Appendix 2

The Cook Islands—Climate Risk Profile[1]

Summary

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

The risk events for which current and future likelihoods are evaluated are extreme rainfall events (both hourly and daily), drought, high sea levels, strong winds, and extreme high air temperatures. Tropical cyclone frequencies over the past century are also examined. Some climate-related human health and infrastructure risks are also investigated.

Projections of future climate-related risk are based on the output of global climate models, for given emission scenarios and model sensitivity.

All the likelihood components of projected climate-related risk show marked increases as a result of global warming.

A. Introduction

Formally, risk is the combination of the consequence of an event and the likelihood (i.e., probability) of that event taking place.

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 and many sectors. This is due to the spatial scale and pervasive nature of weather and climate. Thus, the likelihood of, say, an extreme event or climate anomaly is often evaluated for a country, state, small island, or similar geographical unit. While the likelihood may well vary within a given unit, information is often insufficient to assess this spatial variability, or the variations are judged to be of low practical significance.

The following climate conditions are considered to be potential sources of risk:

- extreme rainfall events,
- drought,
- high sea levels and extreme wave heights,
- strong winds, and
- extreme high air temperatures.

Some climate-related human health and infrastructure risks are also investigated.

B. Methods

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

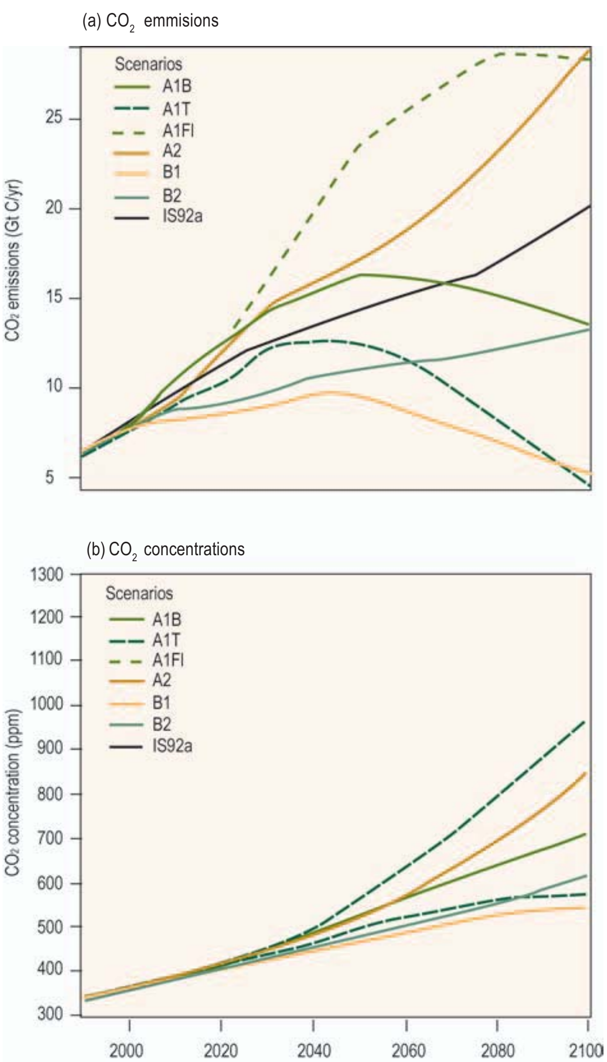
Climate change scenarios are used to develop projections of how the likelihoods might change in the future. For rainfall and temperature projections, the Australian Commonwealth Scientific and Industrial Research Organization global climate model (GCM) was used, as it is considered to work best in the South Pacific. For drought, strong winds, and sea level, the Canadian GCM was used to

[1] At this time the profile is limited to Rarotonga.

develop the projections, as this was the only GCM for which the required data were available.

The SRES A1B greenhouse gas emission scenario was used when preparing rainfall, temperature, and sea-level projections. Figure A2.1 shows that this scenario is close to the middle of the envelope of projected emissions, and hence of greenhouse gas concentrations. For drought, both the A2 and B2 emission scenarios were used, while for extreme wind gusts, only the A2 scenario was used. Again, the required projections were available only for these scenarios.

Figure A2.1. Scenarios of CO_2 Gas Emissions and Consequent Atmospheric Concentrations of CO_2



Notes: CO_2 = carbon dioxide; Gt C/yr = gigatonnes of carbon per year.
Source: IPCC 2001.

C. Information Sources

Daily and hourly rainfall, daily temperature, and hourly wind data were obtained through the Cook Islands Meteorological Service Office. Sea-level data for Rarotonga were supplied by the National Tidal Facility, The Flinders University of South Australia, and are copyright reserved.

D. Uncertainties

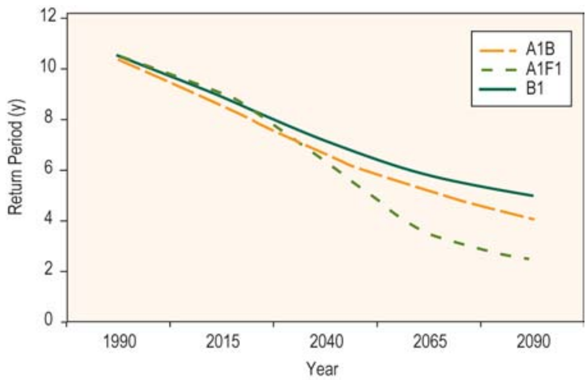
Sources of uncertainty in projections of the likelihood components of climate-related risks are numerous. These include uncertainties in greenhouse gas emissions and those arising from modelling the complex interactions and responses of the atmospheric and ocean systems. Figure A2.2 shows how uncertainties in greenhouse gas emissions impact on estimates of the return periods of a daily precipitation of at least 250 mm for Rarotonga.

Similar graphs can be prepared for other GCMs and extreme events, but are not shown here. Policy and decision makers need to be cognizant of uncertainties in projections of the likelihood components of extreme events.

E. Graphical Presentations

Many of the graphs that follow portray the likelihood of a given extreme event as a function of a time horizon. This is the most appropriate and useful way in which to depict risk, since design life (i.e., time horizon) varies depending on the nature of the infrastructure or other development project.

Figure 2.2. Return Periods for Daily Rainfall of 200 mm in Rarotonga for Given Greenhouse Gas Emission Scenarios



Note: Calculations used Hadley Center global climate model (GCM) with Best Judgment of Sensitivity.
Source: CCAIRR findings.

F. Extreme Rainfall Events

Daily Rainfall

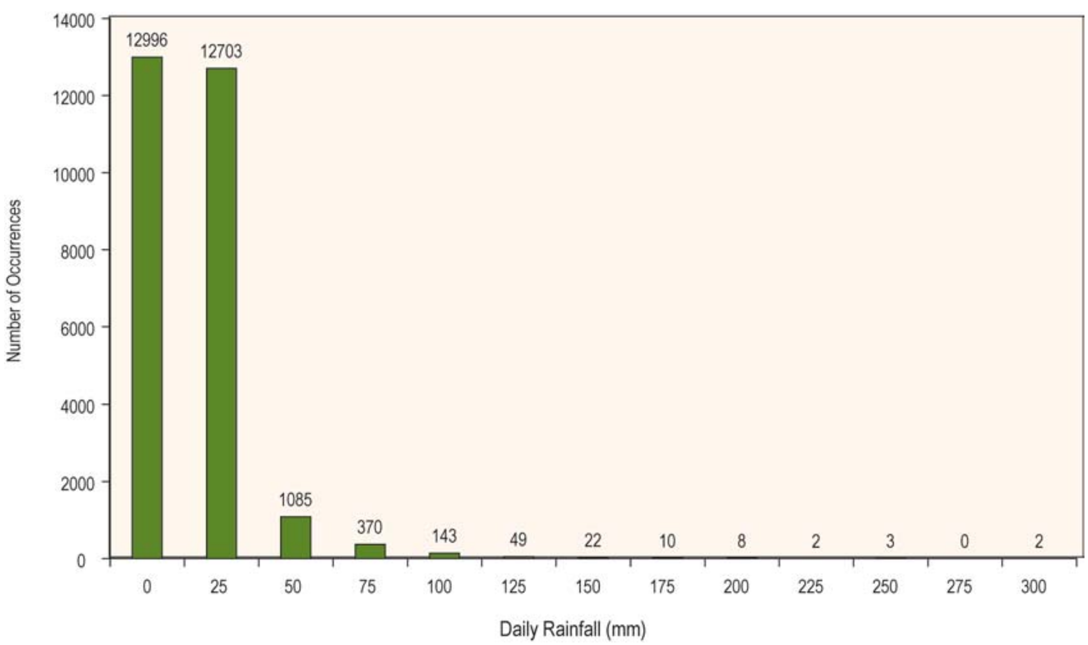
Figure A2.3 shows the frequency distribution of daily precipitation for Rarotonga. A daily total above 200 millimeters (mm) is a relatively rare event, with a return period (i.e., recurrence interval) of 11 years.

Figure A2.4 shows the likelihood of such an extreme rainfall event occurring in Rarotonga within a given time horizon ranging from 1 to 50 years.

It is clear that the frequency of extreme rainfall events has increased markedly since 1929, when records began.

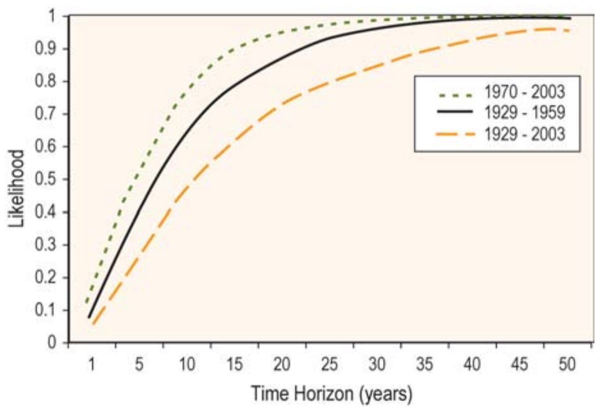
As shown in Table A2.1, global warming will significantly alter the return periods, and hence the likelihoods, of the extreme rainfall events. For example, Figure A2.5 illustrates how the likelihood of a daily rainfall of 200 mm will increase over the remainder of the present century.

Figure A2.3. Frequency Distribution of Daily Precipitation for Rarotonga
(1929–2003)



Note: The values above the bars represent the number of occurrences, for the given data interval.
Source: CCAIRR findings.

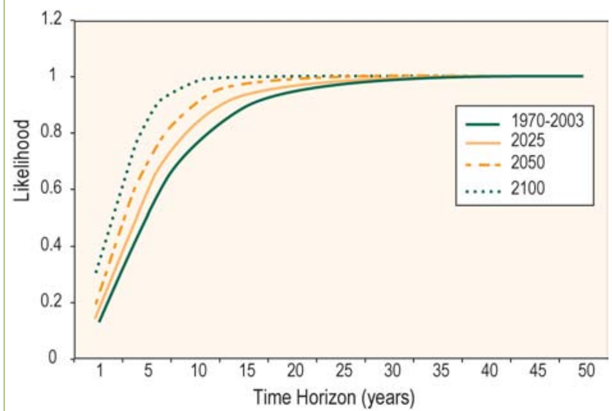
Figure A2.4. Likelihood of a Daily Rainfall of at Least 200 mm Occurring within the Time Horizon
(years)



Note: 0 = zero chance; 1 = statistical certainty. Data for Rarotonga, for indicated data periods.

Source: CCAIRR findings.

Figure A2.5. Likelihood of a Daily Rainfall of at Least 200 mm Occurring within the Indicated Time Horizon
(years)



Note: 0 = zero chance; 1 = statistical certainty. Data for Rarotonga.

Source: CCAIRR findings.

Table A2.1: Return Periods and Likelihood of Occurrence in 1 Year[1] for Daily Rainfall in Rarotonga

Rainfall (mm) (at least)	Present (1970–2003)		2025		2050		2100	
	RP	LO	RP	LO	RP	LO	RP	LO
100	1	0.78	1	.81	1	0.83	1	0.87
150	3	0.34	3	.38	2	0.44	2	0.56
200	7	0.14	6	.16	5	0.20	3	0.31
250	18	0.06	13	.08	10	0.10	6	0.17
300	38	0.03	26	.04	19	0.05	11	0.09
350	76	0.01	47	.02	35	0.03	19	0.05
400	141	0.01	81	.01	59	0.02	31	0.03
450	248	0	130	.01	95	0.01	50	0.02
500	417	0	201	0	148	0.01	78	0.01

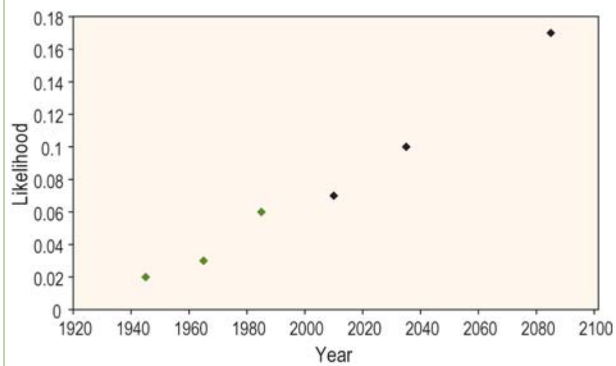
Notes: RP = return period; LO = likelihood of occurrence.

[1] A likelihood of 0 equals zero chance while a likelihood of 1 equates to a statistical certainty that the event will occur within a year.

Source: CCAIRR findings.

An obvious question arises: are the past changes in the probability component consistent with the changes projected to occur in the future as a result of global warming? The trend of increasing likelihood that was apparent in the historical data for much of the last century is projected to continue, in a consistent manner, through the present century. Observed and projected likelihoods of at least 250 mm of rain falling in a day are presented in Figure A2.6. A high degree of consistency is apparent. It is important to note that this consistency does not prove the existence of a global warming signal in the observed data. More detailed analyses are required before any such attributions can be made.

Figure A2.6. Observed and Projected Likelihoods of a Daily Rainfall of at Least 250 mm Occurring in a Year

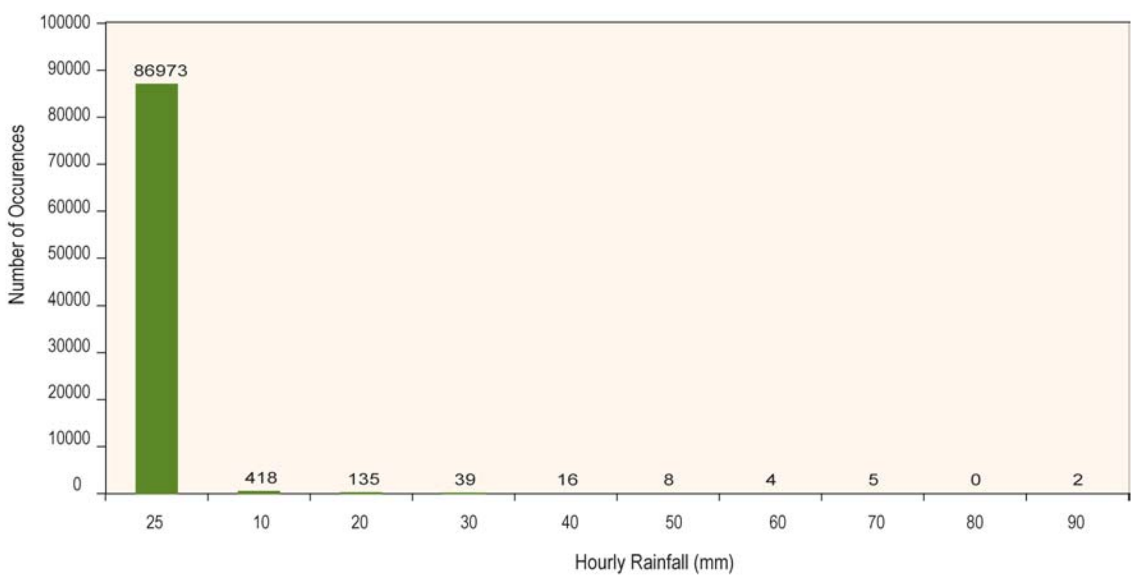


Notes: black symbols = observed likelihoods; green symbols = projected likelihoods. Data for Rarotonga.
Source: CCAIRR findings.

F. Hourly Rainfall

Figure A2.7 shows the frequency distribution of hourly precipitation for Rarotonga. An hourly total above 50 mm is a relatively rare event. Table A2.2 shows such a rainfall has a return period of 3 years, and that global warming will have a significant impact on the return periods of extreme rainfall events.

Figure A2.7. Frequency Distribution of Hourly Precipitation for Rarotonga



Notes: Data for 1970–1979. The values above the bars represent the number of occurrences for the given data interval.
Source: CCAIRR findings.

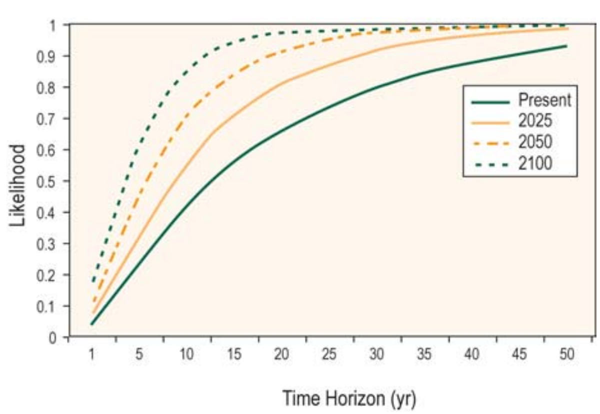
Table A2.2: Return Periods and Likelihood of Occurrence in 1 Year for Daily Rainfall Rarotonga

Rainfall (mm) (at least)	Present		2025		2050		2100	
	RP	LO	RP	LO	RP	LO	RP	LO
25	1	0.93	1	0.92	1	0.93	1	0.93
50	3	0.29	3	0.36	3	0.39	2	0.45
75	18	0.05	12	0.08	8	0.12	6	0.18
100	91	0.01	57	0.02	25	0.04	13	0.08
125	384	0	246	0	67	0.01	25	0.04
150	N/A	N/A	980	0	159	0.01	46	0.02

Notes: RP = return period in years; LO = likelihood of occurrence.
Source: CCAIRR findings.

Figure A2.8 depicts the impact of global warming on the likelihood of an hourly rainfall of 75 mm for Rarotonga.

Figure A2.8. Likelihood of an Hourly Rainfall of at Least 75 mm Occurring Within the Indicated Time Horizon in Rarotonga
(years)



Notes: Likelihood 0 = zero chance; 1 = statistical certainty. Values for present day based on observed data for 1980–2002, with gaps.
Source: CCAIRR findings.

F. Drought

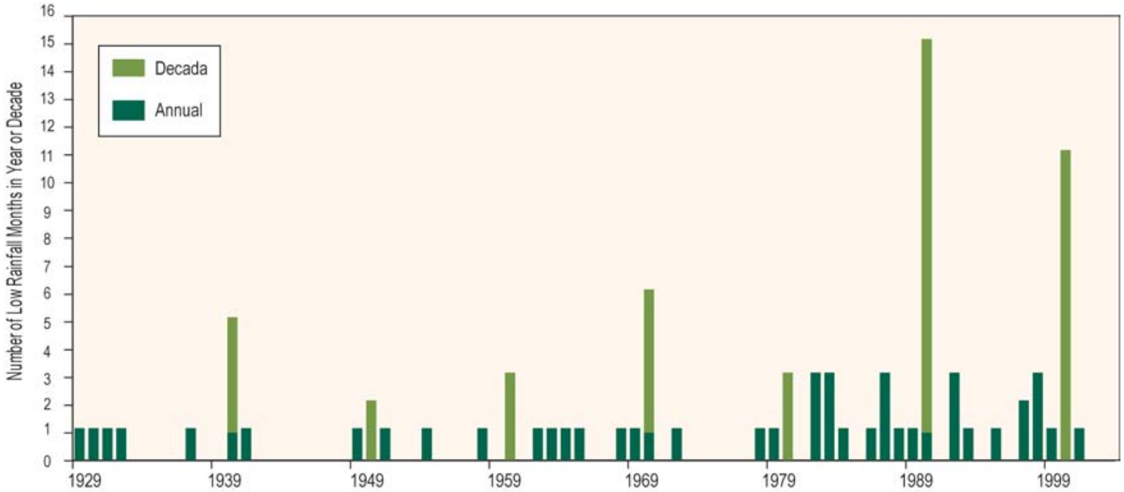
Figure A2.9 presents, for Rarotonga, the number of months in each year (1929–2003) and each decade for which the observed precipitation was below the 10th percentile. Monthly rainfall below the fifth percentile is used here as an indicator of drought.

Most of the low rainfall months are concentrated in the latter part of the period of observation, indicating that the frequency of drought has increased since the 1930s. The years with a high number of months below the fifth percentile coincide with El Niño Southern Oscillation (ENSO) events.

Figure A2.10 shows the results of a similar analysis, but for rainfall estimates (1961–1990) and projections (1991–2100).

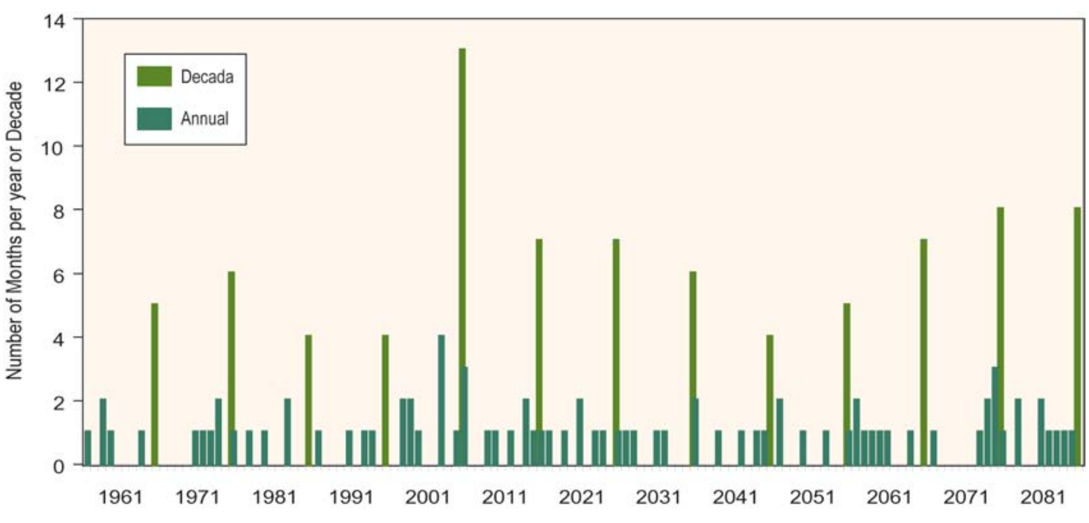
The results indicate that prolonged and more intense periods of drought will occur during the remainder of the 21st century.

Figure A2.9. Number of Months in Each Year and Decade for which the Precipitation was Below the Fifth Percentile



Note: data for Rarotonga.
Source: CCAIRR findings.

Figure A2.10. Number of Months Per Year and Per Decade for Which Precipitation in Rarotonga was Observed, and is Projected to Be, Below the Fifth Percentile



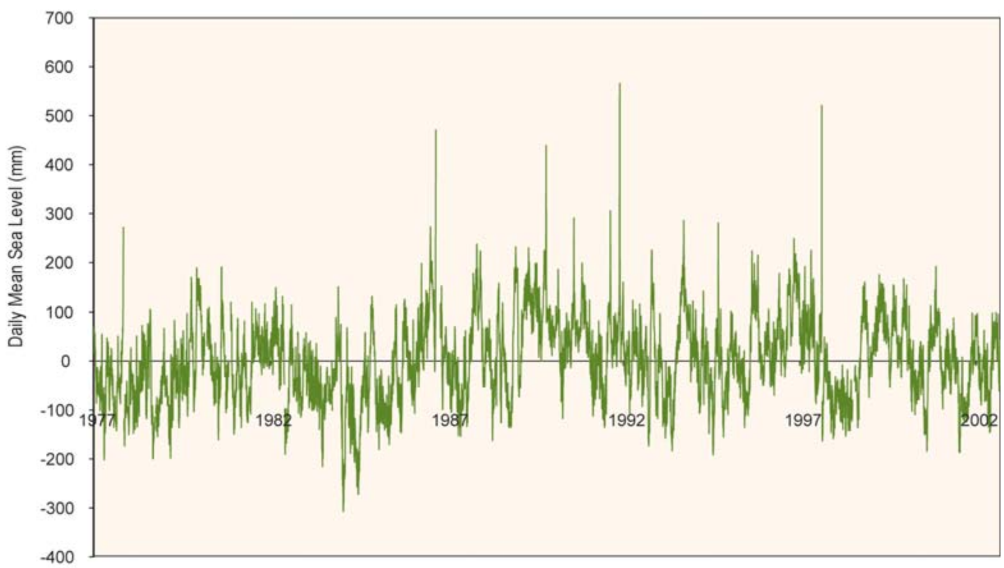
Notes: data from the Canadian global climate module (GCM), with A2 emission scenarios and best estimate for GCM sensitivity.
Source: CCAIRR findings.

G. High Sea Levels and Extreme Wave Heights

Figure A2.11 shows daily mean values of sea level for Rarotonga, relative to mean sea level. Large interannual variability occurs in sea level. The exceptionally high sea levels shown in Figure A2.11 are all associated with the occurrence of tropical cyclones.

Even more extreme high sea levels occur for time scales less than a day. Table A2.3 provides return periods for given significant on-shore wave heights for Rarotonga, for the present day and projected future. The latter projections are based on the Canadian GCM 1 GS and the A1B emission scenario.

Figure A2.11. Daily Mean Values of Sea Level for Rarotonga
(1977–2002)



Source: CCAIRR findings.

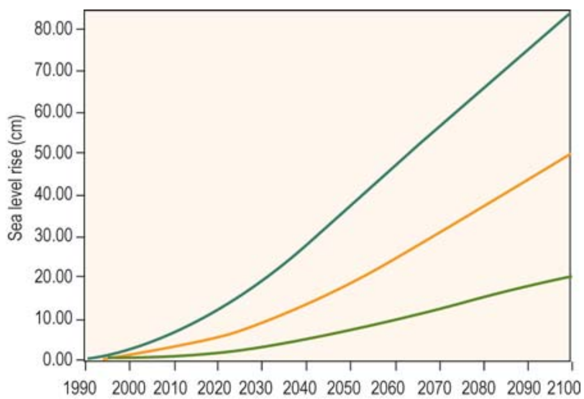
Table A2.3. Return Periods for Significant On-shore Wave Heights, Rarotonga
(years)

Sea Level (m) (at least)	Present Day		2025		2050		2100	
	RP	LO	RP	LO	RP	LO	RP	LO
2	2	0.51	2	0.59	2	0.65	1	0.75
4	4	0.25	3	0.31	3	0.35	2	0.45
6	10	0.10	8	0.13	7	0.15	5	0.21
8	30	0.03	23	0.04	18	0.05	12	0.08
10	112	0.01	80	0.01	62	0.02	39	0.03
12	524	0	349	0	258	0	149	0.01

Notes: LO = likelihood pf occurrence; RP = return period.
Source: CCAIRR findings.

The indicated increases in sea level over the next century are driven by global and regional changes in mean sea level as a consequence of global warming. Figure A2.12 illustrates the magnitude of this contribution.

Figure A2.12. Sea Level Projections for Rarotonga



Notes: Uncertainties related to global climate model sensitivity are indicated by the blue, red and green lines, representing high, best estimate, and low sensitivities, respectively.

Source: CCAIRR findings.

H. Strong Winds

Figure A2.13 shows the annual maximum wind gust recorded in Rarotonga for the period 1972–1999.

Figure 2.14 presents the likelihood of a wind gust of at least 40 m/sec occurring at Rarotonga within the specified time horizon.

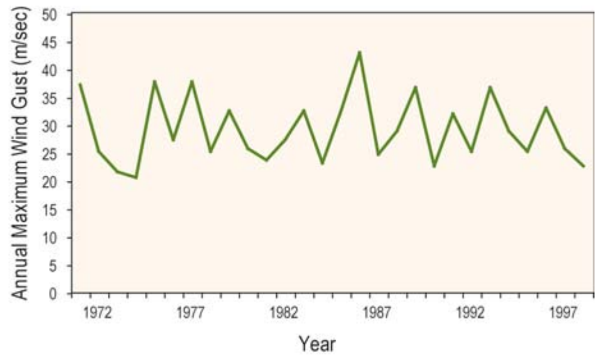
Table A2.4 presents the return periods based on an analysis of the observed maximum hourly wind gust data and the adjusted GCM wind speed data.

The return period estimates of Kirk are for open water conditions. Strong agreement is observed between these and the return periods based on observed data, suggesting that the Rarotonga anemometer provides extreme gust estimates that are reasonably representative of open water conditions.

Comparison of the return period estimates for the 1961–1990 GCM data with the observed data also reveals good agreement, though the GCM data tend to show slightly shorter return periods for lower extreme wind speeds and slightly longer return periods for higher extreme wind speeds.

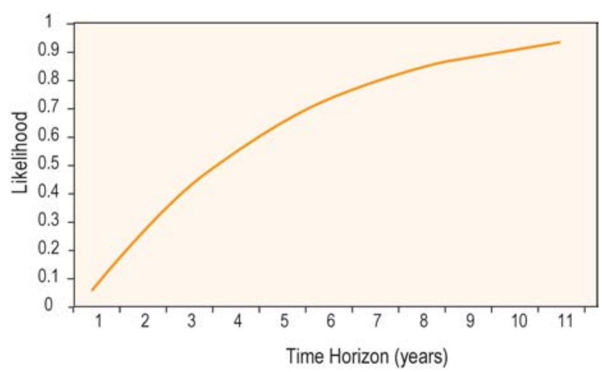
Arguably the most important finding arising from this analysis is the suggestion that, over the coming 50 years or so, the return periods for the most extreme wind speeds will reduce significantly, decreasing by approximately half by 2050.

Figure A2.13. Annual Maximum Wind Gust Recorded in Rarotonga for the Period 1972–1999



Source: CCAIRR findings.

Figure A2.14. Likelihood of a Wind Gust of 40 m/sec (78 kt) Occurring Within the Indicated Time Horizon, Rarotonga



Notes: 0 = zero chance; 1 = statistical certainty. Data for Rarotonga, Cook Islands (1972–1999). A wind gust of 40 ms^{-1} has a return period of 20 years.

Source: CCAIRR findings.

Table A2.4: Estimates of Return Periods for Given Maximum Wind Speeds, Rarotonga
(years)

Wind Speed (m/sec)	Return Period (years)				
	Kirk (1992)	Observed Data (1972–1999)	GCM Based Maximum Wind Speed Data		
			1961–1990	1991–2020	2021–2050
28.5	2	2	1	1	1
33.9	5	5	2	2	2
37.5	10	11	3	4	4
38.8	13	14	5	5	6
41.9	25	29	18	16	14
44.9	50	57	60	45	31
47.8	100	113	120	95	64

Note: GCM = global climate module.
Source: CCAIRR findings.

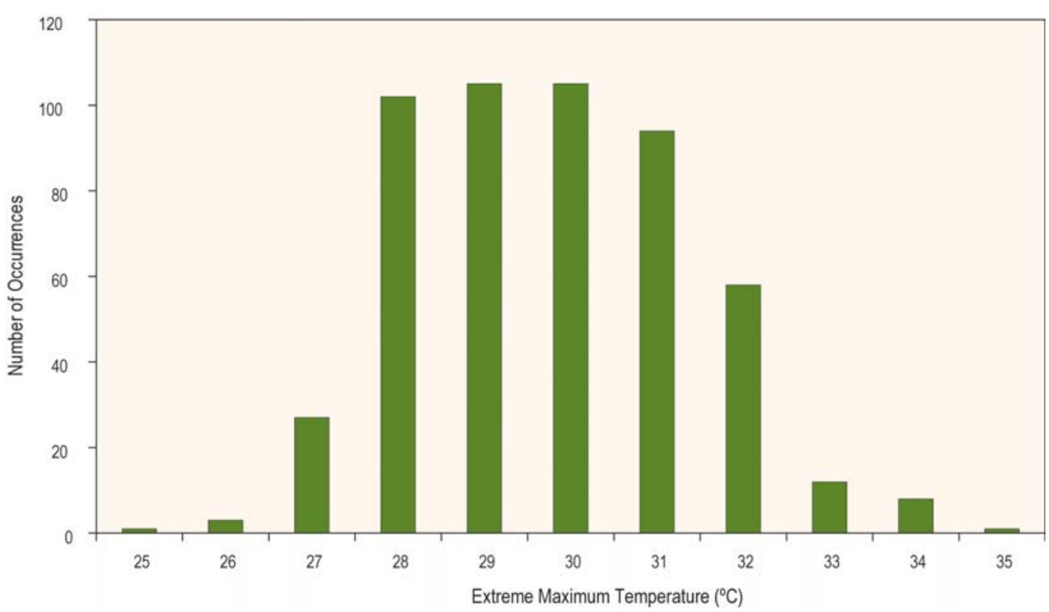
I. Extreme High Temperatures

Figure A2.15 presents the frequency distribution of daily maximum temperature for Rarotonga.

Table A2.5 details the return periods for daily maximum temperature for Rarotonga, based on observed data (1961–2003) and GCM projections.

Figure A2.16 shows the likelihood of a maximum temperature of at least 35°C occurring within the indicated time horizon.

Figure A2.15. Frequency distribution of Monthly Extreme Maximum Temperature for Rarotonga



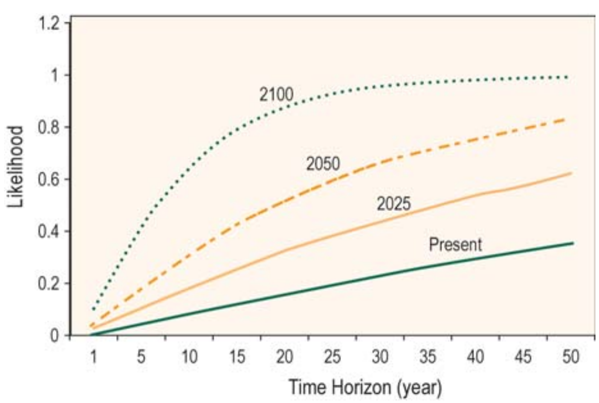
Note: Based on observed data from 1961 to 2003.
Source: CCAIRR findings.

Table A2.5. Return Periods for Monthly Extreme Maximum Temperature, Rarotonga
(years)

Maximum Temperature (°C)	Observed (1961-2003)		Projected 2025		Projected 2050		Projected 2100	
	RP	LO	RP	LO	RP	LO	RP	LO
31	1	0.72	1	0.90	1	0.97	1	1
32	3	0.33	2	0.54	1	0.71	1	0.94
33	9	0.12	5	0.22	3	0.34	2	0.64
34	29	0.03	14	0.07	9	0.12	3	0.29
35	108	0.01	52	0.02	29	0.03	10	0.10
36	435	0	208	0	115	0.01	37	0.03

Notes: LO = likelihood of occurrence; RP = return period.
Source: CCAIRR findings.

Fig A2.16 Likelihood of a Maximum Temperature of at Least 35°C Occurring Within the Indicated Time Horizon in Rarotonga
(years)



Note: 0 = zero chance; 1 = statistical certainty.
Source: CCAIRR findings.

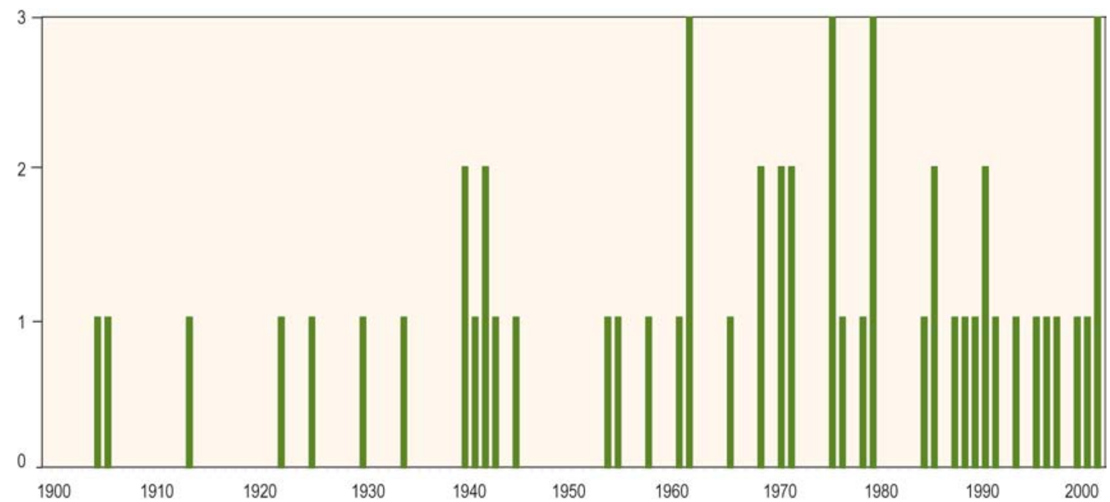
J. Tropical Cyclones

The number of tropical cyclones passing close to, and affecting Rarotonga appears to have increased during the last century (Figure A2.17). However, since observing and reporting systems improved substantially over the same time period, it is unwise to read too much into the marked contrast in frequency between the first and second halves of the 20th century. The record for the last few decades is much more reliable, hence the doubling in decadal frequencies between the 1950s and 1990s may well be closer to the truth. It is certainly consistent with the fact, since the 1970s that El Niño episodes have tended to be more frequent, without intervening La Niña events. The duration of the 1990–95 El Niño is unprecedented in the climate record of the past 124 years.

Studies by Australia's Bureau of Meteorology (Figure A2.18a and b) reveal the consequences of the weakened trade winds and eastward movement of the warm waters of the western tropical Pacific during El Niño events. Because convective systems (e.g., thunderstorms and rainstorms) and tropical cyclones preferentially occur over warmer waters, changes in the pattern of sea surface temperatures is reflected in the distribution of rainfall and tropical cyclones.

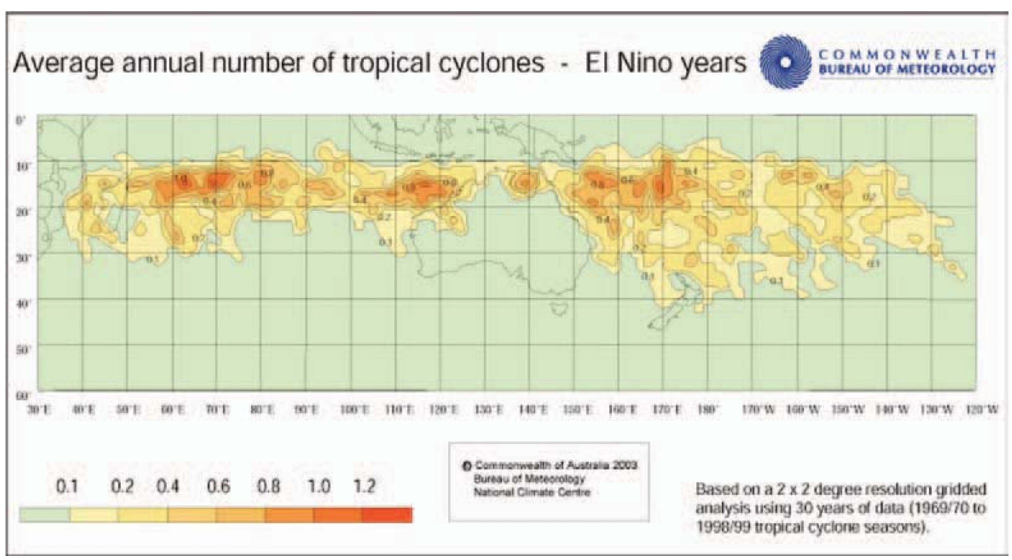
A possible consequence of the increased persistence of El Niño conditions in recent decades is the apparent intensification of tropical cyclones, as reflected in the systematic increase in upper 10 percentile heights of open water waves associated with tropical cyclones occurring in the vicinity of Rarotonga (Table A2.6).

Figure A2.17. Number of Tropical Cyclones per Year passing Close to, and Affecting, Rarotonga



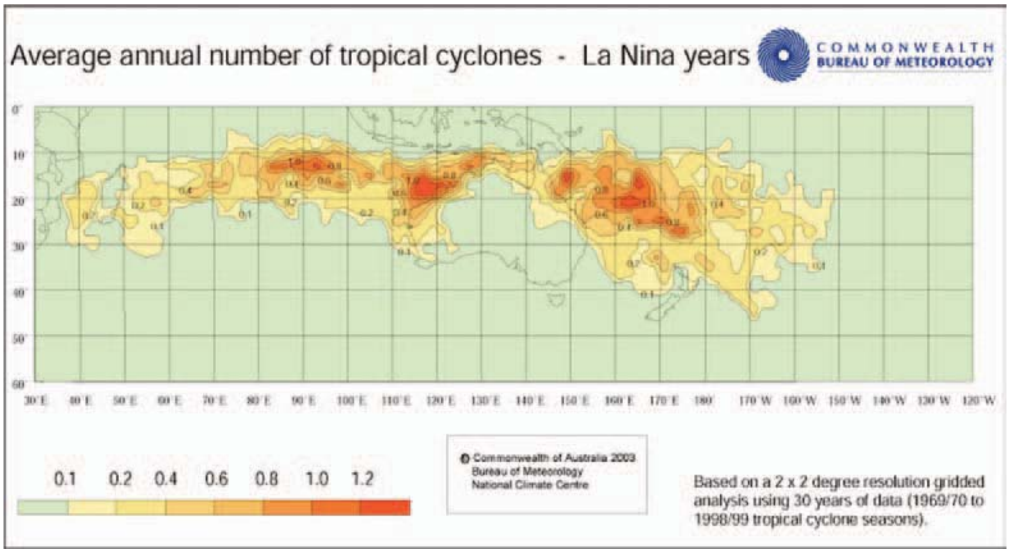
Sources: Kerr 1976, Revell 1981, Thompson et al. 1992, d'Aubert and Nunn 1994, Fiji Meteorological Service 2004, and Ready (personal communication).

Figure A2.18a. Average Annual number of Tropical Cyclones for El Niño Years



Source: Australian Bureau of Meteorology, n.d. Reproduced by permission

Figure A2.18b. Average Annual number of Tropical Cyclones for La Niña Years



Source: Australian Bureau of Meteorology, n.d. Reproduced by permission

Table A2.6. Open Water Wave Height (Average of Top 10%) Associated with Tropical Cyclones Recently Affecting Rarotonga

Cyclone (name and year)	Wave Height (m)
Charles (1978)	11
Sally (1987)	10
Val (1991)	14
Pam (1997)	14
Dovi (2003)	17
Heta (2004)	17
Nancy (2005)	22
Percy (2005)	19

Source: Dorrell (personal communication).