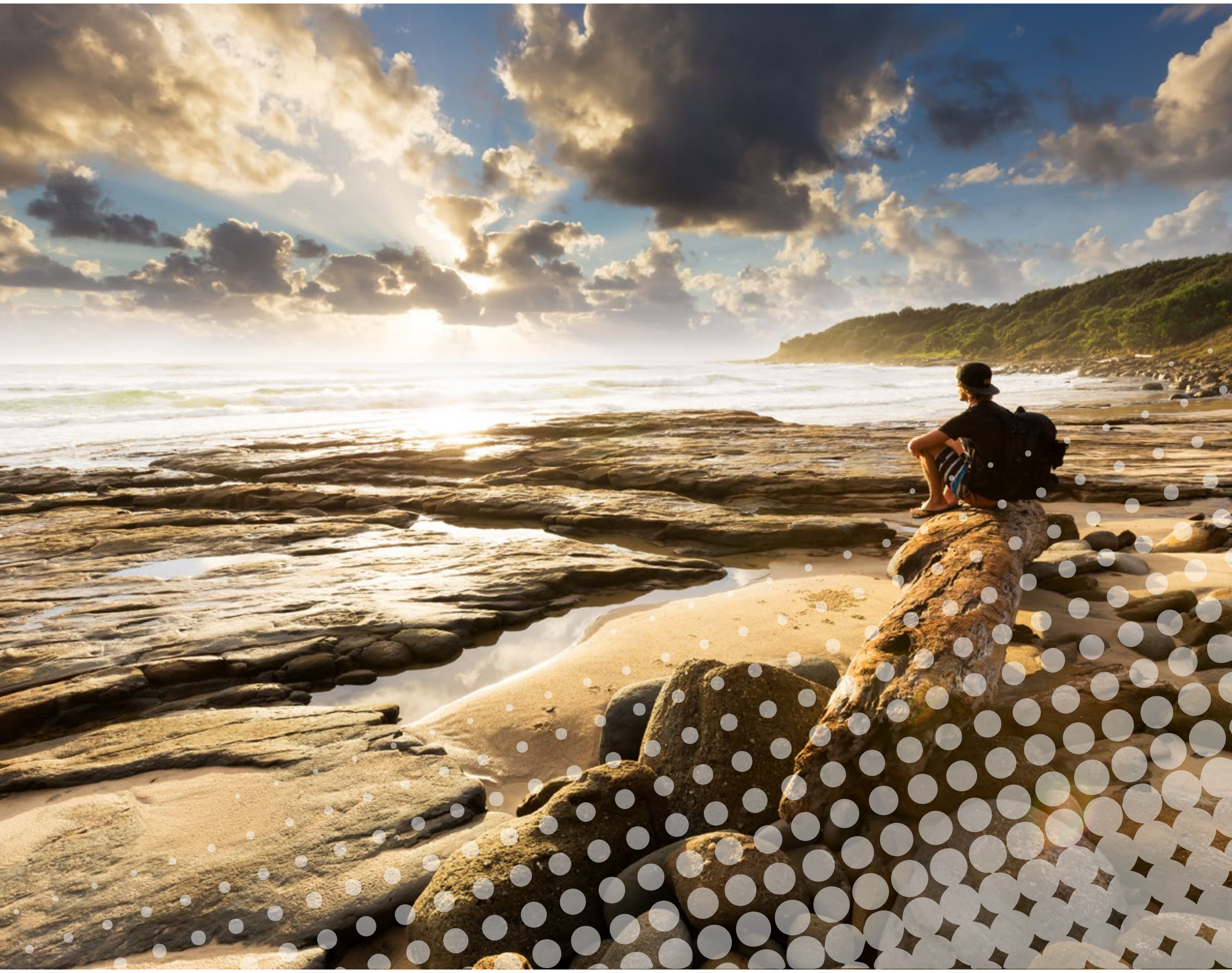
Climate Science Initiative WA



Understanding climate models: the benefits of using convection-permitting models to assess climate change

Key messages

Convection-permitting models are advanced climate models used to generate detailed regional-scale climate projections.

These models have spatial resolutions of approximately 4 km or less and are based on physical processes. They provide essential and detailed information for regional applications such as climate risk assessments, urban planning, and extreme weather projections.

Convection-permitting models can better simulate extreme weather events, such as storms and extreme rain. These models better represent the vertical movement of air (convection), and as a result can outperform coarser resolution models, especially in regions of complex topography.

Like any model, convection-permitting models are not without issues and limitations. Higher resolution does not always guarantee better results, and this needs to be carefully assessed on a case-by-case basis.

State and territory governments across Australia are committed to investing in these models to support local and regional adaptation planning.

Understanding climate models

Climate models simulate the Earth's climate system using mathematical representations of processes such as cloud formation, ocean currents, and many other processes across various spatial and temporal scales (Figure 1). Climate models are essential for understanding past climate and projecting how our climate may change under different scenarios of greenhouse gas emissions. They are therefore critical for informing climate change mitigation and adaptation.

Global climate models

Global climate models, often referred to as general circulation models (GCMs), are specifically designed to simulate the large-scale global atmospheric and ocean circulation processes. Most global climate models have spatial resolutions ranging from 100 km to 250 km and have shown considerable skill in simulating processes at the global scale. However, these models were not designed to simulate regional processes that occur at much smaller scales (~4 to 20 km). To achieve this, global climate models can be downscaled to higher resolutions using dynamical or statistical downscaling techniques.

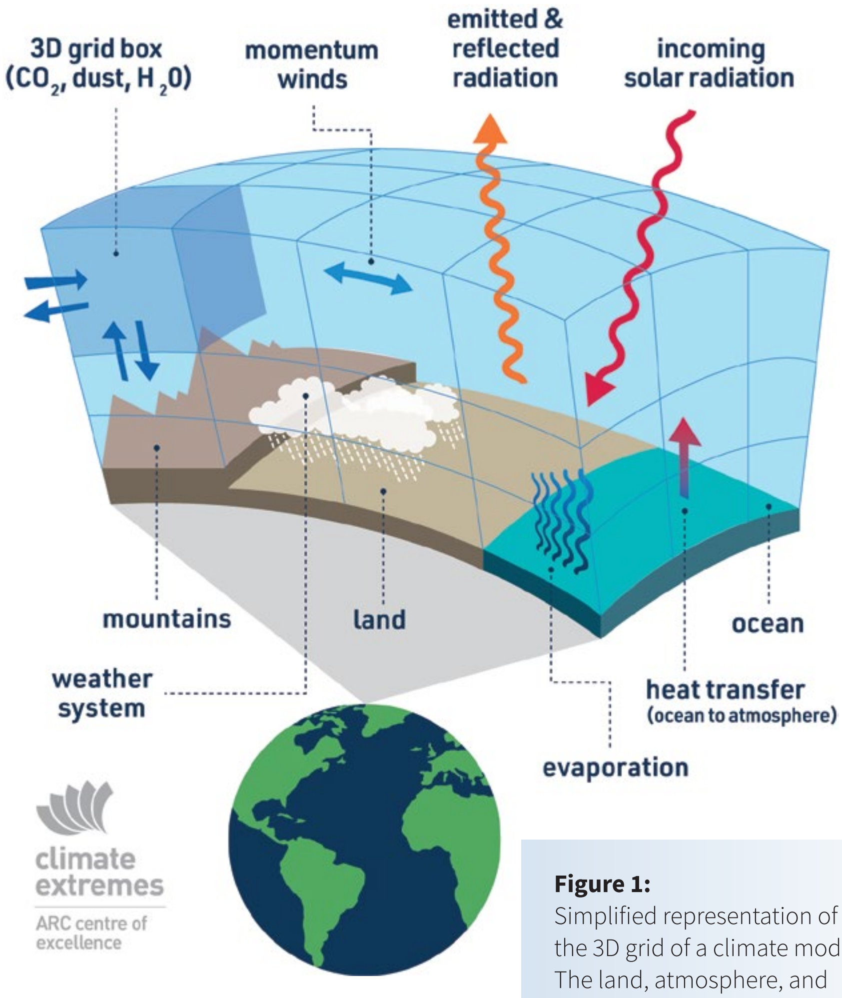


Figure 1:
Simplified representation of the 3D grid of a climate model. The land, atmosphere, and ocean components and climate processes are illustrated, noting many more processes are included in climate models.

Source: Georgina Harmer – Graphic Designer, ARC Centre of Excellence for Climate Extremes

Key definitions

Statistical downscaling: uses historical observations and climate model data to develop statistical relationships. These relationships are then applied to the future, assuming the relationships do not change.

Dynamical downscaling: uses regional climate models to dynamically downscale global climate models to higher resolutions, based on physical principles.

Convection-permitting models: regional climate models that dynamically downscale global models to resolutions of approximately 4 km or less. These models can directly simulate convective processes (the vertical movement of atmospheric heat and moisture that influences storms and heavy rain) without using approximations.

Downscaling global climate models for regional applications

Global climate models often produce climate information that is too coarse for regional and local decision-making, but they can be downscaled to higher resolutions (Figure 2).

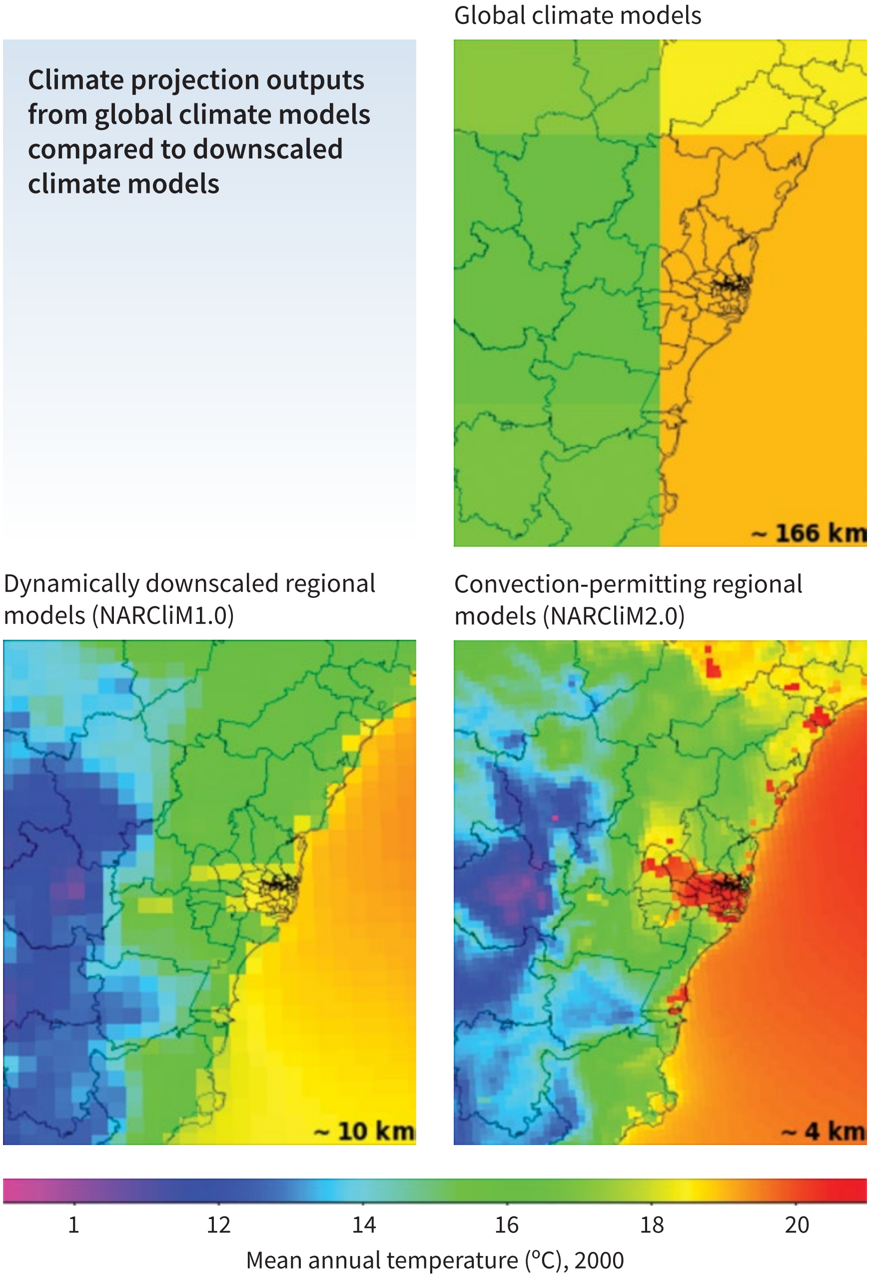


Figure 2: Example of the resolution and detail of mean annual temperature (°C) projections from coarser global climate models (top right), compared with dynamically downscaled regional models from the NSW and Australian Regional Climate Modelling (NARCliM) project (NARCliM1.0) (bottom left) and convection-permitting models (NARCliM2.0) (bottom right).

Source: Courtesy of the Climate Research Team, NSW Government

Statistical downscaling

Statistical downscaling relies on relationships between historical observed climate and large-scale patterns (such as sea-level pressure) from coarser-resolution climate models. These statistical relationships are then used to develop climate projections.

Statistical models can be useful and are an efficient method for developing climate projections. However, they assume that past relationships between large-scale and local climate variables will continue in the future – a concept known as stationarity. This assumption may not apply in a future where we may experience rapid and unprecedented climate change. In addition, as statistical downscaling models do not directly incorporate physical principles, their capacity to effectively capture new climate patterns and their applicability for extreme events, such as extreme rainfall, can be limited.

Dynamical downscaling

Dynamical downscaling uses regional climate models, which are based on principles of physics, at high resolutions to refine global climate model outputs to simulate detailed regional climate patterns (Figure 3). Regional climate models can produce more accurate projections of climate and extreme events due to their ability to more accurately represent a region of interest.

Convection-permitting models are regional climate models that operate at spatial resolutions of ~4 km or less. They are generally regarded as the most advanced method of dynamical downscaling and best practice for producing finer and more regional-scale climate projections. This is particularly valuable in undertaking regional climate assessments and adaptation planning.

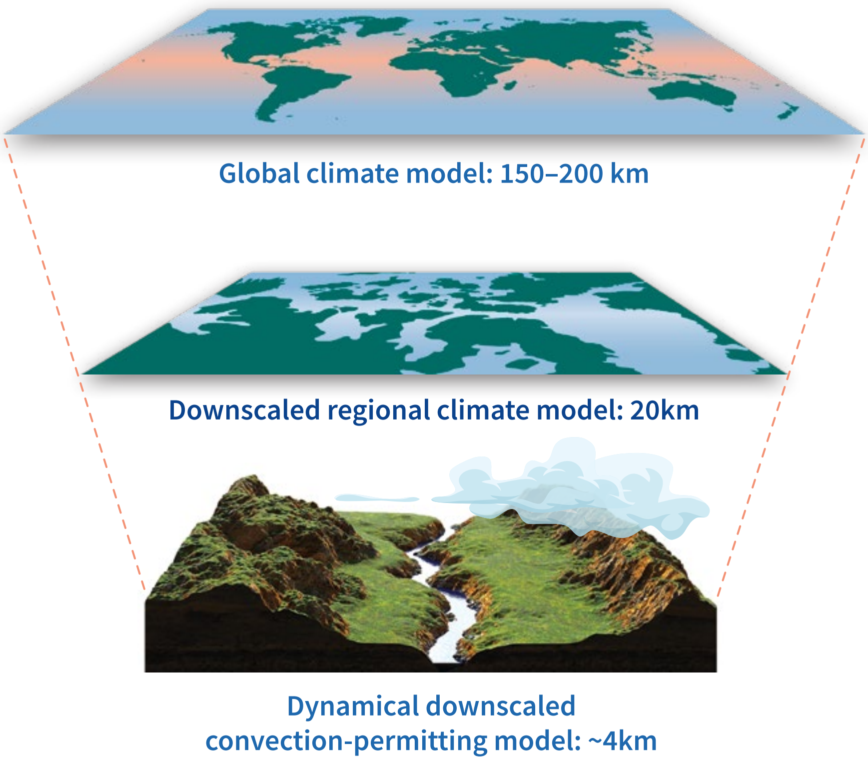


Figure 3: A representation of how dynamically downscaled climate models run regional climate models at fine resolution. They use global climate models to provide large-scale conditions.

Source: Adapted from National Institute of Water and Atmospheric Research, NZ, 2018

Advantages of convection-permitting models

Convection-permitting models can offer several advantages for producing climate data to support climate risk assessments and adaptation planning.

1 Better simulation of extreme weather

One of the main advantages of convection-permitting models is their improved simulation of some extreme weather events. Extreme weather often affects community safety and can lead to significant disruptions and damage to Australia's infrastructure, agricultural productivity, and natural ecosystems. Current climate projections indicate that some extreme weather events may become more frequent, intense and last longer in some regions under a warming climate. Therefore, information on extreme weather events is essential for assessing climate risks.

The ability of convection-permitting models to directly simulate convective processes enables them to simulate climatic patterns more realistically. This provides more reliable information about extreme weather, such as thunderstorms, heavy rainfall, and hailstorms, and how they may change in future. For example, the ability of convection-permitting models to project changes in rainfall intensity and duration on daily and hourly timescales provides crucial information about extreme rainfall events and has been shown to improve flood risk assessments.

2 Better regional-scale accuracy

Convection-permitting models are particularly useful in areas with complex terrain, varied land use, or where there are strong interactions between the atmosphere and the land and ocean – features that can strongly influence regional climate but are often missed in coarser-resolution models.

Due to their fine resolution, convection-permitting models can more accurately represent rainfall intensity, duration, and distribution and better represent local and complex topography and land use, such as high-density urban areas and vegetation. Compared to global climate models, they can more accurately simulate the exchange of energy and moisture between vegetation and the atmosphere, as well as interactions between the land, atmosphere, and ocean.

The ability of convection-permitting models to represent different climates over steep topography and complex coastlines is particularly important for Australia's large variety of terrains. For example, in Western Australia, finer-resolution convection-permitting models have been shown to better capture rainfall influenced by the Darling Scarp (a local topographical feature that affects the region's climate) than coarser-resolution models. For the Australian eastern seaboard, located between the Great Dividing Range and the sea, improvements have been seen in simulations of wind gusts.

This regionalised information is essential for urban planning, disaster management and agriculture decision-making. The greater regional accuracy of convection-permitting models makes them especially valuable for planning in specific communities, cities, and regions.

3 Improved insights into the future

Convection-permitting models are based on the principles of physics, including thermodynamics. This physical basis is particularly important for simulating plausible future climates, making these models more reliable than purely statistical models that rely on past climate data to infer future changes.

As a result, convection-permitting models are ideal for providing future-oriented insights that are critical for long-term planning and assessing new and emerging climate risks. They offer advantages over coarser resolution climate data and statistically downscaled data. However, they require substantial computational time and data storage, making them more expensive and time-consuming to produce. Like all climate models, these models have biases and uncertainties, and their performance must be carefully evaluated against observations to ensure accuracy. Higher resolution does not always guarantee better results.

Extreme rainfall case study example

Extreme rainfall events, which can lead to flash flooding, are often driven by localised convective processes. These can sometimes be poorly represented by coarser-resolution models, making them a key use case for convection-permitting model data.

Convection-permitting models can significantly improve the simulation of hourly rainfall as they operate at the finer resolution necessary for capturing these events. This has been demonstrated in Australia and across diverse regions.

Choosing fit-for-purpose climate projection outputs

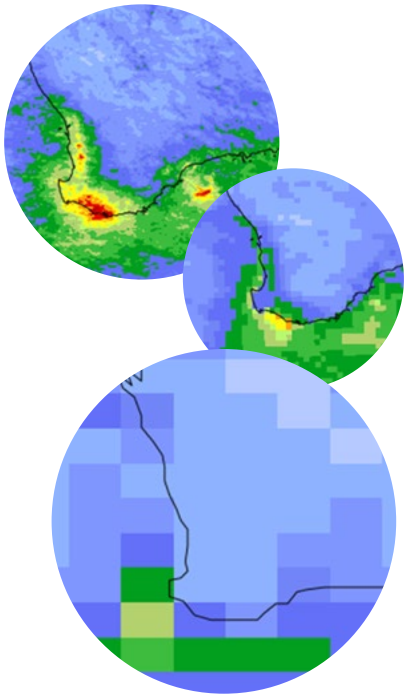
There are multiple climate projection initiatives underway across Australia. Some of these use coarser climate models, such as statistical downscaled models, to produce higher-level or national-scale data. These can be useful for applications such as national climate risk assessments, high-level assessments or for producing national- or sectoral-scale climate services.

Coarser climate models are useful and complement higher-resolution models, such as convection-permitting models. However, for users who require regional-scale climate data, convection-permitting model outputs can provide greater detail and accuracy.

Before using climate data for decision-making, users should always check how the dataset was produced. Some climate datasets may appear to have finer-scale resolutions (e.g. ~5 km), similar to convection-permitting models, but may have been created using statistical methods rather than dynamical downscaling. If the dataset was statistically derived from coarser-resolution models (e.g. ~20 km), it may not provide the same advantages as data generated from dynamically downscaled convection-permitting models. These statistically derived datasets do not add new information on the representation of regional climate processes based on physical principles. It is therefore important to carefully assess any climate dataset intended for a specific purpose.

Capturing added value at regional scales

Convection-permitting models add value by providing the most advanced, detailed and reliable regional-scale climate projections. They support climate risk assessments, resilience planning, and financial disclosures, particularly at the regional scale where climate impacts are most felt.



That's why state governments across Australia, including Western Australia (WA Climate Science Initiative), New South Wales (NSW and Australian Regional Climate Modelling), and Queensland (Queensland Future Climate), have invested in climate projections from dynamical downscaling at convection-permitting scales. These new climate projections will help governments, communities, businesses, and industries better understand future climate risks and adapt to the changing climate.

Artificial intelligence and convection-permitting models

Recent advances in machine learning and artificial intelligence (AI) offer exciting opportunities to complement convection-permitting models. AI can dramatically reduce the computational cost of downscaling, allowing faster calculation of large regional climate datasets. While AI is not a replacement for dynamical approaches, it is likely that AI tools will increasingly be used together with convection-permitting models. This is a rapidly evolving field.

For more information

This factsheet is supported by a range of peer-reviewed research papers on convection-permitting, dynamical, and statistical downscaled climate models. References can be found on the Climate Science Initiative WA website.

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Pawsey

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