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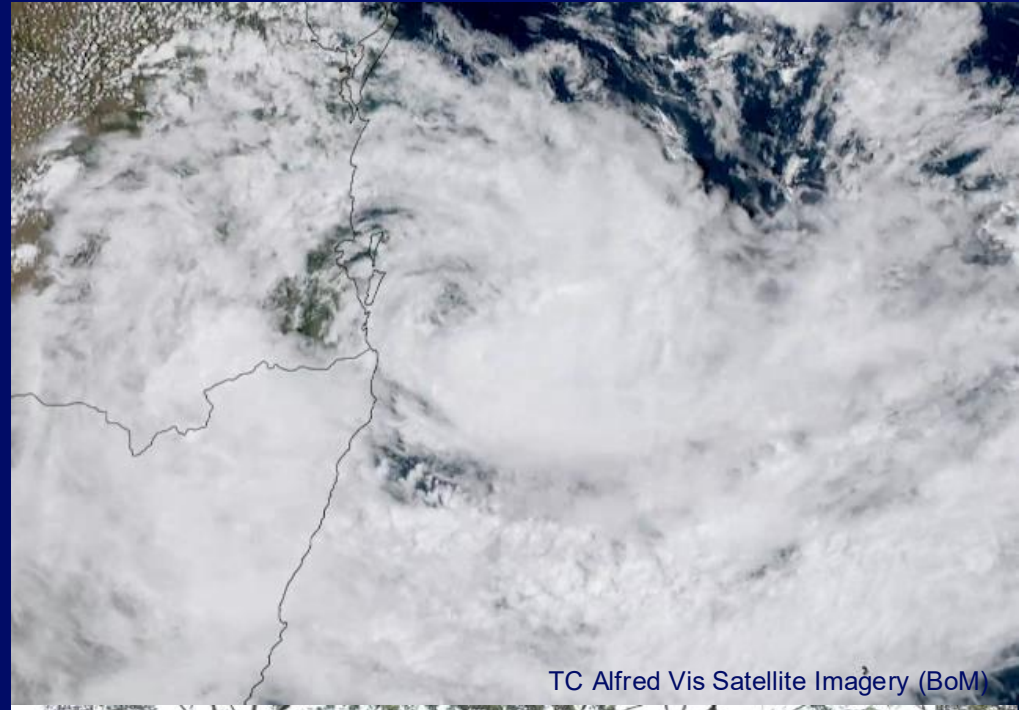
Australian Severe Weather in a Changing Climate



TC Alfred Vis Satellite Imagery (BoM)

August 2025

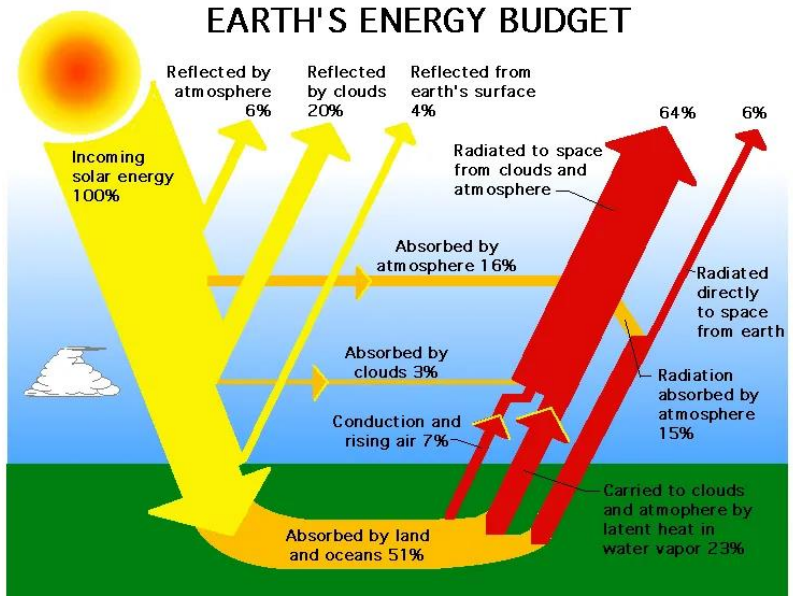
Dr Bruce Buckley
NRMA Principal Meteorologist / Climatologist

Australian Severe Weather – Topics Covered

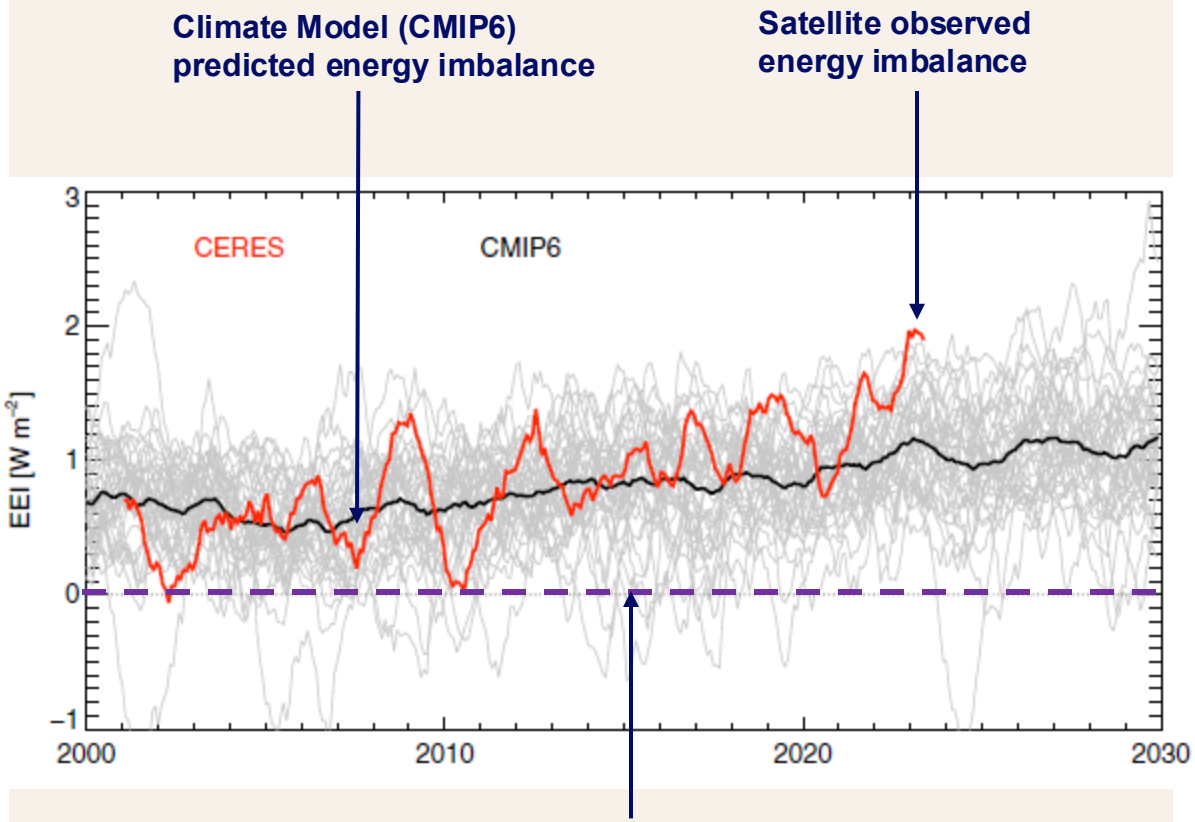
- Global Trends in Severe Weather & Observed Energy Imbalance
- Australia: Tropical Cyclones - Observed & Future Projections in a Regional Context
- Severe Convective Storms - including Hailstorms
- Mid-Latitude Lows - including East Coast Lows
- Sea Level Rise

Global Energy Imbalance

- For an unchanging (stable) climate, the Earth Energy Imbalance (EEI) is zero (incoming energy from the sun = outgoing energy from the earth)
- The CERES satellite sensor (NASA) measures incoming and outgoing energy for the Earth since 2000 - the observed EEI is accelerating since the early 2010s
- The EEI is now greater than any CMIP6 climate model predicts, so the climate change forcing is rising faster than most model predictions
- This means we must be aware that the future rate of change and severity of severe weather phenomena across Australia could exceed current predictions



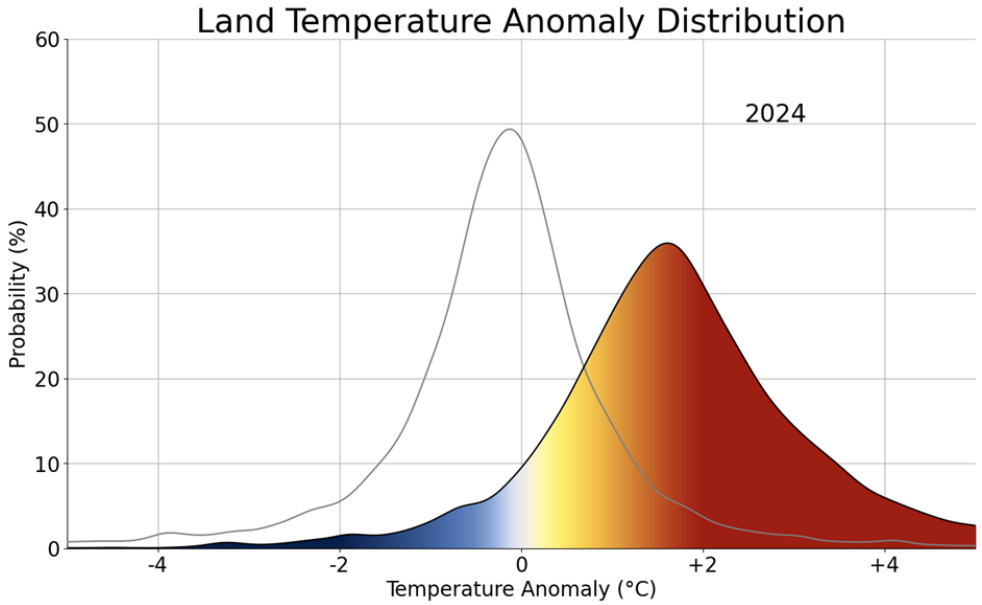
Source: UCAR



Myhre et al 2025 Observed trend in Earth energy imbalance may provide a constraint for low climate sensitivity models. DOI: 10.1126/science.adt064

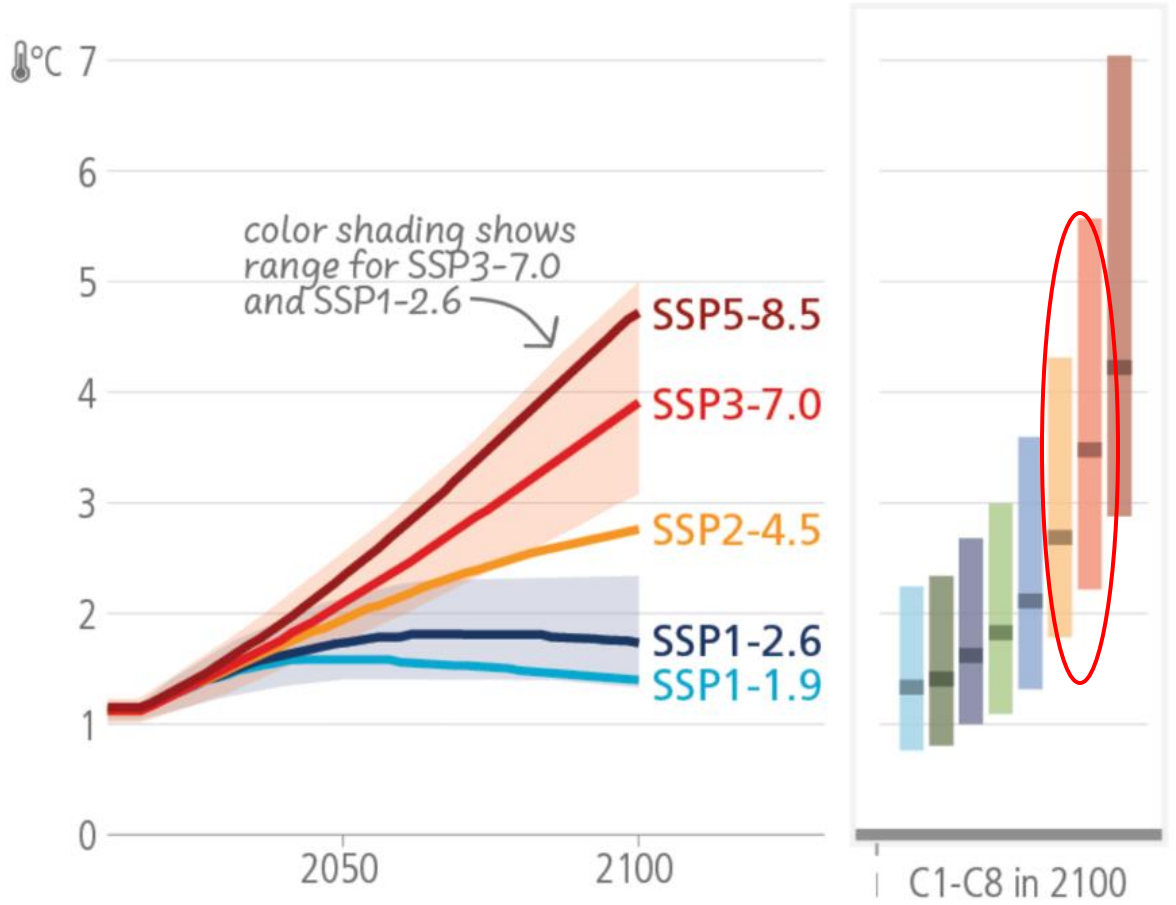
Global Temperatures
The Change in Extremes Matters

- 20 of the last 23 months have exceeded +1.5°C
- Australian temps are rising faster than global averages - likely to reach +3.5°C or more
- The entire temperature distribution is shifting, making previously rare hot days far more common
- This flows onto severe weather phenomena across Australia



Global Temp Anomalies 1964 compared to 2024

Temperature for SSP-based scenarios over the 21st century and C1-C8 at 2100



IPCC AR6 WG III Figure 3.11

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NASA SVS | Shifting Distribution of Land Temperature Anomalies, 1964-2024

A Growing Problem
Recent Natural Disasters

- Cat 1* TC Alfred March 2025
  - 1 death, 125,000 claims, ~$1.4 billion insured cost, $1.2 billion Federal Government cost, ~500,000 people without power for up to a week
- East Australian Floods February / March 2022
  - 246,000 claims, $6.4 billion insured cost
- Christmas Severe Storms & Flooding (QLD, NSW & VIC) December 2023 - January 2024
  - 106,000 claims, $1.6 billion insured cost
- Black Summer Bushfires 2019 – 2020
  - 40,000 claims, $2.4 billion insured losses, massive ecological damage
- Claims costs across the industry have increased Australia-wide over the past few decades

ICA Natural Disasters Data June 2025

* Alfred was Cat 1 inside Moreton Bay, but below TC intensity for the coastal crossing of the eye

Tropical Cyclones – Future Regional Trends

US CESM-HR ensemble model 10 members ~ 20km resolution

Top map shows observed and model trends in TCs 1940 – 2020. Frequency trends left graph. Intensity trends right graph.

Bottom map shows model changes in frequency and intensity of landfalling TCs from 1980 – 2018 to 2060 – 2100.

- There is a gradual decline in frequency of TCs in the future, greatest off the NW of WA
- Risk of severe TCs is expected to increase for the SW of WA, frequency and intensity increase for SE Qld / NE NSW
- Neither of these regions has a tropical cyclone wind loading code, making them highly vulnerable to destructive TC impacts
- In other regions, although frequencies are expected to decline, peak intensities are not, with the NW of WA and Coral Sea seeing more intense future TCs
- TC extreme rainfall expected to increase dramatically, greatly increasing flash and river flood risks, compounded by sea level rise

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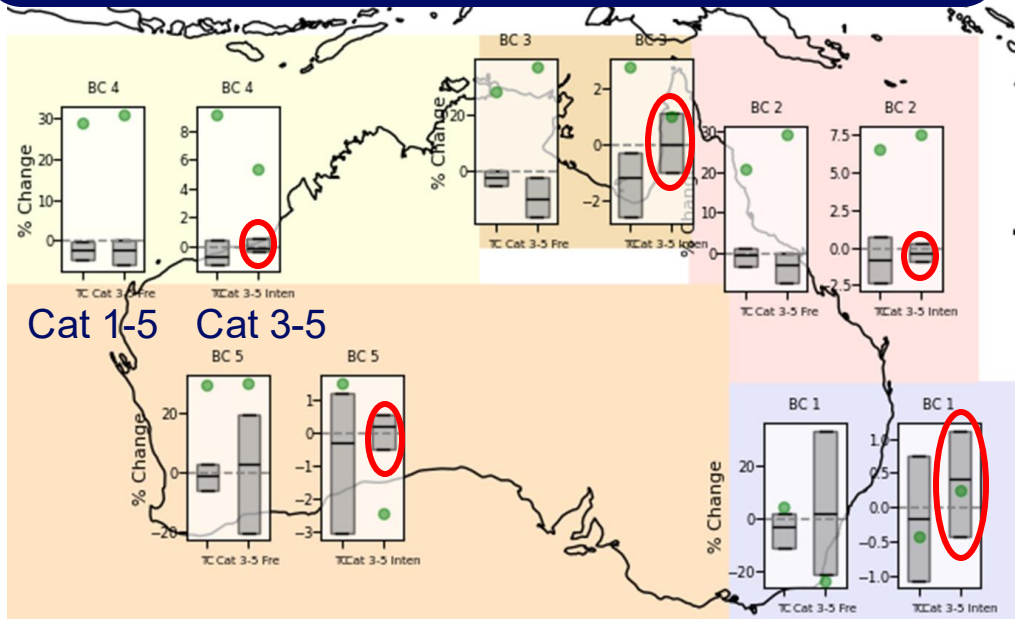
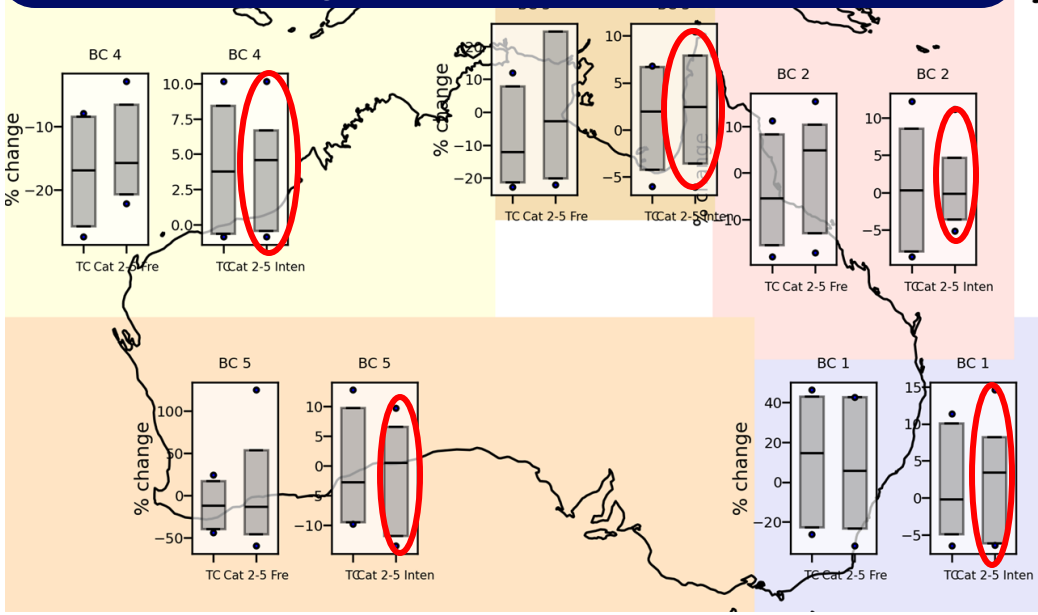
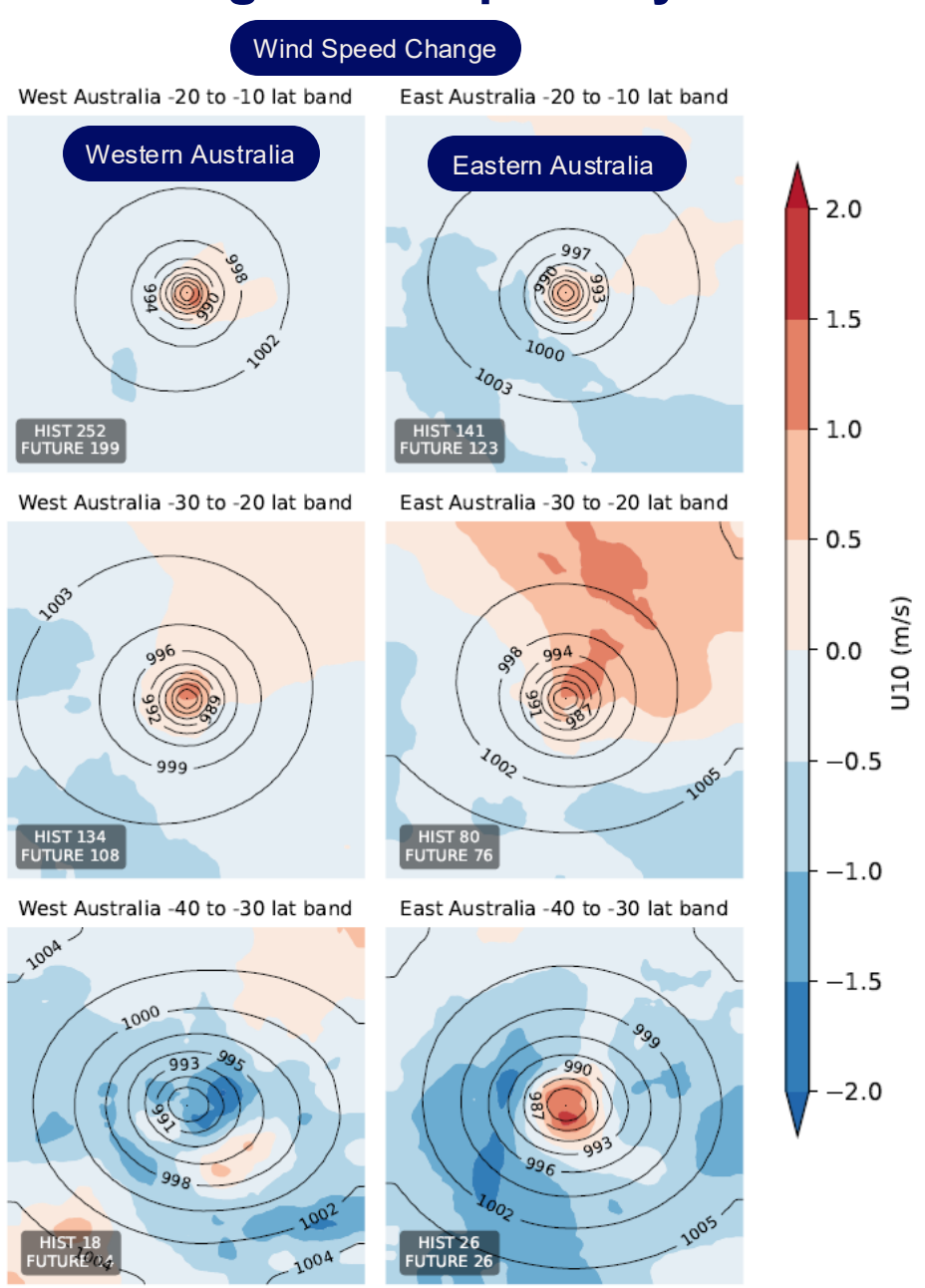
Observed & Modelled TC Changes between 1940 & 2020

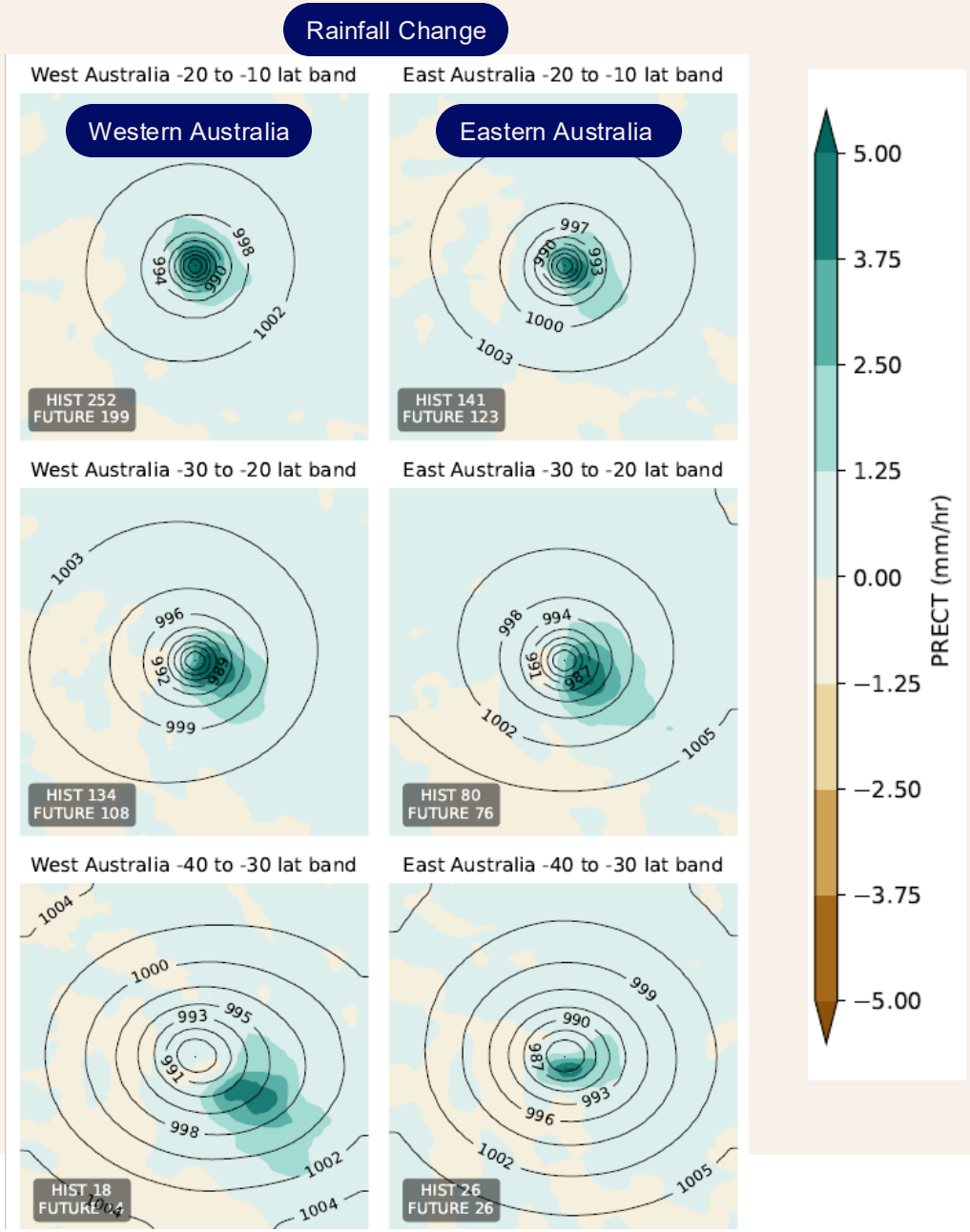


Landfall TC Changes between 1980 - 2018 & 2060 - 2100



Regional Changes in Tropical Cyclone Wind & Rainfall 1975-2005 to 2070-2100





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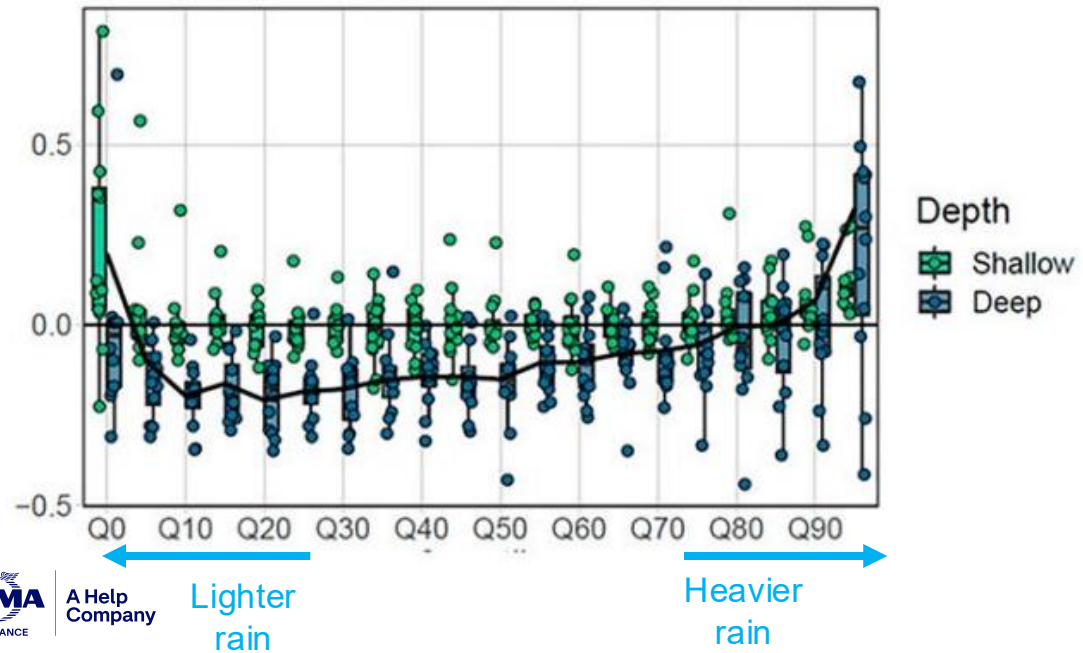
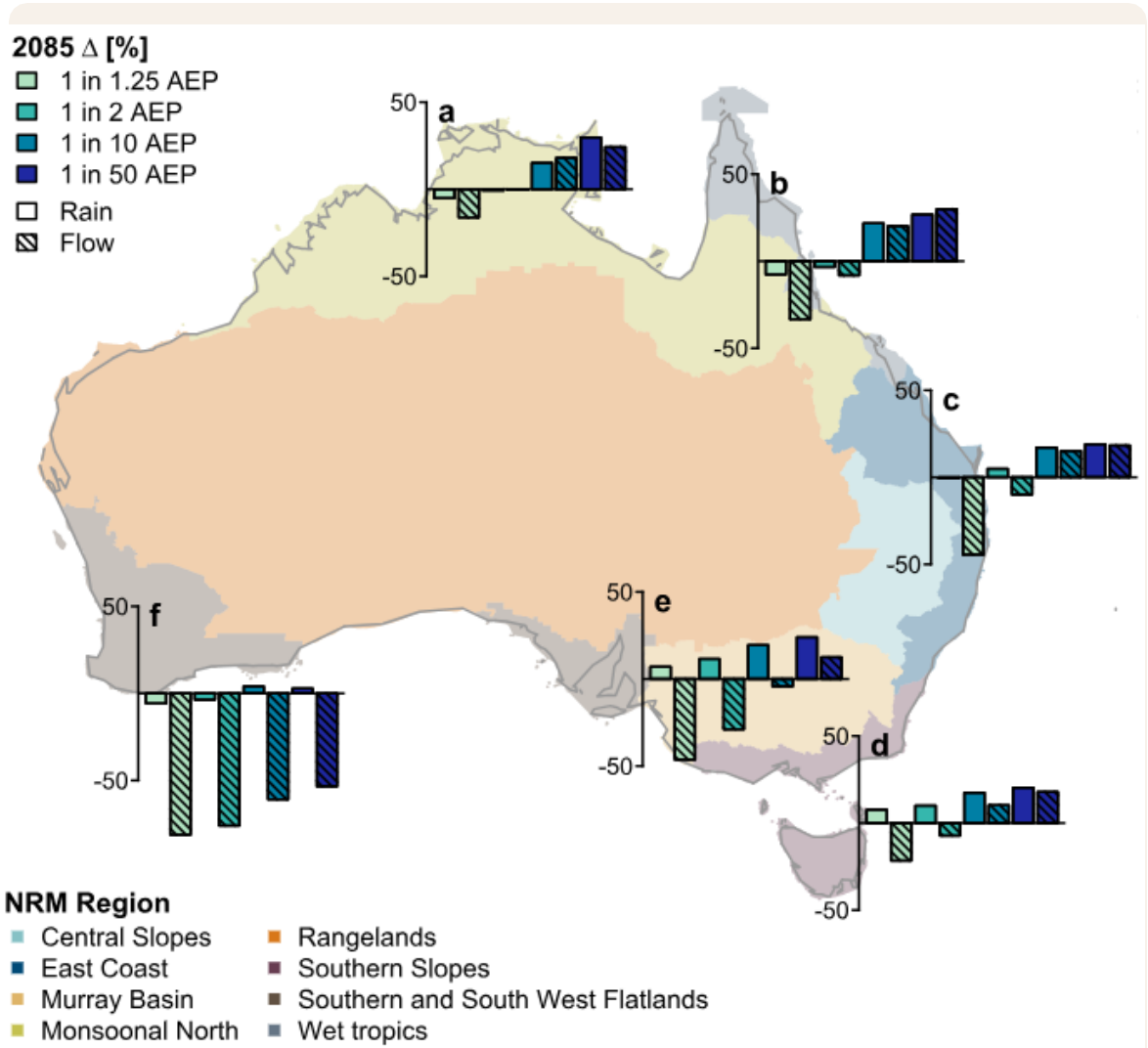
Extreme Rainfall and Flooding

- Light and moderate precipitation has decreased while heavy precipitation has increased over subhourly to daily timeframes, although there are significant geographical variations
- Short-term (hourly time scales) precipitation events (and associated flooding) will intensify further with ongoing climate change, even in places and seasons that experience drying on average
- The risks of more destructive river flooding increases most rapidly in estuarine and near-coastal regions where ongoing sea level rise compounds the flood risk

East Coast rain rate freq change 1980 - 2009 to 2070 - 2099 (RCP8.5)



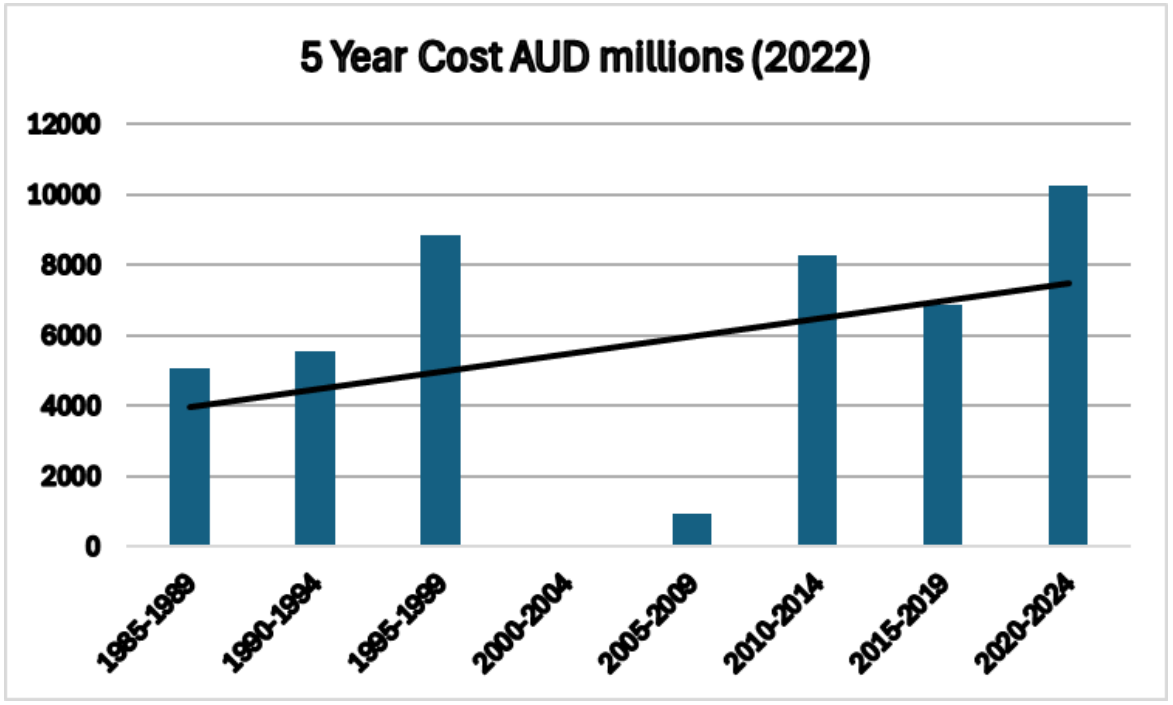


ABOVE: Wasko, C., Guo, D., Ho, M., et al., 2023: Diverging projections for flood and rainfall frequency curves. *Journal of Hydrology*, 620A, 129403

LEFT: Pepler. A., Dowdy. A., 2022, 'Australia's Future Extratropical Cyclones' Journal of Climate 35:23

Australian Destructive Hailstorms

- Six of Australia's capital cities most expensive natural disasters can be attributed to giant hail producing severe thunderstorms
- Every capital city, except Darwin, has seen an increased frequency of damage related to severe thunderstorms since 1990

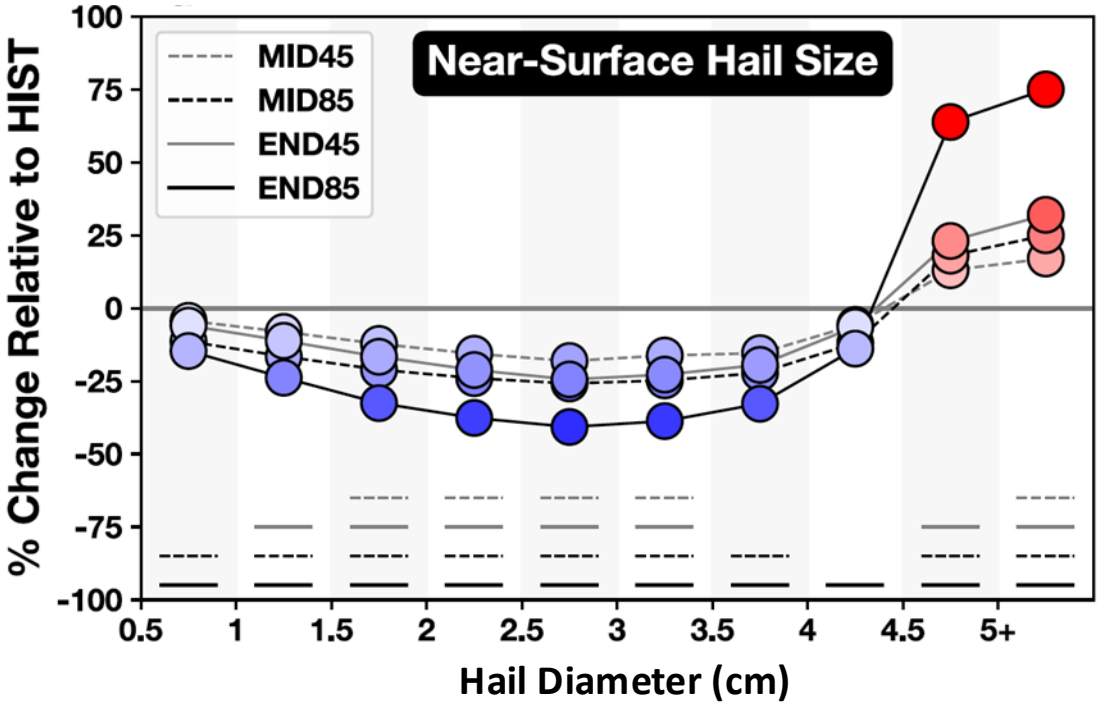


ICA Natural Disasters Data March 2025

City	Date	Max Hail Size	Insured Losses $AUD millions (2022)
Sydney	April 1999	13cm	8,800
Melbourne	March 2010	10cm	2,500
Brisbane	January 1985	7cm	3,700
Perth	March 2010	8cm	1,700
Adelaide	October 2021	5cm	1,000
Canberra	January 2020	7cm	700

Future Trends in Hail Size – a Global View (Gensini et al 2024)

- High resolution model hail size predictions relative to 1990 - 2005 for the epochs 2045 - 2055 (MID) and 2085 - 2100 (END) for RCP 4.5 & 8.5
- Model predictions show reductions in the frequencies of the hail sizes from 1 – 3.5cm but increases for giant hail over 4.5cm
- Giant hail is responsible for much of the damage in Australia's multi-billion dollar hailstorms (Sydney, Brisbane, Canberra, Melbourne & Perth)
- There are likely to be declines in the frequency of the less-damaging hailstorms but increases in the most destructive storms



Gensini, V.A., Ashley, W.S., Michaelis, A.C., et al., 2024: Hailstone size dichotomy in a warming world. NPJ Climate and Atmospheric Science, 7, 185

Australian Severe Thunderstorms including Hailstorms

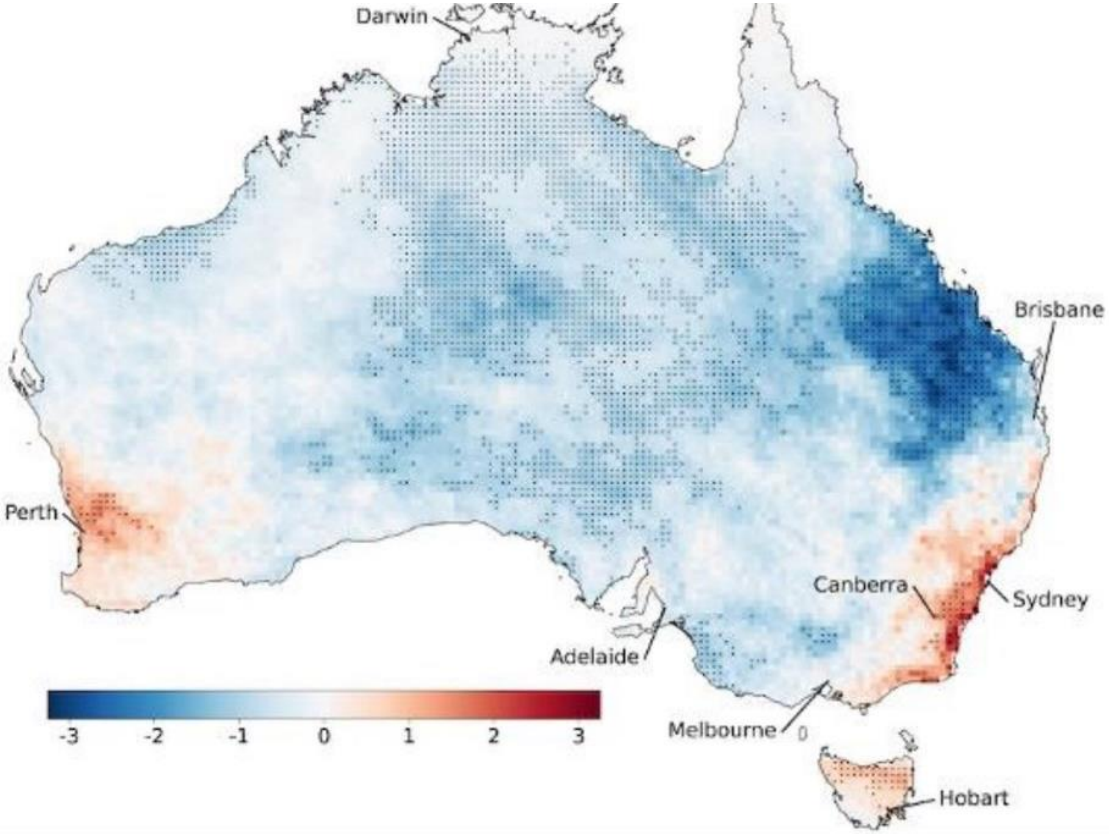
Hail

- Reports of large and giant hail (at least 5cm in diameter), have increased markedly in Australia's largest urban areas over the last several decades
- Southward extension of hail extremes and a significant increase in the number of hailstorms have been observed for the central east Australian coast and should continue
- Higher melting levels in a warming atmosphere will make small hail less frequent but could make large to giant hail more common and/or even larger - giant hail has a higher terminal velocity and melts more slowly

Wind

- Thunderstorm-related wind squalls over central and western Australia have become more common over the past 25 years - wind squall frequency and intensity will likely increase in the future

Trend in Hail Environments 1979 - 2021



Raupach, T.H., Soderholm, J.S., Warren, R.A., and Sherwood, S.C., 2023: Changes in hail hazard across Australia: 1979-2021. npj Climate and Atmospheric Science, 6, 145

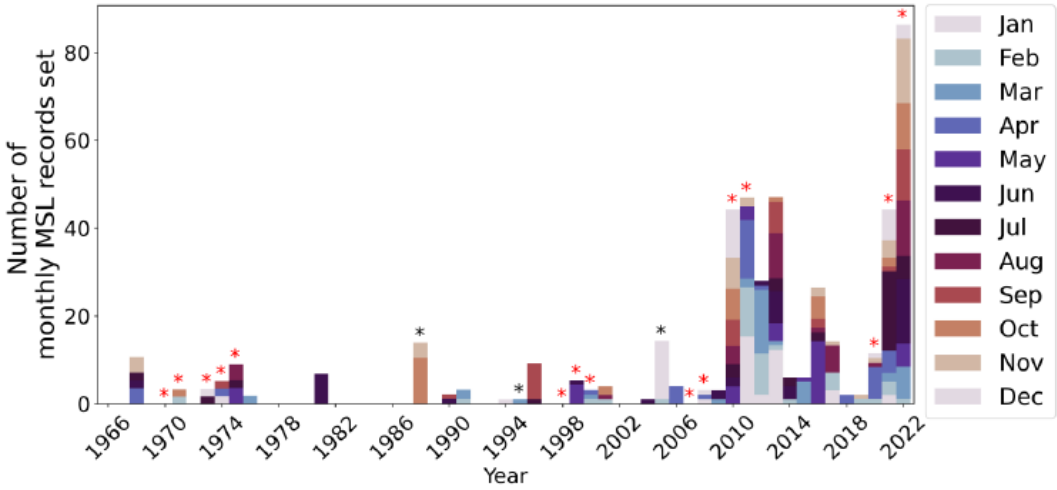
Australian Sea Level Rise

Australian sea level rises have accelerated since 1966. If acceleration continues, the mean Australian sea level (relative to 1995-2014) should be 0.26 +/- 0.03m higher by 2050 and +0.83 +/- 0.20m higher by 2100, following the highest SSP5-85 scenario (Hague et al 2025).

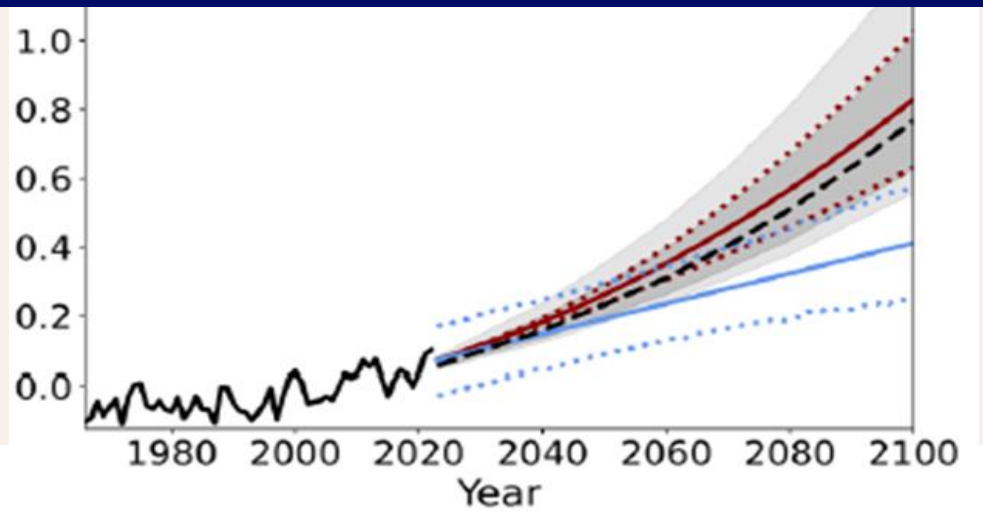
Historically rare extreme sea level events will become annual events by 2050.

Metro Area	Historical 100-yr event (m)	Return Period in 2050 - RCP4.5	Return Period in 2050 – RCP 8.5
Adelaide	3.73	2	1
Perth (Fremantle)	1.91	1	1
Sydney	2.41	3	2

Observed record monthly sea level rise by year



Future sea level rise projections out to 2100 (solid red line) with SSP5-8.5 scenario dashed purple. Add 20cm for sea level rise since pre-industrial. Observed sea levels in black.



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Hague, B.S., Jones, D, West, J and Jakob, D. 2025: Sea level trajectories and recent records at Australian Tide gauges. ES 24039. CSIRO PUBLISHING | JESS

Mid-Latitude Lows (including East Coast Lows)

- Mid-Latitude Lows, including ECLs, have produced some of the greatest damage and highest numbers of insurance claims of any extreme weather events in Australia. The costliest event occurred in March 2022 ($6,119 million insured losses)
- ECL frequency will decline with climate change but there is no sign that the most intense ECLs are becoming less frequent
- Rainfall in ECLs will increase over all time frames, increasing flash and river flood risks

Bushfires

- Extreme fire weather conditions, bushfire extent and fire damage have all increased significantly over the past several decades
- Recent extreme bushfires (2019-20 Black Summer & 2025 LA fires) have exhibited unprecedented behaviours that pose major challenges to firefighting - fire runs can now extend through the night and across multiple days
- Trends show an increased frequency of pyrocumulonimbus, fire tornadoes and other intense fire plumes
- Extreme fire weather frequency, fireline intensity and dryness of vegetation are all projected to increase fire risk significantly during this century

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QUESTIONS

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