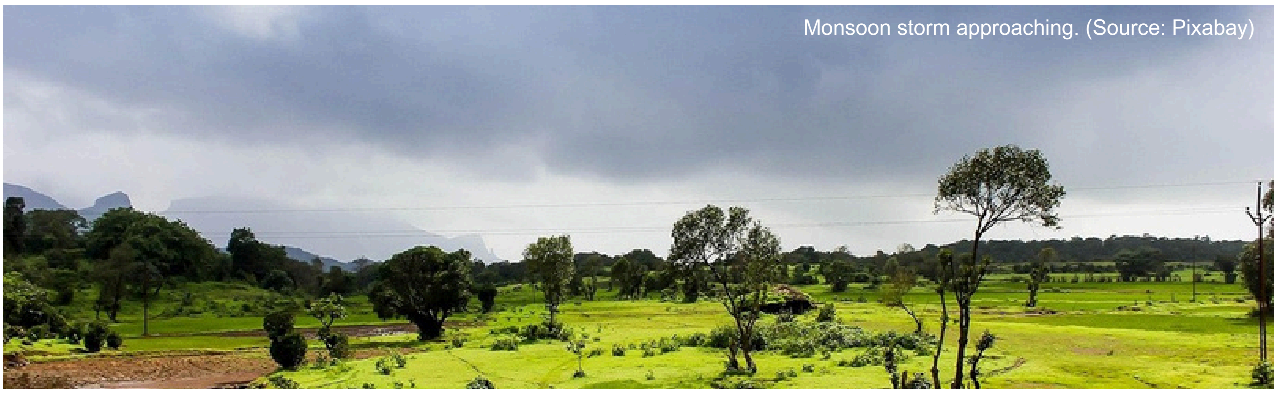
Understanding rainfall variability over northern Australia

Research by the Climate Systems Hub is working on improving our understanding of the reasons behind strong rainfall variability during the 'wet season,' from October to April, with a focus on year-to-year fluctuations.



Monsoon storm approaching. (Source: Pixabay)

Rainfall in northern Australia varies greatly from month to month, year to year, and even decade to decade. This fact sheet highlights research on the key drivers of this variability.

In spring and early summer, rainfall is influenced by El Niño–Southern Oscillation (Figure 1) and local sea surface temperatures. During the summer monsoon, particularly in the northwest, the oceanic wind-evaporation feedback becomes the dominant factor. These findings are crucial for farmers and pastoralists as they navigate the challenges of a warming climate, helping them plan for future productivity and economic sustainability.

High rainfall variability – but why?

Northern Australia receives most of its annual rainfall from October to April. Much of this rain is due to the summer monsoon associated with the tropics. The monsoon is a seasonal shift in the large-scale atmospheric circulation and a reversal in wind direction near the Earth's surface. The change brings westerly wind bursts accompanied by persistent rain over northern Australia. This monsoonal pattern of winds and rain tends to occur between late December and mid-March.

Prior to the monsoon onset and after its retreat, northern Australia experiences a drier, easterly wind regime. Because of this seasonal cycle, the causes of rainfall and its variability over northern Australia change substantially between the months prior to, during, and after the monsoon takes place.

But there is more to the story of northern Australia's rainfall. Climate drivers play a key role in both short and long-term variations of rainfall over the region. These drivers include the Madden–Julian Oscillation, the El Niño–Southern Oscillation, the Indian Ocean Dipole, the Southern Annular Mode and the Interdecadal Pacific Oscillation.

For example, during La Niña, northern Australia often experiences above-average rainfall in spring to early summer and again in autumn. Moisture recycling, vegetation and wind-induced evaporation over the ocean surface are also understood as having an impact on rainfall. Figure 1 depicts these climate drivers and their influence on northern Australia.

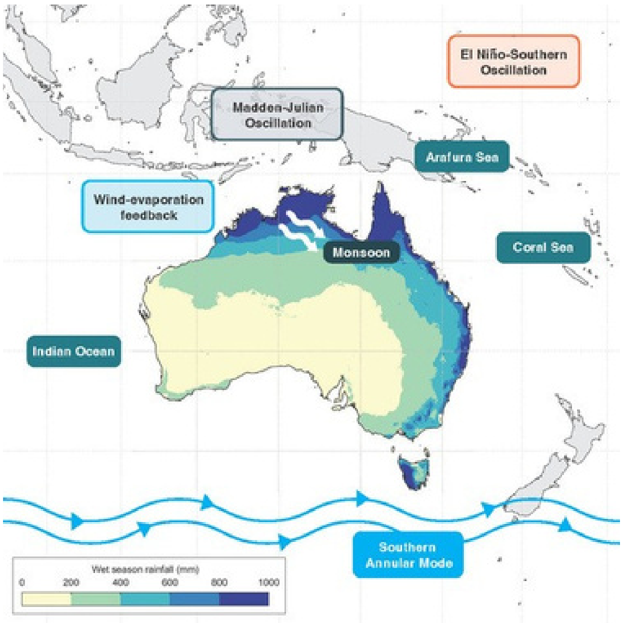


Figure 1 The different climate drivers influencing rainfall variability in northern Australia during the wet season. Adapted from Figure 1 in Heidemann et al. (2023): Main drivers for rainfall variability over northern Australia during the monsoon season.

Understanding rainfall patterns in northern Australia is complex, as many of these processes interact and vary in their influence throughout the wet season. Climate Systems Hub research is identifying key climate drivers affecting rainfall in the northwest and northeast, measuring their impact month by month. These findings improve our understanding of rainfall variability in the region.

The most important driving factors for rainfall

Based on data from the last 100 years, around 80% of the annual rainfall over northern Australia along with the highest variability in rainfall, occurs during the monsoon season (December to March).

This is illustrated in Figure 2, which shows the average rainfall and range in rainfall during each month for northwest and northeast Australia across the months of the year, using data collected from 1920 to 2023.

Hub researchers have identified the main causes for rainfall variability and how they differ between northwest and northeast Australia by building a statistical model that selects the most important predictive variables for rainfall in each month (called stepwise linear regression).

The results have helped build an understanding of the most important climate drivers for rainfall, for both northwest Australia and northeast Australia, and these are discussed in the next sections.

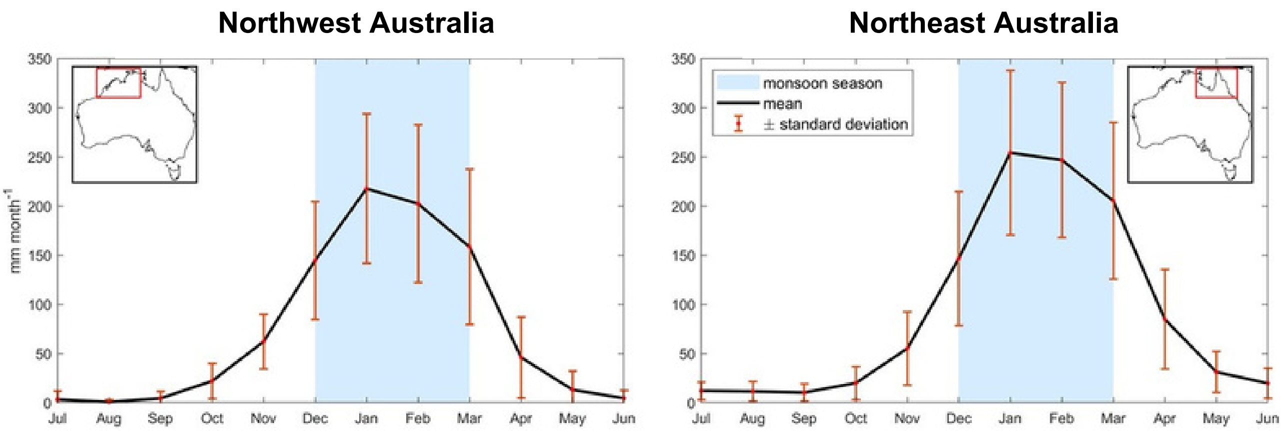


Figure 2 Graph of rainfall averages for both northwest (left panel) and northeast (right panel) Australia shows that the range in how much rainfall occurs each month (shown by the red vertical lines) is greater during the monsoon season (highlighted in blue). That is, there is more variability in rainfall during this time of the year. The average seasonal rainfall cycle is shown by the black line, using data from 1920–2023.

Drivers of variability in Northwest Australia

Over northwest Australia, the research indicated that rainfall variability is linked to several processes and climate drivers. These are summarised in the table below.

Season	Rainfall variability influence	Variability findings
Pre-monsoon (October and November)	El Niño–Southern Oscillation (ENSO)	Contributes up to 50% of the rainfall variability • ENSO is associated with changes in sea surface temperatures in the equatorial Pacific Ocean, affecting weather patterns in Australia
	Local sea surface temperatures (Coral and Arafura Seas)	The second most important factor in rainfall variability, accounting for up to 10% of variability • When the temperature of the ocean surface is warmer, this leads to more moisture availability in the atmosphere and the formation of clouds, which can lead to more rainfall on land areas nearby
Monsoon (December to March)	Wind-evaporation feedback	Fluctuations of the feedback explain around 30-40% of the total rainfall variability • Occurs when evaporation from the ocean north of Australia, caused by monsoonal westerly winds, drives moisture towards the Australian continent and enhances rainfall • The only process that explains some (about 30%) year-to-year variability in January, making it the most uncertain month
	Madden–Julian Oscillation (MJO)	Contributes up to 20% of rainfall variability in December and February • MJO influences where in the tropical regions large-scale convection and rainfall occurs • When MJO is in phases 4, 5 or 6, this means there is more convective activity, and a higher likelihood of rainfall near northern Australia (when in phases 1 or 8, it's the opposite)
	Indian Ocean sea surface temperatures	Contributes around 20% of variability in February
	ENSO	Contributes about 30% of variability in March

Drivers of variability in Northeast Australia

Over northeast Australia, the most important factors for rainfall variability indicated by the research are summarised in the table below.

Season	Rainfall variability influence	Variability findings
Pre-monsoon (October and November)	Coral Sea sea surface temperatures	Contributes approximately 30% of variability in October and 25% of November rainfall variability
	El Niño–Southern Oscillation (ENSO)	Contributes around 30% of variability in November • Strongest predictor for rainfall variability in November
Monsoon (December to March)	Wind-evaporation feedback	The most consistent predictor for variability for this region • Contributes a smaller proportion to variability than for northwest Australia, generally between 15% and 25%, except for March where it is around 40%
	ENSO	Contributes approximately 25% of variability in December and 10% of variability in March
	Indian Ocean sea surface temperatures	Contributes around 15% of variability in February
	Preceding April-May Southern Annular Mode	Contributes a small proportion (up to 15%) of variability in January and February
	Madden–Julian Oscillation (MJO)	Contributes up to 20% of variability in February

What we can say about rainfall variability in northern Australia

The hub's research has evaluated the influence of many climate drivers and processes on northern Australian rainfall and shown changes associated with them throughout the wet season when most of the annual rainfall occurs.

We also highlight regional differences between the northwest and northeast of Australia.

The research shows that the El Niño–Southern Oscillation, as well as local sea surface temperatures north of Australia, have the strongest connection to rainfall variability over northern Australia in spring and early summer.

After the onset of the summer monsoon, the oceanic wind-evaporation feedback dominates the rainfall variability until the monsoon retreats.

The influence of this feedback is particularly strong over northwest Australia, while the northeast retains more influence from remote climate drivers such as the El Niño–Southern Oscillation.

For both the northwest and northeast regions, our research suggests that rainfall is more predictable pre-monsoon due to the strong influence of climate drivers and local ocean temperatures, while these drivers play less of a role during the monsoon season.

Future opportunities and next steps

Hub researchers have shared preliminary findings with northern Australian decision-makers, including pastoralists concerned about drought and heat stress on livestock. Confidence in future monsoon rainfall projections remains low, as climate models disagree on whether the region will become wetter or drier over the next century.

Our research shows that remote climate drivers have little impact on monsoon rainfall variability. While local ocean temperatures play a role before the onset of the monsoon, they are unreliable predictors during the monsoon season due to their direct response to monsoonal westerly winds. This makes it challenging to explain year-to-year monsoon rainfall variations.

To support decision-making, upcoming hub research will examine how wind evaporation feedbacks influence monsoon rainfall variability and assess climate models' ability to capture key drivers of northern Australian rainfall. This will help identify the most reliable models for projecting rainfall changes, providing greater confidence for future planning.

What is the wind-evaporation feedback and how does it impact rainfall in northern Australia?

The wind-evaporation feedback is a process that sustains itself through the monsoon season and reinforces rainfall. Stronger monsoonal westerly winds over the ocean's surface near northern Australia increase evaporation, adding more moisture to the atmosphere. At the same time, these winds also cool the underlying ocean's surface.

The additional atmospheric moisture is then transported onshore towards the Australian continent, enhancing cloud formation and rainfall. As a result, stronger monsoonal winds lead to heavier rainfall over land. This cycle helps sustain the monsoon, and it can vary from year to year. Recent research suggests that the wind-evaporation feedback is a key source of interannual variability of the Australian monsoon.

For further details, read **What drives interannual rainfall variability over northern Australia?**

Visit **www.nesp2climate.com.au**
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References

Chung, C., & Power, S. B. (2017). The non-linear impact of El Niño, La Niña and the Southern Oscillation on seasonal and regional Australian precipitation. Journal of Southern Hemisphere Earth Systems Science, 67(1), 25–45. https://doi.org/10.22499/3.6701.003

Heidemann, H., Cowan, T., Henley, B. J., Ribbe, J., Freund, M., & Power, S. (2023). Variability and long-term change in Australian monsoon rainfall: A review. Wiley Interdisciplinary Reviews: Climate Change. https://doi.org/10.1002/wcc.823

Hendon, H. H., Lim, E. P., & Liu, G. (2012). The role of air-sea interaction for prediction of Australian summer monsoon rainfall. Journal of Climate, 25(4), 1278–1290. https://doi.org/10.1175/JCLI-D-11-00125.1

Narsey, S. Y., Brown, J. R., Colman, R. A., Delage, F., Power, S. B., Moise, A. F., & Zhang, H. (2020). Climate Change Projections for the Australian Monsoon from CMIP6 Models. Geophysical Research Letters, 47(13), 1–9. https://doi.org/10.1029/2019gl086816

Sekizawa, S., Nakamura, H., & Kosaka, Y. (2023). Interannual Variability of the Australian Summer Monsoon Sustained through Internal Processes: Wind-Evaporation Feedback, Dynamical Air-Sea Interaction, and Soil Moisture Memory. Journal of Climate, 36(3), 983–1000. https://doi.org/10.1175/JCLI-D-22-0116.1

Sharmila, S., & Hendon, H. H. (2020). Mechanisms of multiyear variations of Northern Australia wet-season rainfall. Scientific Reports, 10, 1–11. https://doi.org/10.1038/s41598-020-61482-5

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Houses flooded after historic rainfall. (Source: Roschetzky IstockPhoto)