Vanuatu South

Sub-national historical and projected climate overview

Sustainable, transformative and resilient for a Blue Pacific

Vanuatu South:

sub-national historical and projected climate overview

SUB-NATIONAL SUMMARY

KLAEMET SAVE
REDI · ADAPT · PROTEKT

Vanuatu Klaemet Infomesen blong Redi, Adapt mo Protekt

LONG GOD YUMI STANAP

Vanuatu Meteorology and Geo-Hazards Department

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Summary

Vanuatu has a warmer and wetter season from November to April and a slightly cooler and drier season from May to October.

Variability in rainfall and cyclone activity is strongly affected by the South Pacific Convergence Zone (SPCZ) and the El Niño Southern Oscillation (ENSO). In El Niño years, the SPCZ moves north-east in the western tropical Pacific, leading to drier conditions and fewer cyclones over Vanuatu. In La Niña years, the SPCZ moves south-west, leading to wetter conditions and more cyclones over Vanuatu.

The climate is changing. Vanuatu has warmed by 0.7 °C since the pre-industrial period (1850–1900), hot days have increased, cold days have decreased, marine heatwaves have become more frequent and sea level has risen. However, there has been little change in annual average rainfall or extreme daily rainfall. The number of cyclones has decreased since 1971 but the intensity has increased.

Climate projections for the 21st century are derived from climate model simulations driven by different greenhouse gas emissions scenarios. Temperature is projected to continue increasing, with little change in seasonal average rainfall, and an increase in extreme daily rainfall (Table 1). Sea level is projected to continue rising, with more marine heatwaves, fewer cyclones but slightly increased cyclone intensity (Table 2). Extreme La Niña and El Niño events are projected to increase in future.

Summary of projected climate change for Vanuatu South. Changes are provided for annual-average temperature, Nov-Apr rainfall, May-Oct rainfall and extreme daily rainfall intensity (with a 20-year return period). Changes are listed for four 20-year periods centred on 2030, 2050, 2070 and 2090, relative to a 20-year period centred on 1995, for two greenhouse gas emissions scenarios (low RCP2.6 and high RCP8.5). The median value is given with the 10th to 90th percentile range of uncertainty in brackets.

PERIODS	EMISSIONS	TEMPERATURE (°C)	RAINFALL NOV-APR (%)	RAINFALL MAY-OCT (%)	EXTREME RAINFALL (%)
2020-2039	RCP2.6	0.5 (0.3 to 0.7)	-2 (-9 to 7)	-3 (-11 to 12)	
	RCP8.5	0.7 (0.5 to 0.8)	-2 (-14 to 7)	-4 (-15 to 14)	-6 (-12 to 9)
2040-2059	RCP2.6	0.6 (0.4 to 1.0)	-2 (-12 to 7)	-3 (-12 to 12)	
	RCP8.5	1.2 (0.9 to 1.6)	-1 (-17 to 8)	-5 (-18 to 14)	41 (-2 to 57)
2060-2079	RCP2.6	0.6 (0.4 to 0.9)	-5 (-17 to 7)	-5 (-15 to 10)	
	RCP8.5	1.9 (1.5 to 2.4)	-3 (-24 to 19)	-3 (-21 to 17)	28 (10 to 50)
2080-2099	RCP2.6	0.6 (0.4 to 1.0)	-3 (-16 to 6)	-5 (-17 to 4)	
	RCP8.5	2.7 (2.0 to 3.4)	2 (-31 to 22)	-2 (-30 to 25)	23 (13 to 28)

Summary of projected climate change for Vanuatu South. Changes are provided for annual-average sea level (Kirono et al, 2023), cyclone wind speed intensity, cyclone frequency and marine heatwave frequency (see MHW explainer). Changes are listed for four 20-year periods centred on 2030, 2050, 2070 and 2090, relative to a 20-year period centred on 1995, for two greenhouse gas emissions scenarios (low RCP2.6 and high RCP8.5). The median value is given with the 10th to 90th percentile range of uncertainty in brackets. [1]Knutson et al (2020) projections for the southwest Pacific. [2]Van KIRAP (2023) projections for Tafea province.

PERIODS	EMISSIONS	SEA LEVEL (M)	CYCLONE INTENSITY (%)	CYCLONE FREQUENCY (%)	MARINE HEATWAVES (DAYS)
2020-2039	RCP2.6	0.13 (0.10-0.17)			
	RCP8.5	0.14 (0.10–0.18)			
2040-2059	RCP2.6	0.23 (0.17–0.30)			50–150
	RCP8.5	0.28 (0.22–0.37)	1 (-6 to 12)[1]	-12 (-40 to 0)[1]	160–310
2060-2079	RCP2.6	0.32 (0.24–0.43)			
	RCP8.5	0.48 (0.37–0.64)			
2080-2099	RCP2.6	0.42 (0.30–0.56)			80–180
	RCP8.5	0.73 (0.56–0.99)	2 (-6 to 11)[2]		320–360

Introduction

This report provides a sub-national overview of historical and projected climate variability and change for Vanuatu South (Figure 1). Vanuatu South contains the Tafea province. Information is provided for mean and extreme temperature and rainfall, droughts, tropical cyclones, ocean temperature, sea level rise and coastal inundation [1]. It draws on relevant data and information produced as part of the Van-KIRAP project, as well as published data and information where appropriate.

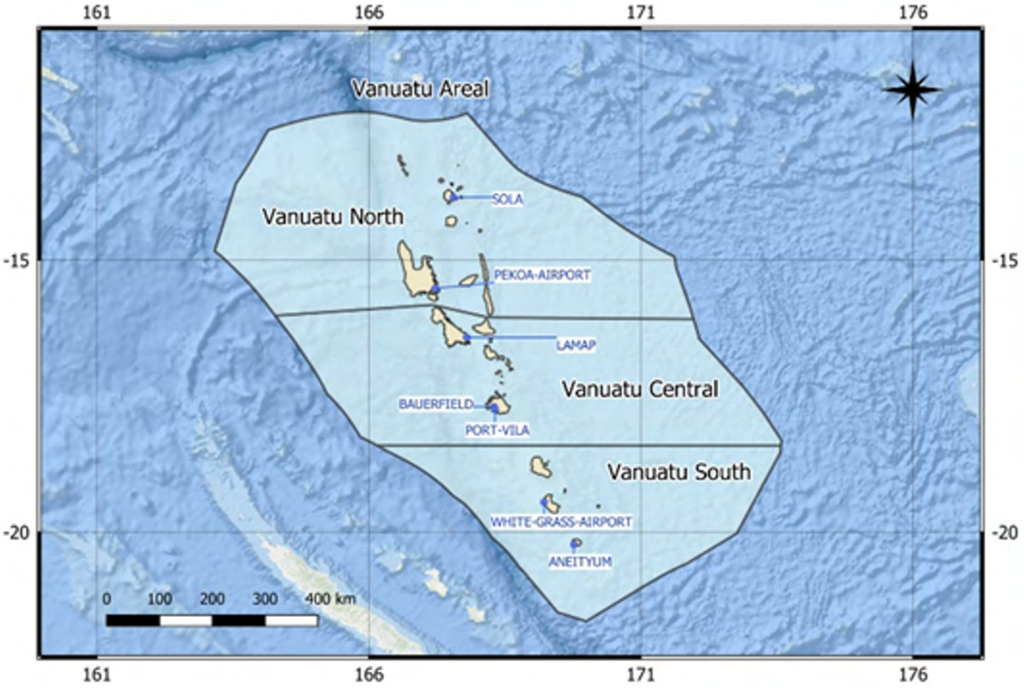


Figure 1 Map of Vanuatu and the three sub-national regions: North, Central and South. Provinces (red labels) and locations of key weather stations (blue labels) used for the study are also shown. The pale blue shaded region delineates the Exclusive Economic Zone (EEZ) of Vanuatu. Latitudes and longitudes are shown around the perimeter of the map.

Temperature and rainfall

Vanuatu's climate has two distinct seasons: a warmer, wetter season from November to April and a slightly cooler, drier season from May to October [2].

For White Grass, mean monthly temperatures ranged from around 21 to 26 °C during the period 1971–2000 [1]. Seasonal rainfall is strongly affected by the South Pacific Convergence Zone (SPCZ), while air temperatures are strongly connected with surrounding ocean temperatures [2].

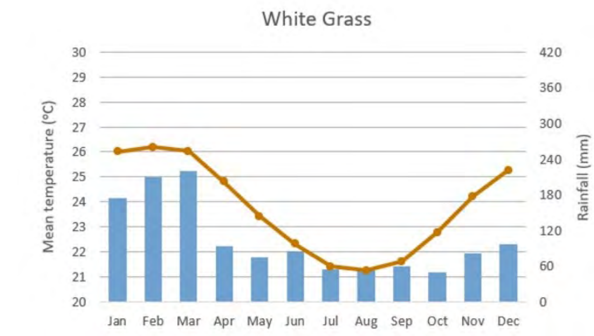


Figure 2 Mean monthly rainfall (bars) and temperature (dots and lines) for White Grass for 1971–2000. Data source: [3]

Increasing concentrations of greenhouse gases are changing the climate. Vanuatu has warmed by 0.7 °C since the pre-industrial period (1850–1900) [4], hot days have increased, cold days have decreased, and sea level has risen. However, there has been little change in annual average rainfall, or dry spells [2]. Past mean annual temperature and rainfall variability are shown in Figure 3 [2].

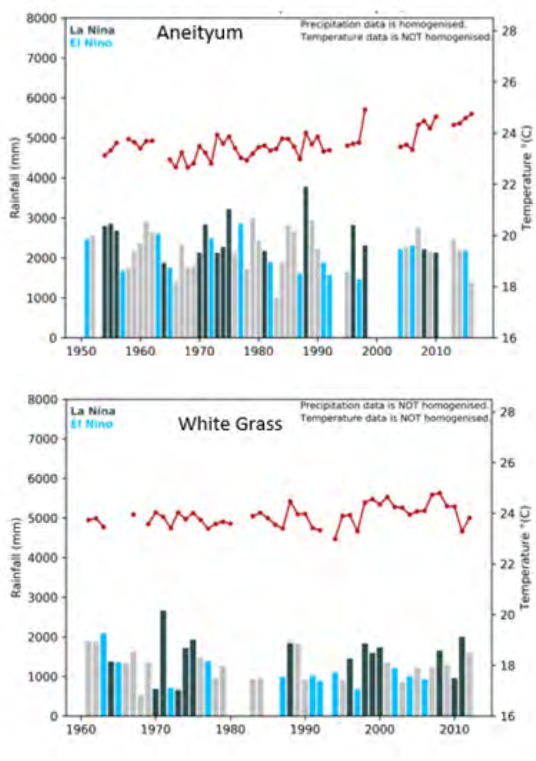


Figure 3 Annual mean temperature (red line with markers) and rainfall (bar) in Aneityum and White Grass (see Figure 1) for the period 1950–2017. Light blue, dark blue and grey bars denote El Niño, La Niña and neutral years, respectively. Data source: [3].

There has been a clear warming of the hottest day and hottest night of the year since 1950, though little change in the coldest night of the year [1] (Table 1). Increasing interannual variability for the number of warm nights and cold days since 1988 has also been detected [2]. Consistent with mean rainfall, maximum daily rainfall is highly variable year-to-year [1], with trends in annual total rainfall and extreme rainfall being small and statistically non-significant (Figure 3) [2]. The occurrence, duration and intensity of droughts varies with location [5] (also see Drought explainer).

Table 1 Daily extremes from weather station data. Average annual values are given with the minimum and maximum annual values in brackets, calculated over the 1986–2005 baseline period. Unless otherwise noted, the values are from unhomogenised data. Data source: [3]

Station	Annual hottest day (°C)	Annual hottest night (°C)	Annual coldest night (°C)	Annual maximum daily rainfall (mm)
White Grass Airport	32.6 (31.4–34.0)	25.7 (24.6–27.0)	12.9 (11.0–15.0)	122 (60–447)
Aneityum#	32.5 (31.0–34.0)	25.7 (24.0–27.6)	12.4 (11.0–15.0)	196 (86–347)

#Rainfall data for Aneityum are homogenised. Additionally, years with more than 10 % missing data were removed and manual quality control was applied to remove obvious data errors.

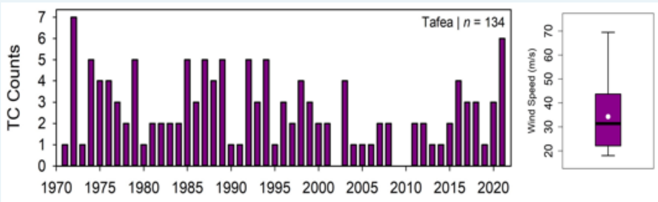
The El Niño Southern Oscillation (ENSO) is a natural, large-scale driver of climate variability in the Pacific, affecting rainfall and temperature [2]. The El Niño phase of ENSO is associated with droughts [5, 6]. This is because in El Niño years the SPCZ moves north-east in the Pacific, leading to drier conditions over Vanuatu. In La Niña years the SPCZ moves south-west, leading to wetter conditions over Vanuatu [7]. Monthly mean historical data presented as maps, with a focus on ENSO influences on temperature and rainfall, have recently been prepared [8] (also see Climate variability explainer).

Tropical cyclones

The frequency of tropical cyclones (TCs) affecting the whole Vanuatu Archipelago has declined by ~28 % over the period 1996–2021 compared with 1971–1995 [9]. Observed cyclone numbers have been higher in the south than the north of Vanuatu [9]. Cyclone attributes for Vanuatu South are presented in Table 2.

Table 2 Observed number (n) of cyclones that have occurred within 500 km of Tafea province, Vanuatu South (1971–2021). Wind speed distributions (boxplots) for the same period are also shown, where the black line represents the median and white dot is the mean. (Data source: SPEArTC; [10]).

Province	TCs/ season	Average wind speed (m/s)
Tafea	2.62	34.28
TC frequency for 1971–2021		



The proportion of severe tropical cyclones (winds greater than 17.5 m/s) has increased over recent decades in Vanuatu, consistent with expectations due to climate change [11]. The severity (i.e. wind speed intensities) of TCs passing near Vanuatu has increased by ~15 % over the period 1996–2021 compared with 1971–1995 [9], due to an increase in greenhouse gases [12].

The TC-related, mean seasonal, maximum daily rainfall has increased considerably over recent decades (i.e. ~20 mm per day between the periods 1970–1993 and 1994–2018) [13].

TCs within 500 km of Vanuatu have been more frequent during La Niña years (~13 cyclones per decade) than during El Niño and neutral years (~9 cyclones per decade) [9].

For more details, see the Tropical cyclone explainer.

Ocean temperatures

In Vanuatu annual average sea surface temperatures (SST) range from about 25.5 °C to 28.5 °C from south to north (Figure 4). For the Southern region, which is the coolest of the three national climate zones, SST ranges from 25.0 to 26.5 °C.

Through the period 1982–2021, the SST has been warming in Vanuatu South, with Port Resolution shown here as an example (Figure 4; top right). While the number of marine heatwaves (MHWs) is around 25 per year on average, the total number and severity of MHW events has been increasing (Figure 4; bottom left), and this is evident across the region more generally (Figure 4; bottom right). For more information on MHW categories see the MHW explainer.

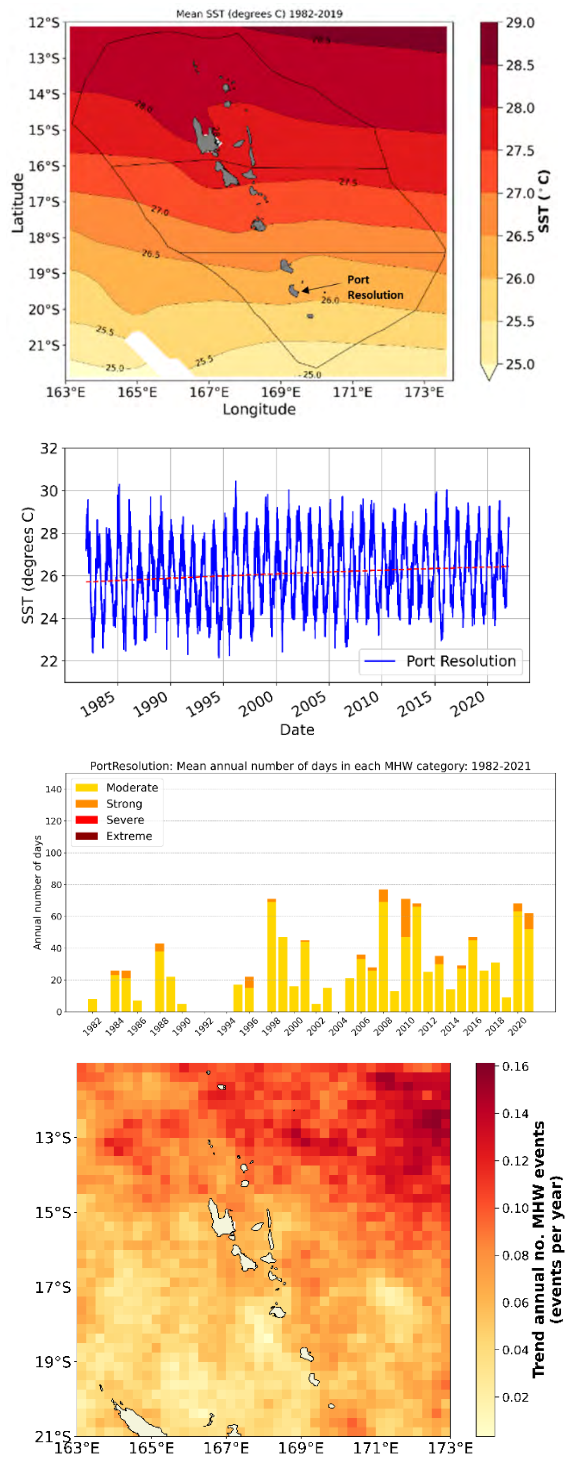


Figure 4 Vanuatu mean SST (°C) (1982–2019) (top). SST (°C) timeseries from 1982–2021 for the Port Resolution region (blue line; second from top). Annual number of days in each marine heatwave category over the period 1982–2021 (third from top). Trend in annual number of MHW events (bottom). Events are defined as: a discrete, prolonged and anomalously warm water event which lasts for five or more days, with temperatures warmer than the 90th percentile. MHWs are considered as separate events if they are separated from a previous MHW by more than two days, Hobday et al. [14, 15]. Source data: NOAA OISST v2-1 SST [16].

For Vanuatu South, Port Resolution and Mystery Island were assessed for heatwave characteristics, through the period 1982–2021. Most sites experienced MHWs that were in the Moderate or Strong category. All sites showed higher incidence of MHW days in later years compared to earlier years. (See MHW explainer).

Sea level

In the western tropical Pacific, including around Vanuatu, sea levels measured by satellites have risen faster than in the central and eastern parts of the tropical Pacific [17], by about 10–15 mm since 1993 [18] (Figure 5).

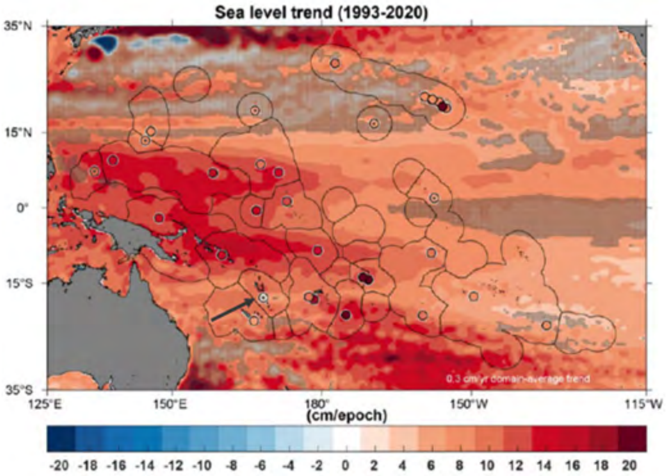


Figure 5 Sea level trends (cm) from satellite altimetry (shaded contours) and sea level trends from tide gauges (circles) during 1993–2020. Trends that are less than interannual variability, which is determined by the standard deviation of monthly anomalies, are indicated by hatching and circles with dots for the altimetry and tide gauges respectively. An arrow points to Port Vila in Vanuatu. Source: [18]

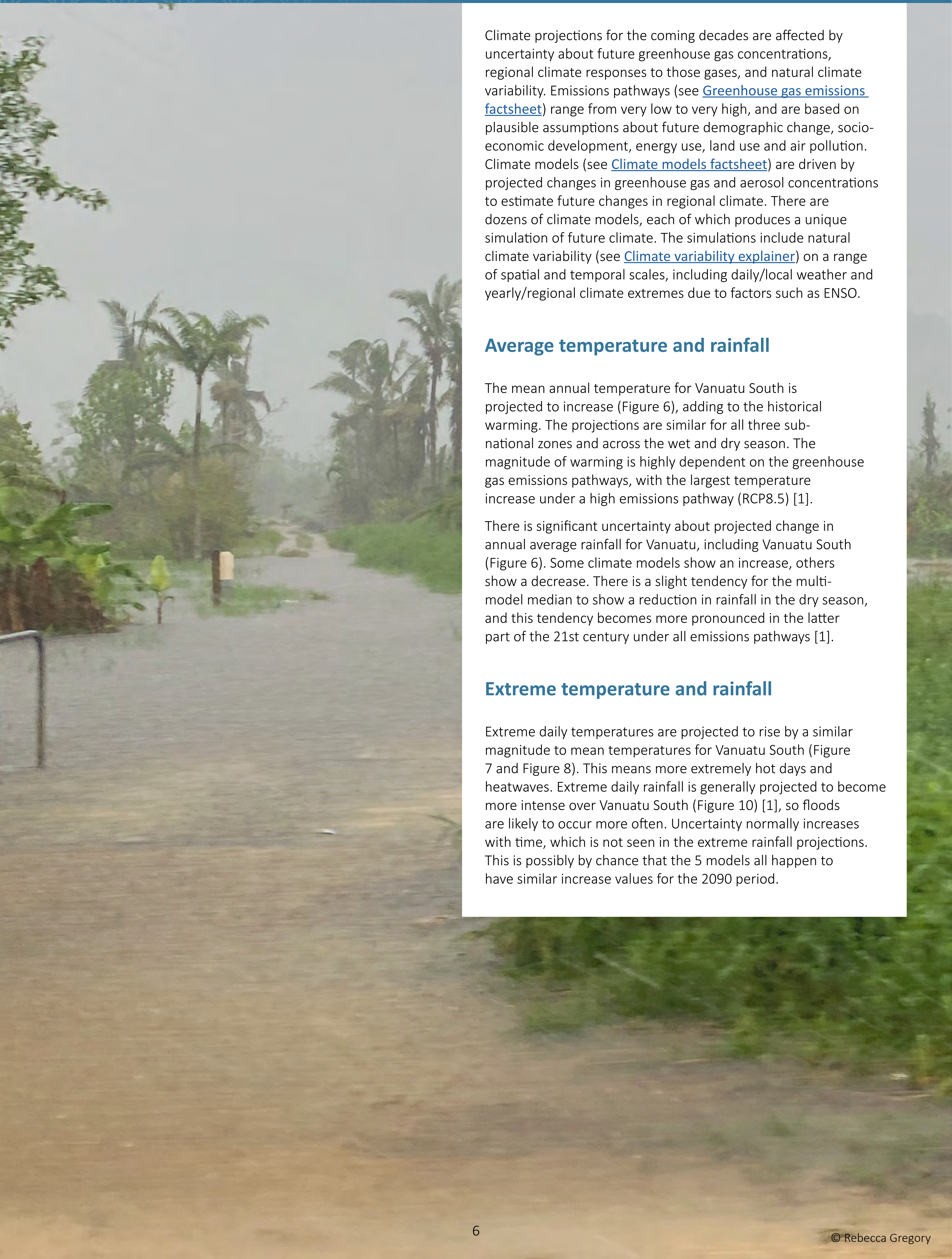
Port Vila has experienced less sea level rise relative to the land because vertical land motion due to earthquakes, around 2008, offset some of the effect of sea level rise [19]. For the period 1993–2020 the Port Vila tide gauge[1], which measures water levels relative to land, indicates no long-term trend in sea level (Figure 5, arrow).

The coastal flood frequency has not increased for Port Vila, counter to the overall increasing flood frequency trends for the Pacific region. This countertrend may change in the future depending on whether local vertical land motion keeps pace with sea level rise.

The interannual-to-multidecadal variability of SST, rainfall, and relative sea level around Vanuatu is influenced by ENSO. Above normal sea levels were recently observed during the prolonged 2020–2023 La Niña event [20]. (See Climate Variability explainer).

[1]Where tide gauge data are not available, e.g. in Northern and Southern Vanuatu, rate and magnitude of vertical land movement is unknown.

Climate projections



Climate projections for the coming decades are affected by uncertainty about future greenhouse gas concentrations, regional climate responses to those gases, and natural climate variability. Emissions pathways (see Greenhouse gas emissions factsheet) range from very low to very high, and are based on plausible assumptions about future demographic change, socio-economic development, energy use, land use and air pollution. Climate models (see Climate models factsheet) are driven by projected changes in greenhouse gas and aerosol concentrations to estimate future changes in regional climate. There are dozens of climate models, each of which produces a unique simulation of future climate. The simulations include natural climate variability (see Climate variability explainer) on a range of spatial and temporal scales, including daily/local weather and yearly/regional climate extremes due to factors such as ENSO.

Average temperature and rainfall

The mean annual temperature for Vanuatu South is projected to increase (Figure 6), adding to the historical warming. The projections are similar for all three sub-national zones and across the wet and dry season. The magnitude of warming is highly dependent on the greenhouse gas emissions pathways, with the largest temperature increase under a high emissions pathway (RCP8.5) [1].

There is significant uncertainty about projected change in annual average rainfall for Vanuatu, including Vanuatu South (Figure 6). Some climate models show an increase, others show a decrease. There is a slight tendency for the multi-model median to show a reduction in rainfall in the dry season, and this tendency becomes more pronounced in the latter part of the 21st century under all emissions pathways [1].

Extreme temperature and rainfall

Extreme daily temperatures are projected to rise by a similar magnitude to mean temperatures for Vanuatu South (Figure 7 and Figure 8). This means more extremely hot days and heatwaves. Extreme daily rainfall is generally projected to become more intense over Vanuatu South (Figure 10) [1], so floods are likely to occur more often. Uncertainty normally increases with time, which is not seen in the extreme rainfall projections. This is possibly by chance that the 5 models all happen to have similar increase values for the 2090 period.

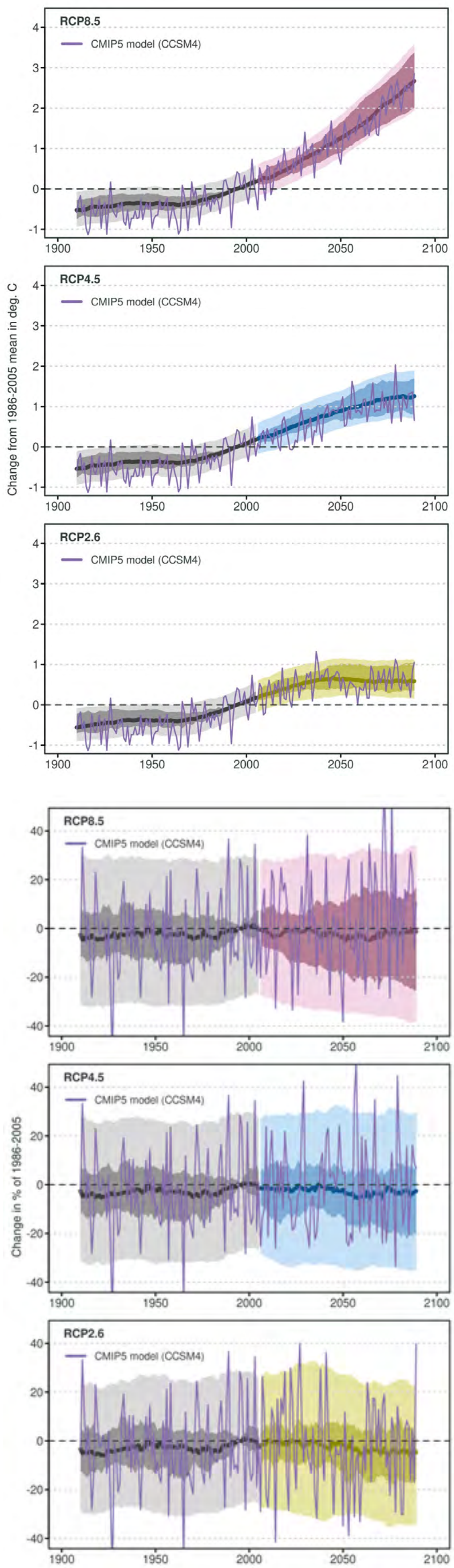


Figure 6 Vanuatu South average temperature (top three plots) and rainfall (bottom three plots) for 1910-2090 as simulated by up to 38 global climate models relative to the 1986–2005 baseline. The thick line is the multi-model median value, and the shading is the 10th and 90th percentile range of 20-year running means (inner) and single year values (outer). The grey shading indicates the period of the historical simulation, while the emissions scenarios are shown with colour-coded shading: high RCP8.5 (purple), medium RCP4.5 (blue) and low RCP2.6 (green). An example of a climate model annual time series is shown as the thin purple line. See Kirono et al. [1] for associated data.

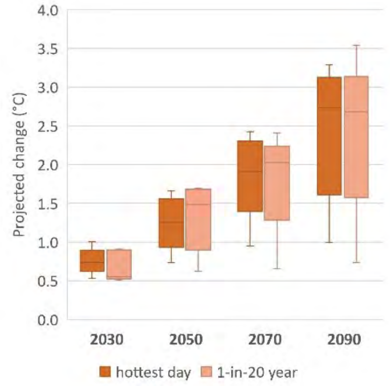


Figure 7 Projected changes relative to 1986–2005 in the annual hottest day of the year and the 1-in-20-year hottest day (i.e. temperature that has on average a 5 per cent chance of happening in any given year) for Vanuatu South over four future time periods (2030, 2050, 2070, 2090).

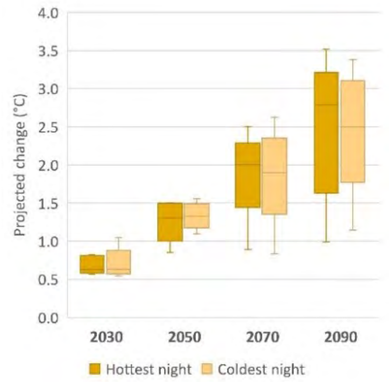


Figure 8 Projected changes relative to 1986–2005 in the annual hottest night (°C) and the annual coldest night (°C) for Vanuatu South over four future time periods (2030, 2050, 2070, 2090).

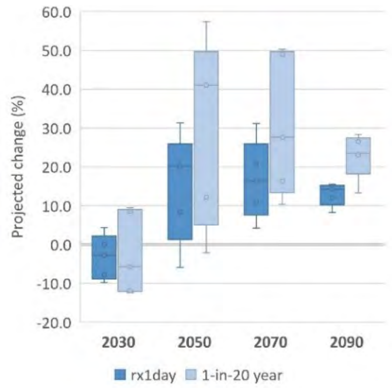


Figure 9 Projected percent change relative to 1986–2005 in annual maximum daily rainfall (rx1day) and 1-in-20-year extreme maximum daily rainfall (i.e. an event that has on average a 5 per cent chance of happening in a particular year) for Vanuatu South, for four future time periods. The small circles show the individual climate models.

The box plots show the multi-model minimum and maximum; 25th and 75th percentile; and median (50th percentile) based on the five regional climate model simulations under a high emissions scenario (RCP8.5). See Kirono et al. [1] for related data.

Drought intensity, frequency and duration have been estimated using the Standardized Precipitation Index (SPI) (see Drought explainer). Most models project a shift toward more intense droughts (Figure 10) [1]. Projections for drought duration and frequency are less clear because there is a large range of uncertainty, with both increases and decreases possible.

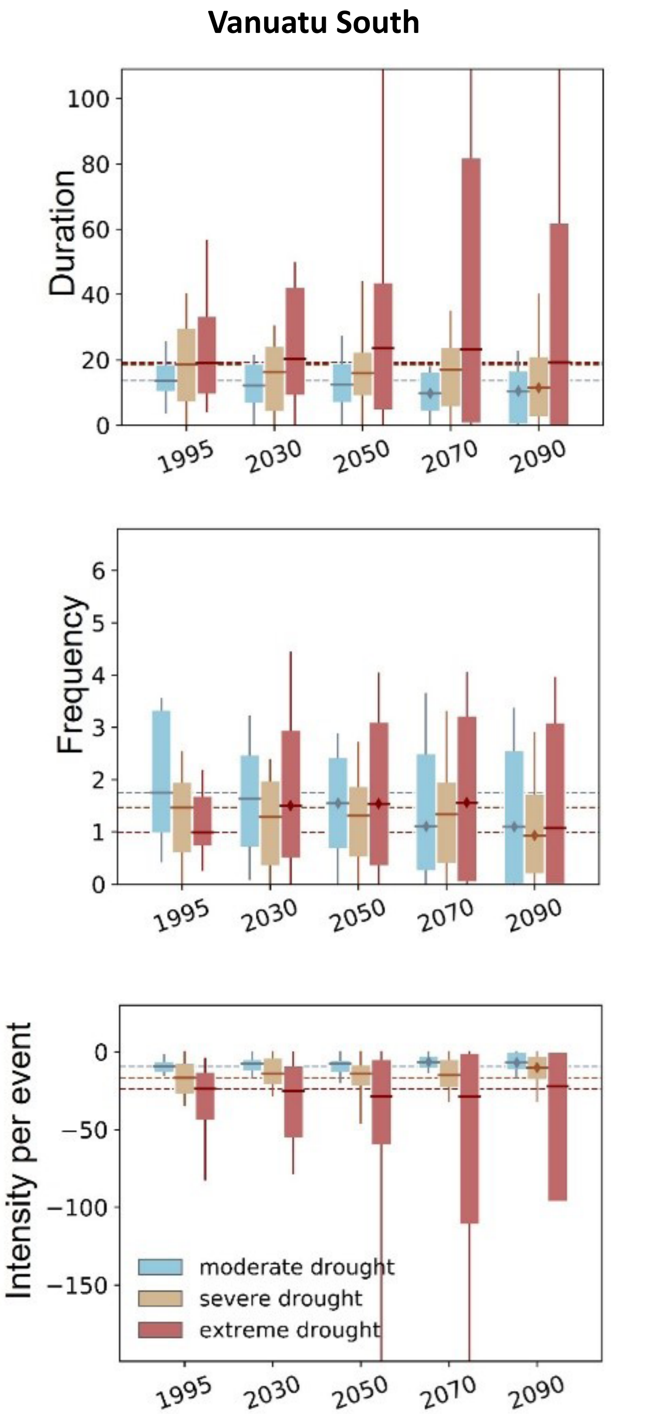


Figure 10 Vanuatu South average of drought duration (top), frequency (middle) and intensity (bottom) in the reference period (20 years centred on 1995) and future periods (20-years centred on 2030, 2050, 2070, 2090) for a high greenhouse gas emission pathway (RCP8.5) based on the Standardized Precipitation Index (SPI). Different drought categories (moderate, severe, and extreme; see [Drought explainer](#)) are given. Drought duration is in months, frequency is number of drought events per 20-year period, while intensity is unitless (NB: the more negative the value the more intense the event). Results from 34 climate model simulations are shown as the median (50th percentile), 10th and 90th percentile (bars) and minimum and maximum values (whiskers). The dashed lines show the multi-model median for the baseline period for each drought category [21, 22]. The SPI is calculated monthly with the value for each month representing the rainfall anomaly over the past 12 months.

Tropical cyclones

Ongoing increases in greenhouse gas emissions will lead to decreases in the average number of cyclones in the Vanuatu region [1, 9, 23-25] (low-medium confidence). A reduction of up to one TC per decade has been projected by the end of the century for Vanuatu (high emissions scenario; RCP8.5), with higher reductions in the northern region (Figure 11) [1]. (See [TC explainer](#)).

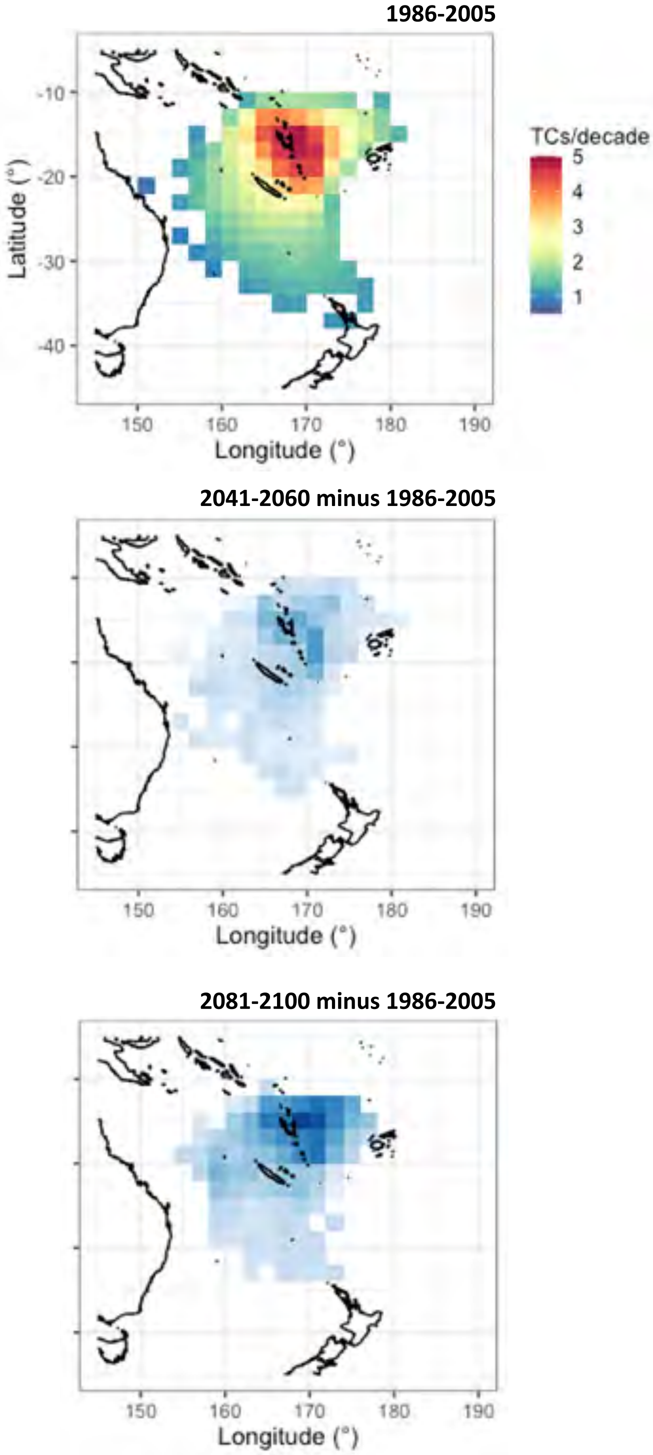


Figure 11 Average number of tropical cyclones (TCs) for the historical period (1986–2005 top panel), and the projected change in the number of cyclones for the mid-century (2041–2060 central panel) and late-century (2081–2100 bottom panel) under a high emissions scenario (RCP8.5) (see [Emission scenarios factsheet](#)). These data are based on the MIT synthetic cyclone tracks model driven by a set of eight CMIP5 global climate models. Note the cyclone trend per decade scale is negative. Source [1].

While TC frequency is projected to decrease for the south-west Pacific region, including Vanuatu, more cyclones are projected in future during El Niño conditions compared with present-climate El Niño conditions, with fewer cyclones in future during La Niña conditions compared with present-climate La Niña conditions (medium confidence) [26].

Average TC wind speed intensity for severe cyclones (categories 3–5) is projected to increase slightly (medium confidence) [9] (Figure 12). For extreme daily wind speeds with return periods of 10–100 years, the projected increase in intensity is 1.2 % for Tafea and 5 of 8 models indicate an increase, but these changes are not statistically significant [9].

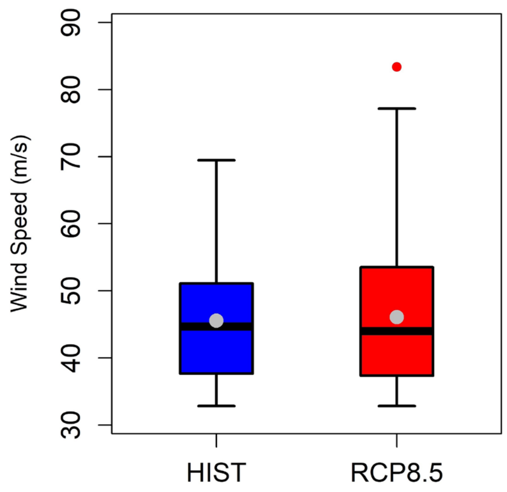


Figure 12 Historical (1970–2000) and projected (2070–2100; RCP8.5) severe cyclone wind speed (m/s) for Tafea province for average return periods of up to 100 years [9]. Boxplots indicate the range of maximum cyclone wind speed. Severe cyclones are defined as category 3–5. Historical data were extracted for a 500 km buffer around each province using the South Pacific Enhanced Archive of Tropical Cyclones (SPEArTC; [10]). Projections are derived from eight climate models following Chand et al. (2017) and Bell et al. (2019) [24, 26].

Sea level rise and an increase in extreme sea level events are projected, which may exacerbate cyclone impacts near the coast [9, 25, 27, 28]. In Pacific Ocean basins, the TC-related rainfall rate is projected to increase (high confidence) [13, 25]. Poleward movement of TCs is possible, but there is substantial uncertainty (low-medium confidence). (See TC explainer for more detailed information).

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Ocean temperature

Over the 21st century the ocean is projected to further warm, and compared to the 1995–2004 period, projected increases are around 0.7 °C by 2050 under low emissions, or up to around 1.1 °C under high emissions (Figure 13).

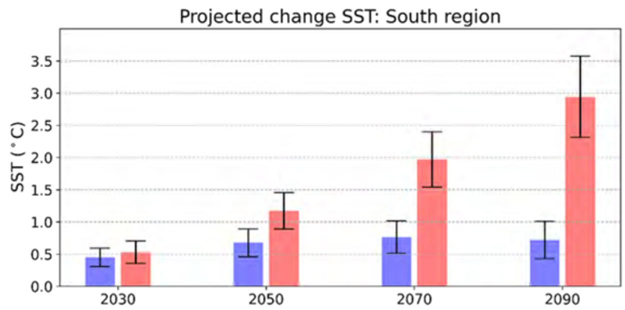

Figure 13 Projected sea surface temperature (°C) change for Vanuatu Central for 20-year periods centred on 2030, 2050, 2070, and 2090 relative to 1995–2004, based on 18 CMIP6 climate models under low (SSP126; purple) and high (SSP585; pink) emission scenarios (see GHG emissions factsheet). Bars indicate the standard deviation. (Data source: NOAA OISST v2-1 SST [16]). NB: high emissions SSP585 (cf. RCP8.5), low emissions SSP126 (cf. RCP2.6).

Historically for Port Resolution, a site important to fisheries and tourism in Vanuatu South, the typical number of MHWs is around 25 days per year (1982–2021) (Figure 14). Under the low emission scenario (SSP126), this increases to about 50–150 days per year by 2050 (Figure 14). Under the high emission scenario (SSP585), this increases to about 160–310 days per year by 2050, with many days in the "Strong" and "Severe" MHW categories (Figure 14).

By 2090, larger increases in MHWs are projected. For a low emissions scenario, the number of MHW days is 80-180, with a substantial increase in 'Strong' events. For a high emissions scenario, the number of MHW days is 320–360, with a big increase in 'Severe' and 'Extreme' events (Figure 14).

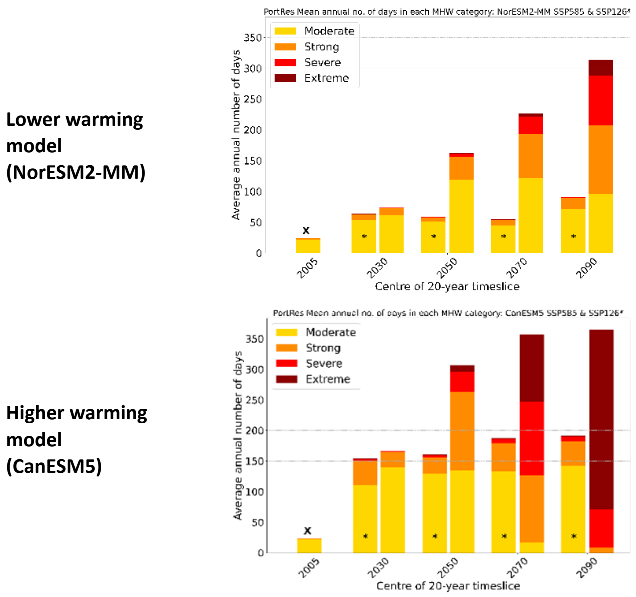

Figure 14 Projected average annual number of marine heatwave days for an area-averaged domain encompassing Port Resolution for a 20-year period centred on 2005 based on observations (x), and a lower warming model (NorESM2-MM; top panel) and higher warming model (CanESM5; bottom panel) under SSP126 (*) and SSP585 based on CMIP6 modelling (see Climate projections for use in impact assessments explainer). Averages for 20-year periods centred on 2030, 2050, 2070, and 2090, are plotted for each of four categories (moderate, strong, severe, and extreme MHW [15]; see Marine heatwave explainer for category definition). (Data source: NOAA OISST v2-1 SST [16]).

Sea level rise and coastal inundation

Sea level projections have been evaluated for Vanuatu and show, by 2050, an increase of about 23 cm for low emissions and 28 cm for high emissions. By 2090, the increase is about 42 cm for low emissions and 73 cm for high emissions (Table 3)'. Insert caption for Table 3: Sea level rise projections for Vanuatu for 4 years (2030, 2050, 2070 and 2090 relative to 1986-2005) and 3 emissions scenarios (RCP2.6, RCP4.5 and RC8.5). Median values are shown, with 10-90 percentile ranges of uncertainty in brackets. Source [4].

Table 3 Median sea level projections for Vanuatu with 5–95 % uncertainty range relative to 1986–2005 for RCPs 2.6, 4.5, and 8.5. Units are metres.

Year	RCP2.6	RCP4.5	RCP8.5
2030	0.13 [0.10–0.17]	0.13 [0.09–0.17]	0.14 [0.10–0.18]
2050	0.23 [0.17–0.30]	0.24 [0.18–0.31]	0.28 [0.22–0.37]
2070	0.32 [0.24–0.43]	0.37 [0.28–0.48]	0.48 [0.37–0.64]
2090	0.42 [0.30–0.56]	0.50 [0.38–0.68]	0.73 [0.56–0.99]

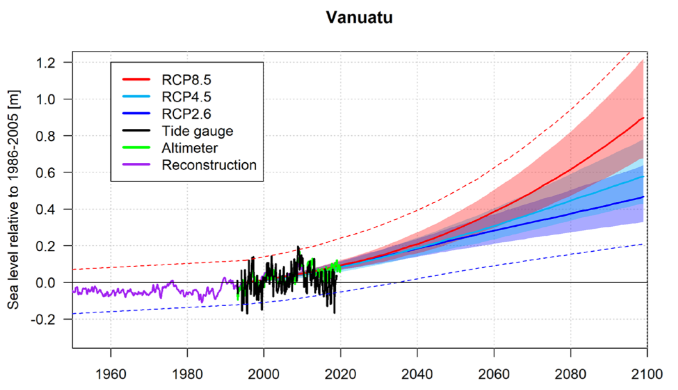

Figure 15 Time series of past and future sea level rise. Port Vila tide gauge records of relative sea level are indicated in black, the satellite record in green, reconstructed sea level data is shown in purple, and all are monthly means relative to mean sea level between 1986–2005. Climate model projections from 1995–2100 are given for three emissions scenarios (RCP2.6, RCP4.5, RCP8.5) with the 5–95 % uncertainty range shown by the shaded regions. The dashed lines are an estimate of month-to-month variability in sea level (5–95 % uncertainty range) and indicate that individual monthly averages of sea level can be above or below longer-term averages.

Projected extreme sea level frequencies and intensities are available for 2 km spacings along the Vanuatu coast (2377 points) [29, 30] (see Coastal inundation explainer). The projections, estimated for RCP2.6, RCP4.5 and RCP8.5 emissions scenarios, include information about tides, waves, storm surges, annual sea level variability and sea level rise. Extreme sea level intensities have been calculated for events with specific frequencies (sometimes called average recurrence intervals or ARIs). Table 4 shows that, for Lenakel, in Tanna, under a high emissions scenario, a 1-in-10-year extreme sea level event could increase on average from 0.87 m in the year 2000 to 1.15 m in 2050 and 1.61 m in 2090. A 1-in-50-year extreme sea level event could increase on average from 0.98 m in the year 2000 to 1.26 m in 2050 and 1.72 m in 2090.

Table 4 Mean extreme sea level intensity (m) for 40-year periods centred on 2000, 2050, and 2090 with average recurrence intervals (ARIs) of 10-years, 50-years and 100-years for selected sites in Vanuatu for RCP8.5 (see Van-KIRAP portal for more data points, and RCP2.6 and RCP4.5 emission scenarios). Node # corresponds with these datasets).

	Location	Node #	10-yr ARI	50-yr ARI	100-yr ARI
2000	**Lenakel**	**92863**	0.87	0.98	1.04
	Aneghowhat	**97735**	1.01	1.24	1.38
2050	**Lenakel**	**92863**	1.15	1.26	1.32
	Aneghowhat	**97735**	1.29	1.52	1.66
2090	**Lenakel**	**92863**	1.61	1.72	1.79
	Aneghowhat	**97735**	1.75	1.98	2.12

When combined with a map of buildings and critical infrastructure such as roads, bridges and other public amenities such as airports, hospitals, schools, evacuation centres etc., this information can highlight exposed assets that are potentially vulnerable to coastal inundation (see Coastal inundation explainer, LiDAR factsheet and Roads infobyte).

Recent reports and associated data relating to current and future climate in Vanuatu

In addition to the data and information in this factsheet, there are other data and information sources available from the Van-KIRAP project, including via the VMGD website and the Vanuatu Climate Futures Portal, as well as from various other regional Pacific projects and initiatives. Users are encouraged to review, access and apply all such data as might be relevant to their needs. For purposes of undertaking climate hazard-based impact assessments for sectoral applications, best-practice projections require consideration of multiple lines of evidence according to guidelines provided by the Van-KIRAP project (see Climate projections for use in impact assessments explainer).

National and sub-national climate projections for Vanuatu. 2023 [1]

This report presents information about long-term climate change projections for Vanuatu and its sub-national regions. This includes projections of mean and extreme temperature and rainfall, droughts, and tropical cyclones. Information about the respective historical climatology and trends are also provided as context for the projection information. The report also highlights implications of the study, including examples of application of the climate projections information, and future research.

'NextGen' Projections for the Western Tropical Pacific: Current and Future Climate for Vanuatu. 2021 [4]

This report presents information about average temperature and rainfall change in Vanuatu, including historical change, interpretation of climate projections, understanding projections as they relate to 'global warming levels', and a set of future climate scenarios for Vanuatu using storylines. It also gives a summary of important new projections information on tropical cyclones, extreme rainfall and sea level rise, and gives a preview of the emerging set of new generation climate modelling.

Climate Change in the Pacific 2022: Historical and Recent Variability, Extremes and Change [31]

This report presents key scientific findings from the second phase of the Climate and Oceans Support Program in the Pacific (COSPPac, July 2018–June 2023), Seasonal Prediction and the Pacific Sea Level and Geodetic Monitoring (PSLGM) Projects. Chapter 1 provides a general introduction to the content, structure and methods used for each country report. Each subsequent country chapter has nine sections that provide: (1) a climate and ocean summary; (2) country description; (3) data availability; (4) rainfall seasonal cycle and observed trends; (5) air temperature seasonal cycle and observed trends; (6) tropical cyclone seasonal cycle and observed trends; (7) sea surface temperature (SST) seasonal cycle and observed trends; (8) sea level seasonal cycle and observed trends; and (9) wave climate, seasonal cycle, trends, and extreme value analysis. Trend lengths vary depending on data availability and quality.

Pacific Climate Change Monitor. 2021 [18]

This report describes variability and change in Pacific Island climates, drawing on the latest meteorological and oceanographic data, information, and analyses. The report primarily focuses on observed changes across the Pacific Islands region in general and includes some country-specific information. It also includes some information about projections and the social, environmental, and economic impacts of rapid climate change. This information is intended to facilitate communication among, and inform decisions of, a broad spectrum of public and private sector stakeholders.

Maps of the Past Climate of Vanuatu: Monthly rainfall and air temperature. 2023 [8]

A range of monthly and seasonal maps were developed by the New Zealand National Institute of Water and Atmospheric Research (NIWA) to illustrate historical average rainfall and air temperature for Vanuatu. These included:

- Monthly average air temperature and rainfall (24 maps)
- Average wet season and dry season (4 maps)
- Composite maps of seasonal and monthly temperature and rainfall patterns and anomalies for each ENSO phase (84 Maps)

References

1. Kirono, D., et al., *National and sub-national climate projections for Vanuatu.* 2023. CSIRO: Melbourne, Australia.
2. McGree, S., et al., *Climate Change in the Pacific 2022: Historical and Recent Variability, Extremes and Change.* 2022. SPC: Suva, Fiji.
3. Australian Bureau of Meteorology. *Pacific Climate Change Data Portal*. 2018. Available from: http://www.bom.gov.au/climate/pccsp/
4. CSIRO and SPREP, *'NextGen' Projections for the Western Tropical Pacific: Current and Future Climate for Vanuatu.* 2021. CSIRO: Melbourne, Australia.
5. McGree, S., S. Schreider, and Y. Kuleshov, Trends and variability in droughts in the Pacific Islands and Northeast Australia. *Journal of Climate*, 2016. 29(23): p. 8377-8397.
6. Dhage, L. and M.J. Widlansky, Assessment of 21st century changing sea surface temperature, rainfall, and sea surface height patterns in the tropical Pacific Islands using CMIP6 greenhouse warming projections. *Earth's Future*, 2022. DOI: 10.1029/2021EF002524
7. Tigona, R. and C. de Freitas, Relationship between the Southern Oscillation and rainfall in Vanuatu. *Weather and Climate*, 2012. 32(1): p. 43-50.
8. Sturman, J. and A. Porteous, *Maps of the Past Climate of Vanuatu: Monthly rainfall and air temperature.* 2023. Available from: https://sprep-my.sharepoint.com/personal/sunnys_sprep_org/_layouts/15/onedrive.aspx?id=%2Fpersonal%2Fsunnys%5Fsprep%5Forg%2FDocuments%2FVan%2DKIRAP%20Doc%20Sharing%20Platform%2F027%2E%20Climate%20Information%20and%20Tools%2Fc%2E%20Vanuatu%20Climate%20Maps&ga=1
9. Sharma, K., et al., Impact of climate change on tropical cyclones over Vanuatu: A case for informing disaster planning and adaptation strategies. *Natural Hazards*, 2023 in prep.
10. Diamond, H., et al., Development of an enhanced tropical cyclone tracks database for the southwest Pacific from 1840 to 2010. *International Journal of Climatology,* 2012. 32(14): p. 2240-2250.
11. Kossin, J.P., et al., Global increase in major tropical cyclone exceedance probability over the past four decades. *Proceedings of the National Academy of Sciences,* 2020. 117(22): p. 11975-11980.
12. Emanuel, K., Evidence that hurricanes are getting stronger. *Proceedings of the National Academy of Sciences,* 2020. 117(24): p. 13194-13195.
13. Deo, A., et al., Tropical cyclone contribution to extreme rainfall over southwest Pacific Island nations. *Climate Dynamics,* 2021. 56: p. 3967-3993.
14. Hobday, A.J., et al., A hierarchical approach to defining marine heatwaves. *Progress in Oceanography,* 2016. 141: p. 227-238.
15. Hobday, A.J., et al., Categorizing and naming marine heatwaves. *Oceanography,* 2018. 31(2): p. 162-173.
16. Huang, B., et al., *NOAA 0.25-degree daily optimum interpolation sea surface temperature (OISST), version 2.1.* 2020. Available from: https://psl.noaa.gov/data/gridded/data.noaa.oisst.v2.html
17. Fasullo, J.T. and S.R. Nerem, Altimeter-era emergence of the patterns of forced sea-level rise in climate models and implications for the future. *Proc. Natl. Acad. Sci.,* 2018. 115(51): p. 12944-12949 DOI: 10.1073/pnas.1813233115
18. Marra, J.J., et al., eds. *Pacific Islands Climate Change Monitor: 2021.* 2022, The Pacific Islands-Regional Climate Centre (PI-RCC) Network Report to the Pacific Islands Climate Service (PICS) Panel and Pacific Meteorological Council (PMC). Available from: https://www.pacificmet.net/pacific-climate-change-monitor-report
19. Brown, N.J., et al., Vertical motion of Pacific Island tide gauges: combined analysis from GNSS and levelling. *Geoscience Australia*, 2020 DOI: 10.11636/Record.2020.003.
20. Thompson, P.R., M.J. Widlansky, and Coauthors, Sea level variability and change [in "State of the Climate in 2021, Global Oceans"]. *Bull. Amer. Meteor. Soc.,* 2022. 103: p. S168–S172 DOI: 10.1175/BAMS-D-22-0072.1
21. Iese, V., et al., Historical and future drought impacts in the Pacific islands and atolls. *Climatic Change*, 2021. 166(1): p. 1-24.
22. Kirono, D.G., et al., Drought projections for Australia: Updated results and analysis of model simulations. 2020. 30: p. 100280.
23. Tory, K.J., H. Ye, and G. Brunet, Tropical cyclone formation regions in CMIP5 models: a global performance assessment and projected changes. *Climate Dynamics*, 2020. 55(11-12): p. 3213-3237.
24. Bell, S.S., et al., Projections of southern hemisphere tropical cyclone track density using CMIP5 models. *Climate Dynamics,* 2019. 52: p. 6065-6079.
25. Knutson, T., et al., Tropical cyclones and climate change assessment: Part II: Projected response to anthropogenic warming. *Bulletin of the American Meteorological Society,* 2020. 101(3): p. E303-E322.
26. Chand, S.S., et al., Projected increase in El Niño-driven tropical cyclone frequency in the Pacific. *Nature Climate Change,* 2017. 7(2): p. 123-127.
27. CSIRO and SPREP, *Tropical Cyclones and Climate Change: implications for the Western Tropical Pacific.* 2022. CSIRO: Melbourne, Australia.
28. Deo, A., et al., Severe tropical cyclones over southwest Pacific Islands: economic impacts and implications for disaster risk management. *Climatic Change*, 2022. 172(3-4): p. 38.
29. Zhang, Y. and A.M. Baptista, SELFE: A semi-implicit Eulerian-Lagrangian finite-element model for cross-scale ocean circulation. *Ocean Modelling,* 2008. 21(3-4): p. 71-96.
30. Zhang, Y., et al., Seamless cross-scale modeling with SCHISM. *Ocean Modelling,* 2016. 102: p. 64-81 DOI: http://ccrm.vims.edu/schismweb/
31. McGree, S., et al., *Climate Change in the Pacific 2022: Historical and Recent Variability, Extremes and Change.* 2022. SPC: Suva, Fiji. p. 220. Available from: https://library.sprep.org/content/climate-change-pacific-2022-historical-and-recent-variability-extremes-and-change