10 Papua New Guinea

10.1 Summary

10.1.1 Climate

- Changes in air temperature from season to season for Papua New Guinea (PNG) island locations and along the coast of the mainland are relatively small and strongly linked to changes in the surrounding ocean temperature.
- Port Moresby has a wet season from December to April influenced by the West Pacific Monsoon (WPM), while Momote Airport (Manus Island), further north, has more consistent rainfall through the year influenced by the Intertropical Convergence Zone (ITCZ).
- Annual and seasonal air temperatures at Port Moresby increased over the period 1951–2019. The annual number of hot days and warm nights has increased, while the number of cool days and cold nights has decreased. The energy required for cooling indoor environments has increased and the difference between daytime and night-time temperatures has decreased.
- There has been little change in annual, seasonal and extreme rainfall at Port Moresby and Momote.
- Tropical cyclones usually affect PNG between November and April. Over the period 1969–2018, an average of 16 cyclones passed within the PNG exclusive economic zone (EEZ) per decade. Tropical cyclones were most frequent in neutral El Niño–Southern Oscillation (ENSO) 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 the 1971/72 season.
- 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.

10.1.2 Ocean

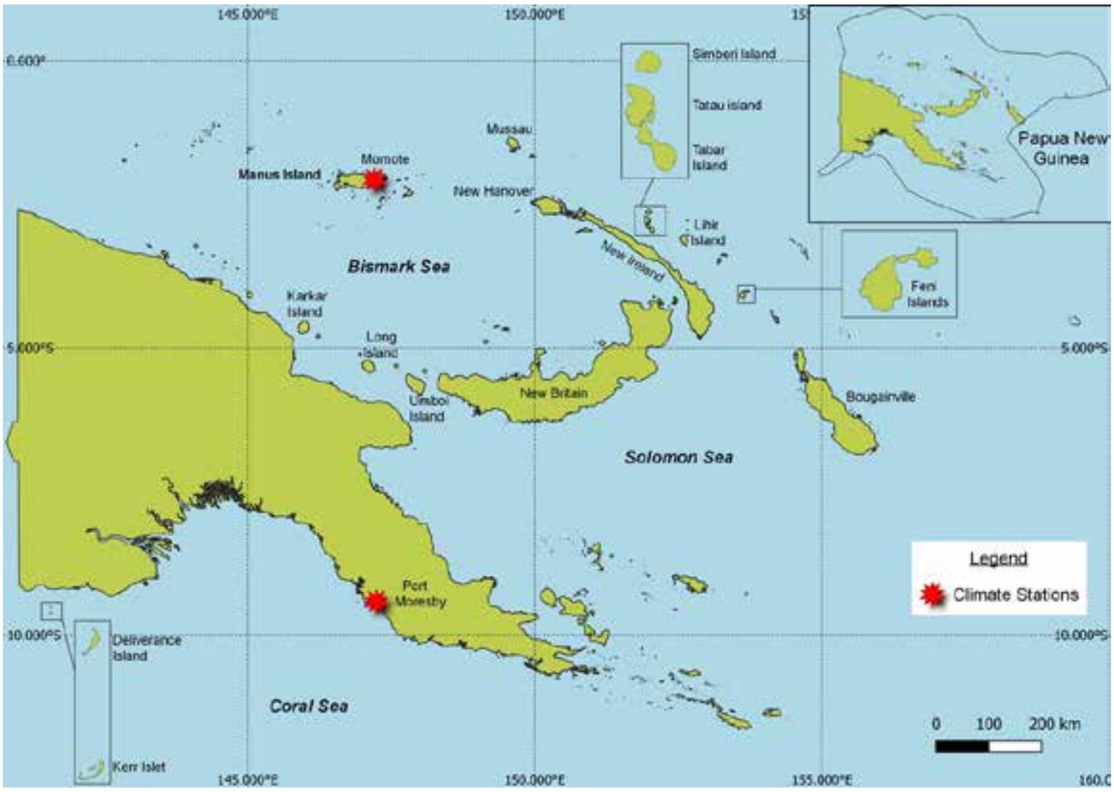
- Highest sea levels typically occur in the months November–February, with the majority in December/January. La Niña brings noticeably higher sea levels in December and January, with the year 2021 representing almost half of the exceedance hours in the 27-year record.
- Sea-level rise within the EEZ, measured by satellite altimeters from 1993 to mid-2020, ranges from about 2.5 to 5.0 mm per year, with highest estimates in the east and southwest.
- Monthly average ocean temperature, as measured by the Lombrum (Manus Island) tide-gauge, ranges from approximately 30 °C in February to 32.7 °C in November and 30.7 °C in May. However, monthly temperatures in any given year can be up to ±2 °C of these averages.
- The sea surface temperature (SST) trend in the EEZ is 0.23 °C per decade.
- Dominant wave direction is from 55° (NE), with an average significant wave height of 0.47 m and average wave period of 9.08 s.
- Severe wave height was defined as 1.23 m, with an average of 2.4 severe events per year.
- Peak average significant wave height occurs between July and September, driven predominantly by strong local winds.

10.2 Country description

The Independent State of Papua New Guinea is located in the equatorial/tropical South Pacific Ocean between latitudes 1°S and 11°S, and longitudes 141°E and 157°E (Figure 10.1). PNG is the world's third-largest island country. The mainland is the eastern half of New Guinea island. Other major islands include New Ireland, New Britain, Manus and Bougainville. There are over 600 lesser islets and atolls to the north and east. PNG has a total land area of 462,840 km^2 and an EEZ of 2.4 million km^2. The highest elevation is 4509 m at Mt Wilhelm. There are several major rivers, including the Sepik River, which runs through lowland swamp plains to the north coast, and the Fly River, which flows to the south coast.

PNG's population is estimated to be just over 9 million. About 87% of the population live in rural areas, with 40% in highlands. PNG's capital, located along its southeast coast, is Port Moresby (population approximately 400,000).

Figure 10.1:
Papua New Guinea and the locations of the climate stations used in this report



10.3 Data

Daily historical rainfall and air temperature records for Port Moresby and Momote (Manus Island) from 1951 were obtained from the PNG National Weather 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 PNG 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 Lombrum (Manus Island), with data spanning from 1994 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 PNG 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 Lombrum tide-gauge station, spanning from 1994 to 2021 at hourly intervals.

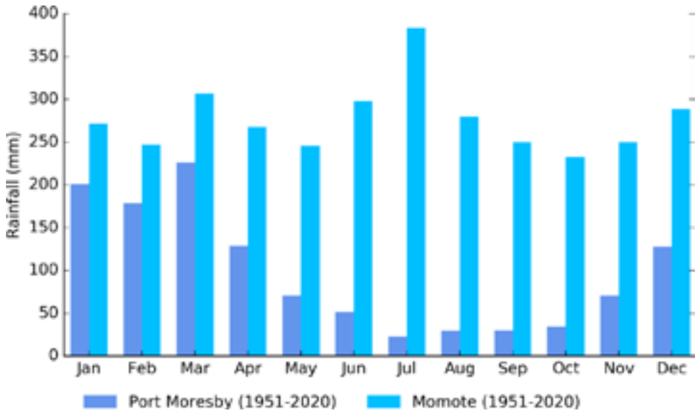
10.4 Rainfall

10.4.1 Seasonal cycle

Port Moresby has a wet season between December and April, with 80% of the annual rainfall occurring during these months (Figure 10.2). The WPM is responsible for most of the rainfall in Port Moresby early in the year. During May–October, dry south-easterly winds are more dominant, leading to reduced rainfall.

Momote has more consistent rainfall throughout the year and with an annual total of over 3300 mm, it receives almost three times the amount of rainfall as Port Moresby. The peak rainfall month is July with an average of 383 mm. Due to its location, Momote is strongly influenced by the ITCZ and the Pacific Warm Pool, which act to bring high rainfall throughout the year.

Figure 10.2:
Mean annual rainfall at Port Moresby and Momote



10.4.2 Trends

Trends in annual and seasonal rainfall are not statistically significant at Port Moresby and Momote (Figure 10.3, Table 10.1).

Annual and seasonal rainfall trends indicate little change at these sites. Annual rainfall has varied from approximately 600 to 1600 mm at Port Moresby and from approximately 1600 to 4700 mm at Momote.

Figure 10.3:
Annual rainfall (bar graph) and number of wet days (where rainfall is at least 1 mm; line graph) at Port Moresby (left) and Momote (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 10.1. Diamonds indicate years with insufficient data for one or both variables.

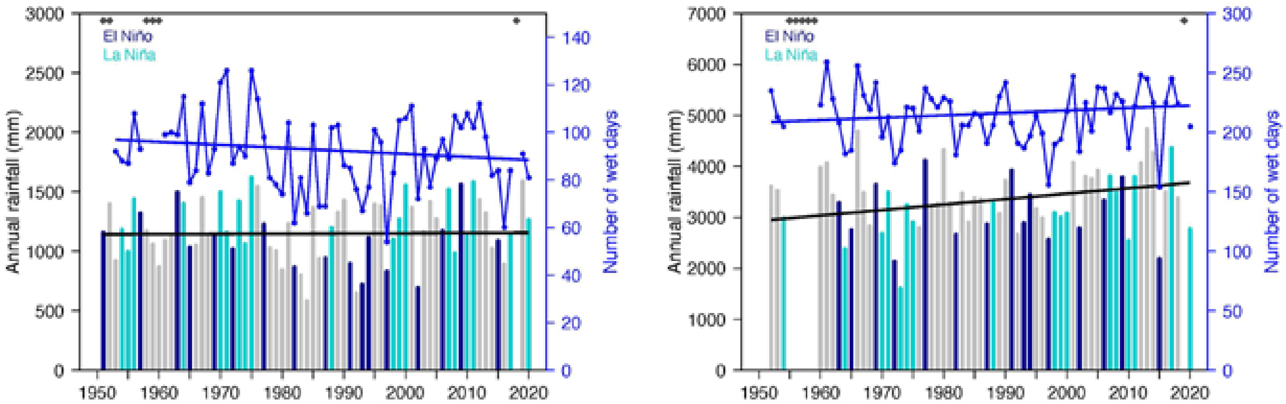
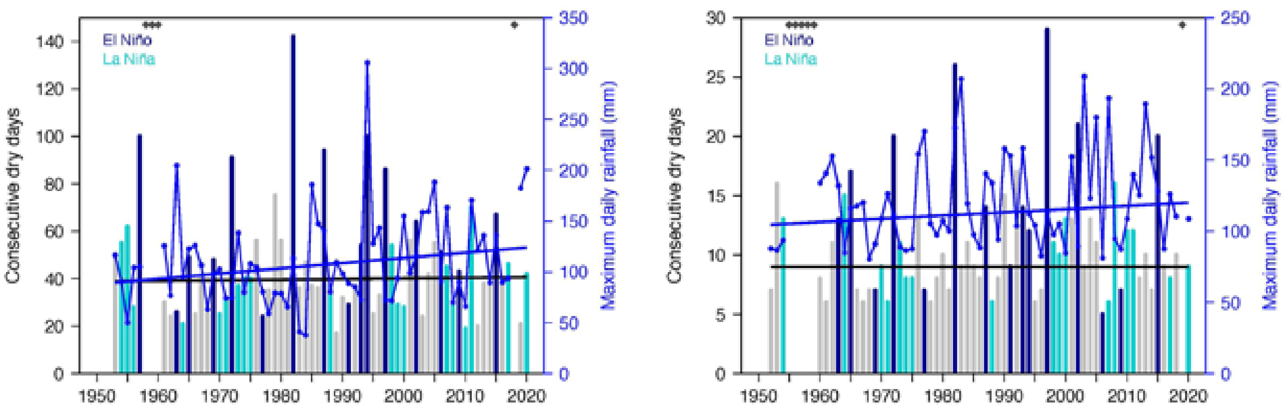


Table 10.1:
Trends in annual, seasonal and extreme rainfall at Port Moresby (left) and Momote (right). The 95% confidence intervals are shown in parentheses. The contribution to total rainfall from extreme events and the standardised rainfall evapotranspiration index are measured relative to 1961–1990 (see Chapter 1 for details). The standardised rainfall evapotranspiration index is not available for Momote due to the lack of daily temperature observations at this site.

	Port Moresby	Momote
	1951–2020	1952–2020
Annual rainfall (mm/decade)	+1.98 (-43.98, +40.46)	+107.02 (-6.69, +201.38)
November–April (mm/decade)	-3.57 (-35.50, +26.04)	+15.86 (-25.30, +57.64)
May–October (mm/decade)	+8.00 (-7.11, +21.33)	+76.60 (-2.28, +142.43)
Number of wet days (days/decade)	-1.27 (-4.54, +1.81)	+2.05 (-2.72, +6.22)
Contribution to total rainfall from extreme events (%/decade)	+1.16 (-0.42, +2.62)	+0.59 (-0.37, +1.54)
Consecutive dry days (days/decade)	+0.25 (-2.14, +2.61)	0.00 (-0.31, +0.64)
Maximum one-day rainfall (mm/decade)	+5.12 (-0.69, +10.61)	+2.25 (-2.16, +6.87)
Standardised rainfall evapotranspiration index (November–April)	0.00 (-0.20, +0.16)	-
Standardised rainfall evapotranspiration index (May–October)	+0.14 (-0.03, +0.29)	-

Similar to annual and seasonal rainfall, no significant trends in extreme rainfall indices, including the standardised rainfall evapotranspiration drought index, were detected (Table 10.1). Figure 10.4 shows change and variability in the longest run of days without rain and maximum daily rainfall at Port Moresby and Momote. Substantial variability associated with ENSO is evident at both sites, with El Niño years typically experiencing longer dry spells than La Niña years.

Figure 10.4:
Annual longest run of consecutive dry days (bar graph) and maximum daily rainfall (line graph) at Port Moresby (left) and Momote (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 10.1. Diamonds indicate years with insufficient data for one or both variables.



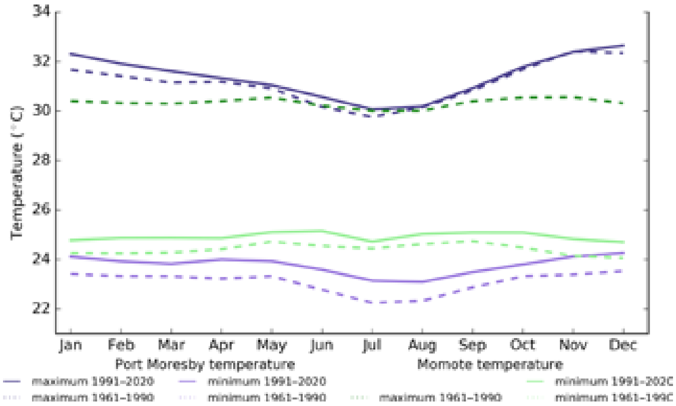
10.5 Air temperature

10.5.1 Seasonal cycle

Coastal locations on the PNG mainland and offshore islands experience small seasonal variations in temperature (Figure 10.5), the largest of which is a maximum temperature range of 1.3 °C at Port Moresby for the 1961–1990 climatology period and 1.2 °C for the 1991–2020 period. There is a peak in maximum temperature during the wet season and a minimum during the dry season months of June–August. The seasonal range in temperature is less than 1 °C for minimum temperature and for both daytime and night-time temperatures at Momote station on Manus Island, which is more strongly influenced by the surrounding sea surface temperature.

There has been a clear shift towards warmer average minimum monthly temperatures between the climatology periods of 1961–1990 and 1991–2020 (Figure 10.5) at Port Moresby and Momote. For maximum temperatures at Port Moresby, temperatures are warmer during the first few months of the year for the most recent climatology period but similar between the earlier and later climatology period for the remainder of the year.

Figure 10.5:
Maximum and minimum air temperature seasonal cycle for Port Moresby (purple) and Momote (green), and for the periods 1961–1990 (dotted lines) and 1991–2020 (solid lines)



10.5.2 Trends

Average annual and seasonal temperatures have increased significantly at Port Moresby (Figure 10.6). Daily minimum temperatures are warming faster than daily maximum temperatures (Table 10.2). The small year-to-year fluctuations in temperature can be attributed to Port Moresby's tropical location.

Figure 10.6:
Average annual, November–April and May–October temperatures for Port Moresby. Straight lines indicate linear trends. The magnitudes of the trends are presented in Table 10.2. Diamonds indicate years with insufficient data for one or more variables.

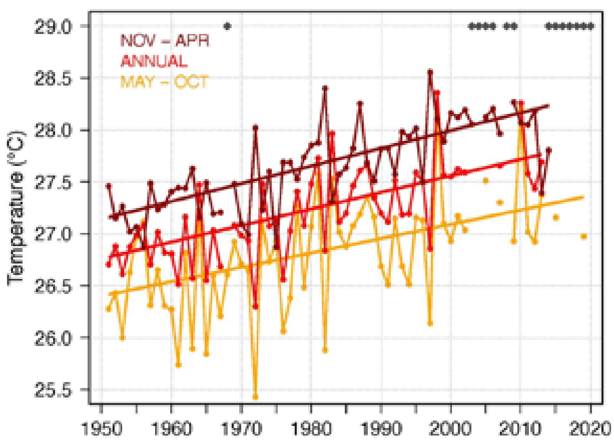


Table 10.2:
Trends in annual and seasonal air temperatures at Port Moresby. The 95% confidence intervals are shown in parentheses, and trends significant at the 95% level are shown in bold.

	Port Moresby Tmax (°C/decade)	Port Moresby Tmin (°C/decade)	Port Moresby Tmean (°C/decade)
	1951–2019		
Annual	**+0.11** (+0.05, +0.16)	**+0.21** (+0.17, +0.25)	**+0.16** (+0.13, +0.19)
November–April	**+0.12** (+0.07, +0.16)	**+0.23** (+0.18, +0.27)	**+0.17** (+0.14, +0.20)
May–October	**+0.08** (+0.01, +0.17)	**+0.22** (+0.17, +0.27)	**+0.14** (+0.08, +0.20)

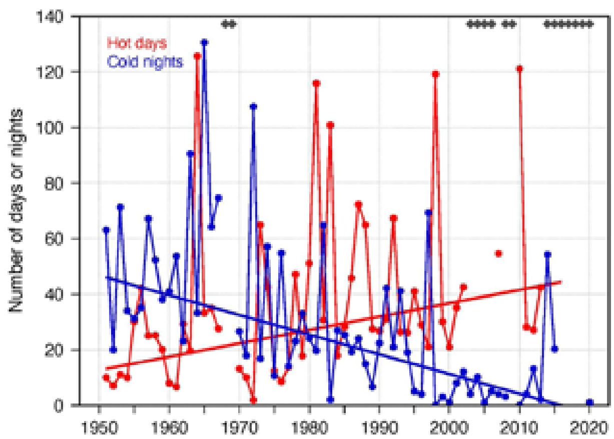
The number of hot days and warm nights has increased, and the number of cool days and cold nights has decreased at Port Moresby (Table 10.3, Figure 10.7). The high year-to-year variability in the number of hot days and cold nights may be related to Port Moresby's tropical location, which requires only small temperature increases for a day to be considered hot or a night to be considered cold, i.e., to be in the hottest or coldest 10% of days or nights compared to 1961–1990 (see Chapter 1 for details).

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 1951. The difference between daytime and night-time temperatures has also been decreasing (Table 10.3).

Table 10.3:
Trends in annual temperature extremes at Port Moresby. 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 1961–1990 (see Chapter 1 for details).

	Port Moresby
	1951–2020
Number of hot days (days/decade)	**+4.81** (+2.23, +7.97)
Number of warm nights (nights/decade)	**+8.47** (+5.46, +11.23)
Number of cool days (days/decade)	**-4.55** (-7.56, 2.00)
Number of cold nights (nights/decade)	**-7.09** (-9.56, 5.41)
Cooling degree days (degree days/decade)	**+49.96** (+36.72, +65.84)
Daily temperature range (°C/decade)	**-0.13** (-0.25, 0.02)

Figure 10.7:
Annual number of hot days and cold nights at Port Moresby. Straight lines indicate linear trends. The magnitudes of the trends are presented in Table 10.3. Diamonds indicate years with insufficient data for one or both variables.



10.6 Tropical cyclones

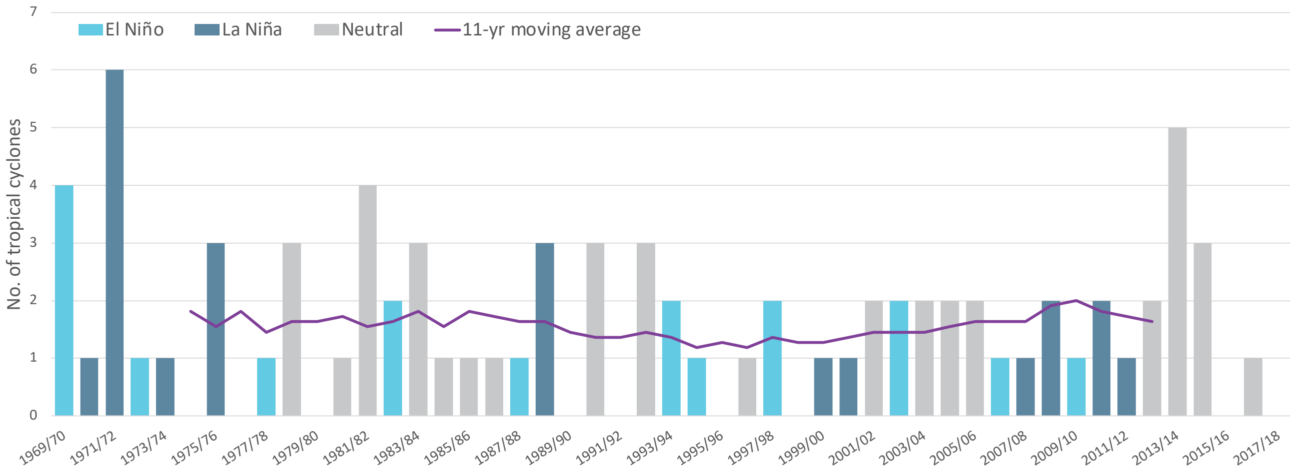
10.6.1 Seasonal cycle

Tropical cyclones usually affect PNG 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, 80 tropical cyclones (Figure 10.8) passed within the EEZ. This represents an average of 16 cyclones per decade. Tropical cyclones were most frequent in neutral years (18 cyclones per decade), followed by La Niña years (16 cyclones per decade) and least frequent in El Niño years (14 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 five in 2013/14 (Figure 10.8). 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 10.8:
Number of tropical cyclones passing within the PNG 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.



10.6.2 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.

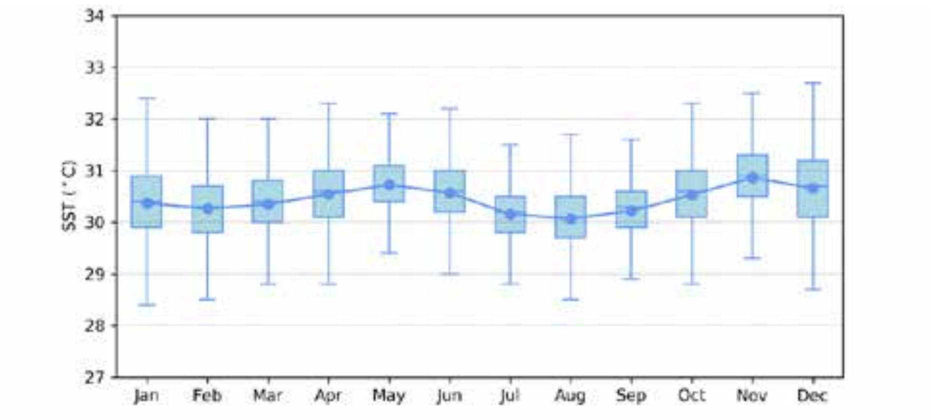
Records of tropical cyclones exist from the late 1800s in some countries in the Southwest Pacific, but trends in tropical cyclones have only been presented from 1981/82. Satellite-based observations began in the Southwest Pacific in the early 1970s, but consistent coverage and reliable intensity estimates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

10.7 Sea surface temperature

10.7.1 Seasonal cycle

Ocean temperature, as measured by the Lombrum tide-gauge from 1994 to 2021, reaches on average a maximum of approximately 31 °C in November with a secondary peak of 30.7 °C in May but can get as high as 32.7 °C in December (Figure 10.9). Minimum average temperature reaches almost 30 °C in February. There is little seasonal variation in the averages. However, temperatures can be up to 2.0 °C higher or lower than these averages, although 50% of observations fall within 1.0 °C of the average.

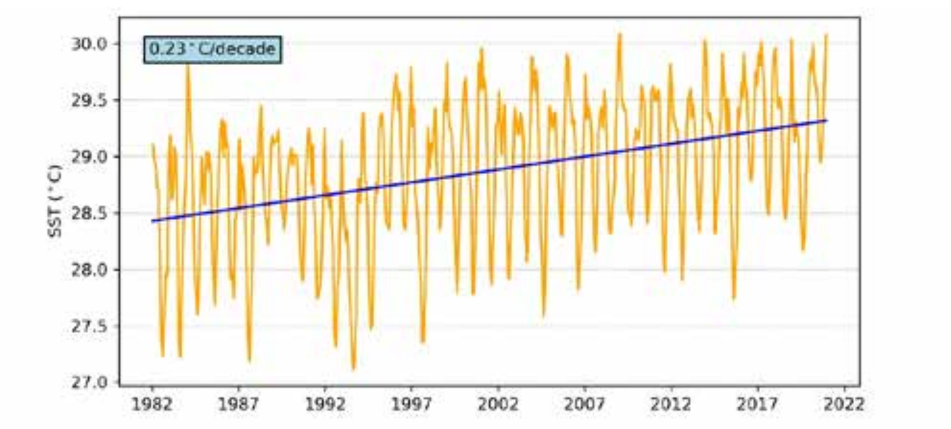
Figure 10.9:
Annual temperatures measured at the Lombrum tide gauge. Blue dots show the monthly average, and shaded boxes show the middle 50% of observations. Lines show the top and bottom 25% of observations.



10.7.2 Trends

Figure 10.10 shows the 1981–2021 sea surface temperature (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 ±0.05 °C.

Figure 10.10:
Sea surface temperature from satellite observations averaged across the PNG EEZ, shown as the orange line. The blue line shows the linear regression trend.



10.8 Sea level

10.8.1 Seasonal cycle

Tidal analysis of Lombrum sea level data shows that it experiences a diurnal tide, meaning only one high and one low tide per day. The highest predicted tides of the year typically occur mostly in December and January. Figure 10.11 shows the number of hours the 99th percentile (1.29 m) sea level threshold is exceeded per month across the entire sea level record at Lombrum. Peak sea levels typically occur between November and February, but they are mostly confined to December/January. La Niña years typically have higher sea levels in December and January. The year 2021 alone accounts for almost half of all exceedance hours in the record.

Figure 10.11:
Number of hours exceeding 99th percentile sea level threshold per month from 1994 to 2021 at the Lombrum 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 1.29 m (Lombrum, Papua New Guinea)

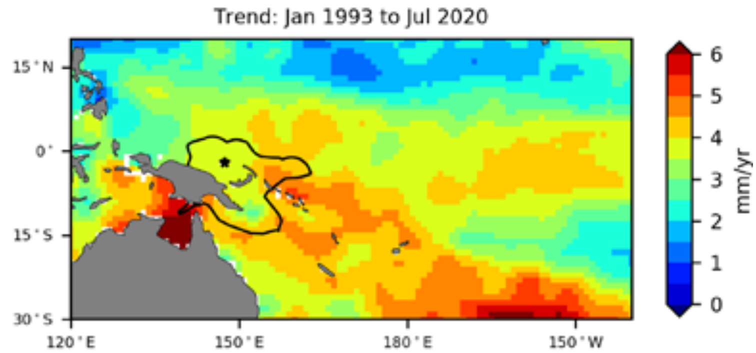
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1994	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0	0	0	0	0	0	0
1996	0	0	0	0	0	0	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	0	2	0	0	0	0	0	0	0	0	0	0	2
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	1	1
2006	10	0	0	0	0	0	0	0	0	0	0	0	10
2007	0	0	0	0	0	0	0	0	0	0	4	2	6
2008	0	2	0	0	0	0	0	0	0	0	0	4	6
2009	13	3	0	0	0	0	0	0	0	0	0	0	16
2010	0	0	0	0	0	0	0	0	0	0	3	5	8
2011	5	1	0	0	2	0	0	0	0	0	0	8	16
2012	6	0	0	0	0	0	0	0	0	0	0	0	6
2013	5	0	0	0	0	0	0	0	0	0	0	0	5
2014	7	0	0	0	0	0	0	0	0	0	0	0	7
2015	0	0	0	0	0	0	0	0	0	0	0	0	0
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	1	1
2018	17	0	0	1	0	0	4	0	0	4	0	2	28
2019	0	0	0	0	0	0	0	0	0	0	0	0	0
2020	0	0	0	0	0	0	0	0	0	1	0	13	14
2021	34	10	0	0	0	0	4	0	0	0	8	50	106
Monthly Totals (%)	42	8	0	0	1	0	3	0	0	2	6	37	

10.8.2 Trends

Sea level at PNG, measured by satellite altimeters (Figure 10.12) since 1993, has risen between 2.5 and 5.0 mm per year, with highest estimates in the east and southwest (around Torres Strait and the Gulf of Papua). For most of the Papua New Guinea EEZ, sea-level rise is larger than the global average of 3.1 ± 0.4 mm per year (von Schuckmann et al. 2021). The 95% confidence interval ranges from ±0.6 to ±1.2 mm. This rise is partly linked to a pattern related to climate variability from year to year and decade to decade.

Trend estimates at the Lombrum tide-gauge over a shorter time span than the altimetry observations (September 1994 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 Lombrum, the trend is reported as 5.1 mm per year, a higher trend than the altimetry trends shown in Figure 10.12 (tide-gauge indicated by star symbol). This difference is most likely attributed to subsidence occurring at Lombrum (Brown et al. 2020).

Figure 10.12:
The satellite altimetry annual trend for the Pacific from 1993 to 2020, with the PNG EEZ highlighted. The star symbol indicates the location of the tide-gauge at Lombrum, Manus Island.



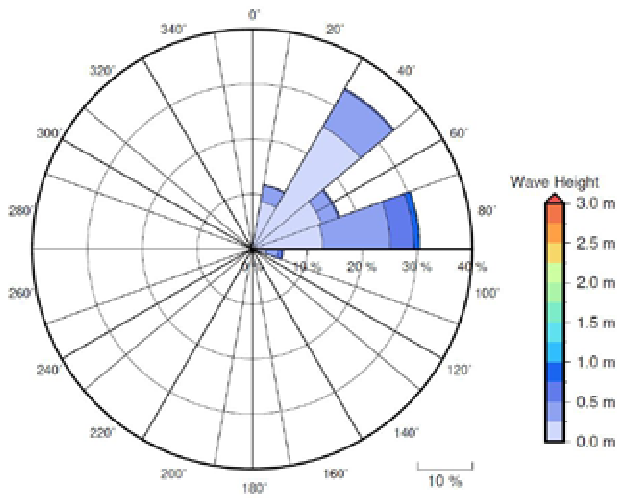
10.9 Waves

10.9.1 Seasonal cycle

The average wave climate in Madang (south of Karkar Island in the Bismarck Sea) 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.

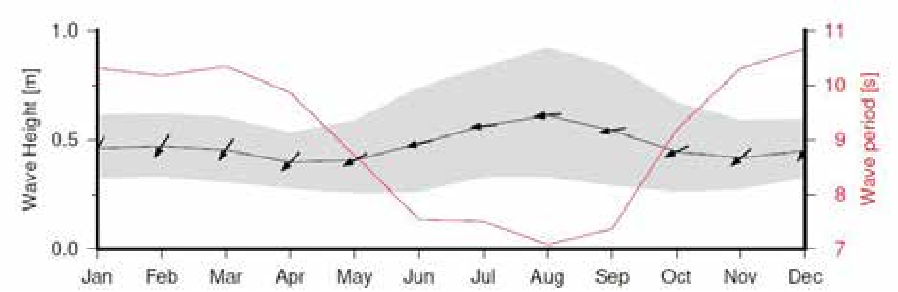
The average sea state is dominated by wind seas from the northeast. The annual mean wave height is 0.47 m, the annual mean wave direction is 55° and the annual mean wave period is 9.08 s. In the Pacific, waves often come from multiple directions and for different periods at a time. In Madang, there are often more than four different wave direction/period components coming from the southeast to southwest (Figure 10.13).

Figure 10.13:
Annual wave rose for Madang. Note that direction is where the wave is coming from.



The significant wave height peaks around August. However, the period peaks between November and March, and is significantly less between June and September (Figure 10.14), showing that waves at PNG are predominantly driven by strong easterly local winds between July and September.

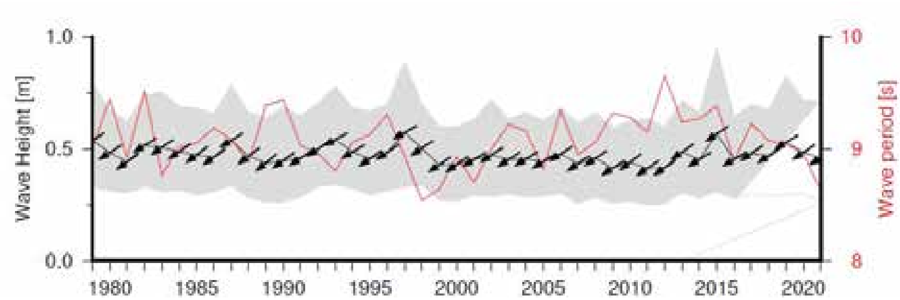
Figure 10.14:
Monthly wave height (black line), wave period (red line) and wave direction (arrows). The grey area represents the range of wave height between calm periods (10% of lowest wave height) and large wave events (10% of highest wave height).



10.9.2 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. At Madang, the mean annual wave height has remained unchanged since 1979 (Figure 10.15). The mean annual wave height in Madang is not significantly correlated with the main climate indicators of the region.

Figure 10.15:
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).



10.9.3 Extreme waves

Extreme wave analysis completed for Madang was done by defining a severe height threshold and fitting a generalized Pareto distribution (GPD). The optimum threshold selected was 1.23 m. In the 42-year wave hindcast, 102 wave events reached or exceeded this threshold, averaging 2.4 events per year. The GPD was fitted to the largest wave height reached during each of these events (Figure 10.16, Table 10.4). 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 10.16:
Extreme wave distribution for Madang. 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.

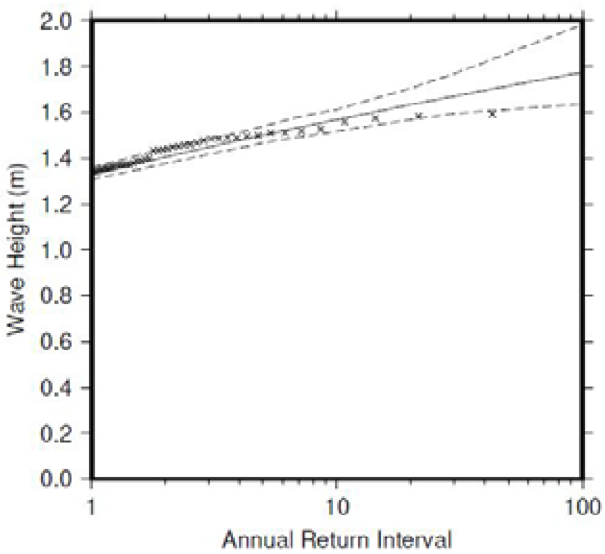


Table 10.4:
Summary of the results from extreme wave analysis in Madang

Large wave height (90th percentile)	0.69 m
Severe wave height (99th percentile)	0.99 m
1-year ARI wave height	1.33 m
10-year ARI wave height	1.57 m
20-year ARI wave height	1.63 m
50-year ARI wave height	1.71 m
100-year ARI wave height	1.77 m