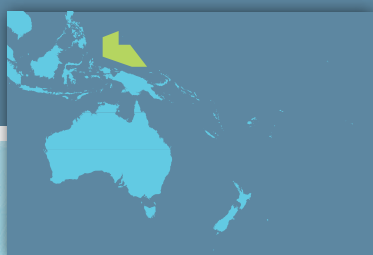


# Pacific-Australia Climate Change Science and Adaptation Planning Program



## Current and future climate of **Palau**



- > Palau National Weather Service Office
- > Australian Bureau of Meteorology
- > Commonwealth Scientific and Industrial Research Organisation (CSIRO)



**Australian Government**

# Palau's current climate

## Temperature

The average daily temperature in Palau is 82.4°F (28°C) throughout the year. Changes in the temperature from season to season are relatively small (1.5°F or 0.8°C) and strongly tied to changes in the surrounding ocean temperature. The main wet season is from May to October, while the driest months are February to April (Figure 1).

## Rainfall

On average Palau receives more than about 8 inches (200 mm) rainfall every month, on average. This is due to Palau's location on the edge of the Pacific Warm Pool and the year-long influence of the Intertropical

Convergence Zone. This band of heavy rainfall is caused by air rising over warm water where winds converge, resulting in thunderstorm activity. It extends across the Pacific just north of the equator and is most intense in the Northern Hemisphere wet season (Figure 2).

Between June and August the West Pacific Monsoon brings heavy rainfall to Palau. The Monsoon is driven by large differences in temperature between the land and the ocean. It moves north to mainland Asia during the Northern Hemisphere summer and south to Australia in the Northern Hemisphere winter.

Palau's climate is also influenced by the trade winds. From December to March the winds come from the

north-east. During April, the frequency of the trade winds decreases. In May, the winds are predominantly from south-east to north-east.

## Year-to-year variability

Palau's climate varies considerably from year to year due to the El Niño-Southern Oscillation. This is a natural climate pattern that occurs across the tropical Pacific Ocean and affects weather around the world. There are two extreme phases of the El Niño-Southern Oscillation: El Niño and La Niña. There is also a neutral phase. In Koror, El Niño events tend to bring dry seasons that are drier and cooler than normal, while La Niña events usually bring wetter than normal conditions.

During the strong 1997/98 El Niño event Palau experienced severe drought and the increase in sea surface temperatures caused widespread coral bleaching and impacted subsistence fishing.

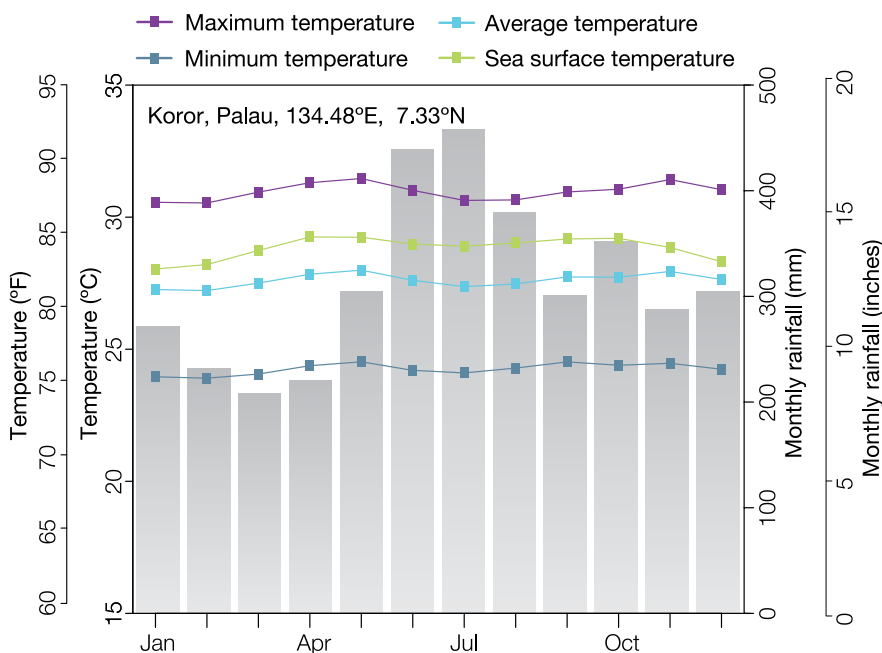
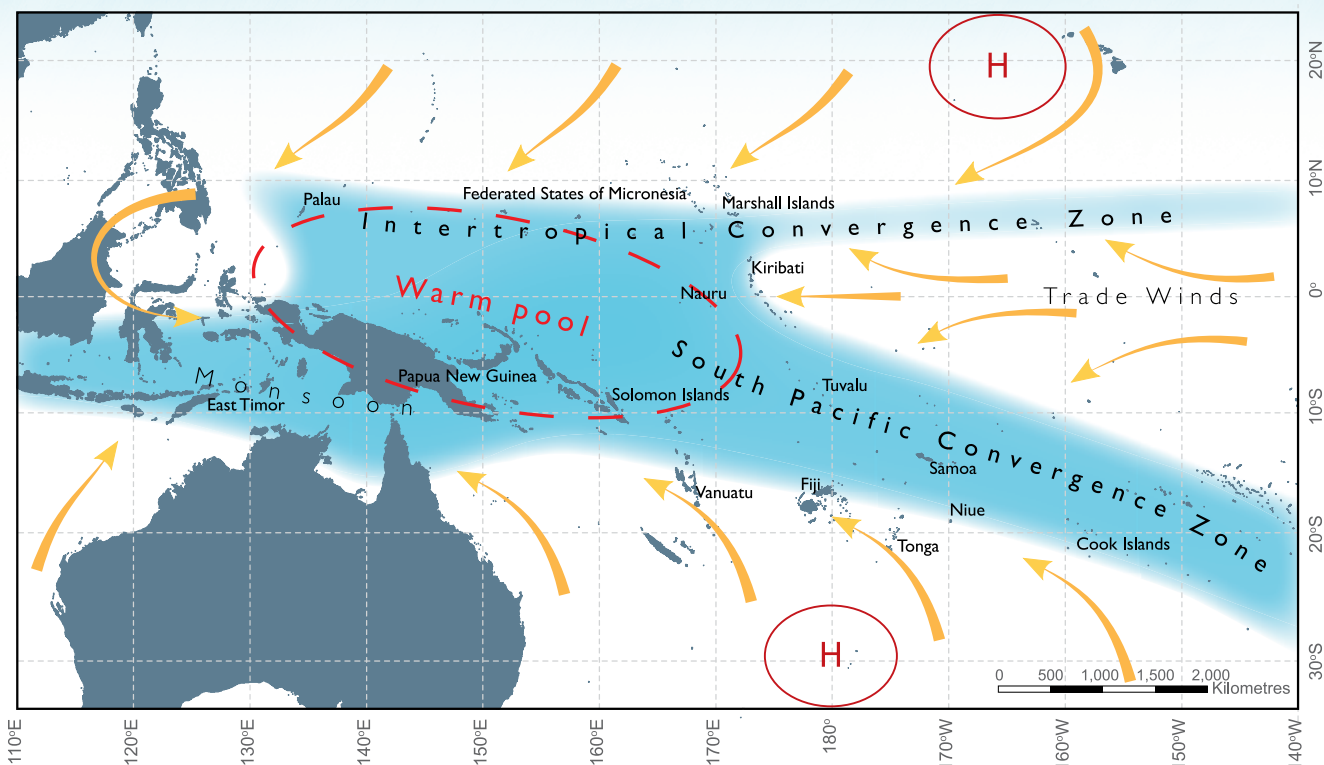


Figure 1: Seasonal rainfall and temperature at Koror.



Palau National Weather Service Office

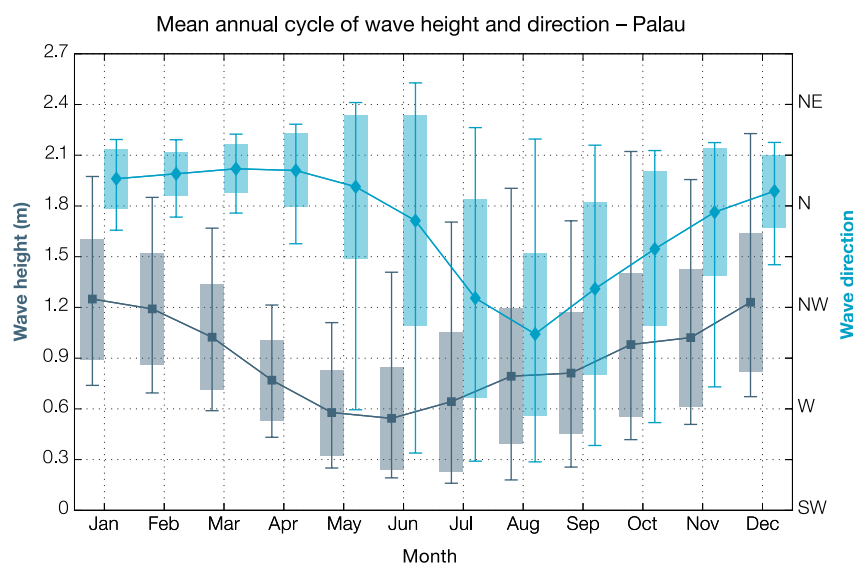
Ngerimel Water Reservoir in Airai State during the 1998 drought.



**Figure 2:** Average positions of the major climate features in November to April. The arrows show near surface winds, the blue shading represents the bands of rainfall convergence zones, the dashed oval shows the West Pacific Warm Pool and H represents typical positions of moving high pressure systems.

## Wind-driven waves

Variability of wind-waves at Palau is characterised by trade winds and monsoons seasonally, and by the El Niño–Southern Oscillation and location of the Intertropical Convergence Zone from year to year (Figure 3). Waves on the north-west coast are directed from the north-east due to trade winds during December to March, with slightly increased wave heights and longer periods. Waves are directed from the west and north-east during June to September due to monsoon systems and prevailing trade winds, and have smaller heights and shorter periods.

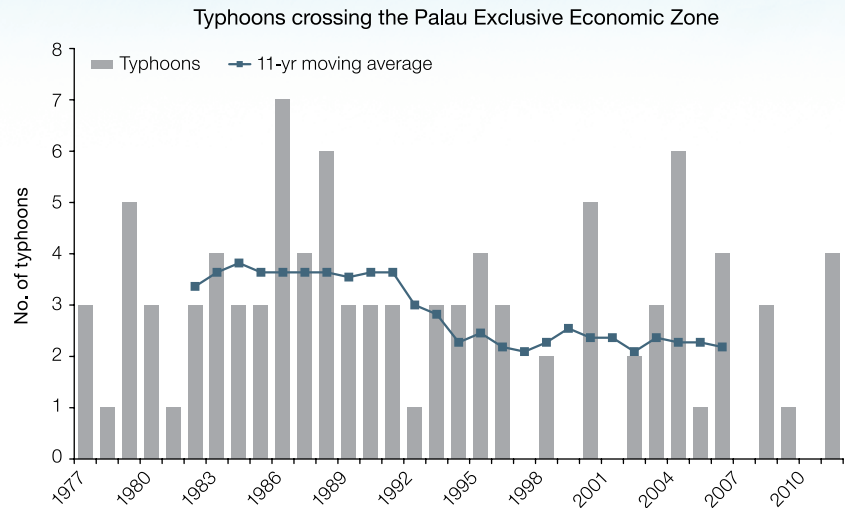


**Figure 3:** Annual cycle of wave height (grey) and wave direction (blue) at Palau based on data from 1979–2009. The shaded boxes represent one standard deviation around the monthly means, and the error bars indicate the 5–95% range, showing the year-to-year variability in wave climate. The direction from which the waves are travelling is shown (not the direction towards which they are travelling).



## Typhoons

Typhoons tend to affect Palau between June and November. In the 42-year period between the 1969 and 2010 seasons, 97 typhoons developed in or crossed into the Palau Exclusive Economic Zone, an average of 23 typhoons per decade (Figure 4). The number of typhoons varies widely from year to year, with none in some seasons but up to seven in others. Over this period typhoons occurred in El Niño, La Niña and neutral years.



**Figure 4:** Number of typhoons developing within and crossing the Palau Exclusive Economic Zone per season. The 11-year moving average is in blue.



Weather balloon launch, Palau National Weather Service.

# Palau's changing climate

## Temperatures have increased

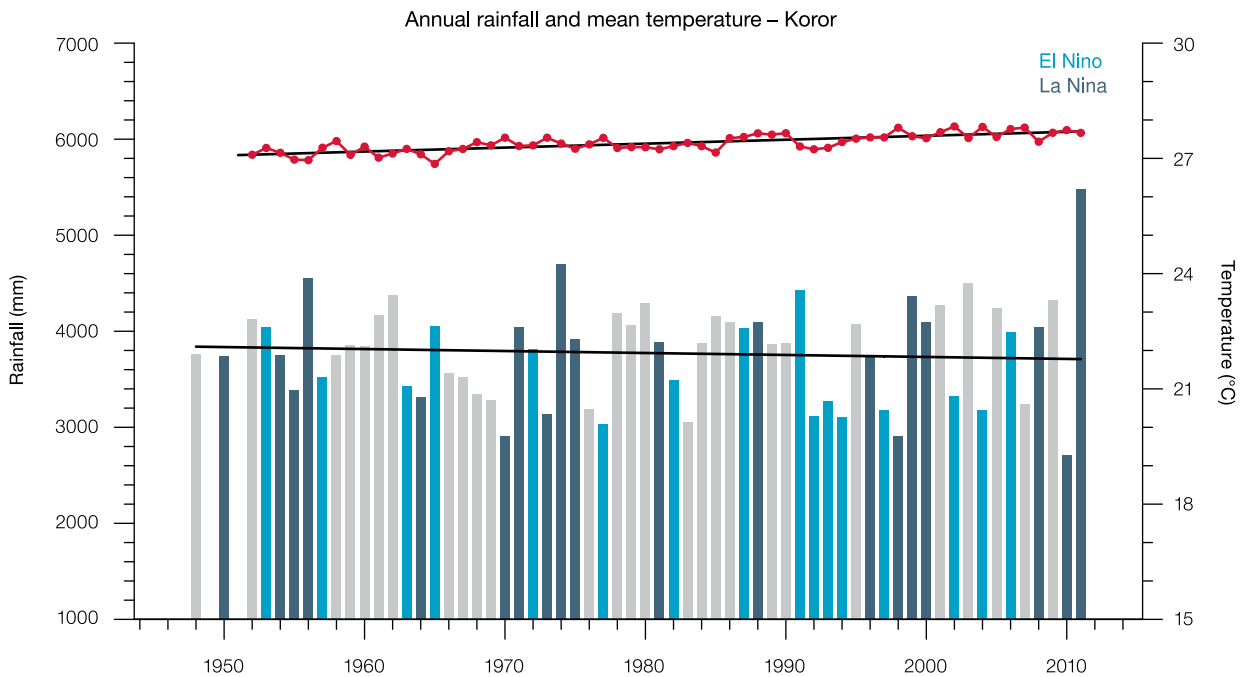
Annual and seasonal maximum and minimum temperatures have increased at Koror since 1951. Maximum annual temperatures have increased at a rate of 0.36°F (0.2°C) per decade and mean temperatures have increased at 0.18°F (0.10°C) per decade (Figure 5). The number of warm days and warm nights has increased since 1952. These temperature increases are consistent with the global pattern of warming.

## Rainfall varies from year to year

There are no clear trends in rainfall over Palau since 1948 (Figure 5). Over this period there has been substantial variation in rainfall from year to year. There has been little change in extreme daily rainfall since the mid-1950s.

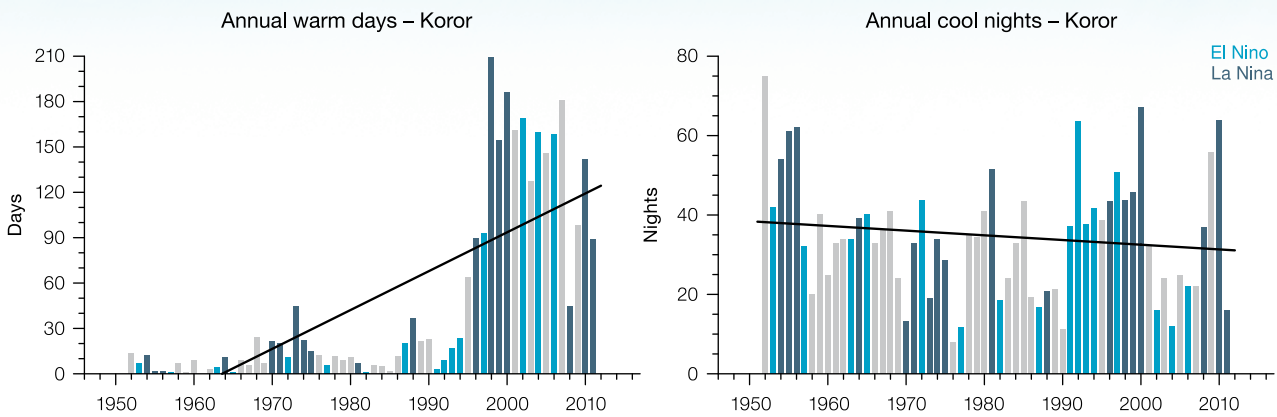


Coral reef, Rock Islands.



**Figure 5:** Annual average air temperature (red dots and line) and total rainfall (bars) at Koror. Light blue, dark blue and grey bars indicate El Niño, La Niña and neutral years respectively. No bars indicate that data is not available. The solid black line shows the trend.





**Figure 6:** Annual total number of warm days at Koror. Light blue, dark blue and grey bars indicate El Niño, La Niña and neutral years respectively. No bars indicate that data is not available. Solid black lines shows the trends.

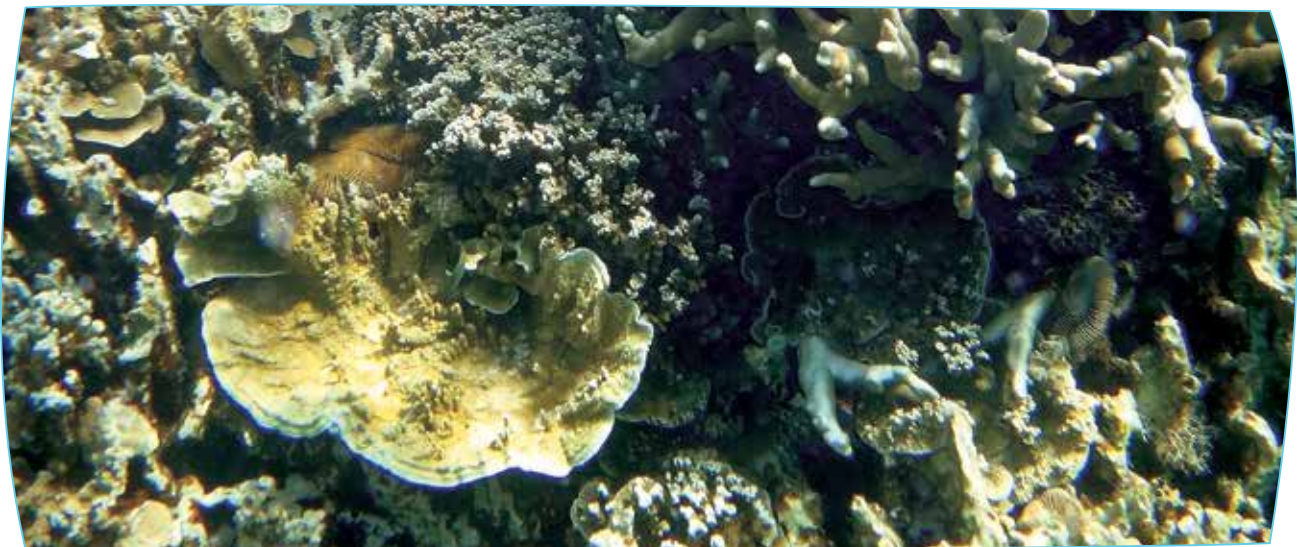
## Sea level has risen

As ocean water warms it expands causing the sea level to rise. The melting of glaciers and ice sheets also contributes to sea-level rise. Instruments mounted on satellites and tide gauges are used to measure sea level. Satellite data indicate the sea level has risen in Palau by about 0.35 inches (9 mm) per year since 1993. This is larger than the global average of 0.11–

0.14 inches (2.8–3.6 mm) per year. This higher rate of rise may be partly related to natural fluctuations that take place year to year or decade to decade caused by phenomena such as the El Niño-Southern Oscillation. The natural variation in sea level can be seen in Figure 7 which includes the tide gauge record since 1969 and the satellite data since 1993.

## Ocean acidification

About one quarter of the carbon dioxide emitted from human activities each year is absorbed by the oceans. As the extra carbon dioxide reacts with sea water it causes the ocean to become slightly more acidic. This impacts the growth of corals and organisms that construct their skeletons from carbonate minerals. These species are critical to the balance of tropical reef ecosystems. Data show that since the 18th century the level of ocean acidification has been slowly increasing in Palau’s waters.



Coral reef, Rock Islands.

# Palau's future climate

Climate impacts almost all aspects of life in Palau. Understanding the possible future climate of Palau is important so people and the government can plan for changes.

## At a glance



- El Niño and La Niña events will continue to occur in the future, but there is little consensus on whether these events will change in intensity or frequency.



- Annual mean temperatures and extremely high daily temperatures will continue to rise.



- Average rainfall is projected to increase, especially in the wet season, along with more extreme rain events
- Droughts are projected to decline in frequency.



- Sea level will continue to rise.
- Ocean acidification is expected to continue.
- The risk of coral bleaching is expected to increase.
- A reduction of wave height in December–March is projected in 2090 but not 2035, with a slight decrease in wave period. In June–September a small decrease in period is projected, with a clockwise rotation toward the south.



- Typhoons are projected to be less frequent but more intense.





## Temperatures will continue to increase

Projections for all emissions scenarios indicate that the annual average air temperature and sea-surface temperature will increase in the future in Palau (Table 1). By 2030, under a very high emissions scenario, this increase in temperature is projected to be in the range of 1.1–1.8°F (0.6–1.0°C). Later in the century the range of the projected temperature increase under the different scenarios broadens.

## More very hot days

Increases in average temperatures will also result in a rise in the number of hot days and warm nights, and a decline in cooler weather.

## Changing rainfall patterns

Rainfall during the wet season is projected to increase over the course of the 21st century. Wet season increases are consistent with the expected intensification of the West Pacific Monsoon and the Intertropical Convergence Zone. However, there is some uncertainty in the rainfall projections and not all models show consistent results. Wet and dry years will still occur in response to natural variability. Droughts are projected to become less frequent throughout this century.

## More extreme rainfall days

Projections show extreme rainfall days are likely to occur more often and be more intense.

## Less frequent typhoons

On a global scale, the projections indicate there is likely to be a decrease in the number of typhoons by the end of the 21st century. But there is likely to be an increase in the average maximum wind speed of typhoons by between 2% and 11% and an increase in rainfall intensity of about 20% within 100 km of the typhoon centre.

Palau is in a region where projections tend to show a decrease in typhoon frequency by the late 21st century.

**Table 1:** Projected changes in the annual average surface air temperature for Palau. Values represent 90% of the range of the models and are relative to the period 1986–2005.

	2030		2050		2070		2090	
	(°F)	(°C)	(°F)	(°C)	(°F)	(°C)	(°F)	(°C)
Very low emissions scenario	0.9–1.6	0.5–0.9	1.1–2.0	0.6–1.1	0.9–2.2	0.5–1.2	0.7–2.2	0.4–1.2
Low emissions scenario	0.9–1.8	0.5–1.0	1.3–2.5	0.7–1.4	1.6–3.2	0.9–1.8	1.8–3.8	1.0–2.1
Medium emissions scenario	0.7–1.6	0.4–0.9	1.3–2.5	0.7–1.4	2.0–3.4	1.1–1.9	2.5–4.5	1.4–2.5
Very high emissions scenario	1.1–1.8	0.6–1.0	1.8–3.4	1.0–1.9	2.9–5.6	1.6–3.1	3.8–7.2	2.1–4.0



Sea defences Ngeruling, Babeldaob.



## Sea level will continue to rise

Sea level is expected to continue to rise in Palau (Table 2 and Figure 7). By 2030, under a very high emissions scenario, this rise in sea level is projected to be in the range of 3.1–7.1 inches (8–18 cm). The sea-level rise combined with natural year-to-year changes will accentuate the impact of storm surges and coastal flooding. As there is still much to learn about sea level, particularly how large ice sheets such as Antarctica and Greenland contribute to sea-level rise, scientists warn larger rises than currently predicted could be possible.

## Ocean acidification will continue

Under all four emissions scenarios the acidity level of sea waters in the Palau region will continue to increase over the 21st century, with the greatest change under the very high emissions scenario. The impact of increased acidification on the health of reef ecosystems is likely to be compounded by other stressors including coral bleaching, storm damage and fishing pressure.

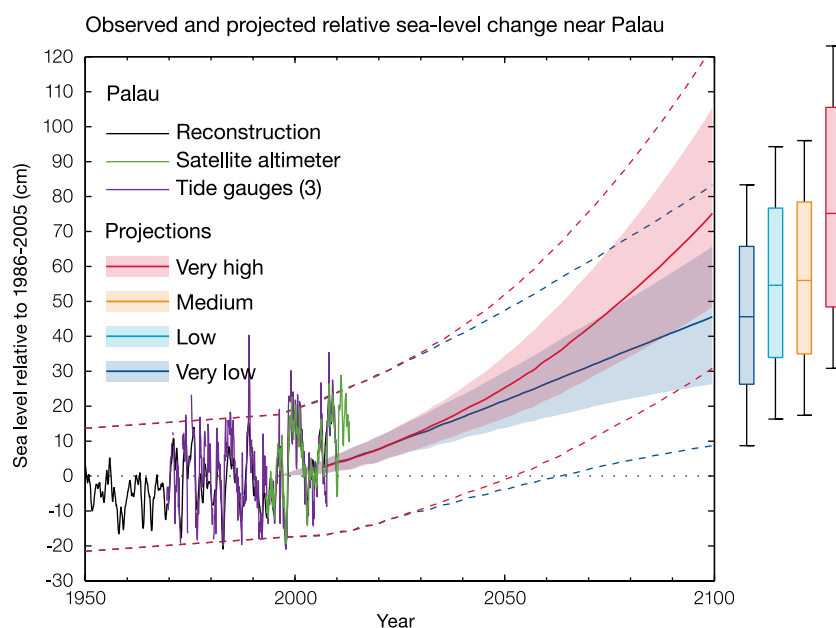
## Wave climate will change

A reduction of wave height in December to March is projected by the end of the century, with a slight decrease in wave period. In June to September a small decrease in wave period is projected, with a clockwise rotation toward the south. Direction is projected to be more variable than in the dry season, similar to the present climate.

**Table 2:** Sea-level rise projections for Palau. Values represent 90% of the range of the model results and are relative to the period 1986–2005.

	2030		2050		2070		2090	
	(in)	(cm)	(in)	(cm)	(in)	(cm)	(in)	(cm)
Very low emissions scenario	3.1–6.7	8–17	5.5–11.8	14–30	7.9–17.3	20–44	9.8–23.2	25–59
Low emissions scenario	3.1–6.7	8–17	5.9–12.2	15–31	9.1–18.9	23–48	11.8–26.4	30–67
Medium emissions scenario	3.1–6.7	8–17	5.5–11.8	14–30	8.7–18.5	22–47	12.2–26.8	31–68
Very high emissions scenario	3.1–7.1	8–18	6.7–13.8	17–35	11.0–22.8	28–58	16.2–34.6	41–88

**Figure 7:** Tide-gauge records of relative sea level (since 1969) are indicated in purple, and the satellite record (since 1993) in green. The reconstructed sea level data at Palau (since 1950) is shown in black. Multi-model mean projections from 1995–2100 are given for the very high (red solid line) and very low emissions scenarios (blue solid line), with the 5–95% uncertainty range shown by the red and blue shaded regions. The ranges of projections for the four emissions scenarios by 2100 are also shown by the bars on the right. The dashed lines are an estimate of year-to-year variability in sea level (5–95% uncertainty range about the projections) and indicate that individual monthly averages of sea level can be above or below longer-term averages.



## How do scientists develop climate projections?

Global climate models are the best tools for understanding future climate change. Climate models are mathematical representations of the climate system that require very powerful computers. They are based on the laws of physics and include information about the atmosphere, ocean, land and ice.

There are many different global climate models and they all represent the climate slightly differently. Scientists from the Pacific-Australia Climate Change Science and Adaptation Planning Program have evaluated models from around the world and found that 26 best represent the climate of the Palau region of the western tropical Pacific. These 26 models have been used to develop climate projections for Palau.

The future climate will be determined by a combination of natural and human factors. As we do not know what the future holds, we need to consider a range of possible future conditions, or scenarios, in climate models. Greenhouse gas and aerosol

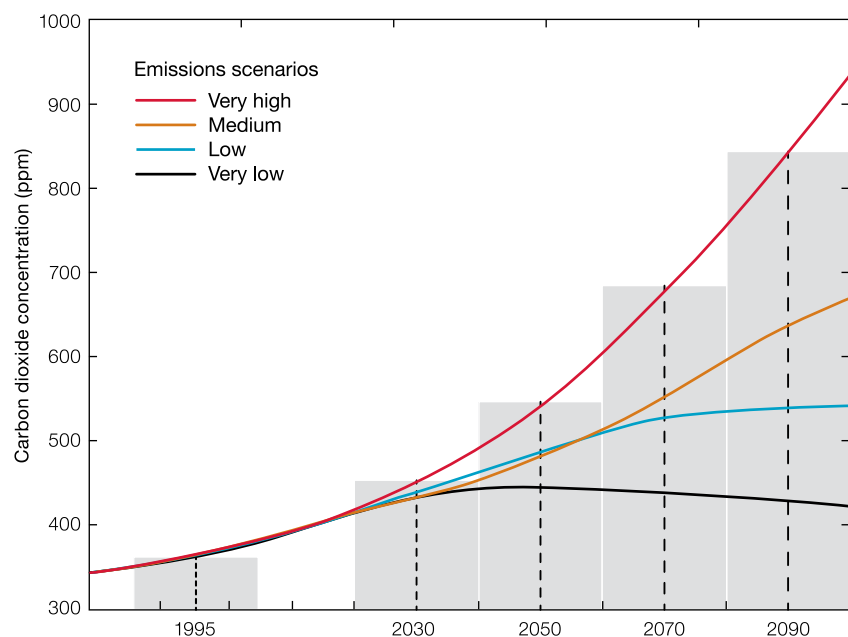
emissions scenarios are used in climate modelling to provide projections that represent a range of possible futures. The Intergovernmental Panel on Climate Change (IPCC) developed four greenhouse gas and emissions scenarios, called Representative Concentration Pathways (RCPs). These scenarios cover a broad range of possibilities. For example, the lowest scenario shows the likely outcome if global emissions are significantly reduced, while the highest scenario shows the impact of a pathway with no policy of reducing emissions.

The climate projections for Palau are based on the four IPCC emissions

scenarios: very low (RCP2.6), low (RCP4.5), medium (RCP6.0) and very high (RCP8.5), for 20-year time periods centred on 2030, 2050, 2070 and 2090, relative to a 20-year time period centred on 1995 (Figure 8). Since individual models give different results, the projections are presented as a range of values.

When interpreting projected changes in the mean climate in the Pacific, it is important to keep in mind that natural climate variability, such as the state of the El Niño-Southern Oscillation, strongly affects the climate from one year to the next.

**Figure 8:** Carbon dioxide concentrations (parts per million, ppm) associated with the very low (RCP2.6), low (RCP4.5), medium (RCP6.0) and very high (RCP8.5) emissions scenarios for 20-year time periods (shaded) centred on 1995 (the reference period), 2030, 2050, 2070 and 2090.



This brochure contains a summary of climate projections for Palau. For more information refer to the technical reports *Climate Change in the Pacific: Scientific Assessment and New Research (Volume 2)* and *Climate Variability, Extremes and Change in the Western Tropical Pacific: New Science and Updated Country Reports*.

These reports are available at [www.pacificclimatechangescience.org](http://www.pacificclimatechangescience.org).

Climate projections are also available through the web-based Pacific Climate Futures tool at [www.pacificclimatefutures.net](http://www.pacificclimatefutures.net).



# Changes in Palau's climate

- > Temperatures have warmed and will continue to warm with more very hot days in the future.
- > Rainfall at Koror shows no clear trend since 1948. Wet season rainfall is generally projected to increase over this century, with more extreme rainfall days and less droughts.
- > By the end of this century projections suggest decreasing numbers of typhoons.
- > Sea level near Palau has risen and will continue to rise throughout this century.
- > Ocean acidification has been increasing in Palau's waters. It will continue to increase and threaten coral reef ecosystems.
- > Wave height in December to March is projected to decrease by the end of the century, with a slight decrease in wave period. In June to September a small decrease in period is projected, with a clockwise rotation toward the south.

This publication updates the original *Current and future climate of Palau* brochure published in 2011.

The content of this brochure is the result of a collaborative effort between the Palau National Weather Service Office and the Pacific-Australia Climate Change Science and Adaptation Planning (PACCSAP) Program – a component of the Australian Government's International Climate Change Adaptation Initiative. The information in this publication, and research conducted by PACCSAP, builds on the findings of the 2013 IPCC Fifth Assessment Report, and uses new emissions scenarios and climate models.

For more detailed information on the climate of Palau and the Pacific see *Climate Variability, Extremes and Change in the Western Tropical Pacific: New Science and Updated Country Reports* (2014) and *Climate Change in the Pacific: Scientific Assessment and New Research. Volume 1: Regional Overview. Volume 2: Country Reports* (2011).

[www.pacificclimatechangescience.org](http://www.pacificclimatechangescience.org)

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