15 Tuvalu

15.1 Summary

15.1.1 Climate

- Changes in air temperature from season to season are relatively small and strongly linked to changes in the surrounding ocean temperature. Tuvalu has two distinct rainfall seasons – a wet season from December to March and a dry season from April to November.
- 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 Funafuti increased over the period 1951–2020. 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 also increased.
- The longest stretch of days without rain each year at Funafuti has increased since 1951. Otherwise, trends in annual, seasonal and extreme rainfall show little change.
- Tropical cyclones usually affect Tuvalu between November and April. Over the period 1969–2018, an average of nine cyclones passed within the Tuvalu 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 2004/05 and 2015/16.
- 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.

15.1.2 Ocean

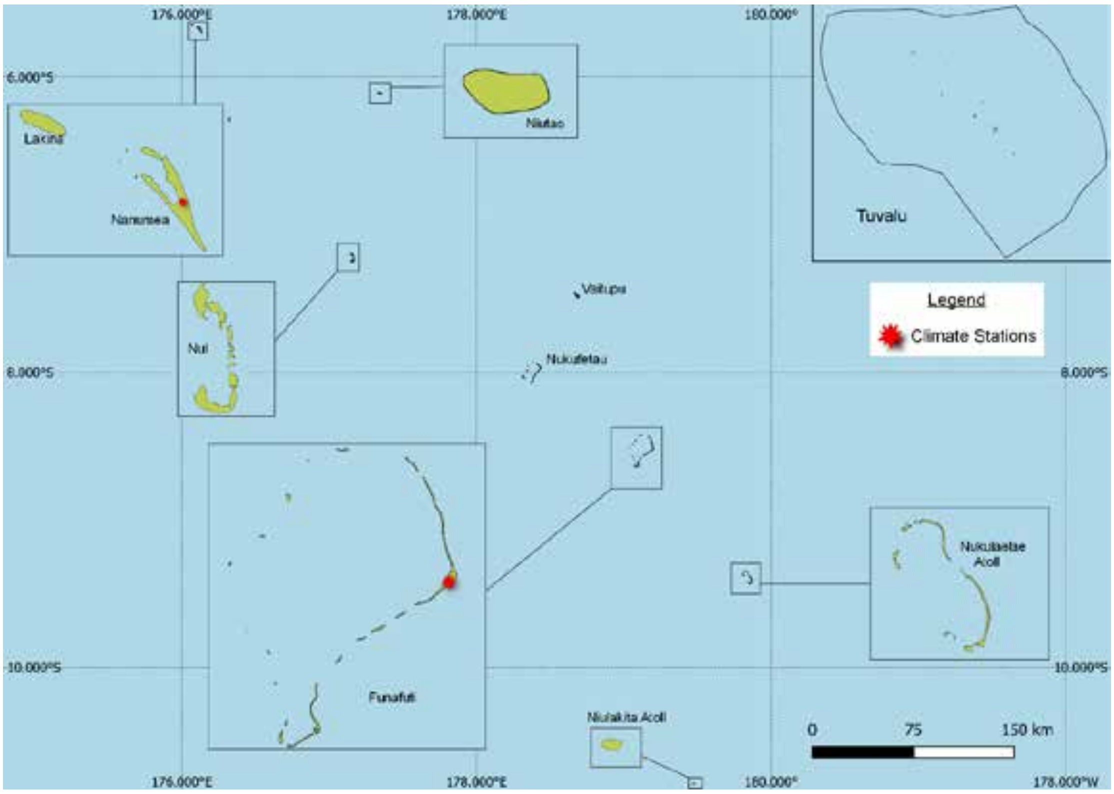
- Highest sea levels typically occur in the months January–April.
- Sea-level rise within the EEZ, measured by satellite altimeters from 1993 to mid-2020, ranges from 3.5 to 4.5 mm per year.
- Monthly average ocean temperature, as measured by the Funafuti tide-gauge, ranges from 29 °C in August to 30 °C in the months November/December and April/May, exhibiting a bimodal peak during the wet season. Monthly temperatures in any given year can be ±2 °C of these averages.
- The sea surface temperature (SST) trend in the EEZ is 0.22 °C per decade.
- Highest waves at Tuvalu occur in June–September, with a distinct lull during November–April.
- Dominant wave direction is from 117° (ESE), with an average significant wave height of 1.29 m and average wave period of 11.37 s.
- Severe wave height was defined as 2.26 m, with an average of 2.8 severe events per year.

15.2 Country description

Located in the tropical western South Pacific Ocean, Tuvalu is composed of three reef islands and six atolls between latitudes 5°S and 10°S, and longitudes 176°E and 180° (Figure 15.1). Tuvalu has a total land area of 26 km^2 and an EEZ of 0.9 million km^2.

Funafuti, the largest atoll at 2.4 km^2, includes the capital of the same name. The highest elevation is 4.6 m above sea level on Niulakita. Tuvalu's population is approximately 12,000. About 60% live on Funafuti.

Figure 15.1:
Tuvalu and the locations of the climate stations used in this report



15.3 Data

Daily historical rainfall and air temperature records for Funafuti and Nanumea from 1951 were obtained from the Tuvalu 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 Tuvalu 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 are 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 Funafuti, 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 Tuvalu 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 Funafuti tide-gauge station, spanning from 1993 to 2021 at hourly intervals.

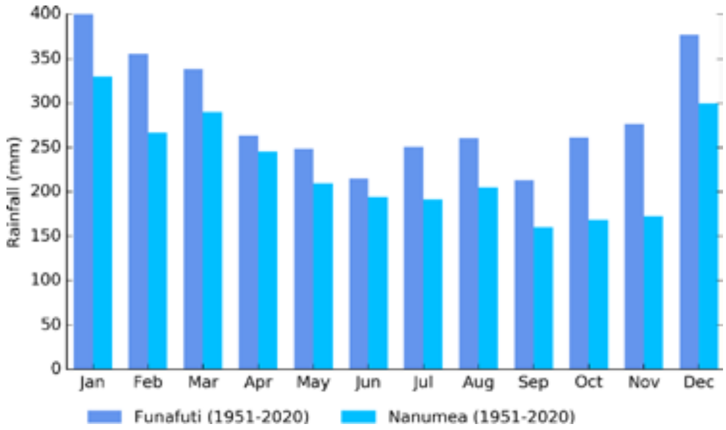
15.4 Rainfall

15.4.1 Seasonal cycle

Tuvalu is characterised by a distinct wet season from December to March (Figure 15.2), driven by the strength of the SPCZ, which is most active during the wet season months. The WPM can also bring high rainfall to Tuvalu during these months.

The percentage of rainfall received at Funafuti and Nanumea during the wet season months of December–March is 43%. Funafuti receives an average of 411 mm in January. The driest months at Nanumea are September–November, with average rainfall during September of 159 mm.

Figure 15.2:
Mean annual rainfall at Funafuti and Nanumea



15.4.2 Trends

Trends in annual and seasonal rainfall since 1951 are not statistically significant at Funafuti (Figure 15.3, Table 15.1). Annual rainfall since 1951 has varied from approximately 2000 to 4800 mm, and on average, over half of the days each year experience rain.

Figure 15.3:
Annual rainfall (bar graph) and number of wet days (where rainfall is at least 1 mm; line graph) at Funafuti. 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 15.1. Diamonds indicate years with insufficient data for one or both variables.

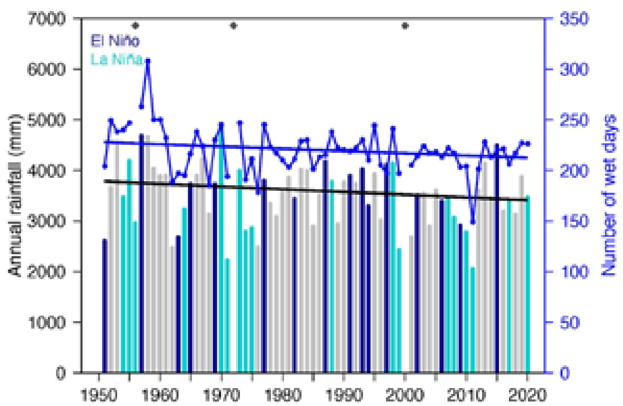
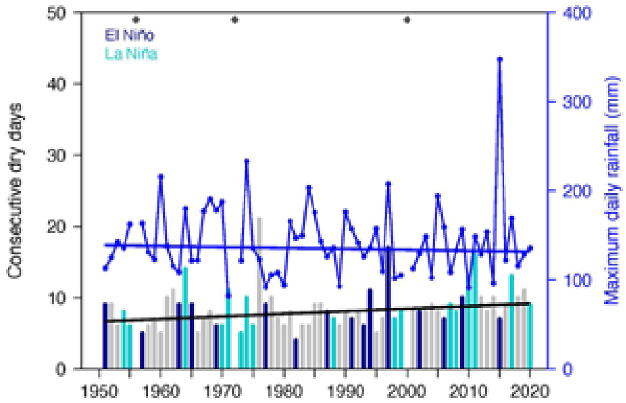


Table 15.1:
Trends in annual, seasonal and extreme rainfall at Funafuti. The 95% confidence intervals are shown in parentheses and trends significant at the 95% level are shown in bold. The contribution to total rainfall from extreme events and the standardised rainfall evapotranspiration index are measured relative to 1961–1990 (see Chapter 1 for details).

	Funafuti
	1951–2020
Annual rainfall (mm/decade)	-53.19 (-129.16, +32.61)
November–April (mm/decade)	-4.87 (-49.71, +43.10)
May–October (mm/decade)	-16.56 (-72.24, +36.81)
Number of wet days (days/decade)	-2.24 (-5.09, +0.97)
Contribution to total rainfall from extreme events (%/decade)	-0.29 (-1.10, +0.72)
Consecutive dry days (days/decade)	**+0.36** (+0.01, +0.63)
Maximum one-day rainfall (mm/decade)	-1.00 (-5.39, +3.17)
Standardised rainfall evapotranspiration index (November–April)	-0.01 (-0.15, +0.12)
Standardised rainfall evapotranspiration index (May–October)	-0.05 (-0.20, +0.09)

The longest run of days without rain each year has increased since 1951 (Table 15.1, Figure 15.4). Trends in all other extreme rainfall indices, including the standardised rainfall evapotranspiration drought index, are not statistically significant.

Figure 15.4:
Annual longest run of consecutive dry days (bar graph) and maximum daily rainfall (line graph) at Funafuti. 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 15.1. Diamonds indicate years with insufficient data for one or both variables.



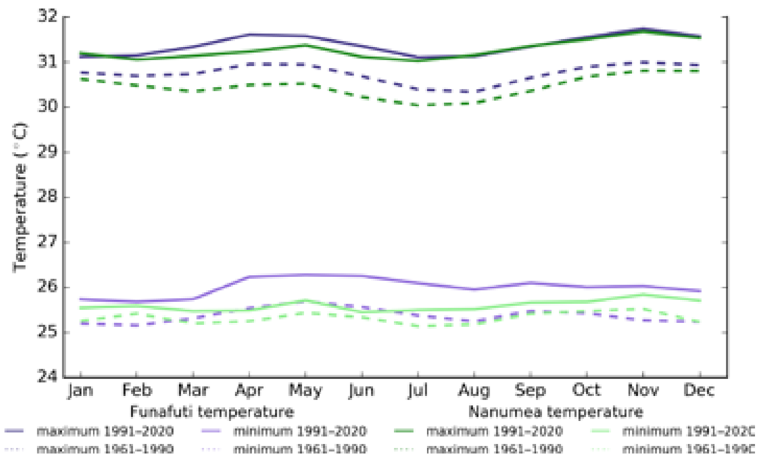
15.5 Air temperature

15.5.1 Seasonal cycle

Air temperatures have a small seasonal cycle at Funafuti and Nanumea, with less than 1 °C change in average monthly maximum and minimum temperatures during the year (Figure 15.5). Being small atoll islands, air temperatures over Tuvalu are strongly linked to the surrounding sea surface temperatures. In El Niño years, minimum air temperatures are typically higher, and conversely, minimum temperatures are typically lower during La Niña years, similarly for maximum air temperatures during the wet season.

There has been a clear shift towards warmer average monthly temperatures between the climatology periods of 1961–1990 and 1991–2020 (Figure 15.14), with warmer average temperatures occurring in all months throughout the year for both Funafuti and Nanumea, with the exception of average minimum temperatures at Nanumea for April and June.

Figure 15.5:
Maximum and minimum air temperature seasonal cycle for Funafuti (purple) and Nanumea (green), and for the periods 1961–1990 (dotted lines) and 1991–2020 (solid lines)



15.5.2 Trends

Average annual and seasonal temperatures have increased significantly at Funafuti (Figure 15.6). May–October temperatures are warming faster than November–April temperatures (Table 15.2). Daily minimum temperatures are warming faster than daily maximum temperatures. The relatively small year-to-year fluctuations in temperature can be attributed to Funafuti's tropical location.

Figure 15.6:
Annual, November–April and May–October average temperatures for Funafuti. Straight lines indicate linear trends. The magnitudes of the trends are presented in Table 15.2. Diamonds indicate years with insufficient data for one or more variables.

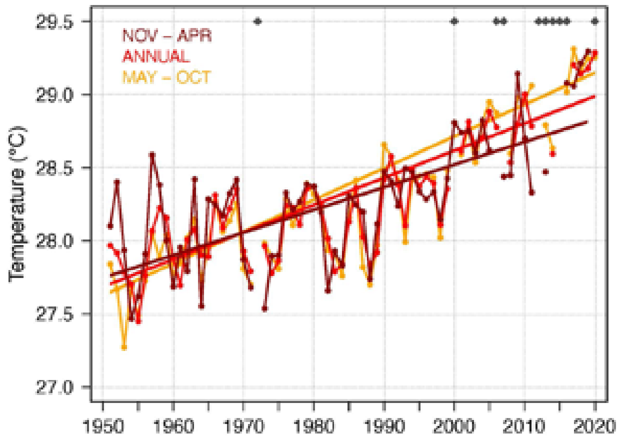


Table 15.2:
Trends in annual and seasonal air temperatures at Funafuti. The 95% confidence intervals are shown in parentheses, and trends significant at the 95% level are shown in bold.

	Funafuti Tmax (°C/decade)	Funafuti Tmin (°C/decade)	Funafuti Tmean (°C/decade)
		1951–2020	
Annual	**+0.17** (+0.07, +0.28)	**+0.21** (+0.17, +0.25)	**+0.19** (+0.12, +0.26)
November–April	**+0.12** (+0.03, +0.2)	**+0.20** (+0.15, +0.25)	**+0.15** (+0.09, +0.21)
May–October	**+0.20** (+0.12, +0.28)	**+0.24** (+0.19, +0.28)	**+0.22** (+0.16, +0.28)

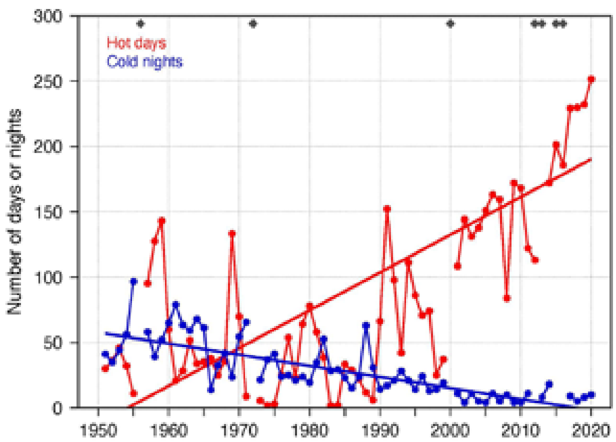
The number of hot days and warm nights has increased, and the number of cool days and cold nights has decreased at Funafuti (Table 15.3). Since 2015, over half of all days each year were considered hot (Figure 15.7). This warming is consistent with increases in annual and seasonal temperatures at Funafuti (Figure 15.6) as well as global climate change. However, the rapid rate of this warming can also be attributed to Funafuti's tropical location, where only small temperature increases are necessary for a day to be considered hot (i.e., in the hottest 10% of days 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 very strong increase in the cooling degree index at Funafuti, suggesting the energy needed for cooling has increased significantly since 1951.

Table 15.3:
Trends in annual temperature extremes at Funafuti. 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).

	Funafuti
	1951–2020
Number of hot days (days/decade)	**+28.92** (+11.15, +44.58)
Number of warm nights (nights/decade)	**+14.16** (+10.27, +18.09)
Number of cool days (days/decade)	**-4.93** (-7.87, 1.65)
Number of cold nights (nights/decade)	**-8.51** (-10.94, 5.84)
Cooling degree days (degree days/decade)	**+71.37** (+52.82, +98.60)
Daily temperature range (°C/decade)	-0.07 (-0.14, 0.00)

Figure 15.7:
Annual number of hot days and cold nights at Funafuti. Straight lines indicate linear trends. The magnitudes of the trends are presented in Table 15.3. Diamonds indicate years with insufficient data for one or both variables.



15.6 Tropical cyclones

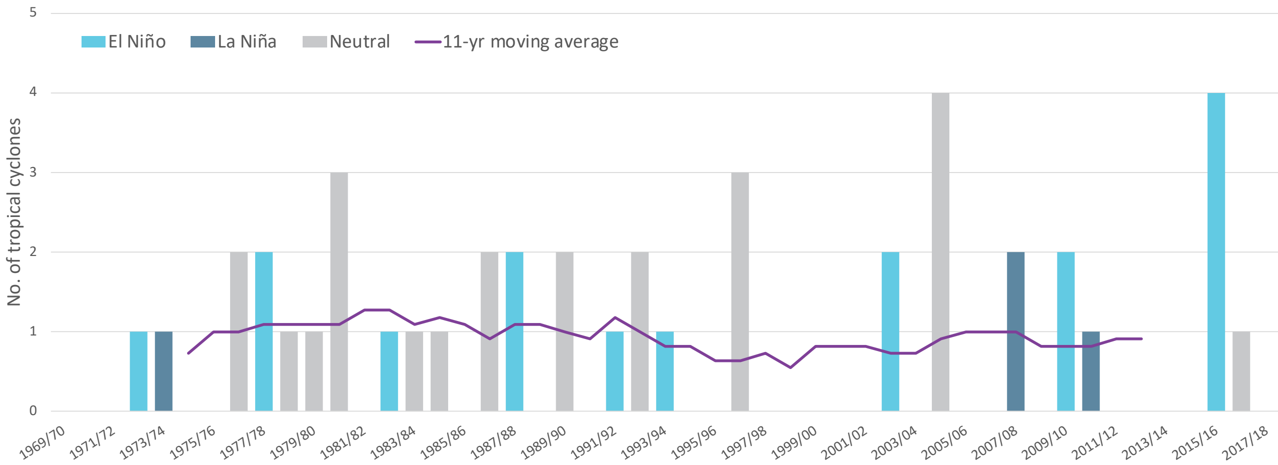
15.6.1 Seasonal cycle

Tropical cyclones usually affect Tuvalu 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, 43 tropical cyclones (Figure 15.7) passed within the EEZ. This represents an average of nine cyclones per decade. Tropical cyclones were most frequent in El Niño years (12 cyclones per decade), followed by neutral years (10 cyclones per decade) and least frequent in La Niña years (3 cyclones per decade).

Interannual variability in the number of tropical cyclones in the EEZ is large, ranging from zero in some seasons to four in 2004/05 and 2015/16 (Figure 15.7). 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 15.8:
Number of tropical cyclones passing within the Tuvalu 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.



15.6.2 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.

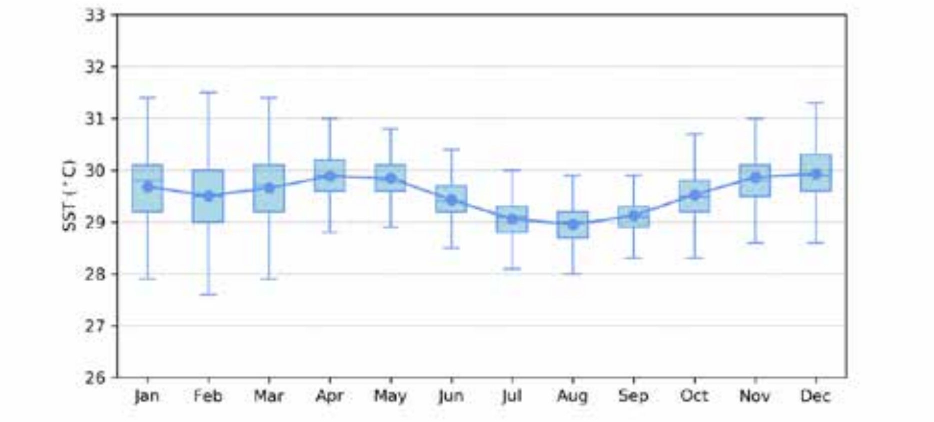
Records of tropical cyclones exist from the late 1800s in some countries in the Southwest Pacific, but trends in tropical cyclones have only been presented from 1981/82. Satellite-based observations began in the Southwest Pacific in the early 1970s, but consistent coverage and reliable intensity estimates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

15.7 Sea surface temperature

15.7.1 Seasonal cycle

Ocean temperature, as measured by the Tuvalu tide-gauge from 1993 to 2021, reaches on average a maximum of almost 30 °C in November/December and then again around April/May, exhibiting a unique bimodal wet season peak (Figure 15.9). Individual monthly temperatures can reach has high as 31.5 °C. Minimum average temperature only dips down to 29 °C in August. The average seasonal cycle only changes by approximately 1 °C. Temperatures can be up to 2 °C higher or lower than these averages, although 50% of observations fall within 1 °C of the average.

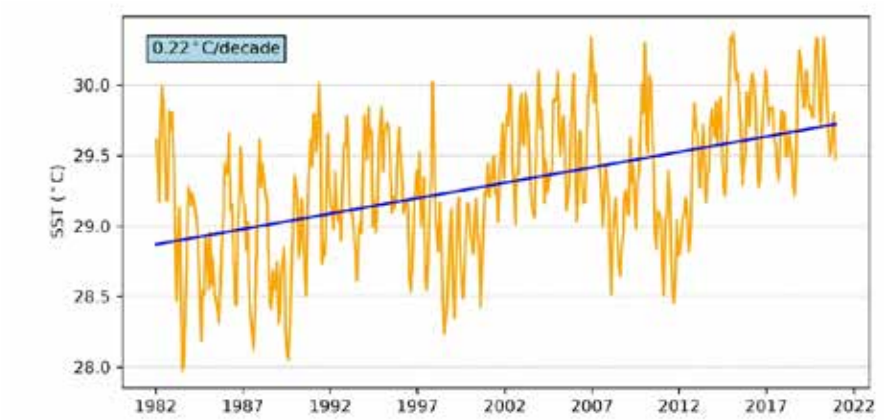
Figure 15.9:
Annual temperatures measured at the Funafuti tide-gauge. Blue dots show the monthly average, and shaded boxes show the middle 50% of observations. Lines show the top and bottom 25% of observations.



15.7.2 Trends

Figure 15.10 shows the 1981–2021 SST from satellite observations averaged over the EEZ. The data show a trend of 0.22 °C per decade with a 95% confidence interval of ±0.03 °C.

Figure 15.10:
Sea surface temperature from satellite observations averaged across the Tuvalu EEZ, shown as the orange line. The blue line shows the linear regression trend.



15.8 Sea level

15.8.1 Seasonal cycle

Tuvalu experiences a semidiurnal tidal cycle, meaning two high and two low tides per day. The highest predicted tides of the year typically occur during the wet season months of December–March. Figure 15.11 shows the number of hours the 99th percentile (3.22 m) sea level threshold is exceeded per month across the entire sea level record at Funafuti. Peak sea levels typically occur between January and April.

Figure 15.11:
Number of hours exceeding 99th percentile sea level threshold per month from 1993 to 2021 at the Funafuti 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 3.22 m (Fongafale, Tuvalu)

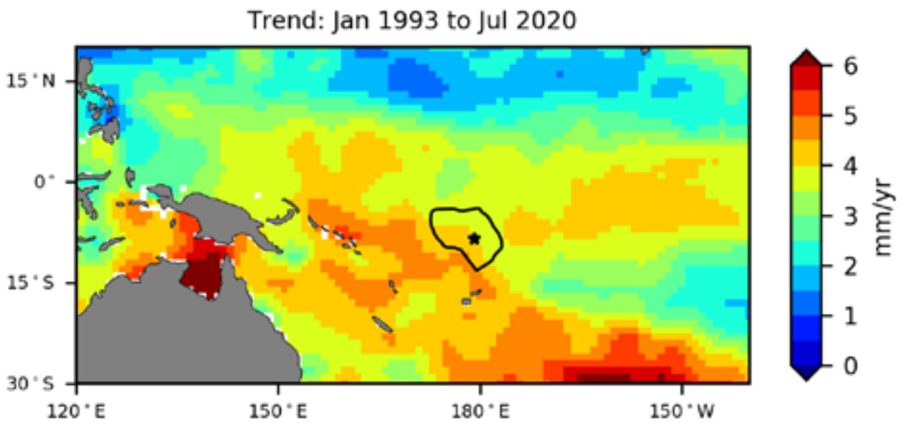
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1993	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	0	2	0	0	0	0	0	0	0	0	0	0	2
1995	0	0	0	0	0	0	0	0	0	0	0	0	0
1996	2	5	0	0	0	0	0	0	0	0	0	0	7
1997	0	2	6	0	0	0	0	0	0	0	0	0	8
1998	0	0	0	0	0	0	0	0	0	0	0	0	0
1999	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	2	0	0	0	0	0	0	0	0	0	0	0	2
2001	0	4	5	0	0	0	0	0	0	0	0	0	9
2002	1	2	7	0	0	0	0	0	0	0	0	0	10
2003	0	0	0	2	4	0	0	0	0	0	0	0	6
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	5	6	5	0	0	0	0	0	0	0	0	0	16
2007	0	0	2	1	0	0	0	0	0	0	0	0	3
2008	0	0	0	0	0	0	0	0	0	0	0	0	0
2009	2	3	0	0	0	0	0	0	0	0	0	0	5
2010	0	0	0	0	0	0	0	0	0	1	0	0	1
2011	4	1	0	0	0	0	0	0	0	0	0	0	5
2012	0	0	0	0	0	0	0	0	0	0	0	0	0
2013	3	0	0	0	0	0	0	0	0	0	0	0	3
2014	1	2	3	0	0	0	0	0	0	0	0	0	6
2015	0	7	6	0	0	0	0	0	0	0	0	0	13
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	5	5
2018	4	5	4	0	0	1	0	0	0	0	0	0	14
2019	1	1	0	0	0	0	0	0	0	0	0	0	2
2020	0	3	5	11	2	0	0	0	1	1	1	0	24
Monthly Totals (%)	18	30	30	10	4	1	0	0	1	1	1	4	

15.8.2 Trends

Sea level at Tuvalu, measured by satellite altimeters (Figure 15.12) since 1993, has risen 3.5 and 4.5 mm per year across the EEZ, with a confidence interval of ±1.0 mm in the south and up to ±0.4 mm in the north. This places most of the EEZ trend higher 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 Funafuti tide-gauge over a similar time span to the altimetry observations (March 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 Funafuti, the trend is reported as 4.5 mm per year, which is very similar to the altimetry trends shown in Figure 15.12 (tide-gauge indicated by star symbol).

Figure 15.12:
The satellite altimetry annual trend for the Pacific from 1993 to 2020, with the Tuvalu EEZ highlighted. The star symbol indicates the location of the tide-gauge at Funafuti.



15.9 Waves

15.9.1 Seasonal cycle

The average wave climate in Funafuti 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 swells from the east. The annual mean wave height is 1.29 m, the annual mean wave direction is 117° and the annual mean wave period is 11.37 s. In the Pacific, waves often come from multiple directions and for different periods at a time. In Funafuti, there are often more than four different wave direction/period components coming from the southeast to southwest (Figure 15.13).

Seasonal wave height peaks between June and September with dominant waves coming from the southeast (Figure 15.14). Wave period is lower during these months. However, waves are still classified as swell-dominated (period > 8 seconds).

Figure 15.13:
Annual wave rose for Funafuti. Note that direction is where the wave is coming from.

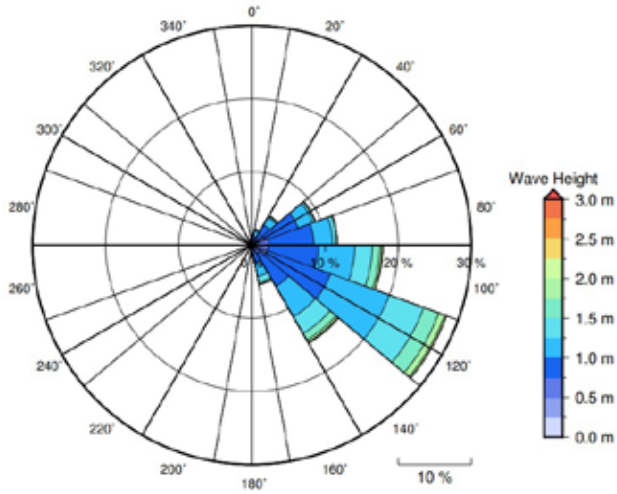
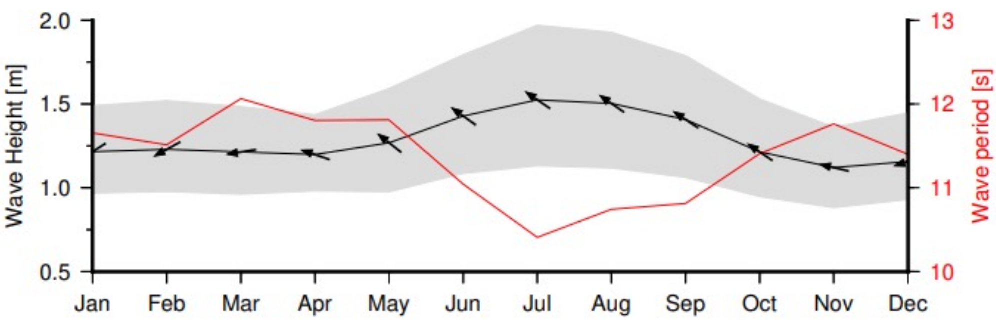


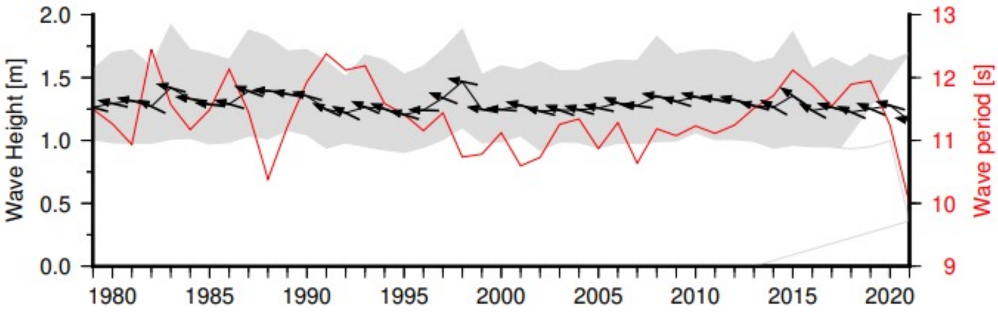
Figure 15.14:
Monthly wave height (black line), wave period (red line) and wave direction (arrows). The grey area represents the range of wave height between calm periods (10% of lowest wave height) and large wave events (10% of highest wave height).



15.9.2 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 Funafuti, the mean annual wave height has remained unchanged since 1979 (Figure 15.15). The mean annual wave height in Funafuti is not significantly correlated with the main climate indicators of the region.

Figure 15.15:
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).



15.9.3 Extreme waves

Extreme wave analysis completed for Funafuti wave buoy was done by defining a severe height threshold and fitting a generalized Pareto distribution (GPD). The optimum threshold selected was 2.26 m. In the 42-year wave hindcast, 117 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 15.16, Table 15.4). 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 15.16:
Extreme wave distribution for Funafuti. 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.

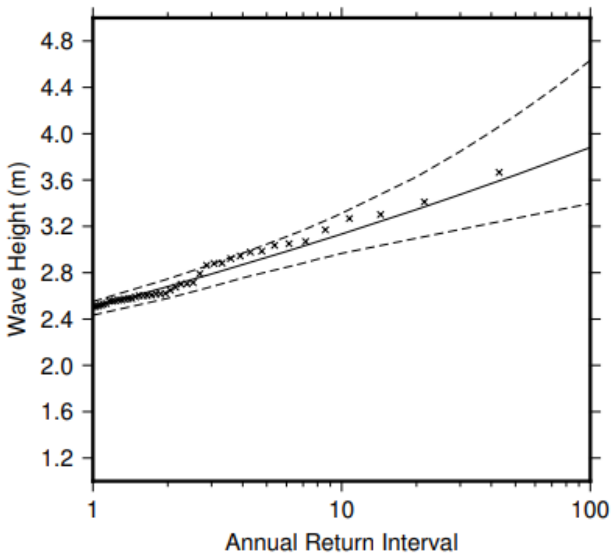


Table 15.4:
Summary of the results from extreme wave analysis in Funafuti

Large wave height (90th percentile)	1.67 m
Severe wave height (99th percentile)	2.13 m
1-year ARI wave height	2.50 m
10-year ARI wave height	3.13 m
20-year ARI wave height	3.35 m
50-year ARI wave height	3.64 m
100-year ARI wave height	3.88 m