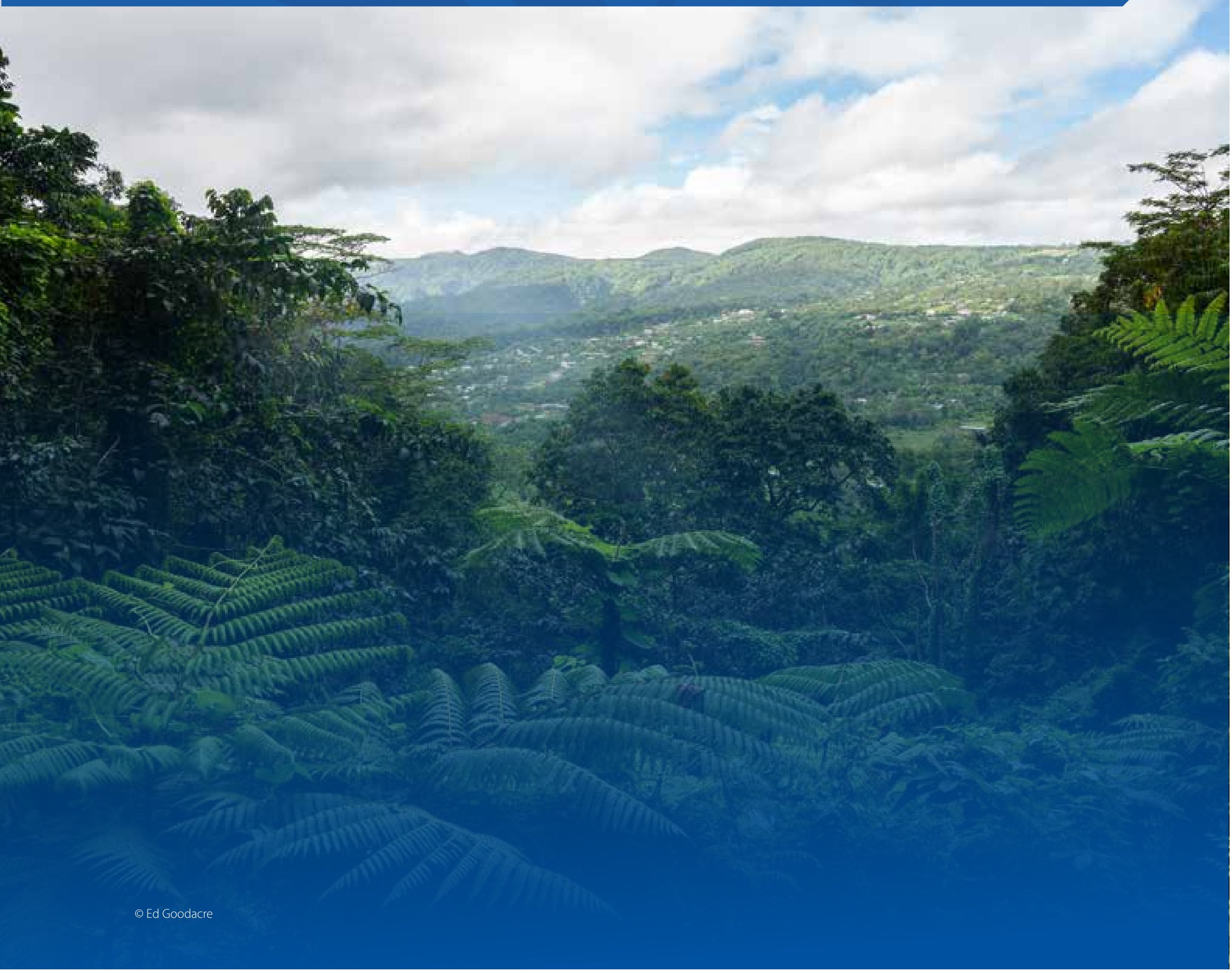
11 Samoa



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11.1 Summary

11.1.1 Climate

- Changes in air temperature from season to season are relatively small and strongly linked to changes in the surrounding ocean temperature. Samoa has two distinct seasons – a warm wet season from November to April and a slightly cooler dry season from May to October.
- The seasonal cycle is strongly affected by the South Pacific Convergence Zone (SPCZ), which is most intense during the wet season.
- Annual and seasonal air temperatures at Apia increased over the period 19792021. The number of hot days and warm nights also increased, while the number of cool days decreased. The energy required for cooling indoor environments has also increased.
- Annual maximum daily rainfall has increased at Apia, along with the contribution of extreme of extreme rainfall events to the total annual rainfall amount.
- Tropical cyclones usually affect Samoa between November and April. Over the period 1969–2018, an average of eight cyclones passed within the Samoa exclusive economic zone (EEZ) per decade. Tropical cyclones were most frequent in El Niño years and least frequent in La Niña years. Year-to-year variability is large, ranging from no tropical cyclones in some seasons to four in 2009/10.
- There has been little change in the total number of tropical cyclones in the Southwest Pacific since 1981/82. The number of severe tropical cyclones has declined over the same period/region.

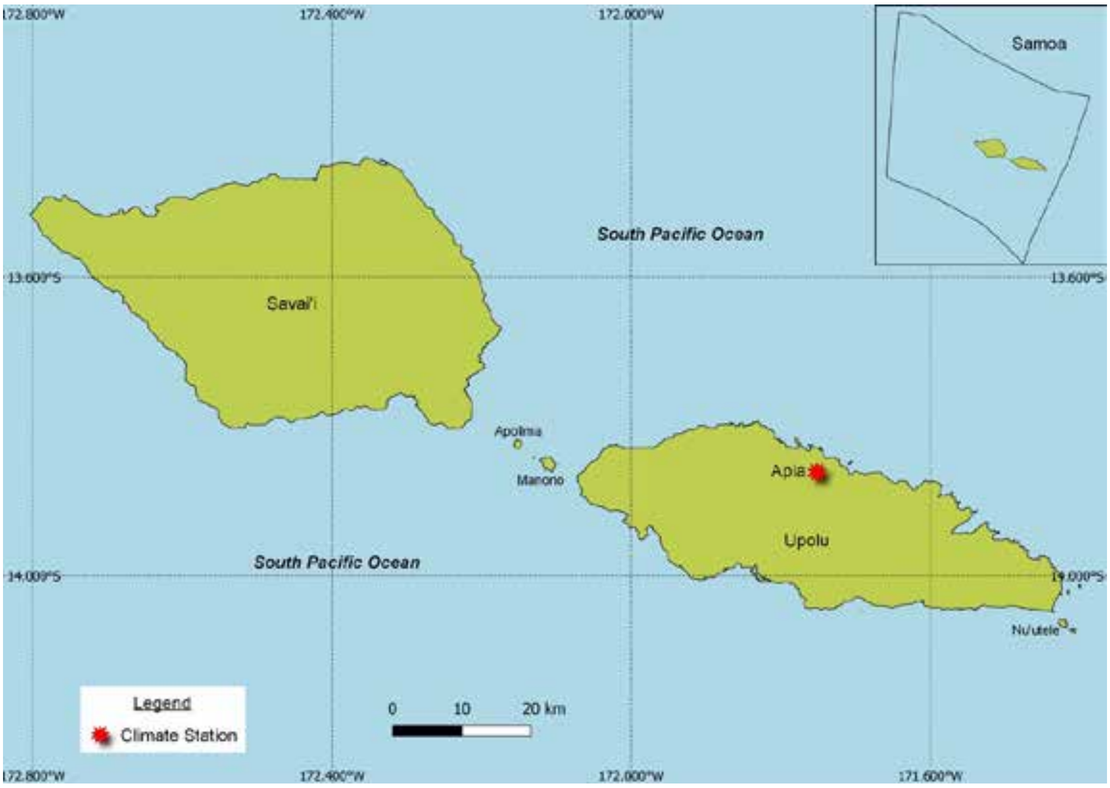
11.1.2 Ocean

- Highest sea levels typically occur in the months December–May.
- Sea-level rise within the EEZ, measured by satellite altimeters since 1993, is about 3.5 to 4 mm per year.
- Monthly average ocean temperature, as measured by the Apia tide-gauge, ranges from 28.2 °C in August to almost 30 °C in April. However, monthly temperatures in any given year can be ±2 °C of these averages.
- The sea surface temperature (SST) trend from satellite observations is 0.31 °C per decade, one of the highest trends in the Southwest Pacific.
- Dominant wave direction is from 35° (NE), with an average significant wave height of 1.26 m and average wave period of 10.54 s.
- Severe wave height was defined as 2.29 m, with an average of 3.9 severe events per year.
- Peak average significant wave height occurs between December and March.

11.2 Country description

The Independent State of Samoa is located in the tropical western South Pacific Ocean between latitudes 13°S and 14.5°S, and longitudes 171°W and 174°W (Figure 11.1). Samoa consists of two main islands (Savai'i and Upolu), two smaller inhabited islands and several small uninhabited islands. It has a total land area of 2842 km^2 and an EEZ of about 128,000 km^2. The main islands account for 99% of the total land area. The capital Apia is located on Upolu. The highest elevation is 1858 m above sea level on Savai'i. Samoa's population is approximately 194,000. About 75% live on the main island of Upolu.

Figure 11.1:
Samoa and the location of the climate station used in this report



11.3 Data

Daily historical rainfall and air temperature records for Apia from 1951 were obtained from the Samoa Meteorological Division. These records have undergone data quality and homogeneity assessment. While Apia rainfall and temperature data have been used to derive climatological information and rainfall trends in this report, there are insufficient maximum or minimum air temperature data to produce long-term trends. ERA5 reanalysis has been used to calculate temperature trends from 1979 to 2021 (further information is provided in Chapter 1). Additional information on historical climate trends for Samoa can be found in the Pacific Climate Change Data Portal http://www.bom.gov.au/climate/pccsp.

Tropical cyclone data and historical tracks starting from the 1969/70 season are available from the SHTC Data Portal http://www.bom.gov.au/cyclone/history/tracks/index.shtml.

SST covering the EEZ was obtained via the daily Optimum Interpolation SST version 2.1 (OISST v2.1) dataset from NOAA (Reynolds et al. 2007; Banzon et al. 2016). In situ ocean temperature data were obtained from the PSLGM Project tide-gauge located at Apia, with data spanning from 1993 to 2021.

Wave data were obtained from the PACCSAP wave hindcast (Smith et al. 2021), available hourly from 1979 to present, with a grid resolution near Samoa of 7 km.

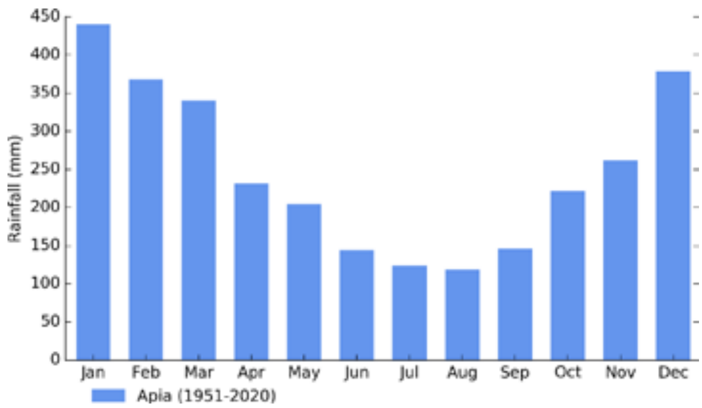
Regional sea level data were obtained from CSIRO satellite altimetry (updated by Benoit Legresy, Church and White 2011), with correction for seasonal signals, inverse barometer effect and glacial isostatic adjustment. Tide-gauge data were sourced from the Apia tide-gauge station, spanning from 1993 to 2021 at hourly intervals.

11.4 Rainfall

11.4.1 Seasonal cycle

Rainfall is Samoa is greatly influenced by the position and strength of the SPCZ. This band of heavy rainfall is caused by air rising over warm water where winds converge, resulting in thunderstorm activity. It extends across the South Pacific Ocean from the Solomon Islands to the Cook Islands and typically lies between Samoa and Fiji during the wet season. The wet season months of November–April receive 68%, or 2021 mm, of the annual rainfall with the peak month in January with 440 mm (Figure 11.2). The dry season averages 960 mm rainfall, with lowest average recorded rainfall of 119 mm in August.

Figure 11.2:
Mean annual rainfall at Apia



11.4.2 Trends

Trends in annual and seasonal rainfall since 1951 are not statistically significant at Apia (Figure 11.3, Table 11.1). Annual and seasonal rainfall trends indicate little change. Notable year-to-year variability associated with El Niño–Southern Oscillation (ENSO) is present, with higher rainfall typically occurring during La Niña years compared to El Niño years (Figure 11.3). Annual rainfall since 1951 has varied from approximately 1700 to 4200 mm, and approximately half of the year experiences rain.

Figure 11.3:
Annual rainfall (bar graph) and number of wet days (where rainfall is at least 1 mm; line graph) at Apia. Straight lines indicate linear trends for annual rainfall (in black) and number of wet days (in blue). The magnitudes of the trends are presented in Table 11.1. Diamonds indicate years with insufficient data for one or both variables.

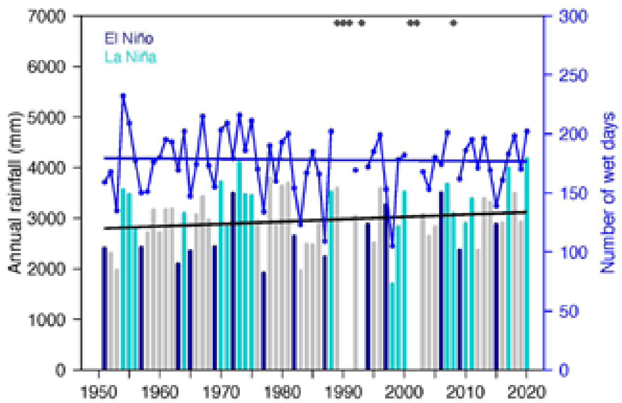
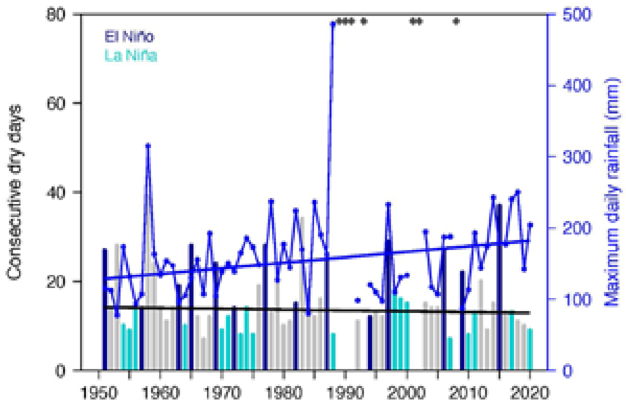


Table 11.1:
Trends in annual, seasonal and extreme rainfall at Apia. The 95% confidence intervals are shown in parentheses, and trends significant at the 95% level are shown in bold. The contribution from very wet days and the standardised rainfall evapotranspiration index are measured relative to 1961–1990 (see Chapter 1 for details).

	Apia
	1951–2020
Annual rainfall (mm/decade)	+46.42 (-26.08, +129.79)
November–April (mm/decade)	+30.27 (-25.36, +83.41)
May–October (mm/decade)	+8.41 (-30.88, +53.83)
Wet days (days/decade)	-0.41 (-4.11, +3.20)
Contribution from very wet days (%/decade)	**+1.65** (+0.75, +2.38)
Consecutive dry days (days/decade)	-0.19 (-0.95, +0.36)
Maximum one-day rainfall (mm/decade)	**+7.71** (+1.55, +13.65)
Standardised rainfall evapotranspiration index (November–April)	+0.02 (-0.11, +0.17)
Standardised rainfall evapotranspiration index (May–October)	-0.08 (-0.24, +0.08)

Maximum daily rainfall, as well as the contribution to annual rainfall from extreme events, has been increasing significantly since 1951 at Apia (Figure 11.4, Table 11.1). All other extreme rainfall indices, including the standardised rainfall evapotranspiration drought index, are not changing significantly. Variability associated with ENSO is evident, with El Niño years experiencing substantially longer dry spells than La Niña years (Figure 11.4).

Figure 11.4:
Annual longest run of consecutive dry days (bar graph) and maximum daily rainfall (line graph) at Apia. Straight lines indicate linear trends for dry days (in black) and maximum daily rainfall (in blue). The magnitudes of the trends are presented in Table 11.1. Diamonds indicate years with insufficient data for one or both variables.



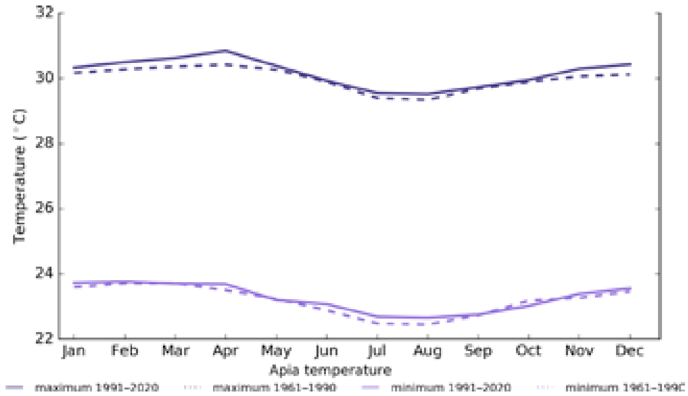
11.5 Air temperature

11.5.1 Seasonal cycle

In Samoa, air temperatures are generally consistent throughout the year, with only very small seasonal differences (Figure 11.5) as temperatures are strongly linked to the surrounding ocean temperatures. The average maximum and minimum temperatures are coldest in August and warmest in April.

The maximum temperature seasonal cycle range for the 1991–2020 period is 1.3 °C, and for minimum temperature it is 1.1 °C. All average maximum temperature months warmed in the 1991–2020 period when compared to the earlier 1961–1990 period, with the strongest difference occurring in April (0.4 °C). For average minimum temperatures, there was marginal warming from June to August.

Figure 11.5:
Maximum and minimum air temperature seasonal cycle for Apia (purple), and for the periods 1961–1990 (dotted lines) and 199–2020 (solid lines)



11.5.2 Trends

Due to quality and completeness issues in the daily temperature record from Apia, reanalysis data have been used to calculate temperature trends. Average annual and seasonal temperatures have increased at Apia since 1979 (Table 11.2).

Table 11.2:
Trends in annual and seasonal air temperatures at Apia from ERA5 reanalysis data (station temperatures have quality and completeness issues). A reanalysis is a global weather simulation merged with observations and represents the most complete picture of historical climate, but shares the same limitations as climate models. The 95% confidence intervals are shown in parentheses, and trends significant at the 95% level are shown in bold.

	Apia-ERA5 Tmax (°C/decade)	Apia-ERA5 Tmin (°C/decade)	Apia-ERA5 Tmean (°C/decade)
	1979–2021		
Annual	**+0.13** (+0.06, +0.2)	**+0.13** (+0.06, +0.18)	**+0.13** (+0.06, +0.19)
November–April	**+0.13** (+0.03, +0.21)	**+0.14** (+0.04, +0.21)	**+0.13** (+0.03, +0.21)
May–October	**+0.15** (+0.08, +0.22)	**+0.15** (+0.08, +0.21)	**+0.15** (+0.08, +0.22)

The number of hot days and warm nights has increased, and the number of cool days has decreased at Apia (Table 11.3). The cooling degree days index provides a measure of the energy demand needed to cool a building down to 25 °C, with the assumption that air conditioners are generally turned on at this temperature. There has been a strong increase in the cooling degree index, suggesting the energy needed for cooling has increased significantly since 1979.

Table 11.3:
Trends in annual temperature extremes at Apia from ERA5 reanalysis data (station temperatures have quality and completeness issues). A reanalysis is a global weather simulation merged with observations and represents the most complete picture of historical climate but shares the same limitations as climate models. The 95% confidence intervals are shown in parentheses, and trends significant at the 95% level are shown in bold. Hot and cool days, and warm and cold nights are measured relative to 1981–2010 (see Chapter 1 for details).

	Apia–ERA5
	1979–2021
Number of hot days (days/decade)	**+17.27** (+9.70, +27.00)
Number of warm nights (nights/decade)	**+14.75** (+9.90, +20.92)
Number of cool days (days/decade)	**-9.08** (-14.45, 3.24)
Number of cold nights (nights/decade)	-7.77 (-14.33, +0.04)
Cooling degree days (degree days/decade)	**+45.27** (+22.40, +67.32)
Daily temperature range (°C/decade)	0.00 (-0.01, +0.02)

11.6 Tropical cyclones

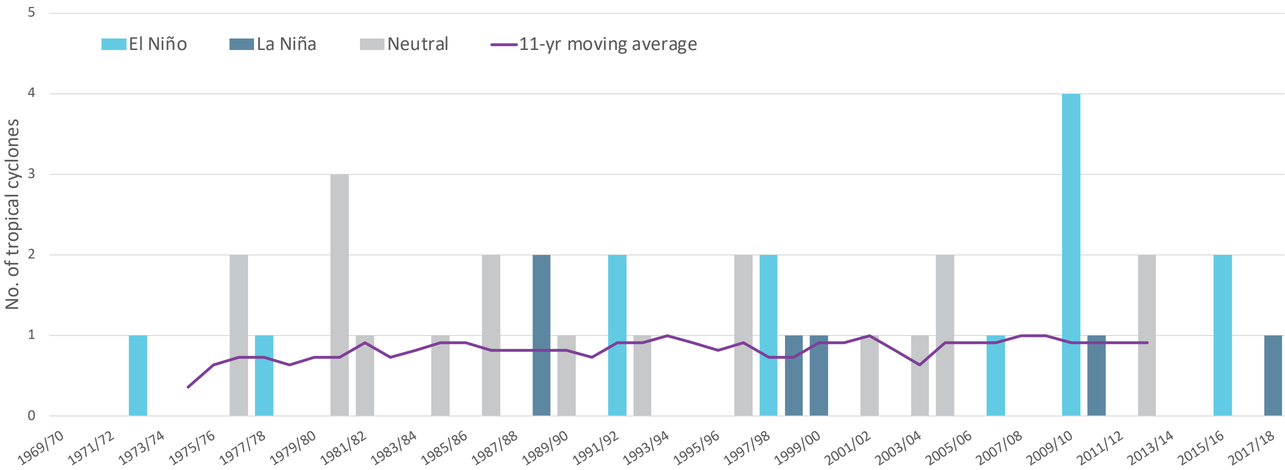
11.6.1 Seasonal cycle

Tropical cyclones usually affect Samoa during the southern hemisphere tropical cyclone season, which is from November to April, but also occasionally occur outside the tropical cyclone season. The Southern Hemisphere Tropical Cyclone Archive indicates that between the 1969/70 and 2017/18 seasons, 38 tropical cyclones (Figure 11.6) passed within the EEZ. This represents an average of eight cyclones per decade. Tropical cyclones were most frequent in El Niño years (10 cyclones per decade), followed by neutral years (9 cyclones per decade) and least frequent in La Niña years (4 cyclones per decade).

Interannual variability in the number of tropical cyclones in the EEZ is large, ranging from zero in some seasons to three in 1980/81 and four in 2009/10 (Figure 11.6). High interannual variability and the small number of tropical cyclones occurring in the EEZ make reliable identification of long-term trends in frequency and intensity difficult.

Some tropical cyclone tracks analysed in this section include the tropical depression stage (sustained winds ≤34 knots) before and/or after tropical cyclone formation.

Figure 11.6:
Number of tropical cyclones passing within the Samoa EEZ per season. Each season is defined by the ENSO status, with light blue being an El Niño year, dark blue a La Niña year and grey showing a neutral ENSO year. The 11-year moving average is presented as a purple line and considers all years.



11.6.2 Trends

Trends in total number of tropical cyclones (<995 hPa) and severe tropical cyclones (<970 hPa) are presented for the period 1981/82–2020/21 for the greater Southwest Pacific (135°E–120°W; 0–50°S). Trends are presented at a regional scale as the number of tropical cyclones occurring within Pacific Island EEZs is insufficient for reliable long-term trend analysis.

For the total number of tropical cyclones, the trend (and 95% confidence interval) is -0.92 (-1.85, 0.01) tropical cyclones/decade. There has been little change/marginal decline in the total number of tropical cyclones over the last 40 seasons. This trend is not statistically significant.

For the total number of severe tropical cyclones, the trend is -0.80 (-1.32, -0.29) tropical cyclones/decade. There is a negative trend in the number of severe tropical cyclones over the last 40 seasons. There has been little change/marginal decline in the proportion of tropical cyclones reaching severe status. The trend is -0.04 (-0.08, 0.00) tropical cyclones/decade. The negative trend is statistically significant.

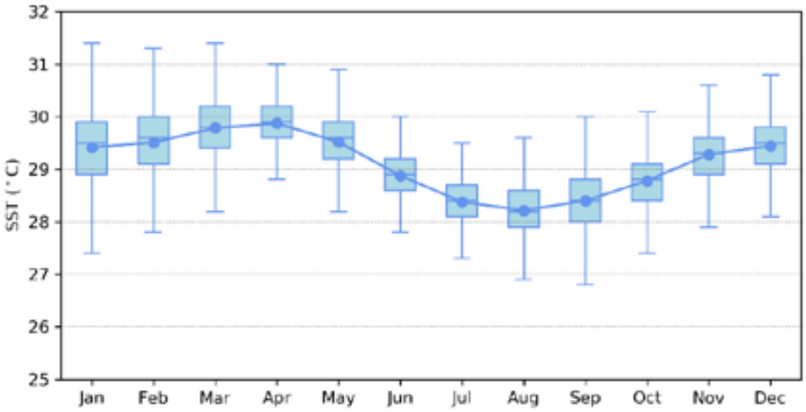
Records of tropical cyclones exist from the late 1800s in some countries in the Southwest Pacific, but trends in tropical cyclones have only been presented from 1981/82. Satellite-based observations began in the Southwest Pacific in the early 1970s, but consistent coverage and reliable intensity estimates have only been available since the early 1980s. Confidence in tropical cyclone trends is moderate as the definition of a tropical cyclone has changed and satellite observation methods have continued to improve over the last 40 years.

11.7 Sea surface temperature

11.7.1 Seasonal cycle

Ocean temperature, as measured by the Apia tide-gauge from 1993 to 2021, reaches on average a maximum of almost 30 °C in April, but individual months can get as high as 31.4 °C (Figure 11.7). Minimum average temperature is 28.2 °C in August. Temperatures can be up to 2 °C higher or lower than these averages, although 50% of observations fall within 1 °C of the average.

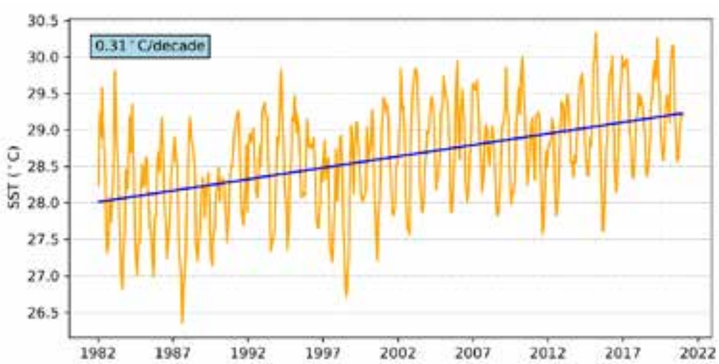
Figure 11.7:
Annual temperatures measured at the Apia tide-gauge. Blue dots show the monthly average, and shaded boxes show the middle 50% of observations. Lines show the top and bottom 25% of observations.



11.7.2 Trends

Figure 11.8 shows the 1981–2021 SST from satellite observations averaged over the EEZ. The data show a trend of 0.31 °C per decade with a 95% confidence interval of ±0.05 °C. This SST trend estimate is one of the highest trends among Southwest Pacific countries.

Figure 11.8:
Sea surface temperature from satellite observations averaged across the Samoa EEZ, shown as the orange line. The blue line shows the linear regression trend.



11.8 Sea level

11.8.1 Seasonal cycle

Samoa experiences a semidiurnal tidal cycle, meaning two high and two low tides per day. The highest predicted tides of the year typically occur from December to February and also July to September. Figure 11.9 shows the number of hours the 99th percentile (1.66 m) sea level threshold is exceeded per month across the entire sea level record at Apia. Peak sea levels typically occur between December and May. Since approximately 2010, increasingly more hours each year exceed the 99th percentile threshold. This is due to a combination of sea-level rise and subsidence occurring at Samoa (Brown et al. 2020).

Figure 11.9:
Number of hours exceeding 99th percentile sea level threshold per month from 1993 to 2021 at the Apia tide-gauge. Blue shading indicates the number of hours, and the final row provides a percentage summary of all the years.

Number of hours exceeding 1.66 m (Apia, Samoa)

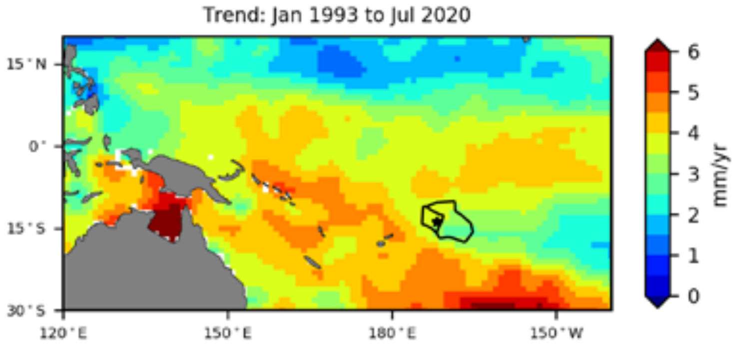
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1993	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0	0	0	0	0	0	0
1996	0	0	0	0	0	0	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	0	0	0	0	0	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	0	0	0	0	0	0
2003	0	0	0	0	0	0	0	0	0	0	0	0	0
2004	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	0	0	0	0	0	0
2007	0	0	0	0	0	0	0	0	0	0	0	0	0
2008	0	0	0	0	0	0	0	0	0	0	0	0	0
2009	0	0	0	0	0	0	0	0	0	0	0	0	0
2010	0	0	0	0	0	0	0	0	0	0	0	0	0
2011	0	1	0	4	0	0	0	0	0	0	0	0	5
2012	0	0	0	0	0	0	0	0	0	0	0	2	2
2013	0	0	0	0	0	0	1	0	0	0	0	0	1
2014	0	0	0	0	0	0	0	0	2	0	0	0	2
2015	0	1	0	0	0	0	0	0	2	0	0	0	3
2016	0	0	0	0	0	0	0	0	0	2	1	4	7
2017	5	1	0	0	0	0	0	0	0	0	0	1	7
2018	2	2	0	0	0	2	1	0	2	0	0	1	10
2019	8	21	11	10	0	0	0	9	7	8	2	0	76
2020	0	0	1	14	8	2	0	0	0	3	0	1	29
2021	5	5	21	12	8	0	0	0	0	1	0	6	58
Monthly Totals (%)	10	16	16	20	8	2	1	4	6	7	2	8	

11.8.2 Trends

Sea level at Samoa, measured by satellite altimeters (Figure 11.10) since 1993, has risen between 3.5 and 4.0 mm per year across the EEZ, with a 95% confidence interval of ±0.6 to ±1.0 mm. This rise is partly linked to a pattern related to climate variability from year to year and decade to decade, and is a higher trend than the global average of 3.1 ± 0.4 mm per year (von Schuckmann et al. 2021).

Trend estimates at the Apia tide-gauge over a similar time span to the altimetry observations (February 1993 to July 2020) are provided in the PSLGM Monthly Data Report for July 2020 (http://www.bom.gov.au/ntc/IDO60101/IDO60101.202007.pdf). For Apia, the trend is reported as 9.8 mm per year, more than double the altimetry trends shown in Figure 11.10 (tide-gauge indicated by star symbol). This difference is largely attributed to subsidence occurring at Samoa (Brown et al. 2020).

Figure 11.10:
Satellite altimetry annual trend for the Pacific from 1993 to 2020, with the Samoa and American Samoa EEZ highlighted. The star symbol represents the location of the tide-gauge.



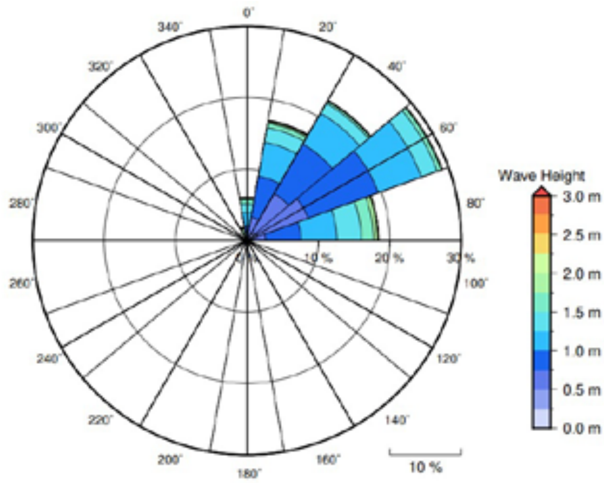
11.9 Waves

11.9.1 Seasonal cycle

The average wave climate in Apia is defined by the significant wave height, peak period and peak direction. The significant wave height is the mean wave height (from trough to crest) of the highest one third of waves and corresponds to the wave height that would be reported by an experienced observer. Peak period is the time interval between two waves of the dominant wave period. Peak direction is the direction from which the dominant waves are coming.

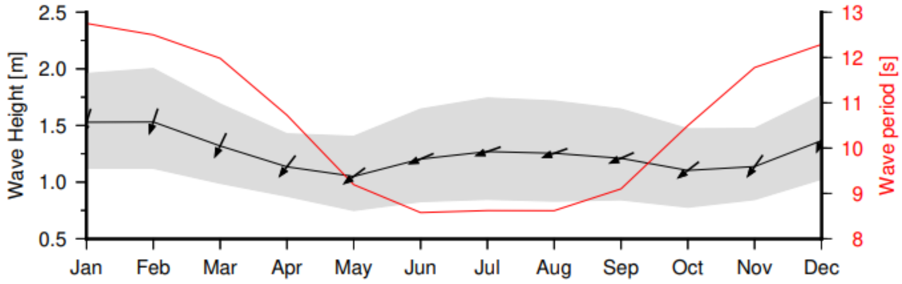
The average sea state is dominated by wind seas from the northeast. The annual mean wave height is 1.26 m, the annual mean wave direction is 35° and the annual mean wave period is 10.54 s. In the Pacific, waves often come from multiple directions and for different periods at a time. In Apia, there are often more than four different wave direction/period components coming from the southeast to southwest (Figure 11.11).

Figure 11.11:
Annual wave rose for Apia. Note that direction is where the wave is coming from.



The significant wave height and wave period peak is from November to March. However, there is a secondary wave height peak from June to September, which is accompanied by lower wave periods (Figure 11.12). This shows that waves at Samoa are predominantly driven by strong easterly local and trade winds from May to September.

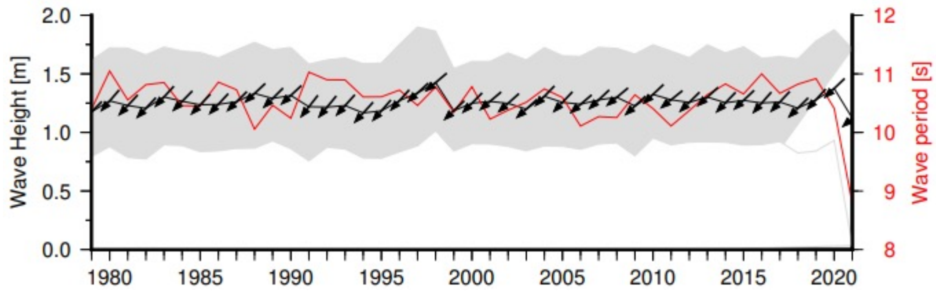
Figure 11.12:
Monthly wave height (black line), wave period (red line) and wave direction (arrows). The grey area represents the range of wave height between calm periods (10% of lowest wave height) and large wave events (10% of highest wave height).



11.9.2 Trends

Waves change from month to month with the seasons, but they also change from year to year with climate oscillations. Typically, these changes are smaller than the seasonal changes but can be important during phenomena such as ENSO. In Apia, the mean annual wave height has remained unchanged since 1979 (Figure 11.13). The mean annual wave height in Apia is not significantly correlated with the main climate indicators of the region.

Figure 11.13:
Annual wave height (black line), wave period (red line) and wave direction (arrows). The grey area represents the range of wave height between calm periods (10% of lowest wave height) and large wave events (10% of highest wave height).



11.9.3 Extreme waves

Extreme wave analysis completed for Apia was done by defining a severe height threshold and fitting a generalized Pareto distribution (GPD). The optimum threshold selected was 2.29 m. In the 42-year wave hindcast, 163 wave events reached or exceeded this threshold, averaging 3.9 events per year. The GPD was fitted to the largest wave height reached during each of these events (Figure 11.14, Table 11.4). Extreme wave analysis is a very useful tool but is not always accurate because the analysis is very sensitive to the data available, the type of distribution fitted and the threshold used. For example, this analysis does not accurately account for tropical cyclone waves. More in-depth analysis is required to obtain results appropriate for designing coastal infrastructure and coastal hazard planning.

Figure 11.14:
Extreme wave distribution for Apia. The crosses represent the wave events that have occurred since 1979. The solid line is the statistical distribution that best fits past wave events. The dashed lines show the upper and lower confidence limits of the fit. There is a 95% chance that the fitted distribution lies between the two dashed lines. Note that the annual return interval is in logarithmic scale.

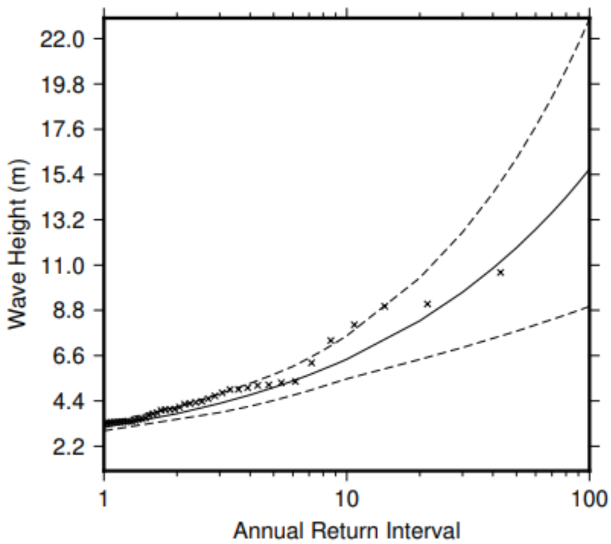


Table 11.4:
Summary of the results from extreme wave analysis in Apia

Large wave height (90th percentile)	1.69 m
Severe wave height (99th percentile)	2.54 m
1-year ARI wave height	3.11 m
10-year ARI wave height	6.42 m
20-year ARI wave height	8.29 m
50-year ARI wave height	11.84 m
100-year ARI wave height	15.66 m