Republic of the Maldives

Climate Risk Profile for the Maldives

Report Prepared by

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April, 2006

Final Report

Summary

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

The risks evaluated are extreme rainfall events (both 3-hourly and daily), drought, high sea levels, extreme winds and extreme high air 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.

The observed long term trend in relative sea level for Hulhulé is 1.7 mm/yr. But maximum hourly sea level is increasing by approximately 7 mm/yr, a rate far in excess of the observed local and global trends in mean sea level. For Hulhulé an hourly sea level of 70 cm above mean sea level is currently a 100-year event. It will likely be at least an annual event by 2050.

No significant long term trends are evident in the observed daily, monthly, annual or maximum daily rainfall. Currently a daily rainfall of at least 160 mm is a relatively rare event at Hulhulé, with a return period of 17 yr. There is large uncertainty in the rainfall projections, with one of the four global climate models indicating a decrease in rainfall in the future. An extreme daily rainfall of 180mm is currently a 100-year event. It will likely occur twice as often, on average, by 2050. An extreme three-hourly rainfall of 100mm is currently a 25-year event. It will likely become at least twice as common, on average, by around 2050.

A monthly rainfall below the ten percentile is used as an indicator of drought. Drought frequency is likely to be lower in the first half of the present century, relative to the latter part of last century and the second half of the present century.

Currently an extreme wind gust of 60 kt has a return period of 16 years. It is estimated that this will reduce to 9 years by 2025.

There is relatively high confidence in projections of maximum temperature. The annual maximum daily temperature is projected to increase by around 1.5 C by 2100. A maximum temperature of 33.5 is currently a 20-year event. It will likely have a return period of three years by 2025.

Introduction

Formally, risk is the product of the likelihood (i.e. probability) of an event or happening, normally referred to as a “hazard”, and the consequence of that hazard.

While the consequence 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 as well as to many sectors. This is due to the spatial scale and pervasive nature of weather and climate. Thus 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 unit, there is often insufficient information to assess this spatial variability, or the variations are judged to be of low practical significance.

This climate risk profile (CRP) is based on observed data for Hulhulé (Latitude 4 N; Longitude 73 E. Except for the sea level data, which were sourced from the University of Hawaii web site, all the data used in preparing this climate risk profile were provided by the Department of Meteorology, Government of the Maldives. The cooperation and assistance of Departmental staff is acknowledged with gratitude. While data for Hulhulé cannot characterize the climate conditions for the entire country[1], they do provide a general indication of current climate risks for the Maldives. But it is highly desirable to repeat the current evaluation of climate-related risks using data for other locations in the Maldives.

Future changes in climate are based on the output of global climate models and are for a 3.75 by 3.75 degree (approximately) grid square covering a large portion of the Maldives. The climate projections are therefore more reflective of changes for the country as a whole, rather than just the Hulhulé-Malé area,.

The following hazards are considered to be among the potential sources of climate-related risk:

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

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 global climate models[2] run for a range of greenhouse gas emission scenarios (Figure 1). Table 1 lists the combination of models and emission scenarios on which the present 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 greenhouse gas emissions and in modelling the complex interactions and responses of the 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 model and emission scenario combinations that produce the maximum and minimum rate of change in future risk levels.

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[1] The Republic of the Maldives is situated between 73 and 74 degrees east longitude and between latitudes 0.25 S and 4 N.

[2] 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).

Estimates of future changes in the frequency of drought use the daily data generated by the Canadian Climate Centre GCM (CGCM).

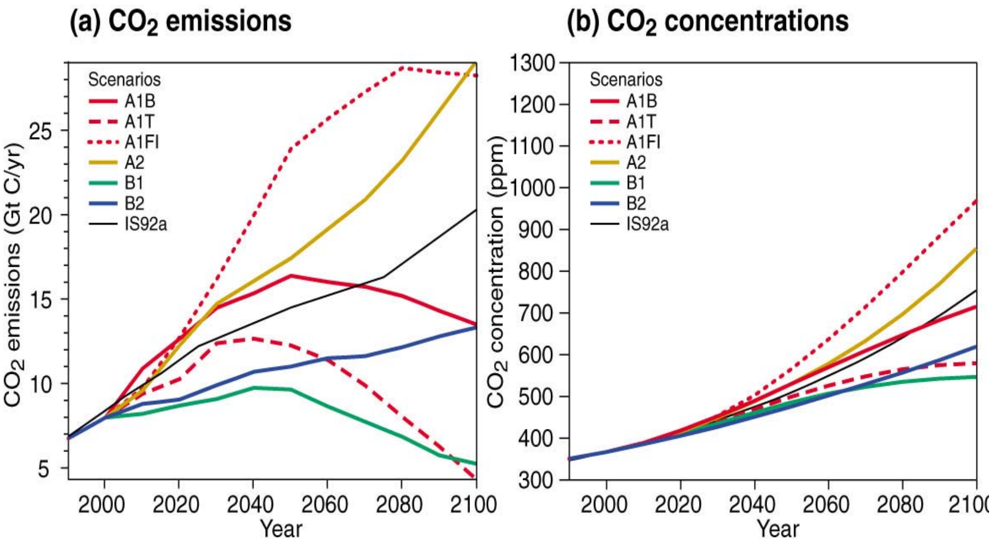

Figure 1 Scenarios of CO_2 gas emissions and consequential atmospheric concentrations of CO_2 (from IPCC, 2001).

Table 1

Available Combinations of Global Climate Models and Emission Scenarios[3]

	CGCM[1]	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. It does not mean that that the event occurs 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.

[3] T = temperature, P = precipitation, S = sea level

Sea Level

a) Current Risks Levels

Figure 2 shows daily mean values of sea level for Hulhulé, relative to mean sea level. There is large interannual variability and extremes (both high and low) in sea level as well as a long term trend of increasing relative sea level. The observed long term trend in sea level for Hulhulé is 1.7 mm/yr. This is towards the upper end of the estimated range of global sea-level rise over the past century, namely 1 to 2 mm/yr, and above the central estimate of 1.5 mm/yr. Thus the recent rise in relative sea level observed at Hulhulé is consistent with global observations for the last 100 years, given that rate of sea-level rise may well be accelerating due to global warming.

Even more 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 Hulhulé. The longer term trend in these maximum values is approximately 7 mm/yr, a rate far in excess of the local and global trends in mean sea level. Such exceptionally high sea levels are associated with short-term flooding, accelerated coastal erosion and salt water intrusion into groundwater.

An hourly sea level of 65 cm above mean sea level is a relatively rare event at Hulhulé, with a return period of 7 yr (Figure 4 and Table 2).

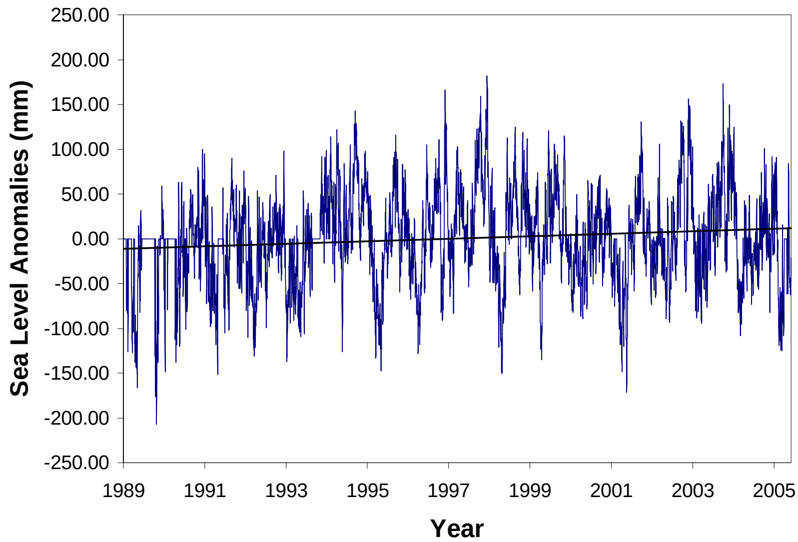

Figure 2: Daily mean values of sea level for Hulhulé (1989 to 2005), relative to mean sea level. Also shown is the linear trend in sea level over the same period.

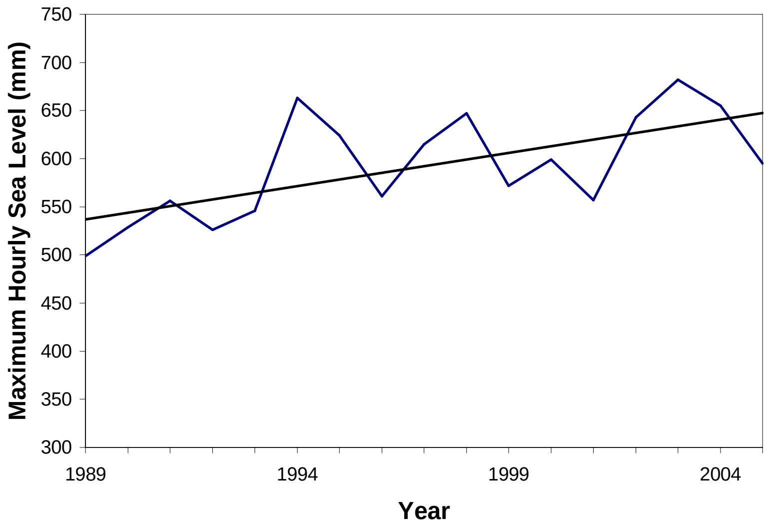

Figure 3 Maximum hourly sea level, by year, for Hulhulé (1989 to 2005). Also shown is the linear trend in these values over the same period.

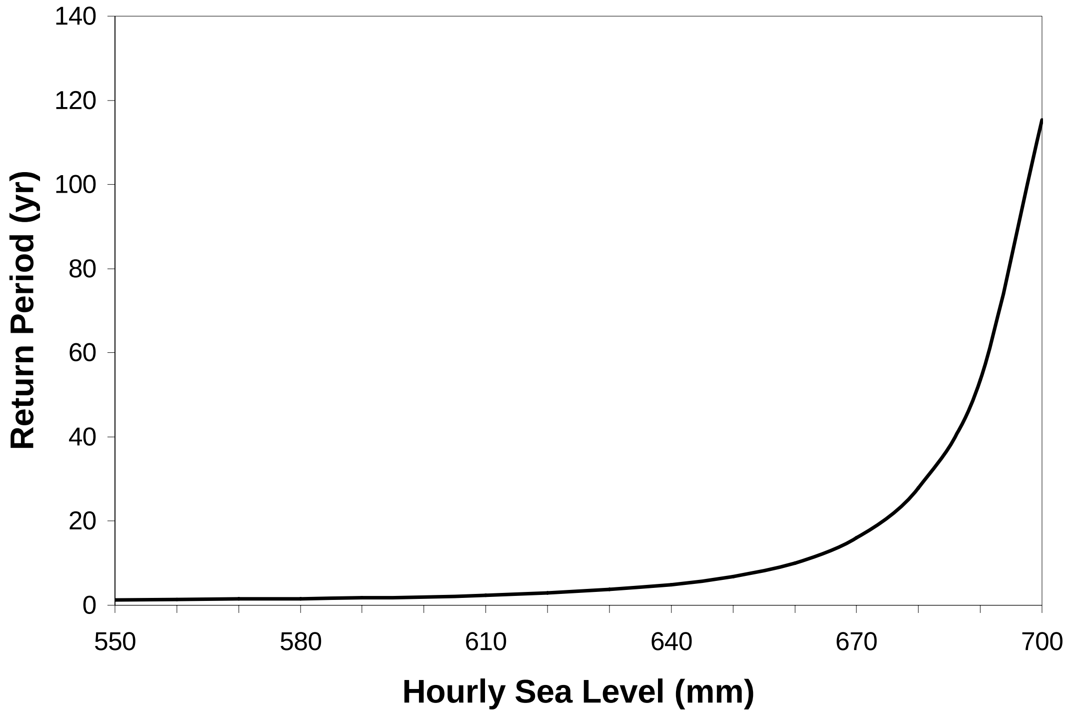

Figure 4 Relationship between hourly sea level and return period for Hulhulé, based on observed hourly sea level for 1989 to 2005.

Table 2

Return Periods (yr), for Hourly Sea Level (cm) at Hulhulé

Sea Level (cm) of at Least	Observed	2025	2050	2075	2100
50	1.1	1.0	1.0	1.0	1.0
60	2.0	1.1	1.0	1.0	1.0
70	115	2.3	1.1	1.0	1.0
80		232	1.6	1.0	1.0
90			31	1.1	1.0
100				2.2	1.0
110				263	1.1
120					3.1
130					>2000

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.

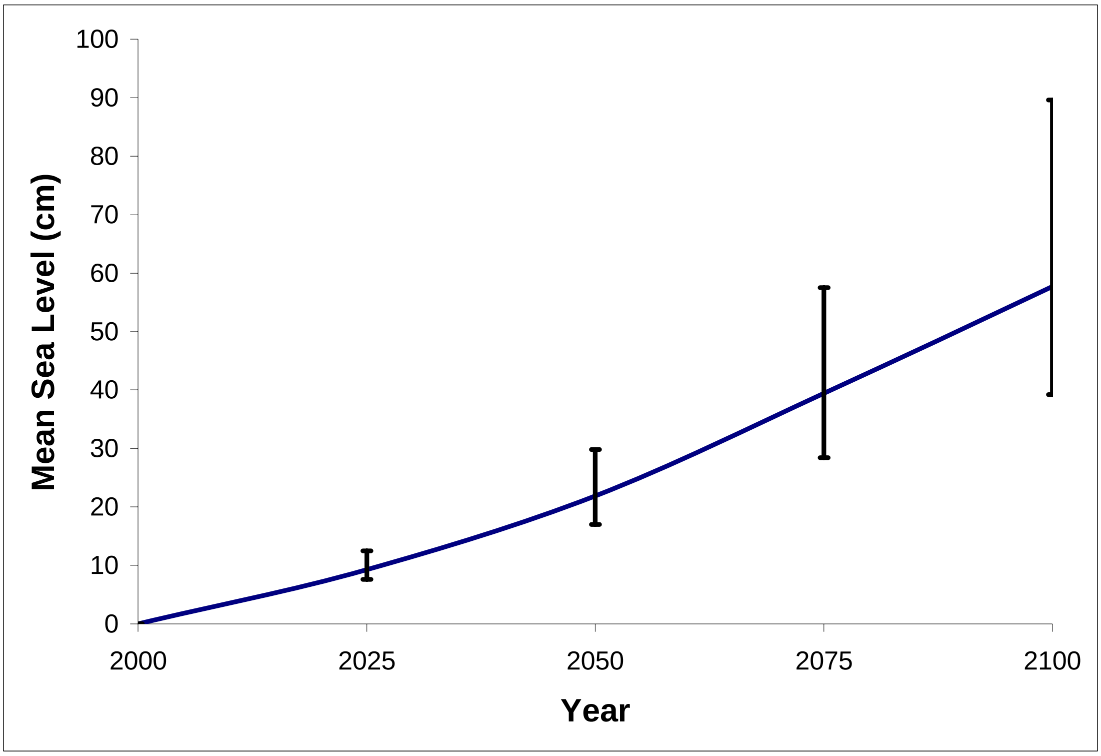

Figure 5 Best estimate of projected increase in sea level for Hulhulé, along with error bars showing the maximum and minimum estimates provided by all possible combinations of the global climate models and emission scenarios shown in Table 1.

As indicated in Table 2 and Figure 6, 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, an extreme high sea level that is currently a 100-year event, will likely be at least an annual event by 2050.

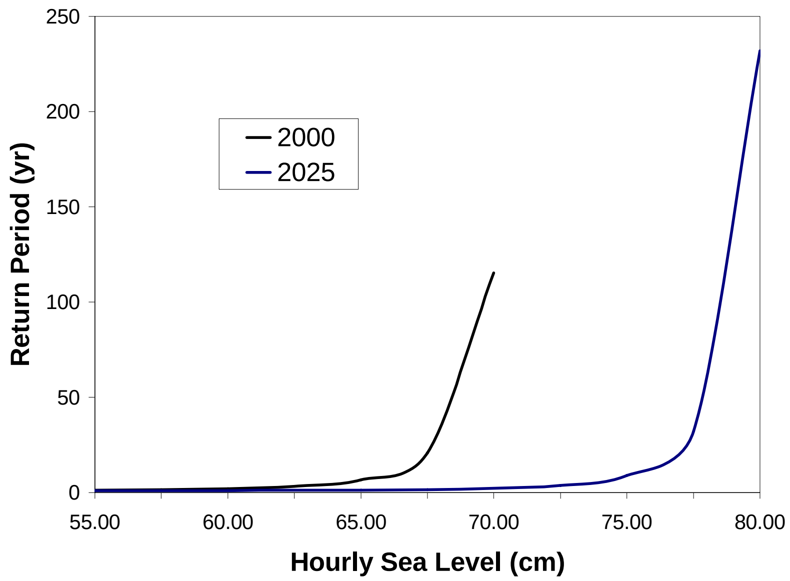

Figure 6 Relationship between hourly sea level and return period for Hulhulé, for present day and 2025.

There is considerable uncertainty in future projections of sea level extremes. This is illustrated in Table 3.

Table 3

Return Periods (yr), for Hourly Sea Level (cm) at Hulhulé

Sea Level (cm) of at Least	Observed	2025		
		Minimum	Best Estimate	Maximum
55.0	1.3	1.0	1.0	1.0
57.5	1.5	1.0	1.0	1.0
60.0	2.0	1.0	1.1	1.1
62.5	3.3	1.1	1.2	1.3
65.0	6.8	1.2	1.3	1.5
67.5	21	1.3	1.6	2.0
70.0	115	1.5	2.3	3.2
72.5	1483	2.0	3.8	6.6
75.0		3.2	8.8	20.3
77.5		6.8	32	114
80.0		21.5	232	1562

Daily Rainfall

a) Current Risks Levels

Figure 7 shows daily rainfall for Hulhulé. High variability, including extremes, is readily apparent, as is also the case for monthly and annual rainfall (Figures 8 and 9, respectively). No significant long term trends are evident in any of the three time series.

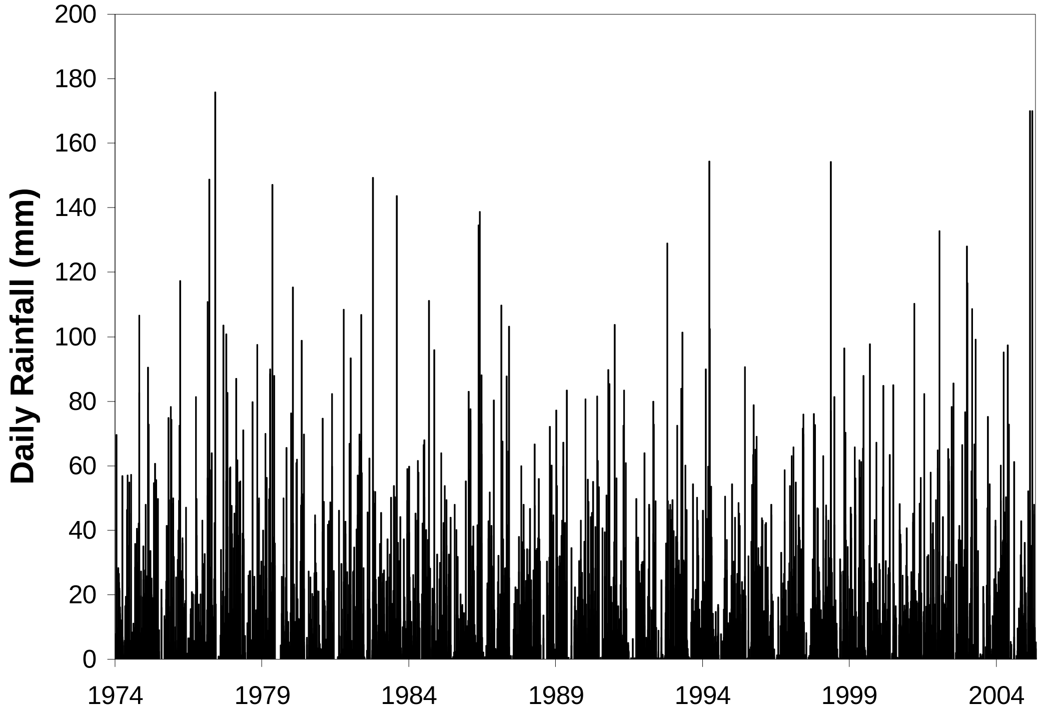

Figure 7 Daily rainfall for Hulhulé (August 1974 to 2005).

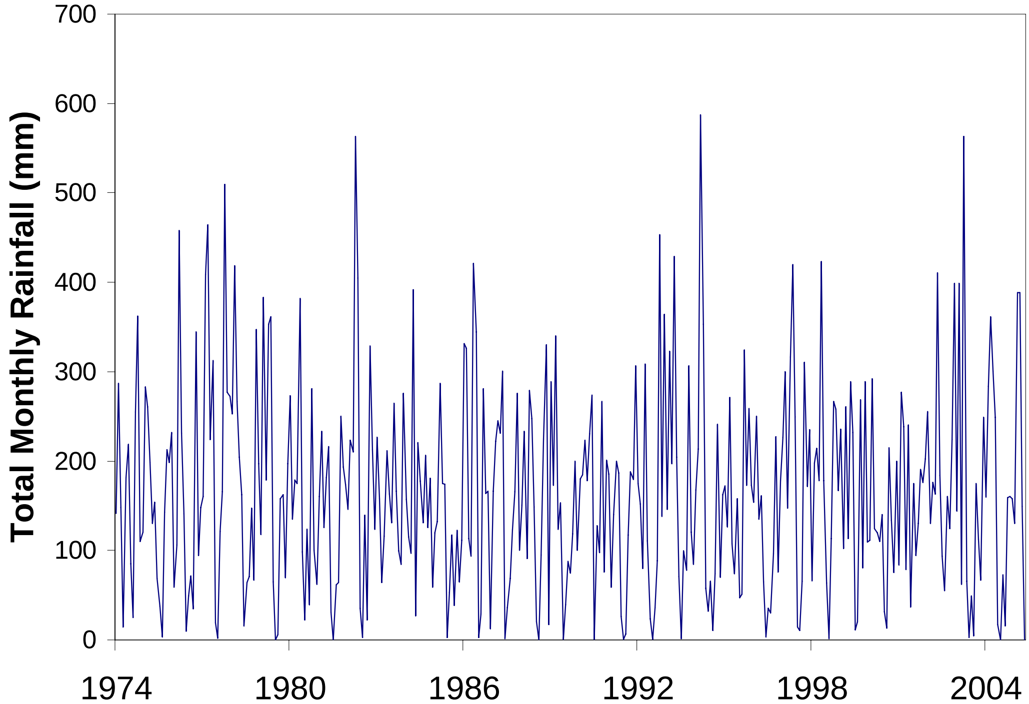

Figure 8 Total monthly rainfall for Hulhulé (August 1974 to 2005).

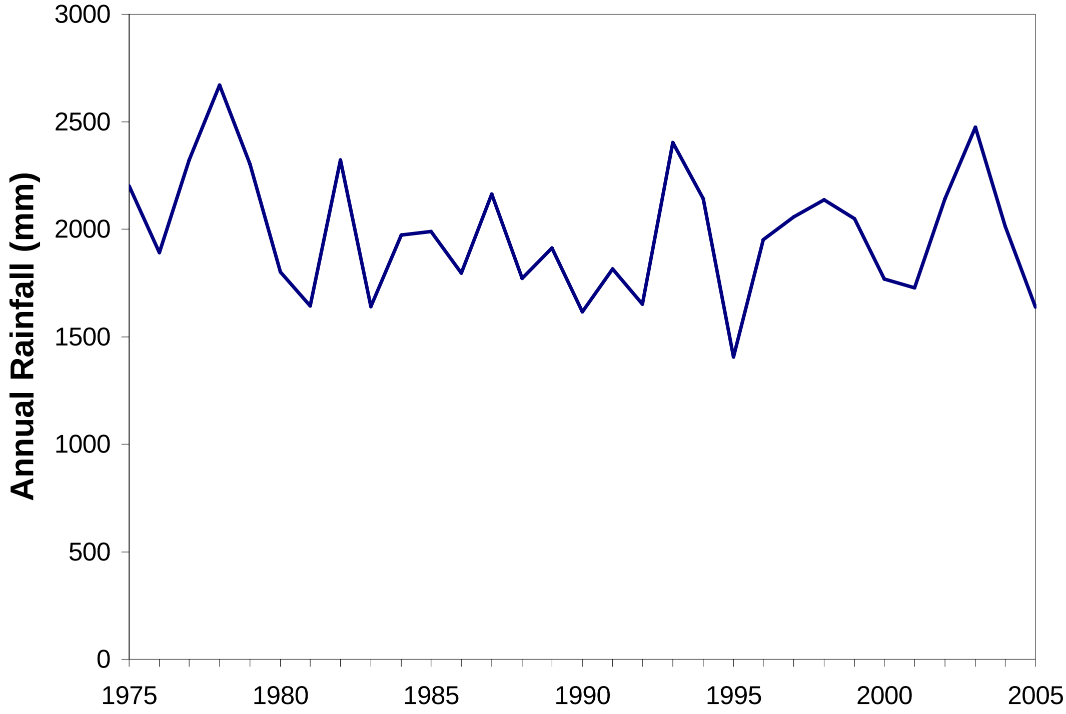

Figure 9 Total annual rainfall for Hulhulé (1975 to 2005).

Figure 10 presents the annual maximum daily rainfall for Hulhulé. Again, considerable interannual variability in extreme rainfall occurrences is evident. A daily rainfall of at least 160 mm is a relatively rare event at Hulhulé, with a return period of 17 yr (Figure 11 and Table 4).

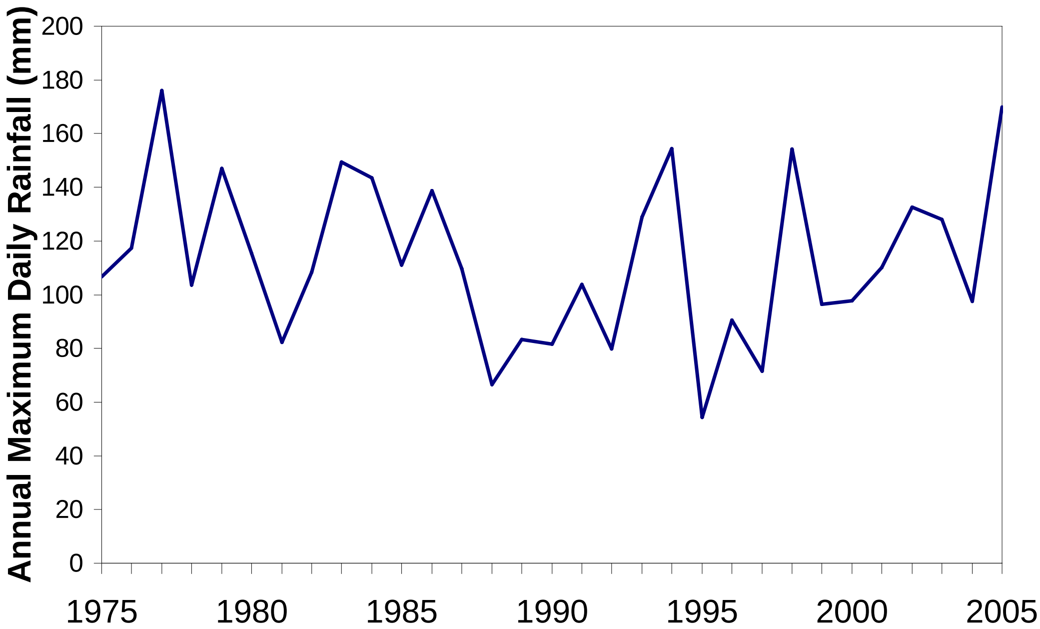

Figure 10 Maximum daily rainfall, by year, for Hulhulé (1975 to 2005).

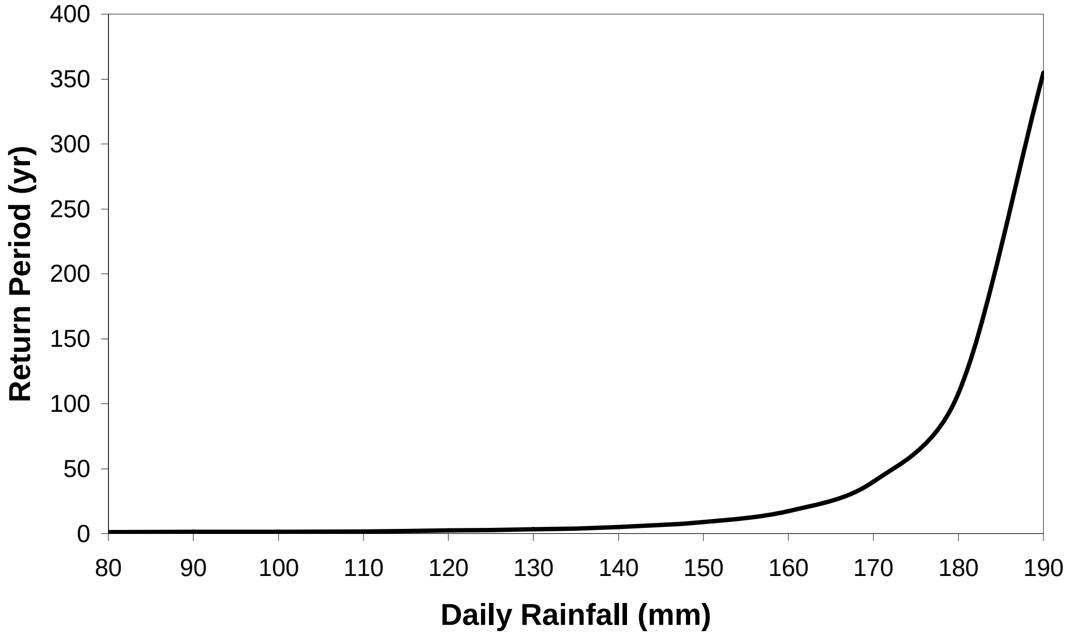

Figure 11 Relationship between daily rainfall and return period for Hulhulé, based on observed daily rainfall for 1975 to 2005.

Table 4

Return Periods (yr), for Daily Rainfall (mm) at Hulhulé

Daily Rainfall (mm) of at Least	Observed	2025	2050	2075	2100
80	1.2	1.1	1.1	1.1	1.1
100	1.5	1.4	1.3	1.3	1.2
120	2.4	2.1	1.9	1.7	1.6
140	5.1	4.3	3.7	3.1	2.8
160	17.4	13.7	10.7	8.2	7.0
180	108	78	56	39	30
200	1450	973	636	389	283

b) Projected Risk Levels

Best estimates of changes in daily rainfall extremes are based on an average of the estimates using a multi model and emission scenario ensemble (see Table 1). Figure 12 shows the best estimate of mean annual total rainfall out to 2100, as well as the band of extreme uncertainty. The latter is estimated using the highest and lowest estimates of extreme daily rainfall, for all model and emission scenario combinations. It is clear that there is large uncertainty in the rainfall projections, with one of the four GCMs indicating a decrease in rainfall in the future.

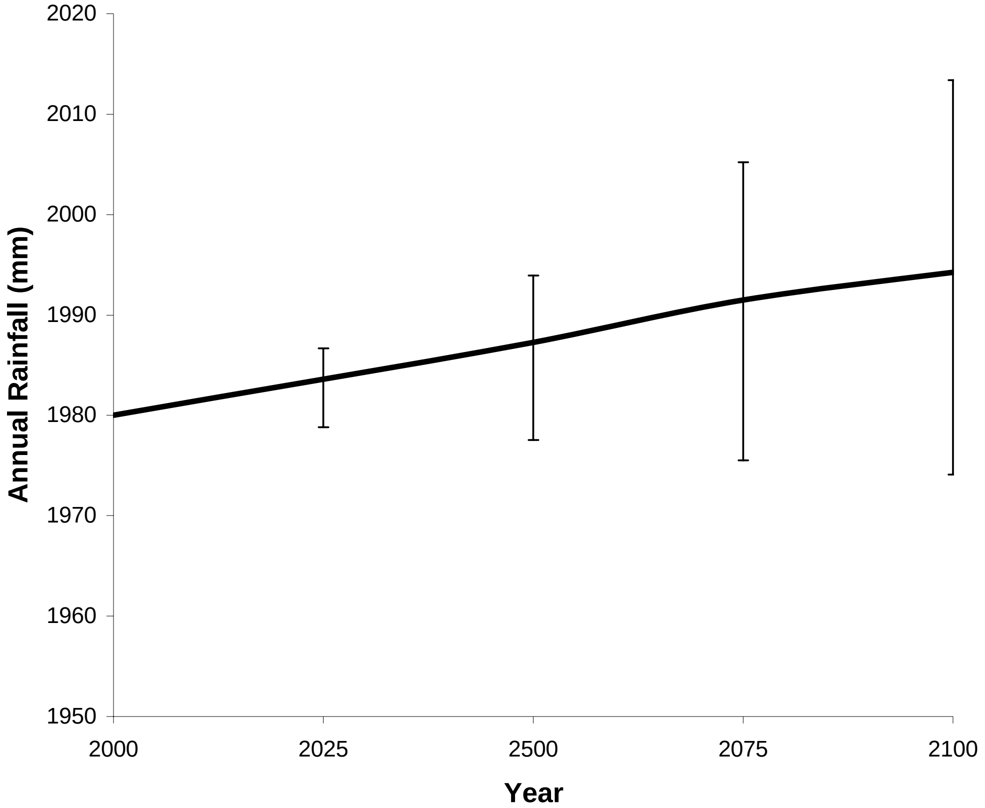

Figure 12 Best estimate of projected increase in mean annual rainfall for Hulhulé, along with error bars showing the maximum and minimum estimates provided by all possible combinations of the global climate models and emission scenarios shown in Table 1.

As indicated in Table 4 and Figure 13, global warming will influence the return periods of extreme daily rainfall events. For example, an extreme daily rainfall that is currently a 100-year event will likely occur twice as often, on average, by 2050.

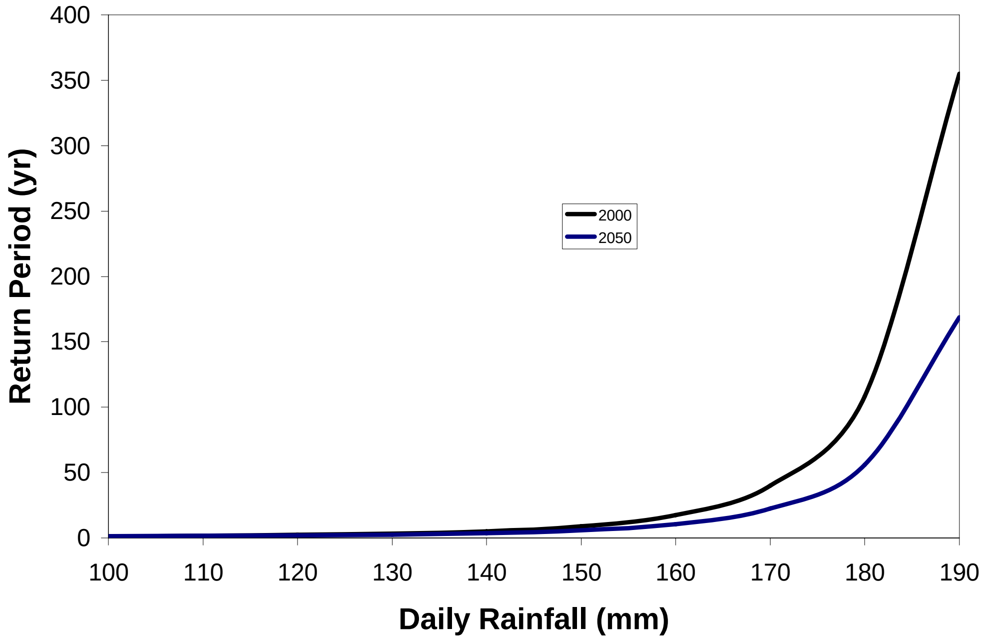

Figure 13 Relationship between daily rainfall and return period for Hulhulé, for present day and 2050.

There is considerable uncertainty in future projections of extreme daily rainfall. This is illustrated in Table 5.

Table 5

Return Periods (yr), for Daily Rainfall (mm) at Hulhulé

Daily Rainfall (mm) of at Least	**Observed**	**2050**		
		Minimum	**Best Estimate**	**Maximum**
100	1.5	1.2	1.3	1.6
120	2.4	1.6	1.9	2.5
140	5.1	2.8	3.7	5.8
160	17	7.1	11	21
180	108	31.3	55.9	135
200	1450	293	636	1892

Three-hourly Rainfall

a) Current Risks Levels

Figure 14 presents the annual maximum three-hourly rainfall for Hulhulé. Some interannual variability in extreme three-hourly rainfall occurrences is evident. A three-hourly rainfall of at least 100 mm is a relatively rare event at Hulhulé, with a return period of 25 yr (Figure 15 and Table 6).

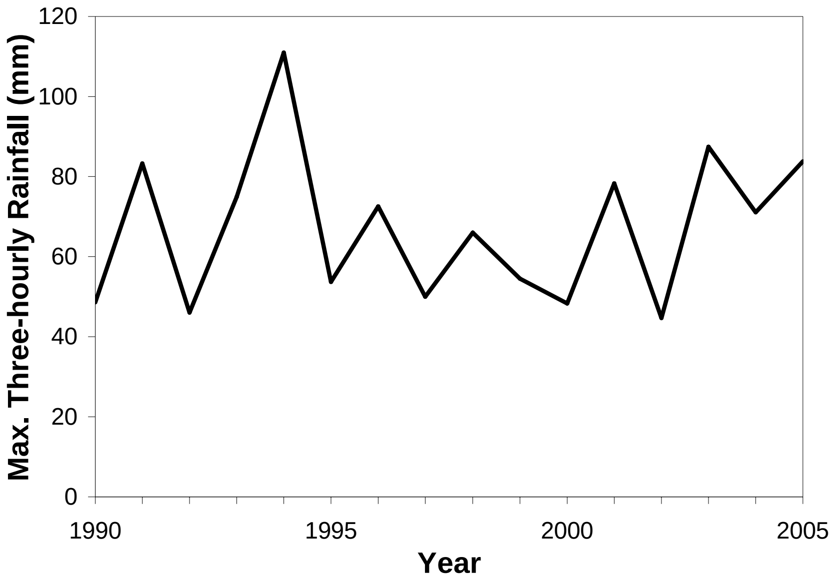

Figure 14 Maximum three-hourly rainfall, by year, for Hulhulé (1990 to 2005).

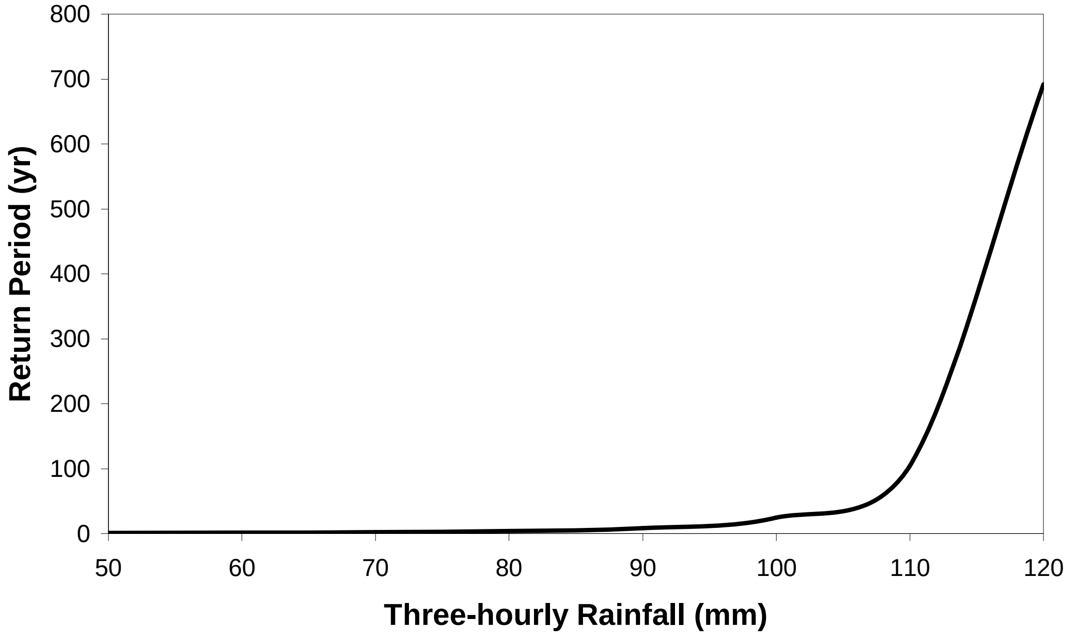

Figure 15 Relationship between three-hourly rainfall and return period for Hulhulé, based on observed three-hourly rainfall for 1990 to 2005.

Table 6

Return Periods (yr), for Three-hourly Rainfall (mm) at Hulhulé

Three-hourly Rainfall (mm) of at Least	Observed	2025	2050	2075	2100
50	1.2	1.2	1.1	1.0	1.0
60	1.5	1.4	1.3	1.2	1.2
70	2.2	1.9	1.7	1.5	1.4
80	3.8	3.0	2.5	2.0	1.8
90	8.3	6.1	4.5	3.4	2.9
100	25	16	11	7.2	5.7
110	105	62	37	22	15
120	690	370	190	97	63

b) Projected Risk Levels

Best estimates of changes in three-hourly rainfall extremes are based on an average of the estimates using a multi model and emission scenario ensemble (see Table 1). As indicated in Table 6 and Figure 16, global warming will influence the return periods of extreme three-hourly rainfall events. For example, an extreme three-hourly rainfall that is currently a 25-year event will likely become at least twice as common, on average, by around 2050.

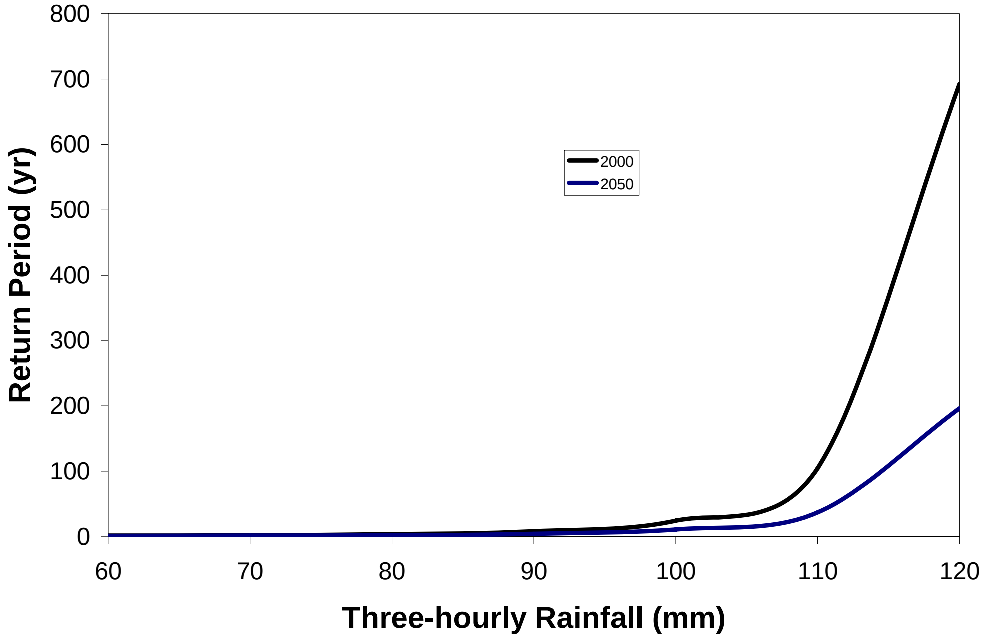

Figure 16 Relationship between hourly rainfall and return period for Hulhulé, for present day and 2050.

There is considerable uncertainty in future projections of extreme three-hourly rainfall. This is illustrated in Table 7.

Table 7

Return Periods (yr), for Three-hourly Rainfall (mm) at Hulhulé

Three-hourly Rainfall (mm) of at Least	Observed	2050		
		Minimum	Best Estimate	Maximum
50	1.2	1.1	1.1	1.3
60	1.5	1.2	1.3	1.7
70	2.2	1.4	1.7	2.5
80	3.8	1.9	2.5	4.5
90	8.3	2.9	4.5	11
100	25	5.9	11	33
110	105	16	37	150
120	690	66	190	1050

Drought

Figure 17 presents, for Hulhulé, the number of months in each year (1975 to 2005), and each decade, for which the observed precipitation was below the ten percentile. A monthly rainfall below the ten percentile is used here as an indicator of drought.

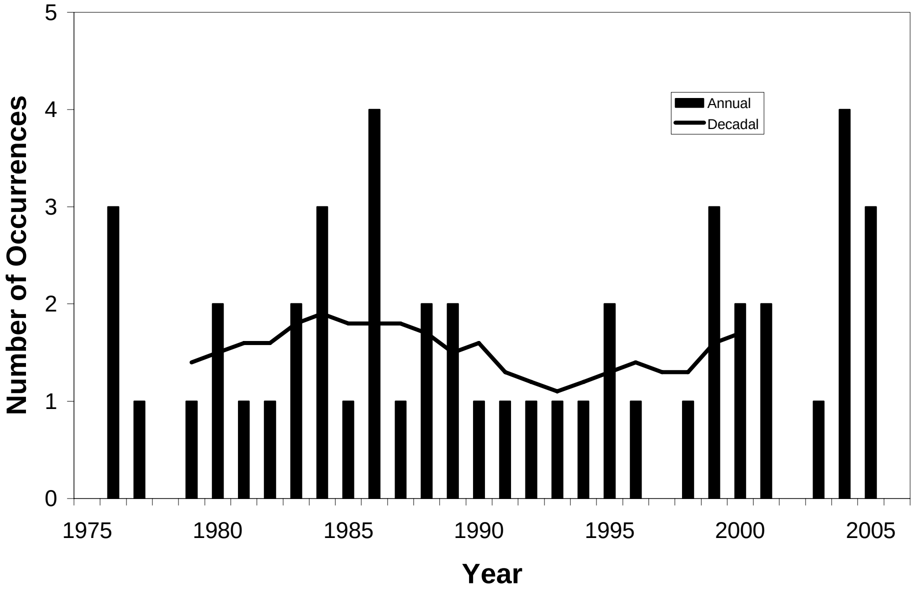

Figure 17 Number of months in each year for which the precipitation was below the ten percentile. Also shown is the average over ten years. Data for Hulhulé.

There is considerable inter-annual and inter-decadal variability in this indicator of drought, with no obvious long term trend.

Figure 18 shows the results of a similar analysis, but for rainfall estimates (1961 to 1990) and projections (1991 to 2100) based on the Canadian GCM and the A2 emission scenario. The results indicate that drought frequency is likely to be lower in the first half of the present century, relative to the latter part of last century and the second half of the present century.

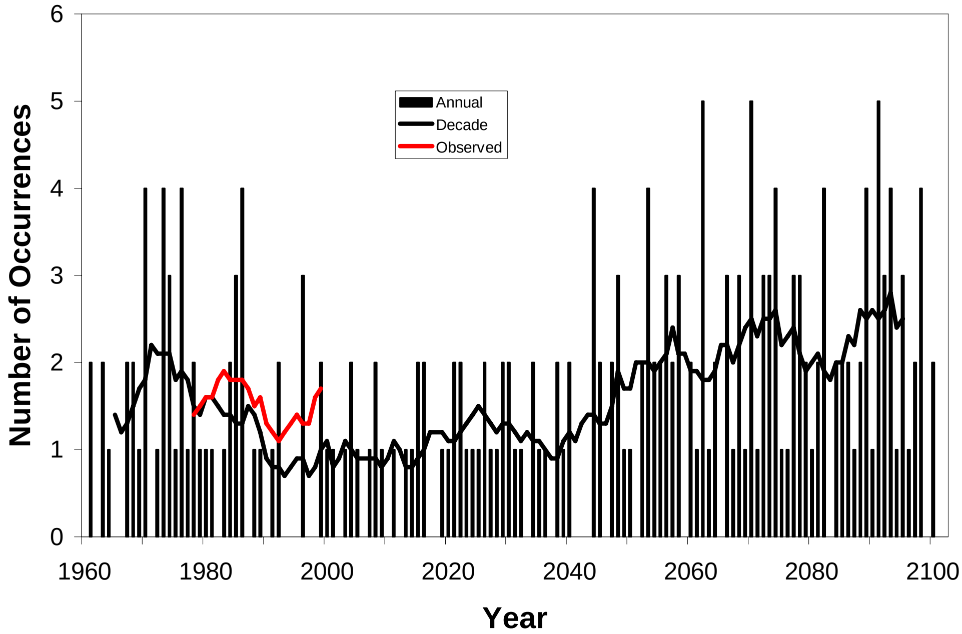

Figure 18 The number of months per year for which the precipitation for Hulhulé is projected to be below the observed (1975 to 2005) ten percentile for the relevant month. Also shown are the averages over ten years, based on the observed (1975 to 2005) and modelled (1961 to 2100) data. Modelled data is from the Canadian GCM, with an A2 emission scenario and best estimate for GCM sensitivity.

Figure 18 also shows that the GCM replicates the observed trends in drought frequency, based on observed data for 1975 to 2005.

Extreme Winds

a) Current Risk Levels

Figure 19 shows the annual maximum wind gust recorded at Hulhulé over the period 2001 to 2005. The short period of record highlights the need to emphasise the tentative nature of any conclusions to be drawn from the analysis that follows.

A peak gust of at least 60 knots can be considered a relatively rare event, with a return period of approximately 16 yr (Table 8 and Figure 20).

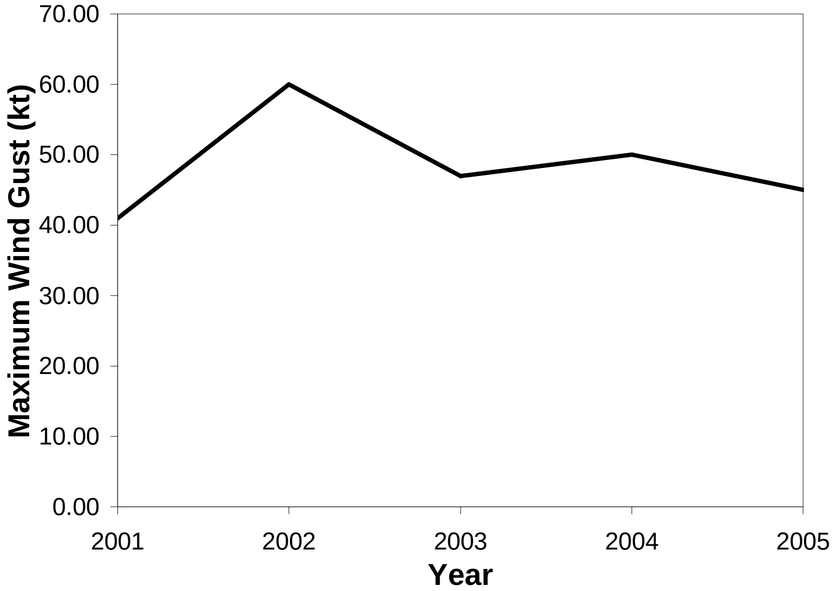

Figure 19 Annual maximum wind gust recorded in Hulhulé for the period from 2001 to 2005.

Table 8

Return Periods (yr), for Peak Gust (knots) at Hulhulé

Peak Gust of at Least (kt)	Observed	2025	2050	2075	2100
40	1.2	1.1	1.1	1.1	1.1
50	2.2	1.9	1.6	1.5	1.4
60	16	9.1	5.8	3.9	3.2
70	>3000	600	160	52	29
80					>4000

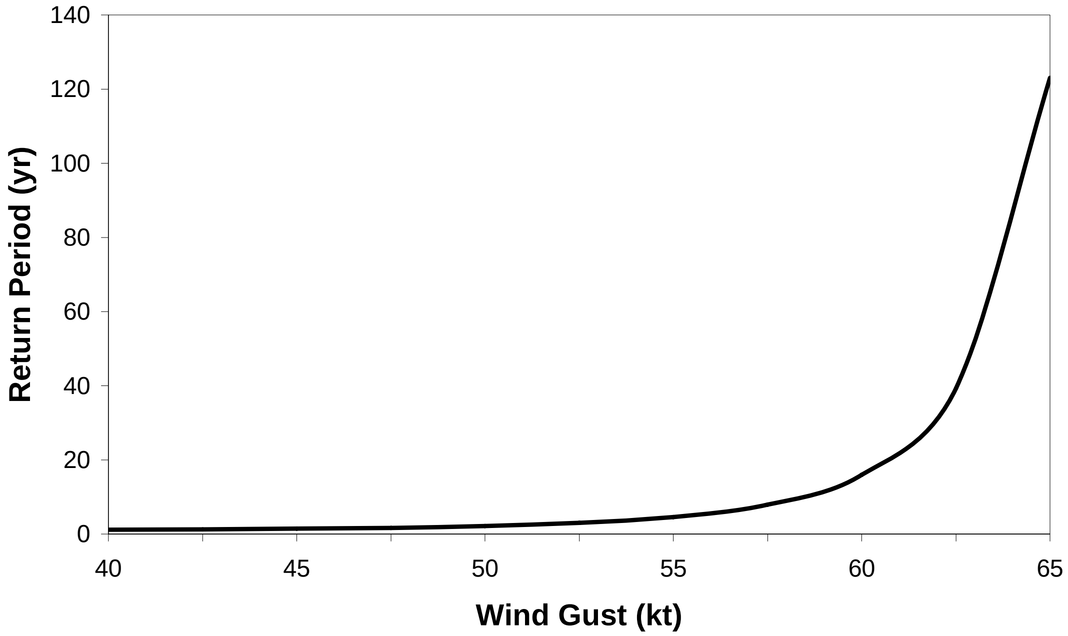

Figure 20 Relationship between maximum wind gust and return period for Hulhulé, based on observed three-hourly peak gust data for 2001 to 2005.

b) Projected Risk Levels

Estimates of changes in extreme wind gusts are based on the assumption that maximum wind gusts will increase by 2.5, 5 and 10 per cent per degree of global warming. Thus the emission scenarios listed in Table 1 are explicitly included in the estimates. The best estimate of the increase in extreme wind gusts is determined by averaging the ensemble of estimates for all combinations of percentage increase and emission scenarios.

Figure 21 shows the best estimate of extreme wind gust out to 2100, as well as the band of maximum uncertainty. The latter is estimated using the highest and lowest estimates of extreme wind gust, for all three percentage increases and emission scenario combinations. It is clear that there is substantial uncertainty in the maximum wind gust projections.

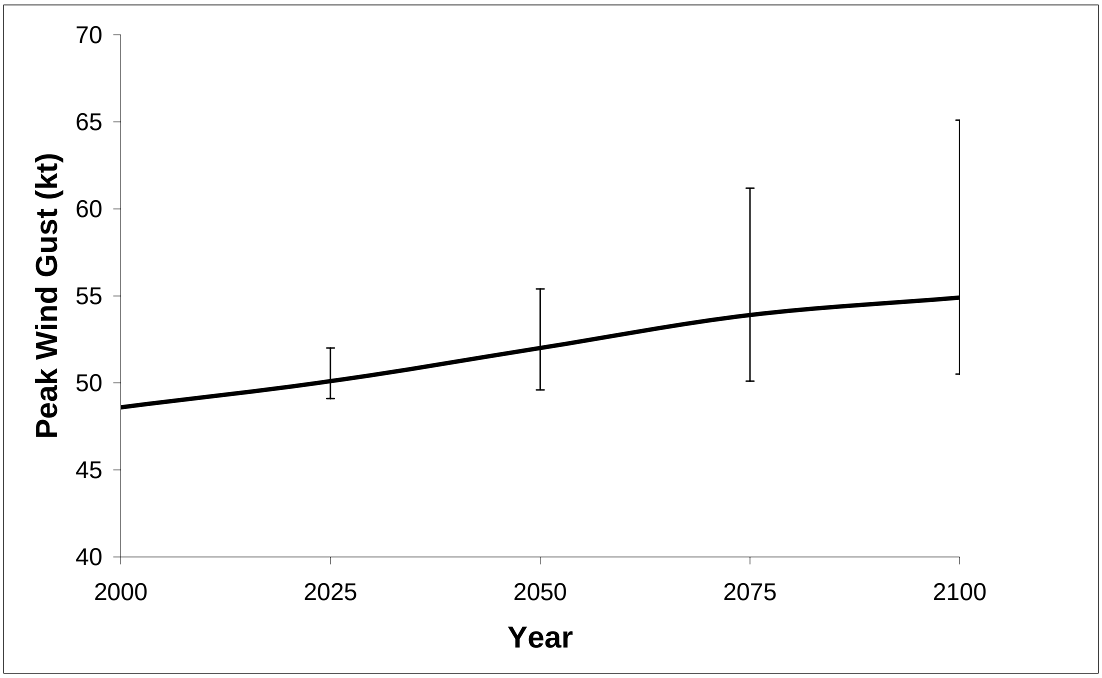

Figure 21 Best estimate of projected increase in extreme wind gust for Hulhulé, along with error bars showing the maximum and minimum estimates provided by all possible combinations of the percentage increase and emission scenarios.

As indicated in Table 8 and Figure 22, global warming will influence the return periods of extreme wind gusts. For example, currently an extreme wind gust of 60 kt has a return period of 16 years. This will reduce to 9 years by 2025.

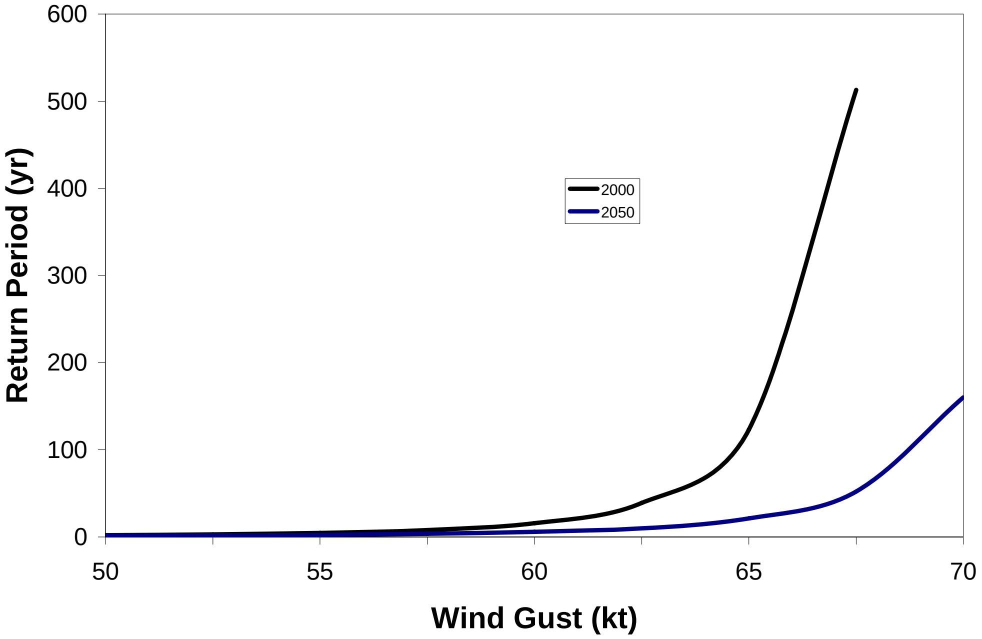

Figure 22 Relationship between peak wind gust and return period for Hulhulé, for present day and 2050.

There is considerable uncertainty in future projections of extreme wind gusts. This is illustrated in Table 9.

Table 9

Return Periods (yr), for Peak Wind Gust (kt) at Hulhulé

Wind Gust (kt) of at Least	Observed	2050		
		Minimum	Best Estimate	Maximum
40	1.2	1.1	1.1	1.2
50	2.2	1.4	1.6	2.0
60	16	3.0	5.8	10.5
70	>3000	25	160	905

Extreme High Temperatures

a) Current Risks Levels

Figure 23 presents the annual maximum temperature for Hulhulé. Again, considerable interannual variability in extreme temperature occurrences is evident. A maximum temperature of at least 33.5 is a relatively rare event at Hulhulé, with a return period of approximately 20yr (Figure 24 and Table 10).

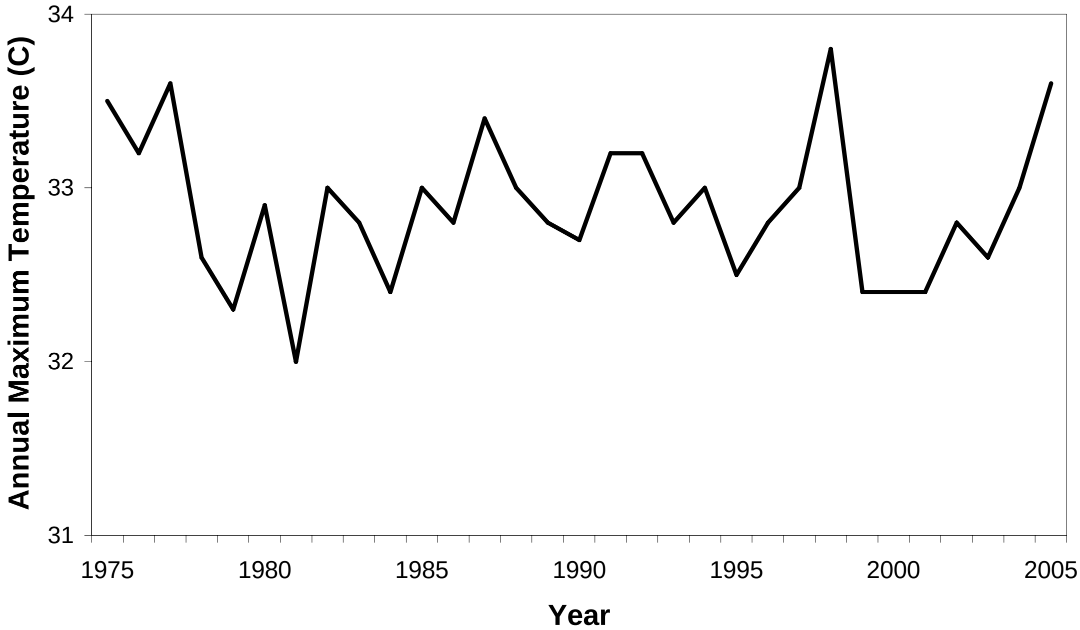

Figure 23 Maximum temperature, by year, for Hulhulé (1975 to 2005).

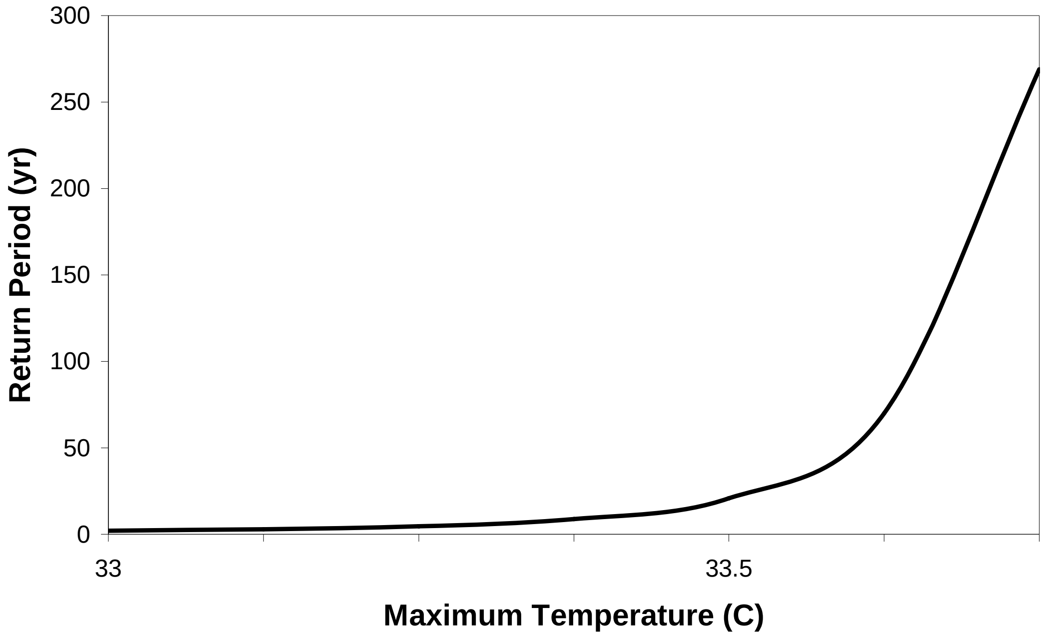

Figure 24 Relationship between maximum temperature and return period for Hulhulé, based on observed daily maximum temperature for 1975 to 2005.

Table 10

Return Periods (yr), for Maximum Temperature (C) at Hulhulé

Maximum Temperature (C) of at Least	**Observed**	**2025**	**2050**	**2075**	**2100**
32.0	1.1	1.0	1.0	1.0	1.0
32.5	1.2	1.1	1.0	1.0	1.0
33.0	2.2	1.3	1.1	1.0	1.0
33.5	21	2.8	1.4	1.1	1.0
34.0	>90,000	53	3.7	1.4	1.2
34.5			152	4.	1.8
35.0				220	11
35.5					>8,000

b) Projected Risk Levels

Best estimates of changes in maximum temperature 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 annual maximum temperature out to 2100, as well as the band of extreme uncertainty. The latter is estimated using the highest and lowest estimates of extreme maximum temperature, for all model and emission scenario combinations. It is clear that there is low uncertainty in the maximum temperature projections, at least in an absolute sense.

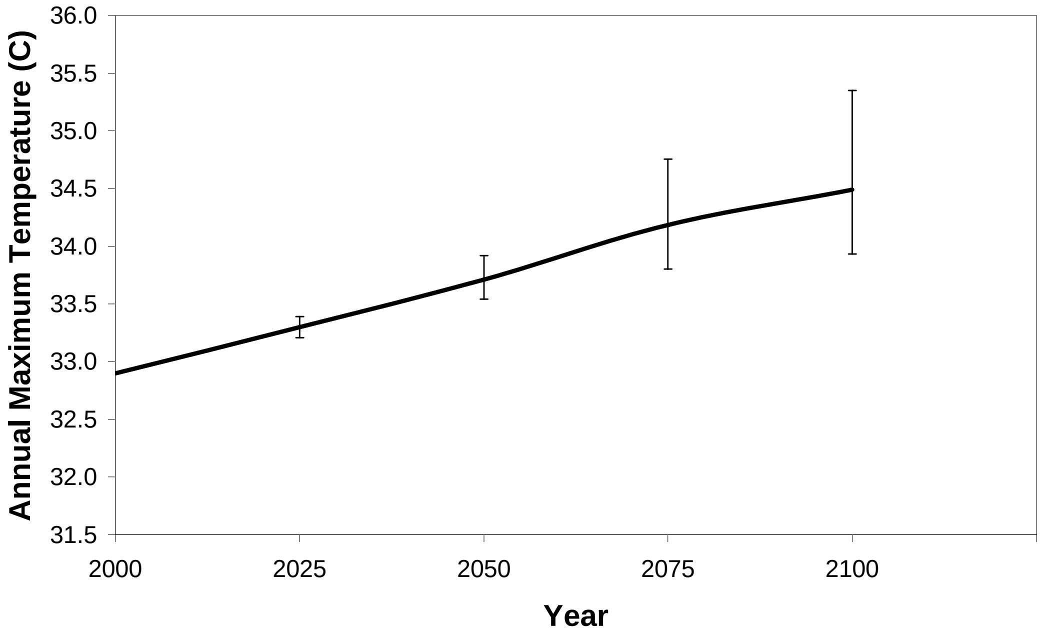

Figure 25 Best estimate of projected increase in annual maximum temperature for Hulhulé, along with error bars showing the maximum and minimum estimates provided by all possible combinations of the global climate models and emission scenarios shown in Table 1.

As indicated in Table 10 and Figure 25, global warming will influence the return periods of maximum temperatures. For example, a maximum temperature that is currently a 20-year event will likely have a return period of three years by 2025.

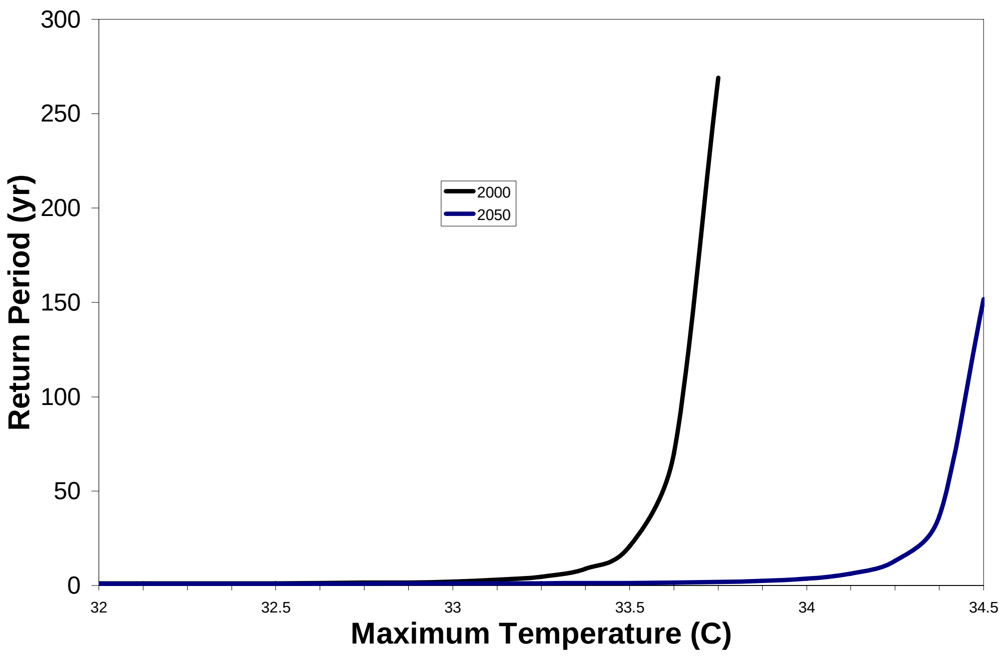

Figure 26 Relationship between maximum temperature and return period for Hulhulé, for present day and 2050.

There is considerable uncertainty in future projections of the return periods for maximum temperature. This is illustrated in Table 11.

Table 11

Return Periods (yr), for Maximum Temperature (C) at Hulhulé

Maximum Temperature (C) of at Least	Observed	2050		
		Minimum	Best Estimate	Maximum
32.0	1.1	1.0	1.0	1.0
32.5	1.2	1.0	1.0	1.0
33.0	2.2	1.0	1.1	1.1
33.5	21	1.2	1.4	1.7
34.0	>90,000	2.1	3.7	7.9
34.5		17.4	152	17.4

Composite Climate Risk Profile

Figure 27 summarises the preceding results by presenting a composite climate risk profile for Hulhulé.

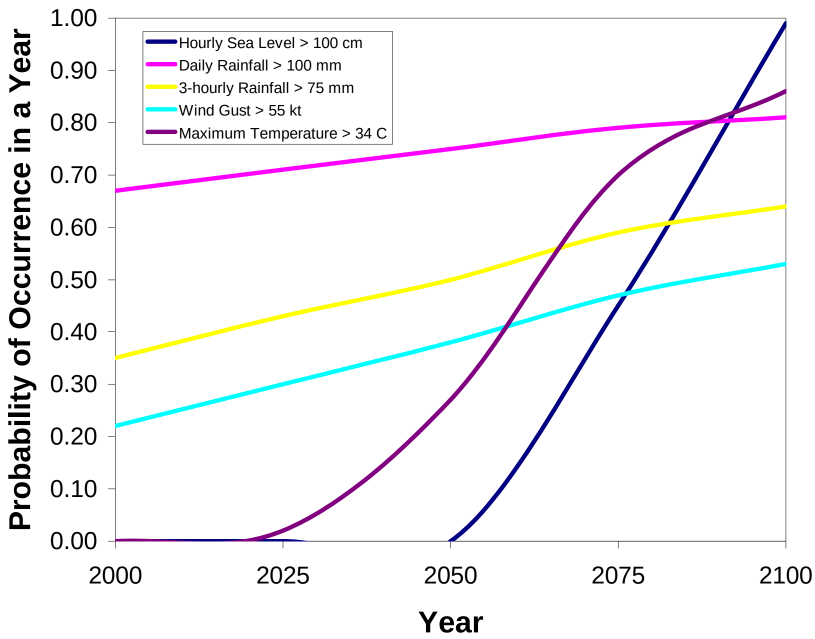

Figure 27 Probability of listed climate events occurring in any one year, based on observed data for 2000 and projected out to 2100 using best estimates of changes based on an average of the estimates for a multi model and emission scenario ensemble.

It is clear from Figure 27 that all climate-related risks evaluated in this study will increase over time, as a result of global warming.