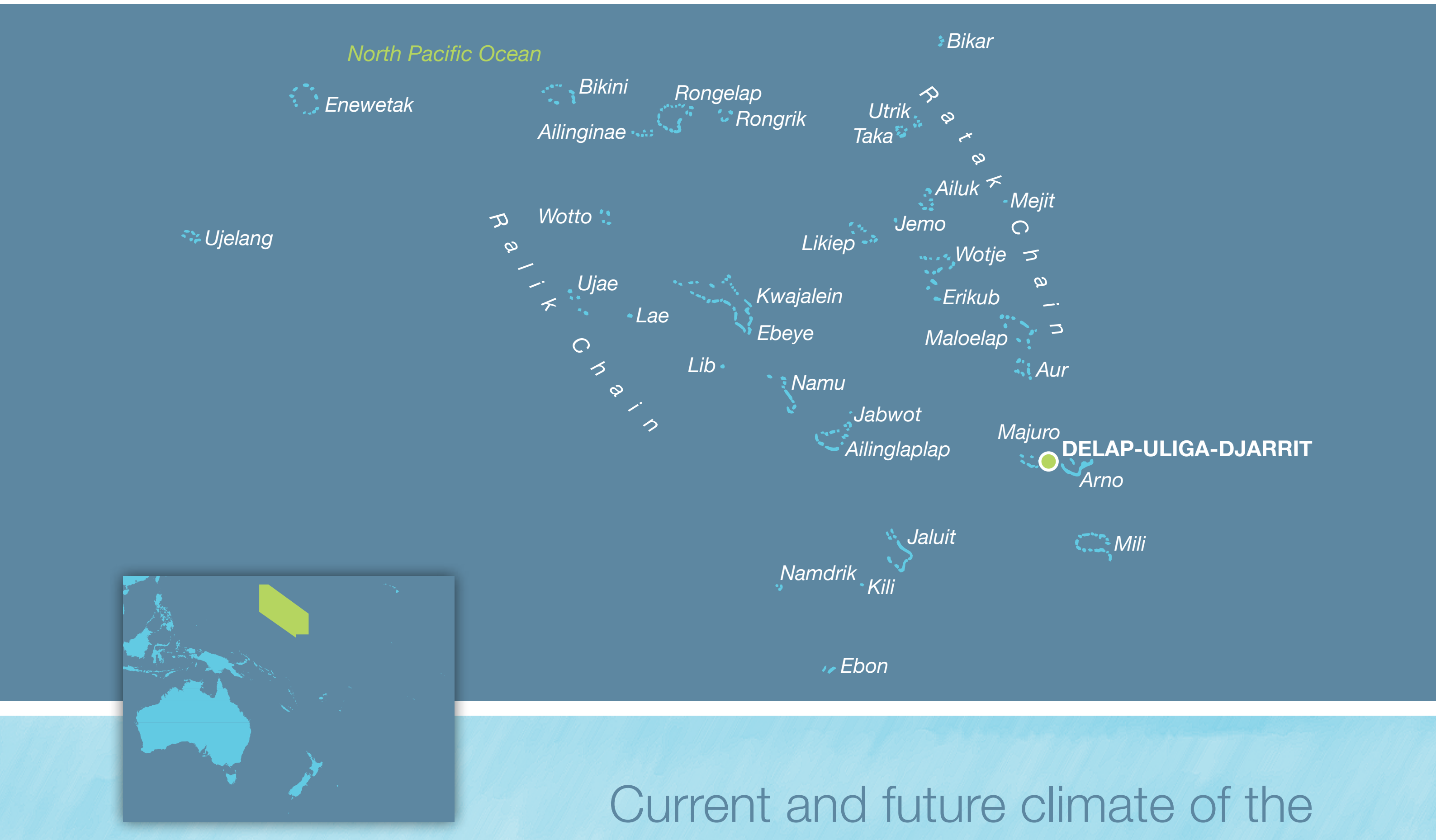
Pacific-Australia Climate Change Science and Adaptation Planning Program



Current and future climate of the **Marshall Islands**

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

Australian Government

Current climate of the **Marshall Islands**

Temperature

Across the Marshall Islands the average temperature is relatively constant year round. Changes in the temperature from season to season are relatively small around 2ºF (1°C) and strongly tied to changes in the surrounding ocean temperature (Figure 1).

Rainfall

Both Majuro and Kwajalein have a dry season from around December to April and a wet season from May to November, however rainfall varies greatly from north to south. The atolls to the north receive less than 50 inches (1250 mm) of rain each year and are very dry in the dry season, while atolls closer to the equator receive more than 100 inches (2500 mm) of rain each year.

The Intertropical Convergence Zone brings rainfall to the Marshall Islands throughout the year. 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 (Figure 2) and is most intense and closer to the Marshall Islands during the wet season. Rainfall is also sometimes influenced by the West Pacific Monsoon, which brings wetter conditions when it is active over the Marshall Islands.

Year-to-year variability

The climate of the Marshall Islands 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. Conditions during La Niña years are generally wetter than normal. El Niño events tend to bring warmer than normal wet seasons and warmer, drier dry seasons.

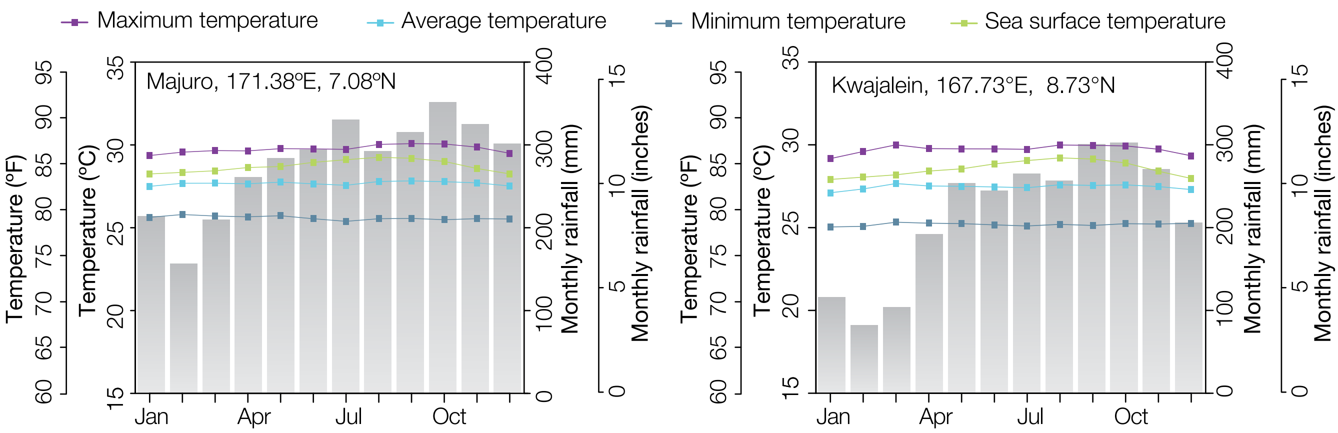


Figure 1: Seasonal rainfall and temperature at Majuro and Kwajalein.

Majuro Lagoon.

Courtesy of Lee Jacklick, National Weather Service Office

Ujae atoll.

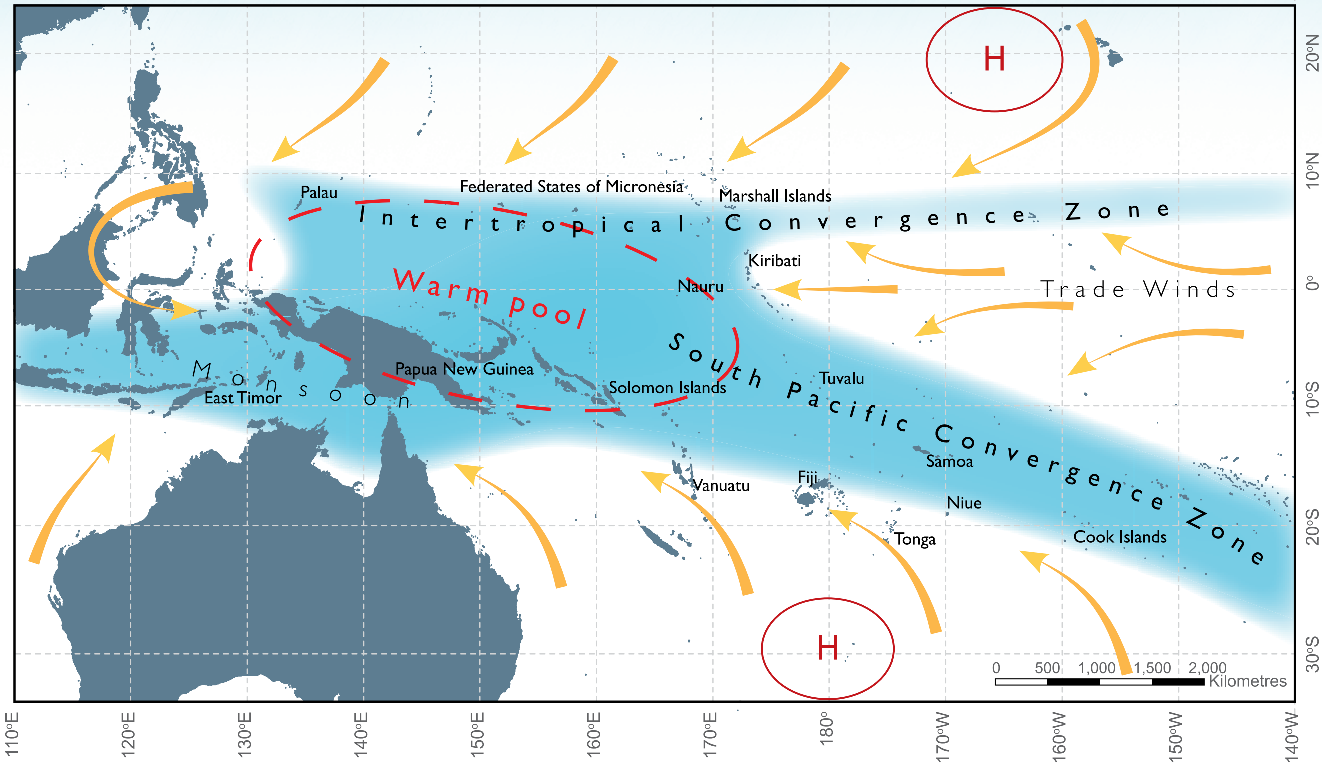


Figure 2: Average positions of the major climate features in November to April. The arrows show near surface winds, the blue shading represents the bands of rainfall convergence zones, the dashed oval shows the West Pacific Warm Pool and H represents typical positions of moving high pressure systems.

Extreme weather events

Typhoons, droughts and storm waves are the main extreme events that impact the Marshall Islands. Typhoons affect the Marshall Islands late in the wet season (June to November). In the 33-year period between the 1977 and 2010 seasons, 78 typhoons developed or crossed into the Marshall Islands Exclusive Economic Zone, an average of 22 typhoons per decade. The number of typhoons varies widely from year to year, with none in some seasons but up to 11 in others. During an El Niño event the sea-surface temperatures increase in and to the east of the Marshall Islands. This allows more intense typhoons to form.

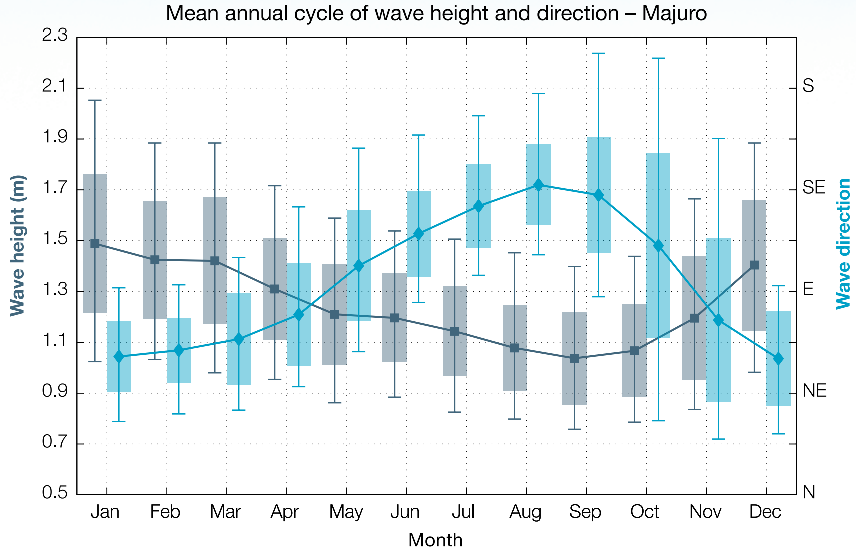
Droughts generally occur in the first four to six months of the year following an El Niño. Following severe El Niño events, rainfall can be reduced by as much as 80%. The dry season begins earlier and ends much later than normal during an El Niño.

Reginald White, National Weather Service Office

High surf event, Majuro, December 2008.

Wind-driven waves

Wind-waves in the Marshall Islands are influenced by trade winds seasonally, and the El Niño–Southern Oscillation from year to year. In the south (e.g. on the south-east coast of Majuro), the wave climate is characterised by trade wind generated waves from the north-east and south-east (Figure 3, top). In the north (e.g. on the sheltered east coast of Kwajalein), waves are characterised by variability of the Northern Hemisphere trade winds (Figure 3, bottom). Wave heights are greater in December to March than June to September in both the north and the south.



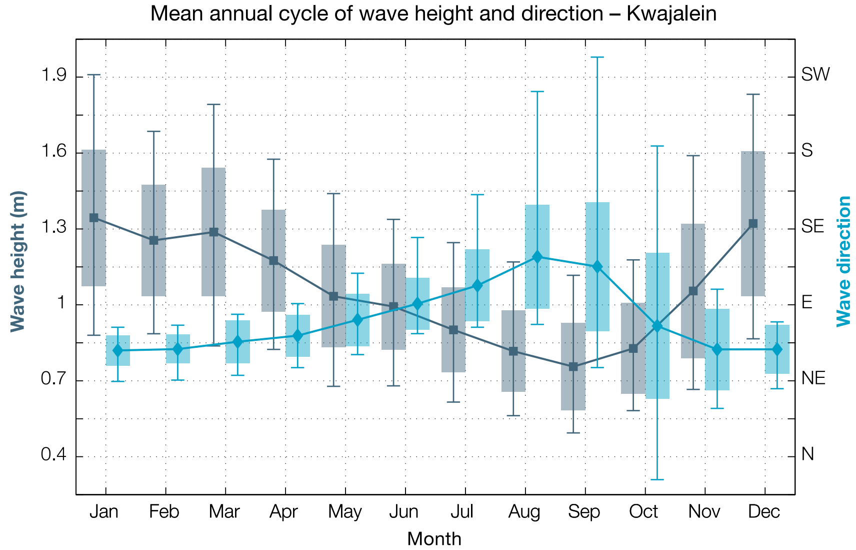


Figure 3: Annual cycle of wave height (grey) and wave direction (blue) at Majuro (top) and Kwajalein (bottom) based on data from 1979–2009. The shaded boxes represent one standard deviation around the monthly means, and the error bars indicate the 5–95% range, showing the year-to-year variability in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

Mr. Jiti Samuel from Namdrik Atoll, Marshall Islands

Flooding during extreme high tide, Namdrik Atoll.

Changing climate of the **Marshall Islands**

Temperatures have increased

Annual mean temperatures have increased in both Majuro and Kwajalein since 1955 and 1949 respectively (Figure 4). In Majuro, annual temperatures have increased at a rate of 0.21ºF (0.12°C) per decade and at Kwajalein the rate of increase has been 0.53ºF (0.30°C) per decade. These temperature increases are consistent with the global pattern of warming.

The number of warm days has increased in both Majuro and Kwajalein since 1956 and 1953 respectively (Figure 5). Over the same period the number of cool nights has decreased.

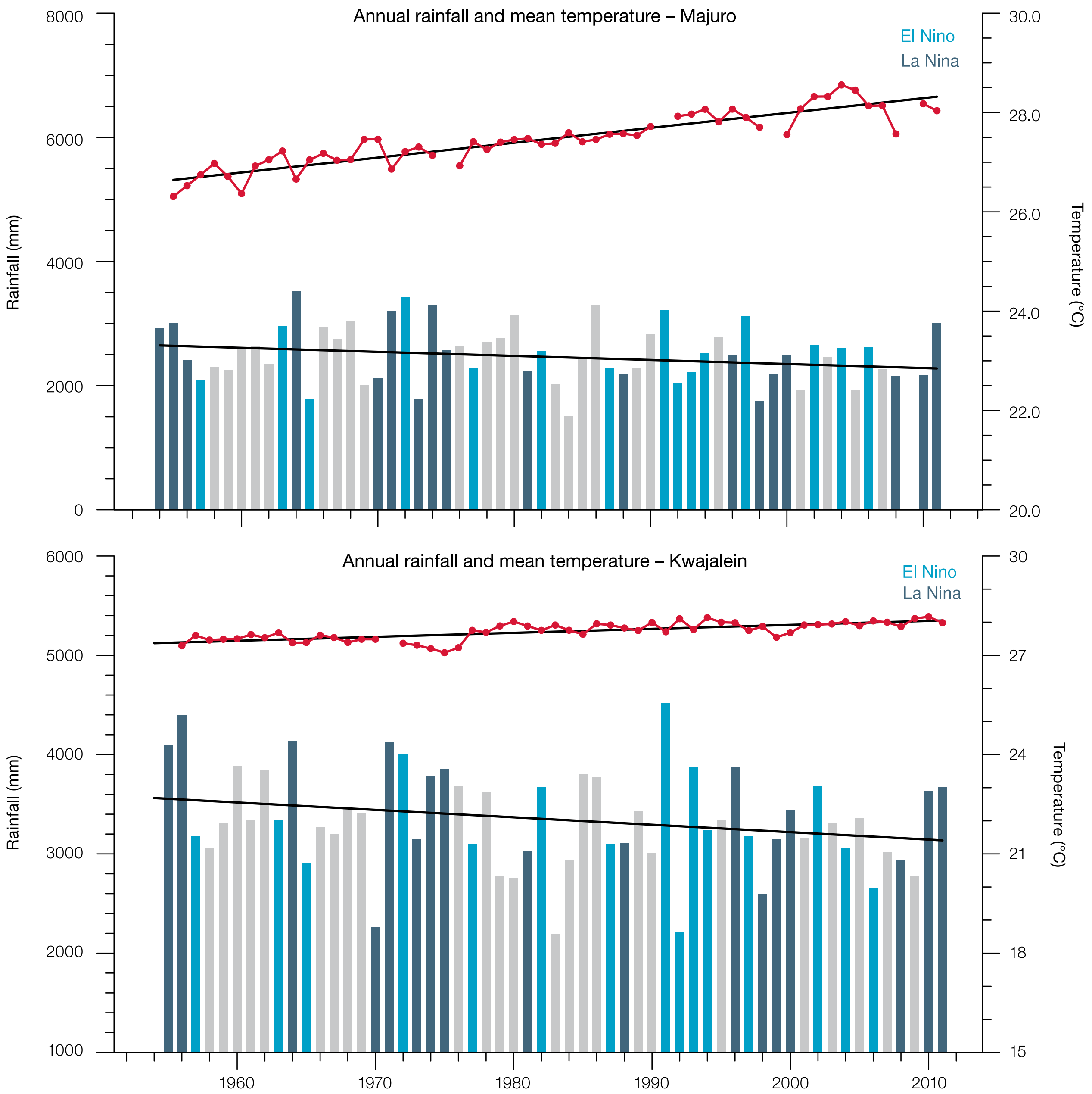


Figure 4: Annual average air temperature (red dots and line) and total rainfall (bars) at Majuro (top) and Kwajalein (bottom). Light blue, dark blue and grey bars indicate El Niño, La Niña and neutral years respectively. No bars indicate that data is not available. The solid black lines show the trends.

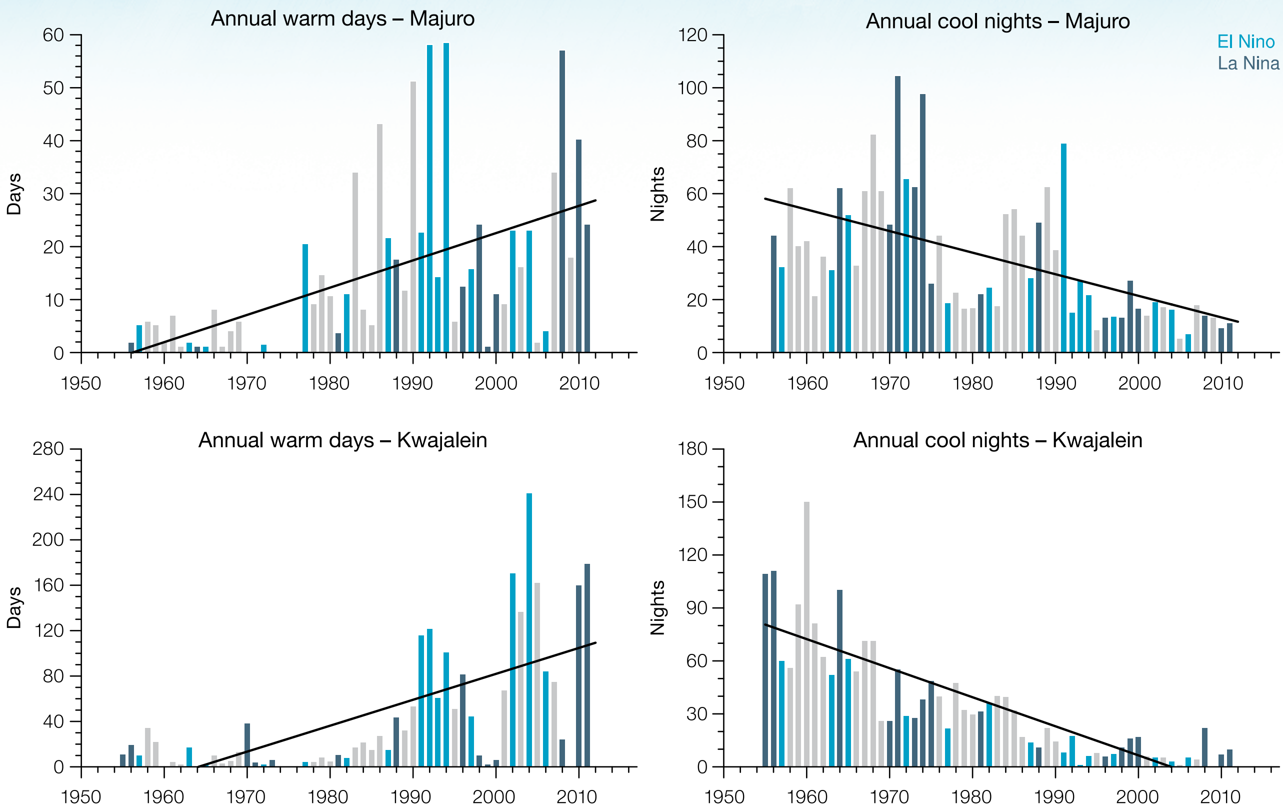


Figure 5: Annual total number of warm days (left) and cool nights (right) at Majuro (top) and Kwajalein (bottom). Light blue, dark blue and grey bars indicate El Niño, La Niña and neutral years respectively. No bars indicate that data is not available. Solid black lines show the trends.

Majuro is getting drier

Data since 1954 for Majuro shows a decreasing trend in annual rainfall (Figure 4, top) and in extreme daily rainfall. There are no statistically significant trends in rainfall at Kwajalein since 1945 (Figure 4, bottom). Over this period there has been substantial variation in rainfall from year to year associated with the El Niño-Southern Oscillation.

Lee Jacklick, National Weather Service Office

Flooding during extreme high tide.

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 near the Marshall Islands by about 0.3 inches (7 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. This variation in sea level can be seen in Figure 6 which includes the tide gauge record since 1950 and satellite data since 1993.

Ocean acidification has been increasing

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 Marshall Islands' waters.

Future climate of the **Marshall Islands**

Climate impacts almost all aspects of life in the Marshall Islands. Understanding the possible future climate of the Marshall Islands 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, 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.
- Wave height is projected to decrease in the dry season and wave direction may become more variable in the wet season.

- 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 the Marshall Islands (Table 1). By 2030, under a very high emissions scenario, this increase in temperature is projected to be in the range of 0.8–1.8ºF (0.5–1.1°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

Almost all of the global climate models project an increase in average annual rainfall over the course of the 21st century. However, there is some uncertainty in the rainfall projections and not all models show consistent results. 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.

The Marshall Islands 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 the Marshall Islands. 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)
Northern Marshall Islands								
Very low emissions scenario	0.9–1.8	0.5–1.0	1.1–2.2	0.6–1.2	0.9–2.2	0.5–1.2	0.9–2.2	0.5–1.2
Low emissions scenario	0.7–1.8	0.4–1.0	1.3–2.5	0.7–1.4	1.6–3.4	0.9–1.9	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	2.0–3.6	1.1–2.0	2.5–4.7	1.4–2.6
Very high emissions scenario	0.9–2.0	0.5–1.1	1.8–3.4	1.0–1.9	2.9–5.8	1.6–3.2	4.0–7.6	2.2–4.2
Southern Marshall Islands								
VVery low emissions scenario	0.7–1.6	0.4–0.9	1.1–2.2	0.6–1.2	0.9–2.2	0.5–1.2	0.9–2.2	0.5–1.2
Low emissions scenario	0.9–1.8	0.5–1.0	1.3–2.5	0.7–1.4	1.8–3.2	1.0–1.8	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	1.8–3.6	1.0–2.0	2.3–4.7	1.3–2.6
Very high emissions scenario	1.1–2.0	0.6–1.1	1.8–3.4	1.0–1.9	3.1–5.6	1.7–3.1	3.8–7.4	2.1–4.0

Lee Jacklick, National Weather Service Office

Ujae Atoll.

Weather balloon launch, Majuro Weather Service Office.

Sea level will continue to rise

Sea level is expected to continue to rise in the Marshall Islands (Table 2 and Figure 6). By 2030, under a very high emissions scenario, this rise in sea level is projected to be in the range of 3.1–7.5 inches (8–9 cm). The sea-level rise combined with natural year-to-year changes will increase the impact of storm surges and coastal flooding. As there is still much to learn, 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 Marshall Islands region will continue to increase over the 21st century, with the greatest change under the 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

Wave height is projected to decrease in the dry season and wave direction may become more variable in the wet season.

Majuro Atoll.

Table 2: Sea-level rise projections for the Marshall Islands. Values represent 90% of the range of 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	2.8–7.1	7–18	5.1–11.8	13–30	7.5–17.7	19–45	9.1–23.6	23–60
Low emissions scenario	2.8–7.1	7–18	5.5–12.6	14–32	8.3–19.3	21–49	11.0–27.2	28–69
Medium emissions scenario	2.8–6.7	7–17	5.5–12.2	14–31	8.3–19.3	21–49	11.8–27.6	30–70
Very high emissions scenario	3.1–7.5	8–19	6.3–13.8	16–35	10.6–23.6	27–60	16.1–36.2	41–92

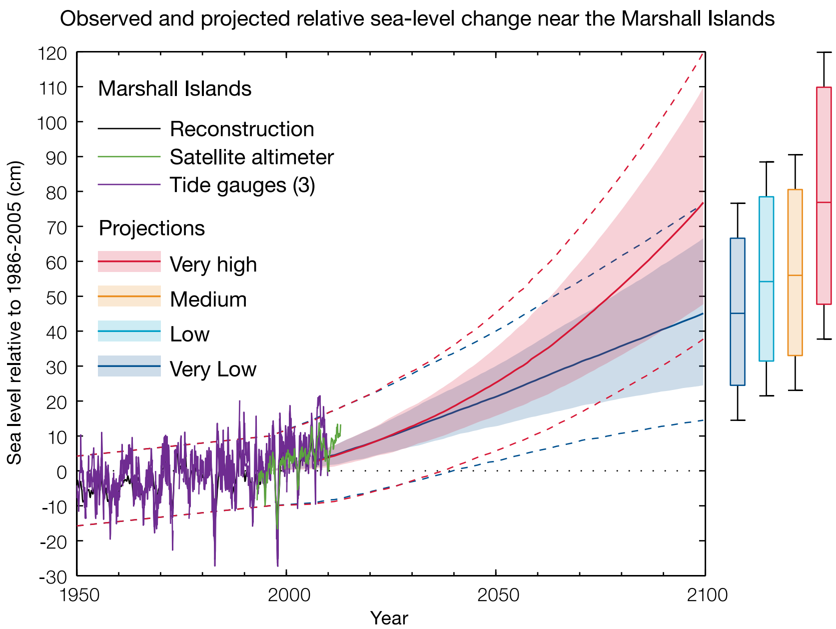


Figure 6: Tide-gauge records of relative sea level (since 1950) are indicated in purple, and the satellite record (since 1993) in green. The reconstructed sea-level data at the Marshall Islands (since 1950) is shown in black. Multi-model mean projections from 1995–2100 are given for the very high (red 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 Marshall Islands region of the western tropical Pacific. These 26 models have been used to develop climate projections for the Marshall Islands.

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 the Marshall Islands 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 7). 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.

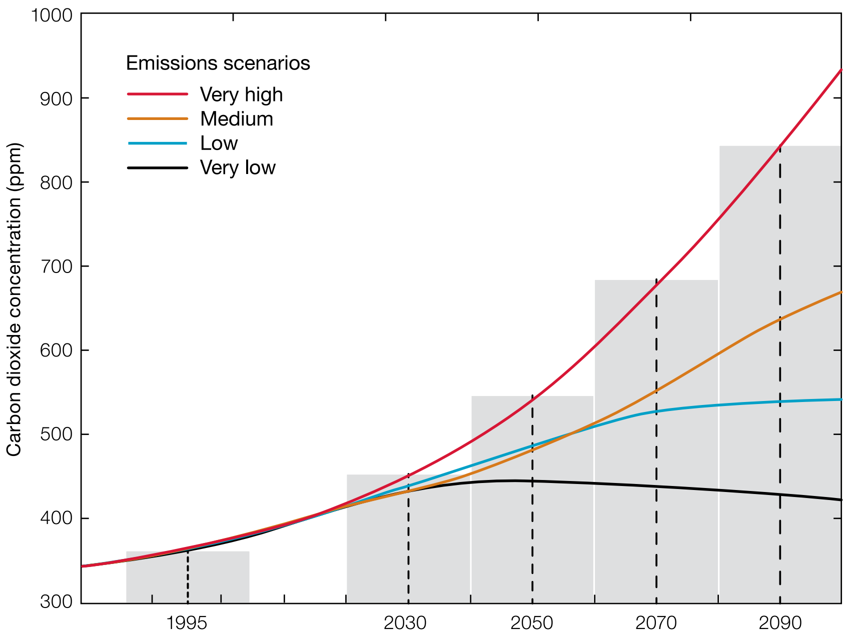


Figure 7: Carbon dioxide concentrations (parts per million, ppm) associated with the very low (RCP2.6), low (RCP4.5), medium (RCP6.0) and very high (RCP8.5) emissions scenarios for 20-year time periods (shaded) centred on 1995 (the reference period), 2030, 2050, 2070 and 2090.

This brochure contains a summary of climate projections for the Marshall Islands. 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**.

Climate projections are also available through the web-based Pacific Climate Futures tool at **www.pacificclimatefutures.net**.

Changes in the

Marshall Islands' climate

> Temperatures have warmed and will continue to warm with more very hot days in the future.

> Annual rainfall is projected to increase. Rainfall extremes are projected to increase. The frequency of drought is projected to to decrease relative to the current climate.

> By the end of this century projections suggest decreasing numbers of typhoons.

> Sea level near the Marshall Islands has risen and will continue to rise throughout this century.

> Ocean acidification has been increasing in the Marshall Islands' waters. It will continue to increase and threaten coral reef ecosystems.

> Wave height is projected to decrease in the dry season and wave direction may become more variable in the wet season.

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

The content of this brochure is the result of a collaborative effort between the Marshall Islands 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 the Marshall Islands 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

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