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Chapter 1
Introduction to the Country Reports

The first volume of Climate Change in the Pacific: Scientific Assessment and New Research provides a regional overview of climate change across the Pacific Climate Change Science Program (PCCSP) region, and includes annual and seasonal climatology, variability and long-term trends, methodology, climate model evaluation, and projected changes in atmospheric and oceanic variables from global and downscaled climate models.

This second and final volume contains individual reports for all 15 Partner Countries. The reports are largely based on the information contained in Volume 1, although some additional country-specific information is also presented. Chapters 2–16 all follow a similar format (Table 1.1) that starts with a brief introduction, a country description and summary of the current and future climate. This is followed by further details on data availability, seasonal cycles, climate variability, observed trends and climate projections.

The following sections provide information about the data sources, methodology and interpretation of country-specific detail provided in Chapters 2–16. It is important background information for understanding the country reports.

Table 1.1: Format for each country chapter

Chapter subsection	Subject	Content
	Introduction	Chapter outline
1	Climate summary	Summary of the current climate and climate trends including temperature, rainfall, sea-level rise, and extreme events, and future climate projections for temperature, rainfall, tropical cyclones, ocean acidification and sea-level rise.
2	Country description	Details of country location, size, population and major geographical features.
3	Data availability	Information about observation networks, data records and data availability.
4	Seasonal cycles	Average rainfall, maximum, minimum and mean air temperatures and the influence of large scale climate features such as the South Pacific Convergence Zone.
5	Climate variability	Influence of patterns of variability, such as the El Niño-Southern Oscillation, and analysis of indices characterising their impact.
6	Observed trends	Analysis of observed climate and trends for temperature, rainfall, extreme events, sea-surface temperature, ocean acidification, mean sea level, extreme sea-level events.
7	Climate projections	Analysis of projections for temperature, rainfall, extreme events, ocean acidification and sea level, followed by a projection summary. Climate projections for these climatic variables are based on up to 18 CMIP3 global climate models (Volume 1, Section 5.5.1 and Appendix 1).

1.1 Climate Summary

This section provides summaries of the current observed climate and projected future climate for each country.

1.2 Country Description

This section provides details of country location, size, population and major geographical features.

1.3 Data Availability

This section provides information about the observation network and data record availability in each country. The length, completeness and quality of historical data records differ from country to country. For many observing sites there have been changes in station position, instrumentation and local environment that have produced artificial changes (inhomogeneities) in the data over time. Where possible, these inhomogeneities have been identified for rainfall and temperature and corrected using statistical techniques.

Monthly-averaged in situ sea-level data (tide gauge data) are available through international archives (e.g. Permanent Service for Mean Sea Level at http://www.psmsl.org/ and Australia's National Tidal Centre at http://www.bom.gov.au/oceanography/projects/spslcmp/spslcmp.shtml). Satellite-altimeter data are available from 1993 to the present from National Aeronautics and Space Administration (NASA) and Centre National d'Etudes Spaciales (CNES). Both satellite (from 1993) and in situ sea-level data (1950–2009) on a regular grid are available from CSIRO. Figure 1.1 shows all the climate observation sites and tide gauges used.

Long-term locally-monitored sea-surface temperature data are unavailable for the this region. As a result large-scale sea-surface temperature (SST) gridded datasets have been used. A gridded data set is a set of climate data that are given for the same time or average period on a regular grid in space. This gives a complete coverage of a particular region (or the whole globe) at regularly spaced points. Data at each grid point represent the average value over a grid box, of which the size is determined by the spacing between the grid points.

Figures in the seasonal cycles section of each chapter show the seasonal variation of the key meteorological factors (1950–2000) from the HadISST dataset. Figures in the climate projections section of each chapter show the 1950–2000 sea-surface changes (relative to a reference year of 1990) from three large-scale, sea-surface temperature gridded datasets (HadSST2, ERSST and Kaplan Extended SST V2; Volume 1, Table 2.3).

1.4 Seasonal Cycles

Total rainfall and average daily maximum, minimum and mean air temperatures for each month of the year are discussed in this section, along with the influence of large-scale features of the climate system. The three main climate features in the PCCSP region are:

West Pacific Monsoon

The West Pacific Monsoon (WPM) refers to the seasonal switch from easterly winds to westerly winds and the onset of very wet conditions. It moves north to mainland Asia during the Northern Hemisphere summer and south to Australia in the Southern Hemisphere summer. It affects countries in the far western Pacific and the Maritime Continent.

Intertropical Convergence Zone

The Intertropical Convergence Zone (ITCZ) is a band of high rainfall stretching across the Pacific just north of the equator and is strongest in the Northern Hemisphere summer. It affects most countries on, or north of, the equator.

South Pacific Convergence Zone

The South Pacific Convergence Zone (SPCZ) is a band of high rainfall that stretches approximately from the Solomon Islands to east of the Cook Islands. It is strongest in the Southern Hemisphere summer and affects most countries in the South Pacific.

For most countries two sites are discussed to reflect regional climate differences, except where data are only available for one site or the country is small, e.g. Niue and Nauru. It is recognised that in other cases two sites may not adequately represent the whole country, e.g. Papua New Guinea and Kiribati, and in future research, additional sites should be included particularly for these countries.
The monthly average sea-surface temperature is also included, showing its influence on seasonal air temperature variations.

Climate averages for the period 1961–1990 are used, unless otherwise specified. For example, other longer periods may be used if there is a longer complete data record.

1.5 Climate Variability

The patterns of climate variability that result in changes from one year to the next are discussed in this section. Indices that monitor these patterns of climate variability are used to determine their influence on temperature and rainfall at sites in each Partner Country. These influences are determined by calculating the strength of the relationship (correlation coefficients) between the indices and temperature and rainfall. The standard indices used are explained in Section 1.5.1.

1.5.1 Climate Indices

El Niño-Southern Oscillation Indices

Year-to-year variations in the climate of all Partner Countries are influenced by the El Niño-Southern Oscillation (ENSO). ENSO events involve basin-wide changes of the tropical Pacific Ocean temperatures. These oceanic events are associated with a fluctuation of a global-scale tropical and sub-tropical surface pressure pattern called the Southern Oscillation. El Niño is the warm phase of the El Niño-Southern Oscillation, while La Niña is the cold phase. It also has a neutral phase. The typical pattern in an El Niño is warming of the ocean east of the International Date Line. This is known as a Canonical El Niño. A variation of El Niño with warming centred near the International Date Line is known as El Niño Modoki. For some regions the impacts of these two types of El Niño events differ. Indices used to monitor the phases of ENSO are:

Niño3.4

One of three indices used to describe ENSO, the Niño3.4 index is the average sea-surface temperature anomaly in the central Pacific (5°N–5°S, 170°W–120°W), as determined using the HadISST dataset (Volume 1, Section 2.2.2; Rayner et al., 2003).

Southern Oscillation Index

Also used to describe ENSO, the Southern Oscillation Index (SOI) is based on the mean sea level pressure difference between Tahiti and Darwin, using data from the Australian Bureau of Meteorology (Troup, 1965).

ENSO Modoki Index

The ENSO Modoki Index (EMI) represents variations in a type of ENSO that is focused more in the western Pacific than canonical ENSO (which is more in the eastern Pacific). Like Niño3.4, the EMI is an average sea-surface temperature anomaly, but over three areas:
(A) 10ºN–10ºS, 165ºE–140ºW,
(B) 5ºN–15ºS, 110ºW–70ºW and
(C) 20ºN–10ºS, 125ºE– 145ºE.
The EMI = A–0.5*B– 0.5*C. The EMI is calculated using the HadISST dataset.

Interdecadal Pacific Oscillation Index

The Interdecadal Pacific Oscillation (IPO) is a multi-decadal ENSO-like oscillation in the ocean and atmosphere centred in the Pacific (Volume 1, Section 3.4.2) which affects climate in the South Pacific, the North Pacific, and Australasia and beyond (Power et al., 1999; Folland et al., 1999; Parker et al., 2007). The Pacific Decadal Oscillation can be regarded as the North Pacific manifestation of the IPO. Data for the IPO index were provided by the UK Meteorological Office. The data are based on the analysis method described by Parker et al. (2007).

Indian Ocean Dipole Index

The Indian Ocean Dipole (IOD) is a pattern of interannual variability in sea-surface temperatures in the Indian Ocean (Volume 1, Section 3.4.8). It usually features opposite changes in temperatures from normal conditions in the western and eastern tropical Indian Ocean. The IOD index measures the difference in sea-surface temperatures between the western tropical Indian Ocean (50°E–70°E and 10°S–10°N) and the eastern tropical Indian Ocean (90°E–110°E and 10°S–0°S). Averages over each of these regions are the monthly-mean anomalies in sea-surface temperature. Thus, a positive IOD event is when the western Indian Ocean is warmer than normal and/or the eastern Indian Ocean is cooler than normal.

Southern Annual Mode Index

The Southern Annular Mode (SAM) is the major mode of atmospheric variability in the southern extra-tropics (Volume 1, Section 2.4.4). It features a north-south shift in the mid-latitude westerly winds and an oscillation in mass and pressure between the mid and high latitudes. The SAM is represented by an index measuring the difference in surface pressure between 50ºS–65ºS. A positive SAM index corresponds to a southward movement and intensification of the extra-tropical westerly winds. Data are from the British Antarctic Survey (Marshall, 2003).

1.5.2 Calculating Relationships between Indices and Climate Variables

The correlation coefficient is a measure of how well year-to-year variations in a climate variable (e.g. rainfall) match the year-to-year variations in the index (e.g. the SOI). The closer the correlation is to 1 or -1, the stronger the relationship. A positive correlation coefficient indicates that the two variables tend to increase or decrease in the same direction together. A negative correlation coefficient indicates that one variable will tend to increase while the other decreases. A correlation near zero means the climate variable and the index do not vary together in any consistent way and therefore are not (linearly) related. Correlations are calculated for wet and dry seasons (usually November-April and May-October) or the reverse in the Northern Hemisphere countries. The statistical significance of correlation coefficients is assessed using the method described by Power et al. (1998), which takes persistence into account.

In this analysis the relationship of interest is between interannual variations in indices and climate variables. However, if there are strong linear trends in the time series of some indices and climate variables this may also result in a significant correlation coefficient between them. Therefore, linear trends have been removed from all data before calculating the correlation coefficients.

The SAM is directly affected by ENSO, and so correlation coefficients between climate variables and the SAM index may simply be relating the ENSO relationship to the variable via the SAM. Thus the partial correlation coefficient between the variables and the SAM index are given, which means the linear

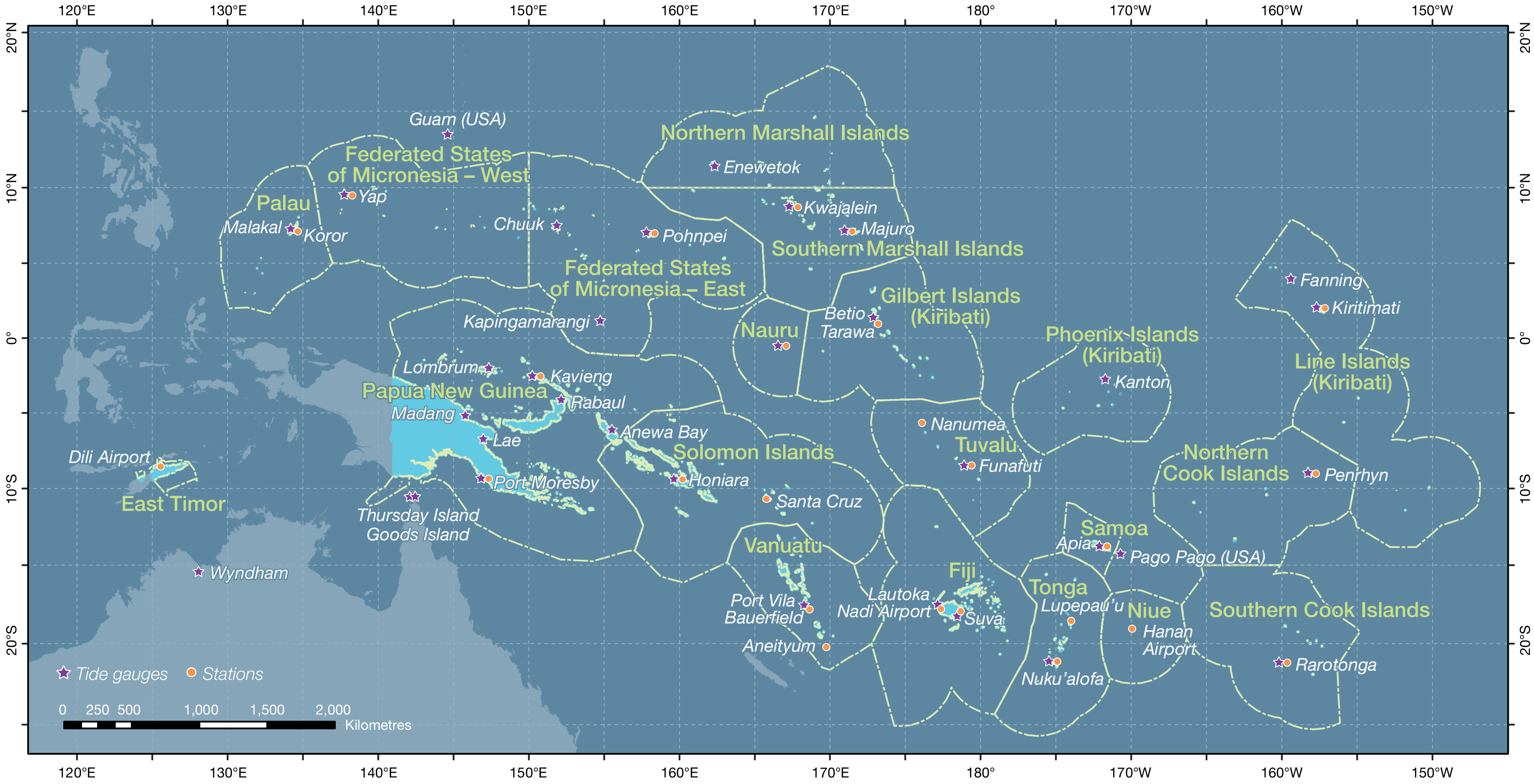

Figure 1.1: Meteorological observation stations, tide gauges and climate projections regions. The green dashed lines represent the regions used for climate projections for each country or country subregion. The tide gauges are indicated by the purple stars and observation stations by the orange circles.

relationship between the variable and Niño3.4 has been removed.

1.6 Observed Trends

This section provides analysis of observed climate and trends for annual and seasonal air temperature and rainfall, extreme events (particularly tropical cyclones), sea-surface temperature, ocean acidification and mean and extreme sea level.

1.6.1 Air Temperature and Rainfall

Sections X.6.1 and X.6.2 in each chapter provide information on trends in annual and seasonal air temperature and rainfall for the period 1950–2009 where data are available. A time series of annual mean air temperatures and total rainfall is presented for each country. A linear trend is fitted to the data record where more than 80% of the data record is available, and colour-coding is used to show the influence of ENSO: light blue columns indicate El Niño years, dark blue columns are La Niña years and grey columns are neutral years. El Niño and La Niña years are defined using the June-December SOI: a La Niña year is when the June-December SOI is greater than 5; an El Niño year is when December-June SOI is less than -5 (Power and Smith, 2007; Callaghan and Power, 2010). The expected ENSO influence from the climate variability section (X.5) of each chapter may not always be clear in the observed record presented in these sections because: (1) these events often start in the middle of one year and continue into the next; and (2) the impact of ENSO on local rainfall and air temperature is not always simultaneous, i.e. there can be a lag of a few months between ENSO development and impact at some locations.

1.6.3 Extreme Events

This section presents information on the number of tropical cyclones that have passed within 400 km of the capital town or city between the 1969/70 and 2009/10 cyclone seasons for countries in the South Pacific and East Timor. Year-to-year changes in tropical cyclone occurrences are described. These are largely characterised by phases of ENSO. Numbers of tropical cyclones within 400 km of a particular town or city are sourced from the PCCSP's Pacific Tropical Cyclone Data Portal (http://www.bom.gov.au/cyclone/history/tracks/). This Portal contains tropical cyclone best track data for the Southern Hemisphere. Trends in tropical cyclone frequency are not analysed in this publication as the data record in the 1970s is not homogeneous with that from the early 1980s to present day. This is for the most part due to the improvement in satellite coverage over the South Pacific Ocean from the early 1980s (Kuleshov et al., 2010). In addition, on a country scale the interannual variability in the number of tropical cyclones is large. This high variability and no cyclones in some seasons make it impossible at present to identify any long-term trends in cyclone frequency. A graph with annual occurrences and an 11-year running mean is provided to display interannual behaviour of tropical cyclones in the South Pacific and East Timor region.

Other extreme climate and weather events are described where information is available.

1.6.4 Sea-Surface Temperature

This section discusses sea-surface temperature trends between the 1950s and the present. These changes are important as they can affect changes in air temperatures, wind and rainfall and the position of climate features like the SPCZ. They also affect marine ecosystems through, for example, coral bleaching and nutrient supply.

1.6.5 Ocean Acidification

This section discusses changes in aragonite saturation (an indicator of ocean acidification) between the late 18th century and the present. Ocean acidification occurs in response to the continuing uptake of anthropogenic carbon dioxide from the atmosphere by the ocean, causing a decrease in seawater pH (a measure of the acidity or alkalinity level of a solution). The pH changes are accompanied by a decrease in the aragonite saturation state of the seawater. Aragonite is the form of calcium carbonate used by many organisms in reef ecosystems, including reef-building corals, to build their shells and skeletal material. Studies indicate that coral growth rates typically decline as the seawater aragonite saturation state decreases. However, not all coral species show the same response and the long-term adaptive capacity of corals to the changes is unknown. The crustose coralline algae, which precipitate calcium carbonate as high-magnesium calcite and act to cement corals into strong reef structures, may be even more susceptible to ocean acidification (Kuffner et al., 2008). By considering the large-scale distribution of coral reefs through the Pacific and the seawater chemistry, Guinotte et al. (2003) suggested that seawater aragonite saturation states above 4 were optimal for coral growth and for the development of healthy reef ecosystems, with values from 3.5 to 4 adequate for coral growth, and values between 3 and 3.5, marginal. Coral reef ecosystems were not found at seawater aragonite saturation state below 3 and these conditions were classified as extremely marginal for supporting coral growth.

1.6.6 Mean Sea Level

This section provides information on changes in mean sea level measured by historical tide gauge and satellite-mounted altimeters (since 1993) and gridded (reconstructed) sea level (since 1950). Information about tide gauges used is provided in the data availability section of each report.

1.6.7 Extreme Sea-Level Events

This section presents a discussion of extreme sea-level events and how they are related to patterns of variability, tidal variations, interannual sea-level variability and extreme events such as tropical cyclones.

Extreme high sea levels are generally caused by a combination of three components: tides; seasonal or longer-term fluctuations due to changing wind, pressure and ocean temperature patterns (such as ENSO); and short-term events due to weather (such as storm surges). To better understand the relative contributions of these components to extreme sea levels, hourly tide gauge data are used to construct annual climatologies of high water levels (Merrifield et al., 2007). These annual extreme sea-level climatologies provide location-specific insight into the causes of high water levels and indicate times of the year when high sea levels and inundation events are most likely to occur.

The climatologies are constructed by performing a harmonic analysis of the hourly tide gauge data, which gives the tidal constants and allows the tide-only component of the measured sea level to be calculated. From this, the highest daily tide for each day is stored and the 95th percentile tide (exceedence level) is estimated from these values. After removal of tides from the hourly tide gauge data, the seasonal component is calculated by identifying month-to-month changes (using a low-pass filter) in the non-tidal water level. These results indicate the influence of steric (temperature driven) sea-level variability and large scale atmospheric circulation on the sea levels. The short-term (high frequency) component is the remainder of the non-tidal water level, after the seasonal component is removed. The highest short-term level for each year day is stored and the 95th percentile short-term component (exceedence level) is estimated from these values. These components are calculated using all years available in a particular tide gauge record. In addition, seasonal and short-term components are also calculated for El Niño and La Niña events, defined as water levels occurring when the monthly multivariate ENSO index (MEI) is greater than 0.5 or less than -0.5 respectively (Wolter and Timlin, 1998). This allows for better identification of interannual variability in extreme water levels.

The MEI combines six observed variables over the tropical Pacific. These six variables are: sea-level pressure, zonal and meridional components of the surface wind, sea-surface temperature, surface air temperature, and total cloudiness fraction of the sky. The MEI is calculated as the first unrotated principal component of all six observed fields combined (Wolter and Timlin, 1993).

Depending on the length of record for the tide gauge station, these annual climatologies may not accurately capture the likelihood of rare cyclone-related storm surge, and do not capture the likelihood of extremely rare tsunamis (which are not considered to be climate related). Therefore the top 10 extreme water-level events in each tide gauge record are also identified, and their relationship to the annual climatology components is discussed in the individual country reports.

1.7 Climate Projections

Climate projections that are presented for each PCCSP Partner Country were derived using output from global climate model simulations of the future climate, performed as part of the international Coupled Model Intercomparison Project (CMIP3; Volume 1, Section 4.3.1; Meehl et al., 2007a). Projections are given for surface air temperature, sea-surface temperature, rainfall, extreme weather events (including temperature, rainfall, drought and tropical cyclones), ocean acidification and sea level. Substantial and additional analysis of CMIP3 output was undertaken to determine many of these projections (Section 1.7.3).

Important information to consider in interpreting the projections and presentation of the projections (including the confidence levels) are explained in the following sections.

1.7.1 Understanding Climate Model Projections

The following issues need to be considered when interpreting projections from climate models:

- **Model Differences**
  Many research institutions around the world develop and maintain their own global climate model. While these models are based on the same physical laws, there are subtle differences between them associated with grid characteristics (e.g. spatial resolution), the representation of small-scale physical processes, and model sub-components (e.g. some models include a representation of atmospheric chemistry, while others do not (Volume 1, Section 4.3)). As a consequence of these differences, each model projects a slightly different future climate.
- **Model Skill**
  Due to model differences, not all climate models are equally skilful. A rigorous evaluation of the ability of the CMIP3 models to simulate the present western tropical Pacific climate revealed that while it is not possible to identify a single best climate model, it is possible to identify a small subset of models that perform consistently poorly across many aspects of a climate model simulation, or that perform poorly on critical aspects (Volume 1, Chapter 5; Irving et al., in press). These poor performing models were eliminated from the original set of 24 CMIP3 models, leaving 18 acceptable models for use in determining projections for each Partner Country (Volume 1, Section 5.5.1).
  While these remaining 18 models are generally able to capture the broad-scale features of the western tropical Pacific climate, a number of systematic deficiencies exist across the models (Volume 1, Chapter 5). For instance, the South Pacific Convergence Zone is typically

too east-west oriented and the westward extent of the Equatorial Cold Tongue is exaggerated. When a country is located in a region with model deficiencies, less confidence can be placed on model projections.

- **Emissions Scenarios**
  Since it is uncertain how society will evolve over the next century, it is difficult to know exactly how emissions of greenhouse gases and aerosols resulting from human activities will change in the future. To assist in modelling the future climate, the Intergovernmental Panel on Climate Change (IPCC) 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 (Volume 1, Section 4.2; IPCC, 2000). Three of the most widely used scenarios are the B1, A1B and A2, which represent a low, medium and high greenhouse gas emissions future, respectively.
- **Multiple Possible Futures**
  As it is not possible to identify a single 'best' climate model, nor a single scenario that will best approximate the future evolution of greenhouse gas emissions, it is not possible to isolate one single projected future climate. Instead, a range of possible futures exist. In the context of the CMIP3 output analysed in this publication, this range of possibilities spans the futures simulated by all 18 acceptably skilful models for the A2 (high), A1B (medium), and B1 (low) emissions scenarios. Possible futures beyond the range simulated by these models and emissions scenarios may exist, however they represent our best estimate of that range at the present time.
- **Natural Variability**
  When interpreting projected changes in the mean climate it is important to keep in mind that natural climate variability, e.g. the state of ENSO, can cause conditions to vary substantially from the long-term mean from one year to the next. For example, within a warming trend it is still possible to experience cold years, however these would be likely to become less frequent (Figure 1.2).
- **Small-Scale Spatial Variability**
  Global climate models have relatively coarse spatial resolution (100 to 400 km between grid-points) and can therefore only make projections on a broad scale. As a result of island topography and other local features, there may be considerable deviation from these large-scale projections at small scales. This small-scale spatial variability that the global climate models are unable to capture may, in some cases, explain why observed trends at individual meteorological stations can be inconsistent with the large-scale projections provided by the models.

For information on other issues and uncertainties associated with climate model projections, see Volume 1, Box 5.2 and Box 6.1.

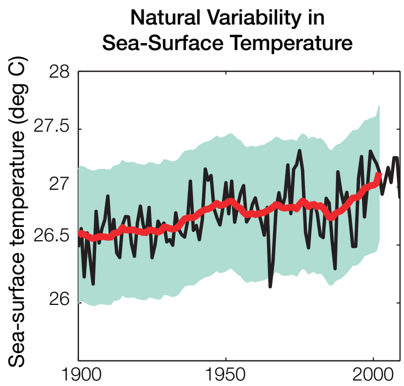

Figure 1.2: Annual mean sea-surface temperature record for an unspecified country. The black line shows the actual values recorded for each year, while the red line is the 20-year running average (i.e. the long-term mean). The deviation of the black line from the red in any given year represents the influence of natural variability. The blue shading is a measure of the interannual variability based on two standard deviations (approximately 95% of the years will fall within this range). It can be seen that the annual mean temperature for any given year can vary substantially from the long term mean.

1.7.2 Presentation of Projections

In order to systematically consider the issues noted in Section 1.7.1, a consistent approach was taken in presenting the projections for each PCCSP Partner Country (Section 1.7.2.1). This approach includes the use of multiple emissions scenarios, downscaling techniques and the assignment of confidence levels:

- **Multiple Emissions Scenarios**
  In general, projections are given for the A2 (high), A1B (medium), and B1 (low) emissions scenarios, for three 20-year time periods centred on 2030, 2055 and 2090 (Figure 1.3).
- **Downscaling**
  Given the fact that global climate models are unable to adequately capture small-scale climate influences, e.g. complex topography, a technique known as dynamical downscaling has been used to enhance the resolution of the CMIP3 output locally (Volume 1, Section 4.5). For this technique, high resolution atmospheric model simulations were conducted, driven by the changes in sea-surface temperature simulated by six of the CMIP3 models. The high resolution model used is the Conformal Cubic Atmospheric Model (CCAM; McGregor and Dix, 2008). It was run at 60 km resolution for all Partner Countries, and at 8 km resolution for seven selected countries. Dynamical downscaling results are only discussed in the presentation of projections for each Partner Country when they highlight small-scale details not present in the global climate model projections. It should be noted that while dynamical downscaling provides more detail at the local level, this does not guarantee increased reliability in representing the future climate (Volume 1, Section 5.3).

- **Confidence Levels**
  The level of confidence associated with a given projection is described as very high, high, moderate, low or very low. The determination of an appropriate confidence level depends upon expert judgement by PCCSP scientists, which takes into account various lines of evidence. These include agreement amongst model simulations (including both the global CMIP3 and dynamical downscaling simulations), model ability in simulating the current climate (including any consistent model biases) and the physical plausibility of the projection (Figure 1.4).

In general, the projections discussed for each Partner Country are not specific to any actual location, such as a town or city. Instead, they refer to an average change over the broad geographic region encompassing the country of interest and the surrounding ocean (Figure 1.1 identifies the regions used for all but the tropical cyclone projections). This is another reason why observed trends at individual meteorological stations may in some cases be different to the projections provided in this publication. Four countries were divided into sub-regions (Cook Islands, Federated States of Micronesia, Kiribati and Marshall Islands) due to the differing influences of large-scale climate features across the country. It should be noted that many research institutions participating in CMIP3 did not provide output for all the model variables and future emissions scenarios requested by the project organisers. As such, the actual number of models used differed between projections (Volume 1, Appendix 1).

1.7.2.1 Approach to Presenting the Projections

The following approach was adopted for projections of each climate variable (surface air temperature, sea-surface temperature, rainfall, extreme weather events, ocean acidification and sea level):

- **Projected Direction of Change**
  Each section begins with a statement of whether the climate variable in question is projected to increase, decrease or show little change over the course of the 21st century. This projected direction of change was determined by considering how projections from the CMIP3 models progress over the next century, for each of the three emissions scenarios. For instance, if 12 models simulate a progressive increase in wet season rainfall and six simulate a decrease for each of the three scenarios, the statement would say that wet season rainfall is projected to increase over the course of the 21st century, i.e. the statement represents the most likely climate future. The statement is followed by a quoted confidence level, which is supported by one or more dot points. Based on multiple lines of evidence (Figure 1.5), this level indicates the confidence PCCSP scientists have in the ability of the models to capture the true most likely direction of change.

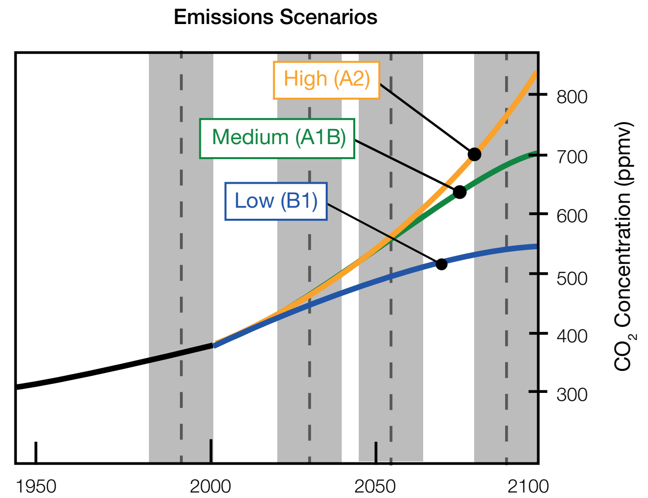

Figure 1.3: Projections in this publication are based on three emissions scenarios: B1 (low), A1B (medium) and A2 (high). The carbon dioxide (CO_2) concentrations projected for each scenario are shown as blue, green and orange lines, respectively. Projections for 2030, 2055 and 2090 (relative to 1990) were calculated using the average value of the 20-year periods 2020–2039, 2046–2065, 2080–2099 (relative to 1980–1999) to minimise the effect of natural variability. The grey bars represent the 20-year periods.

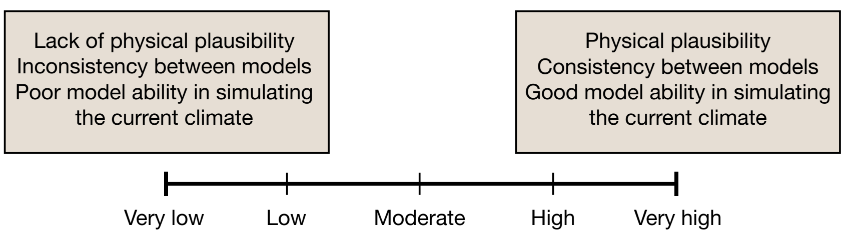

Figure 1.4: Lines of evidence and consequent labels used in describing the confidence associated with climate projections.

- **Range and Distribution of Projections**
  A detailed description of the range and distribution of projections across all three time periods and emissions scenarios is provided next. For instance, the models may simulate little change in annual rainfall by 2030, however by 2090 under the A1B (medium) and A2 (high) emissions scenarios, two-thirds of the models may simulate an increase (>5%) in annual rainfall, while one-third may simulate a decrease (< -5%). The description of the range and distribution of possible futures is followed by a quoted confidence level, which is supported by one or more dot points. Based on multiple lines of evidence (Figure 1.4), this level indicates the confidence PCCSP scientists have in the ability of the models to capture the true range of possible futures.
  It should be noted that the confidence associated with the range and distribution of possible futures need not necessarily be the same as that for the projected direction of change. For instance, if expert judgement suggests that an increase in wet season rainfall is most likely, confidence in a model projected increase in the direction of change might be high. However, if the models are known to systematically underestimate rainfall in the country of interest, then the confidence in the range of the projections might be low.
- **Additional Information**
  At the end of each section, additional information such as projected small-scale changes from dynamical downscaling or possible changes in interannual variability is discussed.

1.7.3 Detailed Projection Methods

For a number of climate variables, substantial analysis of CMIP3 and/or dynamically downscaled output was required to produce climate projections. Important features of these analyses are discussed in the following sections, while a more detailed account is available in Volume 1, Chapter 4.

1.7.3.1 Extreme Daily Temperature and Rainfall

Projected changes in days of extreme temperature and rainfall were made relative to the event that occurs on average once every 20 years. This 1-in-20-year event was calculated using the using the Generalised Extreme Value distribution (Volume 1, Section 6.2.7; Coles et al., 2001; Kharin et al., 2005). In general, two types of projection are given:

- The change in the magnitude of the 1-in-20-year event. For instance, in a warming climate the temperature experienced on the 1-in-20-year hot day may increase by 2°C by 2055 (i.e. 2046–2065), relative to 1990 (i.e. 1980–1999).
- The change in the frequency of the present day 1-in-20-year event. For instance, in a climate of increasing rainfall the current (i.e. 1980–1999) 1-in-20-year daily rainfall total may be projected to be exceeded once every three years by 2090 (i.e. 2080–2099).

1.7.3.2 Drought

Projected changes in the frequency of mild, moderate and severe drought were made using the Standardised Precipitation Index (SPI; Volume 1, Section 6.2.7.3; Lloyd-Hughes and Saunders, 2002). It should be noted that this index is based solely on rainfall (i.e. extended periods of low rainfall are classified as a drought) and does not take into account factors such as evaporation or soil moisture content.

1.7.3.3 Tropical Cyclones

Three separate methods were used to determine projections of tropical cyclone activity, known as the Genesis Potential Index (GPI), Curvature Vorticity Parameter (CVP) and the CSIRO Direct Detection Scheme (CDD) (Volume 1, Section 4.8). All were applied to CMIP3 output, while the latter was also applied to the CCAM 60 km resolution output.

Projections of changes in the statistics of tropical cyclone behaviour, especially at the individual country scale, are subject to greater uncertainty than projections of more uniform atmospheric properties such as temperature. This is because tropical cyclones are relatively compact weather systems that are not well represented in global climate models. Furthermore, global climate models show limited agreement on detailed aspects of atmospheric structure, such as the vertical wind shear and vorticity across the monsoon trough, which are both important determinants for tropical cyclone development and motion. Due to this uncertainty, the PCCSP region is divided into three sub-basins (Table 1.2). In addition, the region 0–20ºS, 100ºE–130ºE has been used for East Timor tropical cyclone projections.

1.7.3.4 Ocean Acidification

Projected changes in aragonite saturation state were calculated using empirical relationships between ocean carbonate chemistry and salinity, projections of ocean temperature and salinity from the CMIP3 models, and predicted changes in atmospheric carbon dioxide (Volume 1, Section 4.9). This information was used as input to an offline carbonate chemistry model. Particular reference is made to when aragonite saturation levels are first projected to fall below 3.5, since values below 3.5 are considered to be increasingly marginal for supporting healthy coral reef growth (Volume 1, Section 3.6.5; Guinotte et al., 2003).

1.7.3.5 Sea Level

Sea-level projections include estimates of ocean thermal expansion, melting of glaciers and ice caps, modelled ice-sheet contributions and an allowance for the estimated contribution from the potential rapid ice-sheet response (Volume 1, Section 4.7; Meehl et al., 2007b). The possibility of larger rates of rise than those projected in this publication cannot be excluded, but adequate understanding of the relevant physical processes is currently too limited to provide a best estimate or an upper bound (IPCC, 2007). To estimate regional sea-level changes, changes in ocean circulation and the associated sea levels, and the redistribution of mass due to changes in ice sheets, glaciers and ice caps have also been taken into account (Volume 1, Section 4.7; Church et al., 2011). The projected changes in sea level are relative to the land, except for local issues such as sediment compaction. In addition to the regional variations in sea level associated with ocean and mass changes, there are ongoing changes in relative sea level associated with changes in surface loading over the last glacial cycle (glacial isostatic adjustment) and local tectonic motions. The glacial isostatic motions are relatively small for the PCCSP region.

Table 1.2: Division of the PCCSP region for tropical cyclone projections

South-east basin 0–40°S, 170°E–130°W	South-west basin 0–40°S, 130°E–170°E	Northern basin 0–15°N, 130°E–180°E
Cook Islands	Papua New Guinea	Federated States of Micronesia
Fiji	Solomon Islands	Marshall Islands
Niue	Vanuatu	Palau
Samoa		
Tonga		
Tuvalu		

1.7.6 Projection Summaries

A summary table of projections is included at the end of each chapter. In some cases there are two tables for different country regions and imperial units are included for the Federated States of Micronesia, the Marshall Islands and Palau.