Abbreviations

CCAM	Conformal Cubic Atmospheric Model
CliCom	CLImate COMputing Project (of the World Meteorological Organization)
CliDE	Climate Data for the Environment
CMAP	Climate Prediction Centre Merged Analysis of Precipitation
CMIP3	Coupled Model Intercomparison Project (Phase 3)
CSIRO	Commonwealth Scientific and Industrial Research Organisation
ECMWF	European Centre for Medium-Range Weather Forecasts
EMI	ENSO Modoki Index
ENSO	El Niño-Southern Oscillation
GCM	Global Climate Model
GPCP	Global Precipitation Climatology Project
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
IPO	Interdecadal Pacific Oscillation
ITCZ	Intertropical Convergence Zone
MJO	Madden Julian Oscillation
NMS	National Meteorological Services
PCCSP	Pacific Climate Change Science Program
PDO	Pacific Decadal Oscillation
SAM	Southern Annular Mode
SPCZ	South Pacific Convergence Zone
SRES	Special Report on Emission Scenarios
TCLV	Tropical cyclone-like vortices
TRMM	Tropical Rainfall Measuring Mission
UNFCCC	United Nations Framework Convention on Climate Change
WMO	World Meteorological Organization
WPM	West Pacific Monsoon

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Authors

Coordinating Lead Author: Jillian Rischbieth

Lead Authors: Simon McGree, Brad Murphy, Damien Irving, Jaclyn Brown

Contributing Authors: Deborah Abbs, Josephine Brown, Gillian Cambers, Belinda Campbell, Dev Capey, John Church, Dean Collins, Kevin Hennessy, Ron Hoeke, Andrew Lenton, Kathleen McInnes, Aurel Moise, Les Muir, Sarah Perkins, Skye Platten, Alexander Sen Gupta, Neil White, Xuebin Zhang

Chapter 2 (Cook Islands): Arona Ngari, Maarametua Vaiimene, David Maihia, Nitoro Bates, Pasha Carruthers

Chapter 3 (East Timor): Terencio Fernandes Moniz, Sebastião da Silva

Chapter 4 (Federated States of Micronesia): David Aranug, Johannes Berdon, Eden Skilling

Chapter 5 (Fiji): Alipate Waqaicelua, Areita B Daphne, Bipendra Prakash, Varanisese Vuniyayawa, Ravind Kumar

Chapter 6 (Kiribati): Ueneta Toorua, Tebwaau Tetabo Riibeta Abeta, Nakibae Teuatabo

Chapter 7 (Marshall Islands): Reginald White, Lee Z. Jacklick, Ned Lobwij

Chapter 8 (Nauru): Andrew Kaierua, Franklin Teimitsi, Douglas Audoa, Russ Kun

Chapter 9 (Niue): Rossylynn Pulehetoa-Mitiepo, Adorra Misikea, Felicia Pihigia Talagi

Chapter 10 (Palau): Maria Ngemaes, Dirutelchii Ngirengkoi, Godwin Sisior

Chapter 11 (Papua New Guinea): Kasis Inape, Maino Virobo

Chapter 12 (Samoa): Fata Lagomauitumua Sunny K. Seuseu, Tumau Faasaoina

Chapter 13 (Solomon Islands): David Hiriasia, Lloyd Tahani

Chapter 14 (Tonga): Ofa Fa'anunu, Mele Lakai

Chapter 15 (Tuvalu): Hilia Vavae, Kilateli Epu

Chapter 16 (Vanuatu): Salesa Kaniaha, Philip Malsale

Other contributors

Other contributors: John Clarke, Gillian Cook, Francois Delage, Timothy Erwin, Andrew Howard and Rod Hutchinson

All staff involved in the Pacific Climate Change Science Program

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Peer Review

Anthony Chen, University of the West Indies, Graeme Pearman, Graeme Pearman Consulting Pty Ltd

Other Reviewers

Australian Agency for International Development, Department of Climate Change and Energy Efficiency, John Clarke, Ian Cresswell, Peter May, Netatua Pelesikoti

Scientific Editors

Kevin Hennessy, Scott Power, Gillian Cambers

Volume Editors

Volume 1: Stephanie Baldwin, Jillian Rischbieth

Volume 2: Jillian Rischbieth

Other Editors

Karen Pearce (Bloom Communication), Whitehorne Communication and Design

Coordination

Stephanie Baldwin, Bernadette Barlow, Gillian Cambers, Gillian Cook, Dev Capey, Lily Frencham, Mandy Hopkins, Lucy Manne, Zarif Raman, Jillian Rischbieth

Design and Layout

Siobhan Duffy, Lea Crosswell, Carl Davies, Soussanith Nokham, Louise Bell


Funafuti Atoll, Tuvalu

Executive Summary

Introduction and Background

Islanders, especially in the Pacific region, have a strong relationship with the land and ocean so changes in climate can represent a threat not only to the physical environment but also to their culture and customs. Already, people living in Pacific Islands and East Timor are experiencing changes in their climate such as higher temperatures, shifts in rainfall patterns, changing frequencies of extreme events and rising sea levels. These changes are affecting peoples' lives and livelihoods, as well as important industries such as agriculture and tourism. In recognition of this, leaders of the Pacific Island Countries and Territories developed the Pacific Islands Framework for Action on Climate Change 2006-2015 to guide the building of resilience to the risks and impacts of climate change.

In 2008, the Australian Government launched the International Climate Change Adaptation Initiative to meet high priority adaptation needs of vulnerable countries within the Asia-Pacific region. Improved understanding of the physical climate system is required to inform effective adaptation and this is being addressed through a component of the International Climate Change Adaptation Initiative called the Pacific Climate Change Science Program (PCCSP). The PCCSP is a collaborative research partnership between Australian Government agencies, East Timor and 14 Pacific Island countries (Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu), carried out in collaboration with regional and international organisations (Figure ES.1).

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007) identified significant research gaps which needed to be filled to better inform climate change adaptation and resilience building in small-island developing States. The report identified a number of information gaps and research priorities, noting in particular that many small islands lacked adequate observational data, and that output from global climate models was not of sufficiently fine resolution to provide specific information for islands. These regional and Partner Country climate change science needs formed the basis for the development of the research of the PCCSP.

The 15 Partner Countries are immensely diverse in terms of their history, geography, climate, natural resource base and culture. As part of the group of small island developing States, they share many similar sustainable development challenges such as small populations, limited resources, remoteness, susceptibility to natural disasters, vulnerability to external shocks and dependence on international trade.

Guided by the Australian Agency for International Development and the Australian Department of Climate Change and Energy Efficiency, the PCCSP is delivered by the Australian Bureau of Meteorology and the Commonwealth Scientific and Industrial Research Organisation, through their research partnership in the Centre for Australian Weather and Climate Research. The PCCSP's objectives are to:

- Conduct a comprehensive climate change science research program aimed at providing in-depth information about past, present and future climate in Partner Countries.
- Build the capacity of Partner Countries' national meteorological services and scientific organisations to undertake scientific research.
- Disseminate the information to Partner Countries' stakeholders and other parties.

Climate is defined as the average weather over 30 years or more. In different chapters in this publication, different averaging periods, such as 20 years, are also used. Climate change is defined as a change in the state of the climate, identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer (IPCC, 2007).

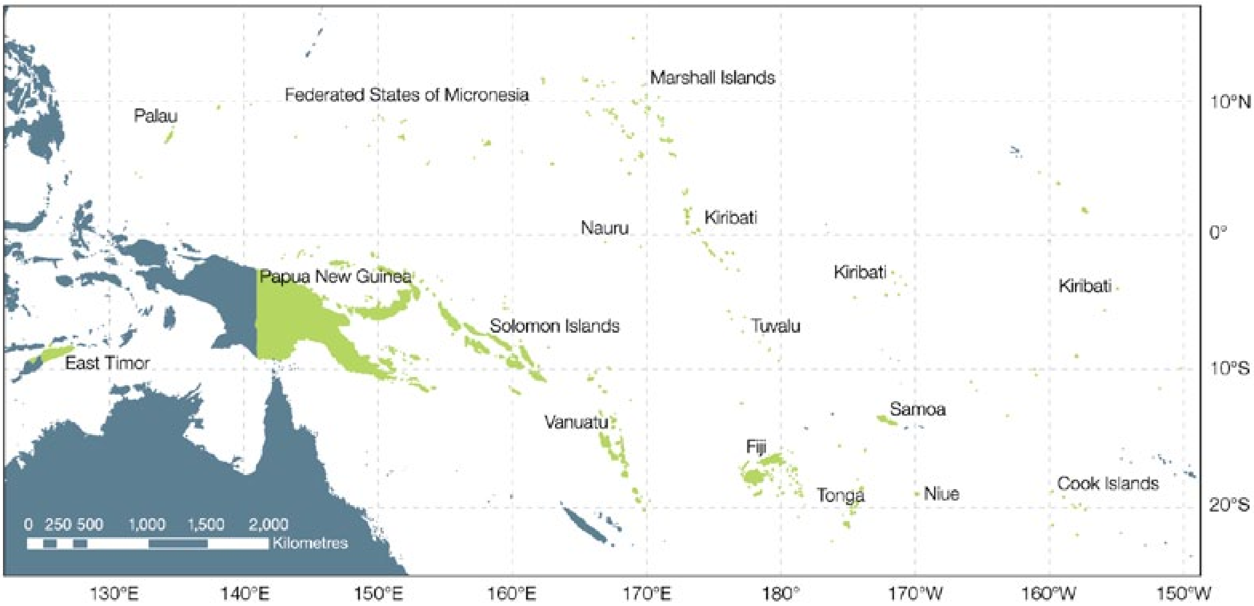

Figure ES.1: PCCSP region, defined by the coordinates: 25°S-20°N and 120°E-150°W (excluding the Australian region south of 10°S and west of 155°E), and Partner Countries: Cook Islands, East Timor, Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu

About this Publication

Building on the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007), this publication draws on recent research conducted by the PCCSP as well as other research, such as the recently published 'Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change' (Bell et al., 2011). It is anticipated that this PCCSP publication and associated products and capacity-building activities will provide senior decision makers and other stakeholders in the Partner Countries, as well as the wider scientific community, with up-to-date, robust, climate change science information for the region and the individual countries.

This publication has two volumes. The first volume presents a detailed assessment and analysis of the PCCSP region encompassing latitudes 25°S-20°N and longitudes 120°E-150°W, excluding the Australian region south of 10°S and west of 155°E. Climate change reports for each Partner Country are presented in the second volume. Each of the 15 reports has four main sections which present and discuss (1) seasonal cycles, (2) climate variability, (3) observed annual trends, and (4) projections for atmospheric and oceanic variables. Projections are provided for temperature, rainfall, extreme events, (including tropical cyclones, extreme hot days and heavy rainfall days), sea-surface temperature, ocean acidification, and sea-level rise for three future 20-year periods centred on 2030, 2055 and 2090, and for three different scenarios of greenhouse gas and aerosol emissions: B1 (low), A1B (medium) and A2 (high).

Current Climate of the PCCSP Region

The PCCSP region is characterised by three extensive bands of large-scale wind convergence and associated rainfall: the Intertropical Convergence Zone (ITCZ), the South Pacific Convergence Zone (SPCZ) and the West Pacific Monsoon (WPM) (Figure ES.2).

The ITCZ lies just north of the equator and influences climate in the Federated States of Micronesia, Kiribati, Marshall Islands, Nauru, Palau and Papua New Guinea. These same countries, together with East Timor, also experience very high seasonal rainfall variations associated with the WPM, although in Nauru and the Marshall Islands this only occurs in some years.

The SPCZ has a significant impact on most of the Partner Countries in the South Pacific: Cook Islands, Fiji, Nauru, Niue, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu; and Kiribati in some years.

Many of the Partner Countries experience marked seasonal rainfall variations, but little variation in temperature. However, they may experience extreme events including tropical cyclones, storm surges, heat waves, drought and heavy rainfall. Tropical cyclones produce damaging winds, heavy rainfall and storm surges which can have devastating impacts.

Large-scale atmospheric circulation patterns influence ocean currents and sea-surface temperature patterns, while the ocean in turn also affects atmospheric winds, temperatures and rainfall. For example, the equatorial trade winds push warm water to the west, giving rise to the Warm Pool, and drive the upwelling of cooler water in the eastern Pacific; while the warmer water near the equator and the Warm Pool in particular, drive strong convection in the overlying atmosphere which helps to draw the trade winds across the Pacific Ocean.

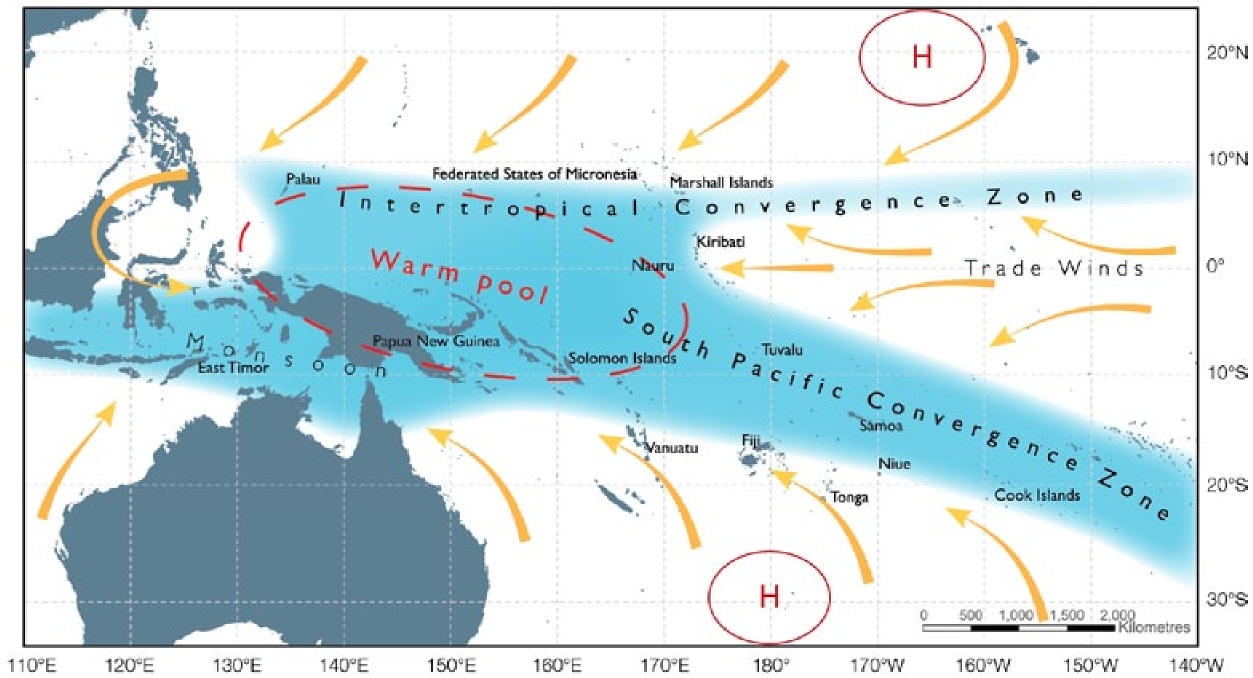

Figure ES.2: The average positions of the major climate features of the PCCSP region in November to April. The yellow arrows show near surface winds, the blue shading represents the bands of rainfall (convergence zones with relatively low pressure), and the red dashed oval indicates the West Pacific Warm Pool. H represents the typical positions of moving high pressure systems.

Climate Variability and Trends

Climate variability in the PCCSP region occurs on a wide range of time scales. Palaeoclimatic records indicate that during the millennia before the Industrial Revolution (around 1750), the climate of the Pacific underwent large variations, primarily associated with changes in the intensity and frequency of the El Niño-Southern Oscillation (ENSO). These climate shifts were driven by natural mechanisms, whereas some of the changes observed over the past decades are also partially driven by human influences. Consequently, it is important to understand the range of climate variability experienced in the past in order to provide a context in which to interpret projections of future climate change.

The major pattern of climate variability in the PCCSP region is ENSO. This is a coupled atmosphere-ocean phenomenon, with time scales of about two to seven years. The term El Niño is identified with a basin-wide warming of the tropical Pacific Ocean east of the dateline. The term La Niña is a basin-wide cooling of the tropical Pacific Ocean east of the dateline. This event is associated with a fluctuation of a global-scale tropical and sub-tropical pressure pattern called the Southern Oscillation.

ENSO is strongly linked with variations in climatic features such as the ITCZ, the SPCZ and the WPM. During El Niño events the SPCZ tends to shift towards the north-east, while the ITCZ tends to shift closer to the equator. These shifts have a profound influence on rainfall, sea level and the risk of tropical cyclones in the region. All PCCSP Partner Countries are affected by ENSO in some way, although the magnitude and timing of this influence varies.

As well as ENSO there are other natural patterns of climate variability that influence the region, including the Interdecadal Pacific Oscillation and the closely related Pacific Decadal Oscillation.

The climate trends for the PCCSP region that are presented in this publication are based on updated and improved climate datasets. This work has involved significant collaboration with Partner Country meteorological services and has resulted in improved data access and security, and enhanced scientific and technical capacity in the region.

All updated temperature records from Pacific Island observation stations show warming over the past 50 years, with trends mostly between 0.08 to 0.20°C per decade, consistent with global warming over this time. Unlike temperature, rainfall across the Pacific Islands displays large year-to-year and decade-to-decade changes in response to natural climate variability. Over the past 50 years, rainfall has increased north-east of the SPCZ, and declined to the south.

Over the 1981-2007 period of satellite measurement there are no significant trends in the overall number of tropical cyclones, or in the number of intense tropical cyclones, in the South Pacific Ocean. However, this is a short period of time for the analysis of infrequent extreme events such as tropical cyclones. Determining trends over longer periods is difficult due to the lack of adequate data prior to satellite measurements.

Sea-surface temperatures of the Pacific Ocean have generally increased since 1950. In addition, the western tropical Pacific Ocean has become significantly less salty, while regions to the east have generally become saltier. In combination, these changes have driven an increase in the stratification of the upper ocean in this region.

A distinctive pattern of intensified warming of surface waters and cooling of sub-surface equatorial waters centred near a depth of 200 m is also apparent over the past 50 years in the Pacific Ocean. These patterns of observed change in the ocean are reproduced in climate model simulations that include increased atmospheric greenhouse gases.

Sea level has been rising globally including in the PCCSP region over recent decades. Extreme high sea levels are also increasing, primarily as a result of increases in mean sea level. There is significant interannual variability of sea level in the region related to ENSO and other natural variability.

As a consequence of higher carbon dioxide (CO_2) concentrations in the atmosphere, the oceans are absorbing more CO_2. The CO_2 taken up by the ocean reacts in water and causes a decrease in the pH of the seawater that is referred to as ocean acidification. Acidification is accompanied by a decrease in the seawater saturation state of carbonate minerals that are secreted as shells and skeletal material by many key species in reef ecosystems. Aragonite is the form of calcium carbonate precipitated by reef building corals and studies have shown that coral growth declines as the aragonite saturation state of seawater decreases.

Aragonite saturation states above a value of 4 are considered optimal for coral growth and for the development of healthy reef ecosystems. Throughout most of the sub-tropical and tropical Pacific Island region, the saturation state in pre-industrial times exceeded 4. By the mid 1990s, the uptake of anthropogenic CO_2 had resulted in a widespread decline in the aragonite saturation state.

Climate Modelling

The complexity of the climate system means that past trends cannot be simply extrapolated to forecast future conditions. Instead, mathematical representations of the Earth's climate system, based on the laws of physics, are used to simulate the fundamental processes affecting weather and climate. Global climate models calculate variables such as temperature and rainfall at points over the globe spaced 100–400 km apart, with about 30 layers in the ocean and 30 layers in the atmosphere. They are run on supercomputers and have been used extensively over recent decades to not only estimate future climate change, but also to help better understand the present and past climate.

Emissions of greenhouse gases and aerosols have played a major role in the climate of the past century. In order to make future climate projections, it is necessary to make plausible estimates of how these emissions will evolve into the future. To assist in modelling the future climate, the IPCC has prepared 40 greenhouse gas and sulphate aerosol emissions scenarios for the 21st century that combine a variety of plausible assumptions about demographic, economic and technological factors likely to influence future emissions. Such estimates can then be put into climate models to provide projections of future climate change. Climate model projections in this publication are based on three of the most widely used emissions scenarios, B1 (low), A1B (medium) and A2 (high).

Performance of Climate Models

To make projections of future climate, it first has to be demonstrated that climate models are sufficiently realistic in simulating the observed climate. This depends on the model's ability to represent several different aspects of climate, including:

- The long-term average pattern of various atmospheric and oceanic characteristics, e.g. temperature, rainfall, wind, salinity and sea level.
- Important regional climate features, e.g. ITCZ, SPCZ and WPM.
- Major patterns of climate variability on various timescales, e.g. ENSO.
- Extreme weather events, e.g. heat waves, tropical cyclones.
- Long-term trends.

How well the models agree with the observed present climate is used to assess model reliability, with the underlying assumption that a model which adequately simulates the present climate will provide more reliable projections of the future. No single model is the 'best' in representing all aspects of climate so a range of models should be considered when making projections of future climate.

After analysing data from 24 global climate models from around the world, the PCCSP identified a set of 18 models which provide a reasonable representation of observed climate over the PCCSP region. These 18 models were used to construct projections of future climate for the PCCSP region and the individual Partner Countries.

These 18 global climate models can simulate many aspects of climate, and generally give a reasonable representation of climate in the Pacific region. Most models, however, show biases, such as a tendency to underestimate sea-surface temperatures and rainfall along the equator. The representation of ENSO in climate models has improved over the years but remains a challenge at the regional scale. For example, sea-surface temperature variability associated with ENSO tends to be too narrowly focused on the equator and extends too far to the west.

Global climate models do not have sufficiently fine resolution to represent small islands and important small-scale climate processes. Downscaling techniques are used to represent important small island effects, however, these techniques are very computer intensive.

Global Climate Model Projections

The IPCC Fourth Assessment Report (2007) presents broad-scale projections for the Pacific. Annual-mean temperature and rainfall projections are averaged over two large Pacific regions (the North Pacific and the South Pacific), for three 30-year periods (2010–2039, 2040–2069 and 2070–2099), based on results from seven global climate models and four emissions scenarios.

The PCCSP provides a more detailed set of climate change projections, building on the IPCC assessment. The projections for the PCCSP region are based on simulations from up to 18 global climate models for three emissions scenarios; B1 (low), A1B (medium) and A2 (high), and three future 20-year periods centred on 2030, 2055 and 2090, relative to a 20-year period centred on 1990. The selection of years and emissions scenarios is limited by data availability.

A summary of the key climate projections for the PCCSP region is outlined on the following pages. Volume 2 of this publication provides detailed discussion on the range of possible futures simulated for each country.

Projected Changes in Major Climate Features and Patterns of Variability

South Pacific Convergence Zone

In the wet season (November-April), the SPCZ is not expected to shift position, but there is some evidence for a projected equatorward shift in the dry season (May-October). Increased rainfall is projected within the SPCZ in the wet season in particular, due to increased atmospheric moisture content in a warmer climate. Many models also suggest that islands located near the eastern edge of the SPCZ will become drier in the wet season as the trade winds in the south-east Pacific become stronger.

Intertropical Convergence Zone

Changes in rainfall averaged over the ITCZ show a general increase in June-August, with little change in December-February, thereby amplifying the current seasonal cycle. There is an increase in the area of the ITCZ in all models in June-August, and in all but three in December-February. Models suggest the ITCZ may shift equatorward in March-May and June-August, although displacement is small.

West Pacific Monsoon

There is a general tendency for rainfall to increase in the WPM region throughout the year, but with an amplification of the seasonal cycle of rainfall. There is no significant projected change in the east-west winds over the region.

El Niño-Southern Oscillation

Year-to-year variability in the region will continue to be strongly affected by ENSO. However, climate models do not provide consistent projections of changes in the frequency, intensity and patterns of future El Niño and La Niña events. As climate changes, however, aspects of climate experienced in some regions during El Niño and La Niña events may differ from the past. For example, if El Niño tends to warm a particular region now, then temperatures experienced during future El Niño events may tend to be higher than those experienced during past El Niño events.

Indian Ocean Dipole

The IOD influences climate both locally and in remote regions, mainly affecting East Timor. It also affects the Indian and Australian monsoons, however, the IOD is a much weaker source of climate variability for the Pacific region than ENSO. Climate models suggest that a more positive IOD mean state will exist with easterly wind trends and a shallowing thermocline (a zone in the ocean separating warm surface waters from cold deep waters) over the eastern Indian Ocean, associated with a weakening of the Walker Circulation.

Atmospheric Projections

Temperature

The magnitude of the projected warming over the PCCSP region is about 70% as large as the magnitude of global average warming for all emissions scenarios. This is linked to the fact that the oceans have been warming, and are projected to warm into the future at a lower rate than land areas. As the PCCSP region is dominated by the ocean, it follows that temperature increases in the region will be less than those seen globally. The projections centred on the three 20-year periods (relative to 1990 baseline temperatures) show that:

- By 2030, the projected regional warming is around +0.5 to 1.0°C, regardless of the emissions scenario.
- By 2055, the warming is generally +1.0 to 1.5°C with regional differences depending on the emissions scenario.
- By 2090, the warming is around:
  - +1.5 to 2.0°C for B1 (low emissions scenario).
  - +2.0 to 2.5°C for A1B (medium emissions scenario).
  - +2.5 to 3.0°C for A2 (high emissions scenario) (Figure ES.3).

Large increases in the incidence of extremely hot days and warm nights are also projected.

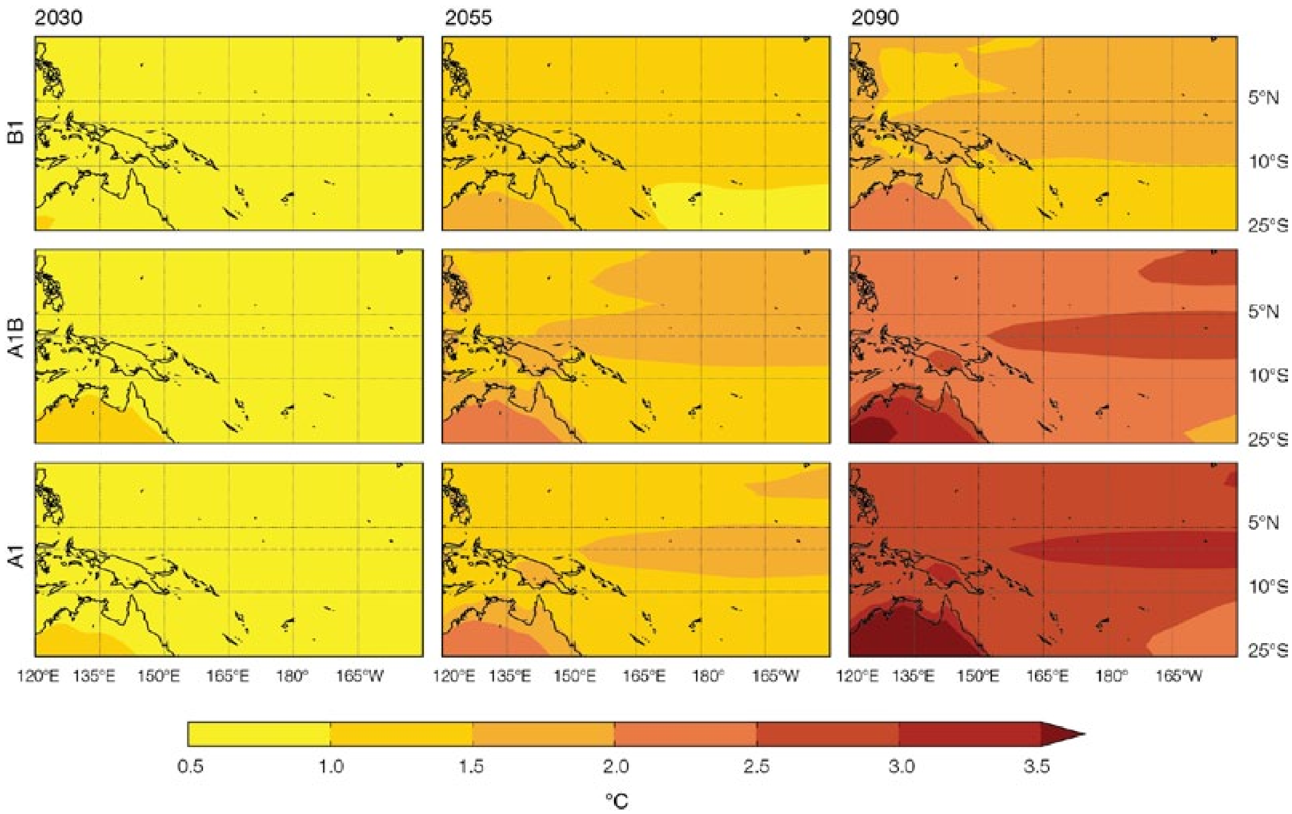

Figure ES.3: Projected multi-model mean changes in annual mean surface air temperature for 2030, 2055 and 2090, relative to 1990, under the A2 (high), A1B (medium) and B1 (low) emissions scenarios. All models agree on warming in all locations.

Rainfall

In the PCCSP region, increases in annual mean rainfall are projected to be most prominent near the SPCZ and ITCZ, with little change in the remainder of the region (Figure ES.4). The annual numbers of rain days (over 1 mm), light rain days (10–10 mm) and moderate rain days (10–20 mm) are projected to increase near the equator, with little change elsewhere in the region. There is a widespread increase in the number of heavy rain days (20–50 mm). Extreme rainfall events that currently occur once every 20 years on average are generally simulated to occur four times per 20-year period, on average, by 2055 and seven times per 20-year period, on average, by 2090 under the A2 (high) scenario. Droughts are projected to occur less often.

Potential Evapotranspiration

Evapotranspiration is the sum of evaporation and plant transpiration from the Earth's land surface to the atmosphere. Potential evapotranspiration is a reflection of the energy available to evaporate water, and of the wind available to transport the water vapour from the ground up into the lower atmosphere. Potential evapotranspiration is highest in hot, sunny, dry (arid), and windy conditions. Increases in potential evapotranspiration are expected in the PCCSP region.

The ratio of annual average rainfall to potential evapotranspiration is a measure of aridity. Aridity increases in most, but not all, of the PCCSP region (i.e. the projected increase in potential evapotranspiration is not being matched by sufficient increases in rainfall).

Humidity and Solar Radiation

Projected changes in humidity and solar radiation are relatively small in the PCCSP region, i.e. less than 5% by 2090.

Wind

Surface wind speed is generally expected to decrease in the equatorial and northern parts of the PCCSP region, while increases are indicated in the south. However these changes are projected to be relatively small in most locations.

Ocean Projections

Salinity and Stratification

Sea-surface salinity is expected to decrease, with regional differences closely matching projected changes in net rainfall (rainfall minus evaporation). The intensified warming and freshening at the surface is projected to make the surface ocean less dense compared to the deep ocean, so the ocean becomes more stratified. This increase in stratification acts to inhibit mixing, thereby reducing the supply of nutrients from the deep to the surface ocean. This has consequences for biological productivity, particularly fisheries.

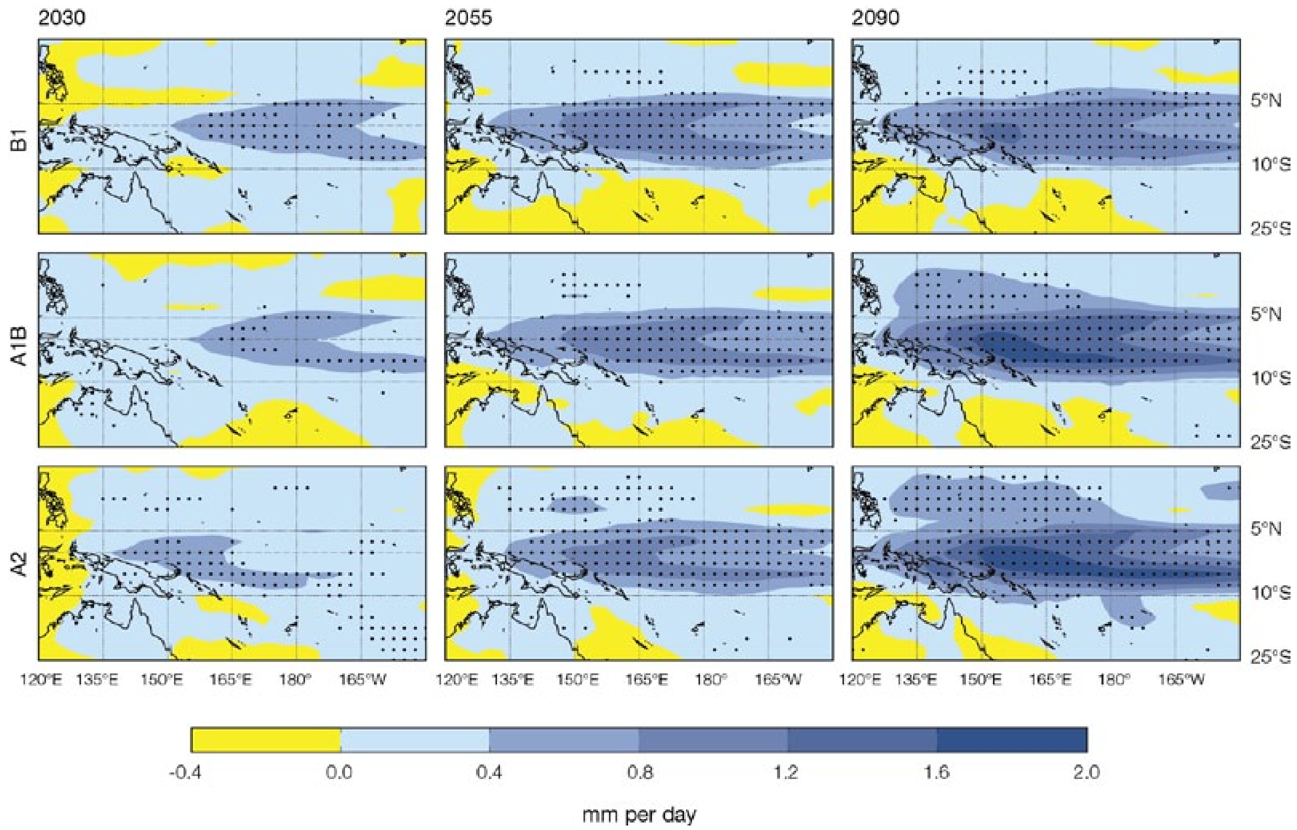

Figure ES.4: Projected multi-model mean changes in annual rainfall (mm/day) for 2030, 2055 and 2090, relative to 1990, under the A2 (high), A1B (medium) and B1 (low) emissions scenarios. Regions where at least 80% of models agree on the direction of change are stippled.

Sea Level

Global climate models reproduce the observed pattern of the regional distribution of sea level reasonably well. Models indicate that the rise will not be geographically uniform. However, deviations between models make regional estimates uncertain (Figure ES.5). In current projections, the sea-level rise in the PCCSP region is similar to the global average.

Projections of sea-level rise require consideration of ocean thermal expansion, the melting of glaciers and ice caps, the surface mass balance and dynamic response of the ice sheets of Antarctica and Greenland, and changes in terrestrial water storage. Current projections indicate sea levels are expected to continue to rise, on average, during this century. The Fourth Assessment Report of the IPCC (IPCC, 2007) states that global average sea level is projected to rise by 0.18 to 0.59 m by 2080-2099, relative to 1980-1999, with an additional potential contribution from the dynamic response of the ice sheets. By scaling to global temperature changes this additional rise was estimated to be 10 to 20 cm but larger increases could not be ruled out. Observations indicate sea level is currently rising at near the upper end of the projected range. Larger rises than in the IPCC projections have been argued by some but one recent study suggests that global-mean sea-level rise greater than 2 m by 2100 is physically untenable and that a more plausible estimate is about 80 cm, consistent with the upper end of the IPCC estimates and the present rate of rise. However, improved understanding of the processes responsible for ice sheet changes are urgently required to improve estimates of the rate and timing of 21st century and longer-term sea-level rise.

Ocean Acidification

The projected growth in atmospheric CO_2 concentration is expected to cause further ocean acidification. Aragonite saturation values below 3.5 are projected to become more widespread and have the potential to disrupt the health and sustainability of reef ecosystems. The lowest values of aragonite saturation in the region of the Partner Countries are projected to occur in the eastern equatorial Pacific, to the east of longitude 160°W, affecting the easternmost islands of Kiribati, with the highest values in the region of the South Equatorial Current, affecting the islands of Cook Islands, Samoa and Tuvalu.

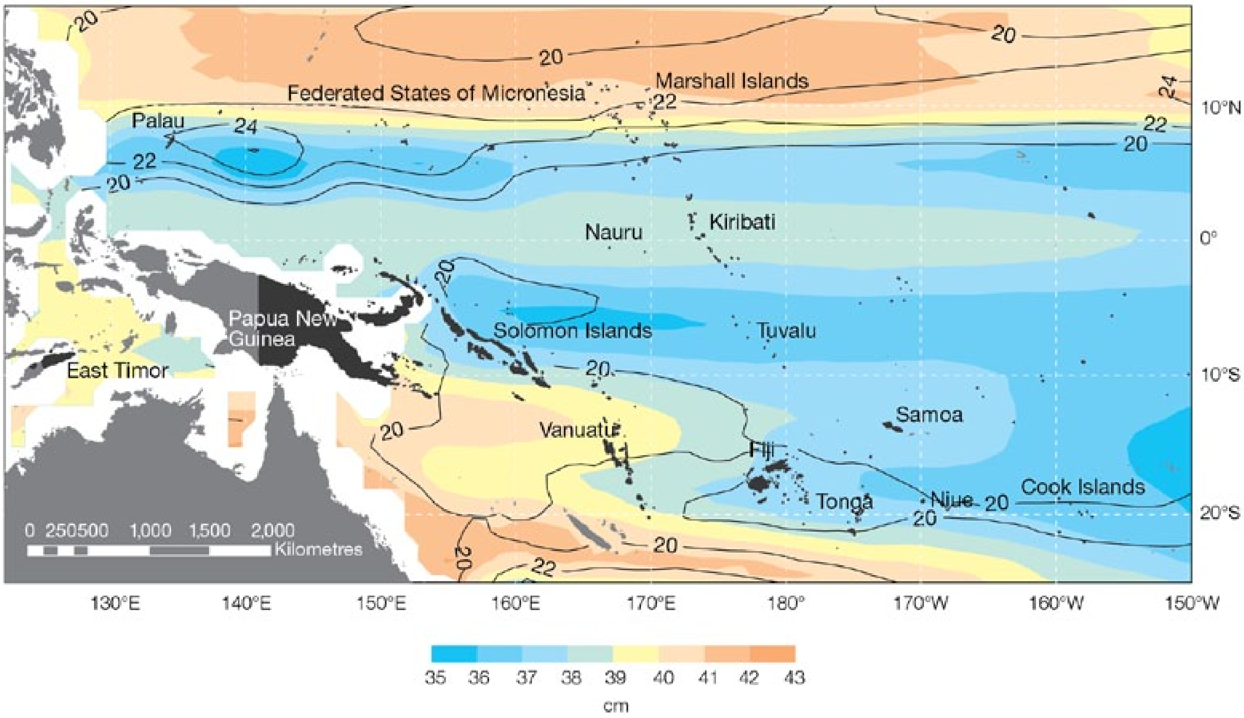

Figure ES.5: Sea-level rise projections for the A1B (medium) emissions scenario in the PCCSP region for 2081-2100 relative to 1981-2000 are indicated by the shading with the uncertainty indicated by the contours (in centimetres). The distribution of the projections of sea-level change is estimated by combining the global average sea-level projections, the dynamic ocean departure from the global average and the regional changes associated with the changing ice-mass distribution. Note that white areas indicate no model data are available for that area.

Downscaled Projections

Dynamical and statistical downscaling techniques were used to provide small-scale (i.e. country-scale and/or individual island-scale) climate projections. The output from six global climate models was downscaled to 60 km over the PCCSP region, and to 8 km for selected islands. The 60 km downscaled projections are broadly consistent with those of the global climate models, however, some differences are noted such as bands of rainfall decrease around latitudes 8°N and 8°S.

The 8 km downscaled projections complement the projections from the global climate models and show regional variations of the climate change signal, largely related to the topography of the islands where significant changes in elevation exist.

Tropical Cyclone Projections

It is difficult to make projections of tropical cyclone activity for two reasons. First, the features of a tropical cyclone occur at a smaller spatial scale than can be represented by most climate models. Second, climate models vary in their ability to simulate large-scale environmental conditions that are known to influence tropical cyclones including patterns of variability such as ENSO and large-scale climate features such as the SPCZ.

Three methods were used by the PCCSP to diagnose tropical cyclones from global climate models. While large uncertainty still remains, the results from this study indicate that the frequency of tropical cyclones in the PCCSP region is projected to decrease by the late 21st century. There is a moderate level of confidence in this direction of change, however, there is little consistency in the magnitude of changes between either the models or the analysis methods.

For the Partner Countries in the south Pacific sub-basins (latitudes 0-35ºS; longitudes 130°E-130ºW), most models indicate a decrease in the frequency of tropical cyclones by the late 21st century and an increase in the proportion of more intense storms. For the Partner Countries in the North Pacific sub-basin (latitudes 0-15ºN; longitudes 130º-180ºE), there is a decrease in the frequency of tropical cyclones and a decrease in the proportion of more intense storms. This decrease in occurrence is more robust in the Southern Hemisphere than in the Northern Hemisphere, and may be due to a combination of increased vertical wind shear in the Southern Hemisphere, and changes in the thermodynamic characteristics of the atmosphere which are associated with tropical storm activity and intensity.

Uncertainties in Climate Model Projections

While climate models are all based on the same physical laws, they are not perfect representations of the real world. As such, there will always be a range of uncertainty in climate projections. The existence of uncertainty is common to all areas of science and does not negate the usefulness of model projections. Uncertainty exists in the projections provided in this publication and it is expected to exist for future projections, so reducing and achieving greater clarity on the uncertainties is still required. It is important that this uncertainty is understood and incorporated into any future impact assessments based on climate model projections. Box ES.1 summarises key uncertainties associated with climate projections (IPCC, 2007).

Box ES.1: Climate Projection Uncertainties

- Since it is uncertain how society will evolve over this century, it is not possible to know exactly how anthropogenic emissions of greenhouse gases and aerosols will change. Each of the 40 emissions scenarios produced by the IPCC is considered plausible, with the range of uncertainty increasing over the 21st century. Subtle differences between models associated with the representation of key physical processes result in a range of climate projections for a given emissions scenario.
- Models differ in their estimates of the strength of different feedbacks in the climate system, particularly cloud feedbacks, oceanic heat uptake and carbon cycle feedbacks.
- Direct and indirect aerosol impacts on the magnitude of the temperature response, on clouds and on precipitation remain uncertain.
- Future changes in the Greenland and Antarctic ice sheet mass are a major source of uncertainty that affect sea-level rise projections.
- 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 in the PCCSP region.
- 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.
- When interpreting projected changes in the mean climate, it is important to remember that natural climate variability (e.g. the state of ENSO) 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.
- It is not currently possible to determine if downscaled projections provide more reliable future climate projections than those from the coarser resolution global models. For this reason, dynamically downscaled projections can provide complementary information, but should be interpreted in conjunction with global climate models over the same region.

Future Research to Advance Climate Science in the PCCSP Region

Better understanding the past climate helps to inform more robust projections of future climate which are essential for underpinning climate change adaptation strategies and contributing to the sustainable development of the Partner Countries.

While there has been excellent progress on many fronts to monitor, document, understand and project climate change relevant to Partner Countries, there are still many challenges. Further work to strengthen the scientific understanding of climate change is required to inform adaptation and mitigation. The following areas have been identified as priorities.

The geographical spread of Partner Countries means that the land- and ocean-based climate observation network in the PCCSP region is sparse. Expanding atmospheric data measurements in the PCCSP region will strengthen the ability of Partner Countries to monitor climate. Enhancing and, in some cases, creating oceanic observation networks is equally important. The rescue and rehabilitation of historical climate data is also needed to extend the climate data record in the PCCSP region. Further analysis of palaeoclimate data will enhance the understanding of climate variability on a wide variety of time scales.

A better understanding of the state of climate features in the PCCSP region, including the SPCZ, ITCZ and WPM, and patterns of variability in the climate, including ENSO, is needed to advance climate science. Determining the extent to which climate trends are attributable to natural variability and to human activities is also a priority. Greater clarity on these issues and more reliable estimates of past variability in the atmosphere and the ocean, including extreme events, will help strengthen the credibility and communication of climate projections.

Analysing the ability of the next generation of climate models to simulate climate in the PCCSP region is essential. This will provide for improved projections for rainfall, extreme weather events, ENSO, sea level and ocean acidification, among other variables. Work needs to continue to improve the global climate models and to rigorously verify downscaling methods so as to provide finer resolution projections over smaller areas.