ADB

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Mainstreaming Environmental Considerations in Economic and Development Planning Processes in Selected Pacific Developing Member Countries

Climate Risk Profile for Vanuatu

Asian Development Bank

The Climate Risk Profile was prepared under ADB Regional Technical Assistance (TA) 6204 *Mainstreaming Environmental Considerations in Economic and Development Planning Processes in Selected Pacific Developing Member Countries.* TA implementation was led by Edy Brotoisworo, Senior Safeguards Specialist, Pacific Department, and the Climate Risk Profile was prepared by John E. Hay & Associates Ltd, New Zealand.

Summary

The likelihood (i.e. probability) components of climate-related risks in Vanuatu are evaluated for both present day and future conditions. Changes over time reflect the influence of global warming.

The risks evaluated are high sea levels, extreme daily rainfall events, extreme winds and extreme high air and water temperatures.

Projections of future climate-related risk are based on the output of global climate models, for given emission scenarios. All the likelihood components of the climate-related risks show increases as a result of global warming, though for some the increases are small relative to the uncertainties.

Best estimates of long term, systematic changes in the average climate for Vanuatu indicate that by 2050 sea level is likely to have increased by 20 cm, maximum air temperatures by 0.2 ^{o}C, maximum water temperatures by 0.19 ^{o}C, extreme wind gusts by 6.8% and rainfall by 0.6%.

The observed long term trend in extreme high sea levels for Port Vila is 1.9 mm/year, a rate similar to global trends in mean sea level but less than the observed trend in local mean sea level (5.5 mm/year). For Port Vila an hourly sea level of at least 1.9 m above mean sea level is currently a 136-year event. It will likely be at least a one in 4-year event by 2050.

There is relatively high confidence in projections of maximum air temperature. Measurements at three sites in Vanuatu show maximum daily air temperatures of between 35 ^{o}C and 37 ^{o}C are currently approximately 150-year events. By 2050 these are likely to be approximately 50-year events.

There are similar projections for extreme water temperatures. A maximum water temperature of 33.5 ^{o}C is currently a one in 200-year event at Port Vila. It will likely be a one in 50-year event by 2050.

Less certainty exists in projections for extreme wind gusts. However, a current one in 150-year event of a maximum daily wind gust of 40 kts is likely to be a one in 60-year event by 2050.

The observed annual rainfall shows an increase at some locations and a slight decrease at others. Currently a daily rainfall of at least 350 - 400 mm is a relatively rare event at the measurement sites in Vanuatu, with return periods of between 80 and 120 years. There is large uncertainty in the rainfall projections, with one model suggesting substantial increases in rainfall, two models suggesting only small increases, and one model indicating a small decrease in rainfall into the future. An extreme daily rainfall of at least 350 mm at these sites will likely have return periods of between 60 and 80 years by 2050.

Introduction

Formally, risk considers not only the potential level of harm arising from an event or condition, but also the likelihood that such harm will occur.

While the level of harm component of a climate-related risk will be site or sector specific, in general the likelihood component of a climate-related risk will be applicable over a larger geographical area, and to many sectors. This is due to the spatial scale and pervasive nature of weather and climate. As a result, the likelihood of, say, an extreme climate event or anomaly, is often evaluated for a country, state, small island or similar geographical unit.

While the likelihood may well vary within a given geographical unit, there is often insufficient information to assess this spatial variability, or the variations are judged a priori to be of low practical significance.

This climate risk profile (CRP) is based on observed data for the following locations and variables in Vanuatu.

- Port Vila (17 44 S, 168 19 E): Sea Level, Water Temperature, Wind Gust
- Sola (13 52 S, 167 33 E): Daily Rainfall, Air Temperature
- Lamap (17 30 S, 168 30 E): Daily Rainfall, Air Temperature
- Pekoa (15 40 S, 167 12 E): Daily Rainfall
- Aneityum (20 20 S, 169 40 E): Daily Rainfall
- Bauerfield (17 40 S, 168 14 E): Air Temperature

While data for these locations cannot necessarily characterize the climate conditions for all of Vanuatu, they do provide a general indication of current climate risks facing the country. The CRP can be extended by analysing data from other locations in Vanuatu.

Future changes in climate are based on the output of global climate models (GCMs), and are for a 3.75 by 3.75 degree (approximately) grid square centred on Vanuatu. The climate projections are therefore more reflective of changes for a larger area than just the locations where data were collected.

The following hazards are considered to be among the potential sources of climate-related risk for which the relevant observed data are available:

- high sea levels;
- extreme high daily rainfall events
- extreme high air temperatures
- extreme high water temperatures; and
- damaging winds.

Methods

Preparation of a CRP for a given geographical unit involves an evaluation of current likelihoods of all relevant climate-related risks, based on observed and other pertinent data.

Future changes in risk are estimated using the outputs of selected GCMs[1] run for a range of greenhouse gas emission scenarios (Figure 1). Table 1 lists the combination of models and emission scenarios on which the CRP is based.

Differences in the climate projections give rise to uncertainties in the estimated values of future climate risks. There are numerous sources of uncertainty in projections of the likelihood components of climate-related risks. These include uncertainties in future greenhouse gas emissions as well as in modelling the complex interactions in, and responses of, the global atmospheric and ocean systems. Policy and decision makers need to be cognizant of uncertainties in projections of the likelihood components of extreme events.

Best estimates of future risk levels are based on an average of the estimates using a multi model and emission scenario ensemble. The range in uncertainty is determined using a

[1] Hadley Centre (United Kingdom) , Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO), Japan's National Institute for Environmental Science (NIES), the Canadian Climate Centre GCM (CGCM) and the Goddard Fluid Dynamics Laboratory (GFDL).

model and emission scenario combination that produces, in turn, the maximum and minimum rate of change in future risk levels.

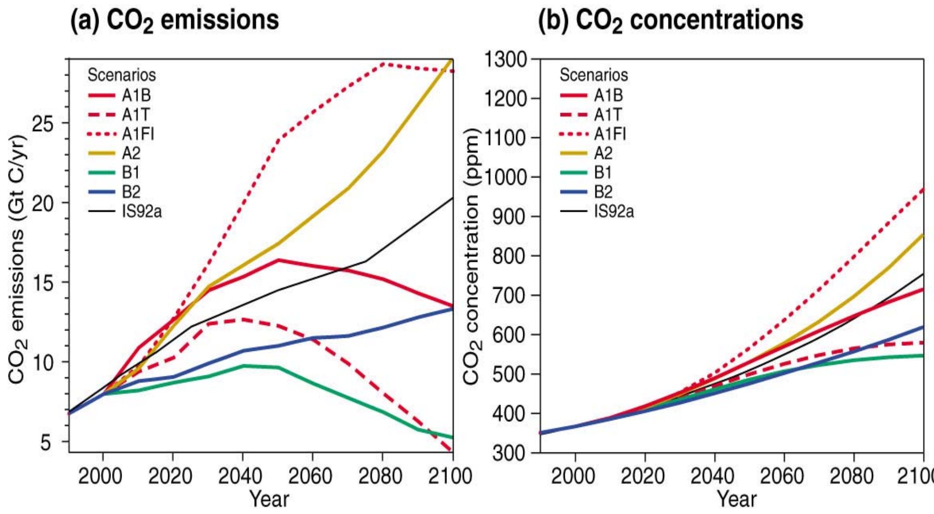

Figure 1 Scenarios of CO_2 gas emissions and consequential atmospheric concentrations of CO_2 (from IPCC, 2001).

Table 1

Available Combinations of Global Climate Models and Emission Scenarios[1]

	CGCM[2]	CSIRO	Hadley	NIES	GFDL	See Text
A1B	T, P, S	T, P, S	T, P, S	T, P	S	W
A1F	T, P, S	T, P, S	T, P, S	T, P	S	W
A1T	T, P, S	T, P, S	T, P, S	T, P	S	W
A2	T, P, S	T, P, S	T, P, S	T, P	S	W
B1	T, P, S	T, P, S	T, P, S	T, P	S	W
B2	T, P, S	T, P, S	T, P, S	T, P	S	W

[1] T = temperature, P = precipitation, S = sea level, W = wind
[2] In addition to monthly data, daily data are available for this model, but for the A2 and B2 emissions scenarios only.

Data Specifications and Terminology

The *return period* (sometimes referred to as the *recurrence interval*) is used as a measure of the likelihood of an extreme event. The *return period* is a statistical estimate of how often an extreme event of a given magnitude is likely to be equalled or exceeded. Thus the "hundred-year event" is one which will, on average, be equalled or exceeded once in any hundred-year period. Importantly, it does not mean that that the event occurs once every hundred years. In fact, in every year there is a 1 percent chance that an event with a 100 year return period will occur.

Sea Level

a) Current Risks Levels

Figure 2 shows annual mean values of sea level for Port Vila, relative to mean sea level. A long term trend of increasing sea level is evident. The trend in the observed long term sea level is 5.5 mm/year. This is greater than the estimated range of global sea-level rise over the past century, namely 1 to 2 mm/year.

Extreme high sea levels are evident in the mean hourly sea-level data. Figure 3 presents the maximum mean hourly sea level, by year, for Port Vila. Such exceptionally high sea levels are associated with flooding, accelerated coastal erosion and salt water intrusion into groundwater. The long term trend in the extreme hourly sea levels is 1.9 mm/year, which is less than the trend for the daily mean sea level. The long term trends in sea level are small relative to the large interannual variability.

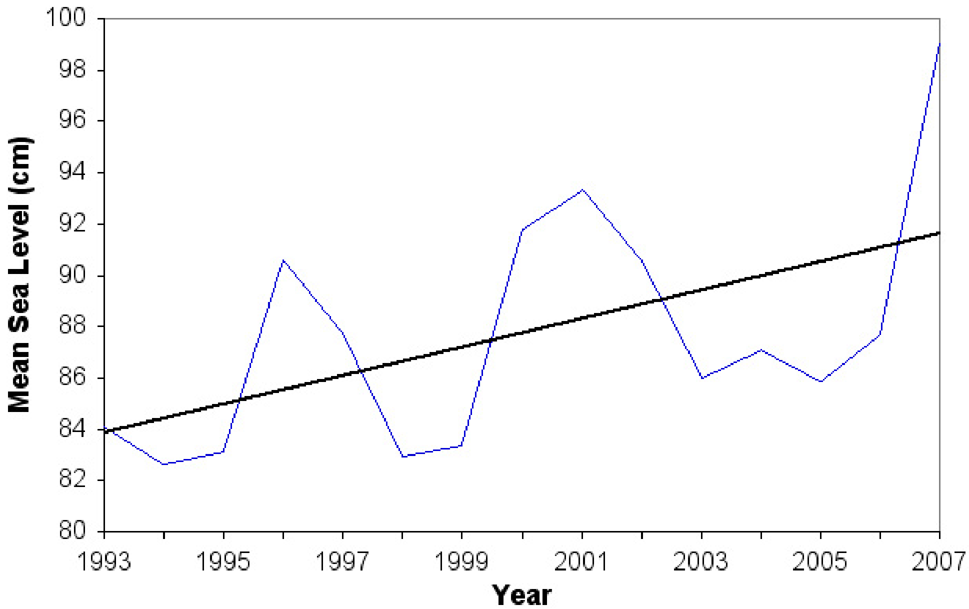

Figure 2 Mean annual sea level for Port Vila (1993 to 2007), relative to mean sea level. Also shown is the linear trend in sea level over the same period (5.5 mm/year).

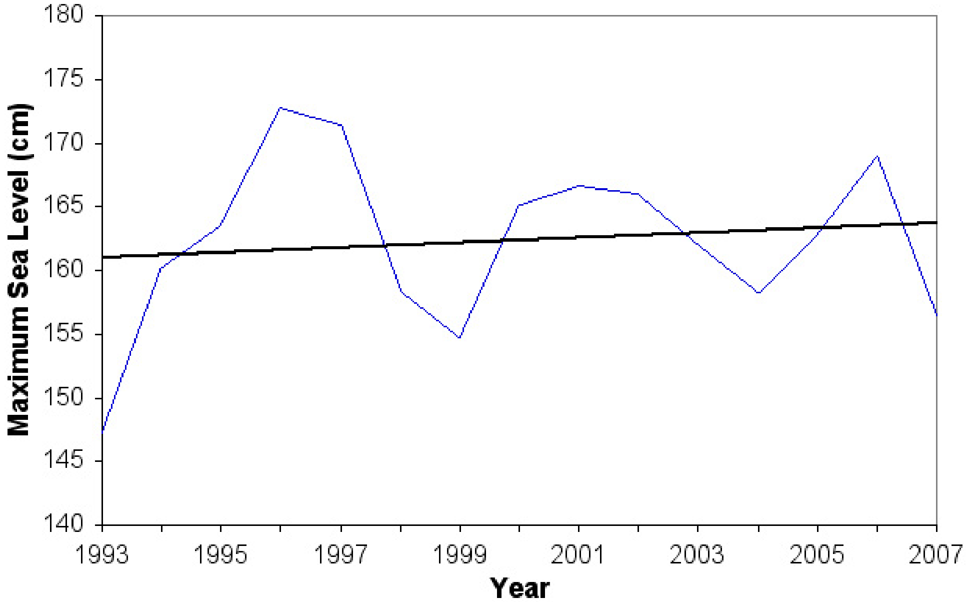

Figure 3 Maximum hourly sea level, by year, for Port Vila (1993 to 2007). Also shown is the linear trend in sea level over the same period (1.9 mm/year).

An hourly sea level of at least 1.9 m above mean sea level is a relatively rare event for Port Vila, with a return period of approximately 136 years (Figure 4 and Table 2).

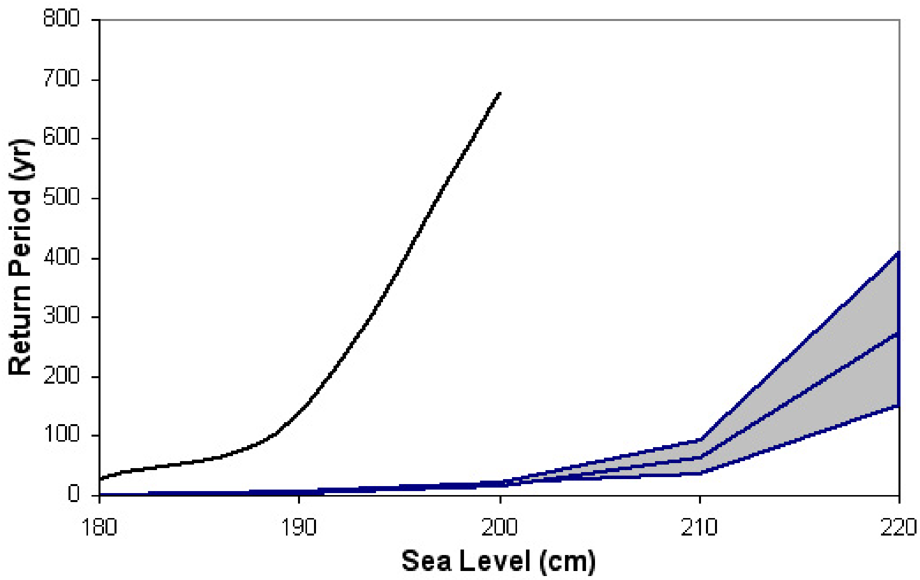

Figure 4 Relationship between hourly sea level and return period for Port Vila, for present day (black line) and 2025 (blue lines). The uncertainty envelope shows the maximum and minimum estimates of return periods for 2025, based on all possible combinations of the available global climate models and emission scenarios.

Table 2

Return Periods (years), for Hourly Sea Level (m) at Port Vila

Sea Level (m) of at Least	Observed	2050
1.5	1	1.0
1.6	1.7	1.0
1.7	6.0	1.1
1.8	28	1.4
1.9	136	3.8
2.0	674	15
2.1	>1000	63
2.2	>1000	274

b) Projected Risk Levels

Best estimates of future sea-level rise are based on an average of the estimates using a multi model and emission scenario ensemble (see Table 1). Figure 5 shows the best estimate of mean sea level out to 2100, as well as the band of extreme uncertainty. The latter is estimated using the highest and lowest estimates of sea-level rise for all model and emission scenario combinations.

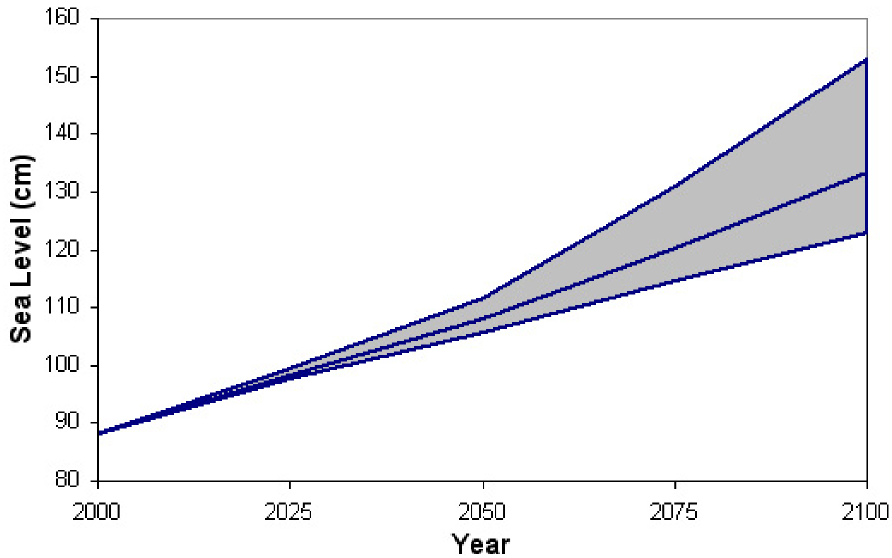

Figure 5 Best estimate of projected increase in mean sea level for Port Vila, along with the uncertainty envelope as given by the maximum and minimum estimates using all possible combinations of the available global climate models and emission scenarios.

As indicated in Figure 4 and Table 2, global warming will also have a significant impact on the return periods of extreme high sea levels that persist for at least an hour. For example a sea level of at least 1.9 m is currently a 136-year event. It will likely be a 4-year event by 2050. Figures 4 and 5 also show the relatively low level of uncertainty in future projections of mean sea level.

Air Temperature - Bauerfield

a) Current Risks Levels

Figure 6 shows annual mean air temperatures for Bauerfield. The long term trend is 0.03 ^oC/year. Figure 7 presents the maximum air temperature, by year, for Bauerfield. The long term trend in the extreme daily air temperatures is 0.01 ^oC/year. This is less than the trend for annual mean air temperature. Given the large interannual variability, these trends can be considered insignificant.

A daily maximum air temperature of 35.5 ^oC is a relatively rare event for Bauerfield, with a return period of approximately 73 years (Figure 8 and Table 3).

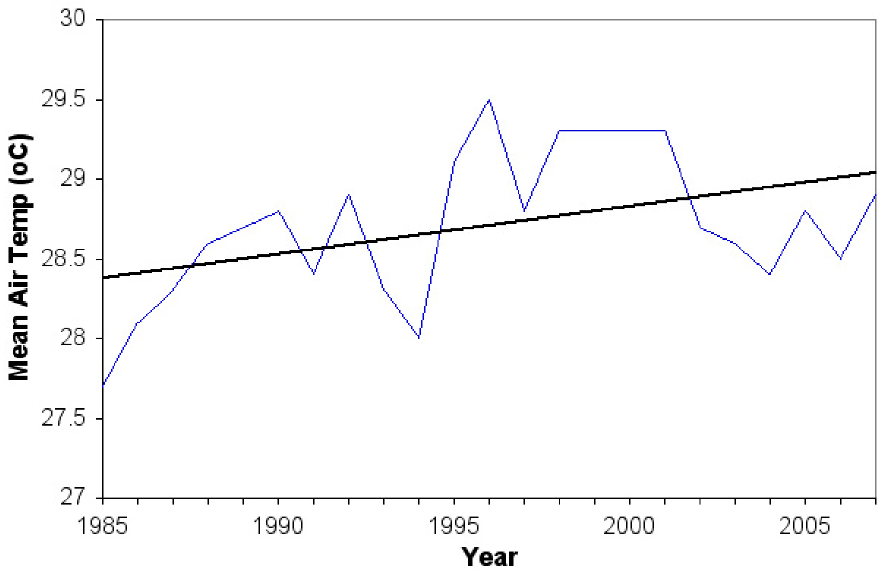

Figure 6 Annual mean air temperatures for Bauerfield (1985 to 2007). Also shown is the linear trend in annual mean air temperature (0.03 ^oC/year).

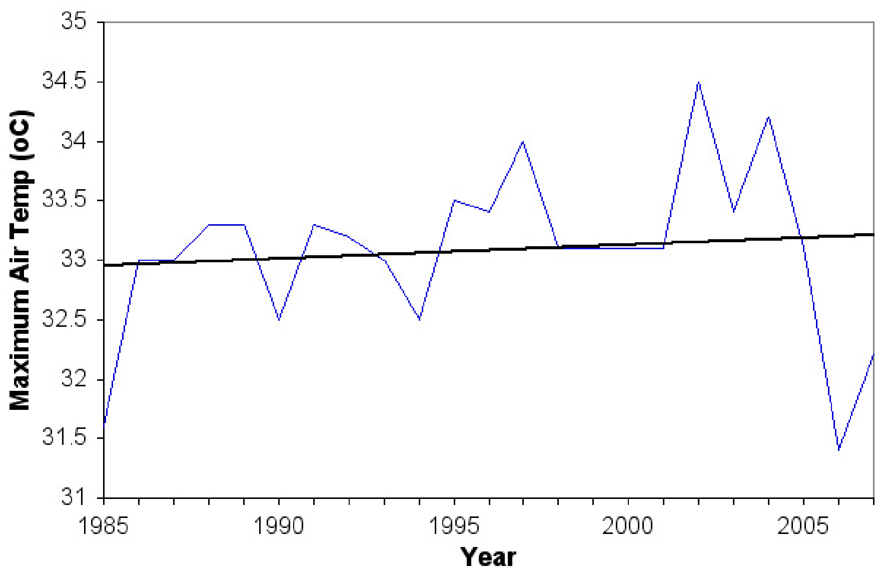

Figure 7 Annual maximum air temperature, by year, for Bauerfield (1985 to 2007). Also shown is the linear trend in the annual maximum air temperature over the same period (0.01 ^oC/year).

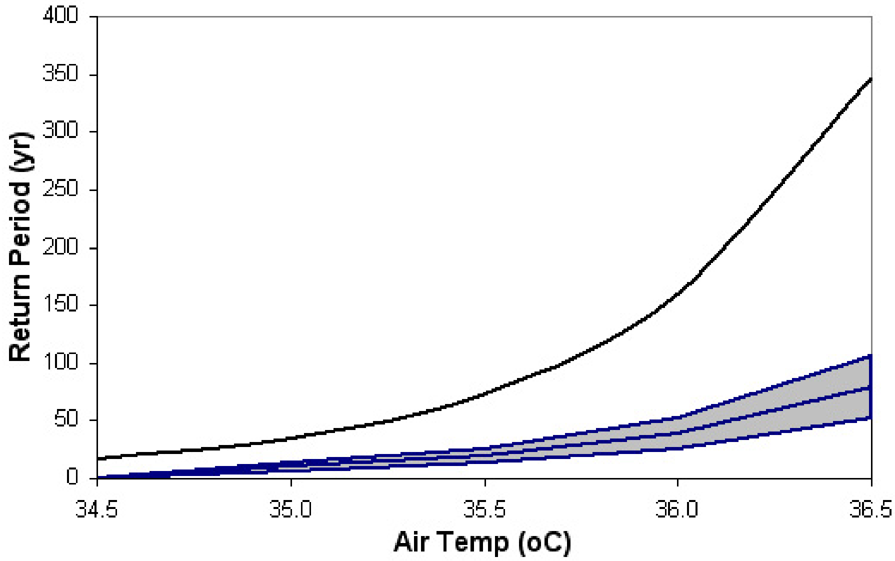

Figure 8 Relationship between hourly air temperature and return period for Bauerfield, for present day (black line) and 2025 (blue lines). The uncertainty envelope shows the maximum and minimum estimates of return periods for 2025, based on all possible combinations of the available global climate models and emission scenarios.

Table 3

Return Periods (years), for Air Temperature (^{o}C) at Bauerfield

Air Temp (^{o}C) of at Least	Observed	2050
33	2.1	1.2
33.5	3.8	1.7
34	7.6	2.7
34.5	16	5
35	34	9.7
35.5	73	19
36	159	39
36.5	346	79
37	751	161

b) Projected Risk Levels

Best estimates of future air temperatures are based on an average of the estimates using a multi model and emission scenario ensemble (see Table 1). Figure 9 shows the best estimate of mean air temperature out to 2100, as well as the band of extreme uncertainty. The latter is estimated using the highest and lowest estimates of air temperature projections for all model and emission scenario combinations.

As indicated in Figure 8 and Table 3, global warming will also have a significant impact on the return periods of extreme high temperatures. For example a maximum daily air temperature of at least 36 ^{o}C is currently a one in 160-year event. It will likely be a 40-year event by 2050. Figures 8 and 9 also show the relatively low level of uncertainty in future projections of maximum air temperature extremes.

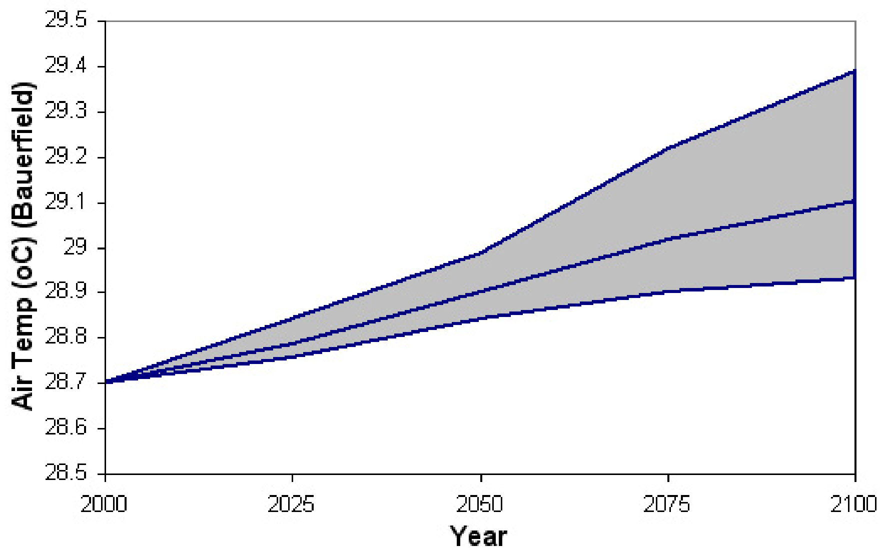

Figure 9 Best estimate of projected increase in mean air temperature for Bauerfield, along with the uncertainty envelope as given by the maximum and minimum estimates using all possible combinations of the available global climate models and emission scenarios.

Air Temperature - Lamap

a) Current Risks Levels

Figure 10 shows annual mean air temperatures for Lamap. The long term trend is -0.01 ^{o}C/year. Figure 11 presents the maximum air temperature, by year, for Lamap. The long term trend in the extreme daily air temperatures is –0.07 ^{o}C/year. Given the large interannual variability, these trends can be considered insignificant.

A daily maximum air temperature of 36 ^{o}C is a relatively rare event for Lamap, with a return period of approximately 50 years (Figure 12 and Table 4).

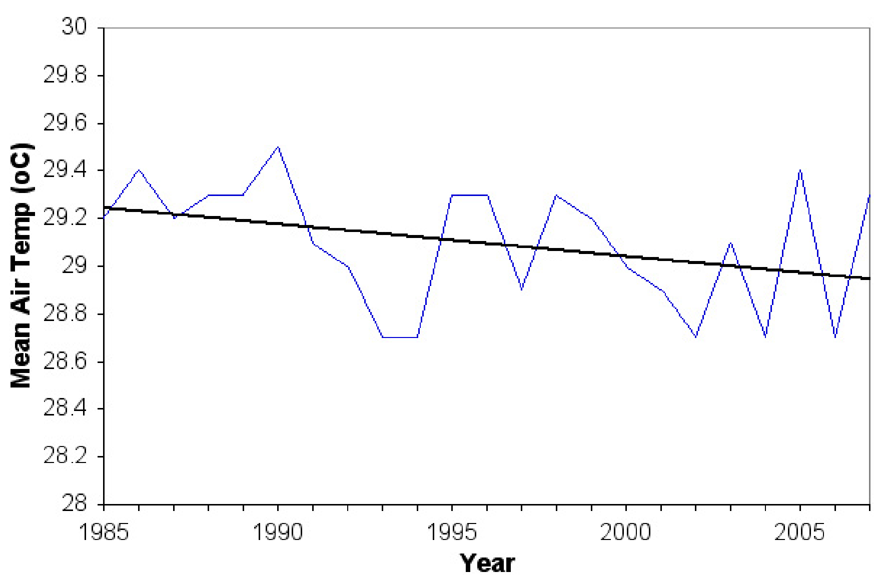

Figure 10 Annual mean air temperatures for Lamap (1985 to 2007). Also shown is the linear trend in annual mean air temperature (-0.01 ^{o}C/year).

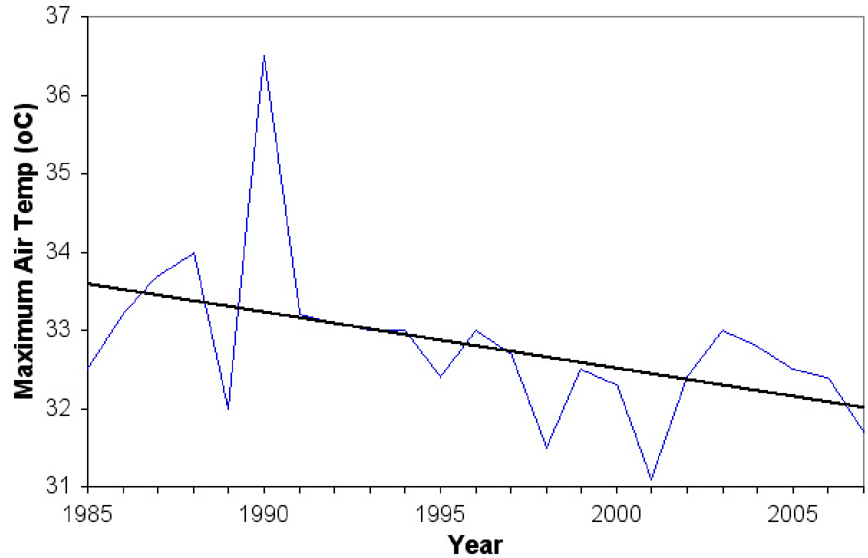

Figure 11 Annual maximum air temperature, by year, for Lamap (1985 to 2007). Also shown is the linear trend in the annual maximum air temperature over the same period (-0.07 ^{o}C/year).

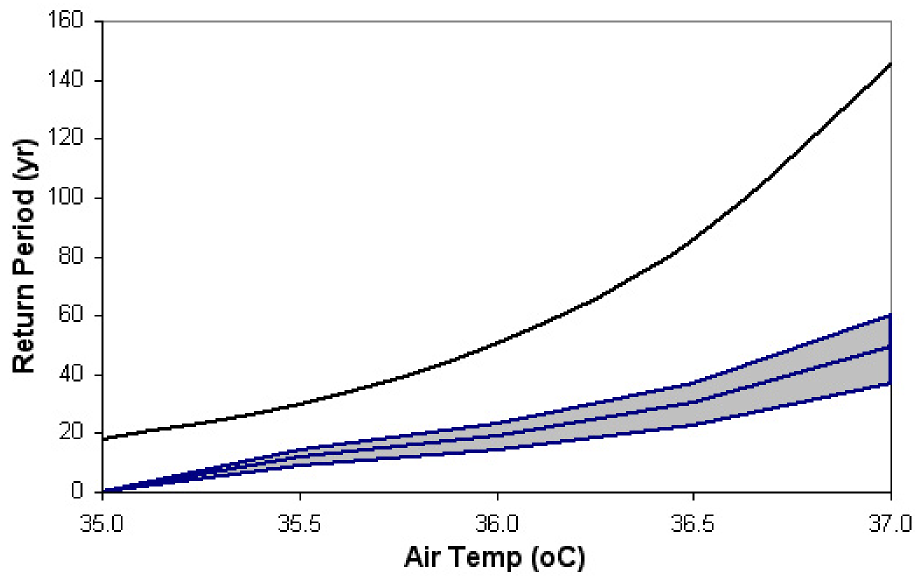

Figure 12 Relationship between hourly air temperature and return period for Lamap, for present day (black line) and 2025 (blue lines). The uncertainty envelope shows the maximum and minimum estimates of return periods for 2025, based on all possible combinations of the available global climate models and emission scenarios.

Table 4

Return Periods (years), for Air Temperature (^oC) at Lamap

Air Temp (^oC) of at Least	Observed	2050
32	1.3	1.1
33	2.6	1.6
34	6.5	3.1
35	18	7.4
36	51	19
37	145	49
38	418	129

b) Projected Risk Levels

Best estimates of future air temperatures are based on an average of the estimates using a multi model and emission scenario ensemble (see Table 1). Figure 13 shows the best estimate of mean air temperature out to 2100, as well as the band of extreme uncertainty. The latter is estimated using the highest and lowest estimates of air temperature projections for all model and emission scenario combinations.

As indicated in Figure 12 and Table 4, global warming will also have a significant impact on the return periods of extreme high temperatures. For example a maximum daily air temperature of at least 37 ^oC is currently a one in 145-year event. It will likely be approximately a 50-year event by 2050. Figures 12 and 13 also show the relatively low level of uncertainty in future projections of maximum air temperature extremes.

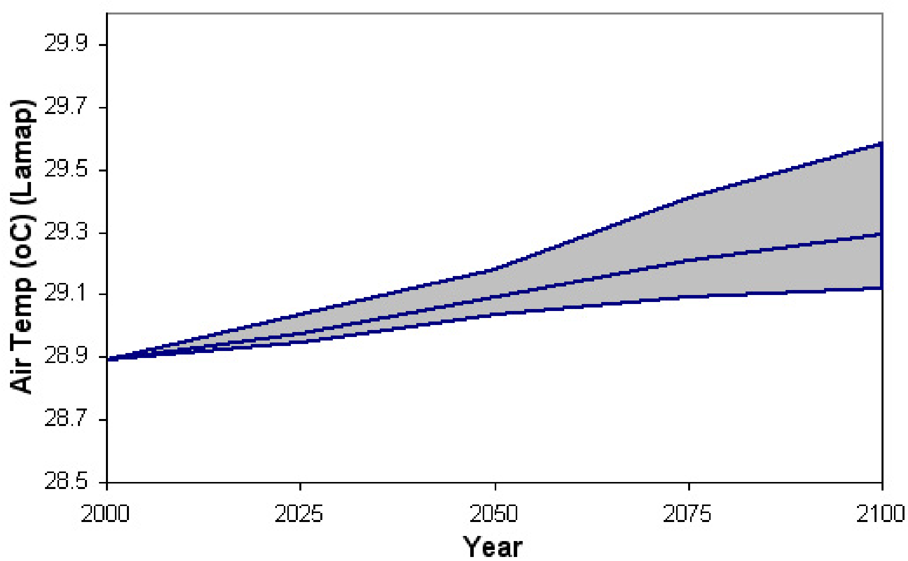

Figure 13 Best estimate of projected increase in mean air temperature for Lamap, along with the uncertainty envelope as given by the maximum and minimum estimates using all possible combinations of the available global climate models and emission scenarios.

Air Temperature - Sola

a) Current Risks Levels

Figure 14 shows annual mean air temperatures for Sola. The long term trend is -0.01 ^{o}C/year. Figure 15 presents the maximum air temperature, by year, for Sola. The long term trend in the extreme daily air temperatures is 0.01 ^{o}C/year. Given the large interannual variability, these trends can be considered insignificant.

A daily maximum air temperature of 34 ^{o}C is a relatively rare event for Sola, with a return period of approximately 45 years (Figure 16 and Table 5).

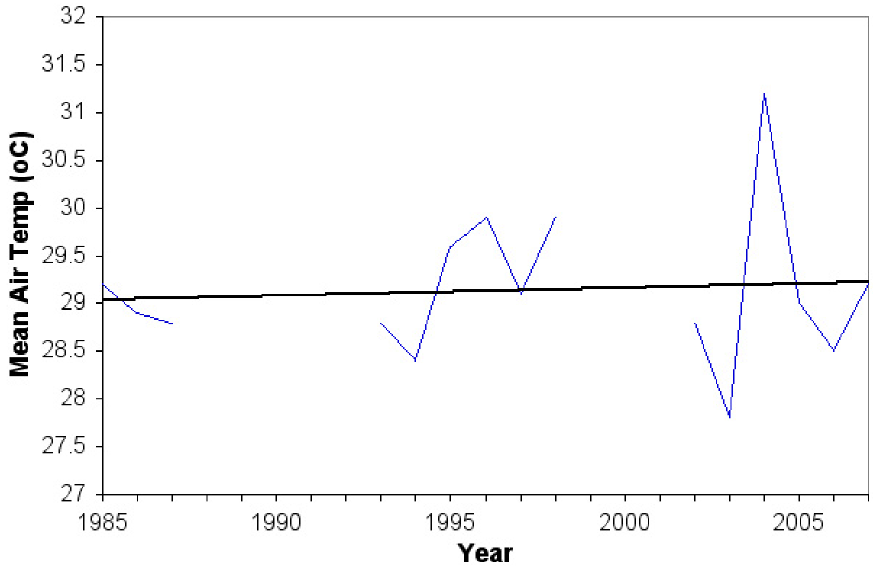

Figure 14 Annual mean air temperatures for Sola (1985 to 2007). Also shown is the linear trend in annual mean air temperature (0.01 ^{o}C/year).

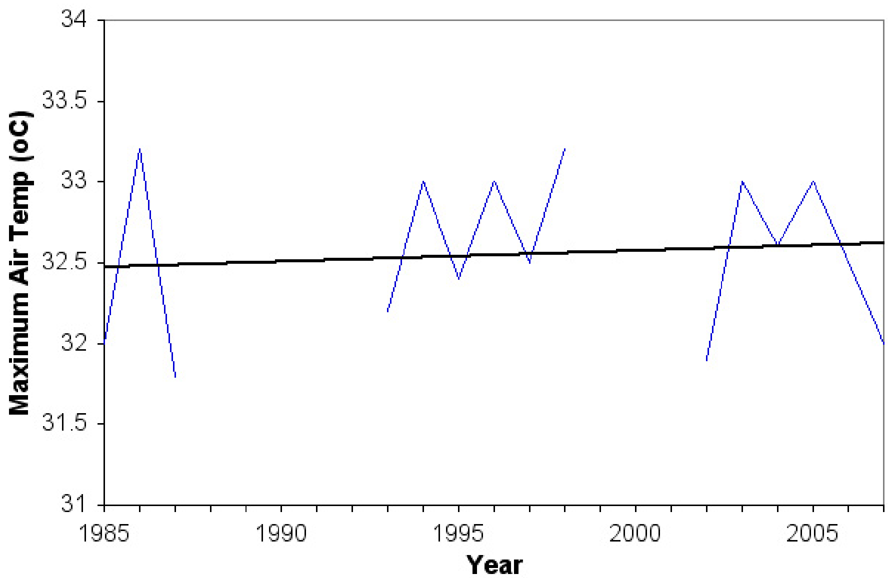

Figure 15 Annual maximum air temperature, by year, for Sola (1985 to 2007). Also shown is the linear trend in the annual maximum air temperature over the same period (0.01 ^{o}C/year).

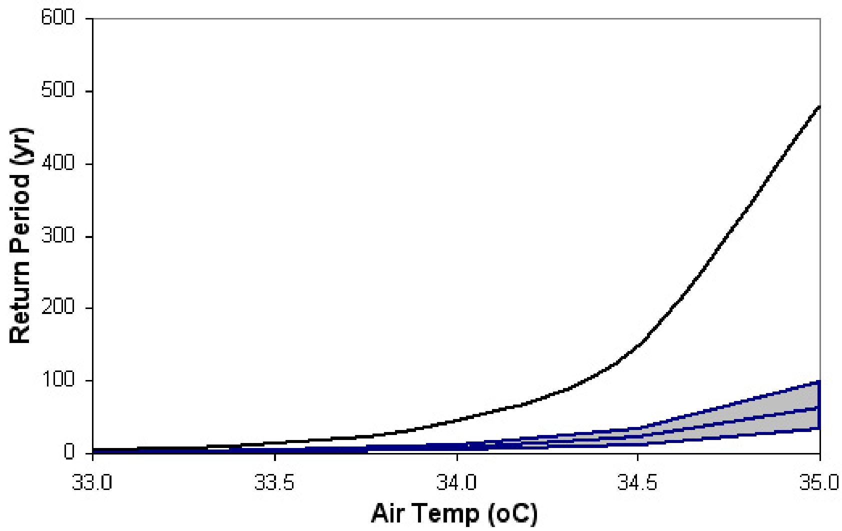

Figure 16 Relationship between hourly air temperature and return period for Sola, for present day (black line) and 2025 (blue lines). The uncertainty envelope shows the maximum and minimum estimates of return periods for 2025, based on all possible combinations of the available global climate models and emission scenarios.

Table 4

Return Periods (years), for Air Temperature (^{o}C) at Sola

Air Temp (^{o}C) of at Least	Observed	2050
32	1.1	1.0
32.5	1.8	1.0
33	4.7	1.4
33.5	14	2.9
34	45	7.5
34.5	146	21
35	477	62
35.5	>1000	185

b) Projected Risk Levels

Best estimates of future air temperatures are based on an average of the estimates using a multi model and emission scenario ensemble (see Table 1). Figure 17 shows the best estimate of mean air temperature out to 2100, as well as the band of extreme uncertainty. The latter is estimated using the highest and lowest estimates of air temperature projections for all model and emission scenario combinations.

As indicated in Figure 12 and Table 4, global warming will also have a significant impact on the return periods of extreme high temperatures. For example a maximum daily air temperature of at least 34.5 ^{o}C is currently a one in 145-year event. It will likely be approximately a 20-year event by 2050. Figures 16 and 17 also show the relatively low level of uncertainty in future projections of maximum air temperature extremes.

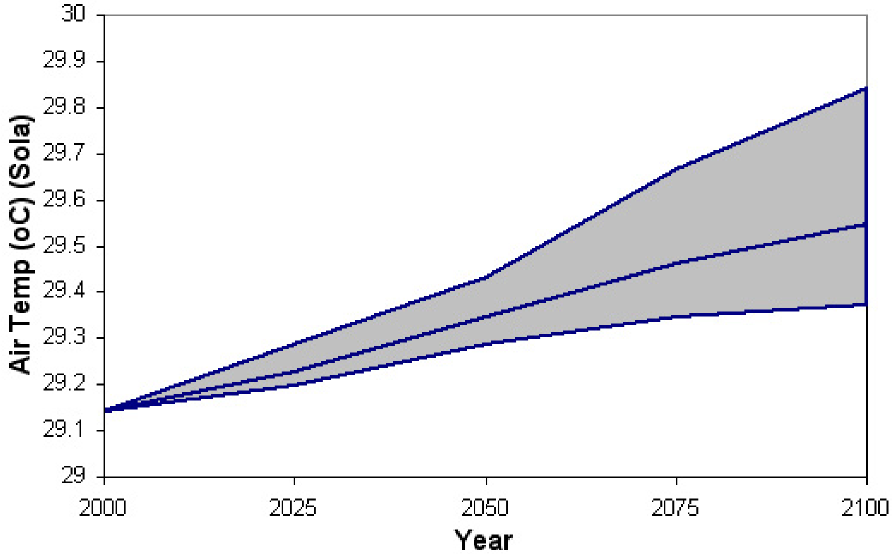

Figure 17 Best estimate of projected increase in mean air temperature for Sola, along with the uncertainty envelope as given by the maximum and minimum estimates using all possible combinations of the available global climate models and emission scenarios.

Comparative Analysis of Risks Related to High Air Temperatures

Figure 18 shows the return periods for maximum daily air temperatures, based on observed data for the three locations for which air temperature data are available. Lamap has the greatest risk of extreme high temperatures, followed by Bauerfield and Sola.

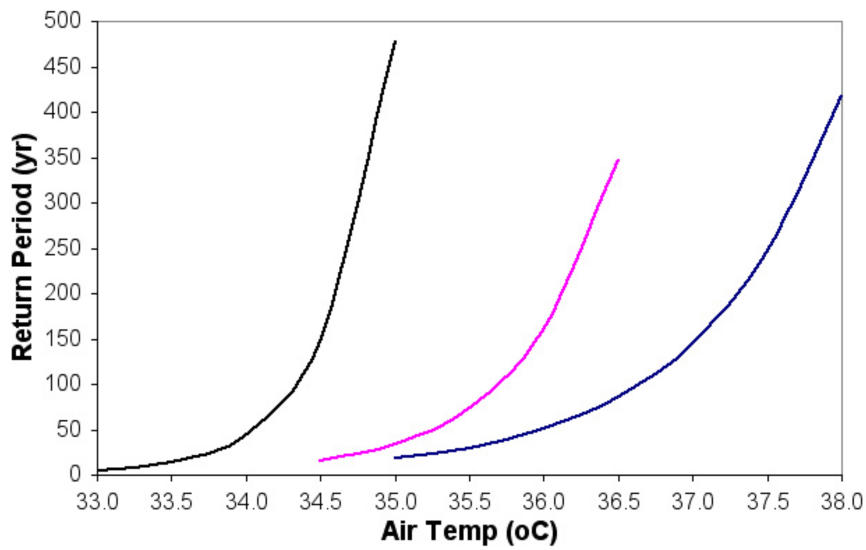

Figure 18 Return periods for maximum daily air temperatures, based on observed data for Sola (black Line), Bauerfield (pink line) and Lamap (blue line).

Water Temperature

a) Current Risks Levels

Figure 19 shows annual mean water temperatures for Port Vila. The long term trend is 0.06 ^{o}C/year. Figure 20 presents the maximum water temperature, by year, for Port Vila. There is no significant long term trend in extreme daily water temperature.

A daily maximum water temperature of 33 ^{o}C is a relatively rare event for Port Vila, with a return period of approximately 95 years (Figure 21 and Table 5).

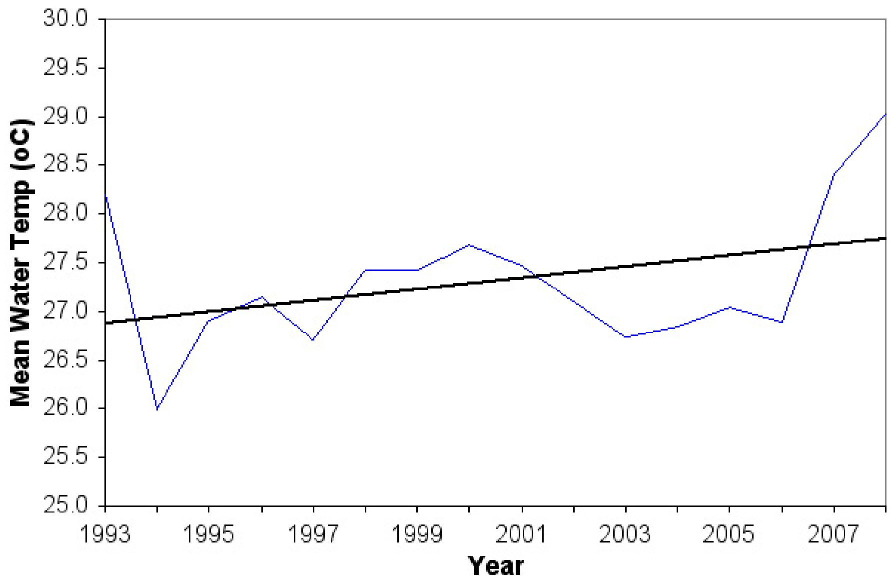

Figure 19 Annual mean water temperatures for Port Vila (1993 to 2007). Also shown is the linear trend in annual mean water temperature (0.06 ^{o}C/year).

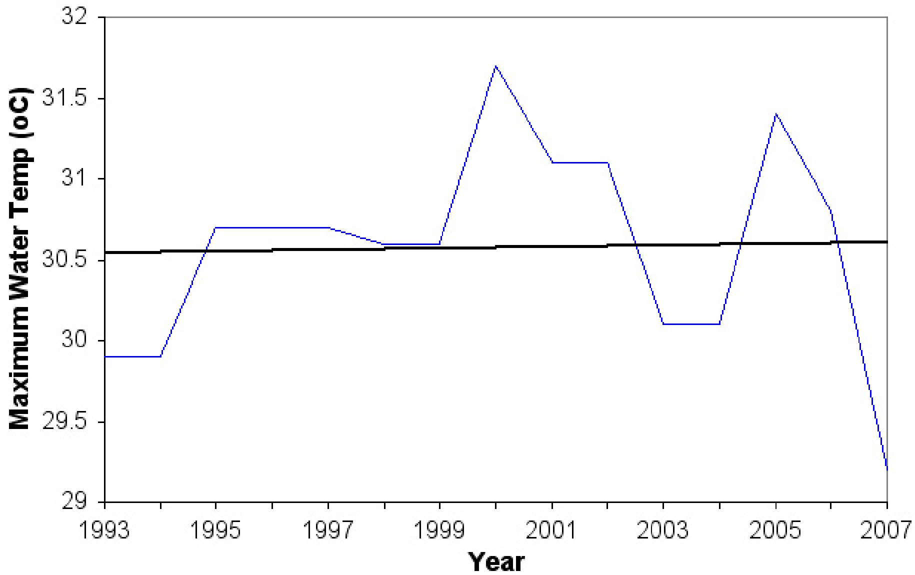

Figure 20 Annual maximum water temperature, by year, for Port Vila (1993 to 2007). Also shown is the linear trend in the annual maximum water temperature over the same period (0.005 ^{o}C/year).

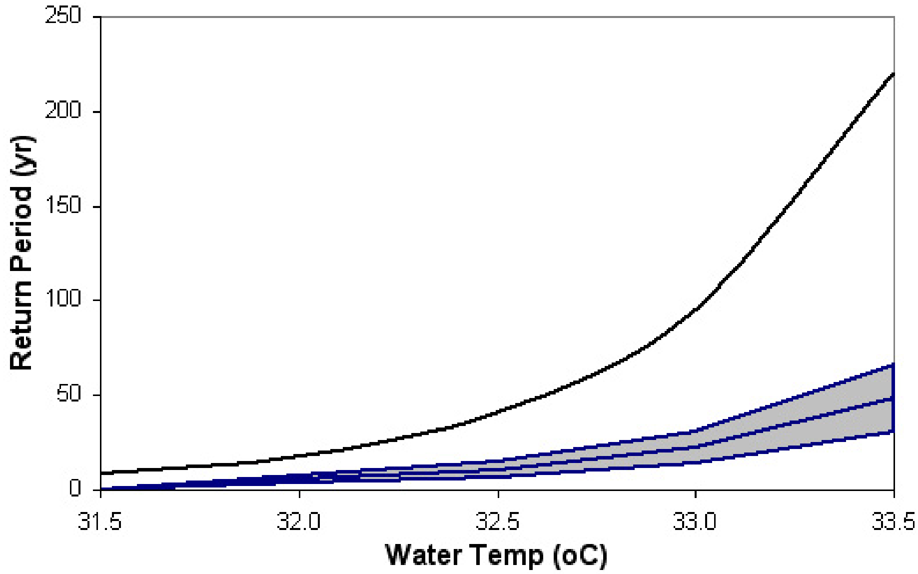

Figure 21 Relationship between hourly water temperature and return period for Port Vila, for present day (black line) and 2025 (blue lines). The uncertainty envelope shows the maximum and minimum estimates of return periods for 2025, based on all possible combinations of the available global climate models and emission scenarios.

Table 5

Return Periods (years), for Water Temperature (^{o}C) at Port Vila

Water Temp (^{o}C) of at Least	Observed	2050
30	1.2	1.0
30.5	2.0	1.1
31	3.8	1.6
31.5	8.1	2.7
32	18	5.2
32.5	41	11
33	95	22
33.5	219	48
34	507	103

b) Projected Risk Levels

Best estimates of future water temperatures are based on an average of the estimates using a multi model and emission scenario ensemble (see Table 1). Figure 22 shows the best estimate of mean water temperature out to 2100, as well as the band of extreme uncertainty. The latter is estimated using the highest and lowest estimates of water temperature projections for all model and emission scenario combinations.

As indicated in Figure 21 and Table 5, global warming will also have a significant impact on the return periods of extreme high water temperatures. For example a maximum daily water temperature of at least 33.5^{o}C is currently a one in 200-year event. It will likely be a 50-year event by 2050. Figures 21 and 22 also show the relatively low level of uncertainty in future projections of maximum water temperature extremes.

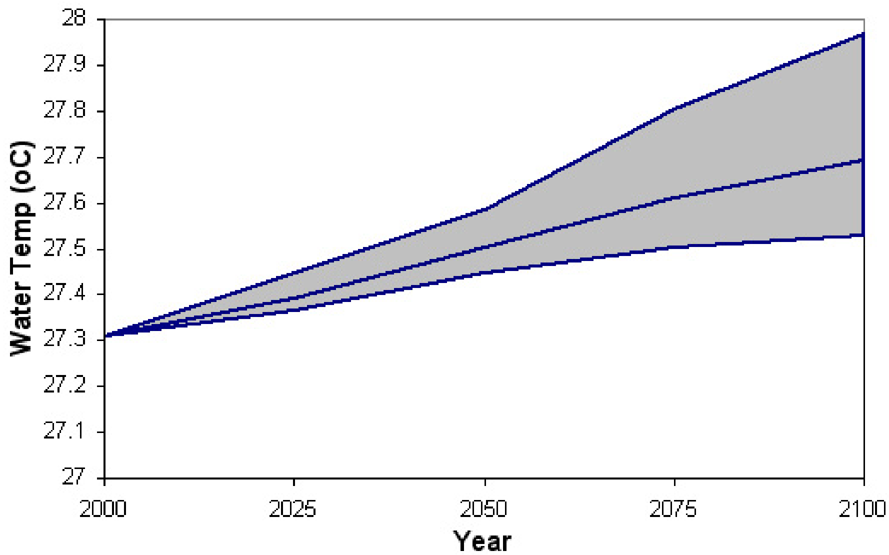

Figure 22 Best estimate of projected increase in mean water temperature for Port Vila, along with the uncertainty envelope as given by the maximum and minimum estimates using all possible combinations of the available global climate models and emission scenarios.

Wind Gusts

a) Current Risks Levels

Figure 23 presents the maximum wind gust, by year, for Port Vila. The long term trend in the annual extreme wind gust is -0.46 m/s / year.

A daily maximum wind gust of 35 m/s is a relatively rare event for Port Vila, with a return period of approximately 53 years (Figure 24 and Table 6).

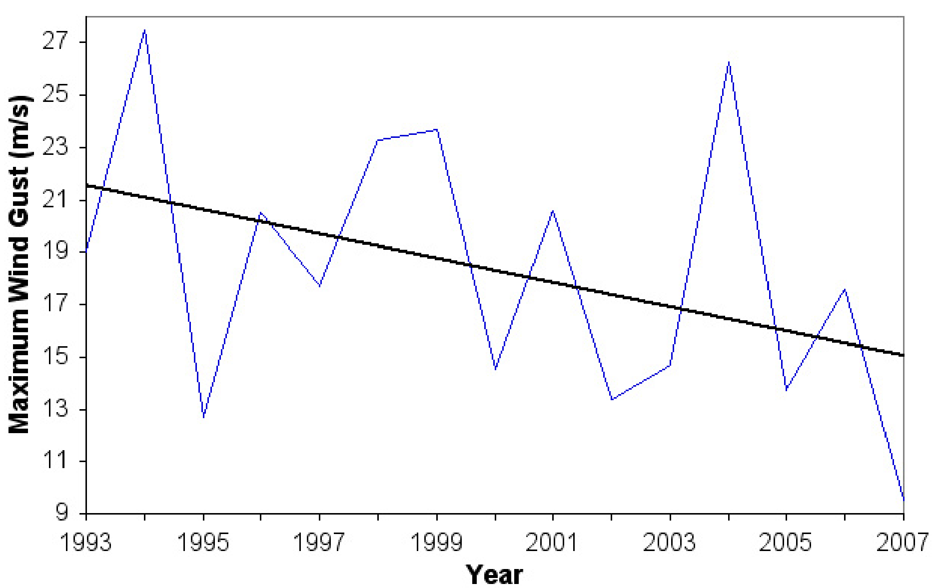

Figure 23 Annual maximum wind gust, by year, for Port Vila (1993 to 2007). Also shown is the linear trend in the annual maximum air temperature over the same period (-0.46 m/s / year).

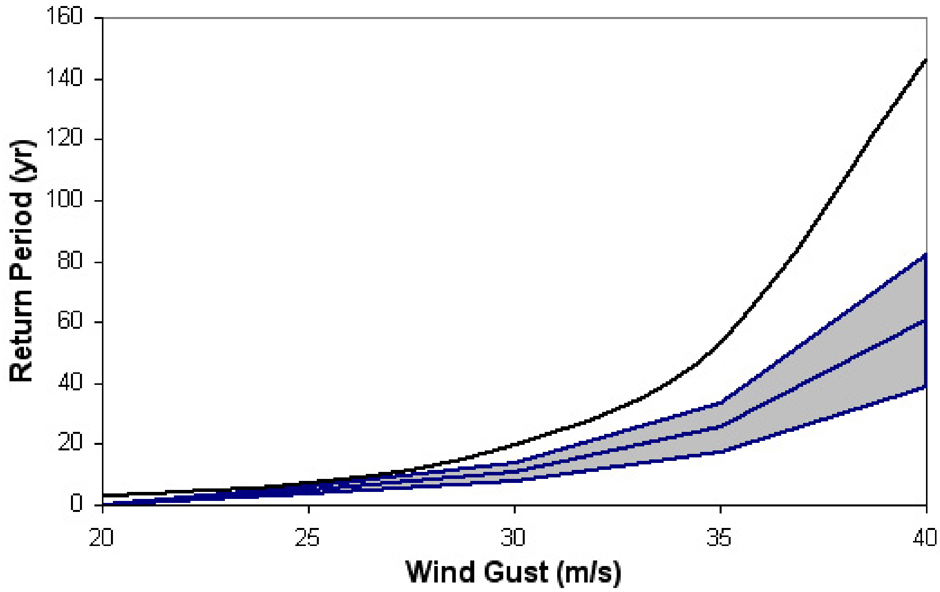

Figure 24 Relationship between wind gust and return period for Funafuti, for present day (black line) and 2025 (blue lines). The uncertainty envelope shows the maximum and minimum estimates of return periods for 2025, based on all possible combinations of the available global climate models and emission scenarios.

Table 6

Return Periods (years), for Wind Gust (m/s) at Port Vila

Wind Gust (m/s) of at Least	Observed	2050
10	1.0	1
15	1.5	1.4
20	3.0	2.4
25	7.4	4.9
30	20	11
35	53	26
40	146	61
45	402	145

b) Projected Risk Levels

Best estimates of future wind gusts are based on an average of the estimates using a multi model and emission scenario ensemble (see Table 1). Figure 25 shows the best estimate of mean wind gust out to 2100, as well as the band of extreme uncertainty. The latter is estimated using the highest and lowest estimates of air temperature projections for all model and emission scenario combinations.

As indicated in Figure 24 and Table 6, global warming will also have a significant impact on the return periods of extreme wind gusts. For example a maximum daily wind gust of at least 40 m/s is currently a one in 150-year event. It will likely be a 60-year event by 2050. Figures 24 and 25 also show the relatively high level of uncertainty in future projections of wind gust extremes.

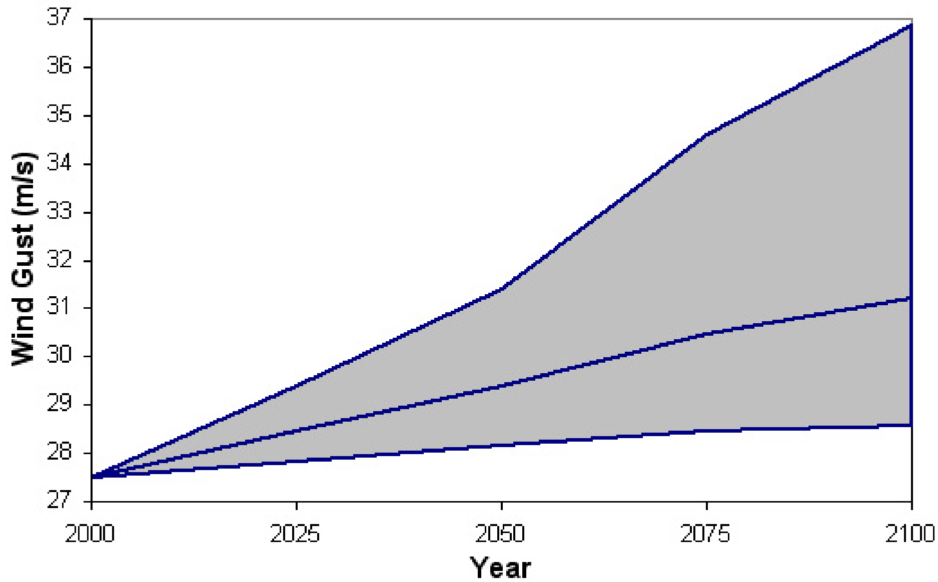

Figure 25 Best estimate of projected increase in mean wind gust for Port Vila, along with the uncertainty envelope as given by the maximum and minimum estimates using all possible combinations of the available global climate models and emission scenarios.

Daily Rainfall - Lamap

a) Current Risks Levels

Figure 26 shows annual mean rainfall for Lamap. The long term trend is 8.6 mm/year. Figure 27 presents the maximum daily rainfall, by year, for Lamap. The long term trend in the extreme daily rainfall is 0.9 mm/year. Given the large interannual variability, these trends can be considered insignificant.

A maximum daily rainfall of 400 mm is a relatively rare event for Lamap, with a return period of approximately 100 years (Figure 28 and Table 7).

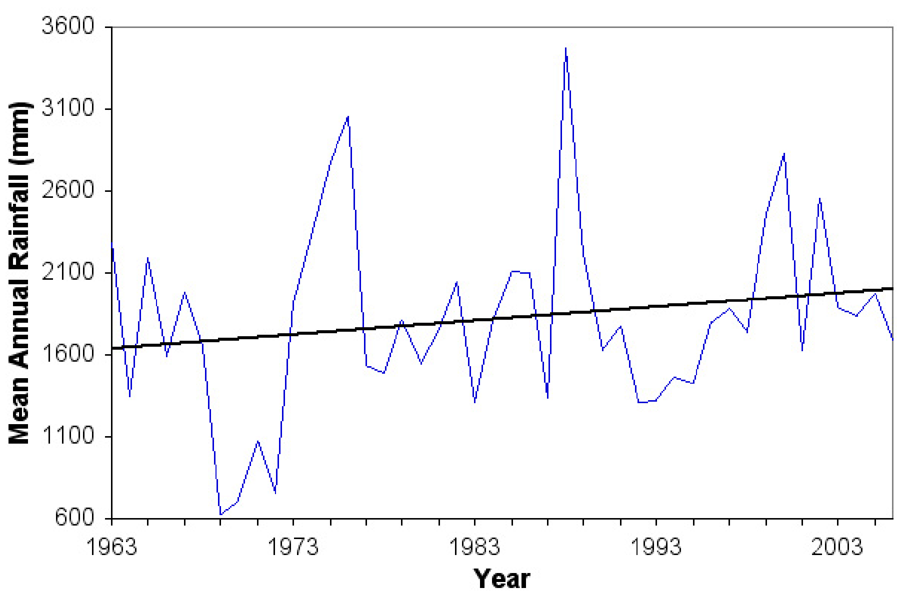

Figure 26 Annual mean rainfall for Lamap (1963 to 2006). Also shown is the linear trend in annual mean rainfall (8.6 mm/year).

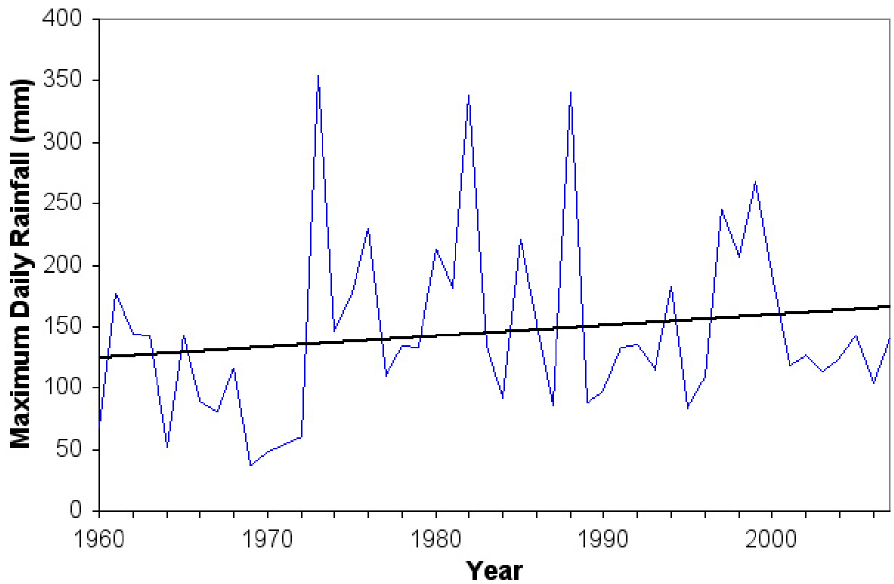

Figure 27 Annual maximum daily rainfall, by year, for Lamap (1960 to 2007). Also shown is the linear trend in the annual maximum daily rainfall over the same period (0.9 mm/year).

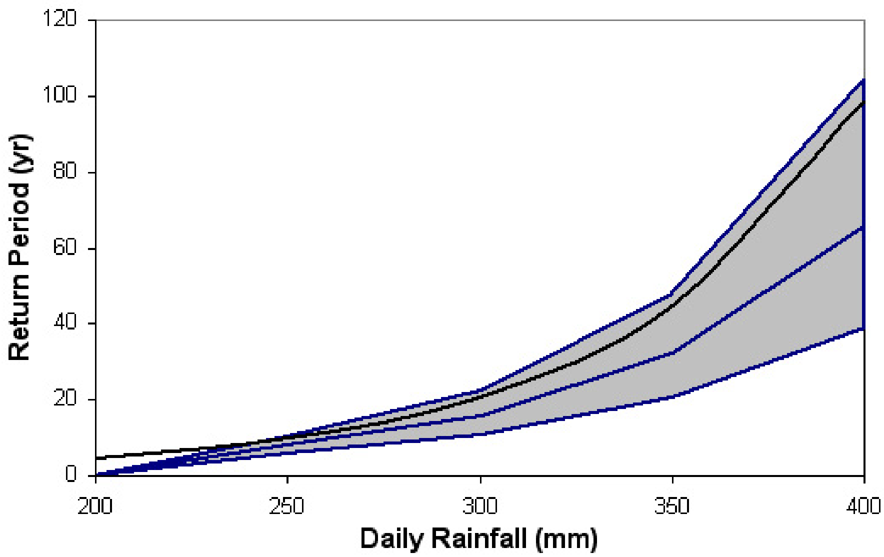

Figure 28 Relationship between maximum daily rainfall and return period for Lamap, for present day (black line) and 2025 (blue lines). The uncertainty envelope shows the maximum and minimum estimates of return periods for 2025, based on all possible combinations of the available global climate models and emission scenarios.

Table 7

Return Periods (years), for Daily Rainfall (mm) at Lamap

Rainfall (mm) of at Least	Observed	2050
100	1.4	1.4
150	2.4	2.3
200	4.6	4.1
250	9.6	7.9
300	21	16
350	45	32
400	98	66
450	216	135
500	476	278

b) Projected Risk Levels

Best estimates of future rainfall are based on an average of the estimates using a multi model and emission scenario ensemble (see Table 1). Figure 29 shows the best estimate of mean daily rainfall out to 2100, as well as the band of extreme uncertainty. The latter is estimated using the highest and lowest estimates of air temperature projections for all model and emission scenario combinations.

As indicated in Figure 28 and Table 7, global warming will also have a significant impact on the return periods of extreme rainfall events. For example a maximum daily rainfall of at least 400 mm is currently a one in 100-year event. It will likely be a 66-year event by 2050. Figures 28 and 29 also show the relatively high level of uncertainty in future projections of maximum rainfall extremes.

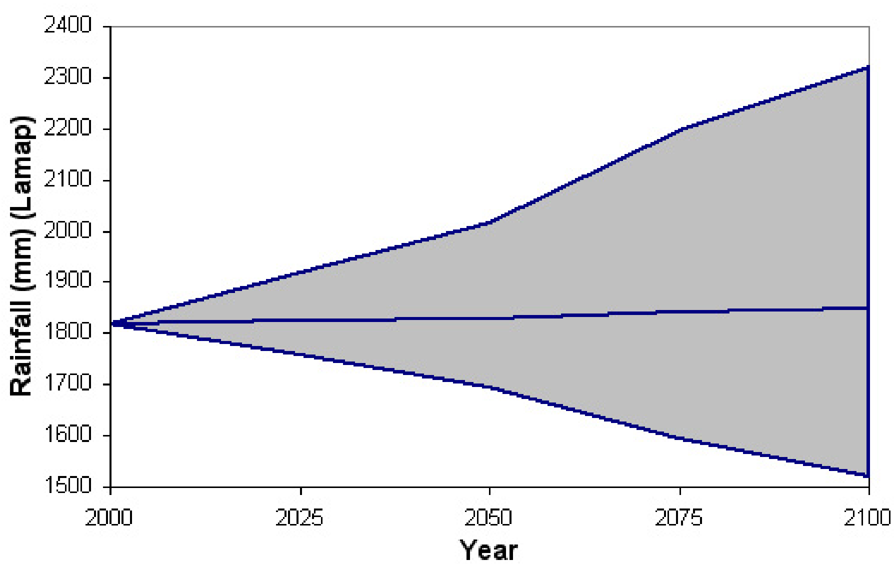

Figure 29 Best estimate of projected increase in mean annual rainfall for Lamap, along with the uncertainty envelope as given by the maximum and minimum estimates using all possible combinations of the available global climate models and emission scenarios.

Daily Rainfall - Sola

a) Current Risks Levels

Figure 30 shows annual mean rainfall for Sola. The long term trend is 9.4 mm/year. Figure 31 presents the maximum daily rainfall, by year, for Sola. The long term trend in the extreme daily rainfall is 0.69 mm/year. Given the large interannual variability, these trends can be considered insignificant.

A maximum daily rainfall of 400 mm is a relatively rare event for Sola, with a return period of approximately 80 years (Figure 32 and Table 8).

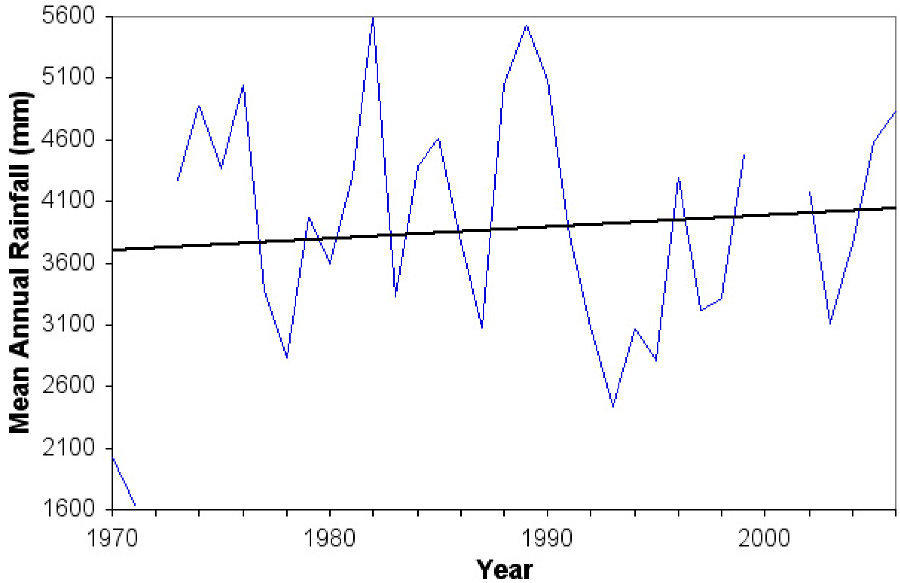

Figure 30 Annual mean rainfall for Sola (1970 to 2006). Also shown is the linear trend in annual mean rainfall (9.4 mm/year).

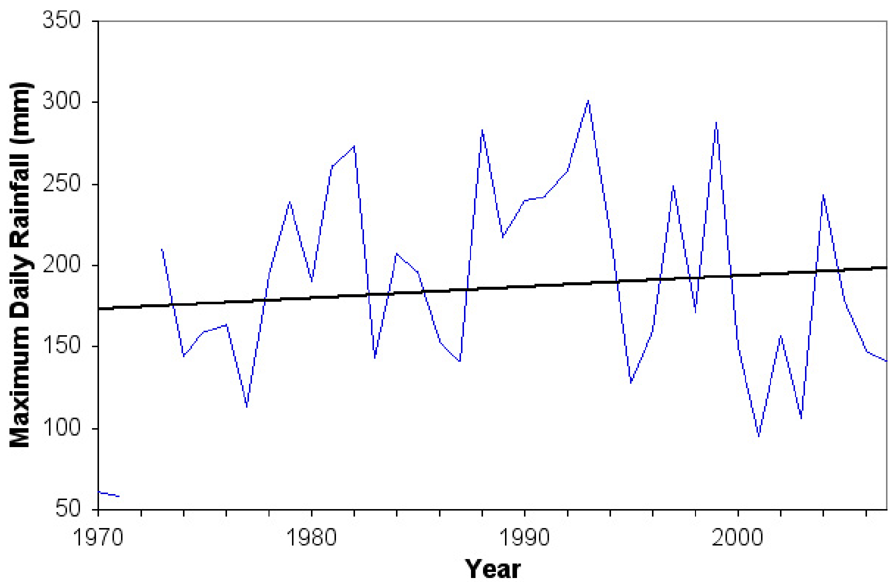

Figure 31 Annual maximum daily rainfall, by year, for Sola (1970 to 2007). Also shown is the linear trend in the annual maximum daily rainfall over the same period (0.69 mm/year).

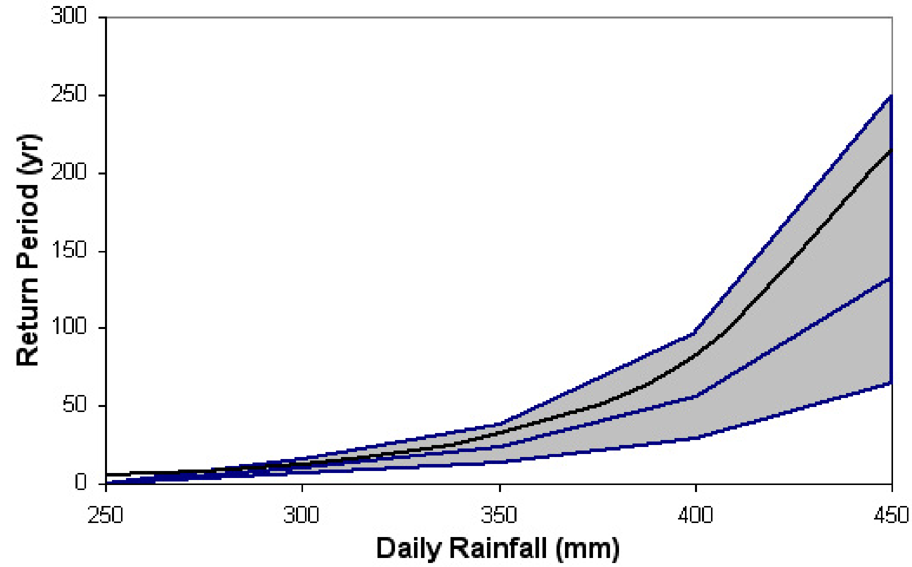

Figure 32 Relationship between maximum daily rainfall and return period for Sola, for present day (black line) and 2025 (blue lines). The uncertainty envelope shows the maximum and minimum estimates of return periods for 2025, based on all possible combinations of the available global climate models and emission scenarios.

Table 8

Return Periods (years), for Daily Rainfall (mm) at Sola

Rainfall (mm) of at Least	Observed	2050
100	1.0	1.0
150	1.3	1.3
200	2.3	2.2
250	5.1	4.5
300	13	10
350	32	23
400	82	56
450	214	133
500	557	317

b) Projected Risk Levels

Best estimates of future rainfall are based on an average of the estimates using a multi model and emission scenario ensemble (see Table 1). Figure 33 shows the best estimate of mean daily rainfall out to 2100, as well as the band of extreme uncertainty. The latter is estimated using the highest and lowest estimates of air temperature projections for all model and emission scenario combinations.

As indicated in Figure 32 and Table 8, global warming will also have a significant impact on the return periods of extreme rainfall events. For example a maximum daily rainfall of at least 400 mm is currently a one in 80-year event. It will likely be a 56-year event by 2050. Figures 32 and 33 also show the relatively high level of uncertainty in future projections of maximum rainfall extremes.

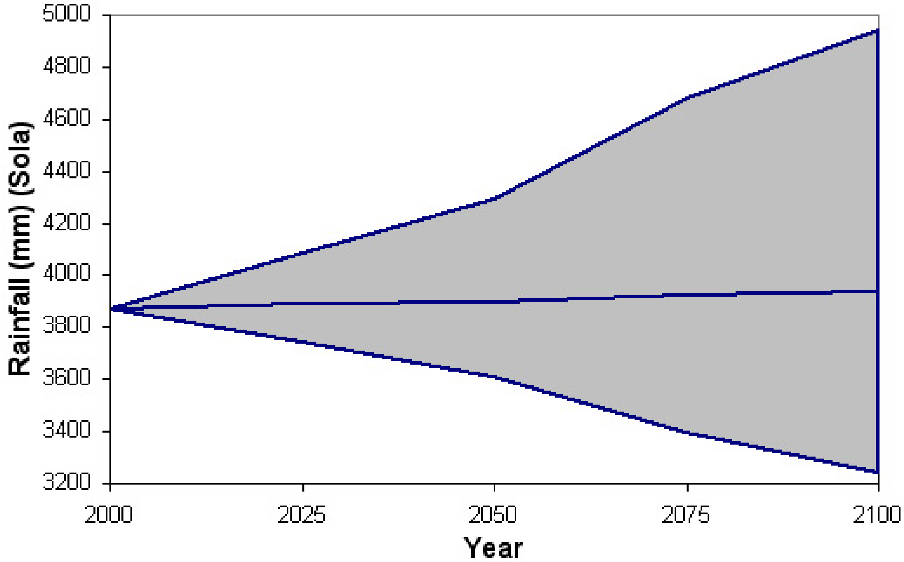

Figure 33 Best estimate of projected increase in mean annual rainfall for Sola, along with the uncertainty envelope as given by the maximum and minimum estimates using all possible combinations of the available global climate models and emission scenarios.

Daily Rainfall - Pekoa

a) Current Risks Levels

Figure 34 shows annual mean rainfall for Pekoa. The long term trend is -25.3 mm/year. Figure 35 presents the maximum daily rainfall, by year, for Pekoa. The long term trend in the extreme daily rainfall is -0.18 mm/year. Given the large interannual variability, these trends can be considered insignificant.

A maximum daily rainfall of 350 mm is a relatively rare event for Pekoa, with a return period of approximately 120 years (Figure 36 and Table 9).

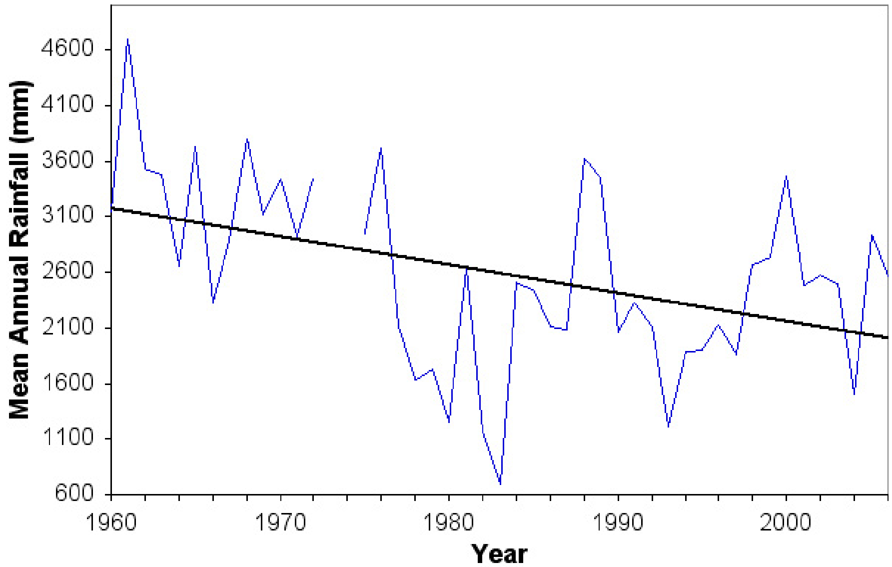

Figure 34 Annual mean rainfall for Pekoa (1960 to 2006). Also shown is the linear trend in annual mean rainfall (-25.3 mm/year).

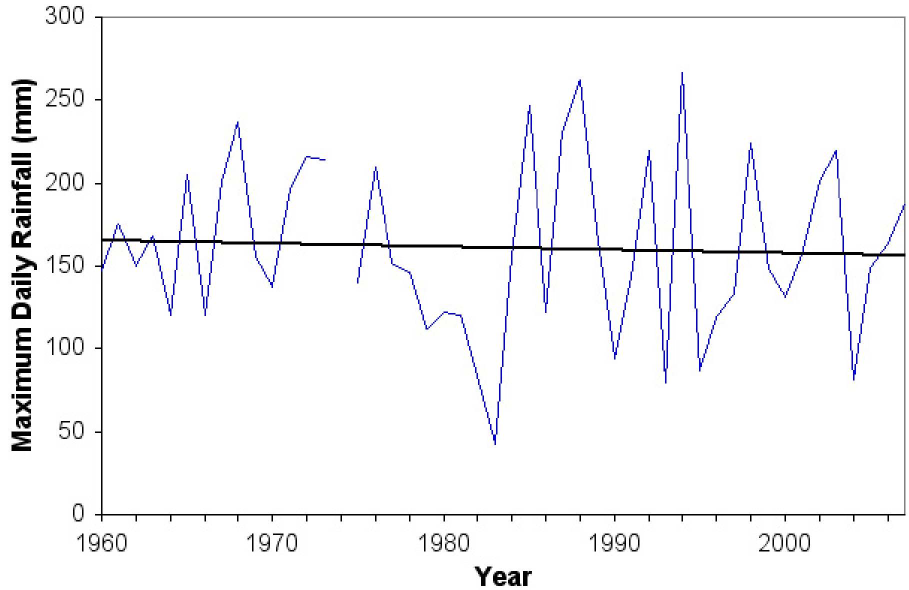

Figure 35 Annual maximum daily rainfall, by year, for Pekoa (1960 to 2007). Also shown is the linear trend in the annual maximum daily rainfall over the same period (-0.18 mm/year).

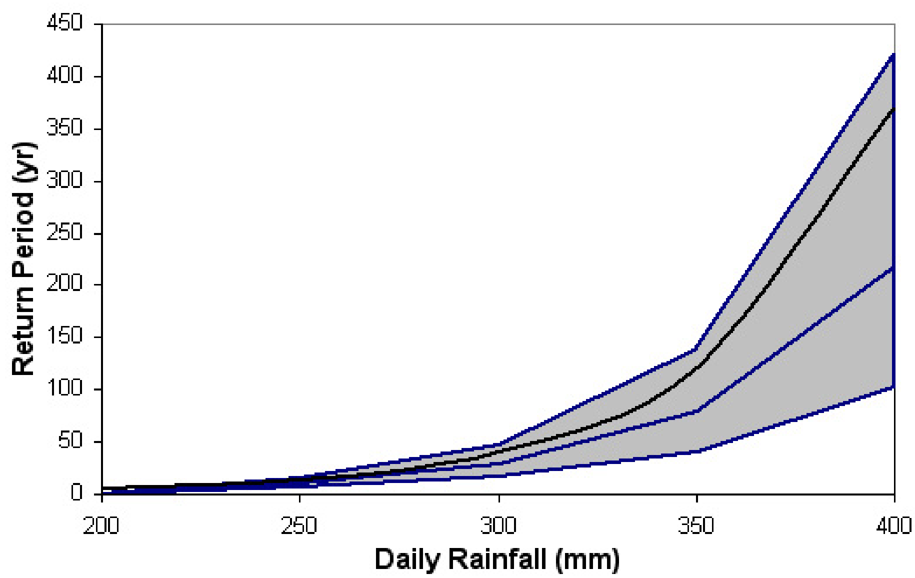

Figure 36 Relationship between maximum daily rainfall and return period for Pekoa, for present day (black line) and 2025 (blue lines). The uncertainty envelope shows the maximum and minimum estimates of return periods for 2025, based on all possible combinations of the available global climate models and emission scenarios.

Table 9

Return Periods (years), for Daily Rainfall (mm) at Pekoa

Rainfall (mm**) of at Least**	**Observed**	**2050**
50	1.0	1.0
100	1.1	1.1
150	1.9	1.9
200	4.7	4.1
250	13	11
300	40	29
350	121	79
400	368	217

b) Projected Risk Levels

Best estimates of future rainfall are based on an average of the estimates using a multi model and emission scenario ensemble (see Table 1). Figure 37 shows the best estimate of mean daily rainfall out to 2100, as well as the band of extreme uncertainty. The latter is estimated using the highest and lowest estimates of air temperature projections for all model and emission scenario combinations.

As indicated in Figure 36 and Table 9, global warming will also have a significant impact on the return periods of extreme rainfall events. For example a maximum daily rainfall of at least 350 mm is currently a one in 120-year event. It will likely be an 80-year event by 2050. Figures 37 and 38 also show the relatively high level of uncertainty in future projections of maximum rainfall extremes.

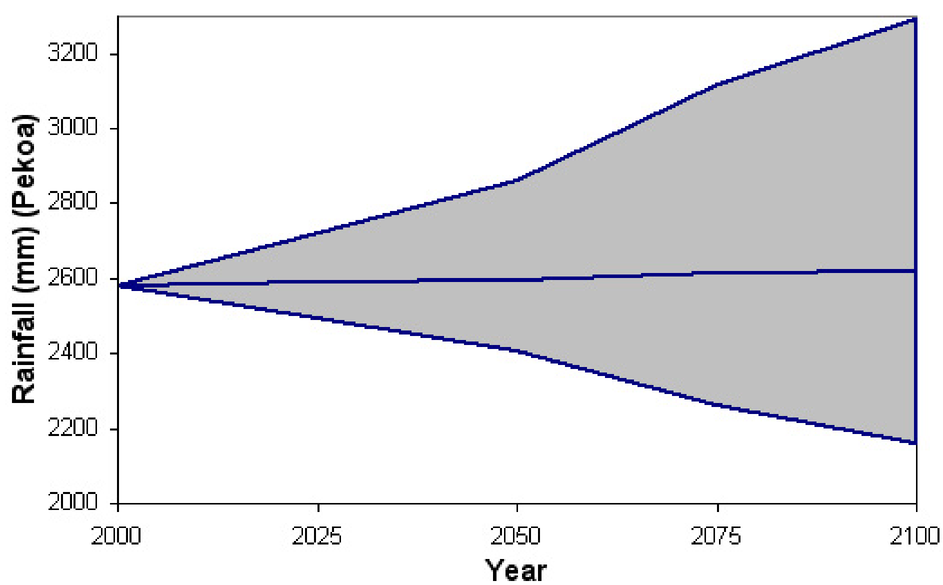

Figure 37 Best estimate of projected increase in mean annual rainfall for Pekoa, along with the uncertainty envelope as given by the maximum and minimum estimates using all possible combinations of the available global climate models and emission scenarios.

Daily Rainfall - Aneityum

a) Current Risks Levels

Figure 38 shows annual mean rainfall for Aneityum. The long term trend is -0.6 mm/year. Figure 39 presents the maximum daily rainfall, by year, for Aneityum. The long term trend in the extreme daily rainfall is 1.4 mm/year. Given the large interannual variability, these trends can be considered insignificant.

A maximum daily rainfall of 400 mm is a relatively rare event for Aneityum, with a return period of approximately 73 years (Figure 40 and Table 10).

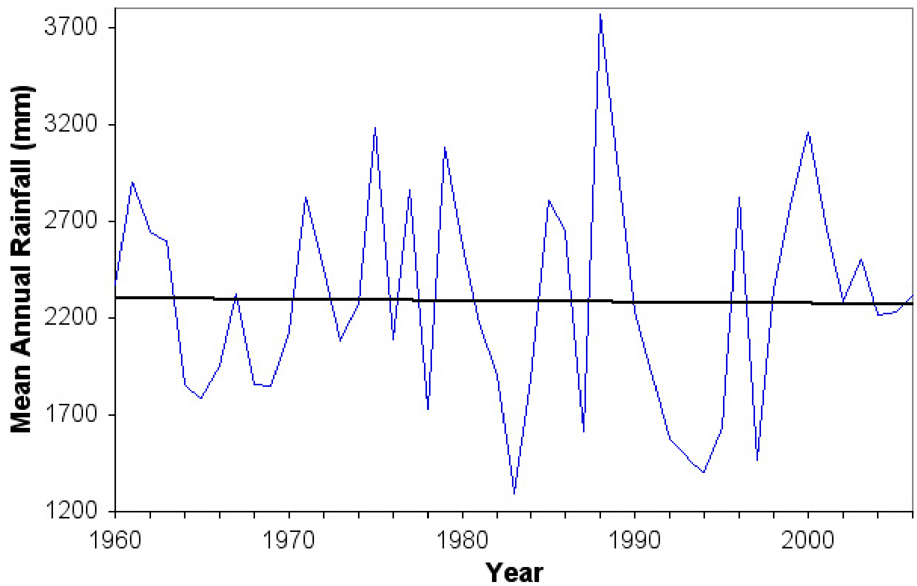

Figure 38 Annual mean rainfall for Aneityum (1960 to 2006). Also shown is the linear trend in annual mean rainfall (-0.6 mm/year).

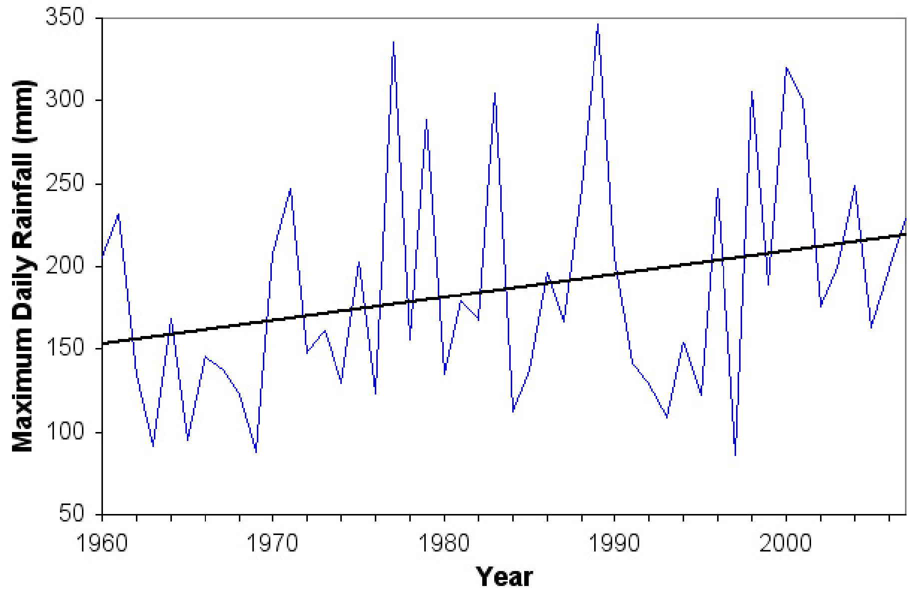

Figure 39 Annual maximum daily rainfall, by year, for Aneityum (1960 to 2007). Also shown is the linear trend in the annual maximum daily rainfall over the same period (1.4 mm/year).

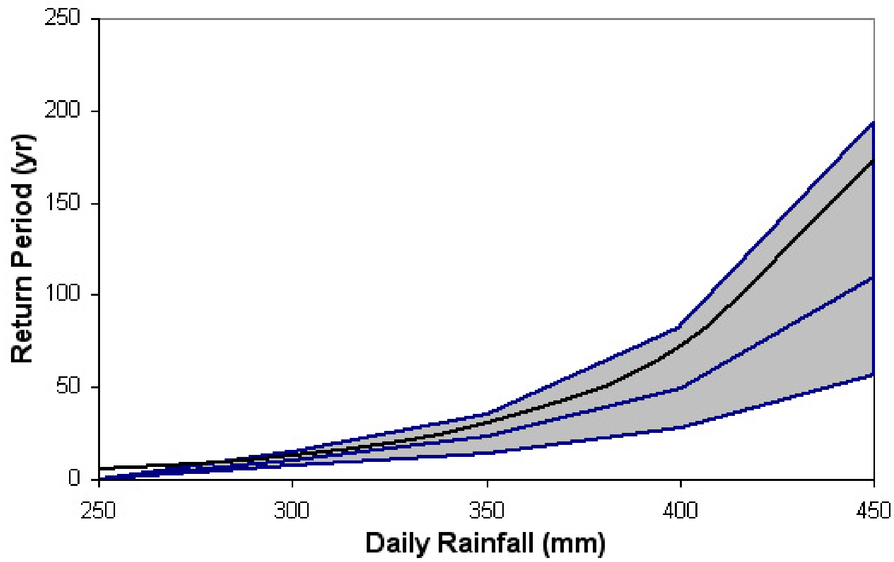

Figure 40 Relationship between maximum daily rainfall and return period for Aneityum, for present day (black line) and 2025 (blue lines). The uncertainty envelope shows the maximum and minimum estimates of return periods for 2025, based on all possible combinations of the available global climate models and emission scenarios.

Table 10

Return Periods (years), for Daily Rainfall (mm) at Aneityum

Rainfall (mm**) of at Least**	**Observed**	**2050**
100	1.1	1.1
150	1.5	1.5
200	2.8	2.6
250	5.9	5.1
300	13	11
350	31	23
400	73	50
450	173	109

b) Projected Risk Levels

Best estimates of future rainfall are based on an average of the estimates using a multi model and emission scenario ensemble (see Table 1). Figure 41 shows the best estimate of mean daily rainfall out to 2100, as well as the band of extreme uncertainty. The latter is estimated using the highest and lowest estimates of air temperature projections for all model and emission scenario combinations.

As indicated in Figure 40 and Table 10, global warming will also have a significant impact on the return periods of extreme rainfall events. For example a maximum daily rainfall of at least 400 mm is currently a one in 70-year event. It will likely be a 50-year event by 2050. Figures 40 and 41 also show the relatively high level of uncertainty in future projections of maximum rainfall extremes.

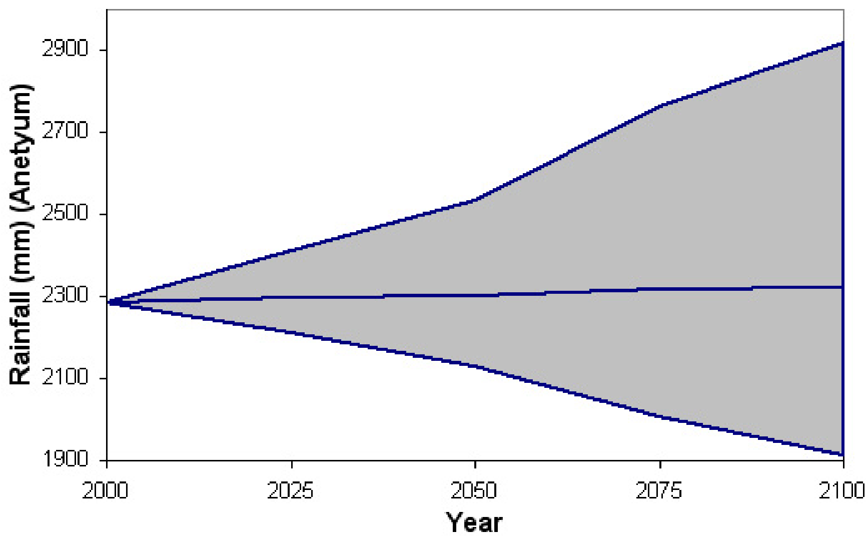

Figure 41 Best estimate of projected increase in mean annual rainfall for Aneityum, along with the uncertainty envelope as given by the maximum and minimum estimates using all possible combinations of the available global climate models and emission scenarios.

Comparative Analysis of Risks Related to High Rainfall Event

Figure 42 shows the return periods for extreme daily rainfall events, based on observed data for the four locations for which daily rainfall data are available. Three locations have similarly high risks of such extreme events. Pekoa has much lower levels of risk.

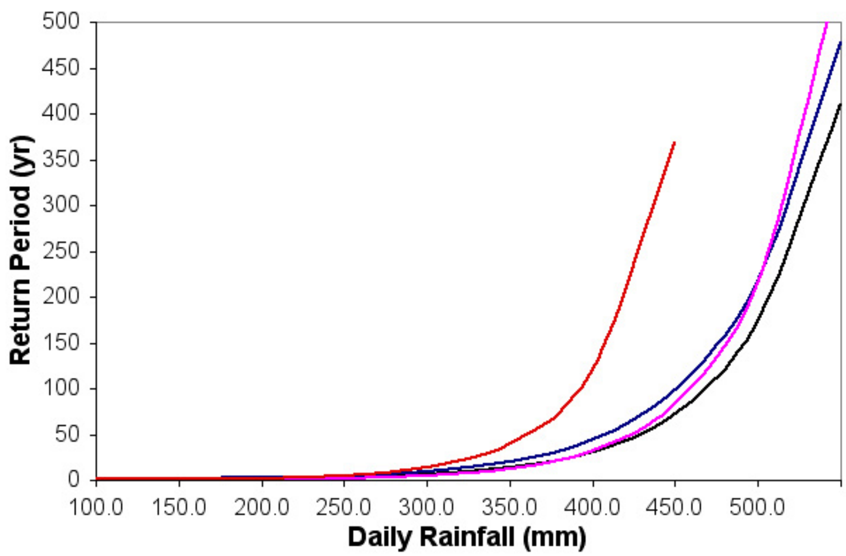

Figure 42 Return periods for extreme daily rainfall events, based on observed data for Pekoa (red Line), Lamap (blue line), Sola (pink line) and Aneityum (black line).

Conclusion

The foregoing analyses convey two key messages: (i) increased occurrences of extreme high sea levels, air/water temperatures and damaging winds are highly likely in the coming decades; and (ii) there is less certainty regarding changes in the frequency of intense daily precipitation events, but there are indications that the frequency of these events will also increase in the future.

The present CRP is the first step in analysing the climate-related risks facing Vanuatu. Additional data for Vanuatu should be analysed, with both the current and additional data being subjected to rigorous quality control.

Data for other locations should also be included in a future climate risk profile, as data from Funafuti are certainly not representative of the entire country.

A future climate risk profile might also include assessments of the consequence components of the climate-related risks, for relevant sectors and social groups.