16 Vanuatu

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16.1 Summary

16.1.1 Climate

- Changes in air temperature from season to season are relatively small and strongly linked to changes in the surrounding ocean temperature. Vanuatu has two distinct seasons – a warm wet season from November to April and a 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.
- Warming trends have been evident in annual and seasonal air temperatures at Aneityum and Port Vila-Bauerfield Airport since 1951. Hot days have also occurred more than twice as frequently in recent years compared to the middle of the 20th century.
- There has been little change in annual and seasonal rainfall at Aneityum and Port Vila, although the number of wet days each year has decreased at Aneityum.
- Tropical cyclones usually affect Vanuatu between November and April. Over the period 1969–2018, an average of 24 cyclones passed within the Vanuatu 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 six in 1971/72 and 1991/92.
- 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.

16.1.2 Ocean

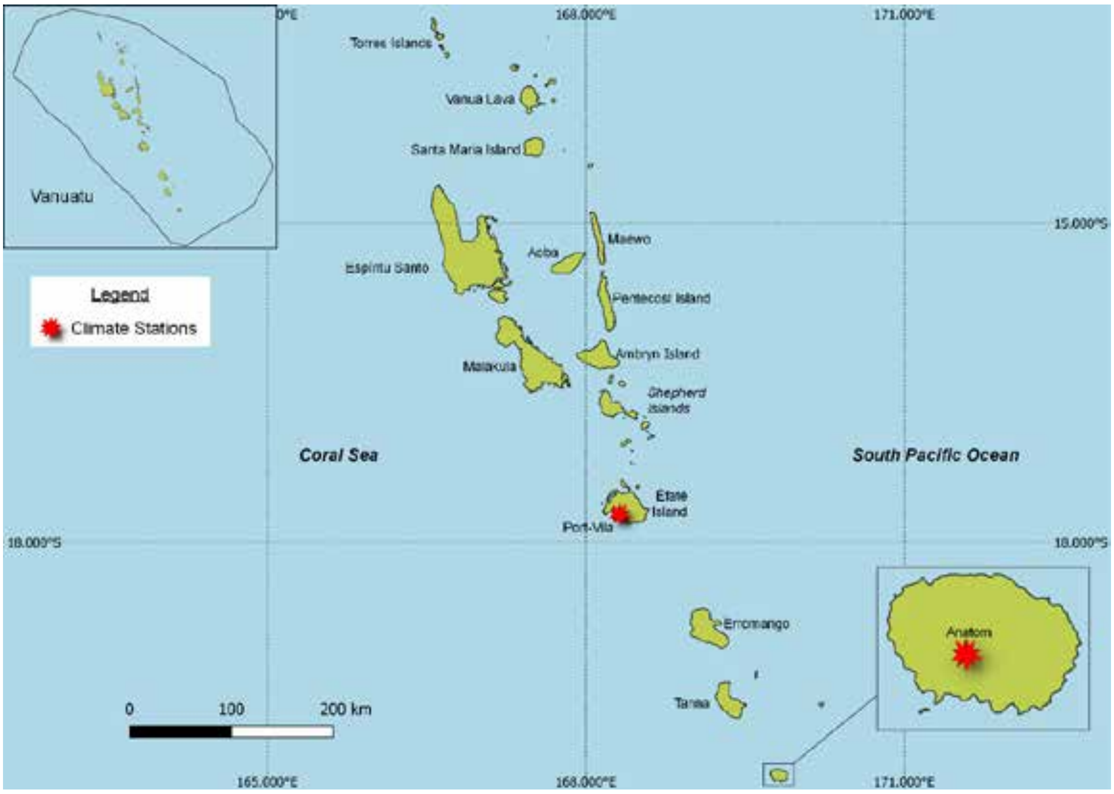
- Highest sea levels typically occur in the months October–March.
- Sea-level rise within the EEZ, measured by satellite altimeters from 1993 to mid-2020, ranges from 3.5 to 5 mm per year.
- Monthly average ocean temperature, as measured by the Port Vila tide-gauge, ranges from 25.5 °C in August to 29 °C in February/March. However, monthly temperatures in any given year can be ±2 °C of these averages.
- The sea surface temperature (SST) trend in the EEZ is 0.23 °C per decade.
- Wave height is fairly consistent throughout the year, while wave period has a definitive peak in May.
- Dominant wave direction is from 182° (south), with an average significant wave height of 0.55 m and average wave period of 9.63 s.
- Severe wave height was defined as 1.83 m, with an average of 2.8 severe events per year.

16.2 Country description

The Republic of Vanuatu is located in the tropical South Pacific Ocean between latitudes 13°S and 21°S, and longitudes 166°E and 171°E (Figure 16.1). The nation consists of 83 islands (65 of them inhabited), with a distance of 1300 km between the most northern and southern islands. Fourteen of Vanuatu's islands have surface areas of more than 100 km^2, including, from largest to smallest: Espiritu Santo, Malakula, Efate, Erromango, Ambrym, Tanna, Pentecost, Epi, Ambae or Aoba, Gaua, Vanua Lava, Maewo, Malo and Aneityum. Vanuatu has a total land area of 12,189 km^2 and an EEZ of 0.7 million km^2. The highest point in Vanuatu is Mount Tabwemasana, at 1879 m, on the island of Espiritu Santo.

The population is approximately 307,000 and predominantly rural. Efate, which includes the capital Port Vila, has a population about 51,000.

Figure 16.1:
Vanuatu and the locations of the climate stations used in this report



16.3 Data

Daily historical rainfall for Port Vila, air temperature records for a Port Vila-Bauerfield Airport (henceforth Port Vila) composite and Aneityum from 1951 were obtained from the Vanuatu Meteorological Service. These records have undergone data quality and homogeneity assessment. Where the maximum or minimum air temperature records were found to have discontinuities, these records have been adjusted to make them homogeneous (further information is provided in Chapter 1). Additional information on historical climate trends for Vanuatu 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 Port Vila, 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 2021, with a grid resolution near Vanuatu 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 Port Vila tide-gauge station, spanning from 1993 to 2021 at hourly intervals.

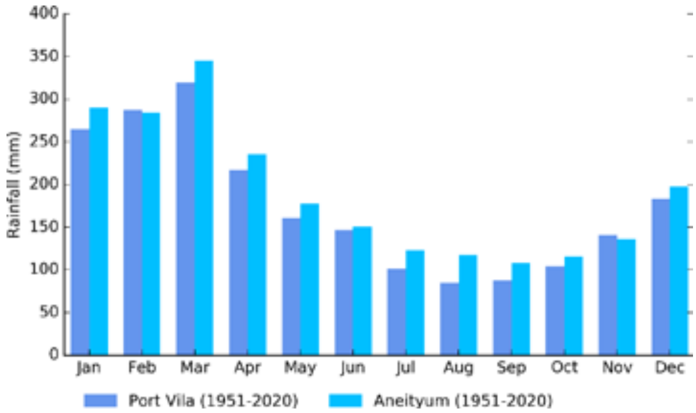
16.4 Rainfall

16.4.1 Seasonal cycle

Rainfall in Vanuatu is strongly influenced by the SPCZ. During the wet season (December–May), the SPCZ intensifies and moves further south, bringing higher rainfall to Vanuatu and leading to about 65% of Aneityum's and 67% of Port Vila's rain to fall during this period (Figure 16.2). Low pressure systems embedded in this band of heavy rainfall often become tropical cyclones during the cyclone season.

Mountains also play a role in variations in rainfall across some islands. During the wet season, rainfall is particularly high on the windward (southeast) side of mountain ranges of the bigger islands and scarce on the leeward (northwest) sides, especially during the dry season.

Figure 16.2:
Mean annual rainfall at Port Vila and Aneityum



16.4.2 Trends

Trends in annual and seasonal rainfall since 1951 are not statistically significant at Aneityum and Port Vila (Figure 16.3, Table 16.1). Annual and seasonal rainfall trends indicate little change at these sites. While trends in rainfall are not significant, the number of wet days each year is decreasing significantly at Aneityum. Annual rainfall has varied from approximately 1000 to 3800 mm at Aneityum and from approximately 900 to 3500 mm at Port Vila. Notable year-to-year variability associated with El Niño–Southern Oscillation (ENSO) is evident, with both sites typically experiencing higher rainfall during La Niña years compared to El Niño years.

Figure 16.3:
Annual rainfall (bar graph) and number of wet days (where rainfall is at least 1 mm; line graph) at Aneityum (left) and Port Vila (right). 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 16.1. Diamonds indicate years with insufficient data for one or both variables.

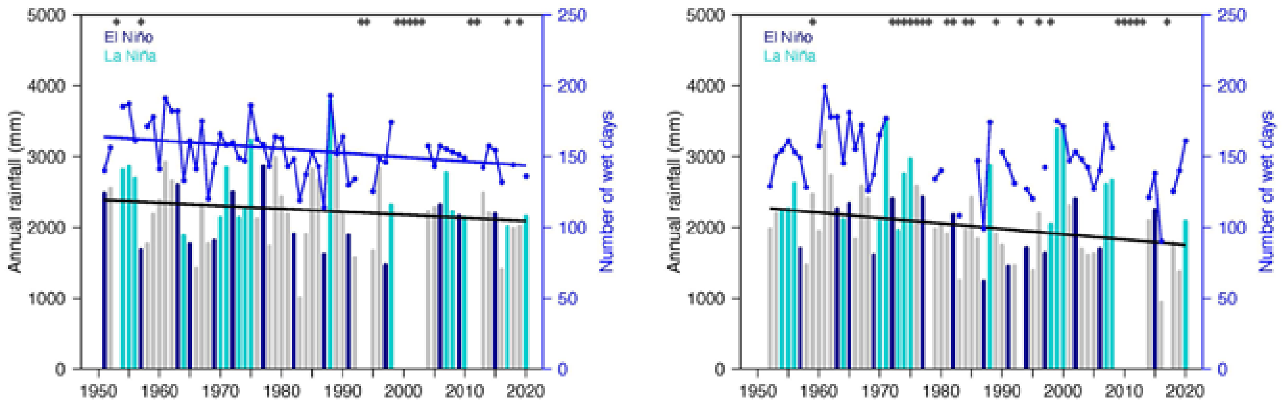
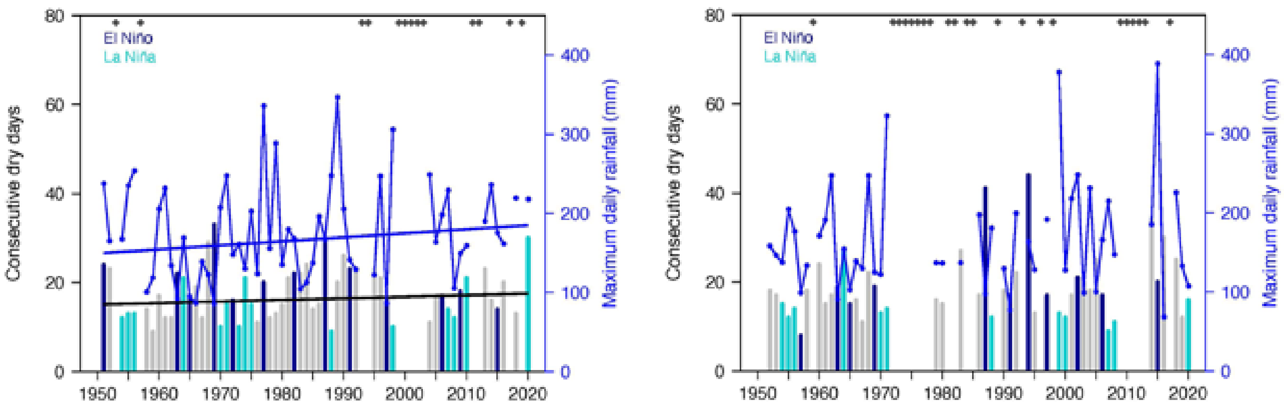


Table 16.1:
Trends in annual, seasonal and extreme rainfall at Aneityum (left) and Port Vila (right). The 95% confidence intervals are shown in parentheses, and trends significant at the 95% level are shown in bold. Criteria for statistical robustness were not met for determining linear trends for rainfall extremes at Port Vila. The contribution to total rainfall from extreme events and the standardised rainfall evapotranspiration index are measured relative to 1961–1990 (see Chapter 1 for details).

	Aneityum	Port Vila
	1951–2020	
Annual rainfall (mm/decade)	-43.22 (-111.51, +40.48)	-75.88 (-177.17, +28.27)
November–April (mm/decade)	+8.86 (-63.81, +60.77)	-45.59 (-115.57, +29.19)
May–October (mm/decade)	-24.94 (-65.70, +7.39)	-28.11 (-70.69, +17.96)
Number of wet days (days/decade)	**-2.94** (-6.26, 0.20)	-
Contribution to total rainfall from extreme events (%/decade)	-0.20 (-2.20, +1.84)	-
Consecutive dry days (days/decade)	+0.36 (-0.62, +1.41)	-
Maximum one-day rainfall (mm/decade)	5.08 (-3.21, +13.66)	-
Standardised rainfall evapotranspiration index (November–April)	0.00 (-0.11, +0.11)	-0.14 (-0.31, +0.01)
Standardised rainfall evapotranspiration index (May–October)	-0.15 (-0.33, +0.03)	-0.09 (-0.23, +0.07)

Numerous gaps in daily data at Port Vila prevent the robust calculation of trends in rainfall extremes (Table 16.1). At Aneityum no trends in rainfall extremes are significant. Similar to annual rainfall, Figure 16.4 shows variability associated with ENSO at both sites, with longer dry spells typically experienced during El Niño years compared to La Niña years.

Figure 16.4:
Annual longest run of consecutive dry days (bar graph) and maximum daily rainfall (line graph) at Aneityum (left) and Port Vila (right). 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 16.1. Criteria for statistical robustness were not met for determining linear trends at Port Vila. Diamonds indicate years with insufficient data for one or both variables.



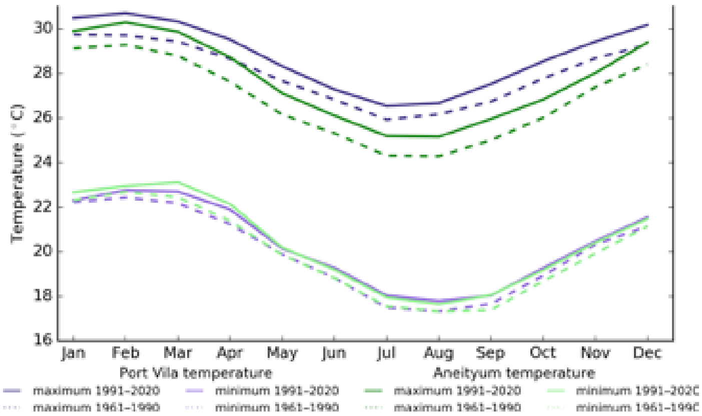
16.5 Air temperature

16.5.1 Seasonal cycle

Seasonal temperature changes in Vanuatu are strongly connected to changes in the surrounding ocean temperature. The country has two distinct seasons – a warm wet season from December to May and a cooler dry season from June to November (Figure 16.5).

The range in average monthly maximum temperatures throughout the year is about 4 ºC for Port Vila and 5 ºC for Aneityum. There has been a clear shift towards warmer average monthly temperatures between the climatology periods of 1961–1990 and 1991–2020 (Figure 16.5), with warmer average maximum temperatures occurring in all months throughout the year for both Port Vila and Aneityum. The range in average monthly minimum temperatures is 5 °C for both Port Vila and Aneityum.

Figure 16.5:
Maximum and minimum air temperature seasonal cycle for Port Vila (purple) and Aneityum (green), and for the periods 1961–1990 (dotted lines) and 1991–2020 (solid lines)



16.5.2 Trends

Average annual and seasonal temperatures have increased at Aneityum and Port Vila (Figure 16.6). All temperature trends at both sites are statistically significant, except for May–October minimum temperatures at Aneityum (Table 16.2). November–April temperatures have increased faster than May–October temperatures, and maximum temperatures have increased faster than minimum temperatures, particularly at Aneityum.

Figure 16.6:
Average annual, November–April and May–October temperatures for Aneityum (left) and Port Vila (right). Straight lines indicate linear trends. The magnitudes of the trends are presented in Table 16.2. Diamonds indicate years with insufficient data for one or more variables.

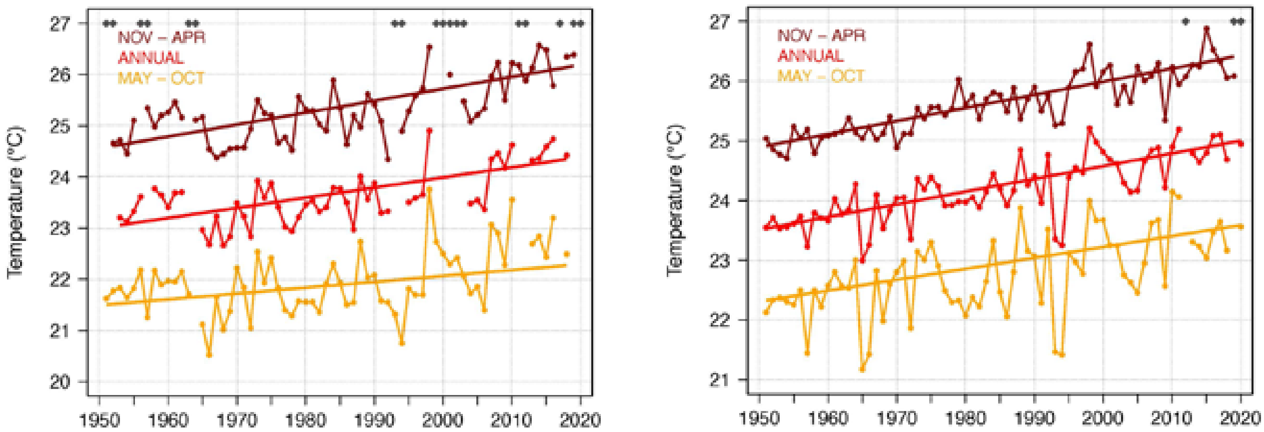
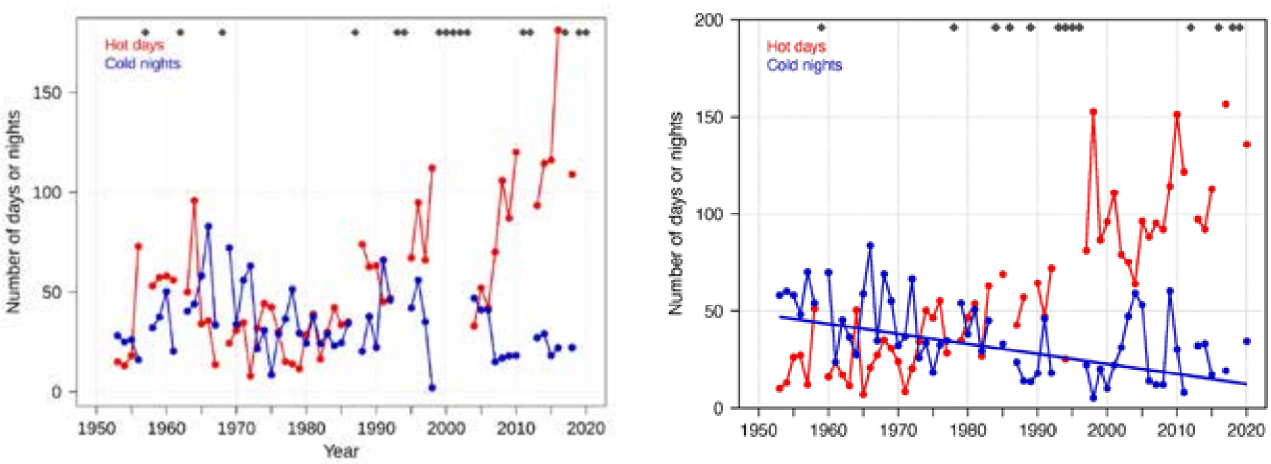


Table 16.2:
Trends in annual and seasonal air temperatures at Aneityum (top) and Port Vila (bottom). The 95% confidence intervals are shown in parentheses, and trends significant at the 95% level are shown in bold.

	Aneityum Tmax (°C/decade)	Aneityum Tmin (°C/decade)	Aneityum Tmean (°C/decade)	Port Vila Tmax (°C/10yrs)	Port Vila Tmin (°C/10yrs)	Port Vila Tmean (°C/10yrs)
	1951–2019			1951–2020		
Annual	**+0.33** (+0.17, +0.47)	**+0.14** (0.00, +0.25)	**+0.20** (+0.08, +0.32)	**+0.24** (+0.20, +0.29)	**+0.17** (+0.10, +0.23)	**+0.21** (+0.16, +0.25)
November–April	**+0.30** (+0.17, +0.44)	**+0.18** (+0.07, +0.28)	**+0.23** (+0.13, +0.34)	**+0.26** (+0.22, +0.31)	**+0.17** (+0.12, +0.22)	**+0.22** (+0.19, +0.25)
May–October	**+0.21** (+0.08, +0.32)	+0.06 (-0.08, +0.22)	**+0.11** (+0.01, +0.24)	**+0.21** (+0.15, +0.28)	**+0.16** (+0.06, +0.27)	**+0.18** (+0.10, +0.27)

Figure 16.7 shows the number of hot days and cold nights at Aneityum and Port Vila. Numerous gaps in daily data prevent the robust calculation of trends in most temperature extremes. However, the number of cold nights at Port Vila is decreasing significantly. Hot days have also occurred more than twice as frequently in recent years at both sites compared to the beginning of their records. This is consistent with the increases in annual and seasonal temperatures (Figure 16.6) as well as trends in temperature extremes for neighbouring Pacific Island countries.

Figure 16.7:
Annual number of hot days and cold nights at Aneityum (left) and Port Vila (right). The straight line indicates the linear trend. Criteria for statistical robustness were not met for determining linear trends at Aneityum and for hot days at Port Vila. Diamonds indicate years with insufficient data for one or both variables.



16.6 Tropical cyclones

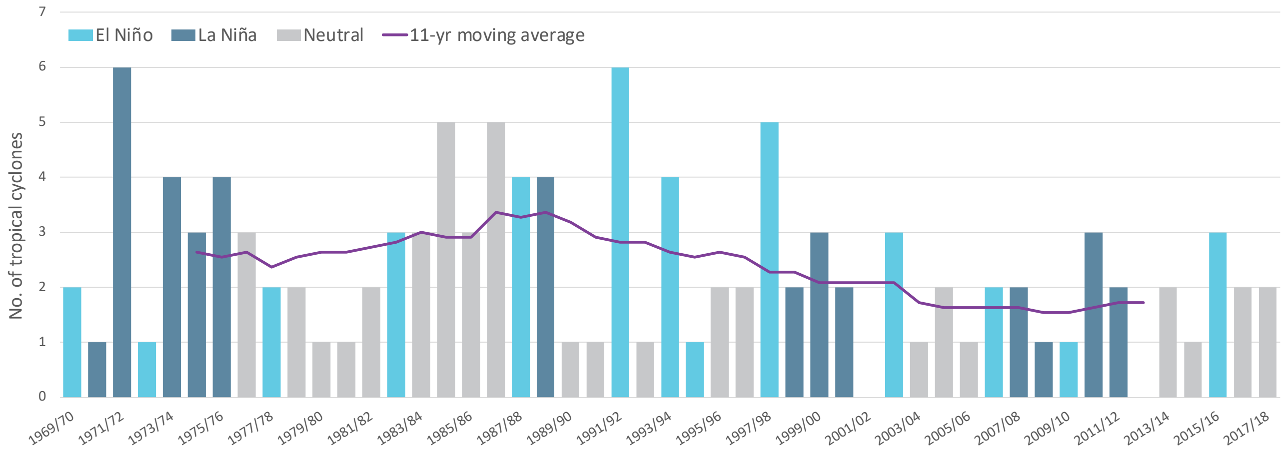
16.6.1 Seasonal cycle

Tropical cyclones usually affect Vanuatu 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, 117 tropical cyclones (Figure 16.8) passed within the EEZ. This represents an average of 24 cyclones per decade. Tropical cyclones were most frequent in El Niño years (28 cyclones per decade), followed by La Niña years (26 per decade) and least frequent in neutral years (20 cyclones per decade).

Interannual variability in the number of tropical cyclones in the EEZ is large, ranging from zero in some seasons to six in 1971/72 and 1991/92, and five in 1984/85, 1986/87 and 1997/98 (Figure 16.8). 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 16.8:
Number of tropical cyclones passing within the Vanuatu 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.



16.6.2 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.

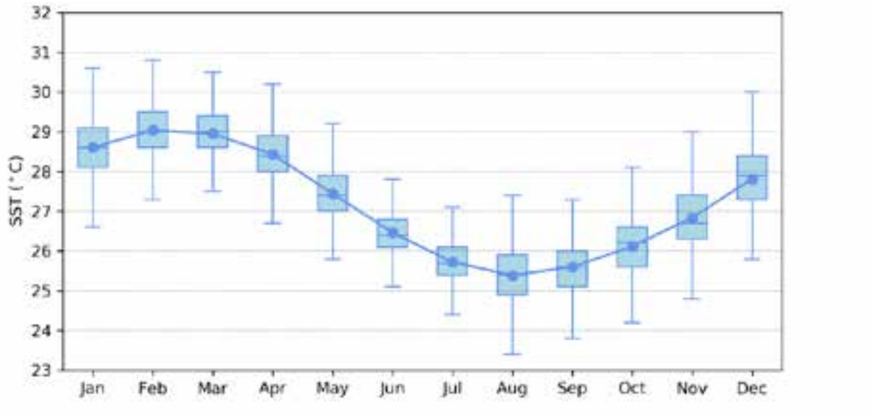
Records of tropical cyclones exist from the late 1800s in some countries in the Southwest Pacific, but trends in tropical cyclones have only been presented from 1981/82. Satellite-based observations began in the Southwest Pacific in the early 1970s, but consistent coverage and reliable intensity estimates 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.

16.7 Sea surface temperature

16.7.1 Seasonal cycle

Ocean temperature, as measured by the Port Vila tide-gauge from 1993 to 2021, reaches on average a maximum of 29 °C in February/March, but individual months can get as high as almost 31 °C in January–March (Figure 16.9). Minimum average temperature is 25.5 °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.

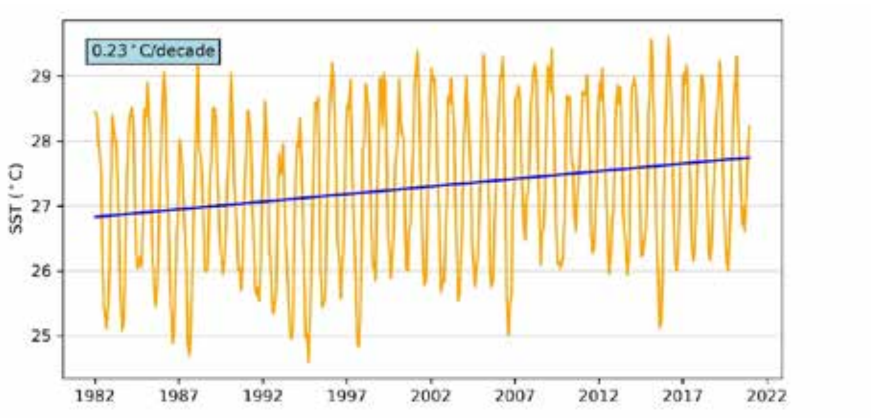
Figure 16.9:
Annual temperatures measured at the Port Vila tide-gauge. Blue dots show the monthly average, and shaded boxes show the middle 50% of observations. Lines show the top and bottom 25% of observations.



16.7.2 Trends

Figure 16.10 shows the 1981–2021 SST from satellite observations averaged over the EEZ. The data show a trend of 0.23 °C per decade with a 95% confidence interval of ±0.1 °C.

Figure 16.10:
Sea surface temperature from satellite observations averaged across the Vanuatu EEZ, shown as the orange line. The blue line shows the linear regression trend.



16.8 Sea level

16.8.1 Seasonal cycle

Vanuatu experiences a semidiurnal tidal cycle, meaning two high and two low tides per day, although high and low tides are often asymmetrical on a given day. The highest predicted tides of the year typically occur during the wet season months of November–February. Figure 16.11 shows the number of hours the 99th percentile (1.63 m) sea level threshold is exceeded per month across the entire sea level record at Port Vila. Peak sea levels typically occur from October to March.

Figure 16.11:
Number of hours exceeding 99th percentile sea level threshold per month from 1993 to 2021 at the Port Vila 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 1.63 m (Port Vila, Vanuatu)

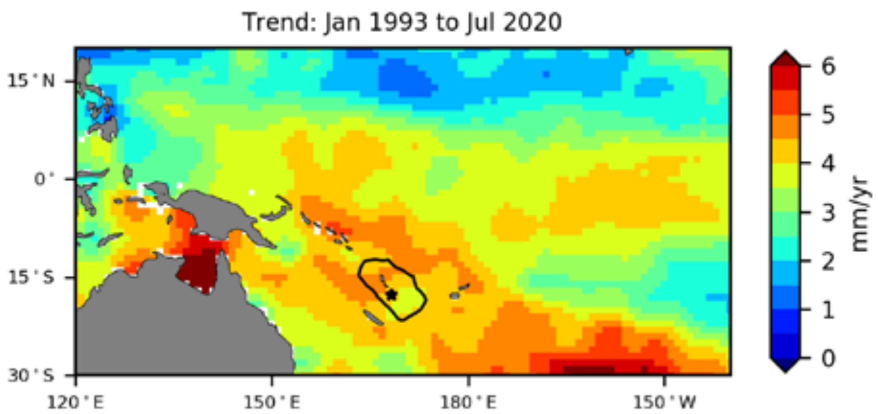
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1993	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0	0	0	0	2	0	2
1996	8	0	0	0	0	0	0	0	0	2	0	1	11
1997	5	0	12	0	0	0	0	0	0	0	0	0	17
1998	0	0	0	0	0	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	2	1	3
2001	1	1	0	2	0	0	0	0	0	1	1	3	9
2002	0	0	3	0	0	0	0	0	0	2	0	0	5
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	1	0	0	0	0	0	0	0	0	0	0	1
2006	4	0	0	0	0	0	0	0	0	0	0	0	4
2007	0	0	0	0	0	0	0	0	0	8	8	0	16
2008	0	0	0	1	1	0	0	0	0	6	14	1	23
2009	14	0	4	0	0	0	0	0	2	5	0	0	25
2010	0	0	2	0	0	0	0	0	0	0	0	0	2
2011	0	0	0	1	0	0	0	0	5	8	0	5	19
2012	0	0	0	0	0	0	0	0	0	0	0	2	2
2013	1	0	0	0	0	0	0	0	0	0	0	0	1
2014	0	0	0	0	0	0	0	0	0	1	0	0	1
2015	0	0	2	0	0	0	0	0	0	0	0	0	2
2016	0	0	0	0	0	0	0	0	0	0	0	0	0
2017	0	0	0	0	0	0	0	0	0	0	0	0	0
2018	3	0	0	0	0	0	0	0	0	0	0	0	3
2019	0	1	0	0	0	0	0	0	0	0	0	0	1
2020	0	0	0	0	0	0	0	0	0	2	0	3	5
2021	0	0	0	0	0	0	0	0	0	2	4	5	11
Monthly Totals (%)	22	2	14	2	1	0	0	0	4	23	19	13	

16.8.2 Trends

Sea level at Vanuatu, measured by satellite altimeters (Figure 16.12) since 1993, has risen between 3.5 and 5 mm per year across the EEZ, with a confidence interval of ±0.4 mm in the south and up to ±1.0 mm in the north. Most of the EEZ exhibits sea-level rise that is larger than the global average of 3.1 ± 0.4 mm per year (von Schuckmann et al. 2021). This rise is partly linked to a pattern related to climate variability from year to year and decade to decade.

Trend estimates at the Port Vila tide-gauge over a similar time span to the altimetry observations (January 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 Port Vila, the trend is reported as 0.3 mm per year, much less than the altimetry trends shown in Figure 16.12 (tide-gauge indicated by star symbol). Vanuatu is one of the few places in the Southwest Pacific that has islands experiencing geodetic uplift (rising land) (Brown et al. 2020). The tide-gauge fixed to land shows the trend relative to the rising land and therefore offsets the effects of sea-level rise.

Figure 16.12: Satellite altimetry annual trend for the Pacific from 1993 to 2020, with the Vanuatu EEZ highlighted. The star symbol indicates the location of the tide-gauge at Port Vila.



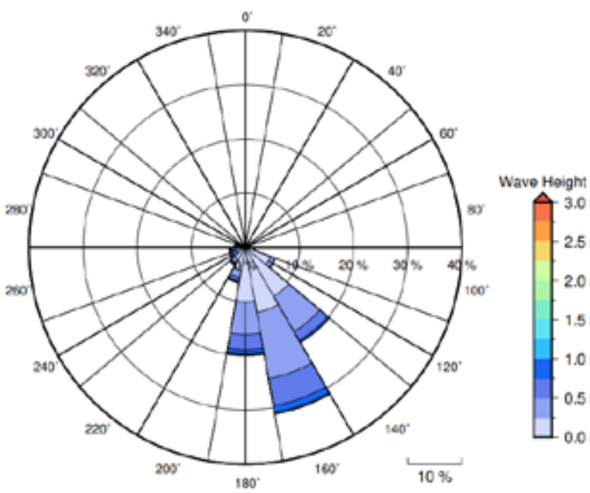
16.9 Waves

16.9.1 Seasonal cycle

The average wave climate at Port Vila 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.

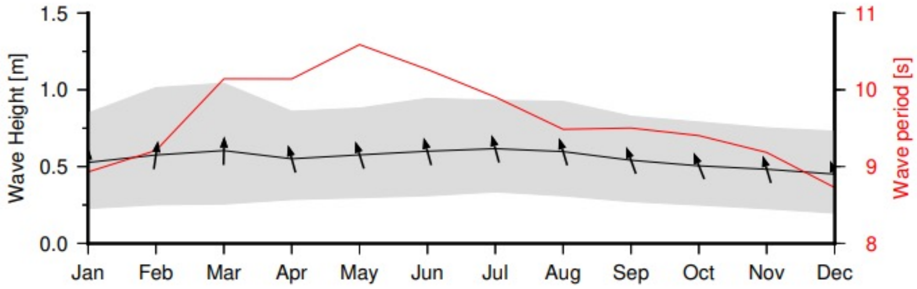
The average sea state is dominated by wind seas from the south. The annual mean wave height is 0.55 m, the annual mean wave direction is 182° and the annual mean wave period is 9.63 s. In the Pacific, waves often come from multiple directions and for different periods at a time. In Port Vila, there are often more than four different wave direction/period components coming from the southeast to southwest (Figure 16.13).

Figure 16.13:
Annual wave rose for Port Vila. Note that direction is where the wave is coming from.



Seasonal wave height remains relatively consistent throughout the year. Wave period has a definitive peak in May (Figure 16.14).

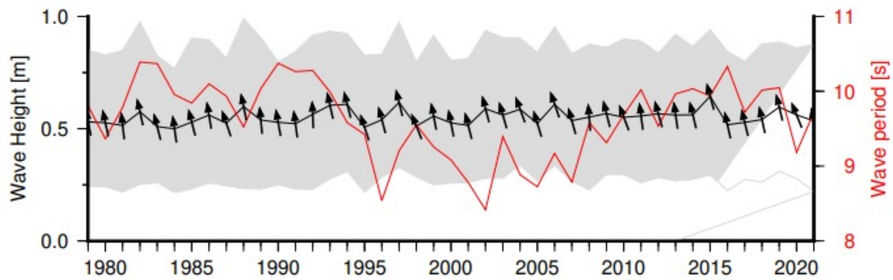
Figure 16.14:
Monthly wave height (black line), wave period (red line) and wave direction (arrows). The grey area represents the range of wave height between calm periods (10% of lowest wave height) and large wave events (10% of highest wave height).



16.9.2 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 Port Vila, the mean annual wave height has remained unchanged since 1979 (Figure 16.15). The mean annual wave height in Port Vila is not significantly correlated with the main climate indicators of the region.

Figure 16.15:
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).



16.9.3 Extreme waves

Extreme wave analysis completed for Port Vila was done by defining a severe height threshold and fitting a generalized Pareto distribution (GPD). The optimum threshold selected was 1.83 m. In the 42-year wave hindcast, 116 wave events reached or exceeded this threshold, averaging 2.8 events per year. The GPD was fitted to the largest wave height reached during each of these events (Figure 16.16, Table 16.4). 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 16.16:
Extreme wave distribution for Port Vila. 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.

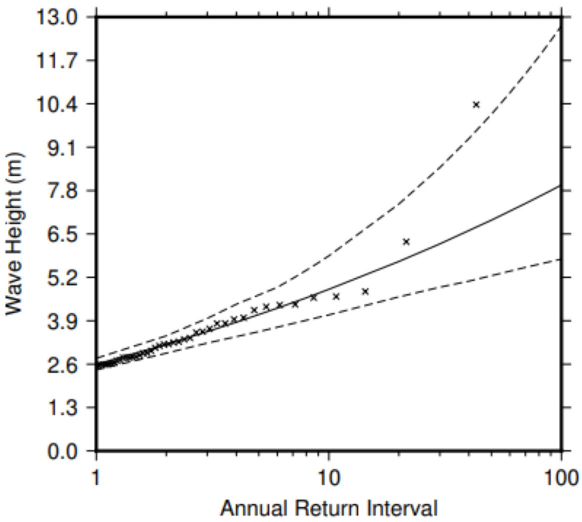


Table 16.4:
Summary of the results from extreme wave analysis in Port Vila.

Large wave height (90th percentile)	0.87 m
Severe wave height (99th percentile)	1.59 m
1-year ARI wave height	2.59 m
10-year ARI wave height	4.84 m
20-year ARI wave height	5.68 m
50-year ARI wave height	6.92 m
100-year ARI wave height	7.97 m