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A national view of storm tide flooding in Australia

Thomas Mortlock

As the summer of 2020/21 fast approaches, the strengthening La Niña in the Pacific not only signals heightened flood risk along the east coast (Ward et al., 2014), but also the probability of above-average tropical cyclone activity (Kuleshov et al., 2008). Storm surge associated with tropical cyclones and extra-tropical storms such as East Coast Lows can cause significant damage to property and loss of life when they coincide with high tides. For example, during tropical cyclone Yasi in 2011 (which coincided with the last major La Niña event in Australia), a 5-metre storm tide (storm surge plus tide) was observed at Cardwell – 2.3 metres above the Highest Astronomical Tide. The Port of Hinchinbrook Marina was destroyed along with millions of dollars' worth of boats (Figure 1) and the Lucinda Bulk Sugar Terminal. Between Cairns and Townsville, damage was reported to roads, sea walls, buildings and vegetation, with significant beach erosion (BoM, 2020).

Recent updates to Risk Frontiers' Address-Based Risk Rating Database means that a risk rating for storm tide inundation, resulting from both tropical cyclones and extra-tropical storms, is now available for every address in Australia, for both present-day and future climate scenarios. This provides an up-to-date national view of storm tide flood risk for the first time since the National Coastal Risk Assessment looked at the impact of sea level rise (and, in some states, storm tide) in 2011 (DCCEE, 2011).

Figure 1. *Damage to boats at Hinchinbrook Marina in the aftermath of Yasi's storm surge. Source:* https://cyclone-yasi.weebly.com/settlements.html

Methods

Storm tide modelling is based on a long-term sea level hindcast (Pattiaratchi et al., 2018) combined with tropical cyclone storm tide exceedances generated in a study using Risk Frontiers' tropical cyclone wind loss model, CyclAUS (Haigh et al., 2014). Tidal attenuation and amplification of the open-coast tide in rivers and estuaries is accounted for after Hanslow et al. (2018). Storm tide flood depths are mapped onto the coast using high-resolution (5 m) digital elevation data and a hydraulic connectivity routine. Hazard data are intersected with Geocoded National Address File (G-NAF) information to estimate storm tide flood depths at the address level.

The present-day storm tide flood hazard is defined as the 1% Annual Exceedance Probability (AEP) combined tide and storm surge water depth. Relative rates of sea level rise from McInnes et al. (2015) are applied to the 1% AEP storm tide to model future changes to exposures under Representative Concentration Pathways (RCP) 2.6 (low emissions scenario) and 8.5 (high emissions scenario), for the 2030s, 2050s and 2090s. Here, sea level rise is regarded as the primary driver of future changes to storm tide risk; future changes to tropical cyclone and extra-tropical storm activity were not included. In this article, present day exposure is compared to changes modelled for RCP 2.6 and 8.5 by the 2090s.

Storm tide risk highest in Queensland

There are approximately 179,000 addresses at risk of the 1% AEP storm tide flood (i.e. properties that have a 1% probability of coastal flooding in any given year under current climate conditions) around Australia. This increases to around 243,000 (+ 36%) by the 2090s with sea level rise projected under a low emissions scenario (RCP 2.6) and 271,000 (+ 51%) under a high emissions scenario (RCP 8.5) (assuming present-day building stock and with no coastal defences in place).

This is comparable to earlier findings by the National Coastal Risk Assessment (DCCEE, 2011), which identified between 157,000 and 247,600 addresses potentially at risk of inundation by sea level rise by the end of the century. However, the DCCEE study did not include storm tide effects on a national basis and for this reason, exposure to coastal flooding is likely to have been underestimated. The increase in

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building stock over the past decade is likely to be another reason for the slightly lower numbers compared to this present study.

As shown in Figure 2, most of the present-day storm tide risk is concentrated in Queensland (almost two-thirds of the national total) and NSW (about one-fifth). The highest at-risk suburbs are located in the Gold Coast area, with almost 32,000 properties currently at risk of storm tide flooding (in Gold Coast, Palm Beach, South Stradbroke, Broadbeach and Southport) and an average increase of 60% in exposed addresses projected across these suburbs for the 2090s. In fact, nine of the top 10 at-risk postcodes in the country are found in Queensland (Mandurah in WA is ranked second, Table 1).

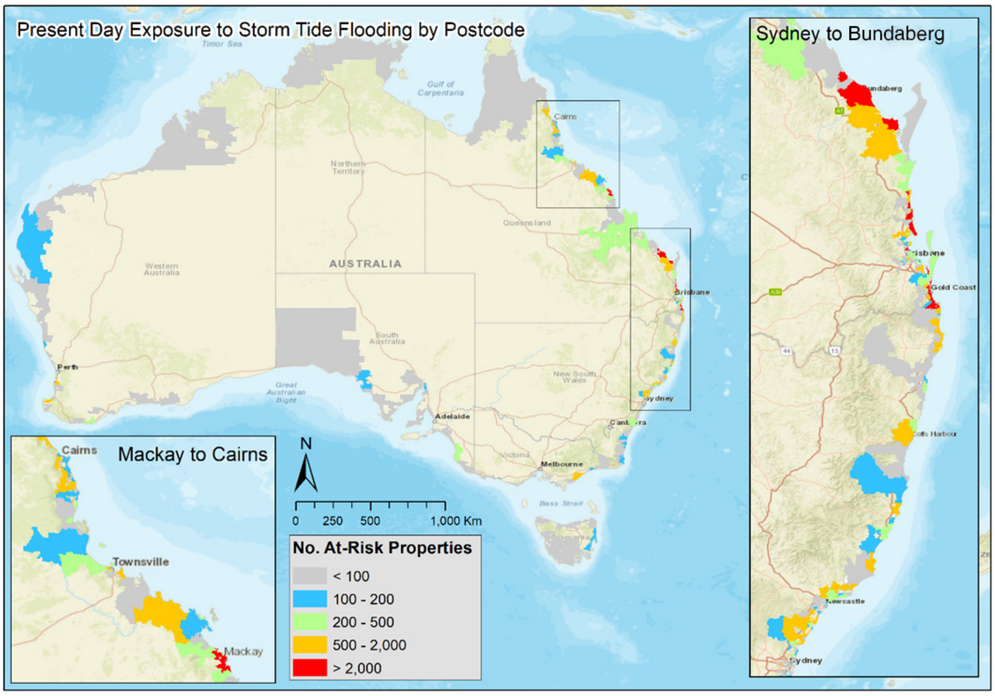

Figure 2. *Present day exposure to 1 % AEP storm tide flooding by postcode.*

Over the last 50 years, most tropical cyclones in Australia have remained equatorward of 25° South but occasionally they track lower into South East Queensland. Risk Frontiers maintains a database of natural hazards in Australia dating back to 1788 (PerilAUS). The PerilAUS database shows there have been 46 tropical cyclones near Brisbane and the Gold Coast. Most have been minor; the most damaging were tropical cyclones Dinah in January 1967 and Wanda in 1974. The large increase in coastal development on the Gold Coast since the 1970s drives present-day storm tide risk much more so than when tropical cyclones Dinah and Wanda impacted this area.

Sydney and Brisbane potential future hotspots for storm tide flooding

While the Gold Coast has the highest concentration of properties at risk of storm tide flooding, the largest increases by the end of the century are projected for Sydney and Brisbane suburbs. In Sydney, the Botany Bay and Tempe areas, and Rozelle and Canada Bay on the Parramatta River, show some of the largest increases in the country, while the Brisbane CBD and Launceston in Tasmania also exhibit a substantive rise in exposure (Table 2). Port Hedland (WA) and Port Adelaide (SA) are other industry hubs where results suggest increases of over 400 % in storm tide risk by the 2090s.

Sydney may benefit more than most from lower rates of sea level rise

As shown in Table 2, there is a big difference in storm tide flooding between low and high future emissions scenarios in Sydney. All Sydney suburbs showing the largest increases in exposure by the 2090s relative to present day under RCP 8.5 (Botany Bay, Rozelle, Tempe, Canada Bay) show no increase under RCP 2.6. This suggests that Sydney may be one of the greatest beneficiaries of emissions reductions by the end of the century in terms of reduced exposure to storm tide flooding in low-lying city suburbs around Botany Bay and along the Parramatta River.

At present, sea level rise of about 0.9 m by 2090 is used as the planning benchmark, synonymous with an RCP 8.5 emissions trajectory. However, it is important to note that the amount of sea level rise we can expect over the coming century is deeply uncertain because of major unknowns around ice sheet dynamics. Some studies (Bakker et al., 2017) suggest if substantive glacial basins of the West Antarctic Ice Sheet were to collapse, it could contribute at least a further two metres to global sea levels.

A national picture with considerable regional variation

This new national picture of storm tide risk exposes a large amount of regional variation, reflective of coastal topography, development, storm surge climate and relative rates of sea level rise. It shows that, while most of the present day risk is concentrated in Southeast Queensland, suburbs in Sydney and Brisbane may see

Table 1. *Top 10 postcodes by number of properties with a 1 % probability of storm tide flooding in any given year. All postcodes experience the same level of change under RCP 2.6 and 8.5 by the 2090s because of non-sea level factors such as location of addresses and coastal topography.*

Postcode	Present day	Change by 2090s
4217 (Gold Coast QLD)	11,607	+ 39 %
6210 (Mandurah WA)	6,589	No change
4221 (Palm Beach QLD)	6,542	+ 31 %
4655 (Hervey Bay QLD)	6,457	No change
4216 (S. Stradbroke QLD)	5,532	+ 88 %
4740 (Mackay QLD)	4,887	+ 65 %
4551 (Shelly Beach QLD)	4,839	+ 47 %
4218 (Broadbeach Waters QLD)	4,104	+ 49 %
4215 (Southport QLD)	4,097	+ 93 %

Table 2. *Top 10 postcodes by magnitude of change by the 2090s.*

Postcode	Present day	Change by 2090s (RCP 2.6)	Change by 2090s (RCP 8.5)
2019 (Botany Bay NSW)	21	No change	+ 1,352 %
2039 (Rozelle NSW)	2	No change	+ 1,200 %
4000 (Brisbane CBD)	9	+ 1,144 %	+ 1,144 %
7248 (Launceston TAS)	11	+ 973 %	+ 973 %
2046 (Canada Bay NSW)	32	No change	+ 634 %
4006 (Newstead QLD)	92	+ 580 %	+ 580 %
2044 (Tempe NSW)	7	No change	+ 557 %
2528 (Warilla NSW)	286	No change	+ 480 %
6721 (Port Hedland WA)	8	+ 463 %	+ 463 %
5015 (Port Adelaide SA)	54	No change	+ 452 %

significant increases in future storm tide flooding, depending on the rates of sea level rise that occur over the coming century, which, as noted, is deeply uncertain.

This dataset forms part of Risk Frontiers' multi-hazard Risk Rating Database, and is suitable for national to suburb-level risk scoping. It does not replace the need for hydraulic modelling required to understand the complexities of localised storm tide flooding.

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From drought to flood: Australia's seasonal forecast for summer 2021

Stuart Browning

Given the confronting bushfire weather experienced last summer there is strong interest in the climate outlook for summer 2021. At seasonal timescales there is a spectrum of predictability, from the immutable fact that summer will be warmer than winter (radiation increases due to Earth's solar orbit and axial tilt), to the complete impossibility of predicting New Year's Eve weather at the start of December (due to the stochastic variability of day to day weather). In between these endpoints are slow-changing components of the climate system, mostly tropical sea surface temperatures (SST), that provide us with some predictability on how each season might unfold.

The Australian Bureau of Meteorology (BOM) recently declared a La Niña event. This is significant for seasonal forecasting as La Niña events, when they occur, tend to persist though most of summer and usually result in wetter than average conditions for much of Australia. La Niña is one state of the world's leading climate driver: the El Niño Southern Oscillation (ENSO). ENSO is usually defined by SST in the Tropical Pacific (a region called Niño 3.4 shown in Figure 1) and influences weather around the globe, including the Americas, Africa, New Zealand and Australia. The latest multi-model ENSO outlook (Niño 3.4 SST) shows moderate to strong La Niña conditions will persist for the remainder of 2020, and probably though until Autumn 2021. For Australian seasonal forecasts, the BOM also monitors tropical SST in the Indian Ocean, described by the Indian Ocean Dipole (IOD; also shown in Figure 1) and winds over the Southern Ocean, described by the Southern Annular Mode (SAM).

The BOM's seasonal forecast model, ACCESS-S, provides outlooks for a range of useful parameters including rainfall and temperature: Figure 2 shows this coming summer will be wetter than normal for most of Australia, and cooler than normal for some regions including coastal NSW. Forecasts for more specific parameters, such as streamflow, fire danger, and tropical cyclone activity can be derived from forecasts models, but are often developed using statistical methods based on historical relationships with major climate drivers. Seasonal forecasting of specific perils is an area of current research focus with a range of statistical, dynamical, and machine leaning approaches being explored.

Past La Niña events provide a useful analogue for what we can expect this coming summer. Tropical cyclone activity has historically been higher during La Niña seasons, with some of the most destructive cyclones on record, such as Tropical Cyclones Yasi (2011) and Wanda (1974) occurring during strong La Niña years. The BOM tropical cyclone outlook, based on the historical relationship with ENSO, is predicting 11 cyclones this season, which is slightly above average. Riverine flooding is also expected to have a higher probability this summer due to model forecasts for high precipitation (Figure 2), and that historically flooding occurs more often during La Niña events, such as 2011 when widespread flooding occurred across the eastern states including the overflow of Wivenhoe Dam and subsequent Brisbane floods. Rainfall during the 2011 La Nina transported so much water from the oceans to inland Australia that global sea levels lowered by ~5mm (Boening et al 2012). Overall increases in

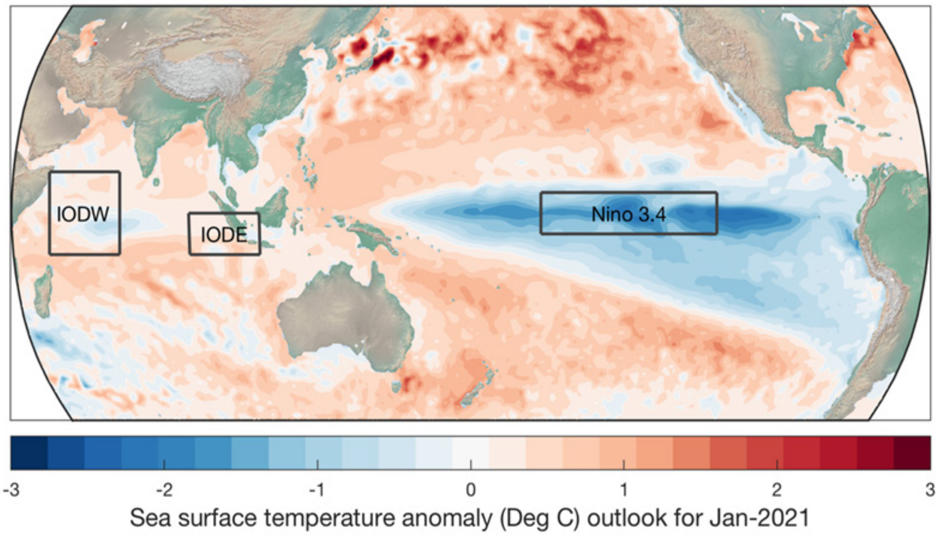

***Figure 1** ECWMF seasonal forecast for global sea surface temperature anomalies (SSTa) during January 2021 showing a classical La Niña cold tongue extending across the tropical Pacific (source: [C3S seasonal forecast](#)). Boxes show the regions typically used for climate driver index calculations: in the central tropical Pacific, SSTa in the Nino 3.4 region are used to represent ENSO; and in the tropical Indian Ocean, the difference between SSTa in the IODW and IODE regions are used to represent the Indian Ocean Dipole. Warmer SSTa in the Australian region are generally associated with lower atmospheric pressure and increased precipitation.*

rainfall and storm activity mean that previous La Niña events have seen an increase in the frequency of compound disasters and overall insured losses.

La Niña-related rainfall also has the unfortunate consequence of increasing mosquito populations and the spread of vector borne disease. The 1974 La Niña saw Australia's wettest year on record contribute to widespread outbreaks of Murry Valley Encephalitis and Ross River virus, while the recent 2010-12 La Niña saw over 1000 cases of Ross River Virus and an outbreak of Barmah Forest Virus in Victoria.

The other major tropical climate driver to influence Australia is the IOD. ENSO and IOD are usually coupled, where El Niño couples with IOD positive and La Niña couples with IOD negative. Anomalously strong IOD positive last year was one of the main climate factors contributing to the Black Summer bushfires. We are facing the opposite situation this year, with IOD negative during spring 2020 having contributed to recent drought-breaking rains across south eastern Australia. Most models are currently forecasting neutral to negative IOD conditions for the remainder of spring and early summer indicating much lower fire risk for this season relative to 2019/20. The unfortunate caveat is that increased springtime precipitation encourages vegetative growth, so that if we do experience a dry period over summer, grasses can cure quickly raising the risk of grass fires. One of the largest areas burned on record for Australia (~1.5 million Ha) occurred during the 1974-75 summer when vast grassfires burned across central NSW: this was during one of the longest and most sustained La Niña periods in the past century.

By this time last year the fire season was well underway with out-of-control blazes in southeast Queensland; the same regions are now being battered by successive storms while Victoria and NSW are dealing with floods. Tumbarumba, for example, was [devastated by last summers fires](#) and is already [under flood waters this spring](#). Such seemingly wild swings from one year to the next are a familiar and defining characteristic of Australia's climate. There are numerous examples where a strong El Niño is followed by a strong La Niña, such as the 1982-83 El Niño and Ash Wednesday fires which were followed by La Niña and flooding in 1984, or the more recent 2009 El Niño and Black Saturday fires which were followed by La Niña and widespread floods in 2010-12. While paleoclimate research shows this is a typical feature of Australia's climate, there is some evidence that ENSO variability (swings from one extreme to the next) has increased in recent centuries and will continue to strengthen in coming decades (Cai et al 2015).

Seasonal outlooks for La Niña and associated increased rainfall might be welcome news for many Australian communities that have been dealing with protracted drought. A milder bushfire season should also be appreciated by those still recovering from the devastation of last summer. However, if this year is similar to previous La Niña events then we should prepare for more rainy days and an overall increase in weather related risk and insured losses.

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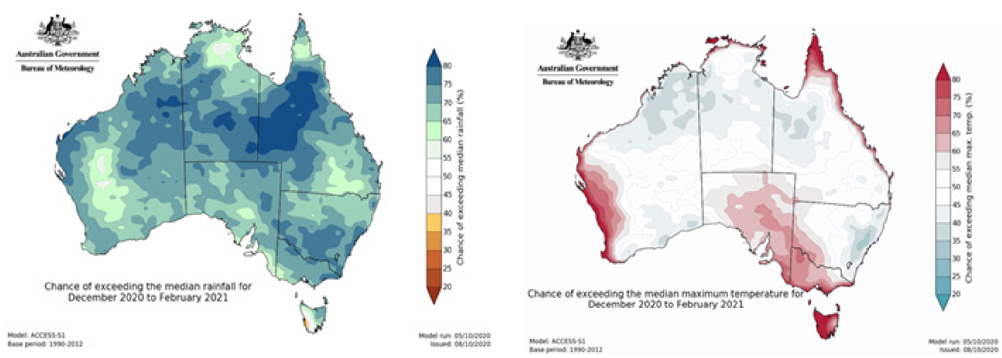

***Figure 2** ACCESS-S outlook for summer rainfall and temperature (source: [BOM](#))*

Risk Frontiers, Level 8, 33 Chandos Street, St Leonards NSW 2065
Telephone +61 2 8459 9770 | Email:info@riskfrontiers.com | Web: www.riskfrontiers.com