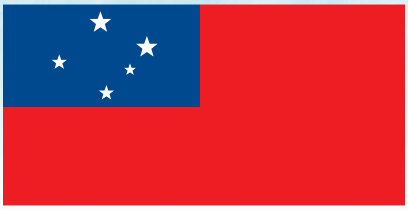

Upolu

Chapter 12
Samoa

The contributions of Fata Lagomauitumua, Sunny K. Seuseu and Tumau Faasaoina from the Samoa Meteorology Division, Ministry of Natural Resources and Environment are gratefully acknowledged

Introduction

This chapter provides a brief description of Samoa, its past and present climate as well as projections for the future. The climate observation network and the availability of atmospheric and oceanic data records are outlined. The annual mean climate, seasonal cycles and the influences of large-scale climate features such as the South Pacific Convergence Zone and patterns of climate variability (e.g. the El Niño-Southern Oscillation) are analysed and discussed. Observed trends and analysis of air temperature, rainfall, extreme events (including tropical cyclones), sea-surface temperature, ocean acidification, mean and extreme sea levels are presented. Projections for air and sea-surface temperature, rainfall, sea level, ocean acidification and extreme events for the 21st century are provided. These projections are presented along with confidence levels based on expert judgement by Pacific Climate Change Science Program (PCCSP) scientists. The chapter concludes with a summary table of projections (Table 12.4). Important background information, including an explanation of methods and models, is provided in Chapter 1. For definitions of other terms refer to the Glossary.

12.1 Climate Summary

12.1.1 Current Climate

- Seasonal temperature differences in Samoa are very small.
- The wet season extends from November to April. Rainfall is greatly influenced by the position and strength of the South Pacific Convergence Zone, which lies between Samoa and Fiji during the wet season.
- There is significant year-to-year variability in rainfall, which is strongly influenced by the El Niño-Southern Oscillation. The impact of the El Niño-Southern Oscillation is more significant in the wet season.
- Positive trends are evident in both annual and seasonal mean air temperatures at Apia for the period 1950–2009.
- Annual and seasonal rainfall trends for Apia for the period 1950–2009 are not statistically significant.
- On average Apia experiences 10 tropical cyclones per decade, usually between November and April. The high variability in tropical cyclone numbers makes it difficult to identify any long-term trends in frequency.
- Droughts and flooding associated with the El Niño-Southern Oscillation have impacted the social and economic livelihoods of the Samoan people on many occasions in the past.
- The sea-level rise near Samoa measured by satellite altimeters since 1993 is about 4 mm per year.

12.1.2 Future Climate

Over the course of the 21st century:

- Surface air temperature and sea-surface temperature are projected to continue to increase (*very high* confidence).
- Wet season and annual mean rainfall is projected to increase (*moderate* confidence).
- Little change is projected in dry season rainfall (*low* confidence).
- The intensity and frequency of days of extreme heat are projected to increase (*very high* confidence).
- The intensity and frequency of days of extreme rainfall are projected to increase (*high* confidence).
- Little change is projected in the incidence of drought (*low* confidence).
- Tropical cyclone numbers are projected to decline in the south-east Pacific Ocean basin (0–40ºS, 170ºE–130ºW) (*moderate* confidence).
- Ocean acidification is projected to continue (*very high* confidence).
- Mean sea-level rise is projected to continue (*very high* confidence).

12.2 Country Description

Samoa consists of four main inhabited islands (Upolu, Savai'i, Manono and Apolima) and six smaller uninhabited islands. The islands lie between 13ºS–14ºS and 170ºW–173ºW and have a total land area of approximately 2934 km^2 (Samoa's First National Communication under the UNFCCC, 2000). Samoa has a rugged and mountainous topography. On Upolu, the central mountain range runs along the length of the island with some peaks rising more than 1000 m above sea level. Savai'i has central volcanic peaks reaching 1860 m (Samoa Country Profile, SOPAC, 2000).

Samoa's 2010 estimated population was 183 123 (Samoa Country Statistics, SOPAC, 2011). More than half of Samoa's resident population live on the island of Upolu, also home to the capital, Apia.

Agriculture and fisheries products have traditionally provided the bulk of Samoa's commodity exports including coconut oil, coconut cream, bananas, taro, kava and fish. Tourism also contributes significantly to Samoa's economy (Samoa's Second National Communication under the UNFCCC, 2010).

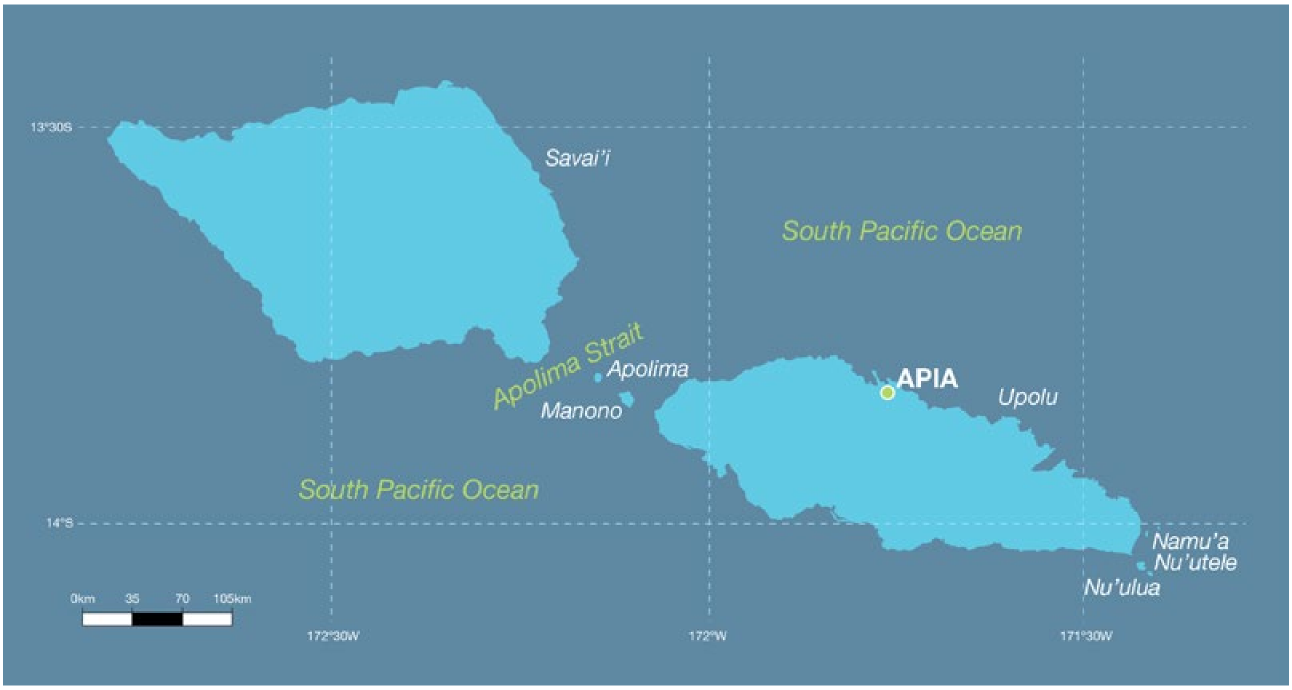

Figure 12.1: Samoa

12.3 Data Availability

There are eight operational meteorological stations in Samoa. The primary meteorological station is located in Apia (Figure 12.1). Apia has rainfall and air temperature data from 1890. Apia, Faleolo and Maota stations take multiple observations within a 24-hour period. The other stations (Afiamalu, Nafanua, Alafua, Togitogiga on Upolu and Asau on Savaii) record rainfall once a day only.

Climate records for Apia from 1950–2009 have been used. The Apia records are homogeneous and more than 98% complete.

Monthly-averaged sea-level data are available from Pago Pago (1948–present, American Samoa) and Apia (1954–1971 and 1993–present). A global positioning system instrument to estimate vertical land motion was deployed at Apia in 2001 and will provide valuable direct estimates of local vertical land motion in future years. Both satellite (from 1993) and in situ sea-level data (1950–2009; termed reconstructed sea level; Volume 1, Section 2.2.2.2) are available on a global 1° x 1° grid.

Long-term locally-monitored sea-surface temperature data are unavailable for Samoa, so large-scale gridded sea-surface temperature datasets have been used (HadISST, HadSST2, ERSST and Kaplan Extended SST V2; Volume 1, Table 2.3).

12.4 Seasonal Cycles

There are only very small seasonal temperature differences in Samoa (Figure 12.2). The coolest month of the year is July. This is also when relatively cool, dry south-east trade winds are strongest. The warmest month is March, which is about 1˚C warmer than July.

Rainfall has a distinct seasonal variation in Samoa. On average 75% of total annual rainfall is received in the wet season, from November to April (Figure 12.2). Average wet season rainfall amounts to approximately 350 mm per month. On average rainfall is about 150 mm per month in the dry season. Samoa's rainfall is greatly influenced by the position and strength of the South Pacific Convergence Zone (SPCZ), which lies between Samoa and Fiji during the wet season. In the dry season the SPCZ is normally to the north-east of Samoa, often weak, inactive and sometimes non-existent. The close proximity of the SPCZ to Samoa during summer results in heavy rainfall throughout the country. Samoa's topography has a significant effect on rainfall distribution. Wet areas are located in the south-east and relatively sheltered, drier areas are in the north-west.

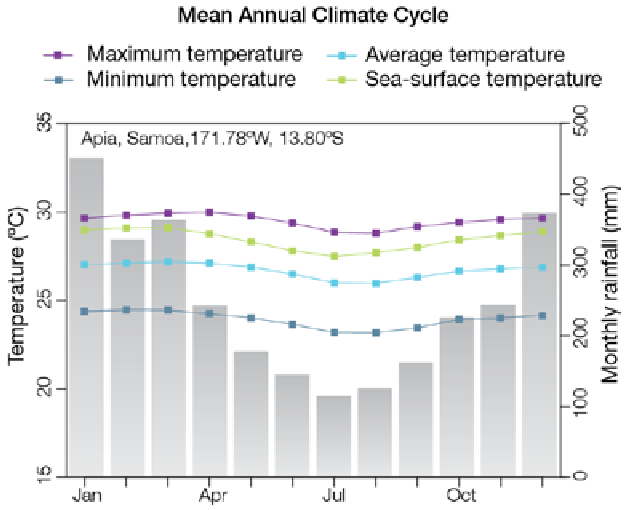

Figure 12.2: Mean annual cycle of rainfall (grey bars) and daily maximum, minimum and mean air temperatures at Apia, and local sea-surface temperatures derived from the HadISST dataset (Volume 1, Table 2.3).

12.5 Climate Variability

There is significant year-to-year variability in rainfall observed in Samoa (Figure 12.4). Annual rainfall in the drier years can be approximately half of that observed in wettest years. This year-to-year variability is strongly influenced by the El Niño-Southern Oscillation (ENSO). The impact of ENSO is more significant in the wet season (Table 12.1). El Niño events tend to bring drier conditions in the wet season due to the SPCZ becoming less active. In La Niña years, rainfall is usually above normal and air temperatures are cooler than normal. ENSO Modoki events (Volume1, Section 3.4.1) have the same impacts but weaker. There is a weaker but still significant correlation between canonical ENSO and ENSO Modoki and dry season rainfall.

A negative correlation exists between the Interdecadal Pacific Oscillation (IPO) and dry season rainfall. This suggests that the El Niño-like pattern of decadal variability that exists in a positive phase of the IPO produces a similar reduction in rainfall as El Niño events, but on longer time periods.

Table 12.1: Correlation coefficients between indices of key large-scale patterns of climate variability and minimum and maximum temperatures (Tmin and Tmax) and rainfall at Apia. Only correlation coefficients that are statistically significant at the 95% level are shown.

Climate feature/index		Dry season (May-October)			Wet season (November-April)		
		Tmin	Tmax	Rain	Tmin	Tmax	Rain
ENSO	Niño3.4			-0.38	0.67	0.68	-0.46
	Southern Oscillation Index		-0.24	0.30	-0.56	-0.65	0.54
Interdecadal Pacific Oscillation Index				-0.23			
Southern Annular Mode Index							
ENSO Modoki Index		0.30	0.29		0.60	0.59	-0.20
Number of years of data		78	75	108	78	77	108

Weather station, Samoa Meterology Division

12.6 Observed Trends

12.6.1 Air Temperature

Positive trends are evident in both annual and seasonal mean air temperatures at Apia for the period 1950–2009. Maximum air temperature trends are considerably greater than minimum air temperature trends. In the wet season, maximum air temperature trends are greater than the trends in the dry season (Figure 12.3 and Table 12.2).

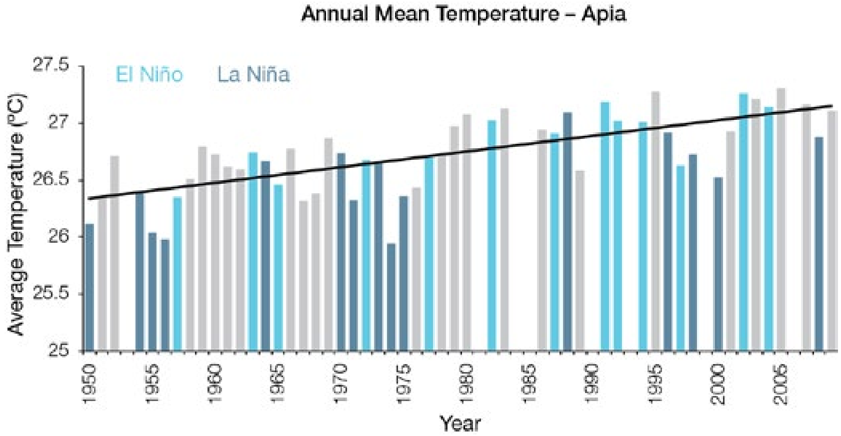

Figure 12.3: Annual mean air temperature at Apia. Light blue, dark blue and grey bars denote El Niño, La Niña and neutral years respectively

12.6.2 Rainfall

Annual and seasonal rainfall trends for Apia for the period 1950–2009 are not statistically significant (Table 12.2 and Figure 12.4).

Table 12.2: Annual and seasonal trends in maximum, minimum and mean air temperature (Tmax, Tmin and Tmean) and rainfall at Apia for the period 1950–2009. Asterisks indicate significance at the 95% level. Persistence is taken into account in the assessment of significance as in Power and Kociuba (in press). The statistical significance of the air temperature trends is not assessed.

	Apia Tmax (°C per 10 yrs)	Apia Tmin (°C per 10 yrs)	Apia Tmean (°C per 10 yrs)	Apia Rain (mm per 10 yrs)
Annual	+0.22	+0.04	+0.14	+8
Wet season	+0.24	+0.04	+0.14	+22
Dry season	+0.18	+0.04	+0.11	0

12.6.3 Extreme Events

The tropical cyclone season in the Samoa region is between November and April. Between 1969/70 and 2009/10 only Tropical Cyclone Keli occurred outside these months in June 1997. The tropical cyclone archive for the Southern Hemisphere indicates that between the 1969/1970 and 2009/10 seasons, the centre of 52 tropical cyclones passed within approximately 400 km of Apia. This represents an average of 10 cyclones per decade. Tropical cyclones were most frequent in El Niño years (16 cyclones per season) and occurrences in La Niña and neutral years are less frequent (10 cyclones per decade). The interannual variability in the number of tropical cyclones in the vicinity of Apia is large, ranging from zero in some seasons to five in the 1980/81 and 2004/05 seasons (Figure 12.5). This high variability makes it difficult to identify any long-term trends in frequency.

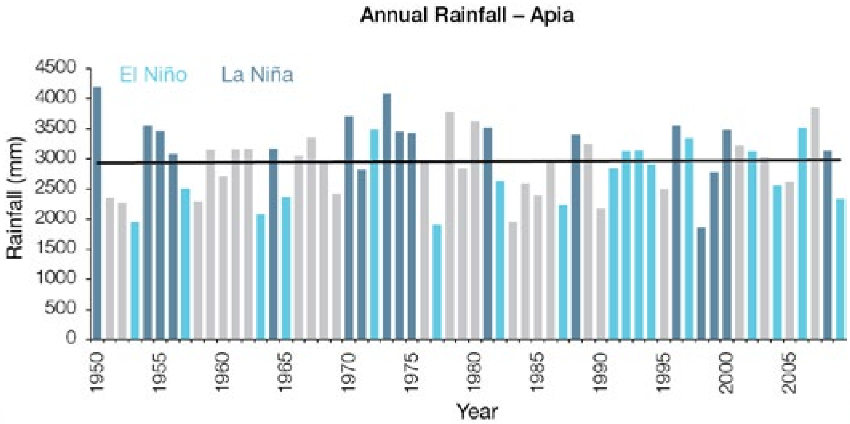

Figure 12.4: Annual rainfall at Apia. Light blue, dark blue and grey bars denote El Niño, La Niña and neutral years respectively

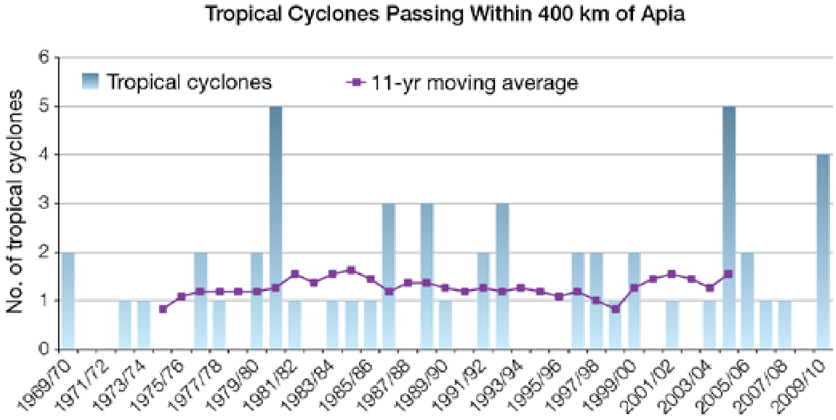

Figure 12.5: Tropical cyclones passing within 400 km of Apia per season. The 11-year moving average is in purple.

Tropical Cyclone Ofa (1990) and Tropical Cyclone Val (1991) caused widespread damage in Samoa, which has been estimated to equal approximately four times the national Gross Domestic Product.

Droughts and flooding associated with ENSO have impacted the social and economic livelihoods of the Samoan people on many occasions in the past. Drought impacts are most notable in the north-west regions of the main islands (Faleolo and Asau) and at times are associated with forest fires. In Asau, there were major forest fires during the dry seasons of 1982/83, 1997/98, 2001/02 and 2002/03.

Flooding associated with tropical cyclones and strong La Niña events has caused widespread damage in Samoa in the past. In early 2008 and 2011, for example, transportation and water infrastructure were severely damaged.

12.6.4 Sea-Surface Temperature

Water temperatures around Samoa declined from the 1950s to about 1980. This was followed by a period of warming (approximately 0.08°C per decade for 1970–present). Figure 12.8 shows the 1950–2000 sea-surface temperature changes (relative to a reference year of 1990) from three different large-scale sea-surface temperature gridded datasets (HadSST2, ERSST and Kaplan Extended SST V2; Volume 1, Table 2.3). At these regional scales, natural variability may play a large role determining sea-surface temperature in the region making it difficult to identify any long-term trends.

12.6.5 Ocean Acidification

Based on the large-scale distribution of coral reefs across 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 states below 3 and these conditions were classified as extremely marginal for supporting coral growth.

In the Samoa region, the aragonite saturation state has declined from about 4.5 in the late 18th century to an observed value of about 4.1 ± 0.1 by 2000.

12.6.6 Sea Level

Monthly averages of the historical tide gauge, satellite (since 1993) and gridded sea-level (since 1950) data agree well after 1993 and indicate interannual variability in sea levels of about 20 cm (estimated 5–95% range) after removal of the seasonal cycle (Figure 12.10). The sea-level rise near Samoa measured by satellite altimeters (Figure 12.6) since 1993 is about 4 mm per year, slightly larger than the global average of 3.2 ± 0.4 mm per year. This rise is partly linked to a pattern related to climate variability from year to year and decade to decade (Figure 12.10).

12.6.7 Extreme Sea-Level Events

The annual climatology of the highest daily sea levels has been evaluated from hourly measurements by the tide gauge at Apia (Figure 12.7). High tides show a small variation throughout the year with an April to May minimum and a July to August maximum. There is no seasonal cycle in the long-term variations in sea level, although during La Niña years sea levels tend to be higher from January to June and during El Niño they tend to be lower from February to September (Volume 1, Section 3.6.3, and Figures 3.20 and 3.21). Short-term variations are slightly higher in December through March. When the tidal, short-term and long-term components are combined, they produce an annual cycle which shows relatively little variation throughout the year. The 10 events in the sea-level record tend occur at different times of the year, however all 10 events occur in either La Niña or ENSO-neutral years.

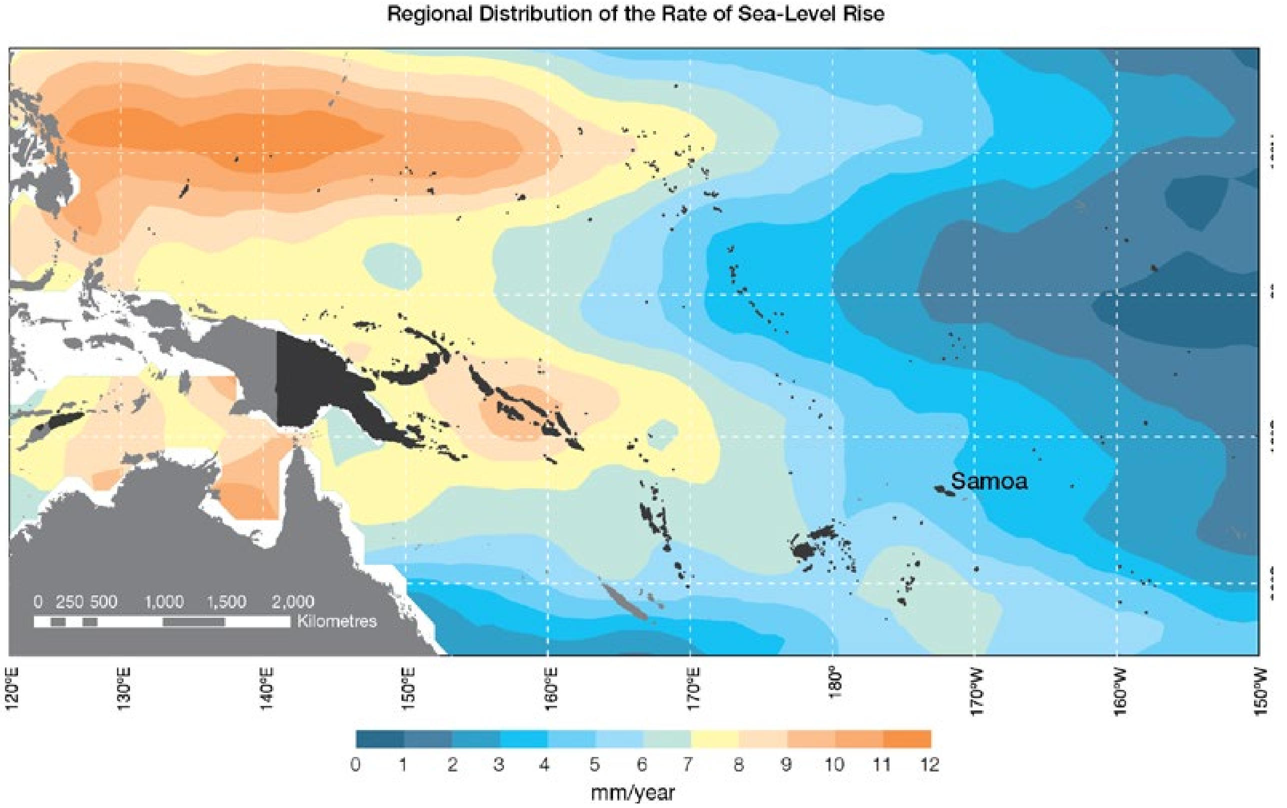

Figure 12.6: The regional distribution of the rate of sea-level rise measured by satellite altimeters from January 1993 to December 2010, with the location of Samoa indicated. Further detail about the regional distribution of sea-level rise is provided in Volume 1, Section 3.6.3.2.

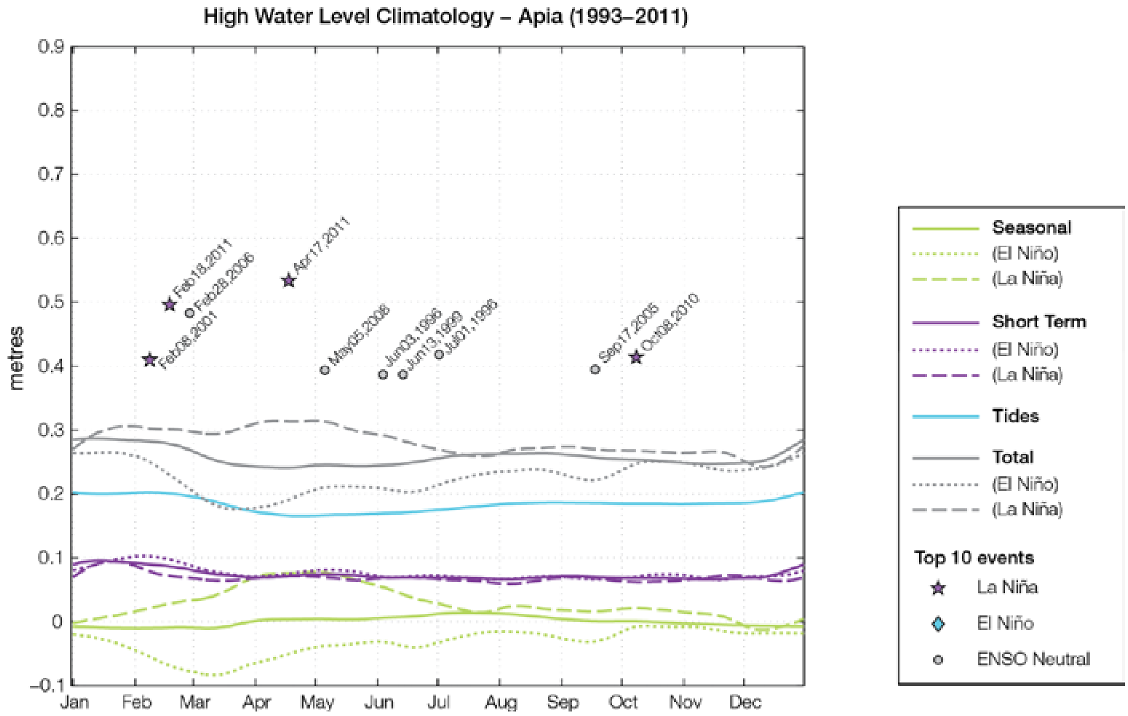

Figure 12.7: The annual cycle of high waters relative to Mean Higher High Water (MHHW) due to tides, short-term fluctuations (most likely associated with storms) and seasonal variations for Apia. The tides and short-term fluctuations are respectively the 95% exceedence levels of the astronomical high tides relative to MHHW and short-term sea level fluctuations. Components computed only for El Niño and La Niña years are shown by dotted and dashed lines, and grey lines are the sum of the tide, short-term and seasonal components. The 10 highest sea level events in the record relative to MHHW are shown and coded to indicate the phase of ENSO at the time of the extreme event.

12.7 Climate Projections

Climate projections have been derived from up to 18 global climate models from the CMIP3 database, for up to three emissions scenarios (B1 (low), A1B (medium) and A2 (high)) and three 20-year periods (centred on 2030, 2055 and 2090, relative to 1990). These models were selected based on their ability to reproduce important features of the current climate (Volume 1, Section 5.2.3), so projections from each of the models are plausible representations of the future climate. This means there is not one single projected future for Samoa, but rather a range of possible futures. The full range of these futures is discussed in the following sections.

These projections do not represent a value specific to any actual location, such as a town or city in Samoa. Instead, they refer to an average change over the broad geographic region encompassing the islands of Samoa and the surrounding ocean (Figure 1.1 shows the regional boundaries). Some information regarding dynamical downscaling simulations from the CCAM model (Section 1.7.2) is also provided, in order to indicate how changes in the climate on an individual island-scale may differ from the broad-scale average.

Section 1.7 provides important information about understanding climate model projections.

12.7.1 Temperature

Surface air temperature and sea-surface temperature is projected to continue to increase over the course of the 21st century. There is *very high* confidence in this direction of change because:

- Warming is physically consistent with rising greenhouse gas concentrations.
- All CMIP3 models agree on this direction of change.

Almost all of the CMIP3 models simulate a slight increase (<1°C) in annual and seasonal mean temperature by 2030, however by 2090 under the A2 (high) emissions scenario temperature increases of greater than 2.5°C are simulated by the majority of models (Table 12.3). Given the close relationship between surface air temperature and sea-surface temperature, a similar (or slightly weaker) rate of warming is projected for the surface ocean (Figure 12.8). There is *moderate* confidence in this range and distribution of possible futures because:

- There is generally a large discrepancy between modelled and observed temperature trends over the past 50 years in the vicinity of Samoa (Figure 12.8).

The 8 km CCAM simulations suggest that projected changes in the average daily minimum air temperature over land can be up to 0.5°C greater than over the surrounding ocean. This suggests that the CMIP3 models may slightly underestimate future increases in daily minimum air temperature.

Interannual variability in surface air temperature and sea-surface temperature over Samoa is strongly influenced by ENSO in the current climate (Section 12.5). As there is no consistency in projections of future ENSO activity (Volume 1, Section 6.4.1) it is not possible to determine whether interannual variability in temperature will change in the future. However, ENSO is expected to continue to be an important source of variability for the region.

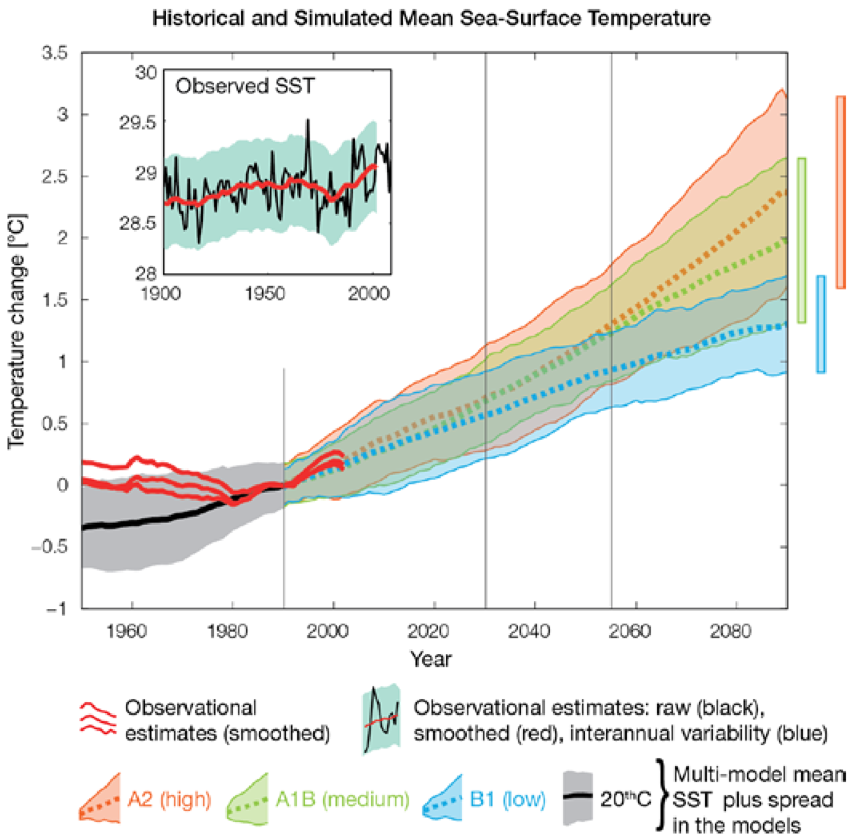

Figure 12.8: Historical climate (from 1950 onwards) and simulated historical and future climate for annual mean sea-surface temperature (SST) in the region surrounding Samoa, for the CMIP3 models. Shading represents approximately 95% of the range of model projections (twice the inter-model standard deviation), while the solid lines represent the smoothed (20-year running average) multi-model mean temperature. Projections are calculated relative to the 1980–1999 period (which is why there is a decline in the inter-model standard deviation around 1990). Observational estimates in the main figure (red lines) are derived from the HadSST2, ERSST and Kaplan Extended SST V2 datasets (Volume 1, Section 2.2.2). Annual average (black) and 20-year running average (red) HadSST2 data is also shown inset.

12.7.2 Rainfall

Wet Season (November-April)

Wet season rainfall is projected to increase over the course of the 21st century. There is *moderate* confidence in this direction of change because:

- An increase in wet season rainfall is consistent with the projected likely increase in the intensity of the South Pacific Convergence Zone (SPCZ) which lies over Samoa in this season (Volume 1, Section 6.4.5).
- The majority of CMIP3 models agree on this direction of change by 2090.

The majority of CMIP3 models simulate little change (-5% to 5%) in wet season rainfall by 2030, however by 2090 under the higher emissions scenarios (i.e. A2 (high) and A1B (medium)) the majority simulate an increase (>5%), with very few models simulating decline (< -5%) (Table 12.3). There is *moderate* confidence in this range and distribution of possible futures because:

- In simulations of the current climate, the CMIP3 models generally locate the SPCZ in the correct location relative to Samoa in the wet season (Brown et al., 2011).
- The CMIP3 models are unable to resolve many of the physical processes involved in producing rainfall. As a consequence, they do not simulate rainfall as well as other variables such as temperature (Volume 1, Chapter 5).

The 8 km CCAM simulations suggest that any changes in wet season rainfall will be relatively uniform across Samoa, with no significant topographic differences indicated between the eastern and western sides of Savai'i or Upolu.

Dry Season (May-October)

Little change is projected in dry season rainfall over the course of the 21st century. There is *low* confidence in this direction of change because:

- There is little agreement amongst the models, with approximately equal numbers simulating an increase (>5%), decrease (<-5%) and little change (-5% to 5%) by 2090 across the three emissions scenarios.
- In simulations of the current climate, some CMIP3 models have an SPCZ that extends too far east during the dry season, with too much rainfall over Samoa (Brown et al., 2011).
- The CMIP3 models are unable to resolve many of the physical processes involved in producing rainfall.

The 8 km CCAM simulations suggest that any changes in dry season rainfall will be enhanced on the eastern side of Savai'i and Upolu. This is a physically consistent response on the windward side of mountainous islands.

Annual

Total annual rainfall is projected to increase over the course of the 21st century. There is *moderate* confidence in this direction of change because:

- Approximately half of the CMIP3 models agree on this direction of change by 2090.
- There is moderate and low confidence in wet and dry season rainfall projections respectively, as discussed above.

Interannual variability in rainfall over Samoa is strongly influenced by ENSO in the current climate, via the movement of the SPCZ (Section 12.5). As there is no consistency in projections of future ENSO activity (Volume 1, Section 6.4.1), it is not possible to determine whether interannual variability in rainfall will change in the future.

12.7.3 Extremes

Temperature

The intensity and frequency of days of extreme heat are projected to increase over the course of the 21st century. There is *very high* confidence in this direction of change because:

- An increase in the intensity and frequency of days of extreme heat is physically consistent with rising greenhouse gas concentrations.
- All CMIP3 models agree on the direction of change for both intensity and frequency.

The majority of CMIP3 models simulate an increase of approximately 1°C in the temperature experienced on the 1-in-20-year hot day by 2055 under the B1 (low) emissions scenario, with an increase of over 2.5°C simulated by the majority of models by 2090 under the A2 (high) emissions scenario (Table 12.3). There is *low* confidence in this range and distribution of possible futures because:

- In simulations of the current climate, the CMIP3 models tend to underestimate the intensity and frequency of days of extreme heat (Volume 1, Section 5.2.4).
- Smaller increases in the frequency of days of extreme heat are projected by the CCAM 60 km simulations.

Rainfall

The intensity and frequency of days of extreme rainfall is projected to increase over the course of the 21st century. There is *high* confidence in this direction of change because:

- An increase in the frequency and intensity of extreme rainfall is consistent with larger-scale projections, based on the physical argument that the atmosphere is able to hold more water vapour in a warmer climate (Allen and Ingram, 2002; IPCC, 2007). It is also consistent with the projected likely increase in SPCZ intensity (Volume 1, Section 6.4.5).

- Almost all of the CMIP3 models agree on this direction of change for both intensity and frequency.

The majority of CMIP3 models simulate an increase of at least 20 mm in the amount of rain received on the 1-in-20-year wet day by 2055 under the B1 (low) emissions scenario, with an increase of at least 25 mm simulated by 2090 under the A2 (high) emissions scenario. The majority of models project that the current 1-in-20-year extreme rainfall event will occur, on average, four times per 20-year period by 2055 under the B1 (low) emissions scenario and three times per 20-year period by 2090 under the A2 (high) emissions scenario. There is *low* confidence in this range and distribution of possible futures because:

- In simulations of the current climate, the CMIP3 models tend to underestimate the intensity and frequency of extreme rainfall (Volume 1, Section 5.2.4).
- The CMIP3 models are unable to resolve many of the physical processes involved in producing extreme rainfall.

Drought

Little change is projected in the incidence of drought over the course of the 21st century. There is *low* confidence in this direction of change because:

- There is only low confidence in the range of dry season rainfall projections (Section 12.7.2), which directly influences projections of future drought conditions.

The majority of CMIP3 models project that mild drought will occur approximately seven to eight times every 20 years in 2030 under all emissions scenarios, decreasing to six to seven times by 2090. The frequency of moderate and severe drought is projected to remain approximately stable, at once to twice and once every 20 years, respectively.

Tropical Cyclones

Tropical cyclone numbers are projected to decline in the south-east Pacific Ocean basin (0–40ºS, 170ºE–130ºW) over the course of the 21st century. There is *moderate* confidence in this direction of change because:

- Many studies suggest a decline in tropical cyclone frequency globally (Knutson et al., 2010).
- Tropical cyclone numbers decline in the south-east Pacific Ocean in the majority assessment techniques.

Based on the direct detection methodologies (Curvature Vorticity Parameter (CVP) and the CSIRO Direct Detection Scheme (CDD) described in Volume 1, Section 4.8.2), 65% of projections show no change or a decrease in tropical cyclone formation when applied to the CMIP3 climate models for which suitable output is available. When these techniques are applied to CCAM, 100% of projections show a decrease in tropical cyclone formation. In addition, the Genesis Potential Index (GPI) empirical technique suggests that conditions for tropical cyclone formation will become less favourable in the south-east Pacific Ocean basin, for all analysed CMIP3 models. There is *moderate* confidence in this range and distribution of possible futures because in simulations of the current climate, the CVP, CDD and GPI methods capture the frequency of tropical cyclone activity reasonably well (Volume 1, Section 5.4).

Despite this projected reduction in total cyclone numbers, five of the six CCAM 60 km simulations show an increase in the proportion of the most severe cyclones. Most models also indicate a reduction in tropical cyclone wind hazard north of 20ºS latitude and regions of increased hazard south of 20ºS latitude. This increase in wind hazard coincides with a poleward shift in the latitude at which tropical cyclones are most intense.

12.7.4 Ocean Acidification

The acidification of the ocean will continue to increase over the course of the 21st century. There is *very high* confidence in this projection as the rate of ocean acidification is driven primarily by the increasing oceanic uptake of carbon dioxide, in response to rising atmospheric carbon dioxide concentrations.

Projections from all analysed CMIP3 models indicate that the annual maximum aragonite saturation state will reach values below 3.5 by about 2060 and continue to decline thereafter (Figure 12.9; Table 12.3). There is *moderate* confidence in this range and distribution of possible futures because the projections are based on climate models without an explicit representation of the carbon cycle and with relatively low resolution and known regional biases.

The impact of acidification change on the health of reef ecosystems is likely to be compounded by other stressors including coral bleaching, storm damage and fishing pressure.

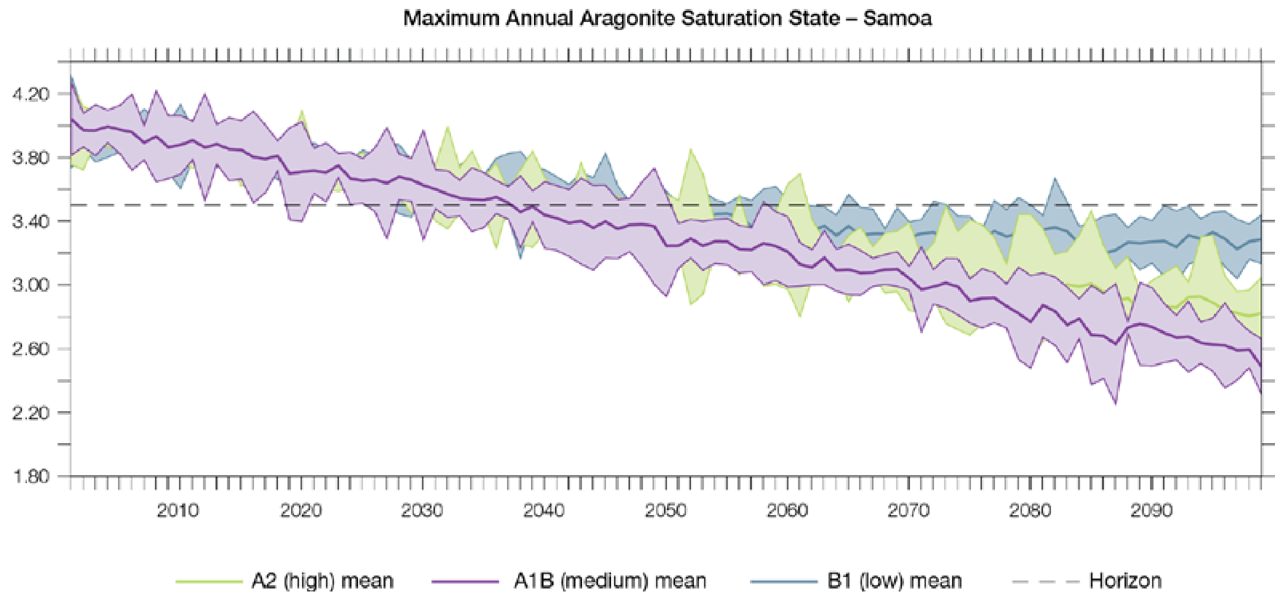

Figure 12.9: Multi-model projections, and their associated uncertainty (shaded area represents two standard deviations), of the maximum annual aragonite saturation state in the sea surface waters of the Samoa region under the different emissions scenarios. The dashed black line represents an aragonite saturation state of 3.5.

12.7.5 Sea Level

Mean sea level is projected to continue to rise over the course of the 21st century. There is *very high* confidence in this direction of change because:

- Sea-level rise is a physically consistent response to increasing ocean and atmospheric temperatures, due to thermal expansion of the water and the melting of glaciers and ice caps.
- Projections arising from all CMIP3 models agree on this direction of change.

The CMIP3 models simulate a rise of between approximately 5–15 cm by 2030, with increases of 20–60 cm indicated by 2090 under the higher emissions scenarios (i.e. A2 (high) and A1B (medium); Figure 12.10; Table 12.3). There is *moderate* confidence in this range and distribution of possible futures because:

- There is significant uncertainty surrounding ice-sheet contributions to sea-level rise and a rise larger than projected above cannot be excluded (Meehl et al., 2007b). However, understanding of the processes is currently too limited to provide a best estimate or an upper bound (IPCC, 2007).
- Globally, since the early 1990s, sea level has been rising near the upper end of these projections. During the 21st century, some studies (using semi-empirical models) project faster rates of sea-level rise.

Interannual variability of sea level will lead to periods of lower and higher regional sea levels. In the past, this interannual variability has been about 20 cm (5–95% range, after removal of the seasonal signal; dashed lines in Figure 12.10 (a)) and it is likely that a similar range will continue through the 21st century. In addition, winds and waves associated with weather phenomena will continue to lead to extreme sea-level events.

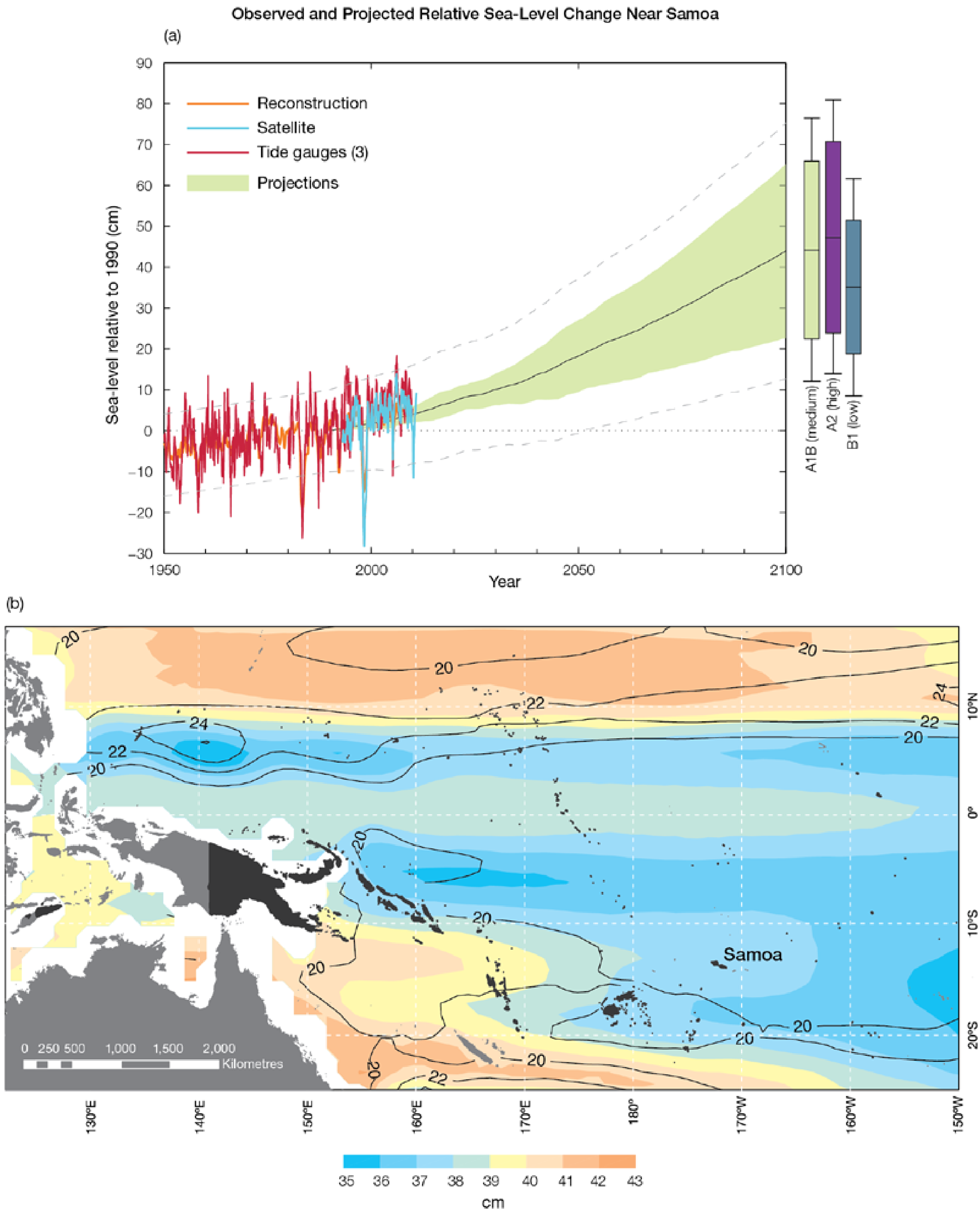

Figure 12.10: Observed and projected relative sea-level change near Samoa. (a) The observed in situ relative sea-level records are indicated in red, with the satellite record (since 1993) in light blue. The gridded sea level at Samoa (since 1950, from Church and White (in press)) is shown in orange. The projections for the A1B (medium) emissions scenario (5–95% uncertainty range) are shown by the green shaded region from 1990–2100. The range of projections for the B1 (low), A1B (medium) and A2 (high) emissions scenarios by 2100 are also shown by the bars on the right. The dashed lines are an estimate of interannual variability in sea level (5–95% range about the long-term trends) and indicate that individual monthly averages of sea level can be above or below longer-term averages. (b) The projections (in cm) for the A1B emissions scenario in the Samoa region for the average over 2081–2100 relative to 1981–2000 are indicated by the shading, with the estimated uncertainty in the projections indicated by the contours (in cm).

12.7.6 Projections Summary

The projections presented in Section 12.7 are summarised in Table 12.3. For detailed information regarding the various uncertainties associated with the table values, refer to the preceding text in Sections 12.7 and 1.7, in addition to Chapters 5 and 6 in Volume 1. When interpreting the differences between projections for the B1 (low), A1B (medium) and A2 (high) emissions scenarios, it is also important to consider the emissions pathways associated with each scenario (Volume 1, Figure 4.1) and the fact that a slightly different subset of models was available for each (Volume 1, Appendix 1).

Table 12.3: Projected change in the annual and seasonal mean climate for Samoa, under the B1 (low; blue), A1B (medium; green) and A2 (high; purple) emissions scenarios. Projections are given for three 20-year periods centred on 2030 (2020–2039), 2055 (2046–2065) and 2090 (2080–2099), relative to 1990 (1980–1999). Values represent the multi-model mean change ± twice the inter-model standard deviation (representing approximately 95% of the range of model projections), except for sea level where the estimated mean change and the 5–95% range are given (as they are derived directly from the Intergovernmental Panel on Climate Change Fourth Assessment Report values). The confidence (Section 1.7.2) associated with the range and distribution of the projections is also given (indicated by the standard deviation and multi-model mean, respectively). See Volume 1, Appendix 1 for a complete listing of CMIP3 models used to derive these projections.

Variable	Season	2030	2055	2090	Confidence
Surface air temperature (°C)	Annual	+0.6 ± 0.4 +0.8 ± 0.4 +0.7 ± 0.3	+1.0 ± 0.4 +1.4 ± 0.5 +1.4 ± 0.4	+1.4 ± 0.6 +2.2 ± 0.7 +2.6 ± 0.7	Moderate
Maximum temperature (°C)	1-in-20-year event	N/A	+1.0 ± 0.5 +1.4 ± 0.6 +1.5 ± 0.4	+1.3 ± 0.5 +2.1 ± 1.0 +2.6 ± 1.3	Low
Minimum temperature (°C)	1-in-20-year event	N/A	+1.2 ± 1.8 +1.6 ± 1.6 +1.5 ± 1.9	+1.5 ± 1.6 +2.0 ± 2.2 +2.3 ± 1.9	Low
Total rainfall (%)*	Annual	+1 ± 6 +2 ± 9 +4 ± 11	+3 ± 9 +4 ± 15 +5 ± 14	+3 ± 13 +5 ± 17 +7 ± 24	Moderate
Wet season rainfall (%)*	November-April	+1 ± 8 +2 ± 10 +3 ± 11	+4 ± 11 +5 ± 15 +5 ± 11	+4 ± 14 +6 ± 16 +8 ± 22	Moderate
Dry season rainfall (%)*	May-October	+2 ± 9 +3 ± 15 +4 ± 14	+3 ± 11 +4 ± 23 +6 ± 23	+2 ± 14 +3 ± 26 +5 ± 36	Low
Sea-surface temperature (°C)	Annual	+0.6 ± 0.4 +0.7 ± 0.3 +0.7 ± 0.4	+0.9 ± 0.3 +1.2 ± 0.4 +1.3 ± 0.5	+1.3 ± 0.4 +2.0 ± 0.7 +2.4 ± 0.8	High
Aragonite saturation state (Ωar)	Annual maximum	+3.6 ± 0.1 +3.6 ± 0.2 +3.6 ± 0.2	+3.4 ± 0.1 +3.2 ± 0.2 +3.2 ± 0.2	+3.2 ± 0.2 +2.9 ± 0.2 +2.6 ± 0.2	High
Mean sea level (cm)	Annual	+10 (5–15) +10 (6–14) +10 (5–15)	+18 (10–26) +21 (11–30) +20 (10–29)	+31 (17–45) +38 (20–57) +40 (21–59)	Moderate

*The MIROC3.2(medres) and MIROC3.2(hires) models were eliminated in calculating the rainfall projections, due to their inability to accurately simulate present-day activity of the South Pacific Convergence Zone (Volume 1, Section 5.5.1).