only ten days later, led to further erosion of the upper beach and foredune.

What drives ECL clustering?

An analysis of the drivers of Australian ECLs has shown that clustering has been a feature of all high impact ECL seasons since 1851 (Browning and Goodwin, 2016). Over this period, it was found that when the large-scale climate conditions were conducive to ECL formation it was likely that successive storms would occur. When this happened, they were often similar types of ECLs forming along similar storm tracks.

Climate conditions conducive to ECL formation may include a neutral to negative Indian Ocean Dipole (IOD) and neutral to La Niña-like ENSO conditions in the Pacific. Extratropical circulation, described by the Southern Annular Mode (SAM), influences the latitude of impacts: with central and northern NSW impacted under positive SAM and central to southern NSW impacted under negative SAM. All these climate states essentially promote convective behaviour in the vicinity of Southeast Australia.

Another observation is that ECL clustering occurs during a shift in the underlying Pacific climate, specifically the transition from Interdecadal Pacific Oscillation (IPO) El Niño to IPO La Niña (Hopkins and Holland, 1997). The IPO describes low frequency ENSO-like conditions in the Pacific that may persist for periods of years to decades and can either enhance or dampen the intensity of individual ENSO events.

Storm clustering and coastal risk

During an ECL, sediment is usually stripped from the upper beach and deposited seaward below the water line as a surf zone bar (Figure 3 top panel). If the water level is high enough (with a sufficient combination of waves, storm surge and high tides), the foredune may also be eroded, leading to dune instability.

After the storm, a process of beach recovery takes place on the order of weeks to months, whereby sediment is transported landward from the bar back to the beach. The wider the beach, the better the buffer for the dune (and anything built on top of it) when the next storm arrives.

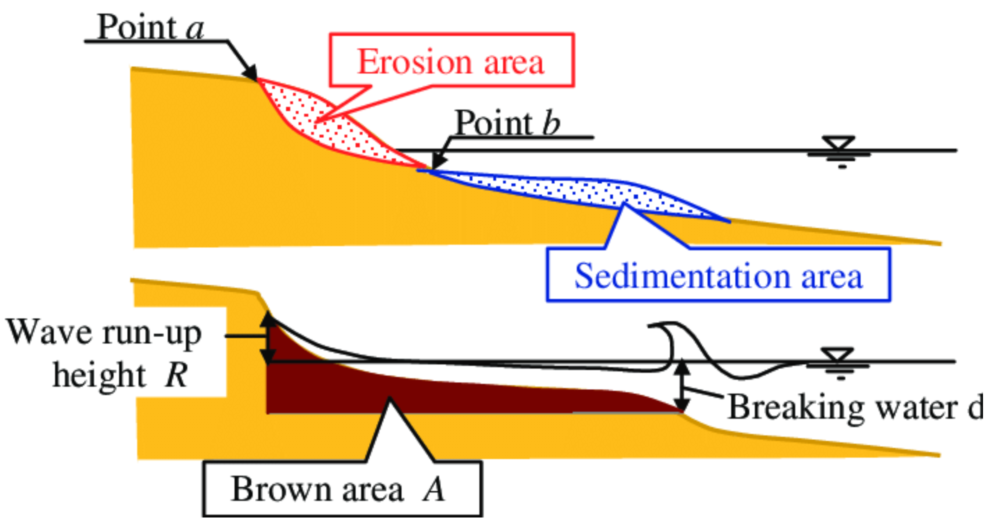

Figure 3. A cross-sectional beach profile showing simplified erosion during a storm event (top panel), and consequential depleted beach and higher water mark post-storm (bottom panel). Source: Yamamoto et al. (2012)

When a series of storm events occur in quick succession, there is no time for beach recovery. Each successive storm after the initial one thus erodes the beach from an already depleted state – similar in nature to a heavy rain event occurring on an already-saturated catchment. Because the beach is lower after the first storm, the high tide mark is further landward, making it easier for subsequent storm waves to erode the base of the dune (Figure 3 bottom panel).

It follows, therefore, that a series of low-magnitude storms in a cluster may have a comparable cumulative erosion impact as a single, higher-magnitude storm (assuming other characteristics, such as wave direction and storm duration, are the same).

It could be argued that a cluster of coastal storms should be regarded as a single event for erosion response, even if from an atmospheric perspective they are identifiably independent systems. In this case, it should be reflected in the return period estimate of coastal storms when wave height exceedance is being used as a metric to define erosion risk.

How many storms make a big storm?

To address this, we use a worked example:

If there were a pair of ECL events, separated less than one month apart (i.e. insufficient time for beach recovery), both with a nominal return period of 2 years, what would be the single-storm return period that delivers an equivalent amount of energy to the beach?

Using hourly wave height observations at the Sydney buoy from 1992 to 2019, the 2-year return period hourly significant wave height is approximately 6.2 m[1] (Figure 4, left panel).

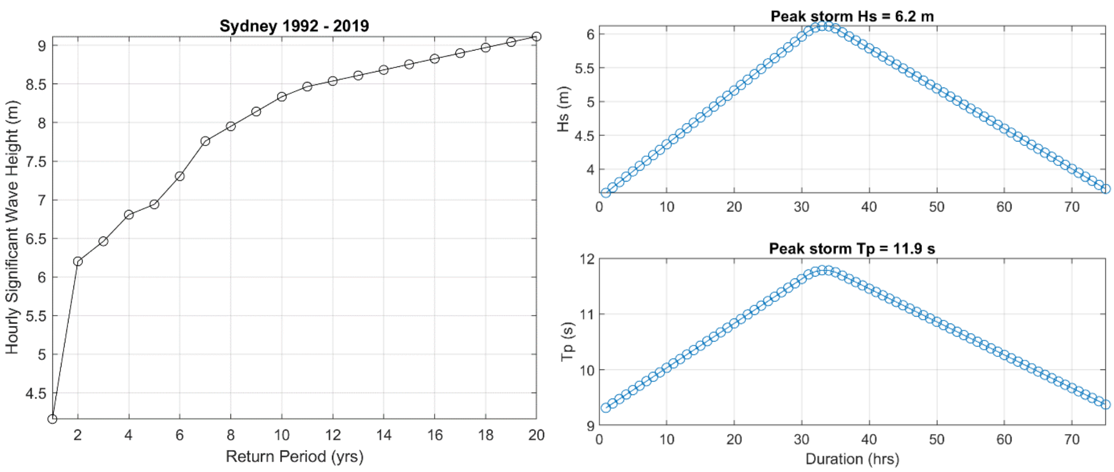

Figure 4. Left panel: return periods associated with wave heights at Sydney. Right panel: synthetic storm curve for the 2-year return period storm for wave height (top) and wave period (bottom). Hs = significant wave height, Tp = peak energy wave period. The Sydney wave buoy is maintained and operated by Manly Hydraulics Laboratory (MHL). Wave data are available on request from MHL.

[1] An empirical estimation of the return periods was used here, where the return period = number of years in dataset / rank. Wave heights were linearly interpolated to obtain estimates for whole number of years.

Using a method developed by Mortlock et al. (2017b)[2], we can take this peak-storm value to build a synthetic storm curve to estimate the total energy delivered to the beach during a storm of this magnitude (Figure 4, right panel, for a 2-year return period storm). Here we are assuming that the wave direction of both storms is the same.

From this, we can estimate the total wave energy flux of the storm. Wave energy flux is a measure of the total amount of power delivered by the storm along a metre length of beach[3], in Gigajoules per metre (GJ/m).

Using this approach, a 2-year return period storm contains approximately 41.2 GJ/m. This means that two of these storms occurring in quick succession have a combined energy of 82.4 GJ/m. Repeating this exercise for different return periods indicates that a pair of two ECL events, each with a nominal return period of 2 years, delivers an equivalent amount of energy to the beach as a single 8 to 9-year return period event (Figure 5, left panel).

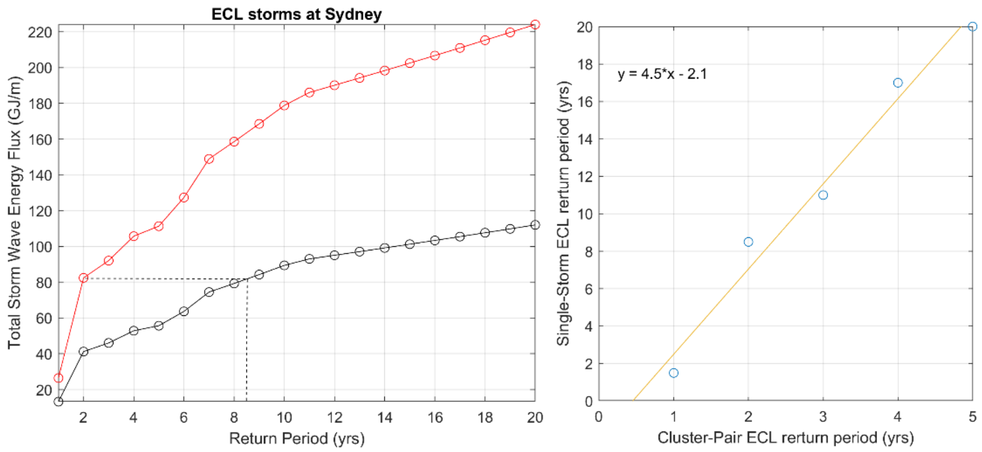

Figure 5. Left panel: return periods of total storm wave energy flux for ECLs at Sydney, for when storms are treated as individual events (black line), and in the case where two storms of similar magnitude occur in quick succession (red line). Right panel: the difference between the red and black curves in left panel, with linear fit.

If we take the view that these two hypothetical storms should be considered a single event for erosive potential – and absent beach recovery in between – then it shows that we underestimate the recurrence estimate of storm damage.

Taking the difference between return periods of equivalent energy between the cluster-pair ECLs (red curve Figure 5, left panel) and single-storm ECLs (black curve), we can illustrate the extent to which we are underestimating erosion frequency (Figure 5, right panel). Using this

[2] This is based on an analysis of observed storm events and accounts for the relationship between peak-storm wave height and wave period after Goda (2000) and modified by Shand et al. (2011). Storm duration is capped at 76 hours. All storms modelled here reached the duration cap.

[3] The formula for the calculation of total storm wave energy flux is given in full in Mortlock and Goodwin (2015). The water depth these values were calculated for was 20 m, which is prior to wave breaking.

approach, two 5-year ECLs occurring in quick succession may lead to erosion equivalent to a 20-year return period single ECL storm event.

Summary

In some years, there may be more potential for ECL occurrence and clustering, than in others. The winter of 2019 was quiescent for coastal storms on the east coast of Australia because of a very strong positive Indian Ocean Dipole (IOD). In 2020, a neutral IOD means climate variability on the east coast is driven more by what is happening in the Pacific, which appears to be tending towards La Niña, which typically allows for more convective low-pressure storms to develop. The point here is that for some years, it may be pertinent to consider the effects of ECL clustering for coastal risk assessment than for other years.

Using the method described above, we can estimate that the first ECL in July had a return period of four years and the second a return period of less than one year, but if treated as a single storm, the total energy was equivalent to the amount of erosive potential that could be expected of a single ECL of a return period of approximately seven years.

While this analysis is only for illustration, it demonstrates how there can be an under-estimation of coastal risk by assuming all ECLs drive independent erosion responses. If the cumulative erosion potential that exists with clustered ECL events is not incorporated into coastal hazard panning, then we may continue to under-appreciate the importance of event clustering.

References

Browning, S. and Goodwin, I.D. (2016). Large-scale drivers of Australian East Coast Cyclones since 1851. Journal of Southern Hemisphere Earth Systems Science, 66, 125–151.

Hopkins, L. C., and Holland, G. J. (1997). Australian heavy-rain days and associated east coast cyclones: 1958–92. Journal of Climate, 10, 621–635.

Goda, Y. (2010). Random seas and design of maritime structures. World Scientific, Singapore, pp 464.

Mortlock, T.R. and Goodwin, I.D. (2015). Directional Wave Climate and Power Variability along the Southeast Australian Shelf. Continental Shelf Dynamics, 98, 36-53.

Mortlock, T.R. et al. (2017a). The June 2016 Australian East Coast Low: Importance of Wave Direction for Coastal Erosion Assessment. Water, 9(2), 121.

Mortlock, T.R. et al. (2017b). Open Beaches Project 1A – Quantification of Regional Rates of Sand Supply to the NSW Coast: Numerical Modelling Report. A report prepared by Department of Environmental Sciences and Risk Frontiers, Macquarie University, for the SIMS-OEH Coastal Processes and Responses Node of the NSW Adaptation Research Hub, May 2017, pp 155.

Shand, T. et al. (2011). NSW coastal inundation hazard study: coastal storms and extreme waves. Water Research Laboratory, University of New South Wales & Climate Futures, Macquarie University.