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Acute hazards in a future climate: guidance provided to the Australian Prudential Regulation Authority

An updated assessment based on the CMSI Science Report and further expert judgement

Mitchell Black, Dörte Jakob, David Jones, Richard Matear, Hamish Ramsay, Acacia Pepler, Naomi Benger, Lynette Bettio, Karl Braganza, Judith Landsberg, Shoni Maguire, Michael Grose, Andrew Dowdy

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Executive Summary

In July 2023, the Australian Prudential Regulation Authority (APRA) announced its intention to conduct an Insurance Climate Vulnerability Assessment on behalf of the Council of Financial Regulators. This Insurance Climate Vulnerability Assessment will be a scenario analysis exercise that seeks to better understand where and how climate change may impact insurance affordability across Australia.

In designing the Assessment, APRA requested input from the Australian Climate Service (ACS) to provide guidance on how climate perils may change across Australia under a particular scenario: an approximate 2.5°C increase in global mean temperature (relative to pre-industrial temperatures) by 2050. In particular, APRA were seeking advice on interpreting and applying the climate science guidance on physical hazards set out in the Climate Measurement and Standards Initiative (CMSI) report produced through the National Environmental Science Program (NESP).

This report documents the advice provided to APRA by the ACS. Guidance is provided for a number of hazards including tropical cyclones, riverine floods, large hail, extratropical storms, extreme rainfall and bushfire weather.

1. Introduction

The Australian Prudential Regulation Authority (APRA) is undertaking a Climate Vulnerability Assessment for the insurance sector, to examine how household insurance affordability may be affected under different future climate scenarios.

To support this endeavour, APRA has approached the Australian Climate Service (ACS) seeking guidance on how specific hazards may evolve under a changing climate. These hazards are:

- Tropical cyclones
- Riverine floods (specifically, flood height and inundation)
- Large hail
- Extratropical storms (including east coast lows)
- Extreme rainfall
- Bushfires (specifically, bushfire intensity approximated by the Bushfire Attack Levels).

In addressing this request, ACS subject matter experts have reviewed the material presented in the Climate Measurement Standards Initiative (CMSI) Technical Report (NESP 2020) and, where possible, have provided additional guidance for APRA consistent with (and often limited to) that presented by CMSI.

The guidance for each of the requested hazards is presented within the context of the following narrative, per the request from APRA: *a future climate centred around 2050 under a high emissions pathway (e.g., RCP8.5 or its equivalent)*.

For each of the specified hazard types, ACS subject matter experts reviewed the information within the CMSI report and were guided by the following:

- *Is there any additional information that the ACS can provide (in particular, where projections are lacking or qualitative)?*
- *Is it suitable for APRA to use the upper bound (or lower bound, as appropriate) to characterize the hazard in lieu of the central estimate, for the purpose of their stress-testing exercise?*

For most hazards, CMSI provided projected changes as a central estimate and a range of plausible change (based on 10th–90th percentile estimates considering multiple lines of evidence). Where possible, the ACS has provided further commentary around extremes. In some cases, a narrative has been provided which could be used for scenarios to assess financial risk. This information should be considered possible, with no indication of probabilities.

2. Key considerations

This support for APRA was undertaken over a short period of time by a small group of subject matter experts within the ACS. The commitment was to provide additional Australian hazard-specific intelligence about physically plausible climate extremes so that scenarios could be developed by APRA to assess possible socio-economic implications from extreme hazard events.

For noting: It was not possible within the specified time and resources for the ACS to deliver a comprehensive portfolio of responses to update the CMSI information. This considers that:

1. The CMSI science report was produced by the National Environmental Science Program (NESP)'s Earth System and Climate Change Hub over an extended period, in collaboration with finance sector experts, and represents a significant and prolonged contribution from a large body of experts. Some of the subject matter experts who contributed to the CMSI report now work for the ACS and have contributed to this document, including key development of CMSI report Table TS2 by Michael Grose and Table TS1 by Andrew Dowdy (now at University of Melbourne).
2. The information from CMSI already provides a thorough review of existing climate datasets and relevant literature (including a recent CMIP6 addendum that hasn't notably changed for acute hazards from the original Table TS1; Climate-KIC 2022).
3. The projected changes in acute hazards presented in the CMSI reports were developed using multiple lines of evidence and credible scientific assessment (i.e., it provides a thorough assessment of the 'state of the science') including with external peer review process by subject matter experts not from NESP.

3. Guidance for specific hazards

CMSI assessment of the projected changes for most hazard types included quantitative values for central estimates as well as 10th and 90th percentile ranges (e.g., for bushfire weather, extreme rain, tropical cyclones (TCs) and east coast lows (ECLs)). A number of hazards were limited to more qualitative statements (e.g., for hail and flood). This reflects the ongoing scientific challenges associated with studying some hazard types (e.g., inability to accurately resolve damaging hail and flood hazard within existing climate projections and/or suitable long-term homogenous observational records). This commentary has been updated here in some cases, where possible, with associated likelihood and confidence information.

How to interpret the hazard projection tables: Tables within this document present the observed and projected changes for each hazard. The average in the baseline period (1986 – 2005) is given, along with the observed change averaged over recent decades (from 1986 onward). Projected changes are provided for the 20-year period centred on 2050 (2040 – 2059) under the RCP8.5 emission pathway, per the request from APRA. Wherever possible, projections are presented as a central estimate and a range of plausible change (based on 10th – 90th percentile estimates considering multiple lines of evidence). These are typically broad estimates for Australia as a whole, or large regions of Australia. Confidence ratings, using the IPCC guidance, provide an assessment of confidence that the range of change is a reliable and complete description (Table 1).

Additional commentary is included after each of the tables. This includes expert assessment with more detail of how plausible extremes could be considered and discusses the possible implications for each identified hazard where no further quantitative information is available.

Terminology	Degree of confidence in being correct
Very high confidence	At least 9 out of 10 chance
High confidence	About 8 out of 10 chance
Medium confidence	About 5 out of 10 chance
Low confidence	About 2 out of 10 chance
Very low confidence	Less than 1 out of 10 chance

Table 1: IPCC confidence ratings and likelihood. Source: IPCC (2007).

3.1. Tropical cyclones

Hazard	Average (1986–2005)	Observed change	2050 Scenario, RCP8.5 emission pathway	Confidence in projected changes
Tropical cyclone (TC) frequency in Australian region (Categories 1–5)	10–11 per year	−10%	East: −8% (−15% to +2%)* West: −12% (−20% to −4%)*	Medium
Category 4 – 5 TC frequency	2–3 per year	Little change	Increase more likely than decrease	Low-Medium
TC location (latitude)	10–20°S common (30°S less common)	Little change or small poleward expansion	Little change or poleward expansion	Low

** The 'central estimate' is based on multiple lines of evidence and expert judgment, with values in parentheses indicating the 10th–90th percentile likelihood range.*

Table 2: Observed and projected changes for tropical cyclones in Australia, extracted from CMSI Technical Report (NESP 2020). The average in the baseline period (1986–2005) is given, along with the observed change averaged over recent decades (from 1986 onward). Projected changes are provided for the 20-year period centred on 2050 under the RCP8.5 emission pathway. See main text for details on how to interpret this table. Further details used to produce the table content for acute hazards as used here are in Section 3.2 of NESP (2020).

Key commentary (drawing on CMSI reports and ACS expert feedback):

- *The upper bound (rather than the central estimate) of the projected change could be used to characterize the hazard for the purpose of APRA stress testing.*
- Projections from climate models indicate, at global scale, increases in average tropical cyclone (TC) peak wind speeds (high confidence), the proportion of very intense TCs (high confidence), and TC rainfall rates (high confidence). TC frequency is likely to decrease (medium confidence), especially in the Southern Hemisphere. There is low confidence in projections of other aspects of TCs, such as poleward movement and changes in absolute number of very intense TCs (as opposed to proportion).
- Climate models indicate that TC numbers in the Australian region are likely to decrease this century due to continued emissions of greenhouse gasses. These projections are broadly consistent with a range of other studies. There is medium

confidence in the direction of change (i.e., fewer TCs in total are expected for the Australian region), while noting that the exact magnitude of the decrease is more challenging to predict given the large spread in projected changes between different modelling approaches and different studies (e.g. CSIRO-BoM 2015; Walsh et al. 2016; Bhatia et al. 2018; Knutson et al. 2020 and references therein).

- Projected changes in the frequency of Category 4 TCs and Category 5 TCs have low-medium confidence for the Australian region, as well as for details such as regional extent (in latitude or longitude) and landfall frequency.
- Increases in the average value of TC maximum wind speeds are of the order of 5% for about 2°C global warming around the middle of this century (Knutson et al. 2020) corresponding to about 2.5% per degree of global warming. Similarly, a recent report on Australian climate hazards noted a future increase of about 5 – 10% per degree of warming in the maximum wind speed of TCs (from a report produced by IAG and NCAR in 2020).
- Although there are large uncertainties around the influence of climate change on some aspects of TC-related hazards, there is high confidence that rising sea levels will contribute to higher storm inundation levels from TCs, and an increase in atmospheric water vapour content with warming is expected to increase extreme rainfall intensities from TCs in the future (see, for example, Knutson et al. 2020 and references therein).
- In relation to the latitudinal range of TCs, some studies have shown a trend towards a small increase in poleward range in some TC metrics. These include the latitude of TC formation (Sharmila and Walsh 2018), and the latitude of maximum intensity (e.g. Kossin et al. 2014), including values reported of 62 km per decade for the Southern Hemisphere, while noting considerable uncertainties (Knutson et al. 2019, 2020; Chand et al. 2019; Tauvale and Tsuboki 2019). Similarly, the IAG/NCAR 2020 report for Australia found poleward shifts in the latitude of maximum TC intensity that ranged between 0.3° and 1.8° for the period 1989-2020, depending on subregion, with the largest trend occurring in the Coral Sea region. Major uncertainties include the large interannual variability for TC observations in the Australian region and the ability of models to accurately simulate some TC processes.
- Projections of TC intensity at national and regional scale are needed. Work is ongoing in ACS and NESP to assess projected intensity changes in CMIP6 global and regional climate models.
- Projections of the latitudinal range of TC tracks, including the locations of peak intensity, are needed at national and regional scales. Work is ongoing in ACS and NESP to assess potential poleward shifts of TCs in the Australian region.
- Projections of TC rainfall at national and regional scale are needed and remain a major knowledge gap for Australia. Work is planned in ACS and NESP to assess TC rainfall changes in global and regional climate models.
- Work is ongoing to improve synthetic track models developed for other TC basins, which do not perform as well in the Australian region.

- The effect of human-induced climate change on historical TC trends remains largely unclear due to large natural variability and a relatively short period of reliable TC observations.

3.2. Riverine floods

Hazard	Average (1986–2005)	Observed change	2050 Scenario, RCP8.5 emission pathway	Confidence in projected changes
Floods	Spatially variable and dependent on flood type	No clear signal	Increase more likely than a decrease for most types of floods	Low for large catchments and large floods in general.

Table 3: As per Table 2, but for riverine floods.

Key commentary (drawing on CMSI reports and ACS expert feedback):

Note: APRA are specifically interested in being able to quantify the impact of riverine flooding on residential dwellings. The ACS is yet to develop capability for providing projections of riverine flood height and inundation.

- There are considerable uncertainties around observed trends and future projections of flood events in Australia. This is due to inhomogeneities in the observed records as well as the relatively limited ability of climate models to simulate the range of physical processes that can influence the occurrence of floods.

- Increased moisture content in the atmosphere due to global warming can increase rainfall extremes, thereby increasing this risk factor for flood occurrence. However, the relationship between increased rainfall and flood characteristics (e.g. depth, extent or speed of flow) may not be linearly related to increased rainfall (Johnson et al. 2016). In a global study of trends in streamflow events, Wasko et al. (2021) found that small floods, responsible for filling our water supplies, are decreasing, while the large flood events which pose a risk to life and infrastructure, are increasing.

3.3. Hail

Hazard	Average (1986–2005)	Observed change	2050 Scenario, RCP8.5 emission pathway	Confidence in projected changes
Large hail (>2.5 cm diameter) frequency in city scale regions	About 5-10 per year in eastern regions and 0-5 per year elsewhere	No information	Little change, but potential increase in east and poleward shift in features	Low

Table 4: As per Table 2, but for large hail.

Key commentary (drawing on CMSI reports and ACS expert feedback):

- The influence of climate change on hail occurrence has considerable uncertainties due to the limited period of consistent observations needed for historical trend analysis studies (Allen et al. 2020), as well as the limited ability of models to accurately represent the physical processes required for simulating future hail events (including fine-scale convective processes and microphysics).
- There is some indication of projected increases in severe thunderstorm environments for parts of eastern Australia (Leslie et al. 2008; Allen et al. 2014) as well as a poleward shift in suitable environments for hail occurrence, while noting a wide range of uncertainties around long-term changes in hail occurrence as discussed in Walsh et al. (2016).
- In general, the influence of climate change on hail characteristics, as well as on severe thunderstorm-related hazards in general, represents a significant gap in knowledge.
- A recent review by Raupach et al. (2021) identified that:
  - Efforts to understand the effects of climate change on hail are complicated by the small scale and relative rarity of hailstorms, which make hail hard to observe and model.
  - A scarcity of hail observations and high-resolution modelling studies, and gaps in the understanding of physical processes, contribute to the current high uncertainty around the effects of climate change on hailstorms worldwide.
- Work is underway at the Bureau of Meteorology and elsewhere to develop a new radar-derived hail product using a large dataset of hail damage insurance claims and radar observations (e.g., Ackermann et al. 2023).

3.4. Extratropical storms (including east coast lows)

Hazard	Average (1986–2005)	Observed change	2050 Scenario, RCP8.5 emission pathway	Confidence in projected changes
East coast low (ECL) frequency	20 per year	−10% (but with large variability)	−20% (−30% to −10%)*	Medium (Low for summer and High for winter)
Intense ECLs impacting on land	~3 per year	No clear change	−12% (−30% to +8%)*	Low

** The 'central estimate' is based on multiple lines of evidence and expert judgment, with values in parentheses indicating the 10th–90th percentile likelihood range.*

Table 5: As per Table 2, but for east coast lows.

Key commentary (drawing on CMSI reports and ACS expert feedback):

- Climate projections indicate that fewer east coast lows (ECLs) are expected to occur in the future, particularly during the cooler months of the year, as detailed in recent studies and reviews (e.g., Dowdy et al. 2019a and references therein, as well as Cavicchia et al. 2020).
- Global and regional model projections indicate the total number of lows and associated total rainfall is likely to decrease. There is less confidence of any change in the most extreme events, noting that extreme events are likely to be less well simulated than more frequent less intense events.
- Changes in extratropical storms with extreme impacts may also be influenced by other factors (e.g., rising sea levels, increases in atmospheric moisture), resulting in different future changes depending on the aspect of most interest.
- There is little research on future changes in cold fronts or higher level cut off lows.
- Impacts are more likely from long-duration ECL events, which spend at least 24 hours near the coast (climatological frequency ~ 3 per year), for which there is less research. Preliminary analysis of the Electricity Sector Climate Information dataset suggests a smaller decline in these events by 2050 (−12%), but uncertainty is larger, with a confidence interval which includes no change (−30% to +8%). A suitable upper bound is no change in the frequency of impactful east coast lows, and an intensification of associated impacts (rainfall/flooding/coastal impacts). There are currently no indications of a change in the intensity of wind from ECLs.
- Observed datasets of ECLs typically cover 60 years or less, and it is unlikely that they capture the full range of potential, given very severe storms known to have occurred during the 1800s (e.g. the Catherine Hill Gale) fall outside the data period.

It is prudent for stress testing to consider a potential ECL during 2041-2060 with larger impacts than any previously observed, including through higher rainfall intensities (consistent with projections of extreme rain).

- New projections of extratropical lows and cold fronts using ACS regional model output are underway as part of ACS.
- More work is needed to better identify the key characteristics of those extratropical lows which are most important to assess, including those with large impacts. These characteristics are likely to be based on hazard indices (e.g., rainfall, wind speed) rather than the weather systems themselves.

3.5. Extreme rainfall

Hazard	Average (1986–2005)	Observed change	2050 Scenario, RCP8.5 emission pathway	Confidence in projected changes
Extreme daily rainfall (considering 20-year return period)	Spatially variable intensity	+10% hourly and +7% daily (but with large spatial variability)	Hourly: +20% (+10% to +30%)* Daily: +15% (+8% to +20%)*	High for direction of change and Medium for magnitude of change

** The 'central estimate' is based on multiple lines of evidence and expert judgment, with values in parentheses indicating the 10th–90th percentile likelihood range.*

Table 6: As per Table 2, but for extreme rainfall.

Key commentary (drawing on CMSI reports and ACS expert feedback):

- A recent review of climate change science relevant to Australian design flood estimation (Wasko et al. 2023) suggests:
    - +15% [+7 to +28% range] scaling for hourly precipitation per degree of warming, and
    - +8% [+2 to +15% range] scaling for daily to multi-day precipitation per degree of warming.

  These projections will be refined as higher resolution modelling becomes available in the next few years, including as part of ACS.
- For the purpose of stress testing, APRA could consider applying the Wasko et al. (2023) scaling factors to projected changes in temperature (focussed on 2050). This would provide alternate estimates of changes in rainfall to the CMSI-derived values listed in the table above.

- Most research indicates smaller increases or possible decreases in the frequency of multi-day extreme rainfall such as the wettest 5-day total per year than for 24-hour or sub-daily extremes. However, there is less research on the ability of climate models to accurately simulate the persistence of synoptic systems that cause long-duration heavy rainfall, decreasing confidence in this result.

3.6. Bushfire

Hazard	Average (1986–2005)	Observed change	2050 Scenario, RCP8.5 emission pathway	Confidence in projected changes
Extreme fire weather days (exceeding 95th percentile)	About 18 days per year to once every few years depending on location	+15%	In general: +40% (+10% to +70%)* Eastern Aus: +30% (+0% to +60%)*	High; Medium in East

** The 'central estimate' is based on multiple lines of evidence and expert judgment, with values in parentheses indicating the 10th–90th percentile likelihood range.*

Table 7: As per Table 2, but for bushfire weather.

Key commentary (drawing on CMSI reports and ACS expert feedback):

Note: APRA are specifically interested in fire intensity as measured by Bushfire Attack Levels (BALs). The ACS is currently unable to provide future projections of BALs.

- The upper bounds (rather than the central estimate) of the projected changes could be used to characterise the hazard for the purpose of APRA stress testing.
- The atmospheric conditions in which fires are more difficult to supress are referred to as fire weather. Changes to fire weather are the focus of most research as fire ignition has many factors that are generally not predictable (usually linked to human activity). Changes in ignitions due to lightning is an active area of research, noting an observed trend towards increased lightning occurrence in parts of southeast Australia (Dowdy 2020).
- Bushfire weather indices (e.g., Forest Fire Danger Index, FFDI) do not directly translate to Bushfire Attack Levels, which is the focus of this request. APRA should consult with the National Bushfire Intelligence Capability (CSIRO) for quantifying Bushfire Attack Levels.
- The frequency of dangerous fire weather days has increased significantly in recent decades across many regions of Australia, especially in the south and east (Dowdy

2020). This increase is expected to continue due to climate change, the main components contributing to this increase are increasing temperatures and decreasing moisture for most regions of Australia.

- Projected changes in extreme fire weather risk factors were recently produced for Australia, drawing on a comprehensive range of modelling techniques (Dowdy et al. 2019b). Those projections indicate an increase in the number of days with very high fire weather conditions (based on FFDI above 25 and FFDI above the 95th percentile for 1990-2009), with similar results also seen for projections of rarer extremes such as FFDI above 50 and FFDI above the 99th percentile (Dowdy 2020).
- The Working Group 2 of the Intergovernmental Panel on Climate Change Sixth Assessment Report places high confidence on observed increases in the length of the fire season, the number of dangerous fire weather days, and the frequency of extreme pyroconvection since the late 1970s for Australia. These observed trends are particularly apparent in eastern and southern Australia.
- Very dangerous types of fire events have also been examined in relation to climate change, including extreme pyroconvection conditions (i.e. associated with thunderstorms that form in fire plumes, known as pyrocumulonimbus cloud or 'pyroCb'). These occurred for the Black Saturday 2009 and the Canberra 2003 fires as well as many examples during the 2019/20 'Black Summer' fires (e.g., Peterson et al. 2021). Significant trends have been found for extreme pyroconvection risk factors, including based on historical data (Dowdy and Pepler 2018) and future projections (Di Virgillio et al. 2019; Dowdy et al. 2019b).

4. Possible future work

It may be possible in a longer timeframe to develop a strategic agreement and address the APRA request in more detail through new datasets (e.g., for hail), methodology (floods) or in-depth literature review (as for the Australian Rainfall and Runoff project). This may be included as part of the National Climate Risk Assessment but requires more structured requirements gathering, scoping of the work and analysis. The availability of the new ACS downscale projections commencing in mid-2024 will provide an opportunity to assess the robustness of hazard projections, including allowing the use of update emissions scenarios (SSPs).

The extra commentary and APRA-specific narrative guidance provided by ACS is an initial effort to tailor climate information for the insurance industry and the ACS looks forward to further discussion.

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