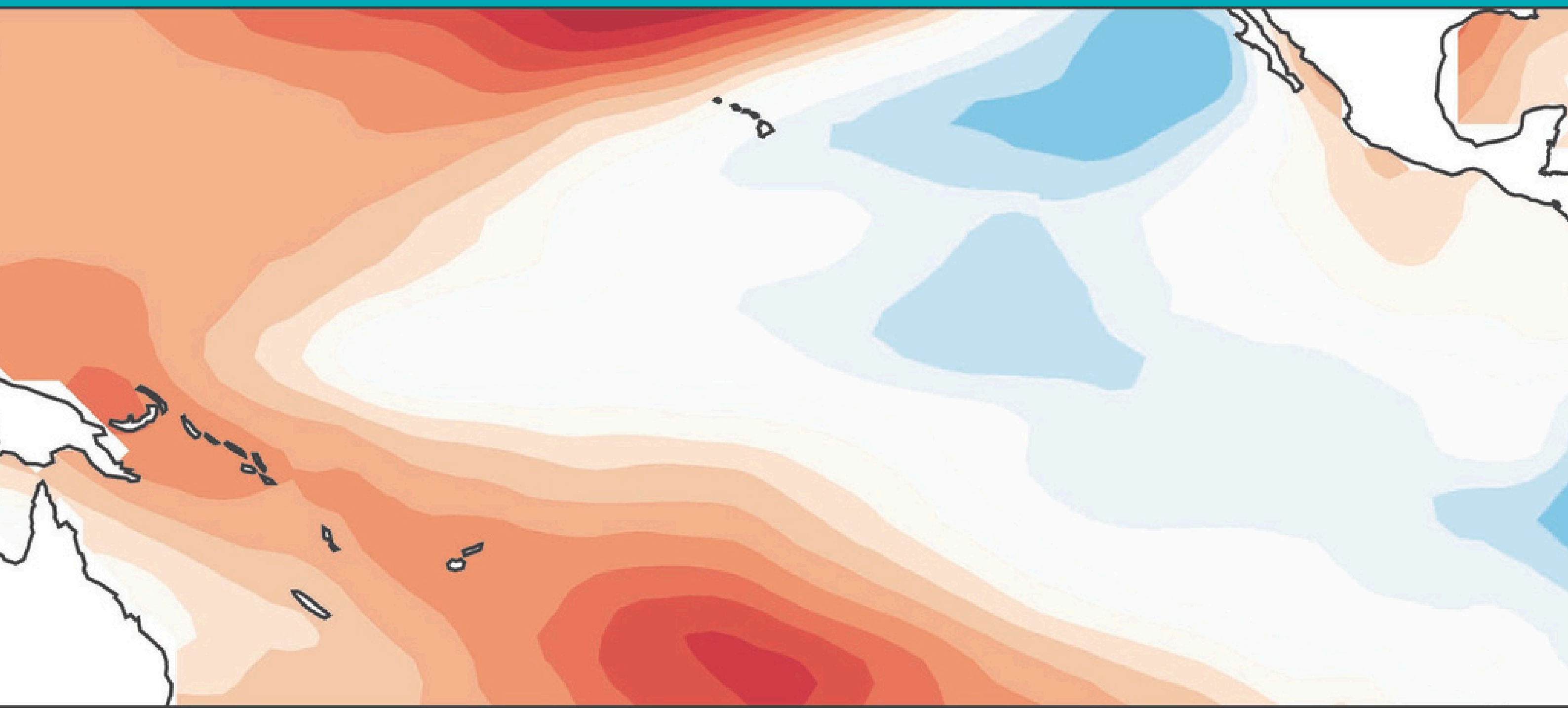
Climate Systems

National Environmental Science Program

What climate models miss about Pacific Ocean changes and why it matters for Australia

May 2026



Andrea S. Taschetto, Christine T. Y. Chung, Huazhen Li, Ghyslaine Boschat, Zoe E. Gillett, Shayne McGregor, Abhik Santra, Sugata Narsey

Sea surface temperatures (SSTs) influence weather patterns and affect the global climate. The tropical Pacific Ocean – the part of the ocean stretching from South America to Australia, along the equator – can shift atmospheric circulation patterns and influence global mean temperatures.

Year-to-year variations in tropical Pacific SSTs during El Niño and La Niña, the two phases of the El Niño–Southern Oscillation (ENSO), influence Australia's rainfall and drive extreme weather events such as storms, heatwaves, droughts, and floods. El Niño is characterized by warming in the central-eastern Pacific Ocean and La Niña by cooling.

As our planet warms, the Pacific Ocean will change significantly, but exactly how remains an active area of research. Both models and observations agree that global temperatures are rising in response to increasing greenhouse gases. However, this warming does not occur uniformly in space. And the pattern of change has important implications for Australia's climate.

While the ocean continues to oscillate between the two phases of El Niño and La Niña, the background warming pattern of the Pacific Ocean since the 1980s has resembled a La Niña-like state, with relatively warmer ocean conditions closer to Australia and stronger trade winds, which blow east to west. However, most global climate models simulate a Pacific Ocean warming pattern that looks more El Niño-like instead, in contrast to the changes observed in the real world.

When models and observations differ, it can mean the climate system is showing us something we need to understand better, which is why Hub researchers are closely examining whether Pacific processes may be missing or misrepresented in climate models.

Pacific ocean pattern scenarios

Based on observed climate trends and climate model projections, there is a spectrum of plausible futures for the Pacific Ocean. These depend on which side of the Pacific the warming pattern emerges, and that ranges between two quite distinct scenarios (Figure 1):

1. where the temperature difference between the east and west Pacific Ocean weakens, along with a weakening of the trade winds, leading to warmer waters across the eastern Pacific, closer to South America – a warming pattern scenario that looks 'El Niño-like'.
2. where this temperature difference and the trade winds strengthen, leading to warming waters mostly in the western Pacific, closer to Australia, and the eastern Pacific Ocean remains cooler by comparison - a warming pattern scenario that looks 'La Niña-like'.

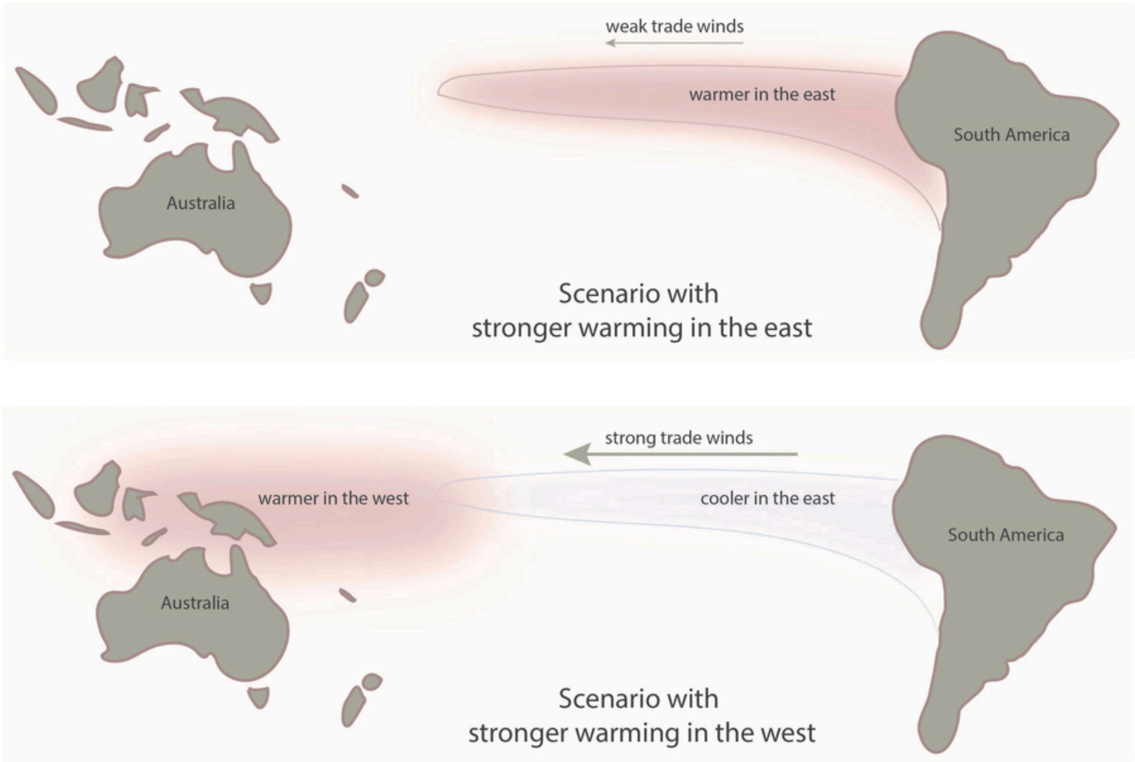


Figure 1. Two possible future warming patterns in the tropical Pacific. In the top panel, warming is stronger near South America and trade winds are weaker (El Niño–like). In the bottom panel, warming is stronger near Australia and trade winds are stronger (La Niña–like). In both cases the entire region warms, but the impacts on Australian climate depend on where the greatest warming occurs.

Projected warming patterns for the Pacific Ocean are sometimes referred to as an El Niño-like pattern or a La Niña-like pattern because they resemble the sea surface temperature structure associated with those ENSO phases. However, the impacts and dynamics are different, and they need to be understood or interpreted differently to the year-to-year variability produced by those phases.

Some examples of the implications of different Pacific Ocean future scenarios could be:

- **Global warming rate:** An El Niño-like shift would speed up global warming because the ocean would absorb less heat, causing air temperatures to rise faster. A La Niña-like shift would temporarily slow global surface warming by absorbing more heat in deeper ocean waters.
- **Rainfall and drought patterns:** Sectors such as agriculture, energy, and tourism, and our general ways of living, have been shaped under a relatively stable past climate with predictable rainfall patterns. An El Niño-like future suggests a shift of rainfall away from areas like Australia and Indonesia, while potentially bringing more rain to southern parts of South America. Conversely, a La Niña-like future could potentially intensify current rainfall patterns, causing stronger wet seasons in Asia and Australia, but worsening drying conditions elsewhere.
- **Extreme weather events:** An El Niño-like shift could mean more frequent severe droughts or floods in certain regions, whereas a La Niña-like scenario might intensify storms and droughts in different areas. Tropical cyclones could become more frequent to the northeast and northwest of Australia under a La Niña-like scenario.
- **Marine life and ecosystems:** Fish populations, coral reefs, and ocean biodiversity all depend on stable Pacific Ocean temperature patterns. Warmer, less nutrient-rich waters of an El Niño-like mean state could threaten coral reefs through persistent heat stress. In contrast, a La Niña-like state might increase the risk of marine heatwaves off the west coast of Australia.

What climate models are projecting about tropical Pacific sea surface temperatures

Climate adaptation decisions are based on future scenarios of greenhouse warming simulated by global climate models. This means that reducing climate projection uncertainties and understanding the processes behind climate change are crucial for decision-making and future planning. While most climate models project a tropical Pacific warming pattern that is El Niño-like (Figure 2 bottom row), these projections span a range of magnitudes (and even directions) of warming (Ying et al. 2025). Some models project only a very slight weakening of the east to west Pacific sea surface temperature difference, and a few models have even shown near-neutral or weakly La Niña-like (the opposite) patterns under certain scenarios (Lee et al. 2022). For the latest climate models in the Coupled Model Intercomparison Project phase six (CMIP6), however, virtually no model produces a La Niña-like trend (Cai et al. 2021).

Interestingly, real-world observations have shown the opposite trend in recent decades (Fig. 2, top row). Since 1980, the east to west ocean temperature difference has increased, with relative cooling in the east and an intensification of the trade winds, resembling a La Niña-like pattern. This observed pattern is not well-simulated in climate models (Seager et al. 2022; Fig. 2 middle row). This discrepancy suggests that the cooling trend we are witnessing in the eastern tropical Pacific is either incredibly rare or there is a gap in the models.

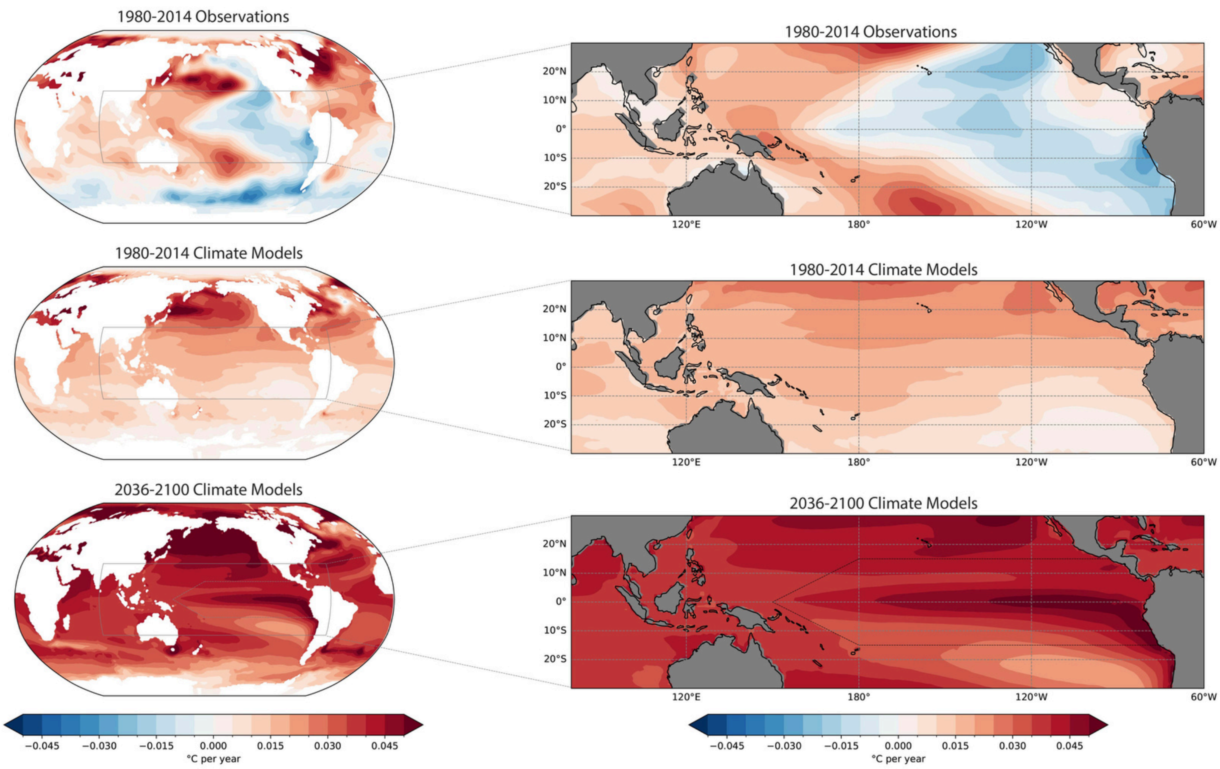


Figure 2: Sea surface temperature (SST) trends in climate models and observations. Top row: Observations (based on ERSSTv5 data) between 1980 and 2014. Middle row: CMIP6 multi-model mean for the period 1980 to 2014. Bottom row: Projected CMIP6 SST trends for the period 2036 to 2100. Global (left panels) and tropical Pacific (right panels) regions are presented. Warmer colours indicate warming SSTs and cooler colours indicate cooling SSTs.

Do we know which projection is more likely?

While the spatial pattern of the Pacific Ocean warming trend is difficult to accurately project, there is no doubt global mean temperatures will continue to rise in the next decades.

The fact that the observed eastern tropical Pacific Ocean cooling (the La Niña-like pattern) is not captured by the current generation of climate models suggests that critical processes influencing the Pacific climate might be missing or are misrepresented in climate models. But there is also a possibility that the current observed trend is simply part of our climate's natural variability and that the models simply under-represent the range of that variability. Or it could be a combination of both. Understanding possible changes in Australia's temperature and rainfall patterns in the future is crucial to adaptation planning, so it is more important than ever to understand what is contributing to the model and observation discrepancies.

Researchers in the Hub are puzzled by this inconsistency between models and observations. Given how significant the future warming is for Australia's agriculture, water availability and community wellbeing, the Hub researchers are determined to get to the bottom of this issue. The questions they are posing:

- Where and how are the models and observations different?
- Why are climate models not simulating the observed trends in SSTs? What is missing in the models?
- How is the existing trend of La Niña-like warming affecting rainfall patterns already?
- What ocean processes lead to the warming and cooling patterns and what effect would they have on Australia in the future?

What do these patterns mean for Australia?

Australian weather and climate are significantly influenced by what happens in the tropical Pacific. Up to 50% of Australia's rainfall variability can be explained by a combination of climate influences with ENSO being the most important across the country, including over large parts of Queensland, New South Wales, Victoria, and Northern Territory (Chung et al. 2023; Hobeichi et al. 2024; Boschat et al. 2025; Figure 3 – darker red areas).

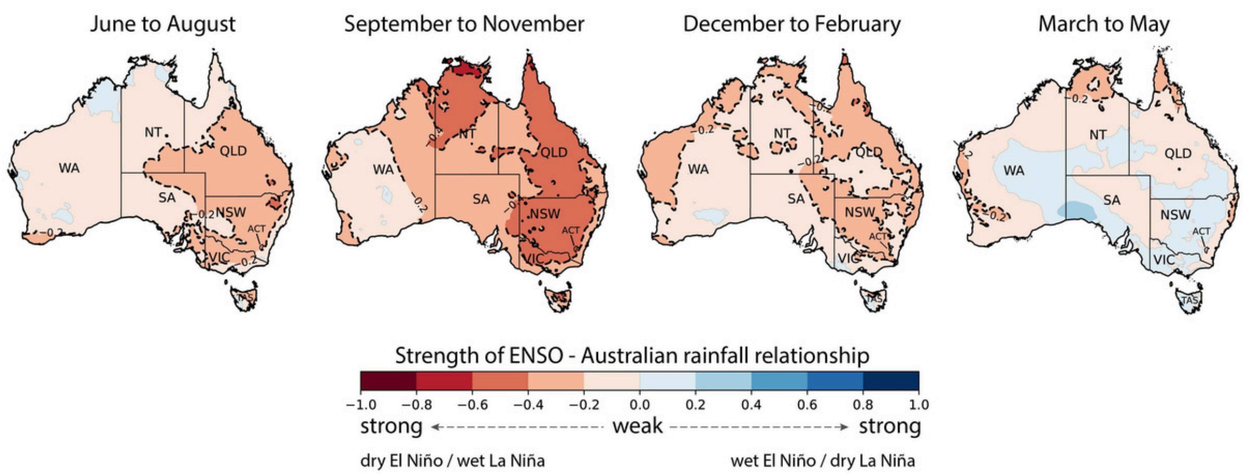


Figure 3: Relationship (measured by correlation coefficients) between El Niño/La Niña conditions in the tropical Pacific Ocean (based on the Niño3.4 index) and rainfall across Australia. Source: Huang et al. 2023. Darker colours show where this relationship is stronger. Warm (red) colours indicate a strong relationship between El Niño and below average, or drier, rainfall seasons, and La Niña with above average, or wetter, rainfall seasons

While El Niño increases the chance of dry weather in winter and spring and La Niña typically brings increased rainfall over much of Australia (Gillett et al. 2023; Chung et al. 2023; McGregor et al. 2024), their impacts can vary. No two El Niño or La Niña events are the same, and their links to Australian rainfall depend on the background state of the Pacific Ocean that also undergoes natural decade-to-decade swings between cooler and warmer phases known as the Interdecadal Pacific Oscillation (IPO). During the cooler Pacific Ocean SST decade, or negative IPO, the influence of ENSO on Australian rainfall is amplified. This means that rainfall associated with La Niña, and drying conditions related to El Niño, are usually more intense than they would otherwise be during these decades.

Recent Climate Systems Hub research has shed light on some of the nuances of this relationship (Tozer et al. 2023; Huang et al. 2024; Sengupta et al. 2025; see Taschetto et al. 2025 for a review). For example, where the water warms most in the tropical Pacific Ocean matters: some El Niño events may bring very dry conditions to Australia, others have a weaker impact. In recent years, eastern Australia has experienced extreme heatwaves, droughts and floods with swings from back-to-back El Niño events (2019–2020) to three consecutive La Niña years (2020–2022), all of which occurred during cooling Pacific SST background.

Whether the tropical Pacific Ocean moves to a more El Niño-like or La Niña-like state in the future could have significant impacts on the frequency and intensity of ENSO events, which in turn can lead to unexpected shifts in regional climate patterns and rainfall variability. This matters for future decisions including about how we live, farm and manage water.

What does this mean for climate change policy and adaptation planning?

Improving climate model representation of Pacific Ocean processes will have far-reaching consequences for improving regional or localised climate projections that are crucial for informing adaptation policy and strategies.

The current assumption, based on climate models, is that a warmer global climate will lead to a warmer tropical Pacific Ocean mean state. However, the recent cooling trend in the eastern Pacific seen in observations suggests the possibility of a future scenario in which Pacific Ocean SSTs warm less than the other tropical ocean basins. This scenario is not reflected in climate model simulations, which limits our confidence in having a comprehensive set of projections of all possible future climates.

If the observed trends in the tropical Pacific Ocean continue to persist in the future, the behaviour of El Niño and La Niña, as well as their influence on Australian climate, may change. This uncharted climate state might produce unforeseen consequences for Australian weather systems, affecting, for example, agriculture, water resources, and natural ecosystems.

Given the likely changes for our climate under an El Niño-like future scenario or a La Niña-like future scenario, we urgently need additional focused research to understand the implications of both these futures. Since virtually none of the models currently project a La Niña-like future, this means we need to conduct new simulations in order to quantify some of these potential differences.

Understanding the Pacific Ocean's future is ultimately about safeguarding Australia's liveability for the decades ahead so planning now for a range of possible climate futures helps protect those communities and investments.

The Climate Systems Hub is actively addressing this current gap by analysing why models and observations differ, running targeted experiments, and testing how different Pacific futures would change Australia's rainfall and climate extremes so decision makers can act with greater confidence.

Please cite as: Taschetto A.S., Chung, C.T.Y., Li, H., Boschat, G., Gillett, Z.E., McGregor, S., Santra, A., Narsey, S. Understanding how changes in the Pacific Ocean can influence our future climate, National Environmental Science Program Climate Systems Hub, Australia.

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