Earth Systems and Climate Change Hub

National Environmental Science Programme

Our changing climate

How will rainfall change in Northern Australia over this century?

Climate change means that the past climate of Northern Australia is no longer a reliable indicator of future climate conditions.

Our warming world is affecting a range of climate processes, including those responsible for rainfall in Northern Australia. Rainfall change and variability can have huge environmental, social and economic impacts across Northern Australia, especially when linked to extreme events. Water, energy, infrastructure, transport, industry, regional development, agri-business and tourism will all be affected.

Understanding how these processes are changing, and what this means for the timing and amount of rainfall, is important information for development and planning decisions.

What influences rainfall in Northern Australia?

The vast majority of rainfall over northern Australia falls in the summer 'wet season', due to the Australian monsoon. The monsoon onset occurs when the easterly trade winds reverse, becoming moisture-laden westerlies. This usually happens in late December and the monsoon persists until April. The winter months (May to November) are climatologically dry.

However, there is enormous variability in rainfall both from year to year ('interannual') and within each individual wet season ('sub-seasonal'). For example, the total amount of rainfall received each wet season can vary by up to a factor of three.

Periods of relatively wet or dry conditions within a wet season are known as monsoon **'bursts' and 'breaks'**, respectively. There is large variability in the number of monsoon bursts from year to year and in the time interval between consecutive monsoon bursts.

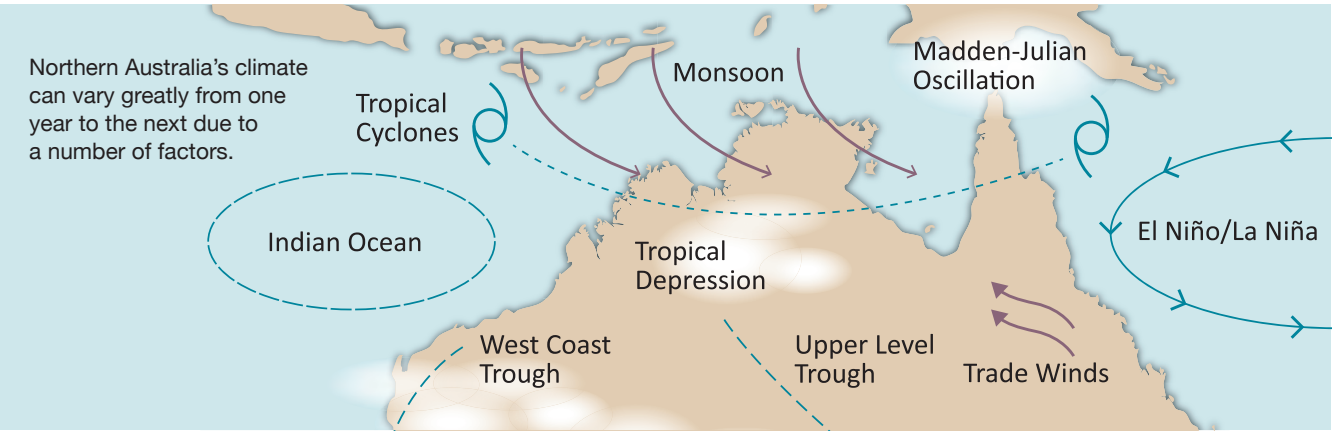
Monsoon bursts are more likely to occur when the active phase of the **Madden–Julian Oscillation (MJO)** is in the vicinity of Australia. The MJO is as an eastward moving 'pulse' of cloud and rainfall near the equator that typically recurs every 30 to 60 days. It originates mostly in the equatorial Indian Ocean and travels eastward across tropical Australia then on into the Pacific Ocean. The MJO influences tropical weather on a timescale of weeks to months. In between these pulses of the MJO, the monsoon westerly flow can become quite weak or even reverse and periods of no or little rain (monsoon breaks) occur before the next burst brings another significant rainfall event.

The changes in atmospheric circulation at the start of the rainfall burst can also be influenced by **mid-latitude weather systems (e.g. cold fronts)** bringing moisture from the mid-latitudes into the monsoon region.

The arrival of the eastward-moving MJO as well as the intrusion of middle latitude systems are identified as the primary triggers of the onset of the **Australian monsoon**. The average monsoon onset date across all years in the vicinity of Darwin is around 25 December. However, the onset is also influenced by the **El Niño–Southern Oscillation (ENSO)**, typically occurring later during El Niño years and earlier during La Niña.

Several recent studies[1] suggest that the **Indian-Ocean Dipole (IOD)** – an east-west see-sawing of temperatures in the Indian Ocean – also affects the monsoon development, especially the onset of the Australian monsoon which often happens following the peak of the IOD.

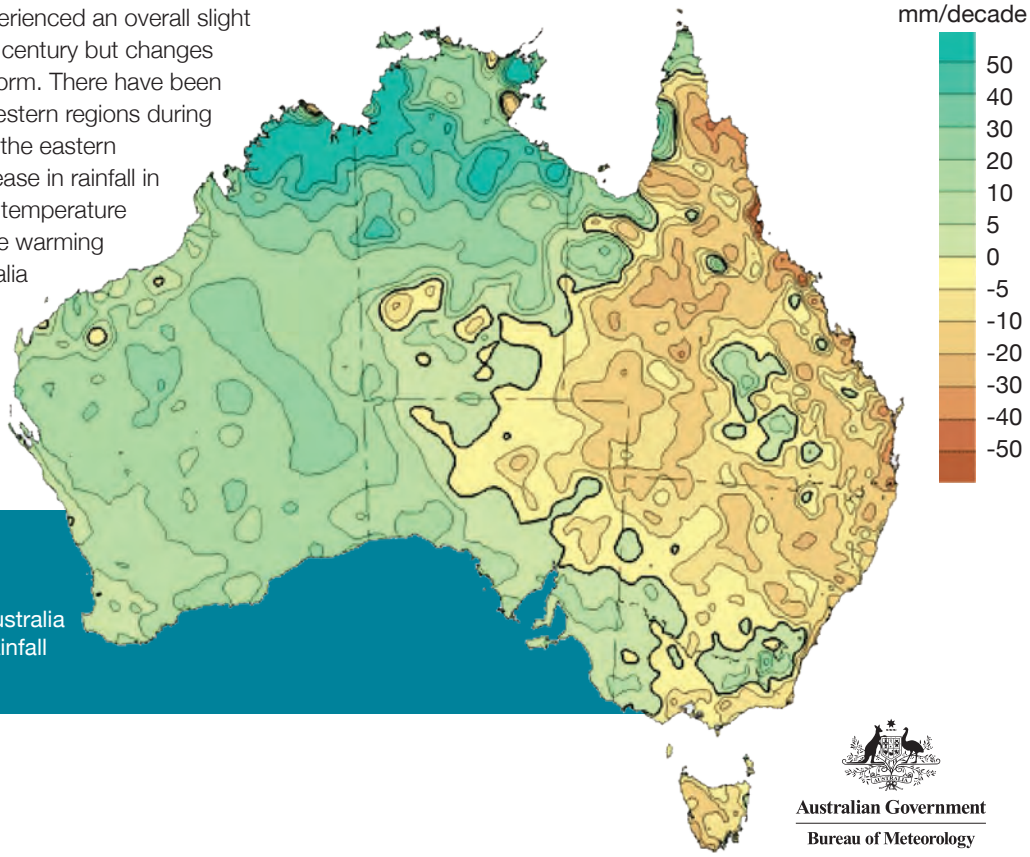
Tropical cyclones often originate over the ocean near the 'monsoon trough' and can then travel towards northern Australia, bringing extreme rainfall to surrounding areas. For some regions across tropical Australia, rainfall from tropical cyclones can on average contribute up to 30% to the annual rainfall amount.



1. See references in Zhang H and Moise AF (2016) The Australian Summer Monsoon in Current and Future Climate. In: *The Monsoons and Climate Change – Observations and Modeling*. (Eds LMV de Carvalho and C Jones), Springer, pp 67–120

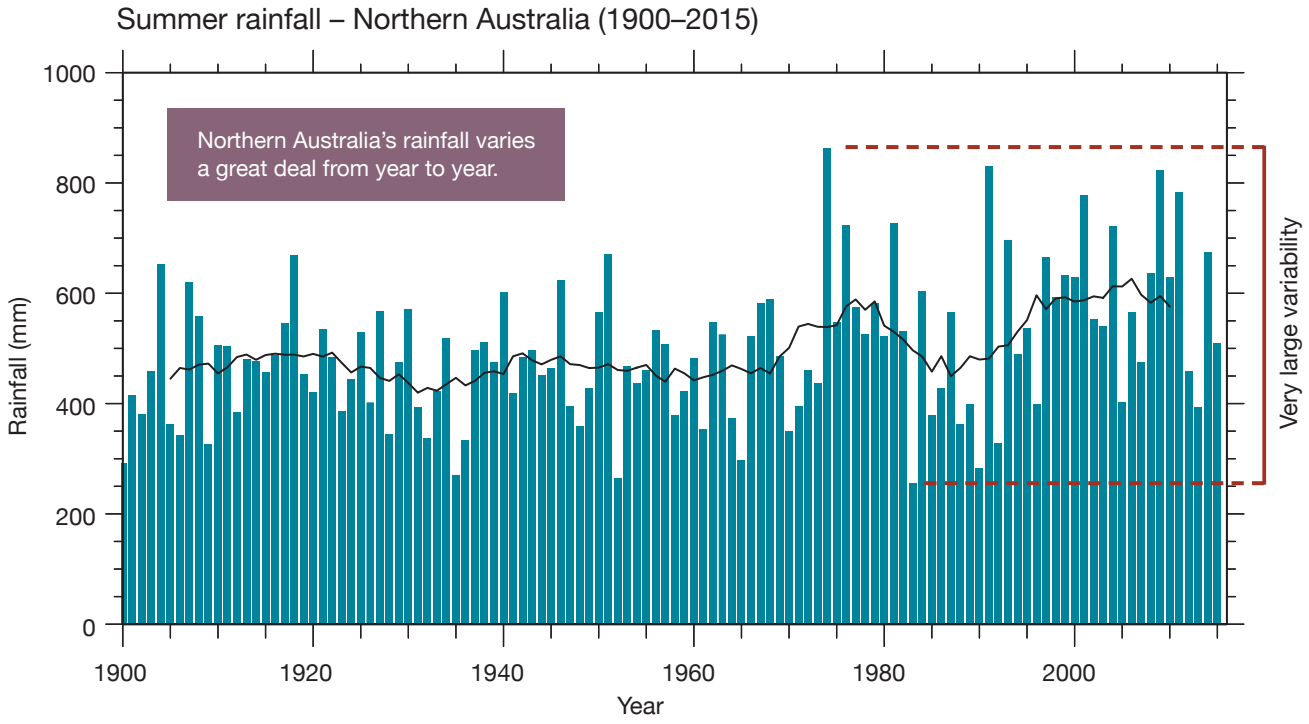
Rainfall in Northern Australia over the 20th century

Northern Australia as a whole experienced an overall slight increase in rainfall during the 20th century but changes have not been geographically uniform. There have been marked increases across north-western regions during recent decades, but decreases in the eastern sector over Queensland. The increase in rainfall in the north-west has influenced the temperature trend over this region, reducing the warming trend over parts of northern Australia compared with the surrounding region.[2] Superimposed on these longer-term changes is large year-to-year variability, which is strongly influenced by the El Niño–Southern Oscillation.



Trend in rainfall
December–February 1970–2016

Since 1970, the north-west of Australia has become wetter while total rainfall in the north-east has decreased.



2. Grose, M.R., Risbey, J.S. and Whetton, P.H. (2017) Tracking regional temperature variations from the early 1990s in the light of variations in regional warming, including 'warming holes'. *Climatic Change*, 140: 307-322, doi:10.1007/s10584-016-1840-9.

Northern Australian rainfall in the 21st century

Will the wetting trend continue?

The increasing rainfall observed over north-western Australia over the 20th century is thought to be mainly due to natural variability, with some possible influence from greenhouse gases and aerosols (tiny airborne particles of soot and dust) from industrial pollution across Asia and globally.

Northern Australian rainfall will continue to be strongly influenced by natural year-to-year and decade-to-decade variability over the coming century. As global warming due to greenhouse gases increases, beyond around 2030, changes in average rainfall may occur in response to this warming.

However, projections of average rainfall over northern Australia are inconclusive – some climate models show increases while others show decreases. By 2090, annual rainfall differences of up to 25% are projected under the high emissions scenario (RCP8.5), but some climate models indicate this will be a decrease while others indicate an increase.

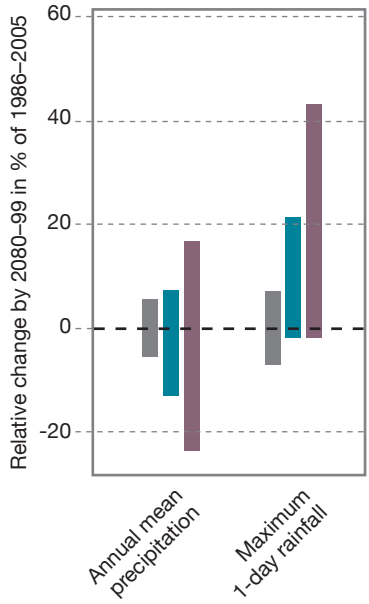
We can improve our confidence in climate projections by analysing the model simulations to determine which are most realistic. For example, we have more confidence in models that show a wetter or little changed Australian monsoon because the climate models that show a drier Australian monsoon in the future tend to have sea-surface temperatures that are too cold in the western Pacific in the current climate.[3] (Sea-surface temperatures influence rainfall patterns, particularly in the tropics.)

How will the warming climate affect rainfall variability and extremes?

We have high confidence that rainfall variability will increase, and that extreme rainfall events will become more intense. Rainfall will be more variable across all time scales – from day to day, month to month and year to year.[4] This is mainly because the warming atmosphere will hold more moisture, so when it rains it will get heavier.

Given the importance of ENSO for rainfall in northern Australia, it is worth noting that there is some indication that extreme El Nino and La Nina events will be more frequent in a warmer climate[5] and that the rainfall extremes due to ENSO will become more intense.[6]

Tropical cyclones are projected, with medium confidence, to occur less often, but with a greater proportion of high intensity storms (bringing stronger winds and greater rainfall).



Mean rainfall change is uncertain for both low (blue bar) and high (red bar) emissions scenarios. Increases in extremes, such as maximum one-day rainfall, are much more confidently projected for low and high emissions cases. The grey bars show the year-to-year variability.

Mike Rosel, Bureau of Meteorology

3. Brown J.R., Moise A.F., Colman R. and Zhang H. (2016), Will a warmer world mean a wetter or drier Australian monsoon? Journal of Climate, 29, 4577–4596, doi:10.1175/JCLI-D-15-0695.1.
4. Brown J.R., Moise A.F. and Colman R.A. (2017), Projected increases in daily to decadal variability of Asian-Australian Monsoon Rainfall. *Geophysical Research Letters*, 44, 5683-5690, doi:10.1002/2017GL073217.
5. Cai, W. and co-authors (2014), Increasing frequency of extreme El Nino events due to greenhouse warming, Nature Climate Change, 4, 111-116, doi:10.1038/nclimate2100; Cai, W. and co-authors (2015), Increased frequency of extreme La Nina events under greenhouse warming, *Nature Climate Change*, 5, 132-137, doi:10.1038/nclimate2492.
6. Power, S., F. Delage, C. Chung, G. Kociuba and K. Keay (2013), Robust twenty-first century projections of El Nino and related precipitation variability, *Nature*, 502, 541-545, doi:10.1038/nature12580.

Why is it difficult to model northern Australian rainfall?

There are several reasons that climate models disagree about the direction of future changes in northern Australian rainfall (wetter or drier). Firstly, models are not able to reproduce all the details of the current climate correctly, including the spatial pattern and timing of rainfall. For example, models may have overly cold sea surface temperatures nearby in the tropical Pacific, which causes rainfall amounts to be too low over northern Australia. The details of tropical convection, which is the main source of monsoon rainfall, are also not easy to simulate in models which have grid spacing of around 100-300 km, larger than many tropical storm systems.

Modelling the balance between different influences on future monsoon rainfall is also difficult. Higher temperatures will lead to more moisture in the atmosphere, which supports heavier rainfall on average. However, the warming climate also tends to slow the circulation of the atmosphere in the tropics, weakening the upward motion that produces rainfall in the monsoon regions. In addition, future reductions in aerosols (tiny particles produced by industrial pollution) are likely to cause regional shifts in rainfall and temperature that favour a drier Australian monsoon. Other shifts in the atmospheric circulation, such as changes in wind strength or direction, may also change where the bands of heaviest rainfall occur. Some of these factors will lead to increased Australian summer monsoon, while others will have the opposite influence – and the relative importance of each factor may be different in different climate models.

While climate models do not show clear agreement on future changes in total summer monsoon rainfall, almost all models agree on changes in extremes and variability. Scientists are working to better understand the sources of uncertainty in rainfall changes, and to narrow the range of likely future change.

Northern Australia's warming climate

Rainfall changes are not occurring in isolation. They are happening against a backdrop of broader climate change that they influence and are influenced by.

For example, increases in mean temperature allow the atmosphere to hold more moisture, leading to heavier rainfall events. At the same time, this increase in temperature modifies the larger circulation patterns in the atmosphere, which could lead to a change in strength and location of wind regimes. All this will influence how water is distributed across tropical Australia with follow-on effects on humidity, evaporation, storms, flooding and bushfires.

Mean temperatures in northern Australia have increased by around 0.9°C between 1910 and 2013, although areas of north-west Australia have seen a decrease in mean temperature since 1960, due in part to increases in cloudiness.

Temperatures in Northern Australia are projected to continue to rise throughout the 21st century. The rate of warming will depend on the concentration of greenhouse gases in the atmosphere. In the near term (that is, to 2030), the warming will be 0.5°C to 1.3°C with only small differences for different emissions scenarios. In contrast to the case for rainfall, the warming is large compared with year-to-year variability in temperature.

The effect of greenhouse gas concentration is much more pronounced by the end of the century. Under a high emissions scenario (RCP8.5) projected warming for 2090 is 2.8°C to 5.1°C (compared to the period 1986–2005). Under a lower emissions scenario (RCP4.5), expected warming is 1.3°C to 2.7°C.

Northern Australia can also expect changes to temperature extremes with substantial increases in the number of warm spell days and in the hottest days of the year. There will also be an increase in the number of days with maximum temperatures above a threshold such as 35°C and 40°C. For example, for Darwin, days above 35°C is projected to increase from 11 in the current climate to 43 by 2030, and 111 (RCP4.5) or 265 (RCP8.5) by 2090 (depending on greenhouse gas concentrations).

Northern Australia's future climate

- Average temperatures will continue to increase in all seasons
- More hot days and warm spells

- Changes in average rainfall are possible, but uncertain; large decreases are less likely than increases or little change
- Increased intensity of extreme daily rainfall events

- Mean sea level will continue to rise. Height of extreme sea level will also increase

- Fewer but more intense tropical cyclones

More detailed climate projections for Northern Australia are available at **www.climatechangeinaustralia.gov.au.**

Implications for policy and decision making

Impacts of climate change in Northern Australia

Many economic, social and environmental aspects of Northern Australia are likely to be sensitive to climate change. Impacts may include:

- increased **human health** risks due to the increase in the number of hot days and heatwaves. Under a high emissions scenario, Darwin and Broome may experience temperatures over 35°C for two-thirds of the year by the end of the century. This will increase heat stress, particularly for the outdoor workforce.
- damage to cultural sites and loss of natural resources that are important to **Indigenous communities**. Due to poorer health and socioeconomic disadvantage Indigenous Australians are likely to be disproportionately vulnerable to climate change.
- **grazing**, **cropping** and plans for **agricultural expansion** may be affected by changes in summer rainfall and the incidence of droughts.
- damage to **settlements and infrastructure** due to increased frequency and intensity of floods
- damage to the composition and structure of the **Great Barrier Reef** and significant loss of biodiversity due to ocean warming and acidification. This will have flow on impacts for many **tourism** operators.
- changes in **ecosystems**, such as the expansion of monsoon rainforest at the expense of eucalypt savannah and grassland, with associated biodiversity and economic impacts.

For more information, please contact:
Dr Jo Brown
Project 2.6
josephine.brown@bom.gov.au

www.nespclimate.com.au

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Planning for a changing climate

Because of the wide-ranging impacts, climate change needs to be considered as an integral part of a risk analysis in policies and decisions about Northern Australia. In considering climate risk, it is vital to bear in mind that projected changes of different aspects of the climate have different levels of scientific certainty.

The scientific community has extremely high confidence in further *warming* and *sea level rises* over Northern Australia in all seasons: these are virtually certain. The size and rapidity of the changes, however, will depend on future greenhouse gas emissions.

Projected rainfall changes are less certain. There is very high confidence that *rainfall variability* (from daily to seasonal timescales) will increase, and that heavier *rainfall extremes* will occur. However, changes in *average rainfall* (i.e. seasonal totals) are less clear. Therefore, rainfall-sensitive projects and industries in Northern Australia will need to include the possibility of both increases and decreases in future average rainfall amounts.

Different types of climate change projections information may be needed for different purposes. In many instances, decision makers may want to know the likely direction and magnitude of change in a few key climate variables, such as mean temperature, humidity, sea level or extremes such as heat waves. Ranges and probabilities may also be needed, and these can be obtained by considering the full set of climate model projections. For more detailed studies, such as impacts assessments, output from global or high resolution models may be required.

Many different climate models are used to develop projections for the future. More than 40 climate models are available, each with slightly different components and resulting differences in the simulated future climate. For variables or regions where all or most models agree on future changes, the results have a higher level of confidence. However, models showing possible but less likely future states may also be useful in a risk management context. The **Climate Futures Tool** on the Climate Change in Australia website (**www.climatechangeinaustralia.gov.au**) can be used to help select internally consistent climate projections datasets for impact assessments and adaptation planning, based on combinations of key variables. These datasets can be applied to impact models, for example in simulating the effect of climate change on different crops, or on future bushfire risk.

Climate change science to support policy and decision making

Research undertaken through the Earth Systems and Climate Change Hub is improving confidence in climate change projections as a result of improved understanding of climate feedbacks and key climate processes.

The Hub is also working with a range of stakeholders to improve the usability and uptake of climate change information for adaptation and related activities.

With greater access to and confidence in climate change projections, policy and management decisions can be effectively informed by climate change science, ensuring the best possible response to Australia's variable and changing climate.