Pacific-Australia Climate Change Science and Adaptation Planning Program

Climate in the Pacific:

A regional summary of new science and management tools

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Foreword

Small island developing states in the tropical Pacific are increasingly vulnerable to the impacts of climate variability, extremes and change, including loss and damage to infrastructure and natural assets from climate-related natural disasters and associated threats to health and wellbeing of the population. Climate science plays a critical role in understanding the causes and providing information on impacts (the evidence base) to inform decision-making for purposes of climate risk reduction and adaptation in this region. It follows that enhanced scientific knowledge facilitates more effective and efficient decisions by all stakeholders at regional, national, sectoral and local community levels, thereby facilitating sustainable and resilient development for the benefit of all.

Over the period 2011/12–2013/14, the Pacific-Australia Climate Change Science and Adaptation Planning (PACCSAP) Program has delivered a regional climate science program for 14 Pacific partner countries and Timor-Leste, with a focus on current climate observations and trends, and future climate projections for each country. To complement the new science, PACCSAP has developed a suite of customised climate science tools and communication products to enhance awareness of climate impacts and to support decision-making by stakeholders. The program has also undertaken development of climate science capacity within regional partner countries, including national meteorological services, to facilitate the long-term sustainability of program outcomes.

PACCSAP was funded by the Australian Government through the Department of Foreign Affairs and Trade. It was managed by the Australian Department of the Environment, and the science component was delivered by the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Bureau of Meteorology in collaboration with partner countries and regional organisations, including the Secretariat of the Pacific Regional Environment Programme (SPREP). This report tells the story of the climate science delivered by PACCSAP in mostly non-technical language for stakeholders, including policy-makers, planners and associated decision-makers. For its part, the climate change team at SPREP has been an active and committed collaborative partner with CSIRO, the Bureau and partner countries throughout the PACCSAP Program and is very pleased to be able to support the preparation and publication of this report.

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About this publication

This publication aims to provide a summary of the science and tools developed through the Pacific-Australia Climate Change Science and Adaptation Planning (PACCSAP) Program, and the Pacific Climate Change Science Program (PCCSP) prior to that, in an easily accessible and largely non-technical format. It is intended as a key point of reference on the latest science for policy developers, planners and associated decision-makers and stakeholders in partner countries.

For more detailed projections and information on the science used in this publication, please see the companion 2014 PACCSAP technical report, *Climate Variability, Extremes and Change in the Western Tropical Pacific: New Science and Updated Country Reports**, available at **www.pacificclimatechangescience.org**.

There are four sections in this publication.

Section I is an introduction, providing a brief history of the science programs.

Section II is a summary of regional climate observations, trends and projections developed through the programs, with a focus on five key climate components:

CLIMATE VARIABILITY & LARGE-SCALE FEATURES

TEMPERATURE

RAINFALL

OCEANS

TROPICAL CYCLONES

This section also contains a summary of climate projections for each partner country. Detailed projections are available in the 2014 PACCSAP technical report.

Section III contains information on the range of management tools, developed through the PCCSP and the PACCSAP science program. These tools are designed to help partner countries to both better understand their changing climate and to inform decision-making, enabling them to more effectively and efficiently plan for and adapt to the future.

Section IV provides a brief overview of the scientific data, methods and terminology underpinning this report. More in-depth information is available in the 2014 PACCSAP technical report.

Impacts of a changing climate

This publication also provides an indication of the types of climate-related impacts that can be expected in the region, in light of the projections developed in the program. There are six key impact sectors:

INFRASTRUCTURE

HEALTH

WATER

TOURISM

FOOD & NATURAL RESOURCES

BIODIVERSITY

These impacts are based on projected changes in the following key climate hazard indicators:

- Annual mean air temperature (and by association sea-surface temperature)
- Extreme daily maximum and minimum temperatures
- Annual mean rainfall
- Wet and dry season mean rainfall
- Frequency of drought
- Frequency of heavy rainfall
- Frequency of tropical cyclones
- Annual mean sea level
- Aragonite saturation state.

These projections are available in the technical report.

The level of climate risk and vulnerability in relation to any one climate hazard for any one country, island or sector in the western tropical Pacific will vary according to exposure and the time frame(s) under consideration as well as the adaptation capacity of local communities. Risks may also be considered in the context of positive offsets from any impacts, particularly in terms of socio-economic benefits from possible new agricultural, fisheries, energy and tourism opportunities resulting from a changing climate.

* Australian Bureau of Meteorology and CSIRO (2014). *Climate Variability, Extremes and Change in the Western Tropical Pacific: New Science and Updated Country Reports*. Pacific-Australia Climate Change Science and Adaptation Planning Program Technical Report, Australian Bureau of Meteorology and Commonwealth Scientific and Industrial Research Organisation, Melbourne, Australia.

I. INTRODUCTION

Understanding the changing climate of the Pacific and Timor-Leste

Small island developing states are among the most vulnerable to our changing climate. People living in the Pacific Islands and Timor-Leste are already experiencing higher temperatures, shifts in rainfall patterns, rising sea levels and changes in frequency and intensity of extreme climate events, with further changes expected long into the future as a result of climate change associated with human activity. These changes are occurring on top of a naturally variable climate.

Changes in the climate have far-reaching consequences that will affect communities and the environment. Areas that will be impacted include human health, infrastructure, coastal resources, disaster management, fresh water availability, agriculture, fisheries, forestry, marine ecosystems and tourism.

Climate science for the Pacific

To deal with these changes, small island developing states in the region need credible, useful scientific information about what drives the climate in the Pacific, how it may change in the future and what the impact of these changes might be.

As further climate change appears inevitable, adaptation is an essential element in the region's response. The Pacific Islands Framework for Action on Climate Change 2006–2015 recognised that there was a clear need for sound scientific information to inform local, national and regional responses to climate change. Unfortunately this information was extremely limited prior to 2009. The 996-page Working Group 1 component of the Intergovernmental Panel on Climate Change's Fourth Assessment Report in 2007 contained fewer than 10 pages on regional climate projections for all small island developing states across the Caribbean, Indian Ocean and the Pacific.

In 2009 the Australian Government, through AusAID and the Department of Climate Change, established the Pacific Climate Change Science Program (PCCSP). Through this program the Australian Bureau of Meteorology and Commonwealth Scientific and Industrial Research Organisation (CSIRO) and their collaborative partners in the Pacific undertook fundamental climate research and provided critical scientific information for the region. Importantly, this collaboration included the National Meteorological/Weather Services of 14 Pacific Island countries and Timor-Leste, which resulted in a significant increase in local scientific and technical skills and knowledge. This program concluded in 2012.

Building on the success of the PCCSP and the related Pacific Adaptation Strategy Assistance Program (PASAP), and with further support from the Australian Government through the Department of Foreign Affairs and Trade (and formerly AusAID) and the Department of the Environment, the Australian Bureau of Meteorology and the CSIRO continued to work collaboratively with the 15 partner countries. This generated scientific insight into the state of climate variability, extremes and change in the Pacific now and in the future, under the Pacific-Australia Climate Change Science and Adaptation Planning (PACCSAP) Program. This program concluded in 2014.

What is the difference between climate and weather?

Weather refers to atmospheric conditions such as temperature and rainfall over a short period of time – a few hours or a few days. Climate, on the other hand, is the average pattern of weather for a particular place over a long period of time, usually 30 years or more.

The Pacific-Australia Climate Change Science and Adaptation Planning Program

The key activities undertaken by the science component of the PACCSAP Program were:

- developing a climate database, and collating and digitising meteorological data for Pacific Island countries and Timor-Leste
- examining past climate observations, trends, large-scale climate processes, natural variability and seasonal prediction of selected atmospheric and ocean variables
- providing relevant national-scale climate projections based on global climate model outputs
- developing a number of tools to improve management, access, modelling and analysis of climate data, including enhanced seasonal forecasting capability at a national scale
- communicating key climate science findings and developing in-country climate science capacity.

PACCSAP (2011/12–2013/14) and before that the PCCSP (2009/10–2011/12) worked in collaboration with 15 partner countries: Cook Islands, Timor-Leste, Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu.

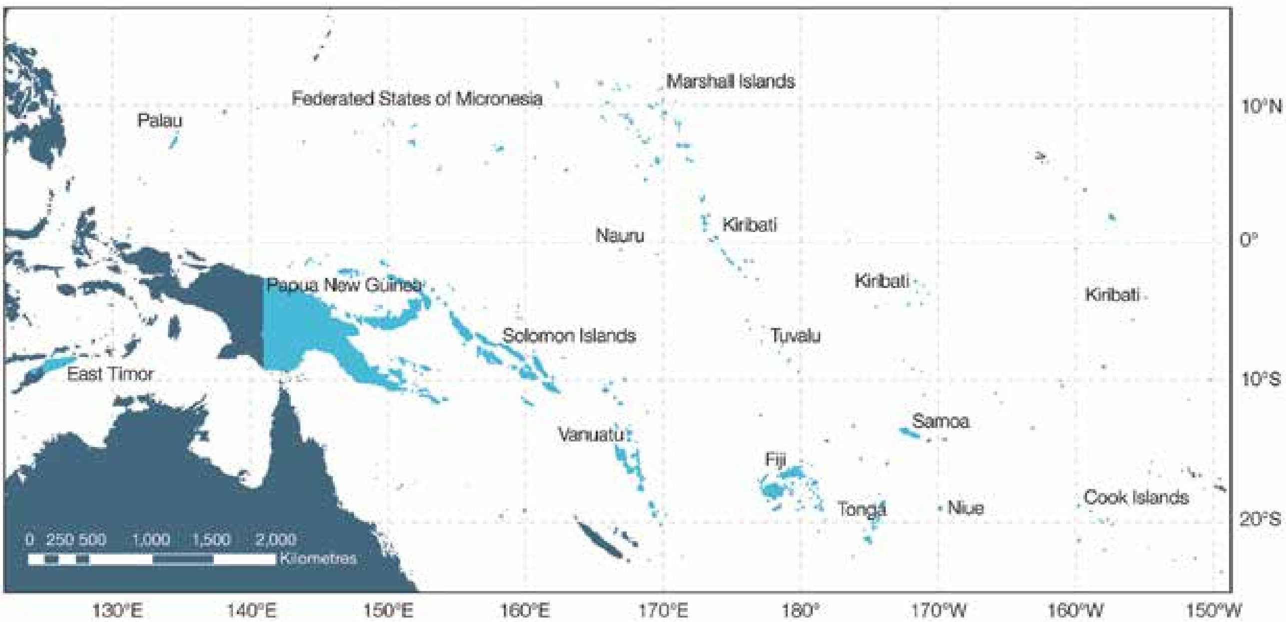


Figure 1: Map showing the western tropical Pacific partner countries involved in PCCSP/PACCSAP

II. CLIMATE OBSERVATIONS, TRENDS AND PROJECTIONS

Climate variability and large-scale climate features

The Pacific Ocean covers almost a third of the Earth's surface and plays an important role in shaping the world's climate. The presence of large-scale climate features and different sized land masses leads to profound regional variations in climate. Of these large-scale features, the El Niño-Southern Oscillation is the major cause of year-to-year climate variations.

Understanding the current climate and large-scale climate features in the Pacific is essential to improve our understanding of how the climate of the Pacific may change in the future. This in turn will help Pacific Island countries prepare for and adapt to these changes.

The El Niño-Southern Oscillation is the major cause of year-to-year climate variability in the Pacific.

In some countries the impacts of El Niño vary for different types of El Niño events.

El Niño events will be warmer in the future.

The Interdecadal Pacific Oscillation influences climate variability over a longer time scale.

Both average and extreme rainfall are expected to change in a warming climate.

Approximately one quarter of all years are El Niño years and one quarter are La Niña years. The remaining years are ENSO neutral. There is no regular pattern between the occurrence of El Niño and La Niña years.

Climate variability

Natural cycles cause variations in the climate on time scales of months, seasons and years. The annual cycle of wet and dry seasons is one example of natural climate variability experienced by every island in the western tropical Pacific. This cycle varies in timing and intensity between years. Much of year-to-year climate variability is caused by natural variations in the conditions of the atmosphere and ocean, such as the El Niño-Southern Oscillation.

The El Niño-Southern Oscillation is the major cause of year-to-year climate variability in the Pacific

The extent and timing of the influence of the El Niño-Southern Oscillation (ENSO) varies between countries. Throughout the region, ENSO affects the year-to-year risk of droughts, floods, tropical cyclones, extreme sea levels and coral bleaching.

ENSO is a natural cycle of the climate system, with two extreme phases: El Niño and La Niña. If neither phase is apparent conditions are termed ENSO neutral.

What is the difference between climate variability and climate change?

Climate variability refers to the natural variations in climate that occur from month to month, season to season and year to year. Climate change refers to the long-term changes in the average pattern of weather.

Climate change occurs over decades, centuries or longer, as a result of both natural and man-made processes. It can mean long-term changes in the average climate conditions (such as average rainfall and temperature) or in the occurrence of extreme events such as tropical cyclones and droughts.

Man-made climate change is primarily caused by increasing greenhouse gas levels in the Earth's atmosphere. Greenhouse gases occur naturally in the atmosphere and trap heat. However, human activities like burning fossil fuels (such as coal, oil and natural gas) are rapidly increasing the concentration of these gases in the atmosphere. This is causing 'global warming', with the climate becoming increasingly warmer and causing weather patterns in some places to change.

El Niño and La Niña events usually begin to develop between May and June and last until the following March to May. While such events tend to follow a typical pattern of development, the strength and timing of each event is different, as is the exact pattern of sea-surface temperature, wind and impacts. If maximum warming occurs in the central tropical Pacific rather than in the east then the El Niño is sometimes referred to as a central Pacific El Niño, or an El Niño Modoki, which can have different impacts on some countries. For example, El Niño Modoki events have had a very different impact on rainfall in Kiribati and Nauru than have other El Niño events.

ENSO has a profound influence on sea level and the risk of tropical cyclones in the region. Temperatures are also affected; year-to-year temperature variations along the equator can be larger than the average variations between the seasons. El Niño and La Niña events have distinct impacts on the rainfall of most Pacific Island countries. Changes in sea-surface temperature and winds associated with El Niño and La Niña cause large-scale shifts in rainfall patterns.

In some countries the impacts of El Niño vary for different types of El Niño events

During very strong El Niño events, such as in 1982/3 and 1997/8, the SPCZ and ITCZ moved towards the equator and merged into one convergence zone. This led to lower than normal rainfall in Nauru and the western part of Kiribati (Gilbert Islands) rather than the above-average rainfall that El Niño normally brings. In many countries (including the Federated States of Micronesia and the southern Marshall Islands in the north-west and Samoa, Niue and the southern Cook Islands in the south-west Pacific) the rainfall in these extreme El Niño years was much lower than normal and significantly drier than other El Niño years.

What is the difference between El Niño and La Niña?

An El Niño brings warmer than average ocean temperatures to the central to eastern Pacific and a weakening of the trade winds. The Intertropical Convergence Zone (ITCZ) and South Pacific Convergence Zone (SPCZ) tend to move closer to the equator, so rainfall increases near the equator and decreases in the north-west and south-west Pacific.

In a La Niña the opposite changes to ocean temperatures occur and the trade winds strengthen. The ITCZ and SPCZ tend to move away from the equator, reducing rainfall near the equator and increasing it to the north of the equator and south-west Pacific.

Table 1: Summary of the impacts of El Niño and La Niña during November to April in each country and region, showing whether there is a clear change in rainfall and sea level. 'El Niño' covers all years of El Niño, and 'Extreme El Niño' includes only the years 1982/3 and 1997/8.

Country	Region	El Niño	Extreme El Niño	La Niña
Cook Islands	North	Wet	Wet	Dry
	South	Dry	Very dry	Wet
Federated States of Micronesia	West	Dry Lower than normal sea level	Very dry Lower than normal sea level	No consistent impact on rainfall Higher than normal sea level
	East	Lower than normal sea level	Dry Lower than normal sea level	Wet Higher than normal sea level
Fiji		Dry	Very dry	Wet
Kiribati	Gilbert Islands	Wet	Dry	Dry
	Line Islands	Wet Higher than normal sea level	Wet Higher than normal sea level	Dry Lower than normal sea level
Marshall Islands	North	Lower than normal sea level	Lower than normal sea level	No consistent impact on rainfall Higher than normal sea level
	South	Lower than normal sea level	Very dry Lower than normal sea level	Dry Higher than normal sea level
Nauru		Wet	Dry	Dry
Niue		Dry	Very dry	Wet
Palau		Dry Lower than normal sea level	Dry Lower than normal sea level	Wet Higher than normal sea level
Papua New Guinea		Lower than normal sea level	Dry Lower than normal sea level	No consistent impact on rainfall Higher than normal sea level in the north
Samoa		Dry	Dry Lower than normal sea level	No consistent impact on rainfall Higher than normal sea level
Solomon Islands		Dry Lower than normal sea level	Dry Lower than normal sea level	Wet Higher than normal sea level
Timor-Leste		Dry	Dry	Wet
Tonga		Dry	Very dry	Wet
Tuvalu		Wet Lower than normal sea level	Wet Lower than normal sea level	Dry
Vanuatu		Dry	Dry	Wet

This table was taken from *The Pacific Adventures of the Climate Crab* toolkit, a resource developed through PACCSAP to raise awareness of the impacts of El Niño and La Niña in the Pacific. This resource is available at **www.pacificclimatechangescience.org/climatecrab**

El Niño events will be warmer in the future

Unfortunately, climate models do not generally provide consistent projections of changes in the frequency, intensity and patterns of future El Niño and La Niña events. However, it is likely that future El Niño events will tend to be warmer than El Niño events experienced in the past. Recent research also suggests that ENSO-driven rainfall changes might intensify in the central-east equatorial Pacific and the western equatorial Pacific.

The Interdecadal Pacific Oscillation influences climate variability over a longer time scale

Just as climate varies from year to year due to ENSO, climate in and around the Pacific Ocean also varies substantially from decade to decade. Much of this variability has been linked to natural ENSO-like patterns of variability operating at decadal and inter-decadal time scales. This variability is known as the Interdecadal Pacific Oscillation (IPO). The countries influenced by the IPO are the same ones influenced by ENSO. Research into the mechanisms responsible for the IPO, and decadal climate variability more generally, is ongoing.

Large-scale climate features

Other large-scale climate features of the western tropical Pacific include the South Pacific Convergence Zone (SPCZ), the West Pacific Monsoon (WPM) and the Intertropical Convergence Zone (ITCZ). These features affect the regional pattern and seasonal cycle in rainfall, winds, tropical cyclone tracks, ocean currents, ocean nutrients and many other aspects of the environment.

How will ENSO change in the future?

There is no consensus from the climate models on whether sea-surface temperature variations driven by El Niño and La Niña events will become more or less frequent, or stronger or weaker in a future warmer climate. All models indicate that El Niño and La Niña events will continue to occur and have a significant impact on year-to-year variability in the region. Extreme El Niño events may become more common in the future and El Niño-driven rainfall variations near the equator may be enhanced under global warming.

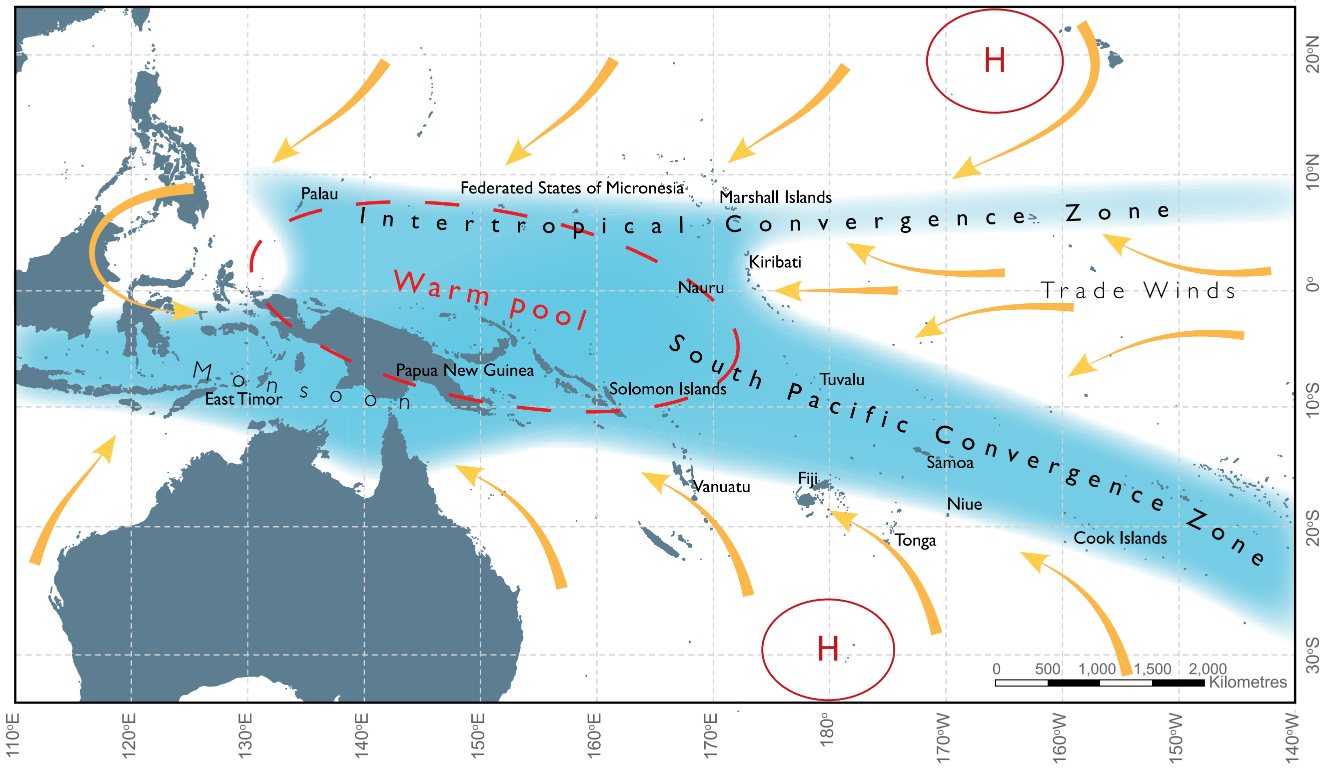


Figure 2: Map showing the average positions of the South Pacific Convergence Zone, Intertropical Convergence Zone and West Pacific Monsoon (all shaded blue) in the western tropical Pacific region in November to April. The yellow arrows show near-surface winds and the red dashed oval indicates the West Pacific Warm Pool. H represents the typical positions of moving high-pressure systems.

Sub-tropical highs, trade winds and tropical cyclones also have a significant influence on the climate of countries in the Pacific. On small, low-lying islands, the climate may be similar across the island and nearby islands. However, on larger, elevated islands, hills and mountains (topography) can produce large variations in the climate across the island. For example, in Fiji rainfall is higher in Suva, which is exposed to the south-east trade winds, than in Nadi, which lies on what is predominantly the lee (sheltered) side of the same island. Notable differences in climate also occur within countries that are spread over a large area, such as the northern and southern Cook Islands. Table 2 lists the main influences in addition to ENSO on climate in each country.

Table 2: Partner countries and the large-scale features (other than ENSO) that influence their climate

Country	Main climate features and influences
Cook Islands	SPCZ, sub-tropical highs, trade winds, tropical cyclones, topography
Timor-Leste	WPM, topography
Federated States of Micronesia	ITCZ, WPM, trade winds
Fiji	SPCZ, trade winds, sub-tropical highs, tropical cyclones, topography
Kiribati	ITCZ, SPCZ, trade winds
Marshall Islands	ITCZ, WPM (in some years), tropical cyclones
Nauru	ITCZ, SPCZ, trade winds
Niue	SPCZ, trade winds, sub-tropical highs, tropical cyclones
Palau	WPM, ITCZ, trade winds
Papua New Guinea	WPM, ITCZ, topography
Samoa	SPCZ, trade winds, sub-tropical highs, tropical cyclones, topography
Solomon Islands	SPCZ, WPM, tropical cyclones, topography
Tonga	SPCZ, trade winds, sub-tropical highs, tropical cyclones, topography
Tuvalu	WPM, SPCZ, trade winds, sub-tropical highs, tropical cyclones
Vanuatu	SPCZ, trade winds, sub-tropical highs, tropical cyclones, topography

Both average and extreme rainfall are expected to change in a warming climate

Any long-term changes to the ENSO, SPCZ, ITCZ or WPM will have an important influence on average rainfall in the Pacific. The SPCZ is not projected to move markedly, and general changes in rainfall in the SPCZ are somewhat uncertain. However, the extreme years when the SPCZ moves north and merges with the ITCZ are projected to become more frequent in a warming climate as the century unfolds. There is also a general tendency for an enhancement of the seasonal cycle of rainfall in the WPM region and in the ITCZ region, with rainfall increasing during the wet season in these regions.

Along with changes to these features, changes to the mean state of the Pacific affect the projected average rainfall climate for Pacific Island countries. We now know that there is a balance between 'thermodynamic' processes (related to higher temperatures) and 'dynamic' processes (such as changes to atmospheric circulation) on the overall average rainfall. We also know that changes to the spatial pattern of sea-surface temperature features and gradients are crucial, and the most likely change to many of these patterns are not yet clear. However, there are some robust projections, including an increase in rainfall for countries along the equator.

Note: Because the exact evolution of each influence is not entirely clear in future, changes to average rainfall are presented with less confidence than some other variables. We advise considering a range of future rainfall change scenarios when making planning decisions.

Temperature

Average air temperature is an important indicator of the state of the climate system, and small changes in temperature can correspond to enormous changes in the environment. However, the impact of temperature on natural systems and human settlements is felt most strongly through changes in extremes. Understanding future changes in temperature is important because increasing temperatures have implications for health, agriculture, water resources and many other sectors.

Temperature variations between the seasons increase with distance from the equator.

Mean air temperature has increased across the Pacific over the past half-century, with the past decade being the warmest on record.

The number of unusually hot days and nights has increased and the number of cool days and nights has decreased.

Hottest days are getting hotter.

Temperatures will continue to increase.

Temperature variations between the seasons increase with distance from the equator

Air temperatures close to the equator are relatively constant throughout the year with seasonal variation increasing with distance from the equator. Temperatures in countries further away from the equator are also influenced by air masses such as cold fronts. Islands closer to the equator tend to experience a maximum of only a 1–2 °C difference in average monthly temperatures over the year. For islands further south, such as Nuku'alofa, Tonga, the average summer to winter maximum and minimum air temperature ranges are more than 6 °C, with the maximum experienced at most sites between December and March.

Mean air temperature has increased across the Pacific over the past half-century, with the past decade being the warmest on record

Data from across the Pacific show an average increase in temperature of 0.9 °C over the 50 years from 1961 to 2011, ranging from 0.25 °C at Nadi Airport in Fiji to 1.70 °C at Tahiti in French Polynesia. The magnitude and rate of warming since 1961 at Port Moresby in Papua New Guinea (0.18 °C per decade) is representative of mean warming across the region.

The trends in overnight (minimum) temperatures and daytime (maximum) temperatures are very similar to each other. Warming is slightly less in the north-west Pacific and the subtropical south Pacific. The level of warming in the western tropical Pacific temperature records is consistent with that expected from human-induced global warming.

Will temperature and rainfall change by the same amount everywhere on the island?

No. The projected temperature increases are an average over the whole Exclusive Economic Zone (EEZ) region. Within an EEZ there is likely to be local variation, with some areas seeing changes somewhat lower or higher than the average for the whole region.

The number of unusually hot days and nights has increased and the number of cool days and nights has decreased

Across the Pacific there has been widespread increases in the frequency of warm extremes and declines in the frequency of cold extremes. The number of unusually warm days and nights have more than tripled over the past 50 years. Once rare extremes, that occurred approximately 20 days per year, are happening much more frequently (between 45 and 80 days per year). The trends in the cool days are approaching the point at which unusually cool conditions have almost ceased to occur.

Hottest days are getting hotter

Not only do records show that have the average number of hot days has increased but the hottest days are also getting hotter. Data from Pacific weather stations with records extending back 60 years or more show that the temperature of a 1-in-20 year maximum temperature event has increased by 0.7 °C over this time. This is similar to the rate of warming seen in the average temperature. The increase in the 1-in-20 year minimum temperature increase has been rather less at 0.3 °C.

Use the **Pacific Climate Change Data Portal** to examine historical temperature data from across the region. *See page 38.*

Temperatures will continue to increase

Average temperatures are very likely to increase further, bringing more extremely hot days and warm nights. Climate models indicate that for daily mean temperature:

- By 2030, the projected warming in the western tropical Pacific is around +0.5 to 1.0 °C relative to 1986–2005, regardless of the emissions scenario
- By 2050 the warming under the very low emissions scenario is projected to plateau at around +0.5 to 1.0 °C, but for the very high scenario the warming is projected to be around +1.0 to 2.0 °C relative to 1986–2005
- By 2090, the projected warming, relative to 1986–2005, is around:
  - +0.5 to 1.0 °C for the very low emissions scenario
  - +1.0 to 2.0 °C for the medium emissions scenario
  - +1.5 to 3.0 °C for the high emissions scenario
  - +2.0 to 4.0 °C for the very high emissions scenario
- Extreme temperatures that occur once every 20 years on average are projected to increase roughly in line with average temperatures (e.g. by up to +2.0 to 4.0 °C by 2090 under the very high emissions scenario).

Use the **Pacific Climate Futures** tool for risk assessment and adaptation planning. *See page 38.*

INCREASING TEMPERATURE MAY RESULT IN :

- Increased incidence of heat stress on coastal infrastructure, including public buildings and roads. This impact will be compounded by the effect of sea level rise and the risk of coastal inundation and associated storm surge/extreme sea levels.
- Increased energy demand for cooling, and greater transmission loss in electrical wires.
- Increased risk of fire damage to infrastructure.

- Increased demand for domestic, industrial and agricultural water use.
- Reduced water quality in fire-affected catchments.

- Increased stress on agricultural crops/animals, inshore fisheries and forestry, which will affect production schedules, practices, quality and overall productivity, market demand/value and local economies.
- Altered timing and intensity of environmental cues, which will impact on established production, harvest and marketing schedules.
- Increased incidence of endemic and exotic plant and animal pathogens and associated disease.
- Increased incidence of forest fire.
- Shift in fish populations (e.g. tuna following warmer water).
- Greater risk of food-borne diseases.

- Increased incidence of vector-borne disease such as malaria, Dengue fever and Chikungunya disease.
- Increased incidence of heat stress and death in local communities, which will particularly affect the young, elderly and infirmed.
- Increased pressure on hospitals and morgues to cope with large numbers of admissions and deaths during heatwaves.

- A change in ambient seasonal climate conditions, which could affect visitation rates.
- Some sub-tropical regions may become more attractive to tourists, while tropical regions may become too hot and humid.

- Increased risk of coral bleaching with higher sea-surface temperatures and ocean acidification.
- Increased stress on ecosystem function, changes in species distribution and abundance/community composition, and increased incidence of exotic/invasive species. The effect of ocean acidification and the risk of coral bleaching will compound this impact.

Rainfall

The timing and amount of rainfall in the Pacific and Timor-Leste has a significant impact on life in the region. In all partner countries there is a significant difference in the regular rainfall that comes in the wet and the dry seasons. A large portion of rainfall in the region occurs in the main rainfall convergence zones, which are where the warm ocean surface leads to high evaporation and enhanced convection when moisture-laden winds converge. Tropical cyclones and storms also contribute to rainfall. Rainfall not only has implications for water resources and agriculture, but also flooding. Extreme rainfall events also affect infrastructure and human health.

Rainfall in the Pacific is highly variable.

Over the past 30 years the south-west Pacific has become wetter and the central Pacific has become drier, mostly due to natural decadal climate variability.

Average rainfall is projected to increase in the future in many locations across the Pacific.

Extreme rainfall events are projected to be more frequent and more intense in the future.

Time spent in drought may decrease in the future in some locations.

Use the **Pacific Climate Change Data Portal** to examine historical rainfall data from across the region. *See page 38.*

Rainfall in the Pacific is highly variable

While many Pacific island countries have clear wet and dry seasons, rainfall can be extremely variable from month to month and year to year – in contrast to the much more stable air temperatures.

Much of this variability is directly attributable to shifts and changes in intensity in the SPCZ, the ITCZ and the WPM. For example, countries in the North Pacific – Palau, the Federated States of Micronesia and the Marshall Islands – experience their wettest months between May and August, when the ITCZ is strongest and at its furthest north. Nauru, Kiribati and Tuvalu, all near or just south of the equator, experience their wettest months between December and March. These countries are also influenced by the SPCZ, especially Tuvalu which is further south. Tuvalu's rainfall is also influenced by the monsoon.

The largest seasonal variations in rainfall occur in regions strongly affected by the monsoon. For example, in Timor-Leste's capital Dili, almost 80% of the total annual rainfall falls during their wet season (November–April).

Much of the year-to-year rainfall variability is linked to ENSO while much of the decade-to-decade variability is linked to the IPO. ENSO and the IPO also cause shifts and changes in intensity in the SPCZ, the ITCZ and the WPM. Many countries can experience much higher than normal rainfall or droughts in El Niño and La Niña years when the rainfall convergence zones move either away from or closer to the countries.

There are other factors that influence rainfall in the region. Tropical cyclones and storms bring significant rainfall. For example, in Vanuatu 15% of the annual rainfall is due to the effects of tropical cyclones. The position and strength of sub-tropical high-pressure systems and cold fronts also impact on rainfall. In hilly or mountainous regions, rainfall will vary depending on the strength and direction of winds, particularly the trade winds.

Over the past 30 years the south-west Pacific has become wetter and the central Pacific has become drier, mostly due to natural climate variability

Natural variability in rainfall across the Pacific region makes it difficult to detect rainfall trends. Most trends are small with no clear spatial patterns over the past 50 years (1961–2011). However, a notable change is evident over the past 30 years (1981–2011). During this period the south-west Pacific has become wetter and the central Pacific has become drier. These trends appear to reflect the influence of variability in the SPCZ, rather than a long-term climate change.

The wetter conditions in the south-west Pacific are due to the south-westward movement of the SPCZ since the late 1990s. This displacement is associated with more frequent La Niña events and a shift to a negative IPO phase. In contrast, the period from 1978–1998 was associated with drier conditions due to the SPCZ being displaced north-eastward, but during this period the IPO was in a positive phase.

Average rainfall is projected to increase in the future in many locations across the Pacific

Average annual rainfall is projected to increase in most areas of the western tropical Pacific in a warmer climate. The effect of climate warming on rainfall is likely to be small to 2030, and mostly obscured by the effect of climate variability. After this time, some general patterns emerge in the model projections and become stronger through the century. The projected rainfall changes are strongest under the very high emissions scenario. During November to April rainfall is projected to increase along the equator, in the north-east near the Marshall Islands and in the middle of the SPCZ region. Rainfall decreases are projected at the north-eastern edge of the SPCZ near the Cook Islands. During May to October, increases in rainfall are projected mainly along the equator and the north-west around Palau and the Federated States of Micronesia, with small increases or decreases south of the equator.

Note: while this is our current central estimate of plausible changes to rainfall patterns, there is uncertainty regarding the exact balance between the various driving influences and changes to the mean state of the Pacific. In some cases models indicate a broad range of projected change, and in some instances changes outside the model range are possible. Therefore, it is useful to consider a few different scenarios of rainfall change when planning for the future.

Extreme rainfall events are projected to be more intense and more frequent in the future

In contrast to the temperature extremes, there are few consistent trends in extreme rainfall across the region over the past 50 years. Maps of station trends illustrate this for annual very wet day rainfall (daily rainfall greater than 95th percentile) and extremely wet day rainfall (daily rainfall greater than 99th percentile). Changes in intensity in rainfall average recurrence intervals (2, 5, 10 and 20-year periods) between 1951–1980 and 1981–2010 periods have been examined for the Pacific region using station data. The change in intensity for the 20-year average recurrence interval had the strongest response with a mean change of +3.5% suggesting that on a regional scale very extreme rainfall events have become greater. The largest extreme rainfall events tend to occur in countries that are situated in the region where tropical cyclones and depressions occur (away from the equator) and that have mountainous areas.

Extreme rainfall events that currently occur once every 20 years on average are projected to occur once every 7 to 10 years by 2090 under the very low emissions scenario, and once every 4 to 6 years by 2090 under the very high emissions scenario. Extreme rainfall is projected to increase, even in regions where average rainfall is projected to decrease, since the physical processes involved are well understood. Note: these projections of extreme rainfall do not include the contribution from tropical cyclones.

Vanuatu Meteorology and Geo-hazard Department

Time spent in drought may decrease in the future in some locations

Projected changes to the average frequency, intensity and duration of drought generally follow the projected change in average rainfall. This includes decreases to the average incidence of drought in countries near the equator such as Nauru and Kiribati, an increase in drought at the eastern edge of the SPCZ including the northern Cook Islands, but little change in other regions such as Timor-Leste and Samoa. The projected changes are stronger in the higher emissions scenarios than in the lower scenarios, and the changes strengthen through the 21st century. Since changes to drought reflect changes to average rainfall as well as changes to rainfall variability (affected by ENSO), the results are less certain than for some other variables.

Use the **Pacific Climate Futures** tool for risk assessment and adaptation planning. *See page 38.*

IN A WETTER CLIMATE WE EXPECT TO SEE:

- Increased risk of storm water exceeding design specifications for urban and rural drainage systems causing increased incidence of floods, flood-related loss and damage, and disturbance to local and national infrastructure (transport, energy, water, telecommunication), economies and livelihoods
- Greater hydro-electricity potential but reduced solar energy potential.

- Reduced risk of drought.
- Reduced demand on stored water resources.
- Increased rate of freshwater recharge of groundwater aquifers and altered hydraulic pressures, reducing risk of salinisation of aquifers from the ocean.
- Reduced risk of blue-green algae outbreaks.
- Increased risk of flooding and associated impacts for infrastructure, food, heath, tourism and biodiversity.

- Altered timing and intensity of environmental cues and rainfall run-off impacting on established production, harvest and marketing schedules.
- Reduced stress on agricultural crops/ animals, inshore fisheries and forestry affecting production schedules, practices and overall productivity, market demand/value and local economies.
- Reduced incidence of forest fire.
- Reduced near-surface ocean salinity, which enhances ocean mixing and nutrient supply.
- Increased incidence of endemic and exotic plant and animal pathogens and associated disease.

- Increased incidence of vector-borne disease such as malaria, Dengue fever and Chikungunya disease
- Increased loss of public utilities (including potable water and sewerage systems) under flood conditions, which will impact on personal hygiene and increase community health risks.
- Floods and landslides causing injury and death.

- Less attractive climatic conditions affecting visitation rates and visitor convenience.

- Increased annual mean rainfall, which may benefit biodiversity in water-stressed regions.
- More flood damage, which would cause increased environmental stress in coastal and inland ecosystems.

A DRIER CLIMATE COULD LEAD TO:

- Reduced risk of storm water exceeding design specifications for urban and rural drainage systems.
- Reduced hydro-electricity potential but greater solar energy potential.

- Increased risk of drought.
- Increased demand on stored water resources, which could exceed supply in both urban and rural areas, reducing water security.
- Decreased rate of freshwater recharge of aquifers and altered hydraulic pressures, increasing risk of salinisation of aquifers from the ocean.
- Increased risk of blue-green algae outbreaks, which would reduce water quality.
- Decreased risk of flooding and associated impacts for infrastructure, food, health, tourism and biodiversity.

- Altered timing and intensity of environmental cues and rainfall run-off impacting on established production, harvest and marketing schedules.
- Increased stress on agricultural crops/ animals, inshore fisheries and forestry affecting production schedules, practices and overall productivity, market demand/value and local economies.
- Increased incidence of forest fire.
- Increased near-surface ocean salinity, which enhances ocean mixing and nutrient supply.
- Reduced incidence of endemic and exotic plant and animal pathogens and associated disease.

- More attractive climatic conditions affecting visitation rates and visitor convenience.

- Decreased annual mean rainfall, which may stress biodiversity in already water-stressed regions.
- More droughts, which would cause increased environmental stress in coastal and inland ecosystems.

Palau National Weather Service Office

Oceans

The atmosphere and the ocean are closely linked. For example, the winds affect the ocean and the ocean's surface temperature affects the overlying atmosphere. ENSO partly owes its existence to changes in the location of warm water in the Pacific Ocean and the resulting changes this causes in the atmosphere. The ocean has a large capacity to store heat, exerting a significant influence on the Earth's climate. Any changes in the state of the ocean strongly influence the global climate.

It is important to understand how the ocean may change in the future because these changes will not only directly affect fisheries and coral reefs, they will also affect the livelihood and wellbeing of the people who rely on them. Additionally, some ocean changes – such as sea-level rise – will have direct impacts on human settlements.

Year-to-year variability in sea-surface temperature is largely due to ENSO, while decade-to-decade variability is linked to the IPO.

Risk periods for coral bleaching will be longer and occur more often.

Sea levels vary spatially across the Pacific and change with major climate influences.

Sea level has risen and will continue to rise in the future.

Extreme sea-level events are the result of a combination of climate and non-climate factors.

Wind-driven waves vary seasonally and from year to year.

Wind-driven waves will change in character with major climate influences.

Ocean currents change with major climate influences.

Ocean acidification varies seasonally and from year to year.

Ocean acidification has increased because of human activities and will continue in the future.

Sea-surface temperature

Year-to-year variability in sea-surface temperature is largely due to ENSO, while decade-to-decade variability is linked to the IPO

Along the equator, the easterly trade winds push the warm surface tropical waters towards the west, creating the West Pacific Warm Pool. The Warm Pool has an average sea-surface temperature of 29 °C, covering an area of 15 million square kilometres. In the eastern tropical Pacific, the oceans are cooler because the equatorial winds upwell deeper cool waters to the surface.

At tropical latitudes, year-to-year variability in sea-surface temperature due to ENSO is often larger than seasonal changes. Changes in ocean temperatures and circulation on longer time scales are associated with the IPO.

For forecasts of ocean temperatures and coral bleaching risk use the **Seasonal Prediction of Extreme Ocean Temperatures and Coral Bleaching** tool. *See page 39.*

Risk periods for coral bleaching will be longer and occur more often

Corals can bleach when they are exposed to elevated sea-surface temperatures over extended periods. As temperatures increase and the length of time temperatures stay warmer than average increase, the risk and potential severity of any bleaching event becomes greater. Corals also need time between events to recover so they do not ultimately die. If severe bleaching events occur more often than once every five years, the long-term viability of coral reef ecosystems becomes threatened. The risk to corals is compounded by the effects of ocean acidification.

AS SEA-SURFACE TEMPERATURES RISE WE EXPECT:

- Increased risk of coral bleaching, compounded by ocean acidification.

Sea level

Sea levels vary spatially across the Pacific and change with major climate influences

The sea level varies spatially across the Pacific Ocean by up to 1 m. For example, along the equator the sea level in the west (e.g. Solomon Islands) is about 0.5 m higher than the sea level in the east (e.g. Galapagos Islands). Sea level can also vary from year to year by more than 20 cm.

The main reason for this year-to-year variability is ENSO, which has a major influence on sea levels across the tropical Pacific. During El Niño events, weakened trade winds reduce sea level in the west and increase sea level in the east. During La Niña events, strengthened trade winds cause higher than normal sea levels in the western tropical Pacific, and lower than normal levels in the east. Pacific islands within about 10° of the equator are most strongly affected by ENSO-related sea-level variations. These changes also modulate the occurrence of extreme sea levels from year-to-year.

The IPO affects sea level on decadal and longer time scales.

Sea level has risen

Satellite records from the early 1990s to the present indicate that global averaged sea level has been rising at 3.2 ± 0.4 mm/year. Estimates from reconstructed sea level data confirm the satellite record, and indicate that, over the longer period, global averaged sea level has been rising at about 1.7 ± 0.2 mm/year since 1900. Together with other data, they also indicate the rate of rise has increased from the 19th to the 20th century.

From 1993 to the present, measurements from satellites and tide gauges indicate a higher than global average rate of rise in the western Pacific and eastern Indian Oceans – up to about three times the global average. This high rate is partially due to decadal climate variability with the IPO shifting from a positive to a negative phase over this period. Some researchers believe the high rates are a result of an intensification of the trade winds across the tropical Pacific Ocean.

Sea level will continue to rise in the future

Sea-level rise in the western tropical Pacific over the 21st century is likely to be close to the global average, which could range from 0.26 m to 0.82 m by 2100, depending on emissions. There is still some uncertainty in projected contributions from ice sheets in Greenland and Antarctica. Additionally, regional sea level will continue to be significantly affected by natural climate variability.

Extreme sea-level events are the result of a combination of climate and non-climate factors

Extreme sea-level events are caused by a combination of:

- tides
- seasonal or longer-term fluctuations due to changing winds, pressure and ocean temperature patterns such as ENSO
- short-term events due to weather, such as storm surge, ocean waves and tsunamis.

Although tsunamis can cause the most devastating extreme sea-level events, they are not affected by climate. Tides are also independent of climate.

Tonga Meteorological Service

Tropical cyclones can cause severe short-term sea-level extremes in the Pacific due to storm surges and/or ocean waves. Falling atmospheric pressures associated with cyclones draw the ocean surface upwards and onshore winds can build up water levels against the coast. While cyclone intensity strongly influences the severity of waves and storm surge, the cyclone's size, direction and speed of movement also play an important role, as do coastal landforms.

Tropical cyclone-induced storm surges tend to be localised and concentrated in the region of maximum onshore winds close to the cyclone centre. While their impacts are potentially devastating, they are rare at any given location.

On the other hand, ocean waves produced by either tropical cyclones or extratropical storm systems in both the Northern and Southern Hemispheres can travel long distances in the deep ocean as swell, with little loss of energy and can therefore affect a larger number of more distant coastlines. (Recent inundation events in the Marshall Islands (December 2008) and the Fiji Coral Coast (May 2011) were a result of waves generated thousands of kilometres away by extratropical storms.) As the waves encounter shallow coastal waters, they steepen and break, progressively losing energy and producing an increase in coastal sea levels known as wave setup. Atolls with steep shelf margins may be particularly affected by remotely generated swell causing wave setup in lagoons, thereby contributing to sea-level extremes. As a wave breaks at the coast the maximum vertical extent of the wave uprush on a beach or structure above the still water level is known as wave run-up.

The coastal impacts resulting from the cyclone-induced storm surges and waves also depend on the shape of the sea bed (bathymetry), the shape of the coastline in relation to the cyclone path, and the landform (geomorphology). Wide and shallow continental shelves amplify the storm surge while bays and channels can funnel and increase the storm surge height. The presence of reefs will cause waves to break and lose energy before they reach coastal areas.

Why are sea levels rising?

At any given location on the planet, sea level can change hourly or even from one minute to the next. It can also change over months and years and can evolve slowly over decades and centuries. These changes have a number of causes, and include the atmosphere, storm surges and movements in the Earth's crust (e.g. tsunamis). Overall changes in trade wind patterns and temperature due to ENSO in the Pacific can cause sea-level changes of more than 20 cm, depending on the time of year and location. ENSO-related changes in sea level generally occur over months to several years.

Rising temperatures are also causing sea levels to rise, through thermal expansion (as water heats up, it expands causing an increase in sea levels) and the melting of glaciers and ice sheets on land (the melting of floating ice does not cause sea-level rise). Over the past century, higher temperatures have caused more ice to melt than usual. The melting ice turns to water and runs to the sea contributing to sea levels rising all over the world.

For seasonal sea level forecasts use the **Seasonal Prediction of Sea Level Anomalies in the Western Pacific** tool. *See page 39.*

AS SEA LEVEL RISES WE EXPECT TO SEE:

- Increased risk of coastal inundation and associated storm surge/extreme sea levels damaging land-based infrastructure such as coastal buildings, roads, ports, power stations, communication facilities and sites of cultural significance.

- Increased risk of salinisation of fresh groundwater from overtopping of aquifers by seawater.

- Increased risk of loss and damage to arable land/fertile soils and associated agricultural crops and productivity from saline incursion.

- Increased risks to health centres located by the coast (for most atoll islands)
- Stress associated with loss of coastal assets, including sites of cultural significance.
- Trauma associated with potential relocation of communities.

- Loss of public amenity due to beach inundation and/or erosion, our building of sea walls and groynes.

- Inundation and long-term degradation of critical habitat in coastal and inshore areas, including wetlands, beaches, reefs, lagoons, mangroves and seagrasses.

Investigating storm surges – Fiji

To investigate storm surges along the entire Fiji coastline, a synthetic tropical cyclone and storm surge modelling study was undertaken. Tropical cyclones that have affected Fiji were characterised in terms of intensity, track and frequency for all years and for both La Niña and El Niño years separately. The modelling showed that the north-western coastlines of the main island of Viti Levu and the second largest island Vanua Levu experienced the highest storm surges because they face the most common direction of approach for tropical cyclones. The 1-in-100-year storm surge heights on north-west coasts were found to be around twice the values at locations in the south-west. Due to differences in tropical cyclone paths and frequencies, the northern island was slightly more at risk of storm surges during El Niño years.

Reginald White, Marshall Islands National Weather Service Office

Wind-driven waves

Waves in the Pacific are generated by a combination of trade winds, tropical cyclones and swell from the extratropical storm belts. The contribution of each of these components depends on location: Islands located on or north of the equator have wave fields dominated by the north-easterly trade winds and the northern Pacific generated swell. Islands located south of the equator have wave fields dominated by the south-easterly trade winds. Southern Pacific generated swell is also a major contributor to the wave climate at those islands that are not sheltered by other islands.

Surface-wind waves can impact on many aspects of the coastal environment. They can cause flooding and coastal erosion, and play a role in the structure of reefs and marine habitats, and the distribution of marine species.

Wind-driven waves vary seasonally and from year to year

From December to February, Pacific waves consist of trade wind generated waves, swell waves generated in both the Northern and Southern Hemisphere extratropical storm belts, and waves generated by tropical cyclone events. The relative fraction of each of these components depends on location. These components vary seasonally and from year to year, independent of each other.

The northerly swell waves generated in the North Pacific peak and have a greater influence on the wave field of the Pacific Island region. Southerly swell waves generated in the Southern Ocean are more consistent than the northerly swell, but show seasonal peaks in energy during the southern winter (June–August) when the southern extratropical storm belt moves northwards. Trade wind generated waves peak during the respective winter (December–February north of the equator and June–August south of the equator). In the western Pacific, the seasonal variability in the position of the monsoon trough (located near 20°S in February to near 40°N in August) further influences the wave climate of the region, including the occurrence of tropical cyclone driven waves.

Most year-to-year variability in the Pacific wave climate is associated with ENSO. The eastward shift in tropical cyclone activity during El Niño years leads to increases in wave height over large portions of the equatorial Pacific. Changes in the direction of wind waves with different ENSO phases are also observed. Changes in Pacific wave climate from year to year are also affected by swell generated in the Southern Ocean due to changes in the Southern Annular Mode (SAM). During positive phases of the SAM, a wave height increase and greater southerly component is observed over large regions of the Pacific Ocean.

Wind-driven waves will change in character with major climate influences

Dynamical wave climate projections over the 21st century under medium to very high emissions scenarios suggest an increased contribution of swell waves generated at the higher latitudes, particularly from the Southern Ocean, and reduced influence of the north-easterly trade wind waves.

Throughout the western Pacific in the ocean surrounding the Pacific Island countries, there may be some changes in wave height, period and direction in the future.

- During December–March, average significant wave height is projected to decrease slightly in the western equatorial Pacific by approximately 0.2 m (about 5–10%), with greater decreases to the north of the equator.
- During June–September, projections suggest little increase in wave heights and periods. With projected increases in trade wind strength and Southern Ocean storms for these months, wave directions in the equatorial western Pacific display increasing southerly and easterly components, but these changes may simply be due to natural variability.

These changes, accompanied with projected changes in wave direction should be considered within the context of long-term coastal response to physical drivers of change.

Ocean acidification

The ocean is a major sink for atmospheric carbon dioxide, absorbing about one quarter of the carbon dioxide emissions resulting from human activities each year. This helps to slow the rate of atmospheric carbon dioxide increase but results in ocean acidification. This in turn decreases the capacity of reef building corals, calcareous algae and many other key species in tropical ecosystems to grow calcium carbonate skeletons and shells.

A range of marine ecosystem services such as fisheries, aquaculture, coastal protection, tourism and cultural identity are threatened by ocean acidification.

Ocean acidification varies seasonally and from year to year

The level of acidity of surface seawater varies across the region and over time and can change from season to season in many countries. The seasonal variation in aragonite saturation state is small over most of the region, but is larger than the annual decrease associated with increasing atmospheric carbon dioxide levels. The largest seasonal variation (0.1–0.2) is found in the Central Equatorial Pacific and South Equatorial Current regions, and is driven by upwelling and transport respectively. Variability in the West Pacific Warm Pool and North Equatorial Counter Current are much less (<0.1) and are due to a combination of physical and biological processes.

From year to year changes in ocean acidity can be influenced by ENSO. There is less acidity associated with El Niño events than with La Niña events. Values of aragonite saturation can drop by 0.6 or increase by 1 when switching between ENSO phases. During El Niño conditions, the eastward expansion of the Warm Pool water can lead to surface waters with lower acidity. These conditions may benefit calcification for corals and can offset the increased risk of coral bleaching brought by warmer sea-surface temperatures during El Niño.

Scientists use the ocean aragonite saturation state to measure ocean acidification. Aragonite is the most common form of calcium carbonate crystal found in tropical reefs, and it is used by many marine organisms, including corals, to build shells and skeletons. As the ocean gets more acidic, aragonite saturation values decrease. The best conditions for corals to grow are at an aragonite saturation state above 4. Between 3.5 and 4 conditions are adequate; between 3 and 3.5 conditions are marginal; and below 3, conditions are critical.

Ocean acidification has increased because of human activities

Since the start of the industrial revolution (around 1750) increased carbon dioxide has led to lower aragonite saturation levels of the Pacific Ocean. Across the region this has meant an annual average decrease in aragonite saturation of 0.4 from 4.2 to 3.8.

Ocean acidification will continue in the future

Regionally, conditions that are considered marginal for supporting healthy reefs (aragonite saturation rate of <3.5) will occur in the central equatorial Pacific in the next few decades. The reef ecosystems in the region of the South Equatorial Current will be the last to experience these conditions. While only some reefs in the Pacific Island region are predicted to be exposed to marginal growing conditions (aragonite saturation <3.5) by about 2050 under a very low emissions scenario, all reefs will experience marginal conditions by 2050 under higher emissions scenarios. The greatest increase in ocean acidification will occur under the highest emissions scenario.

AS OCEAN ACIDIFICATION INCREASES WE EXPECT TO SEE:

- Erosion of reef structures, reduced buffering of wind waves and associated storm surge and coastal inundation. Increasing sea-surface temperature and the risk of coral bleaching will compound this impact.
- Increased stress on ecosystem function, changes in species distribution and abundance/community composition. Increasing sea-surface temperature and the risk of coral bleaching will compound this impact.
- Increased stress on inshore fisheries, affecting availability of food supplies.
- Increased risk of health issues related to poor diet as seafood supplies are impacted.
- Loss of coral reefs for tourism.

Tropical cyclones

Tropical cyclones are the most significant extreme events in much of the Pacific, often associated with heavy rain, strong winds, storm surges and large waves. Tropical cyclones are mostly confined to the latitudes 10°–25° in both hemispheres, where the ocean is warm enough to provide the energy for them to form and the Coriolis effect (related to the Earth's rotation) is large enough for them to spin up.

Tropical cyclones can cause extensive damage to communities, agriculture and infrastructure, and causing injury and loss of life. Understanding future changes in the number, intensity and location of tropical cyclones is important for planning infrastructure and emergency management services.

Tropical cyclones are influenced by ENSO.

Tropical cyclone numbers have decreased in the western Pacific.

Tropical cyclones are projected to be less frequent but more severe.

National Environment Service, Government of the Cook Islands

Tropical cyclones are influenced by ENSO

The South Pacific experiences most of its tropical cyclones during the period November to April, with most activity between January and March. On average, 10 cyclones occur in a season with significant year-to-year variability. Very occasionally a cyclone occurs in the months of May and October, usually in an El Niño year. In 1997 a cyclone (Keli) developed near Tuvalu in June.

The spatial distribution of the average number of tropical cyclones per year shows that the most tropical cyclones occur in the South Pacific in the area between the Australian coast and the International Date Line, from about 12°S to 22°S.

ENSO plays a key role in modifying tropical cyclone risk throughout the tropical Pacific, predominantly through its influence on winds and sea-surface temperatures. When the western equatorial Pacific warms relative to the eastern equatorial Pacific during the La Niña phase, cyclones occur with greater frequency in the western Pacific close to Australia. Conversely, during the El Niño phase, when the eastern equatorial Pacific warms compared to the western equatorial Pacific, greater cyclone activity occurs further east.

Tropical cyclone numbers have decreased in the western Pacific

Analysing trends in tropical cyclones is difficult as they rarely approach weather stations. This means their intensity needs to be estimated. Some studies show trends towards more intense tropical cyclones in parts of the world (e.g. the North Atlantic Ocean and the north-west Pacific region) while other studies dispute these findings on the basis that changes in observation technology and analysis techniques over time affect results. Using three different tropical cyclone archives, researchers found contrary trends in the proportion of intense tropical cyclones in the western North Pacific over the past few decades.

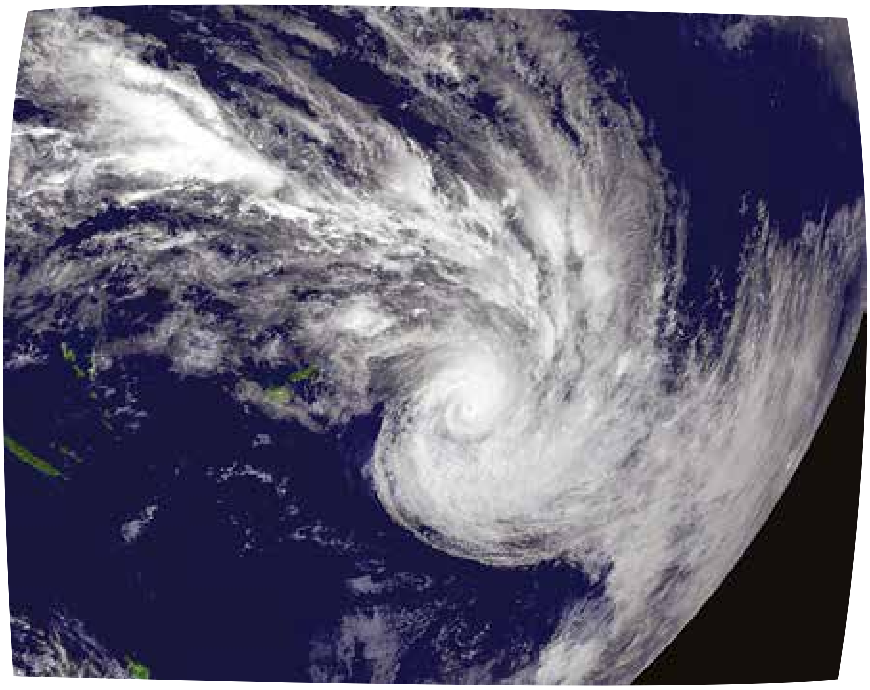
An updated analysis of best track data for the south-west Pacific through to the 2010–11 season shows a slight decrease in the total number of cyclones, with little change in the numbers of the most intense. The record is too short to determine if this decrease is the result of a trend or if it is simply due to natural variability.As complete records of estimated tropical cyclone intensity are only available from 1981, studies of tropical cyclone trends are limited to this time. However, the absence of overall intensity trends for the south-west Pacific does not discount the possibility of local trends.

Tropical cyclones are projected to be less frequent but more severe

Climate models indicate there is a non-significant decrease in the future frequency of cyclones in the south-west Pacific. In contrast, models suggest a non-significant increase in the future frequency of cyclones in the northern Pacific. Projections do indicate a shift in cyclone intensity. There will be relatively fewer cyclones with medium intensity, and increased frequencies of both weaker and very intense cyclones. As these shifts balance out, the average intensity is unlikely to change in the future.

A slight reduction in the overall frequency combined with an increased proportion of the most intense cyclones means that most locations in the Pacific will have a higher chance of experiencing severe winds. Analysis indicates that this trend is consistent across the Pacific, although the impact varies locally.

For information on past tropical cyclones in the region use the **Southern Hemisphere Tropical Cyclone Data Portal** tool. *See page 39.*



LESS FREQUENT BUT A GREATER PROPORTION OF SEVERE TROPICAL CYCLONES WILL RESULT IN:

- Increased high intensity wind and rain causing loss and damage to coastal, inland and urban infrastructure, including public and private buildings, bridges, roads, power generation and transmission infrastructure, communication facilities, airports and sea ports.
- Increased compounding effect on sea-level rise and risk of coastal inundation and associated storm surge/extreme sea levels damaging land-based infrastructure as well as beaches, mangroves, sea grasses and coral reefs.

- Reduced frequency of loss and damage to critical communal and domestic water supply infrastructure but greater loss and damage when it does occur.
- Dams may overflow during more-severe cyclones leading to infrastructure damage.

- Less frequent damage to crops, forestry and inshore fisheries, but greater damage during more-severe cyclones. This includes indirect impacts from loss and damage to transport infrastructure such as roads and bridges as well as associated logistical support.

- Reduced incidence of vector-borne disease such as malaria, Dengue fever and Chikungunya disease, but with more widespread impacts in the immediate aftermath of extreme storm events.
- Less frequent injury and death from associated floods, landslides and airborne debris, but larger impacts during more-severe cyclones.

- Decreased closure of airports and cancellation of flights reducing visitation rates and the economy of local service industry sectors.
- Reduced tourism during the recovery phase following extreme storm events.

- Less frequent damage to ecosystems.
- Increased incidence of extreme storm-related loss of critical habitat in coastal and inshore areas, including beaches, coral reefs, lagoons, seagrasses, wetlands, etc.

Although fewer cyclones might sound like good news, infrastructure damage increases exponentially with wind speed, so an increase in the proportion of severe cyclones will lead to much more damage.


Papua New Guinea National Weather Service

Future climate at a glance

Cook Islands

- 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 annual rainfall is projected to stay similar to the current climate, except for a small decrease in the dry season in the Northern Cook Islands under the high emission scenario, with more extreme rain events
- Drought frequency is projected to remain similar to the current climate in the Southern Cook Islands, but increase slightly in the Northern Cook Islands under the high emission scenario.

- Sea level will continue to rise.
- Ocean acidification is expected to continue.
- The risk of coral bleaching is expected to increase.
- Wave climate is not projected to change significantly.

- Tropical cyclones are projected to be less frequent but more intense.

Timor-Leste

- 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.

- There is a range of projections of average annual rainfall, from a decrease to increase, but with more extreme rain events.
- Drought frequency is projected to remain similar to the current climate.

- 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 period in January is projected.

Federated States of Micronesia

- 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 annual rainfall is projected to increase, with more extreme rain events.
- Drought frequency is projected to decrease.

- 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 December–March, and waves may be more directed from the south in the June–September.

- Tropical cyclones are projected to be less frequent but more intense.

Fiji

- 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.

- There is a range in model projections in mean rainfall, with the model average indicating little change in annual rainfall but an increase in the wet season, with more extreme rain events.
- The proportion of time in drought is projected to decrease slightly.

- 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 across the area in the wet season, with a possible small increase in dry season wave heights.

- Tropical cyclones are projected to be less frequent but more intense.

Kiribati

- 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 December–March, waves may be more directed from the south in October.

Marshall Islands

- 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.

- Tropical cyclones are projected to be less frequent but more intense.

Nauru

- 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.

- Mean 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 and period are projected to decrease in December–March but no significant changes are projected in June–September.

Niue

- 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.

- Mean annual rainfall could increase or decrease with the model average indicating little change, with more extreme rain events.
- The proportion of time in drought is projected to decrease or stay approximately the same.

- Sea level will continue to rise.
- Ocean acidification is expected to continue.
- The risk of coral bleaching is expected to increase.
- Wave heights may decrease in December–March, with no significant changes projected in June–September waves.

- Tropical cyclones are projected to be less frequent but more intense.

Palau

- 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 by 2090, with a slight decrease in wave period. In June–September a small decrease in period is projected, with a clockwise rotation toward the south.

- Tropical cyclones are projected to be less frequent but more intense.

Papua New Guinea

- 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 in most areas, 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.
- No changes in waves along the Coral Sea coast are projected, while on the northern coasts, December–March wave heights and periods are projected to decrease.

- Tropical cyclones are projected to be less frequent but more intense.

Samoa

- 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.

- Little change in mean annual rainfall is projected, with more extreme rain events.
- Incidence of drought is projected to decline or stay approximately the same.

- 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 period in December–March is projected with no change in wave height, while no change is projected in June–September.

- Tropical cyclones are projected to be less frequent but more intense.

Solomon Islands

- 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.

- Annual rainfall is projected to increase slightly, with more extreme rain events.
- Incidence of drought is projected to decrease slightly.

- Sea level will continue to rise.
- Ocean acidification is expected to continue.
- The risk of coral bleaching is expected to increase.
- December–March wave heights are projected to decrease, while there are no significant changes projected in June–September waves.

- Tropical cyclones are projected to be less frequent but more intense.

Tonga

- 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.

- It is not clear whether mean annual rainfall will increase or decrease and the model average indicates little change with more extreme rain events.
- Drought frequency is projected to decrease slightly.

- Sea level will continue to rise.
- Ocean acidification is expected to continue.
- The risk of coral bleaching is expected to increase.
- December–March wave heights and periods are projected to decrease slightly.

- Tropical cyclones are projected to be less frequent but more intense.

Tuvalu

- 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.

- It is not clear whether mean annual rainfall will increase or decrease, the model average indicating little change, with more extreme rain events.
- Incidence of drought is projected to decrease slightly.

- Sea level will continue to rise.
- Ocean acidification is expected to continue.
- The risk of coral bleaching is expected to increase.
- December–March wave heights and periods are projected to decrease slightly.

- Tropical cyclones are projected to be less frequent but more intense.

Vanuatu

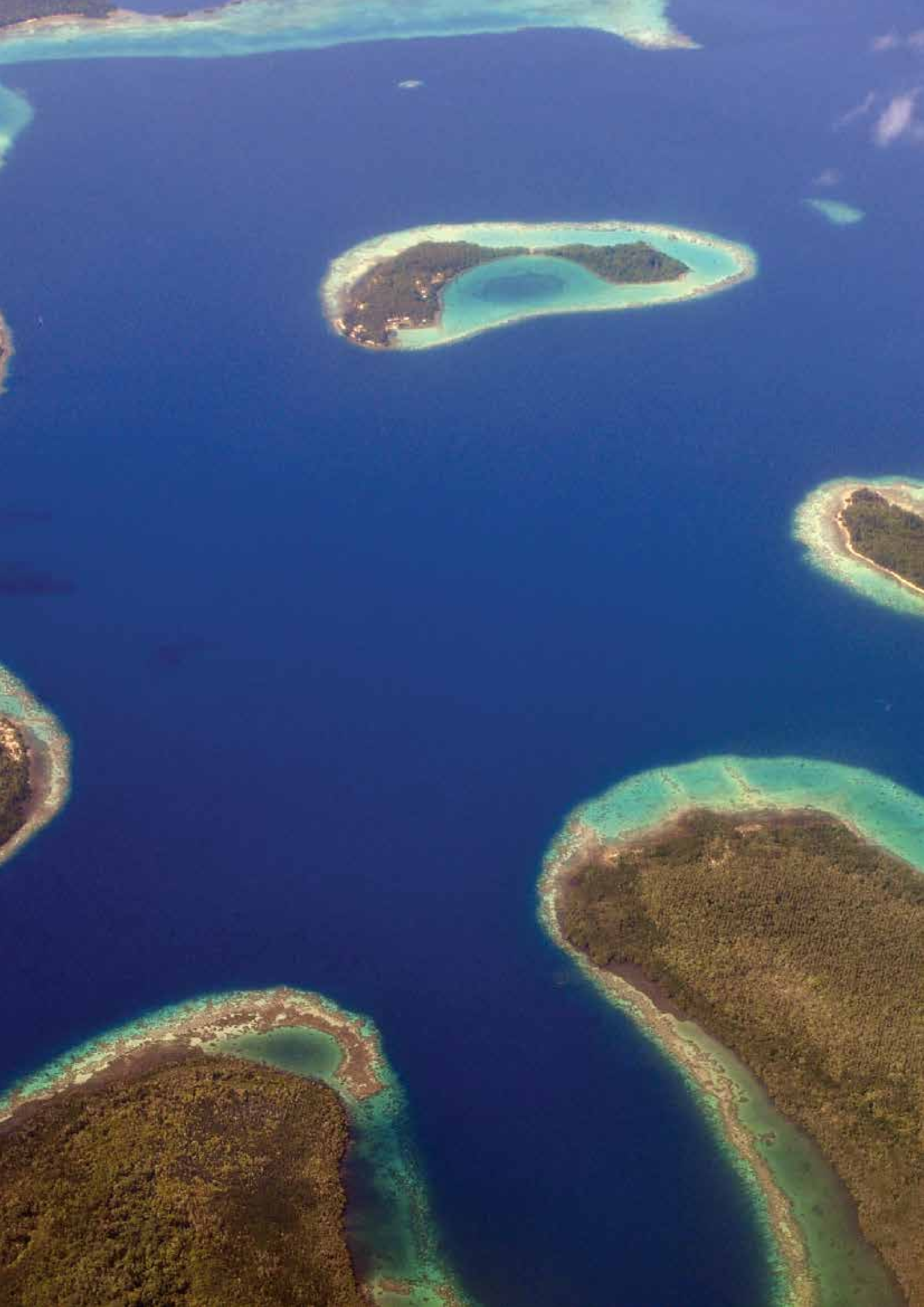
- El Niño and La Niña events will continue to occur in the future, but there is little consensus on whether these events will change in intensity or frequency.

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

- Mean annual rainfall could increase or decrease with the model average indicating little change, with more extreme rain events.
- Incidence of drought is projected to decrease slightly under the high emission scenario and stay approximately the same under the other emissions scenarios.

- Sea level will continue to rise.
- Ocean acidification is expected to continue.
- The risk of coral bleaching is expected to increase.
- Wet season wave heights and periods are projected to decrease slightly, with no significant changes projected in the dry season.

- Tropical cyclones are projected to be less frequent but more intense.



III. TOOLS FOR PLANNING AHEAD

PACCSAP (and the PCCSP) have developed a suite of climate tools and portals to assist Pacific Island countries and Timor-Leste to better understand their climate and, more specifically, to support communities and governments to make the decisions necessary to manage and adapt to a changing climate.

Climate science tools and portals

Pacific Climate Futures

Pacific Climate Futures is a web-tool developed in collaboration with Pacific Island countries that provides free and easy access to climate projections data. These data can be used for risk assessment and adaptation planning.

The tool groups projections from individual models into a small set of internally consistent climate futures, such as 'warmer and wetter' or 'hotter and drier'. Each climate future is given a likelihood so the user can readily identify the most likely future, as well as less likely futures that might represent a 'best case' or 'worst case'. Users can select a small set of climate models that represent key climate futures, then download data from these models into an Excel spreadsheet. Observed climate data can be imported into the spreadsheet and combined with model data to create synthetic future in climate data for use climate impact assessments.

Access to the basic and intermediate levels of this tool is available to the public, while advanced level access is subject to training and accreditation.

The tool can be found at **www.pacificclimatefutures.net**

The Pacific Climate Change Data Portal

The Pacific Climate Change Data Portal allows users to visualise historical monthly temperature and rainfall data and to explore trends from more than 100 individual observation sites across the Pacific Islands and Timor-Leste. As the largest web-based data source for the Pacific region, this tool allows users to plot time-series graphs, linear trends, multi-year running averages and long-term averages. In PACCSAP, this web tool has been updated with to include trends in daily rainfall and temperature extremes.

This tool is available to users approved by relevant national governments and can be found at **www.bom.gov.au/climate/pccsp/**

CliDE: Climate Data for the Environment

CliDE is a PC-based, desktop climate database management system installed in National Meteorological Services in 15 countries to support day-to-day operations, including the archiving and basic analysis of historical and recent meteorological data. CliDE provides a reliable and functional platform for countries to rescue and secure hard copy and electronic data, the former of which in some countries date back more than 100 years. Accurate climate records are critical for building an understanding of how the climate is changing and for verifying climate projections, monitoring and comparing droughts and other extreme events.

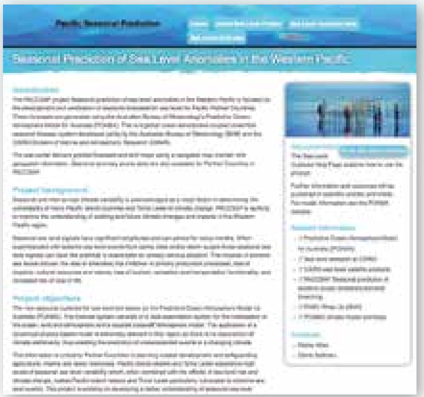
CLiDE is used by the National Meteorological Services of each of the PACCSAP Program's partner countries. More information can be found at **www.bom.gov.au/climate/pacific/about-clide.shtml**

The Southern Hemisphere Tropical Cyclone Data Portal

The Southern Hemisphere Tropical Cyclone Data Portal improves knowledge of past tropical cyclone activity in the Pacific Islands and Timor-Leste by plotting tracks of cyclones in the South Pacific from the 1969/70 season through to the 2009/10 season, allowing users to see the characteristics and paths of past tropical cyclone events.

Meteorologists and stakeholders can use this tool to analyse the tracks of historical tropical cyclones and relate them to the impacts on lives and infrastructure recorded on the ground.

This tool is available to the public and can be found at **www.bom.gov.au/cyclone/history/tracks/**



Seasonal Prediction of Sea Level Anomalies in the Western Pacific

The Seasonal Prediction of Sea Level Anomalies in the Western Pacific tool is focused on the development and verification of seasonal forecasts for sea level for Pacific partner countries. These forecasts are generated using the POAMA dynamical model and are aimed at developing a better understanding of seasonal sea level prediction, and prototype forecast products for the Western Pacific.

This tool is accessible to interested users who apply to the Australian Bureau of Meteorology to use the tool. Meteorological agencies from PACCSAP partner countries in the Pacific are the primary users of this tool. It is available at **www.bom.gov.au/climate/pacific/about-sea-level-outlooks.shtml**

Seasonal Prediction of Extreme Ocean Temperatures and Coral Bleaching

The Seasonal Prediction of Extreme Ocean Temperature and Coral Bleaching tool provides POAMA-based dynamical seasonal forecasts of ocean temperature and coral bleaching risk. This information is critical to partner countries in planning coastal development and safeguarding agricultural, marine and water resources.

This tool is accessible to interested users who apply to the Australian Bureau of Meteorology to use the tool. Meteorological agencies from PACCSAP partner countries in the Pacific are the primary users of this tool. It is available at **www.bom.gov.au/climate/pacific/about-seasonal-extremes.shtml**

Pacific Climate Change Portal

The Pacific Climate Change Portal (PCCP) has been developed by the Secretariat of the Pacific Regional Environment Programme (SPREP) in collaboration with its partners. The portal aims to ensure that climate change-related information and tools developed by regional and national institutions in the Pacific Island region are readily accessible to stakeholders in a coordinated and user-friendly manner. The major target groups for the portal are national stakeholders within Pacific Island countries and territories, regional stakeholders including Council of Regional Organisations in the Pacific (CROP) agencies, and development partners. The PCCP will also provide a metadata catalogue and associated access guidelines for all project-based climate science data collections generated by PCCSP and PACCSAP through the Australian Government-funded Pacific iClim project, which is being delivered jointly by Griffith University and SPREP.

The PCCP is available at **www.pacificclimatechange.net**

Seasonal climate outlooks

National meteorological services prepare seasonal climate outlooks for their countries. Recently, dynamical downscaled climate models, which factor in climate change signals from global climate models, have been developed by PACCSAP to complement existing statistical methods for informing seasonal outlooks over periods of several months. Communication and partnerships between national meteorological services, government and non-government organisations in Pacific Island countries are important for disseminating the seasonal climate outlooks to different sectors and local communities.

Using seasonal outlooks – Vanuatu

Since 2011 the Vanuatu Meteorological and Geo-Hazard Department (VMGD) has called a meeting of all relevant government departments and non-government organisations every quarter to inform them about expected climate conditions for the next three months. There is a particular emphasis on the rainfall outlook. Climate extremes related to excessive rainfall (and associated flooding) as well as rainfall deficit which leads to droughts are of major concern for the local communities, as they are very much dependent on rain-fed water resources. During these meetings, VMGD provides the seasonal outlook and then the government departments and non-government organisations translate the climate information into examples of how communities may respond to the predicted conditions. For example, if the risk of rainfall deficit is increased, there are recommendations for communities to mulch, plant drought-resilient crops, reduce cattle heads per paddock or sell livestock. This information is then passed through the extension networks all the way down to local communities.

Using seasonal outlooks – Samoa

In Samoa seasonal outlooks are sent each month to the disaster management office and members of the National Disaster Advisory Committee. The Committee meets each month and discusses issues with regards to any hazards, including climate-related hazards, which are presented in the seasonal climate outlook, to take further actions.

For example, in 2012 drought conditions were experienced in Samoa. Information about the increased risk of drought was derived from models, and presented in the national seasonal climate bulletin. This information was used to formulate practical responses by the different authorities to mitigate impact of drought.

IV. ABOUT THE SCIENCE

This section provides an overview of the scientific data, methods and associated terminology used to collate and analyse observations and trends, and generate the projections referred to in this summary publication. For more comprehensive technical details please refer to the 2014 PACCSAP technical report, *Climate Variability, Extremes and Change in the Western Tropical Pacific: New Science and Updated Country Reports*.

Climate data

Reliable climate data are crucial for documenting current climate and observed climate trends in the Pacific, and for testing the climate models used to investigate the climate system and make projections about the future.

Significant effort has gone into cataloguing, digitising and quality checking records from observation stations around the Pacific.

The station data used in the PCCSP and PACCSAP were collated from partner country climate databases and spreadsheets, the Australian Bureau of Meteorology, New Zealand's National Institute of Water and Atmospheric Research (NIWA), and the US National Oceanographic and Atmospheric Agency (NOAA).

The ongoing continuous collection of climatological data in the Pacific Islands is important to science and society. As impacts of climate variability and climate change are observed, long-term climate records can assist with identifying shifts between average conditions of the past and potential future conditions.

Modelling the climate

We don't know for certain what the future holds, but using sophisticated computer models and information about our past and current climate, we can get an indication of how the climate may change.

Climate models

Climate models are mathematical representations of the Earth's climate system, based primarily on the laws of physics. They simulate the processes affecting weather and climate. The models are tested using data from climate observations – models that reproduce observed conditions and past climate changes well are considered likely to be more successful in projecting future climate with some skill. All models have strengths and weaknesses: those that are considered acceptable for the current climate give a legitimate projection of the future, so we consider the range of change from many models rather than try to pick the best single model.

The newest generation of global climate models are able to provide information on variables such as temperature and rainfall over the globe down to spatial scales of about 60–300 km, and on about 40 layers in the ocean and 40 layers in the atmosphere. These models have been used extensively over recent decades to not only estimate future climate change, but also to help us understand the causes of past climate change.

Emissions scenarios

Greenhouse gases will continue to increase in future due to human activities, so further climate change is inevitable. We do not know exactly what the concentration of greenhouse gases will be in the future, because this depends on a range of social, economic and environmental factors. To deal with this we use emissions scenarios in climate models that allow us to see what will happen under varying greenhouse gas conditions.

The projections in this report use four Intergovernmental Panel on Climate Change emissions scenarios, which are known as representative concentration pathways (RCPs):

- RCP2.6 (very low emissions)
- RCP4.5 (low emissions)
- RCP6.0 (medium emissions)
- RCP8.5 (very high emissions).

These new emissions scenarios span a broader range of possibilities than previous studies based on the B1-low, A1B-medium and A2-high scenarios from the Intergovernmental Panel on Climate Change's Special Report on Emissions Scenarios (the SRES scenarios, see Figure 3), and include pathways of other emissions that can affect our climate, such as aerosols. The lowest RCP scenario assumes the carbon dioxide concentration peaks at 440 parts per million (ppm) by the year 2040 then declines to 420 ppm by 2100, while the highest scenario reaches 940 ppm by 2100. (Measurements of recent carbon dioxide emissions have been tracking the highest scenario.)

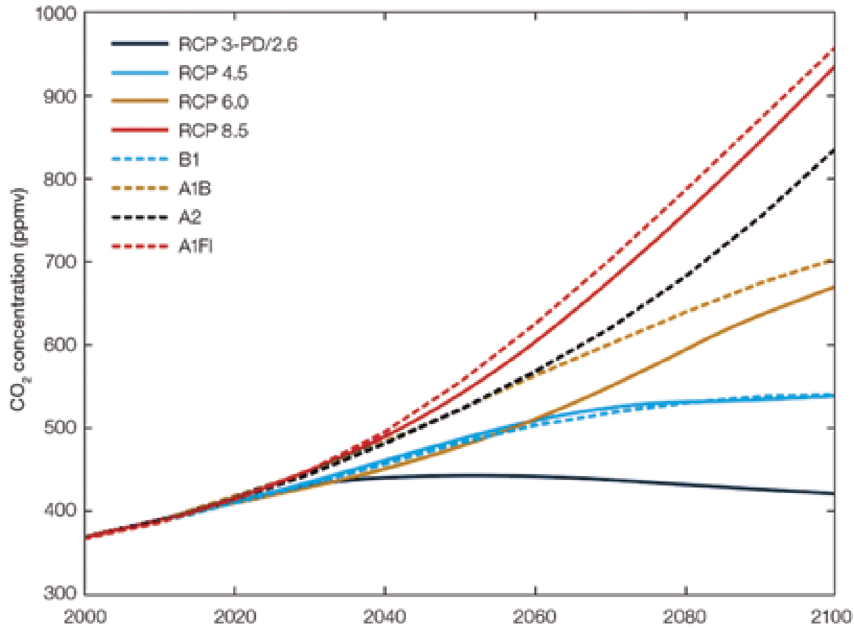


Figure 3: Comparison of carbon dioxide concentrations in parts per million by volume (ppmv) for SRES (CMIP3, dotted lines) and RCP (CMIP5, solid lines) emissions scenarios.

Uncertainty

While climate models are all based on the same physical laws, they cannot produce a single perfect forecast of the future. There will always be a range of uncertainty in climate projections, because:

- we do not know how society will evolve over this century, so it is not possible to know exactly how greenhouse gas and aerosol emissions will change
- different models give different estimates of the strength of different climate system feedbacks, such as cloud feedbacks, oceanic heat uptake and carbon cycle feedbacks, and we are not able to confidently reduce this range
- climate projections show the response to the emissions given in the emissions scenarios, but the actual pathway of the climate will be a combination of this response along with natural climate variability.

There are also uncertainties in regards to our knowledge of the climate system, and how to represent the relevant processes in models. For instance, we are still learning about the impact of aerosols on temperature, clouds and precipitation, and we do not know the extent of changes in the Greenland and Antarctic ice sheets in the future. These gaps in our knowledge add to the overall uncertainty that is context for all climate projections.

The existence of uncertainty is common to all areas of science and does not make model projections any less useful or valid. However, it is important that uncertainty is understood and incorporated into any future impact assessments based on climate model projections.

Confidence

Confidence in projections is higher for some variables (e.g. temperature) than for others (e.g. precipitation), and it is higher for larger spatial scales and longer averaging periods. Conversely, confidence is lower for smaller spatial scales, which represents a particular challenge for projections for partner countries.

The PACCSAP Program has provided confidence ratings for projected changes in different climate variables, based on five lines of evidence: ability of models to simulate past climate, consistency between observed and projected trends, understanding of physical processes causing the projected change, agreement between individual climate model simulations, and consistency between projections based on global and regional climate models.

Some of the most difficult aspects of understanding and projecting changes in regional climate relate to possible changes in the circulation of the atmosphere and oceans, and their patterns of variability and change.

When interpreting projected changes in the mean climate, it is important to remember that natural climate variability (e.g. the state of the El Niño-Southern Oscillation) will be superimposed and can cause conditions to vary substantially from the long-term mean from one year to the next, and sometimes from one decade to the next.

Projections in this publication

Projections referred to in this publication have been developed using up to 26 global climate models for four 20-year time periods with four different emissions scenarios. Downscaling has also been used. Full details are available in the 2014 PACCSAP technical report.

General climate projections

The PACCSAP Program has derived climate projections for the western tropical Pacific from up to 26 new global climate models that have been judged to perform acceptably well over the region. This means there is range of possible futures for each country, expressed as a multi-model average change with a range of uncertainty due to differences between models. Given the coarse spatial scale of the models, projections do not represent a specific city. Instead, they refer to changes averaged over a broad region. Projections are given for four 20-year periods (centred on 2030, 2050, 2070 and 2090), relative to a 20-year period centred on 1995, and four emissions scenarios (RCP2.6, 4.5, 6.0 and 8.5).

Downscaling

CSIRO's Conformal Cubic Atmospheric Model (CCAM) was used to provide 60 km downscaled projections for the western tropical Pacific region. Six global climate models (GCMs) were selected for dynamical downscaling using the A2 (high) emissions scenario. The results from the CCAM 60 km downscaling are broadly consistent with those of the global climate models. However, some differences between the global climate model projections and the CCAM projections are noted, such as bands of rainfall decrease around latitudes 8°N and 8°S. Seven countries were chosen for 8 km downscaling: Timor-Leste, Papua New Guinea, Solomon Islands, Vanuatu, Fiji, Samoa and the Federated States of Micronesia. The 8 km downscaled projections show regional variations in climate change largely related to topography, e.g. increases in rainfall on one side of a mountain and decreases on the other side. The robustness of these simulations is still being analysed.

In collaboration with other international organisations, five additional regional climate models were used to provide 60 km downscaled projections. The main research finding was that although the various models used different dynamics, physics and model set-ups, the climate changes were broadly similar.

What is the difference between statistical and dynamical downscaling?

Statistical downscaling uses equations to change global scale model output to a regional scale. These equations are based on observed relationships between large-scale and small-scale climate features.

Dynamical downscaling uses the output of GCMs to run regional climate models. These regional climate models can typically resolve information down to spatial scales of 10–60 km over a region of interest.

Dynamical downscaling allows better representation of local weather processes, including coastal and mountain effects and extreme events, however this technique is very computer-intensive. Dynamically downscaled projections should be interpreted in conjunction with global climate models over the same region.

Ocean acidification projections

The average value of the aragonite saturation state (Ω) in surface waters of the study region has declined from about 4.2 in pre-industrial times to present day values of about 3.8. To project changes in ocean acidification in the future we used CMIP5 (IPCC Fifth Assessment Report) models to project aragonite saturation state for the period 2010–2099. An ensemble of six models under very low, low and very high emissions scenarios (RCP2.6, 4.5 and 8.5) was used. To have confidence in these future projections we first assessed how well these models captured the mean state over the recent historical period by comparing this with observations.

Tropical cyclone projections

Cyclones are usually too small to be explicitly represented in GCMs, even though these models generally represent the large-scale atmospheric features important for cyclone formation (tropical cyclone-like vortices, TCLVs). In the PCCSP and PACCSAP, scientists have used three independent methods to assess the ability of climate models to simulate cyclones and how they might change in future:

- A detection and tracking scheme that looks for features resembling a cyclone (7 out of 17 models with suitable data performed well)
- A detection scheme that looks for environments conducive to cyclone formation (8 out of 13 models with suitable data performed well)
- Empirical techniques that relates cyclone formation to environmental conditions (17 models used).

Important features of tropical cyclones, such as the extreme wind and rain associated with the eye wall, are typically smaller than the finest spatial scales that GCMs can resolve. Assessing potential changes in the intensity of cyclone wind and rain requires dynamical downscaling to provide more detailed information. Dynamical downscaling uses the detection of TCLVs to determine what systems are downscaled and uses the GCM data to force the model.

Statistical downscaling is also used. These techniques make projections on future changes in intensity and rainfall of tropical cyclones directly from changes in the TCLVs from the GCMs. There are advantages and disadvantages of the different approaches, however they are complementary.

FOR MORE INFORMATION

VISIT

Pacific-Australia Climate Change Science and Adaptation Planning Program **www.pacificclimatechangescience.org**

READ

Australian Bureau of Meteorology and CSIRO (2014). *Climate Variability, Extremes and Change in the Western Tropical Pacific: New Science and Updated Country Reports.* Pacific-Australia Climate Change Science and Adaptation Planning Program Technical Report, Australian Bureau of Meteorology and Commonwealth Scientific and Industrial Research Organisation, Melbourne, Australia.

CONTACT

Country specific data are available from national meteorological services in each partner country.

Cook Islands Meteorological Service
www.cookislands.pacificweather.org
Phone +682 20603 or +682 25920

Federated States of Micronesia
National Weather Service Office

Yap
www.prh.noaa.gov/yap
Phone +691 350 2194

Chuuk
www.prh.noaa.gov/chuuk
Phone +691 330 2548

Pohnpei
www.prh.noa.gov/pohnpei
Phone +691 320 2248

Fiji Meteorological Service
www.met.gov.fj
Phone +679 672 4888

Kiribati Meteorology Service
www.met.gov.ki
Phone +686 26459

Marshall Islands National
Weather Service Office
www.prh.noaa.gov/majuro
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Nauru Department of Commerce,
Industry and Environment
www.naurugov.nr
Phone +674 444 3133

Niue Department of Meteorology
and Climate Change
www.informet.net/niuemet
Phone +683 4601 or +683 4600

Palau National Weather Service Office
www.prh.noaa.gov/koror
Phone +680 488 1034

Papua New Guinea National
Weather Service
Phone +675 325 2557

Samoa Meteorology Division, Ministry of
Natural Resources and Environment
www.mnre.gov.ws/meteorology
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Solomon Islands Meteorological Service
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Timor-Leste National Directorate
of Meteorology and Geophysics
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Tonga Meteorological Service
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Tuvalu Meteorological Service
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Vanuatu Meteorology and
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www.pacificclimatechangescience.org

Australian Government
Bureau of Meteorology

CSIRO

Australian Government
Department of the Environment

SPREP
Secretariat of the Pacific Regional Environment Programme