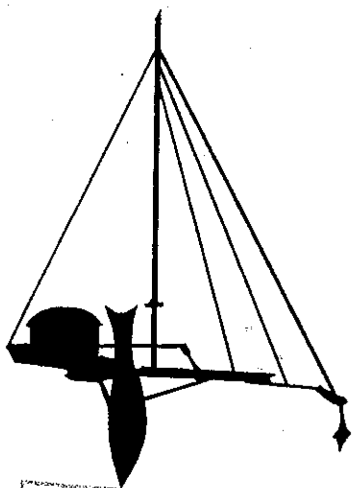
The climate and weather of the SOUTHERN COOK ISLANDS



New Zealand Meteorological Service
Wellington, New Zealand

Corrections.

The climate and weather of the Southern Cook Islands.
(Misc Pub 188(2)).

Page 8. Table 3. bottom line should read...

	Dec	Jan	Feb	Mar	Apr	Speed Range(knots)
Filling or intensifying			2	2		< 34

Page 26. Table 13. should read...

Location	V_m	c	Total time between 6 and 30 knots		Wind power kWh/m^2/yr	
			Obs.	Est.	Obs.	Est.

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THE CLIMATE AND WEATHER

OF

THE SOUTHERN COOK ISLANDS

C. S. Thompson

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CONTENTS

Note to 188 series

This publication is one in a series on the climate and weather of selected South Pacific island groups.

This series replaces an earlier Meteorological Service series entitled: 'Climatological Notes - South Pacific Region' (N.Z.M.O. Series C), published in 1943.

The following titles have been published, or are in preparation:

188(1)	Climate and Weather of Niue	(published)
188(2)	Climate and Weather of Southern Cook Islands	(published)
188(3)	Climate and Weather of Northern Cook Islands	
188(4)	Climate and Weather of Tokelau	
188(5)	Climate and Weather of Tonga	
188(6)	Climate and Weather of Tuvalu	
188(7)	Climate and Weather of Western Kiribati	
188(8)	Climate and Weather of Western Samoa	

Cover - an outrigger canoe with asymmetrically cross-sectioned hull from the Caroline islands (after a drawing by Louis Choris in 1815).

THE CLIMATE AND WEATHER OF THE SOUTHERN COOK ISLANDS

C.S. Thompson

Summary

The Southern Cook Islands lie on the southern fringe of the persistent trade wind zone of the South Pacific. The mean wind speed of the open ocean area is 13 knots, but wind speeds on the two largest islands, Rarotonga and Mangaia, are influenced by the orography.

While temperatures remain warm all year round, rainfall is a dominant climatic feature of this island group. There is a pronounced wet season (November to April) when about two-thirds of the annual amount falls and a dry season (May to October). This is also related in part to the seasonal movement of the South Pacific Convergence Zone. Rainfall is highly variable from year to year, and the convective nature of the rain enhances this variability. High intensity short period rainfalls are therefore frequent, leading to surface runoff and soil erosion.

High evaporative water demand by vegetation because of high radiation and sunshine levels creates large soil moisture deficits in most years, and these are especially pronounced in the dry season.

Although an average of just one tropical cyclone per year affects the Southern Cook Islands, there are also many cyclone-free seasons.

1. INTRODUCTION

The Cook Islands (Fig. 1) are situated in the South Pacific Ocean, and include all the islands between latitudes 8°S-23°S, and longitudes 156°W-167°W. The islands take up an area of only 241 km^2 in this zone which has a total area of 1.95 million km^2. There are two clusters of islands, the Northern Cook Islands and the Southern Cook Islands.

The Southern Cook Islands consist of nine main islands, among them Rarotonga, the largest and most populous island of the group. This island has a small surrounding coastal plain, and a mountainous interior with the highest peak, Te Manga, 652 m above sea level. Avarua is the main urban area of Rarotonga as well as being the seat of government of the entire Cook Islands. Mangaia, the second largest island in the Southern

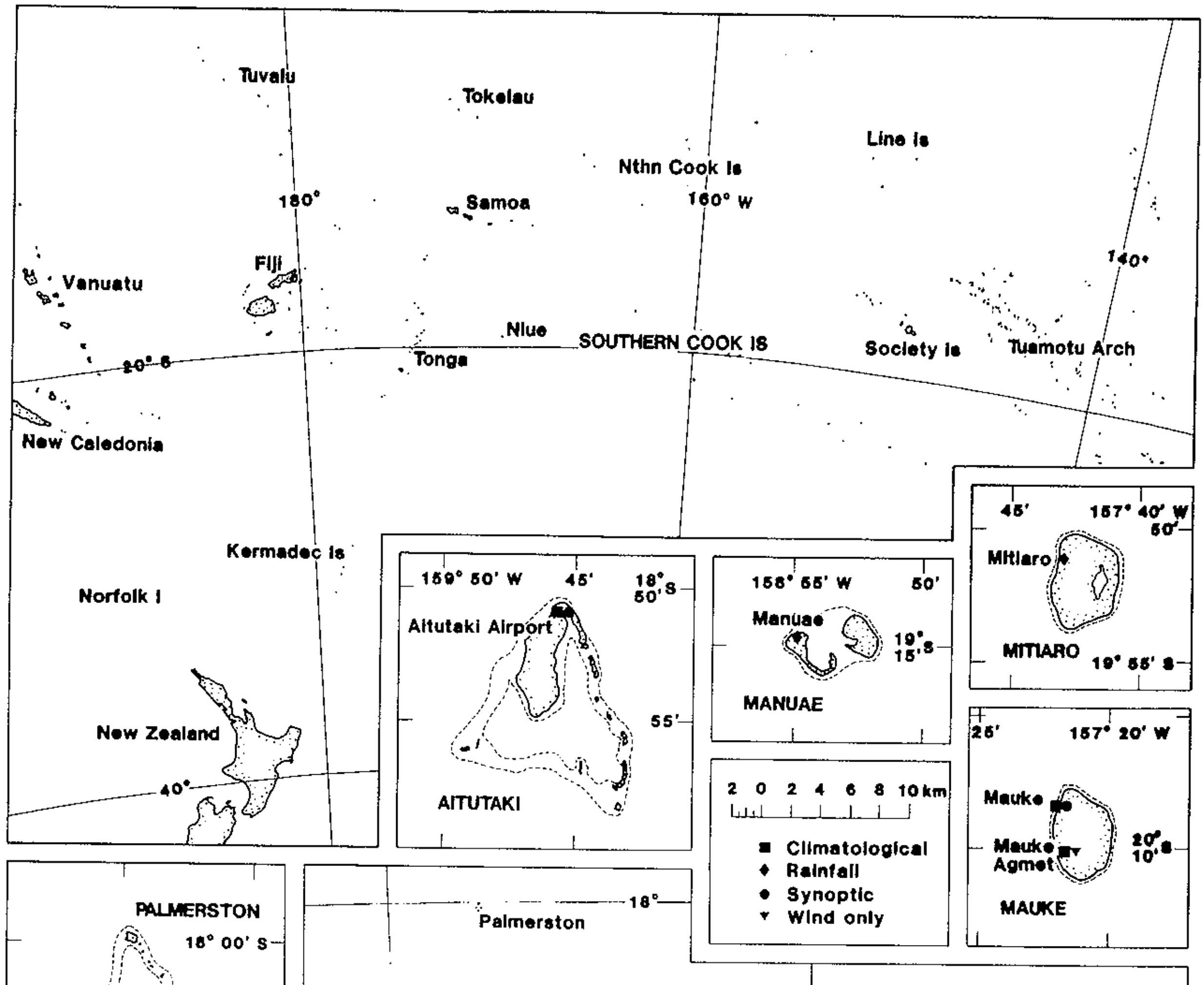

Fig. 1. Location map

Cook Group, is a hilly island reaching 169 m above sea level. Aitutaki is a part volcanic and part coral atoll. It is triangular in shape and the volcanic main island reaches a height of 124 m. The other main islands are Atiu, Mauke, Manuae, Mitiaro, Takutea and Palmerston Atoll. These are low-lying atolls with Mauke having the highest point at 29 m.

The Cook Islands economy is based on the export of primary produce, namely bananas, copra, pineapples and citrus (Carter, 1981), of which 80 percent is exported to New Zealand. Tourism and the sale of stamps and coins are also major sources of revenue in the islands' economy.

Data used in this publication, where not otherwise indicated, were obtained from the New Zealand Meteorological Service's archives. Rainfall records for Rarotonga have been kept since 1899 in the Avarua/Airport area. There are currently 28 stations (climatological, rainfall and wind) in operation, 15 of which have been opened since 1980.

2. GENERAL CIRCULATION OF THE TROPICAL SOUTH PACIFIC

While there is much variability in the general circulation of the tropical South Pacific on both seasonal and even shorter time-scales, the time-averaged state is characterised by four main features:

(i) Sub-tropical high pressure zone

A belt of high pressure spanning the South Pacific is centred on latitudes 25°S-30°S. Within this zone in the eastern South Pacific is a large semi-permanent anticyclone near longitudes 90°W-100°W. On the western margin of the belt of high pressure, anticyclones move eastwards into the Pacific region from the Australia-Tasman Sea region.

(ii) Trade winds

On the northern side of the high pressure belt is an extensive belt where the winds blow consistently from the same general direction. These are the trade winds. They blow from the easterly quarter but some in the western South Pacific have a more southerly component due to the eastward migration of anticyclones (Revell, 1981). Between the permanent anticyclone to the east and the migratory ones to the west is a region of convergence, the South Pacific Convergence Zone.

An important feature of the trade winds is the frequent presence of strong temperature inversions between 1200-2500 m. Over the Southern Cook Islands the inversion height varies seasonally, being 1800-2500 m in the wet season and 1200-1800 m during the dry season. Above the inversion, westerly winds predominate, with dry subsiding air. Consequently the growth of convective clouds to high altitudes is inhibited as cloud tops rarely penetrate the inversion and showers become less likely. Surface wind strengths are normally moderate, although speeds may reach 25-30 knots* at times. Scattered showers on windward slopes of mountainous islands (e.g., Rarotonga) are likely. Clouds are often aligned in bands parallel to the wind direction.

(iii) Equatorial doldrum belt and intertropical convergence zone

The Equatorial Doldrum Belt (EDB) is a region of relatively light winds that is present all year round in the western Pacific Ocean. Lying within about 5° of the Equator, the doldrum belt is a zone of high rainfall and great seasonal variability (Revell, 1981). During the Southern Hemisphere summer when the EDB is furthest south, there is usually a trough of low pressure extending from Northern Australia into the Coral Sea on the southern fringe of the doldrums. This trough is regionally known as the 'monsoon trough'. The resultant light winds reflect in part alternating periods of easterlies and westerlies. The 'monsoon westerlies' are occasionally squally. During the winter season, the doldrum zone lies principally in the Northern Hemisphere, and the Australian monsoon trough is absent.

The zone marking the convergence of the North Pacific trade winds with the South Pacific trades is known as the Intertropical Convergence Zone (ITCZ). It is an extensive area of cloud and showers due to the ascent of air, although the intensity fluctuates with time. The ITCZ follows the passage of the sun, with a lag of about 3 or 4 months (Wyrtki and Meyers, 1975). The range in latitudes of the ITCZ is from 3°N-10°N in the eastern central Pacific, and from 5°N-15°N near America.

(iv) The South Pacific convergence zone

The South Pacific Convergence Zone (SPCZ) is an area of convergence between the equatorial easterly winds and the higher latitude south-easterly trades. It is an area of cyclonic wind shear, and is a semi-permanent cloud feature of the Southern Hemisphere. The SPCZ usually lies north of the Southern Cook Islands, but to the west and south of Western Samoa, Tahiti, and Easter Island (Trenberth, 1976). During summer the SPCZ becomes an extension of the monsoon trough of northern Australia (Fig. 2). The SPCZ varies from month to month, and the weather in the Southern Cook Islands is largely dependent on its position and intensity. There are two dominant seasons, a wet season (November to April) and a dry season (May to October). During the dry season the SPCZ is generally to the north of the group, and the Southern Cooks are affected predominantly by the dry south-east trades. However, in the wet season, the SPCZ is more active and can lie over the island group bringing unsettled weather and heavy rain. Tropical cyclones, forming on the SPCZ between November and April, are major features which also affect the region.

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* One knot (kn) equals 0.515 m/s or 1.85 km/hr.

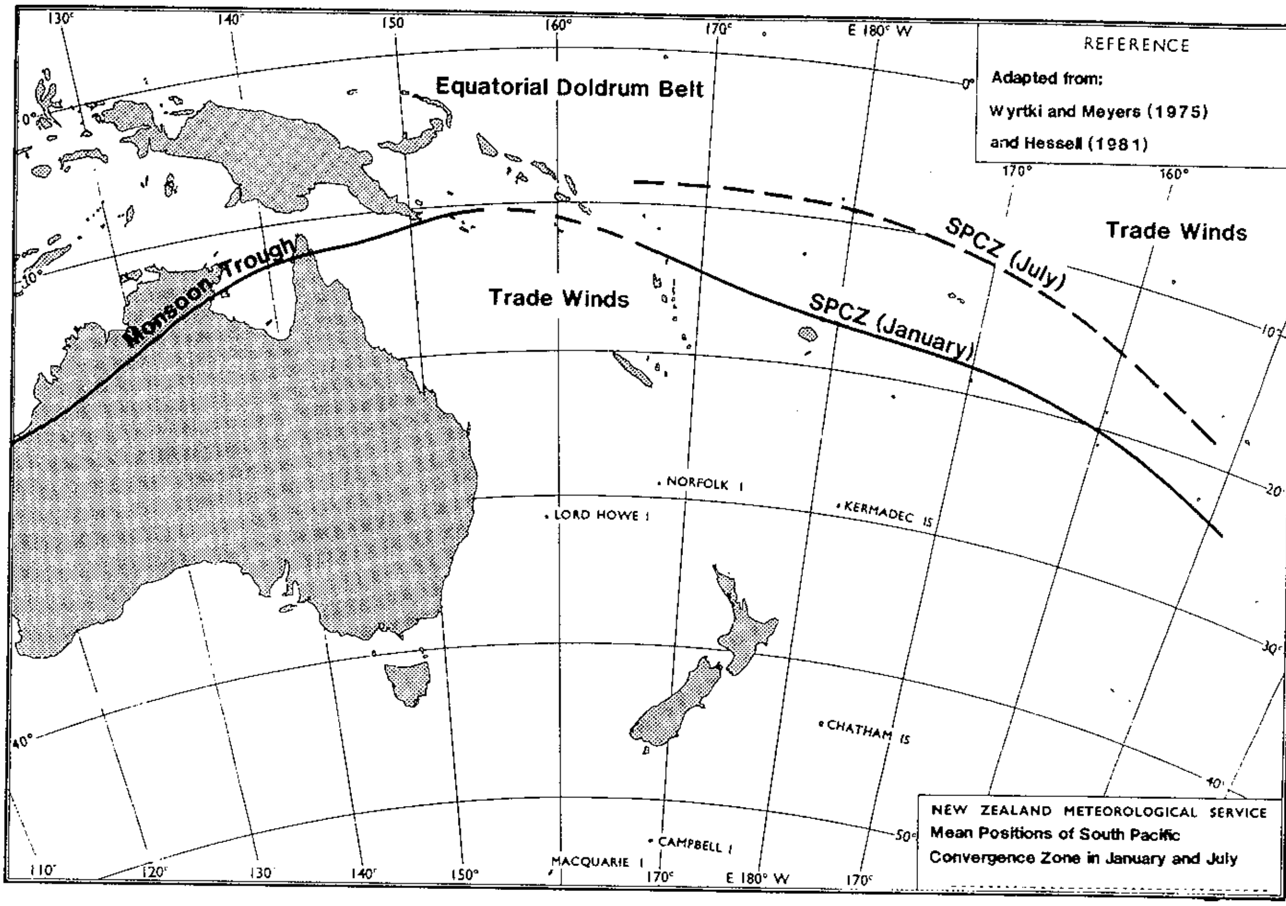

Fig. 2. Mean position of South Pacific Convergence Zone in January and July. Adapted from Wyrtki and Meyers (1975) and Hessell (1981)

Spatial variation in the location of the SPCZ has been noted (Trenberth, 1976) to be associated with the Southern Oscillation Index (SOI). This index represents an oscillation of pressure between the western and eastern regions of the South Pacific Ocean. Trenberth measured the SOI from the normalised differences in pressure between Papeete (Tahiti) and Darwin (Australia). The SOI is reasonably persistent from one month to the next, although the persistence is least in the period March to May when the phase of the SOI is likely to change (Gordon, 1984, pers. comm.). Serial correlation of monthly SOI values, as a measure of persistence is given in Table 1.

Table 1. Persistence (serial correlation) of monthly values of the Southern Oscillation Index

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.62	0.59	0.49	0.54	0.35	0.58	0.75	0.77	0.83	0.76	0.66	0.62

Figure 3 shows a satellite picture of the SPCZ taken at 11.15 a.m. local time on 5 March 1981. The SPCZ is lying from Samoa to the Austral Islands, and the decaying remnants of tropical cyclone 'Esau' which passed south-west of Rarotonga on 4 March 1981 is at 29°S 150°W.

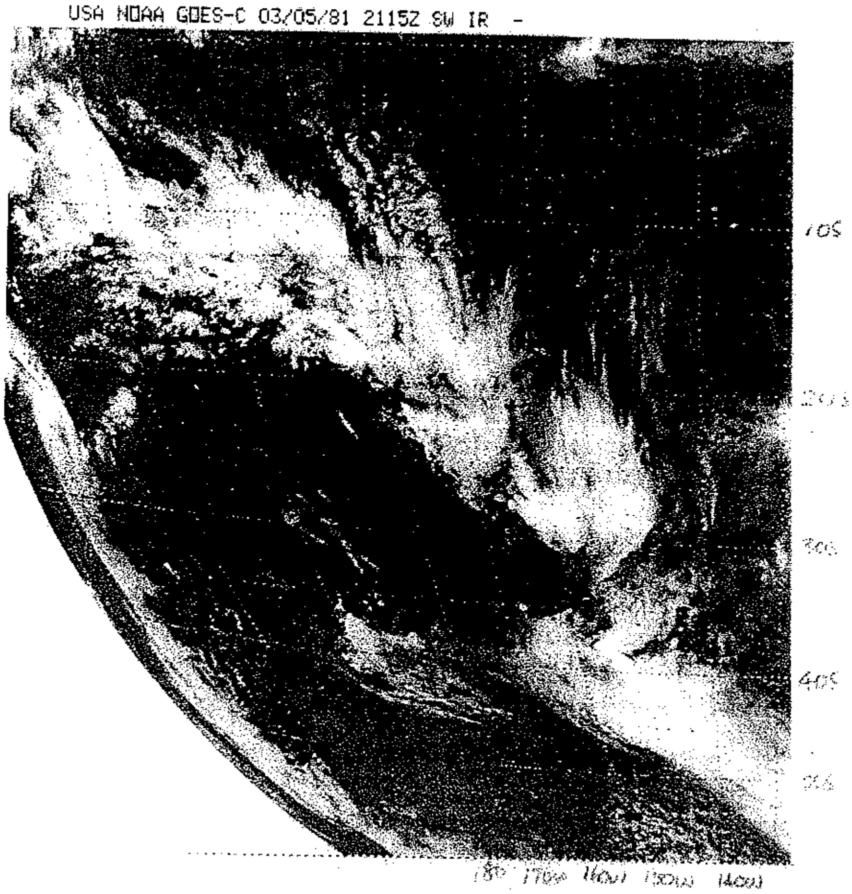

Fig. 3. Satellite view of South Pacific convergence zone on 5 March 1981

When the SOI is negative (i.e., pressures are relatively high at Darwin), the SPCZ lies to the north and east of its mean position (Fig.4). Over the Southern Cook Islands dry conditions are likely. During 1982 and 1983 there was a large eastwards shift of the SPCZ (Rasmusson and Hall, 1983) as a result of the extreme negative phase of the SOI. Rainfalls at Rarotonga Airport, Aitutaki, and Palmerston Island for the 12-month period beginning May 1982 were 808 mm (40 percent of average), 637 mm (34 percent) and 814 mm (41 percent) respectively.

Since 1900 there have been 19 major negative SOI episodes, occurring on average once every 4.4 years. Of the 12 episodes since 1930, the Southern Cooks have experienced low rainfalls on nine occasions. There have been 10 major positive episodes since 1930, one event about every 4.4 years. Eight episodes were associated with above average rainfalls.

Abnormal 12-monthly rainfalls, associated with extreme phases of the SOI are given in Table 2, together with the percentage frequency of surface winds. The predominance of east and south-east winds in the dry years decreases while during the wet years the frequency of winds from between north-west and north-east increases.

Table 2. Abnormal rainfall and surface wind summary at Aitutaki

Year Commencing	Rainfall (mm)	N	NE	E	SE	S	SW	W	NW	Calm	SOI Phase
		Percentage Wind Frequency									
Dec 1937	3258	8	15	34	5	4	4	2	11	6	positive
May 1982	637	4	5	26	37	7	3	2	6	10	negative

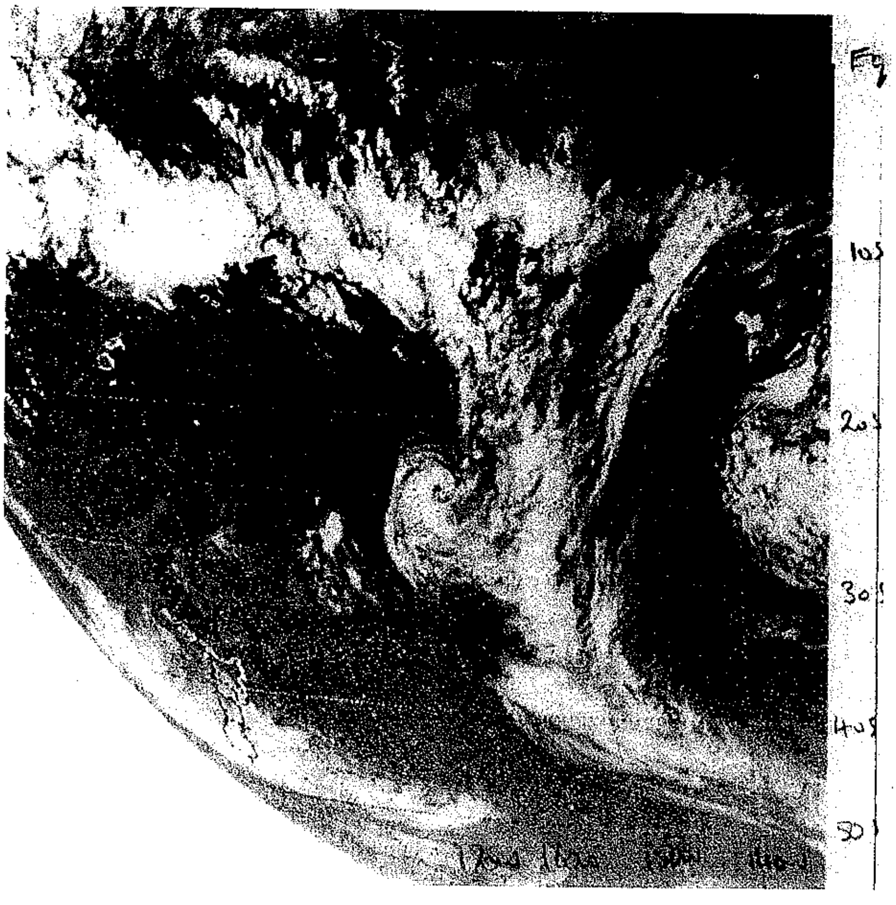

Fig. 4. Satellite view of cloud features over Pacific Ocean on 23 February 1981

Figure 4 shows other important features of the tropical Pacific circulation, other than the SPCZ lying north of its mean position. These features include:

(i) An ITCZ just north of the equator. It is very weak east of the date line, but the SPCZ is merged with the cloud masses associated with the EDB and monsoon trough in the area west of the date line.

(ii) At 25°S, 158°W is the decaying tropical cyclone 'Daman'. 'Daman' affected the Southern Cooks some 12 to 18 hours earlier.

(iii) On the SPCZ at 10°S 175°W is a cluster of cumulonimbus clouds. From this mass of cloud developed an unnamed tropical cyclone which moved east-south-east through the Cook Islands.

3. TROPICAL CYCLONES

Tropical cyclones are usually classified in terms of the maximum sustained winds within the cyclonic circulation. Those disturbances having mean wind speeds in excess of 33 knots are called 'tropical cyclones', and in particular those with wind speeds over 63 knots are classified as 'hurricanes'. They are accompanied by great destructiveness. Disturbances in which the maximum wind speed does not exceed 33 knots are called 'tropical depressions'. They are not generally accompanied by much significant damage. A classification of tropical cyclonic circulations in terms of wind speed is given in Table 3.

Table 3. Frequency of tropical cyclones affecting the Southern Cook Islands, 1969/70-1982/83

Cyclone Intensity	Dec	Jan	Feb	Mar	Apr	Speed Range (knots)
Gale	2	2	1			34 - 47
Storm	3		2	1		48 - 63
Hurricane			3	2		64+
Filling or intensifying			2	2		<34

In the South-West Pacific region, tropical cyclones frequently develop in a trough of low pressure in the zone of cyclonic wind shear characterizing the SPCZ. Other factors favouring the formation of tropical cyclones are a supply of warm moist ascending air lying over a sea surface having a temperature of at least 26-27°C (Gabites, 1963). Tropical cyclones seldom form within 300 kilometres of the Equator where the Coriolis parameter is small, or in zones of strong vertical shear such as beneath jet streams*. Although tropical disturbances may occur all year round, tropical cyclones are usually confined to the warmer months, November to April.

In the 44 years from 1939/40 to 1982/83 there have been 34 tropical cyclones affecting the Southern Cook Islands (Kerr, 1976; Revell, 1982). All cyclones affecting the group have occurred between November and April. Since the advent of weather surveillance by satellites in 1969 which assumes that all tropical storms are detected, 19 tropical cyclones have affected the Southern Cooks, giving an average of 1.4 tropical cyclones each year. This number probably reflects more accurately the true average.

Fig. 5. Satellite view of tropical cyclone 'Tomasi' on 29 March 1983

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* A jet stream is a belt of very strong winds at high levels in the atmosphere.

A satellite picture of tropical cyclone 'Tomasi' is shown in Fig. 5. This picture, taken at 11.15 a.m. on 29 March 1983, shows 'Tomasi' at approximately 14°S 164°W, having an eye characteristic of intense tropical cyclones. Also noticeable are spiralling cloud bands indicating upper-level anticyclonic outflow from the tropical cyclone. 'Tomasi' passed close by Suwarrow Atoll in the Northern Cook Islands. Although it passed about 300 km west of Palmerston Atoll, 97 mm of rain was recorded during 30 March 1983, but no wind damage was reported.

Figure 6 gives an indication of the inter-seasonal variability of the frequency of tropical cyclones that affected the Southern Cooks. In nearly half of the 14 seasons between 1969/70 and 1982/83 no tropical cyclones affected the island group, while there were two occasions (1976/77 and 1980/81) when there were at least three. The high frequency in certain seasons is closely related to the negative phase of the Southern Oscillation. In tropical cyclone free years, the phase of the SOI was mainly positive.

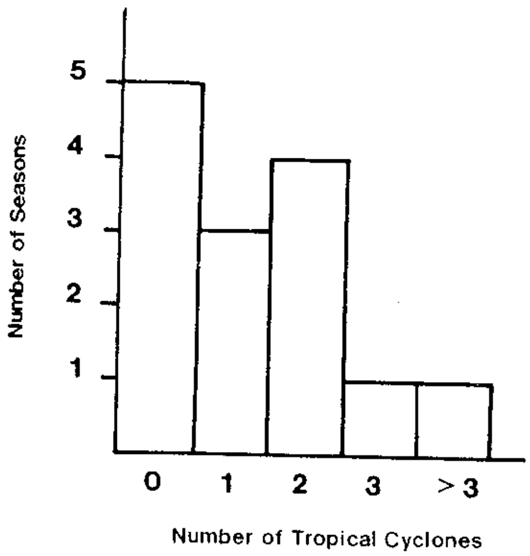

Fig. 6. Number of tropical cyclones that affect the Southern Cooks in a season during the period 1969/70-1982/83

Table 3 presents a summary of the maximum intensity reached in tropical cyclones and the month in which they formed. Sixty-two percent occurred either in February or March. Hurricanes are unlikely before February, and tropical cyclones seldom pass over or near the Southern Cooks in April.

Nearly half of the tropical cyclones affecting the islands originated in the latitudes 10°S-15°S between 160°E and 180°. In this area storms travelled entirely east-south-east or south-east. The cyclones originating east of the date line generally moved south-eastward, or initially southward, then south-eastward. Figure 7 gives a climatological aid as to the probability of a tropical cyclone forming in a particular location and subsequently affecting the Southern Cooks. This figure also identifies the birth place of tropical cyclones that have affected the island group.

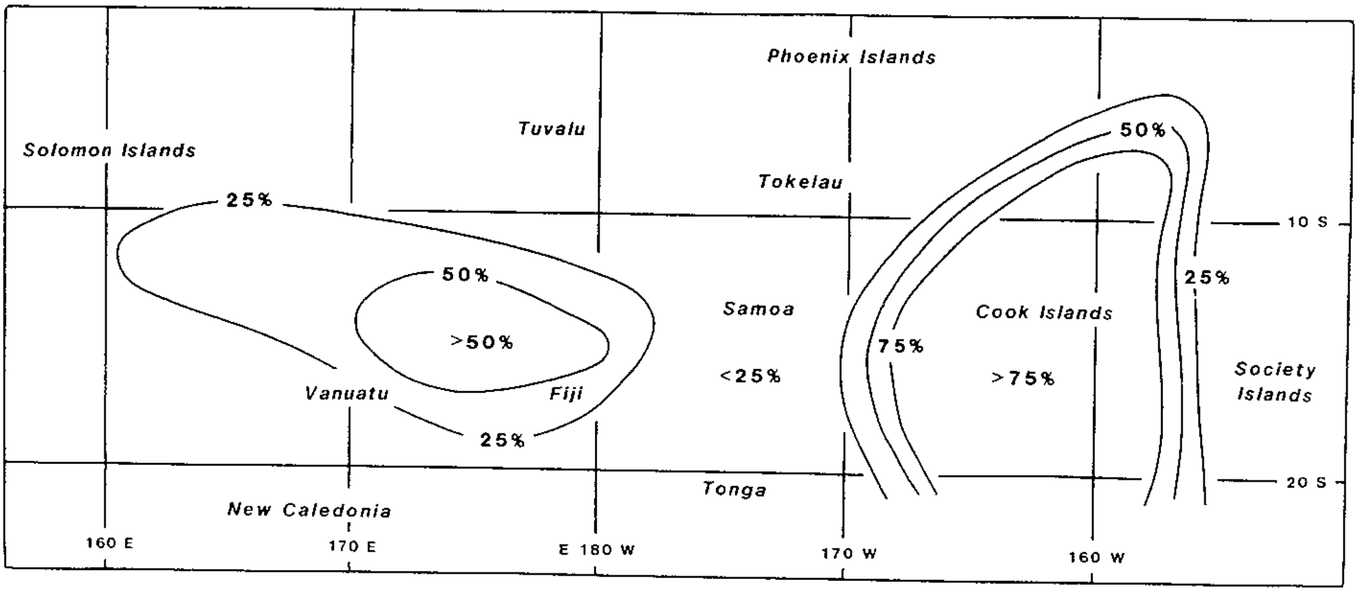

Fig. 7. Probability of tropical cyclones forming in any locality and subsequently affecting the Southern Cook Islands

Most tropical cyclones affecting the Southern Cook Islands have originated within the cloud masses of the SPCZ. Two cyclones developed in the region of the Northern Cooks during the 1982/83 season. At this time the SPCZ was considerably north-east of its normal summertime position, as a result of the extreme negative phase of the southern oscillation.

Case study of tropical cyclone 'Charles' 15-27 February 1978

A particular cyclone that affected the Southern Cooks is considered in detail. Tropical cyclone 'Charles' began developing within the broad cloud mass of the SPCZ north-east of Fiji on 15 February 1978. As it moved eastwards it intensified, the winds reaching storm force by 1200 UT on 17 February. Tropical cyclone 'Charles' slowed down, and did a figure-of-eight loop (Fig. 8) to the north of Palmerston Atoll during the period 18 to 25 February. During this time 'Charles' reached hurricane status for a while on the 19th and 20th, and again from the 23rd to 26th after weakening in the intervening period.

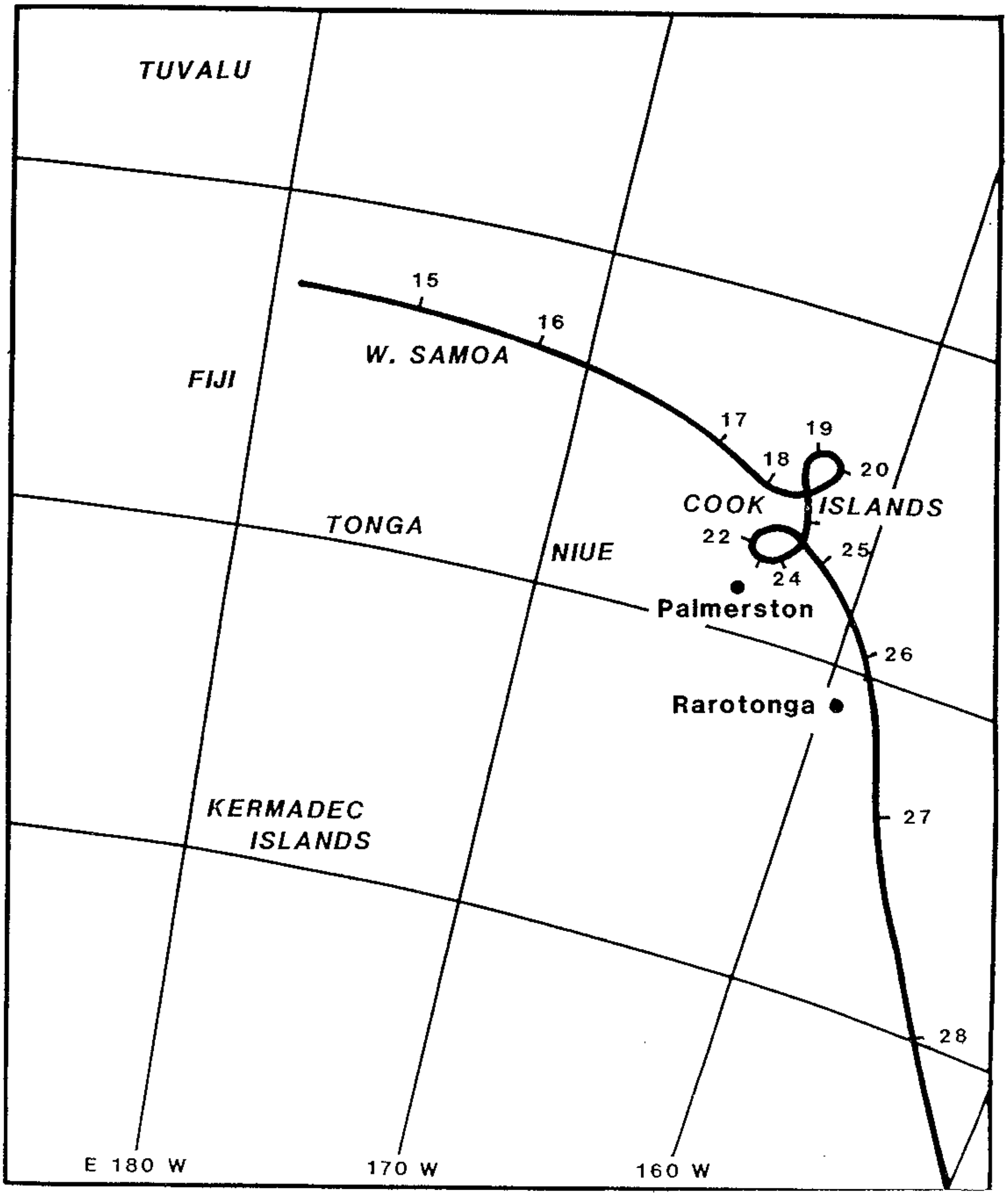

Fig. 8. Track of tropical cyclone 'Charles' during 15 to 28 February 1978

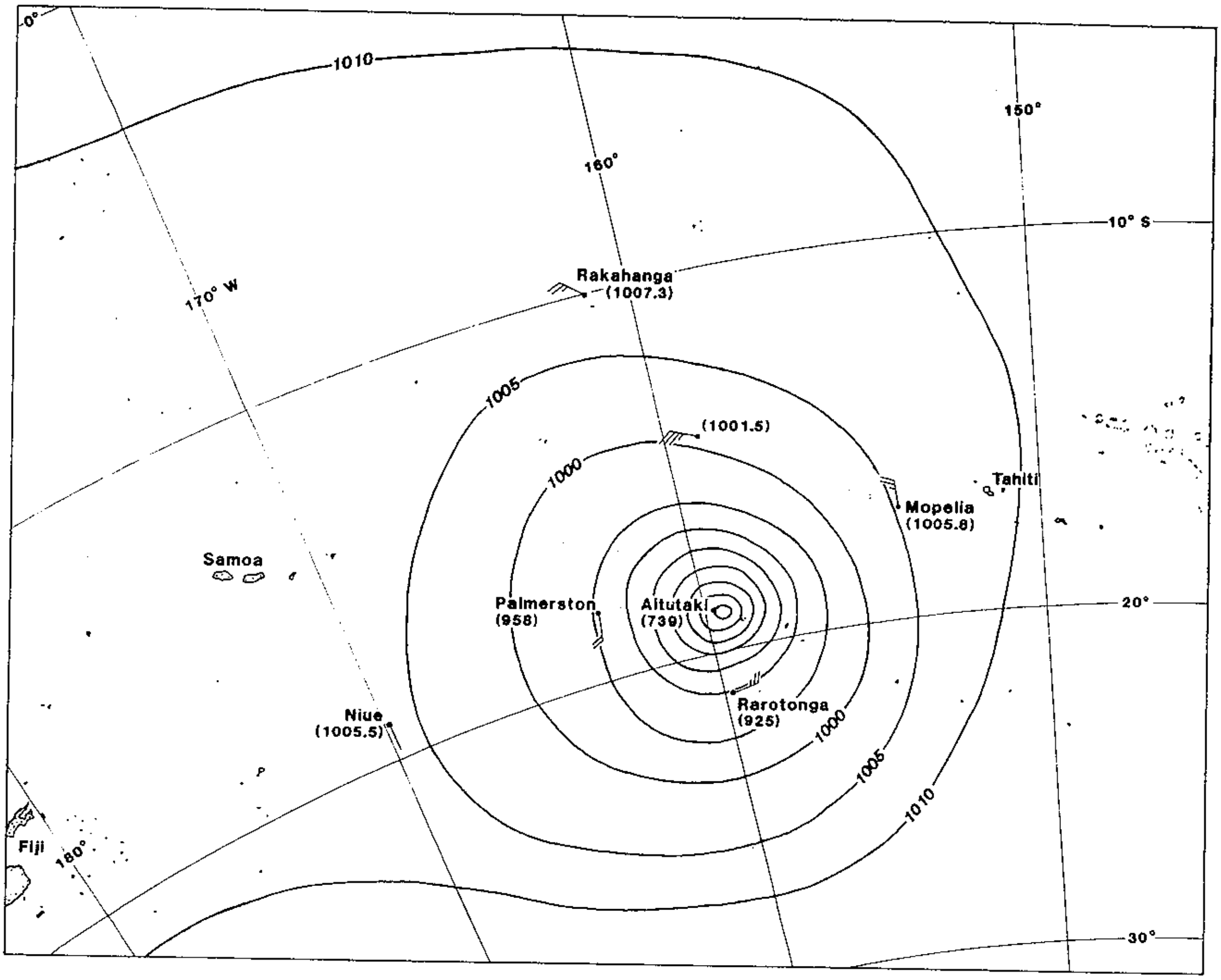

Fig. 9. Sea-level pressure analysis of tropical cyclone 'Charles' over Aitutaki at 1800 UT on 26 February 1978

While 'Charles' remained slow-moving near Palmerston Atoll from 22 to 25 February, it continued to deepen; sustained winds at Palmerston of over 55 knots were estimated. At its closest point to the atoll, only some 55 km distant at 1200 UT on 23 February, the atoll's sea-level pressure was 982 hPa* and winds of 65 knots from the south-south-east were observed. Twenty hours later 'Charles' lay 100 km to the north-east. The wind and pressure on Palmerston at this time were 70 knots and 984 hPa. The lowest central pressure of tropical cyclone 'Charles' was estimated from the empirical relation of Atkinson and Holliday (1975) as being about 960 hPa.

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* One hectopascal (hPa) is equivalent to one millibar (mb).

On 25 February the cyclone began to accelerate and lose intensity. It passed almost directly over Aitutaki (Fig. 9) at 1800 UT on the 25th. The lowest pressure recorded at Aitutaki was 965.4 hPa, giving an estimated maximum wind speed of about 65-70 knots. A list of sea-level pressures is presented in Table 4.

Table 4. Sea level pressures (hPa) Southern Cook Islands 21-27 February 1978 at 0000 UT

Date	Palmerston	Rarotonga	Mauke	Aitutaki
21	996.2	1003.5	1000.9	1004.7
22	990.3	1004.4	1001.1	1006.2
23	985.7	1005.9	1002.3	1008.2
24	983.0	1005.8	1002.6	1007.7
25	986.1	1001.4	992.6	1002.2
26	999.6	982.8	985.9	989.1
27	1006.8	1000.9	1004.5	1002.2

While 'Charles' remained slow-moving near Palmerston Atoll, huge seas were generated. Some damage to the wharf at Rarotonga was reported. Apart from flooding caused by heavy rainfall, most islands reported that damage was confined to the destruction of some banana plantations and wind-thrown coconut trees.

4. EXTRA-TROPICAL INFLUENCES ON TROPICAL WEATHER

In any season, cold fronts from the mid-latitudes move into the trade-wind region of the tropics. When cold fronts enter the trades they usually become slow-moving, lying across the region in a general west-north-west to east-south-east direction (Hutchings, 1961). Cold fronts may become quasi-stationary for several days, or even move southwards again as warm fronts, especially if a marked upper-air trough is approaching from the west. Most frontal systems eventually merge with the SPCZ. The weather associated with cold or quasi-stationary fronts of the tropical regions is normally a broad band of squally showers or rain.

During the dry season when a relatively low-latitude jet stream is strong, mid-latitude disturbances are accompanied by extensive cloud sheets and rainfall (Hill, 1963). The extensive altostratus cloud sheet, and a widespread rainfall, forms downstream of the upper-level trough of low pressure in the region of ascending motion associated with the equatorward entrance of the jet stream. Figure 10 presents two examples of an extensive cloud sheet in the region of the Southern Cook Islands for 30 and 31 July 1983.

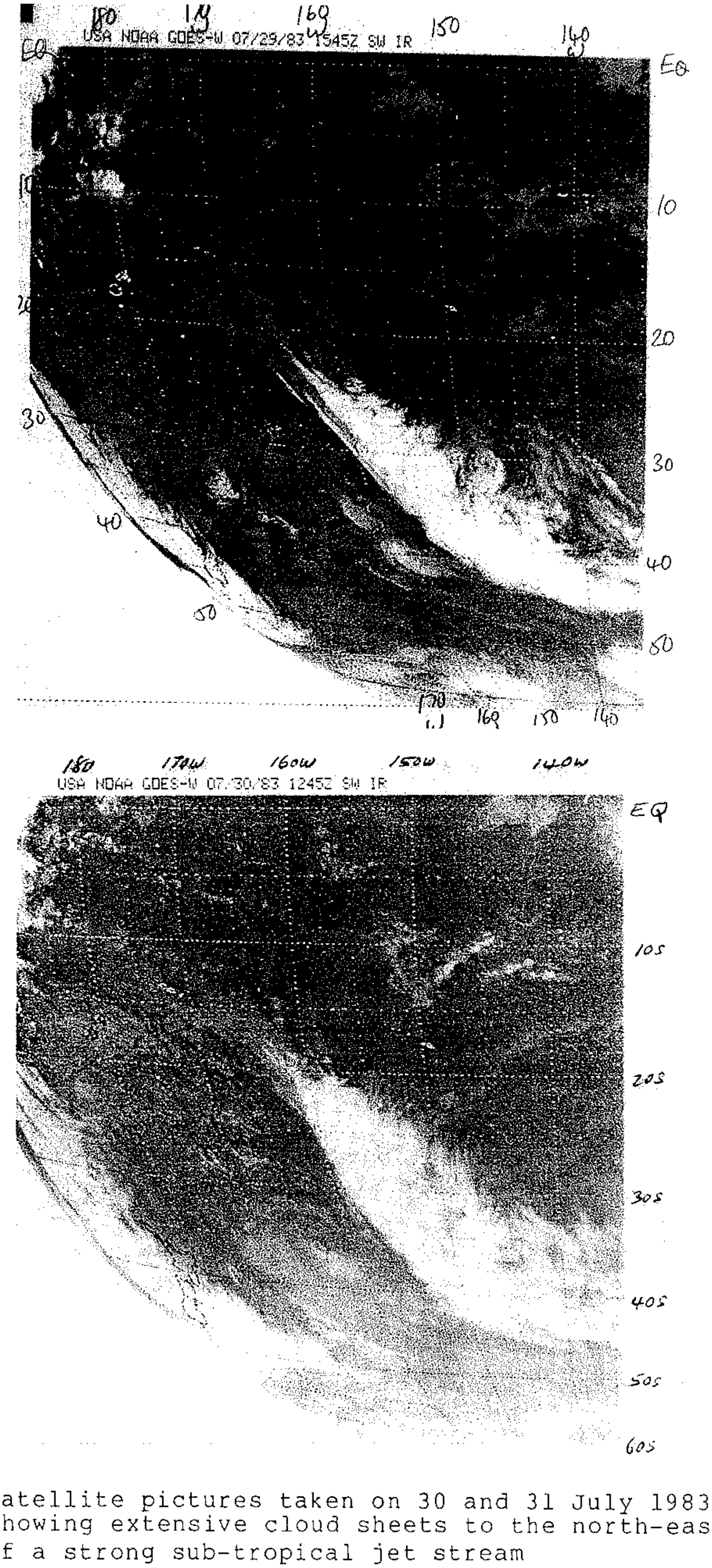

Fig. 10. Satellite pictures taken on 30 and 31 July 1983 showing extensive cloud sheets to the north-east of a strong sub-tropical jet stream

5. CLIMATIC ELEMENTS

Wind

As the Southern Cook Islands lie in the South Pacific trade-wind zone, just to the north of the sub-tropical ridge of high pressure, winds from the easterly quadrant blow for over 50 percent of the time (Fig. 11). The most frequent directions, depending on the time of the year, are between 80 and 140°. Directions are constant during spring when up to 65 percent of all winds blow from the easterly quarter. It is during this time that the SPCZ tends to lie furthest to the north of the group resulting in a high seasonal frequency of dry south-east winds. Lowest directional constancy is during summer when the islands are affected not only by the SPCZ over the group, but also by occasional tropical cyclones and extra-tropical fronts.

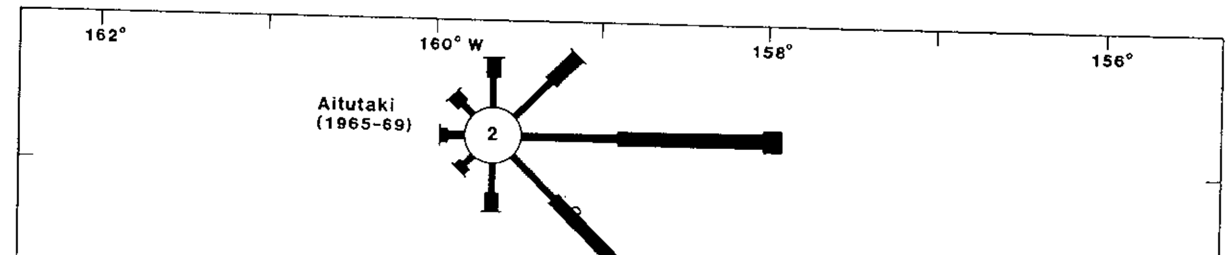

Fig. 11. Mean annual wind roses for Southern Cooks

Wind constancy values are given in Table 5. Constancy is defined as being the percentage of observations in which the wind direction is within 40 degrees of the most frequent direction. Table 6 presents the seasonal wind patterns for the Southern Cooks.

Table 5. Monthly values of wind constancy percent for the Southern Cook Islands

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Aitutaki	49	62	49	39	60	54	53	57	63	69	63	58
Mauke	39	37	49	35	35	45	39	48	50	62	53	46
Rarotonga Air	54	55	47	43	48	43	41	50	58	60	60	61

Mean monthly wind speeds for the Southern Cook Islands are shown in Table 7. Wind speeds during the dry season tend to be about 10 percent stronger than in the wet season. For some locations (marked by an asterisk), monthly wind speeds were estimated by comparisons of wind run cup counter anemometers between that location and at Rarotonga Airport. Preliminary analyses show that on Mauke, the wind run is about 0.79 that of Rarotonga Airport. At Matavera, the coastal site wind run was about 1.08 times that at Rarotonga, while the hill site wind run was 1.3 times as much. The low mean speeds at Totokoitu result from the site being extremely sheltered.

On Mangaia, it was found that the daily wind run at Oneroa was 0.63 times that of Rarotonga Airport. Tamarua and Ivirua recorded on average 2.48 times and 1.34 times as much wind respectively as did Oneroa.

The diurnal variation of wind speed is given in Fig. 12. It is apparent there is a maximum wind speed about the middle of the day when temperatures are highest and atmospheric stability least. There is a small diurnal variation at Aitutaki, but the marked variation at Rarotonga Airport, Mauke, and to a lesser extent the coastal location at Matavera results largely from a nocturnal reduction in speed relative to that over the open ocean (see Aitutaki trace).

There is no apparent diurnal variation in the wind direction at Aitutaki or Mauke, although the frequency of light winds increases at night-time. Since Rarotonga is a sizeable island, diurnal wind direction changes result from local land- and sea-breeze effects. Sea-breeze circulations are enhanced due to convective activity over the highlands (Flohn, 1970).

Table 6. Seasonal wind frequencies - Southern Cook Islands
(Frequencies per thousand observations.)
(Note: A zero indicates occurrences   0.5.)

(a) Rarotonga 1970-1978.

	Spring							Summer						
Speed:	1-3	4-10	11-16	17-21	22-27	28+	Total	1-3	4-10	11-16	17-21	22-27	28+	Total
Dir														
N	2	28	13	2	0	0	46	2	33	22	9	3	1	70
NE	6	63	27	3	0		99	7	93	33	8	2	0	143
E	9	155	178	63	14	1	421	20	216	148	26	5	2	417
SE	8	93	69	19	5	1	194	6	58	40	7	2	1	113
S	3	36	15	2	0	0	56	2	20	7	1	0	0	30
SW	1	20	11	1	0		33	1	12	7	0	1	0	22
W	1	9	5	1	0	0	16	1	14	7	2	1	0	25
NW	1	13	13	3	1		31	1	18	16	5	2	0	42
Calm							105							138
Total	32	416	331	94	21	2		41	463	281	57	14	5	

	Autumn							Winter						
Speed:	1-3	4-10	11-16	17-21	22-27	28+	Total	1-3	4-10	11-16	17-21	22-27	28+	Total
N	4	37	21	7	2	0	71	3	30	18	2	0		53
NE	7	73	24	2	1	0	107	5	45	27	3	1		80
E	17	184	91	17	4	1	314	11	123	121	38	9	1	302
SE	11	85	39	9	3	1	148	8	105	63	15	4	1	197
S	5	36	10	2	0	0	54	6	67	27	3	1	0	104
SW	1	23	9	1	0		34	3	30	21	4	2	0	60
W	2	20	13	2	1		38	2	18	12	4	2	1	38
NW	1	22	21	7	2	0	54	2	22	13	1	1	0	39
Calm							180							126
Total	48	480	229	47	14	2		39	439	301	71	20	3	

(b) Aitutaki 1965–1969.

Spring

Speed:	1–3	4–10	11–16	17–21	22–27	28+	Total
Dir							
N	2	29	14	1			46
NE	1	57	33	2	0		94
E	4	136	194	45	6	4	389
SE	1	100	172	51	12	0	337
S	3	39	13	4			60
SW	0	18	3	0			22
W	1	9	3	1			14
NW	0	15	4	1			20
Calm							19
Total	13	403	437	106	18	5	

Summer

Speed:	1–3	4–10	11–16	17–21	22–27	28+	Total
Dir							
N	2	46	18	3	1	2	71
NE	6	96	48	5	2	1	158
E	4	135	224	52	14	1	431
SE	1	72	106	24	7	1	211
S	1	20	12	1		0	34
SW	1	6	1	1		1	10
W	1	14	3	2		2	21
NW	1	20	11	8	2	1	43
Calm							21
Total	16	409	422	96	26	9	

Autumn

Speed:	1–3	4–10	11–16	17–21	22–27	28+	Total
N	4	50	27	4			85
NE	2	72	50	2	1		128
E	3	135	164	27	7	0	336
SE	2	79	105	23	2	0	210
S	0	40	18	2			61
SW	0	24	6		0		30
W	3	30	12	3			47
NW	1	38	21	2			61
Calm							41
Total	15	468	401	63	11	0	

Winter

Speed:	1–3	4–10	11–16	17–21	22–27	28+	Total
N	1	26	23	3	0		54
NE	1	43	55	2			100
E	3	87	212	68	15	2	387
SE	3	65	137	53	17	3	278
S	2	40	44	4	0		90
SW	1	14	13	1			29
W	0	17	6	2			25
NW	1	14	6	2			22
Calm							13
Total	11	306	496	136	33	5	

Table 7. Mean monthly wind speed (knots)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Aitutaki	11	12	11	10	12	12	12	12	12	12	12	12
Mauke synop +	5	5	5	4	4	6	6	7	6	7	5	5
Rarotonga Air	9	8	7	7	8	9	8	9	10	9	9	9
Mauke agromet*	7	6	6	6	7	7	7	8	8	8	8	7
Matavera coast*	10	9	8	8	9	10	10	10	11	11	10	9
Matavera hill*	12	11	10	10	11	12	12	13	13	13	13	11
Totokoitu *	5	4	4	4	4	5	5	5	5	5	5	4
Oneroa *	5	5	5	5	5	6	5	6	6	6	6	6
Tamarua *	14	13	12	12	12	13	14	13	15	15	15	14
Ivirua *	7	7	6	6	7	8	7	8	8	8	8	8

\+ Visual estimates

* Wind run cup counters.

Inset 4

Seasonal relative wind frequencies from Rarotonga Airport (Table 8) show the sea-breeze component of the wind to have a direction from about 50°-70°. During the daytime in summer and autumn, there is a marked increase in the relative frequencies of east-north-east winds from a night-time minimum. The corresponding night-time land-breeze wind tends to blow from the south-east. It is pertinent to note that other locations on the northern side of Rarotonga may not have the same sea-breeze direction as at the airport, but it is most likely to blow from a north-easterly direction.

Table 8. Seasonal relative frequencies (per thousand) of specified wind directions at Rarotonga Airport, 1970-1979

Direction class	Summer N	Summer M	Summer A	Summer E	Autumn N	Autumn M	Autumn A	Autumn E	Winter N	Winter M	Winter A	Winter E	Spring N	Spring M	Spring A	Spring E
050-070	6	17	20	7	5	10	12	4	5	7	8	3	5	10	11	4
080-100	32	32	30	33	21	26	23	22	20	22	24	21	27	33	34	31
110-130	14	12	12	15	16	14	14	17	17	15	14	19	24	19	17	24

N night midnight - 5am
M morning 6am - 11am
A afternoon noon - 5pm
E evening 6pm - 11pm

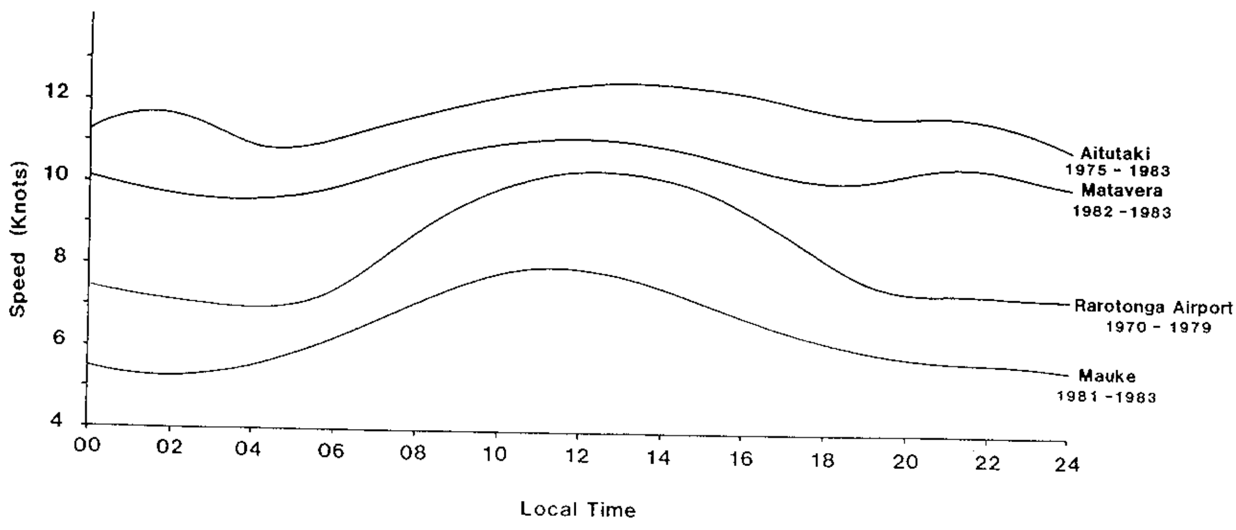

Fig. 12. Mean diurnal variation of surface wind speed for Southern Cook Islands

Table 9. Wind persistence at Rarotonga Airport
Relative frequencies (per 10000)

Period of Persistence (hours) Direction	01-05	06-10	11-15	16-20	21-50	50	Calm
0-15 knots							
350-010	151	89	30	13	21		
020-040	224	139	61	32	9		
050-070	362	228	109	45	20		
080-100	681	501	380	246	407	69	
110-130	623	364	195	111	62	7	
140-160	340	132	51	29	6		
170-190	222	90	28	15	18		
200-220	154	58	23	11	3		
230-250	103	43	12	7	9		
260-280	100	32	17	7			
290-310	103	43	15	3	12		
320-340	131	46	15	12	21		
all dir.	229	232	227	266	875	1309	5751
16-25 knots							
350-010	29	9	13				
020-040	25	7		2	3		
050-070	37	15	2				
080-100	165	113	49	35	68	19	
110-130	144	64	22	9	16		
140-160	40	8					
170-190	16	2	2				
200-220	11	1					
230-250	15	5	9		3		
260-280	19	7					
290-310	23	8	3				
320-340	27	12	7	6			
all dir.	393	232	173	94	141	33	
26+ knots.							
350-010	3	1					
020-040	1						
050-070	1						
080-100	7	4	3				
110-130	7	4					
140-160	3	1					
170-190	1						
200-220		1					
230-250	2						
260-280	1						
290-310	2						
320-340	3						
all dir.	26	8	3	3	6		

On the southern side of Rarotonga Island, it is expected that the sea-breeze component is generally south-easterly, and the land-breeze north-easterly.

Trade winds are a persistent feature of the general circulation. The persistence of winds at Rarotonga Airport for various speed and direction categories are given in Table 9. Light to moderate (80 -100 with speeds to 15 knots) may last up to 50 hours on about 15 occasions each year. High winds are not persistent. Most high winds last no more than 5 hours from any fixed direction. Winds over 34 knots are rare. At Rarotonga they occur for 0.04 percent of the time. Many of the measurements have been made in summer and autumn.

Wind gusts over 33 knots at Rarotonga Airport are evenly distributed throughout the year, being recorded on about 25 days. Gusts over 51 knots are measured about once every year, mostly in summer or autumn. A gust of 78 knots can be expected on average once every 25 years. The corresponding value for 50 years is 83 knots. These events are associated with tropical cyclones.

Table 10. 900 hPa wind frequencies and wind constancy at Rarotonga Airport, 1959-1983

Direction Class	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
North-easterly (005 - 094)	45	46	39	36	32	32	30	34	36	37	34	38
South-easterly (094 - 184)	31	30	32	29	32	38	30	32	34	42	44	37
South-westerly (185 - 274)	7	6	7	12	16	17	23	17	14	11	9	10
North-westerly (275 -004)	18	18	22	22	17	13	17	17	16	12	14	15
Constancy of easterly	58	60	58	44	47	48	39	48	52	60	61	62

The wind flow at the 900 hPa level (a height of approximately 900 m) is usually free of the influence of surface friction, the daily surface heating and cooling cycle and most effects of island topography. Monthly frequencies of the 900 hPa trade winds at Rarotonga and their constancy are given in Table 10. A high frequency of 'easterlies' (5°-184°) can be seen to reach a maximum in October and November. There is a minimum during July when the SPCZ lies to the north of the island group, corresponding to the time when westerlies become more prominent. At this time the sub-tropical ridge of high pressure is further north than in the wet season. The Southern Cook Islands therefore come under the influence of the middle latitude westerlies.

Table 11. Serial correlation (x100) of monthly 900 hPa winds

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
North-west	24	1	23	-44	-13	4	27	-15	-7	-7	7	7
North-east	33	-17	11	-5	-35	12	22	-16	61	36	42	48
South-east	9	-0	21	8	-8	-24	16	54	1	19	-21	11
South-west	22	-24	40	39	-7	-8	39	38	19	67	21	-27

Table 12. Contemporary correlations (x100) between 900 hPa winds and Southern Oscillation Index

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
North-west	29	3	10	-8	-13	-5	30	-37	-26	9	13	40
North-east	45	49	53	25	43	76	38	55	76	35	64	64
South-east	-57	-34	-52	-14	14	1	-7	7	-14	-2	-60	-50
South-west	-31	-32	24	23	-24	-62	-56	-51	-61	-19	1	-73

Serial correlation for each of the four direction classes reveals little persistence from one month to the next (Table 11). While the SOI is persistent, autocorrelation of the SOI and 900 hPa wind class frequencies reveals that the derived pattern (Fig. 13) is dominated by the persistence in the SOI, and is a similar pattern to when the SOI is autocorrelated with itself (Gordon, 1984 pers. comm). Contemporary correlations between wind direction classes at Rarotonga and the SOI are given in Table 12. Absolute values over 0.4 are significant at the 5 percent level. This table indicates that increased frequencies of north-easterlies are associated with positive values of the SOI, i.e. the SPCZ is south of its mean position. South-easterly winds for the most part are negatively correlated with the SOI, as are south-westerlies.

The 900 hPa trade-wind flow over the tropical Pacific Ocean has been found to have about 1.3 times the speed of the surface wind (Atkinson and Sadler, 1970), and differs in direction by about 10 degrees. From 900 hPa wind frequencies, Reid (1982) derived open-ocean wind roses for several South Pacific Islands. The open-ocean wind rose is presented in Table 13 for the Southern Cook Islands.

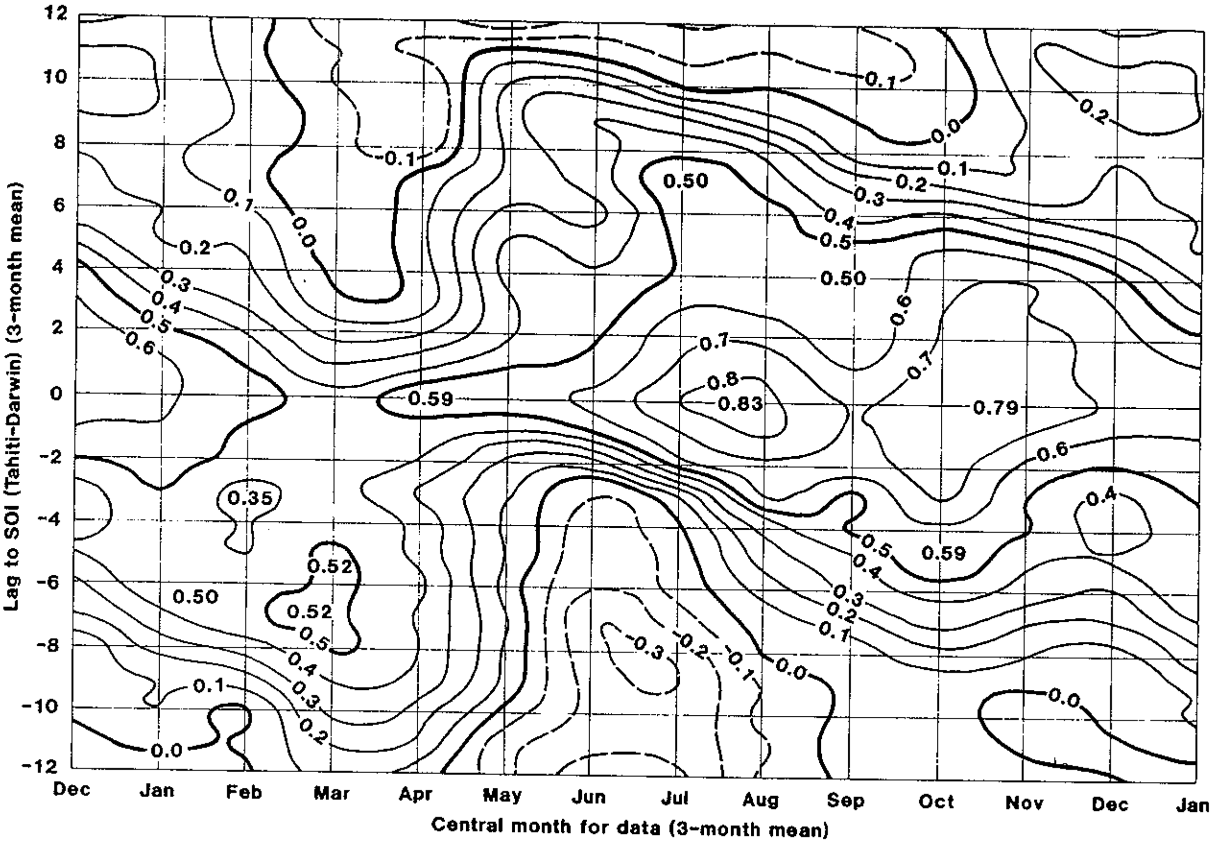

Fig. 13. Cross-correlation diagram of Southern Oscillation Index with the frequency of 900 hPa north-easterly winds at Rarotonga Airport

Wind power. Wind is a perpetual resource. As a resource, whether it be for generating electricity or for pumping water, the wind is the result of interactions between the large-scale synoptic weather patterns and the orographic characteristics of the site. Knowing the prevailing direction and average speed of the wind is important in considering the potential of locations as wind energy sources. It is also important to know what fraction of the time the wind blows in particular speed ranges.

One approach in assessing a location's potential is by the aid of a velocity-duration curve (Fig. 14). Starting with the highest speeds, a velocity-duration curve accumulates the number of hours in a year that the wind blows in excess of a certain speed. Figure 14 shows that at Rarotonga wind speeds between 6 and 30 knots occur for about 6465 hours each year. At Aitutaki the value is 7610 hours and at the Mauke synoptic site 3910 hours. Wind observations at Mauke are visually estimated. They tend to be underestimated since the observing site is on the western side of the island, and is rather sheltered.

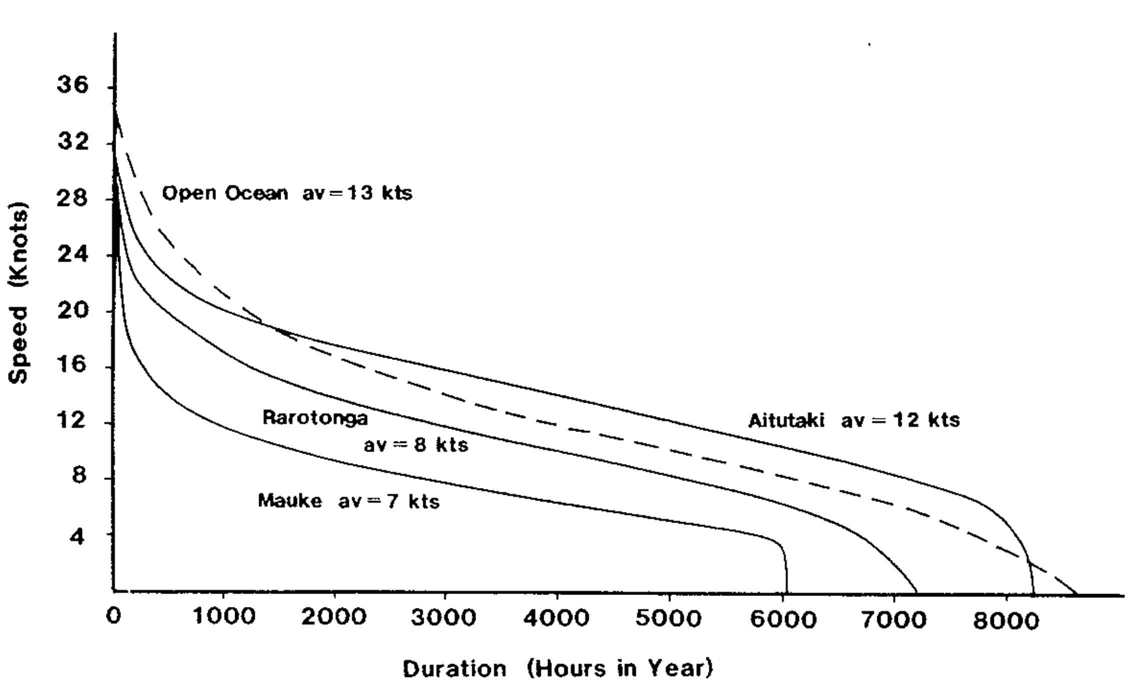

Fig. 14. Velocity-duration curves for Southern Cooks

From wind observations at any location, the 'standard' wind speed, c, is that speed that is exceeded 36.8 percent of the time. Swift-Hook (1979) has shown that the mean (V_m) and standard wind speeds are closely connected by the following relation:

$$c = 1.11\ V_m$$

Wind power is proportional to the cube of the velocity (Swift-Hook, 1979). The total cumulative wind power available (at a speed of 1 knot) in one hour for a blade cross-sectional area of one square metre is 8.82×10^{-5}kWh. An idea of the amount of wind energy available each year is given in Table 13,

Table 13. Wind power in Southern Cook Islands*

Location	V	°C	Total time between 6 and 30 knots Obs.	Est.	Wind Power kWh/m² Obs.	Est.
Aitutaki	11.8	13.1	7610	7131	2165	2273
Mauke Sy	5.3	5.9	3905	3638	370	205
Rarotonga	8.9	9.9	6465	6234	1120	1027
Mauke WR	7.0	7.7		5139		490
Matavera C	9.6	10.6		6259		1293
Matavera H	11.6	12.8		7076		2137
Totokoitu	4.5	5.0		2630		110
Oneroa	5.5	6.1		3837		230
Tamarua	13.6	15.0		7316		2991
Ivirua	7.4	8.2		5454		596
Ocean	13.0	14.6		7292		2844

* Wind power estimates made assuming a Weibull distribution of wind speeds with a shape factor of 1.87.

which compares observed with estimated data. The total energy between 6 and 30 knots per square metre of blade area (derived from Fig. 14) at Rarotonga Airport, Aitutaki and Mauke are 1120 kWh, 2165 kWh, 370 kWh respectively. Aitutaki has nearly six times as much power available from the wind as does the sheltered Mauke synoptic site, while Rarotonga Airport can extract three times as much.

Table 14. Open-ocean surface wind frequencies (percent)

Direction	Speed Categories (knots) 0 - 9	10-14	15-19	20-24	25+
N	2	2			
NE	3	7	5	2	
E	5	13	11	6	5
SE	9	9	4	3	
S	5	2			
SW	1	1	2		
W	1	2			
NW	1				

From open-ocean wind estimates (Table 14), the total time the wind is between 6 and 30 knots is 7292 hours, giving a wind energy potential of 2844 kWh per square metre. Ideal sites in the Southern Cooks for maximising the extraction of power available from the wind are on exposed hilltop sites on Rarotonga, Mauke and Mangaia, or on the eastern and south-eastern sides of the islands.

Rainfall

Precipitation in the tropics consists almost entirely of rainfall, hail being rare. Rainfall is highly variable in the tropics showing large inter-seasonal and inter-annual variation as well as considerable spatial variability. Rainfall is

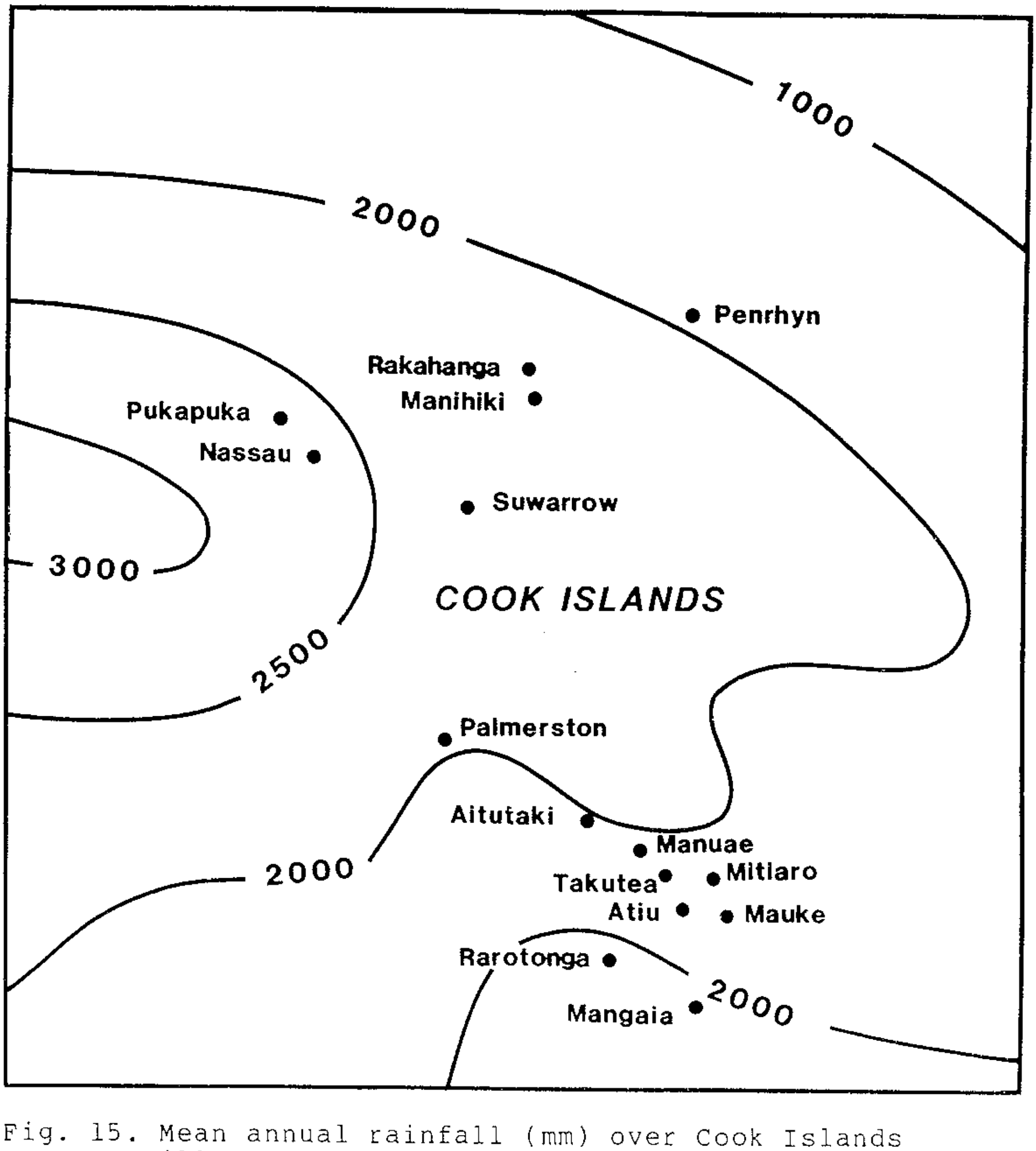

Fig. 15. Mean annual rainfall (mm) over Cook Islands (1951-80)

probably the most important climatic factor influencing agricultural practices in the tropics. Lack of rain can cause serious drought leading to crop failure or reduced yields, while intense heavy rains result in high runoffs and soil erosion. Much of the tropical rain results from convection which is manifested by the usual cumulus and cumulonimbus clouds. Tropical clouds frequently produce large amounts of rainfall in short periods, because airmasses are warmer and more humid than in the mid-latitudes.

Annual, seasonal and monthly rainfalls. The spatial distribution of annual rainfall over the Cook Islands is given in Fig. 15. This figure shows for the Southern Cook Islands a fairly uniform distribution with a long-term average of between 1900-2050 mm per year, although Mauke lies on the western margin of a drier zone which extends eastwards towards French Polynesia and the subtropical high pressure belt (Hessell, 1981).

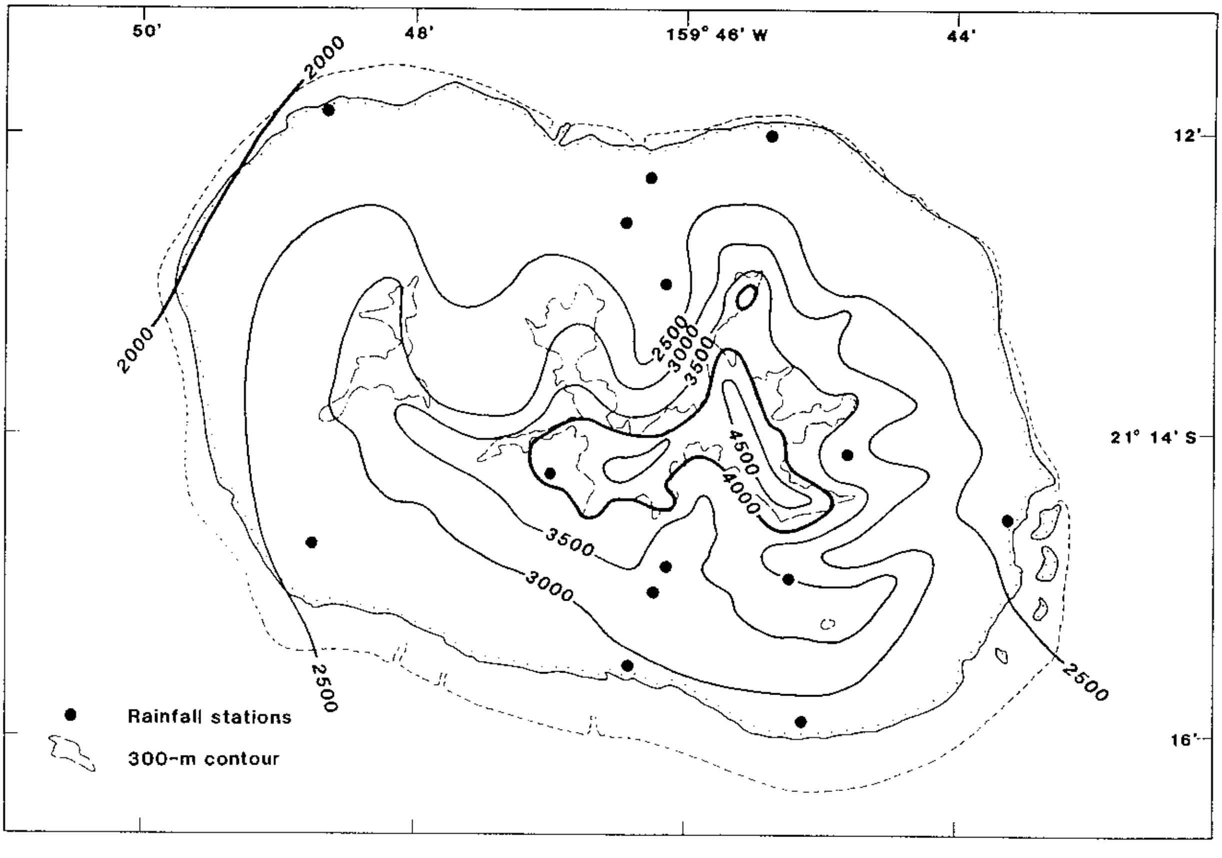

Fig. 16. Distribution of mean annual rainfall (mm) on Rarotonga (1951-80)

The distribution of rainfall on Rarotonga Island (Fig. 16) for a standard 30-year period (1951-1980) shows the effects of elevation and exposure to the south-east trade winds. Most of the computed normals have been based on short records, but it does appear that Papua receives about twice the amount of rainfall as does Rarotonga Airport. The rugged interior around the peaks of Te Manga, Te Atukura and Te Kou receive an estimated 4500 mm per year, while the driest area of Rarotonga is on the north-western side of the island near the international airport.

In the Southern Cook Islands, there is a marked seasonality in the rainfall regime, a dry season (May to October) and a wet season (November to April). The seasonal distribution of rainfall is associated with the seasonal movement of the SPCZ in that the largest amounts on average are in the summer months. Table 15 gives wet and dry season rainfall statistics for the Southern Cooks. About two-thirds of the total rain falls during the wet season.

Table 15. Seasonal distribution of rain

Location	Season (mm) Wet	Season (mm) Dry	percentage of annual total Wet Season	percentage of annual total Dry Season
Palmerston	1337	638	68	32
Aitutaki	1263	617	67	33
Mitiaro	1185	641	65	35
Atiu	1336	634	68	32
Mauke	1030	578	64	36
Rarotonga	1292	729	64	36
Turoa	1706	1094	61	39
Raro. Obs.	1446	835	63	37
Aroa	1662	921	64	36
Mangaia	1230	737	63	37

Month-by-month variation of rainfall is shown in Table 16, and Fig. 17. The 10 and 90 percentile values (Fig. 17) together with the maximum and minimum values indicate the large variability in the rainfalls over the islands. At Aitutaki, for example, 90 percent of all Januaries will have a value less than 393 mm, while only 10 percent of the time will the value be less than 78 mm. Eighty percent of all Januaries will have a rainfall between 393 and 78 mm.

Actual monthly and seasonal rainfalls vary greatly from year to year. This can be seen from the coefficient of variation statistic in Table 16. The greater the coefficient the larger the interannual variability. Dry season rainfall tends to be more variable, and hence less reliable, than does the wet season rainfall.

Inset 5*

Table 16. Monthly rainfall data - Southern Cook Islands. Mean monthly rainfall (mm), highest and lowest recorded, and coefficient of rainfall variation (CV).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
(a) Palmerston Atoll 1958-1982.													
Monthly	251	237	227	200	183	72	65	102	111	105	165	257	1957
Highest	576	563	520	410	614	211	227	227	549	414	359	612	2992
Lowest	18	50	49	75	3	11	8	18	5	12	33	31	1200
CV	60	60	60	50	81	75	72	72	119	90	55	65	23
(b) Aitutaki 1930-1982.													
Monthly	221	244	212	178	164	86	82	84	85	116	174	234	1880
Highest	715	649	521	513	495	268	383	288	259	492	645	789	3093
Lowest	20	22	27	17	2	5	7	10	1	8	18	4	731
CV	60	48	56	63	70	77	80	85	72	81	71	66	25
(c) Mitiaro 1958-1982.													
Monthly	273	204	196	183	138	130	83	88	115	89	149	180	1828
Highest	554	403	473	495	550	931	201	288	303	201	280	418	2770
Lowest	72	46	0	21	6	3	7	14	19	10	19	9	1079
CV	50	58	69	72	103	165	70	88	73	60	61	68	28
(d) Atiu 1958-1982.													
Monthly	209	229	223	206	177	84	81	101	81	110	162	307	1970
Highest	490	732	525	396	752	210	227	488	251	471	479	621	3746
Lowest	5	49	65	7	0	9	0	0	0	0	33	0	690
CV	51	70	48	59	97	63	74	114	93	124	77	69	42
(e) Rarotonga Airport 1930-1982.													
Monthly	249	224	267	185	169	106	97	128	106	123	142	225	2021
Highest	668	509	667	447	693	268	298	475	268	318	381	653	3021
Lowest	24	42	71	30	29	13	12	13	13	16	9	11	1116
CV	60	49	50	57	67	57	64	77	54	63	63	68	20
(f) Turoa 1958-1970.													
Monthly	296	240	366	296	291	128	164	184	194	133	235	273	2800
Highest	540	371	655	618	781	220	300	487	303	292	761	596	4155
Lowest	52	120	108	108	133	35	33	40	77	30	89	31	2174
CV	58	39	51	52	63	55	53	83	45	64	80	68	26
(g) Aroa 1969-1982.													
Monthly	357	271	290	244	217	139	106	195	131	133	210	290	2583
Highest	1099	630	457	376	540	303	250	555	362	337	412	686	3924
Lowest	95	127	81	131	18	20	25	81	39	10	20	6	1188
CV	71	48	48	28	71	61	57	74	68	83	65	81	31
(h) Mangaia 1914-1984.													
Monthly	251	230	224	184	150	119	116	119	109	127	147	191	1967
Highest	721	561	665	498	539	388	339	501	250	481	424	526	2983
Lowest	23	12	23	18	18	5	22	9	16	19	11	24	1024
CV	60	53	63	60	73	72	66	78	57	76	65	64	25

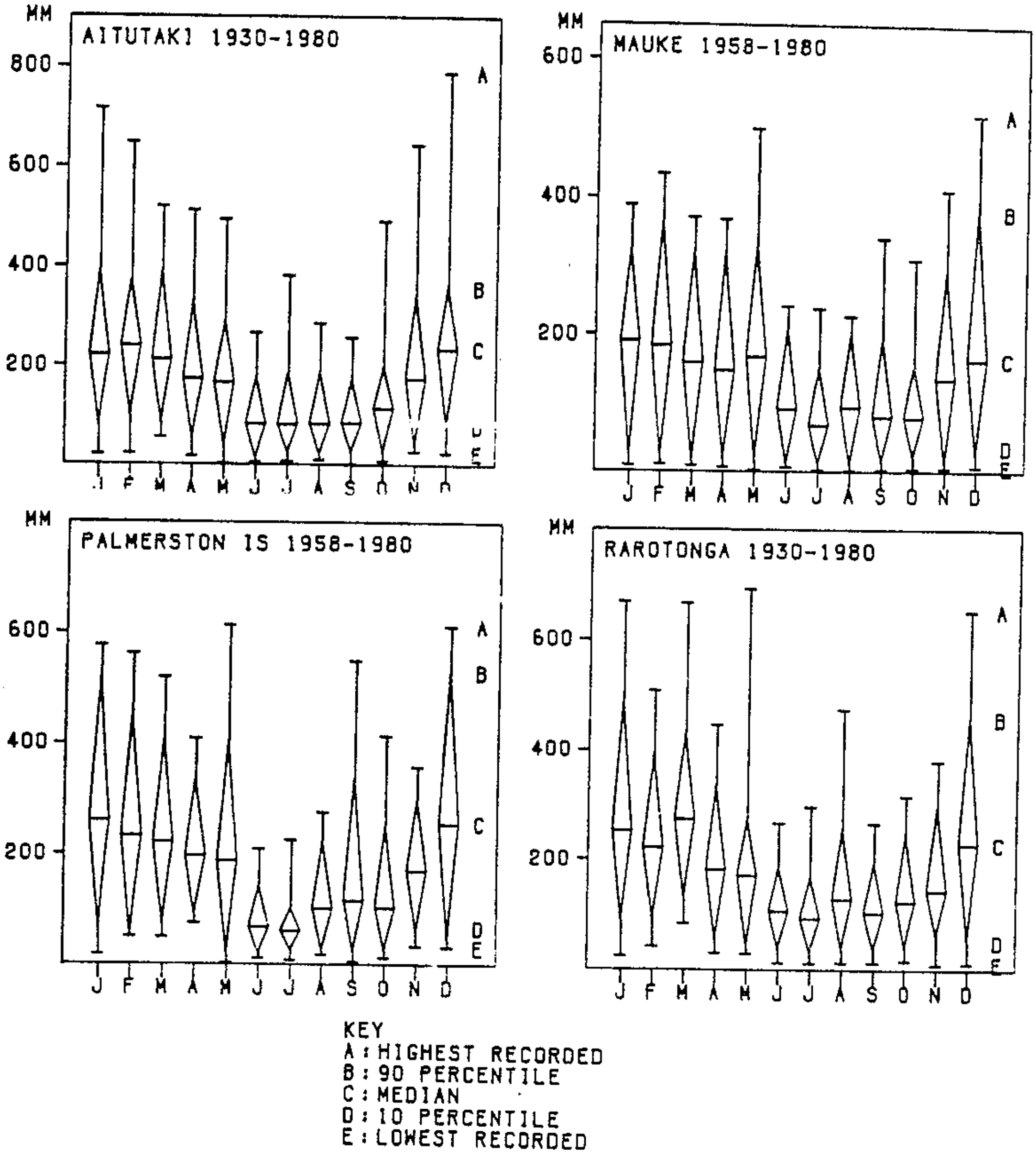

Fig. 17. Monthly rainfall data Southern Cooks

From the point of view of agriculture and water resources, the probability of receiving a certain amount of rainfall every year is of vital concern. It is therefore of interest to know the likelihood of receiving a certain amount of rainfall in at least four out of five years. A binomial frequency distribution has been used to compute the likelihood for threshold values of 1500 and 2000mm. The results are given in Table 17. The probability of receiving less than the threshold values in two successive years is also presented.

Table 17. Rainfall probability - Southern Cook Islands

Location	Percent probability of receiving: at least 1500mm per year	at least 1500mm in 4 yrs out of 5	less than 1500mm in 2 successive yrs
Palmerston	76	66	6
Aitutaki	79	72	4
Mauke	85	83	2
Rarotonga	89	90	1
Mangaia	89	90	1
	Percent probability of receiving: at least 2000mm per year	**at least 2000mm in 4 yrs out of 5**	**less than 2000mm in 2 successive yrs**
Palmerston	43	11	33
Aitutaki	38	7	39
Mauke	31	3	48
Rarotonga	49	18	26
Mangaia	46	14	29

Raindays, rainfall duration, frequency and persistence. The frequency of raindays with at least 1.0 mm of rain is shown in Table 18. Fifty-five to sixty percent of raindays are in the wet season. On Rarotonga most long-term raingauges have been sited along the coastal plains. Totokoitu, on the southern side, has more raindays during the dry season than Rarotonga Airport due to the broad-scale wind flow being more south-easterly, leading to increased cloudiness caused by the orography.

The highland regions of Rarotonga and Mangaia can expect more raindays than the coastal regions. On Mangaia the number of raindays in the highlands is likely to be about 140 to 160 and on Rarotonga up to 180.

Falls of rain of at least 10 mm per day, over most of the islands of the Southern Cooks, are experienced on about 45 or 50 days, but at Mitiaro there are only 35 days. Rainfalls exceeding 50 mm per day are relatively rare, occurring on average on 6 to 10 days a year, and mostly during the wet season.

The inter-annual variability of raindays is more marked at Aitutaki and the other lower latitude islands than on Rarotonga

Table 18. Average number of raindays of at least 1 mm

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wet season	Dry season	Year
Palmerston	15	14	14	13	10	8	8	8	6	9	9	13	78	49	127
Aitutaki	14	15	15	12	11	8	9	8	8	9	11	13	80	53	133
Mitiaro	10	9	7	7	5	5	5	5	6	5	8	5	46	31	77
Atiu	7	9	9	9	6	5	4	3	4	5	6	7	47	27	74
Mauke	10	11	11	11	10	7	6	7	6	8	8	8	59	44	103
Rarotonga	15	15	16	14	12	9	9	10	10	10	11	14	85	60	145
Aroa	13	12	15	12	11	9	8	11	10	8	11	13	76	57	133
Totokoitu	14	14	16	15	14	12	11	11	11	10	11	12	82	58	140
Mangaia	13	12	11	13	11	8	9	7	8	8	9	9	67	51	118

or Mangaia. During the winter, long dry periods are likely, but in summer rainy periods are common especially when disturbances are developing (Revell, 1981). At Aitutaki, the number of raindays of at least 0.1 mm has varied from 105 days in 1946 to 231 days in 1973. At Rarotonga there were 162 raindays in 1949 and 228 days in 1967.

Riehl (1954) noted that the minimum amount of daily rainfall that was required to sustain plant growth was about 2.5 mm. Although Riehl's comment was general, such conditions in the Southern Cook Islands represent 55 to 65 percent of the annual number of raindays.

Table 19. Persistence of rainfall at Rarotonga (i.e. Percent of n-Days with various amounts of rain)

n-Days / Amount	1	5	10	15	20	30
Nil	47	7	1	0	0	0
0.1 - 5mm	33	29	11	4	1	0
5.1 -10mm	7	13	10	5	3	0
10.1-20mm	6	14	15	9	7	2
20.1-30mm	3	9	11	9	7	3
30.1-50mm	2	10	15	15	14	9
50.1-100mm	2	12	21	25	26	22
over 100mm	0	6	17	30	43	64

The average annual duration of rainfall at Rarotonga Airport is 470 hours per year, or about 5.3 percent of the total time. The average monthly durations during the wet and dry seasons are about 41 hours and 37 hours respectively.

The persistence of rainfall over various consecutive days is useful in estimating the 'drought' risk. Such an analysis is presented for Rarotonga Airport in Table 19. For example 47 percent of all days have no rain. For 15-day periods, the probability of no rainfall is almost nil, but there is a 10 percent chance that a total fall of rain will be between 10 and 20 mm.

Extreme short period rainfalls. Characteristics of individual rainstorms in the tropics, especially their intensity, frequency and duration of occurrence, are important. These factors are often more important than the seasonality and variability of rainfall (Jackson, 1977). Intense tropical rainfall in excess of 25 mm per hour can cause severe soil erosion, since soil infiltration rates are greatly exceeded, and surface runoff results.

High intensity rainfall varies according to duration and reflects the characteristics of the disturbance. For up to one or two hours, thunderstorms produce heaviest falls. For longer durations, rainfall is often produced from larger-scale weather systems such as tropical cyclones and quasi-stationary cloud systems.

An assessment of the frequency of high intensity rainfalls for selected durations has been made by Hessell (1980) as

Table 20. Depth(mm)-duration(hrs)-frequency(per year)

Return Period		2yr	5yr	10yr	20yr	50yr	Mean	CV
Palmerston	24hr	189	343	445	543	669	208	64
1967-1980	48hr	229	389	494	595	726	249	55
	72hr	249	406	509	609	738	268	50
Aitutaki	24hr	131	170	196	221	253	137	29
1931-1980	48hr	167	219	253	286	328	175	30
	72hr	187	247	287	325	374	197	31
Mauke	24hr	112	173	213	251	301	120	45
1967-1980	48hr	140	207	252	295	350	148	40
	72hr	157	246	305	361	434	169	47
Rarotonga	24hr	133	196	237	277	328	143	43
1948-1980	48hr	163	231	275	318	374	173	39
	72hr	185	251	294	336	391	195	34

depth-duration-frequency tables (Table 20). This analysis has been derived from annual maximum rainfalls measured at a fixed time (e.g. 9 a.m.) over one, two and three-day periods. These data have been adjusted to provide 24, 48, and 72-hour rainfall estimates for various return-periods. The return period concept is the average interval of time (years) within which a rainfall of a specified amount will be equalled or exceeded once.

An example of the interpretation of Table 20 follows. At Mauke a fall of 207 mm or more in 48 hours can be expected to recur on average once every 5 years.

Rainfall intensity varies with time (Fig. 18). This figure shows that as the duration increases the intensity decreases. Short duration rainfalls (i.e. less than 24 hours) for specific return-periods can be estimated from this diagram. For example a 6-hour rainfall with a return-period of 5 years can expect 122 mm.

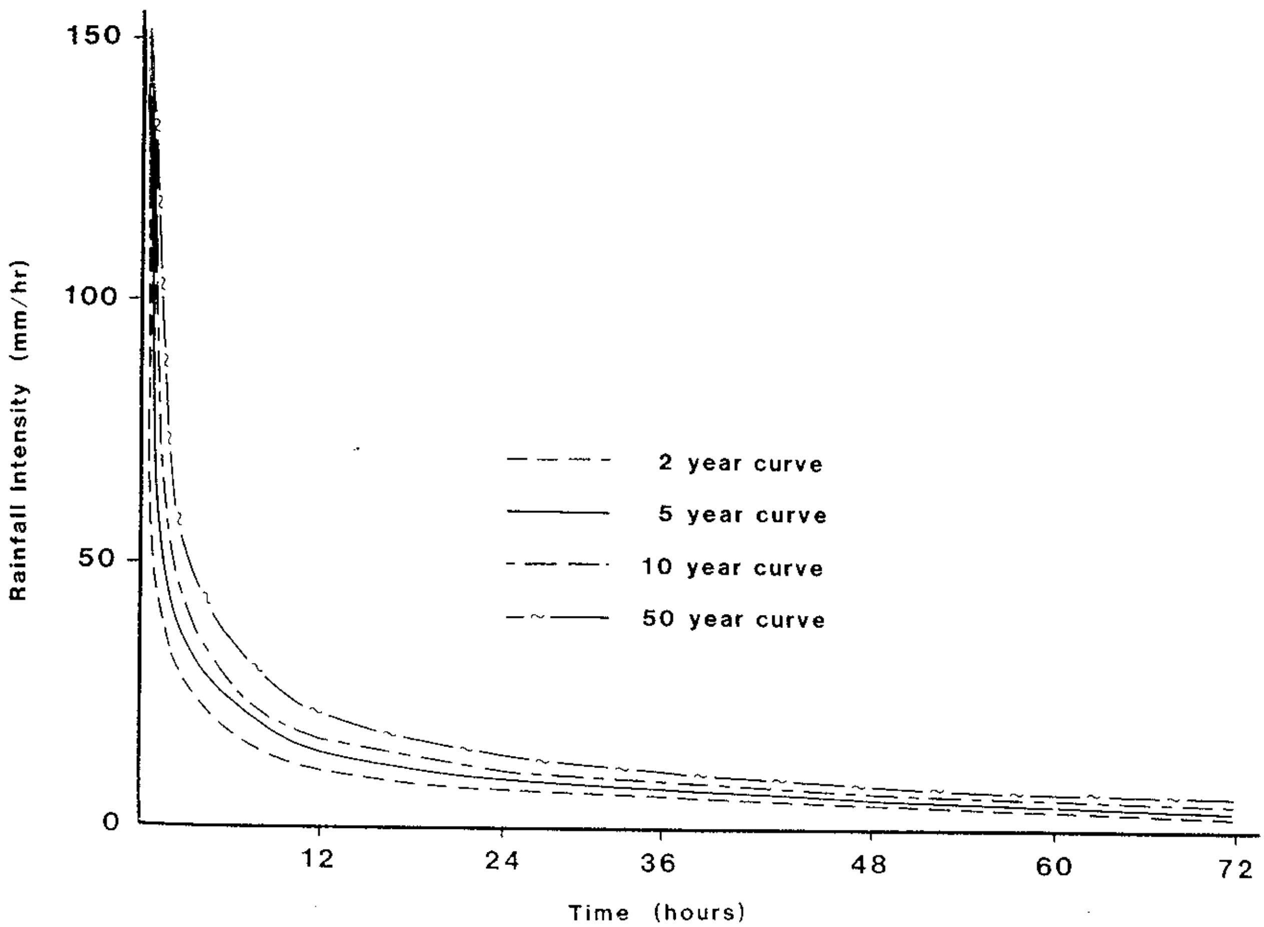

Fig. 18. Rainfall intensity-duration-frequency relationships for Rarotonga (1948-78)

The rainfall amounts are extreme values which may fall at any time of the year, although there is a tendency for the largest amounts to fall during the wet season. Table 21 gives the mean monthly values of the maximum one, two and three-day rainfalls. Like rainfall intensity, the amount of rain which falls on day two and day three is substantially less than the one-day total. Ratios of two-day to one-day rainfall and of three-day to one-day rainfall vary according to the season. In the dry season the two-day rainfall is about 1.2 times the one-day value, and the three-day value is approximately 1.3 times larger than the one-day rainfall. The corresponding wet season ratios are 1.3 and 1.5.

Table 21. Mean maximum 1, 2 and 3-day rainfalls (mm)

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
One-Day												
Palmerston	75	67	61	59	68	35	28	58	93	47	74	78
Aitutaki	61	60	55	58	60	31	37	33	37	45	58	67
Mauke	51	58	36	48	41	44	27	38	41	34	44	39
Rarotonga	69	56	64	53	60	40	38	57	46	38	52	69
Two-Day												
Palmerston	106	84	86	79	83	43	34	71	112	54	93	100
Aitutaki	86	85	73	74	80	38	42	44	46	56	72	89
Mauke	74	82	49	58	54	59	34	44	50	44	65	52
Rarotonga	95	75	83	67	77	57	47	77	54	47	63	90
Three-Day												
Palmerston	124	96	101	96	91	46	37	79	118	56	107	112
Aitutaki	101	103	84	84	90	43	45	48	50	63	82	104
Mauke	86	100	61	65	64	66	36	47	52	48	77	54
Rarotonga	104	91	102	79	84	62	54	81	59	54	70	100

<u>Diurnal variation of rainfall</u>. Hourly observations of rainfall amount are available for Rarotonga Airport. The diurnal variation of rainfall for wet and dry seasons is shown in Fig. 19. Average hourly rainfall amounts have been expressed as a percentage of the 24-hourly total. Figure 19 shows important seasonal differences. Diurnal rainfall variation in the wet season is a mixture of land and ocean effects. There is a prominent rainfall maximum in the middle of the day as a result of enhanced convective processes caused by land heating. There is also a secondary maximum at night, when instability over the oceans is enhanced due to increased radiation cooling from cloud tops (Malkus, 1963; Ruprecht and Gray, 1977). During the dry season, there is a night-time/early

morning maximum and a middle of the day minimum. There is also more rain at night in this season than in the wet season. Fifty-four percent of rain falls between 8 p.m. and 8 a.m. during the dry season, compared with 49 percent in the wet season.

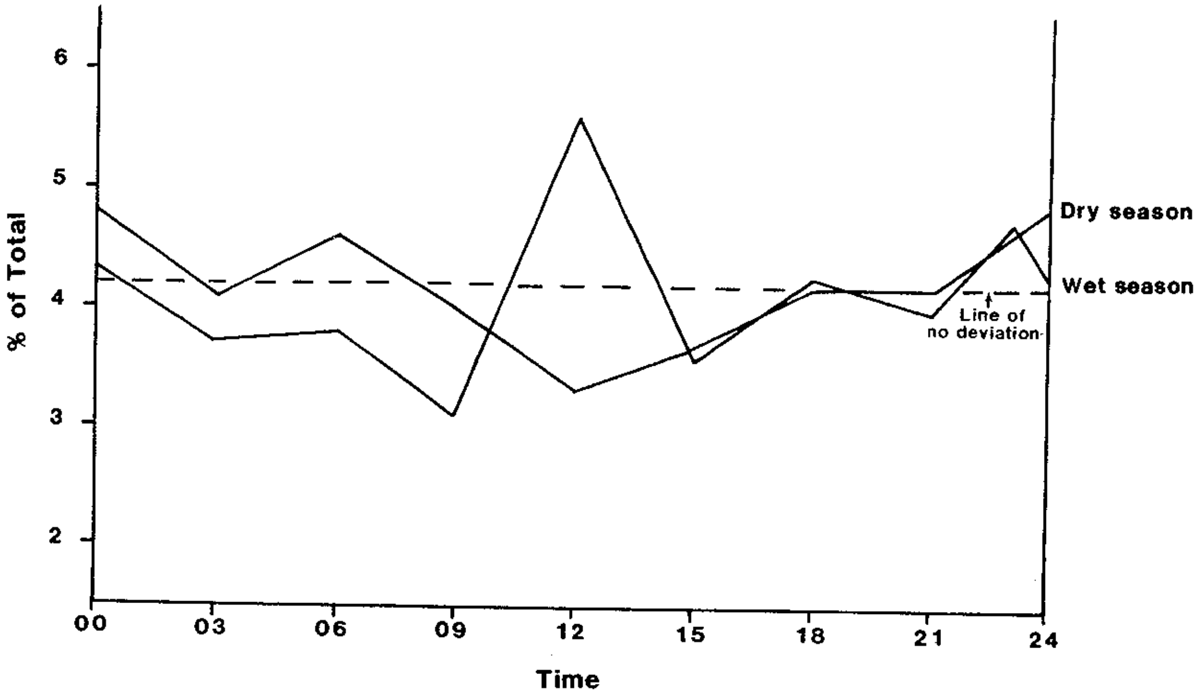

Fig. 19. Diurnal variation of rainfall at Rarotonga (1971-83) for wet and dry seasons

Rainfall in low-lying small islands of the Pacific Ocean tends to show a diurnal maximum in the evening or early morning hours (Finkelstein, 1964; Lavoie, 1963; Dorman and Bourke, 1981). These rainfall characteristics could be expected over the small coral atolls of the Southern Cook Islands.

Rainfall in the highland region of Rarotonga, and possibly Mangaia, would tend to exhibit a diurnal pattern with a maximum in the middle of the day due to increased cloudiness arising from the enhanced convection caused by the orography of the islands.

Dry spells. A dry spell may be defined as at least 15 consecutive days with less than 1 mm of rain per day, and a very dry spell (drought) as 15 or more days with no rain. Table 22 gives statistics of dry and very dry spells for the Southern Cook Islands. This table shows the variability in the frequency of drought conditions ranging from 1.5 occasions per decade at

Rarotonga to over 12 at Palmerston Atoll and Mangaia. Most dry spells are during the dry season. This table further highlights the considerable spatial variability existing in the tropical rainfall regimes.

Table 22. Dry spell and very dry spell statistics

Location	Number/ Decade	Mean and Max. Length (days)		Predominant Time
Very Dry				
Palmerston	12.1	20	34	Dry Season
Aitutaki	6.3	17	31	Dry Season
Rarotonga	1.5	16	17	Dry Season
Mangaia	13.3	17	21	-
Dry				
Palmerston	16.4	21	34	Dry Season
Aitutaki	13.7	19	31	Dry Season
Rarotonga	7.9	17	26	Dry Season
Mangaia	18.3	18	21	-

The frequency or persistence of dry spells in a single year can be measured, and an indication of this characteristic can be derived from Table 23 for Aitutaki which gives the average number of dry spells per decade. One dry spell per year is the most frequent event occurring four times every decade.

Table 23. Average number of runs per decade of dry spells in a single year at Aitutaki, 1930-1980

Runs of dry spells in a single year	0	1	2	3	4	5	6
Frequency	2.2	3.9	2.2	1.0	0.4	0.2	-

<u>Persistence of abnormal monthly rainfall</u>. Abnormal monthly rainfall is defined as a departure of at least 50 percent from the average amount. In the tropics persistence of such rainfall over several months is not uncommon (Seelye, 1950). This is more pronounced in areas close to the equator, and especially in the dry zone of the tropics.

Persistence of abnormal rainfall over the Southern Cook Islands is given for Aitutaki and Rarotonga Airport in Table 24. At least one month each year will have either a high or low rainfall, but it is rare for abnormal rainfall to persist for three or more consecutive months. These have been mostly associated with significant phases of the southern oscillation.

Table 24. Average number of runs per decade of the stated number of consecutive months, each with abnormal rainfall.

	No. consecutive months with over 150 percent of average					No. consecutive months with less than 50 percent of average						
	1	2	3	4	5	1	2	3	4	5	6	7
a. Aitutaki 1930-1983	11.9	2.2	0.6	0.4	0.2	15.0	3.9	0.9	0.9	-	-	0.4
b. Rarotonga 1930-1983	11.9	1.7	0.2			13.1	3.3	1.3	0.4	0.2		

The table shows there is little persistence of abnormal rainfalls. Serial correlation also confirms this. For Aitutaki it is 0.012 and at Rarotonga the value is -0.013.

Air temperature

A characteristic of tropical climates is that while temperatures remain high all year round due to high insolation levels, the seasonal and diurnal variations are quite small. Tropical temperatures are also related to some extent by latitude (Hessell, 1981). In the region of the Southern Cook Islands the mean annual temperatures are 24° to 26°C. The monthly march of temperature can be seen in Fig. 20 for a number of Southern Cook Island locations. This figure shows some increase in the daily and seasonal variations with increasing latitude. Palmerston Island (18.07°S) and Aitutaki (18.82°S) have an average daily range of 5°C, and a seasonal variation of 3°C. On Rarotonga (21.11°S), the corresponding values are 6°C and 4.5°C. The figure also shows the daily maximum and daily minimum temperatures are highest during February and March, and least in July and August. This is about two or three months after the sun reaches the solstices.

Maximum temperatures over 32°C are experienced at Aitutaki on about three to five days each year, but on Rarotonga and Mangaia such temperatures are recorded about once a year. A temperature of 35.6°C has been measured on Aitutaki (February

1933) while at Rarotonga Airport a maximum of 33.6°C was recorded in March 1977.

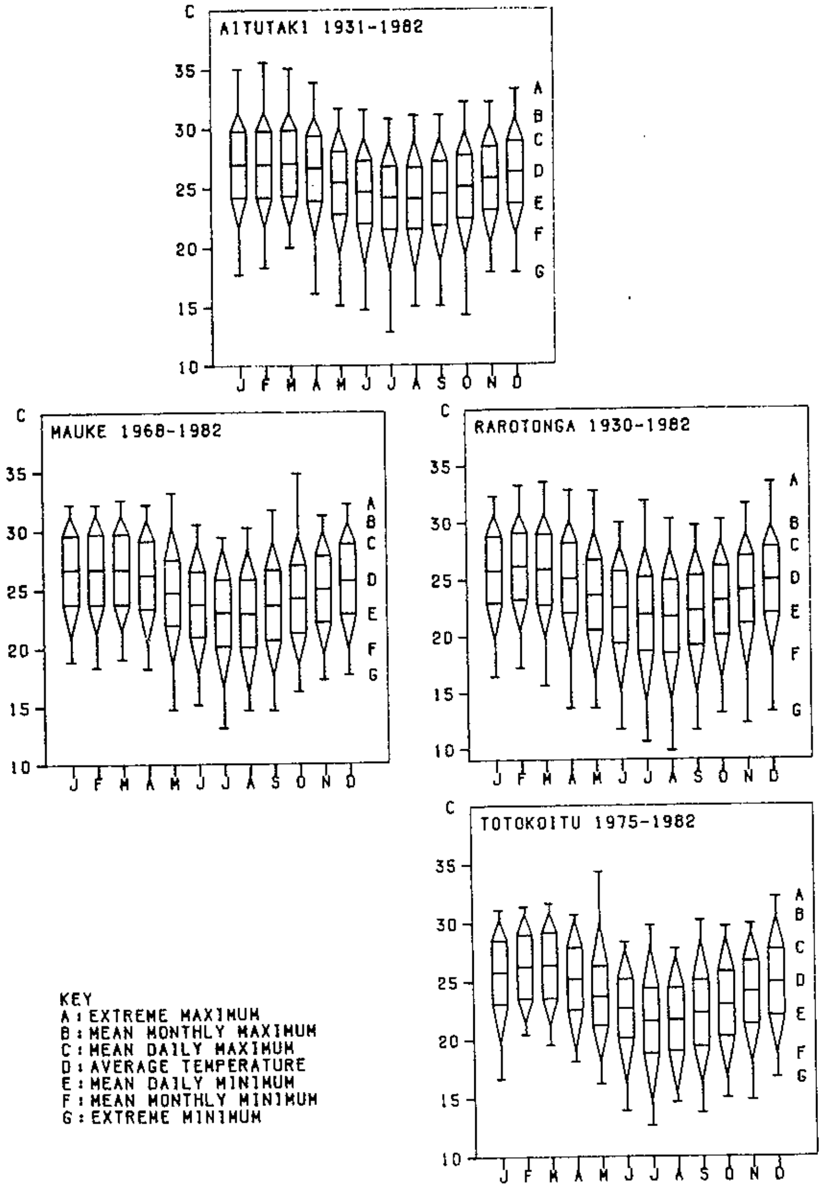

Fig. 20. Monthly temperature data - Southern Cooks

Minimum temperatures at Aitutaki and Palmerston Atoll seldom fall below 18°C, occurring on only two or three days each year. On Rarotonga there are 10 to 15 days, mostly in the dry season, when temperatures drop below 18°C. The lowest recorded temperatures at Aitutaki and Rarotonga are 12.8°C (July 1940) and 8.9°C (July 1915). A table of monthly extremes is presented in Table 25.

Table 25. Monthly extreme temperatures - Southern Cook Islands

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
(a) Maximum												
Palmerston	33.4	35.0	33.0	32.5	32.3	32.9	30.6	31.0	31.3	31.5	32.0	32.0
Aitutaki	35.0	35.6	35.1	33.9	31.7	31.6	30.8	31.1	31.1	32.2	32.2	33.3
Mauke	32.2	32.2	32.6	32.2	33.2	30.5	29.4	30.2	31.7	34.8	31.2	32.2
Rarotonga	33.1	33.3	33.6	32.9	32.8	30.0	31.9	30.3	31.6	31.9	31.6	33.5
Totokoitu	31.1	31.4	31.7	30.7	34.4	28.4	29.8	27.8	30.2	29.7	29.9	32.2
(b) Minimum												
Palmerston	20.5	21.0	21.5	20.9	20.4	19.3	17.0	19.0	18.6	20.0	21.0	21.0
Aitutaki	17.7	18.3	20.0	16.1	15.1	14.7	12.8	15.0	15.0	14.2	17.8	17.8
Mauke	18.8	18.3	19.0	18.2	14.7	15.1	13.1	14.6	14.6	16.2	17.2	17.6
Rarotonga	16.4	17.2	15.6	13.6	11.1	10.6	8.9	9.8	11.6	13.1	12.2	13.2
Totokoitu	16.6	20.4	19.5	18.1	16.2	13.9	12.6	14.6	13.7	15.0	14.8	16.7

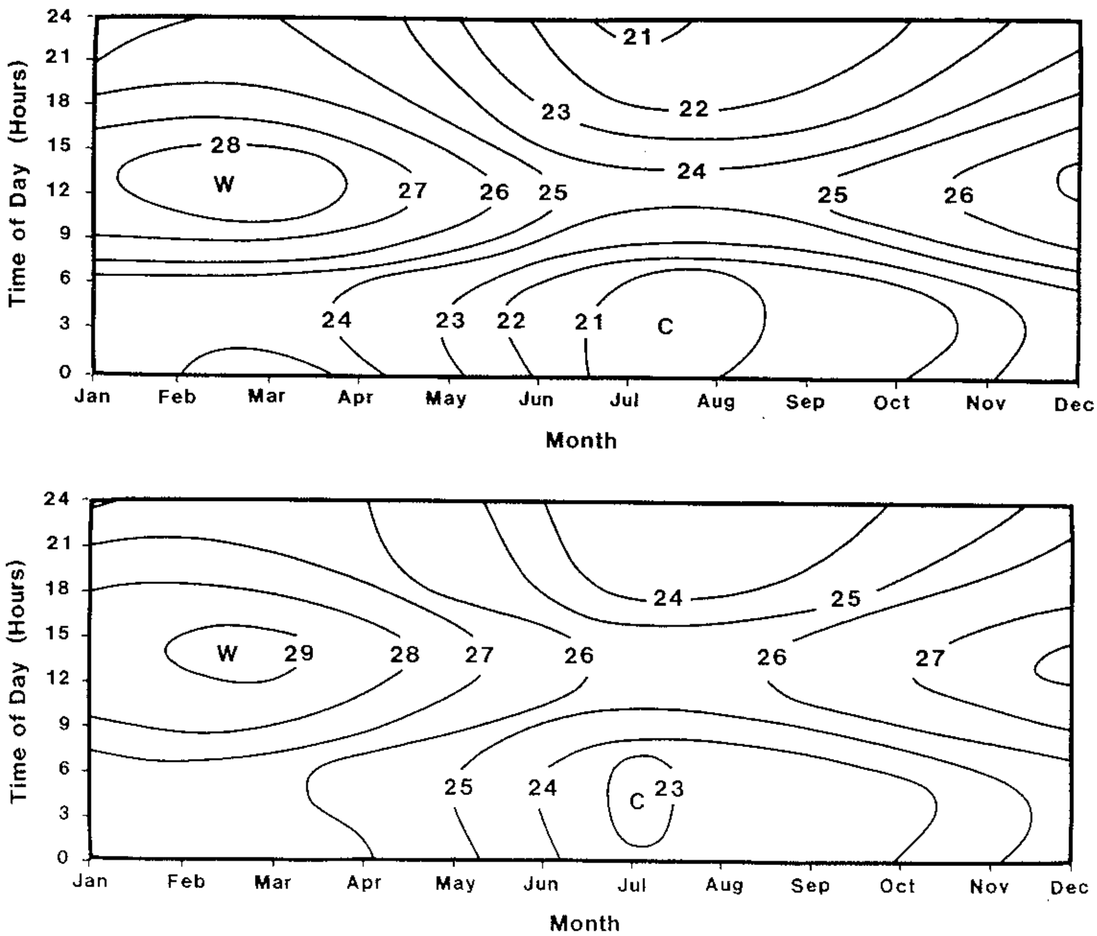

Fig. 21. Diurnal and seasonal temperature variations (0°C) for Rarotonga (1971-80) and Aitutaki (1975-81)

One way of showing the combined effects of seasonal and diurnal variations on Aitutaki and Rarotonga is displayed in Fig. 21. which 21 shows that the diurnal and seasonal variations are more pronounced on Rarotonga than at Aitutaki. The diagram indicates that the temperatures are about 1-2°C higher on Aitutaki than at Rarotonga Airport. Comparisons of the maximum and minimum temperatures at Rarotonga Airport and Totokoitu shows the maximum temperatures at the airport are on average 0.8°C warmer than at Totokoitu, while the minimum is only 0.1°C warmer. On Mauke, the synoptic reporting site has maximum and minimum temperatures which are 0.4° and 0.2°C warmer respectively than the agrometeorological site.

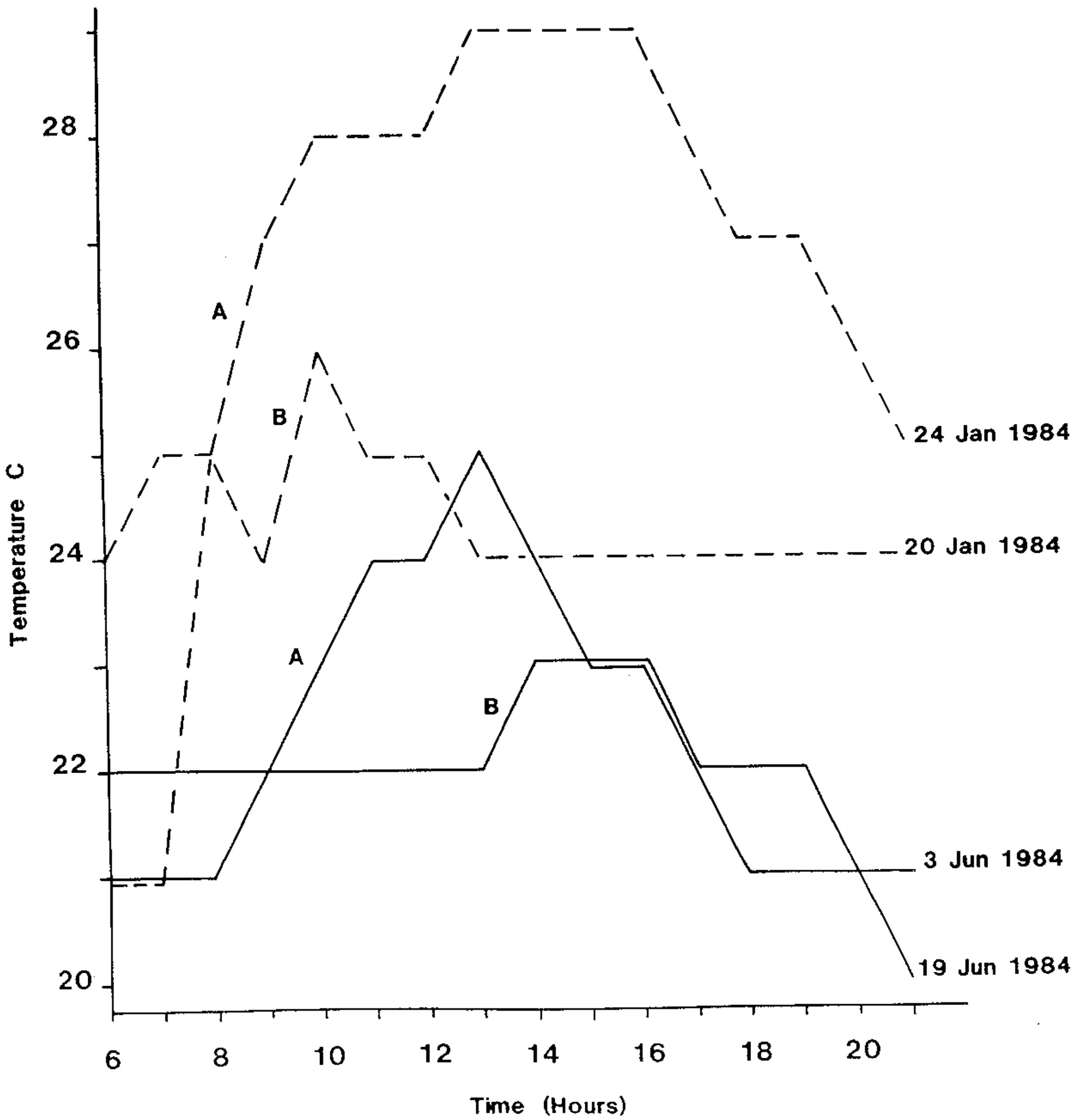

Fig. 22. Temperatures during sunny and cloudy days at Rarotonga

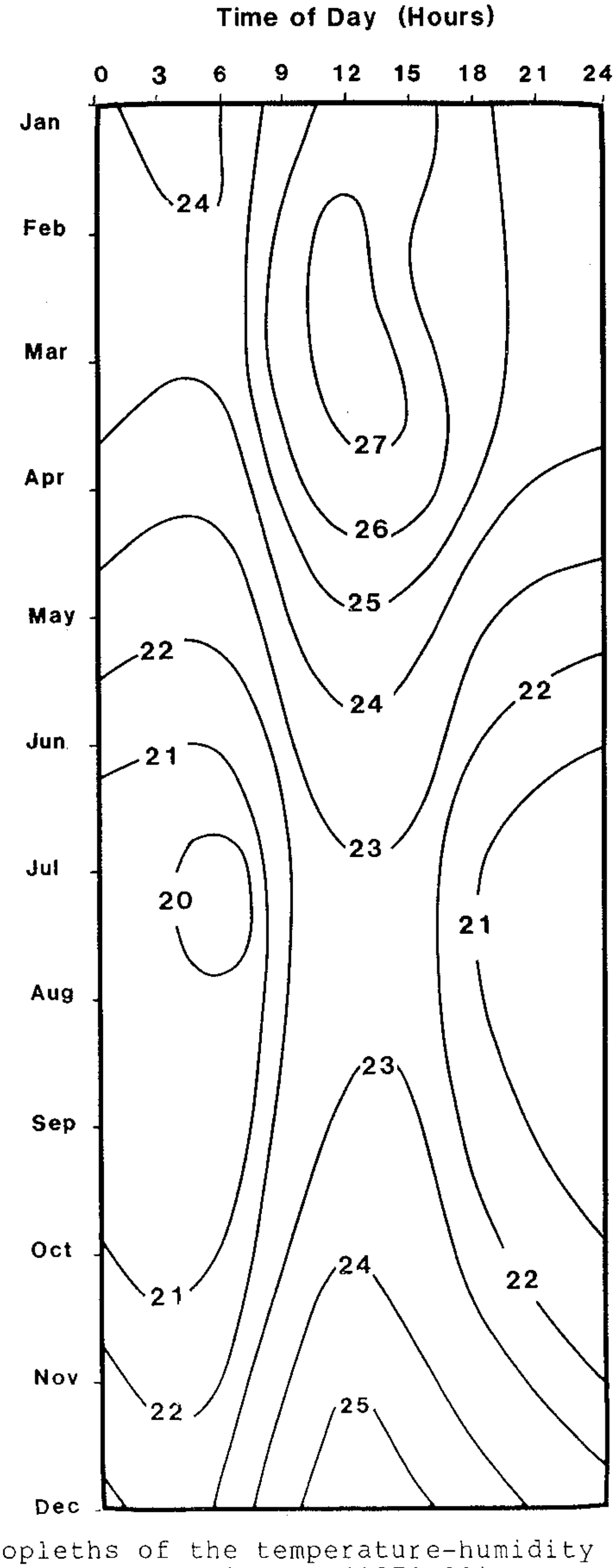

Fig. 23. Isopleths of the temperature-humidity index for Rarotonga Airport (1970-80)

The diurnal variation of temperature in tropical regions on any particular day is associated with changes in cloudiness (Nieuwolt, 1968). Daytime temperature variation is appreciably reduced on cloudy to overcast days (Fig. 22) when global radiation levels are also reduced.

Temperatures decrease with elevation, and a controlling influence on the lapse rate in upland regions is cloudiness. Under cloudy conditions, the lapse rate tends to be that of the free atmosphere (Nieuwolt, 1977) which is about 6°C/km. Due to the greater number of trade wind inversions, lapse rates tend to be larger in the dry season than during the wet season. For the South-West Pacific the lapse rate in January is 8.9°C/km, while in July it is 9.9°C/km (Tomlinson, 1975). Thus at an elevation of 500 m Rarotonga could be expected to have temperatures which are about 4.5-5.0°C cooler than the lowland coastal locations.

<u>Human response to temperature</u>. Temperature is not the only climatic parameter affecting human comfort in the tropics. Relative humidity, solar radiation and air movement are also important (Finkelstein, 1972; Nieuwolt, 1977). A number of indices have been proposed to measure the comfort of humans in warm conditions. One such index is the Temperature-Humidity Index (THI). The THI indicates the temperature of saturated air which causes a sensation of warmth or cold, and is given by the following formula:

$$THI = 0.8T + (RH \times T)/500.$$

where

T = dry bulb air temperature, and
RH = relative humidity.

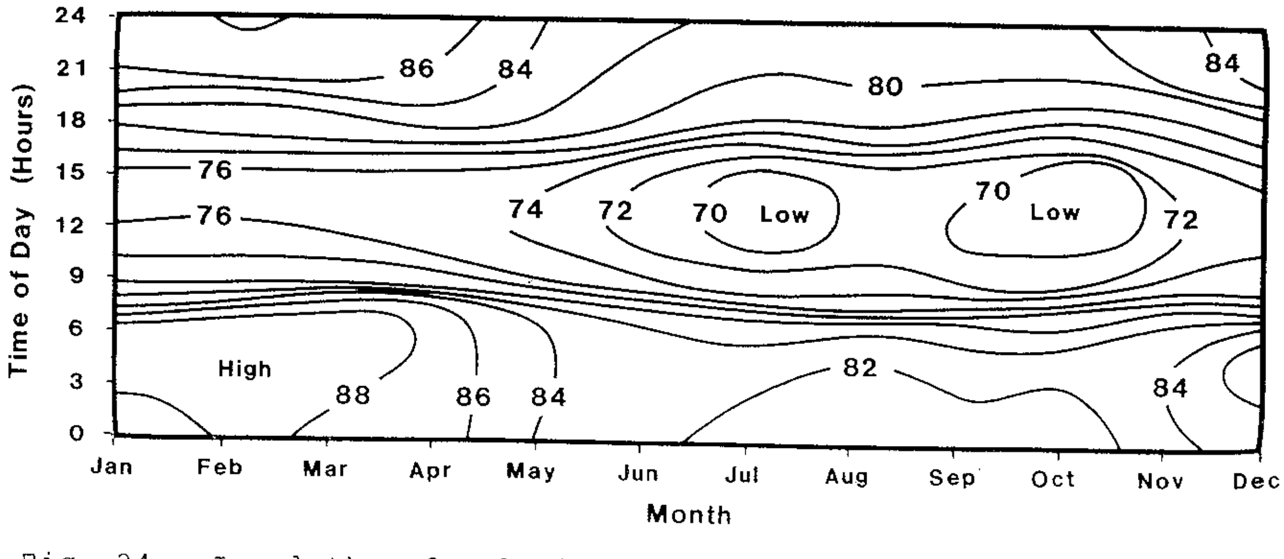

Fig. 24. Isopleths of relative humidity for Rarotonga Airport (1970-80)

The critical value when people are uncomfortably hot is 26°C. It should be noted that the THI excludes consideration of wind, solar radiation and precipitation. It cannot therefore be considered as completely definitive of human comfort which may also depend on clothing, fitness and experience of particular conditions. The diurnal and seasonal variation of the THI at

Rarotonga Airport is given in Fig. 23. The diurnal variation is not as large as the air temperature diurnal variation (Fig. 21). This is caused by the influence of relative humidity (Fig. 24) which is higher at night than during the day. From Fig. 23 it is seen that most human discomfort is likely during the period from mid-December to mid-April, and more especially in the middle of the day.

Sunshine and solar radiation

Sunshine. The proportion of the sky which is covered by clouds affects the amount of sunshine and global radiation received at the surface of the earth. Rarotonga Airport is the only location with a long-term sunshine record. Sunshine recorders were installed in mid-1983 on Mangaia and Mauke. Initial sunshine estimates for Mangaia indicate that it receives about 91 percent of the Rarotonga Airport sunshine. An estimate for Mauke could not be made.

Information about the spatial and temporal variation of sunshine can be obtained from observations of cloud amount. The diurnal variation of cloud cover at Aitutaki and Rarotonga Airport is given in Fig. 25. At Rarotonga there is a pronounced diurnal variation in cloud cover, with a maximum in the afternoon caused by convection. There is a cloud minimum at night when atmospheric stability increases as the temperatures decrease.

At Aitutaki, which is a low-lying volcanic and coral atoll, there appears to be a night-time cloud maximum. Over the oceans

Table 26. Comparison between mean daily cloud cover and mean cloud cover at 9 a.m.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
(a) Aitutaki 1975-1980.												
Mean Daily	5.6	5.3	5.1	5.7	5.7	5.0	5.0	4.9	4.8	5.2	5.6	5.5
Mean 9 a.m	5.5	5.0	4.9	5.6	5.6	4.9	5.1	4.9	4.7	5.1	5.7	5.3
(b) Rarotonga Airport 1970-1980.												
Mean Daily	5.3	5.2	5.2	5.1	5.4	4.8	4.6	4.9	4.8	4.9	5.4	5.2
Mean 9 a.m	5.2	5.0	5.1	5.0	5.5	4.7	4.6	4.9	4.8	4.8	5.4	5.0

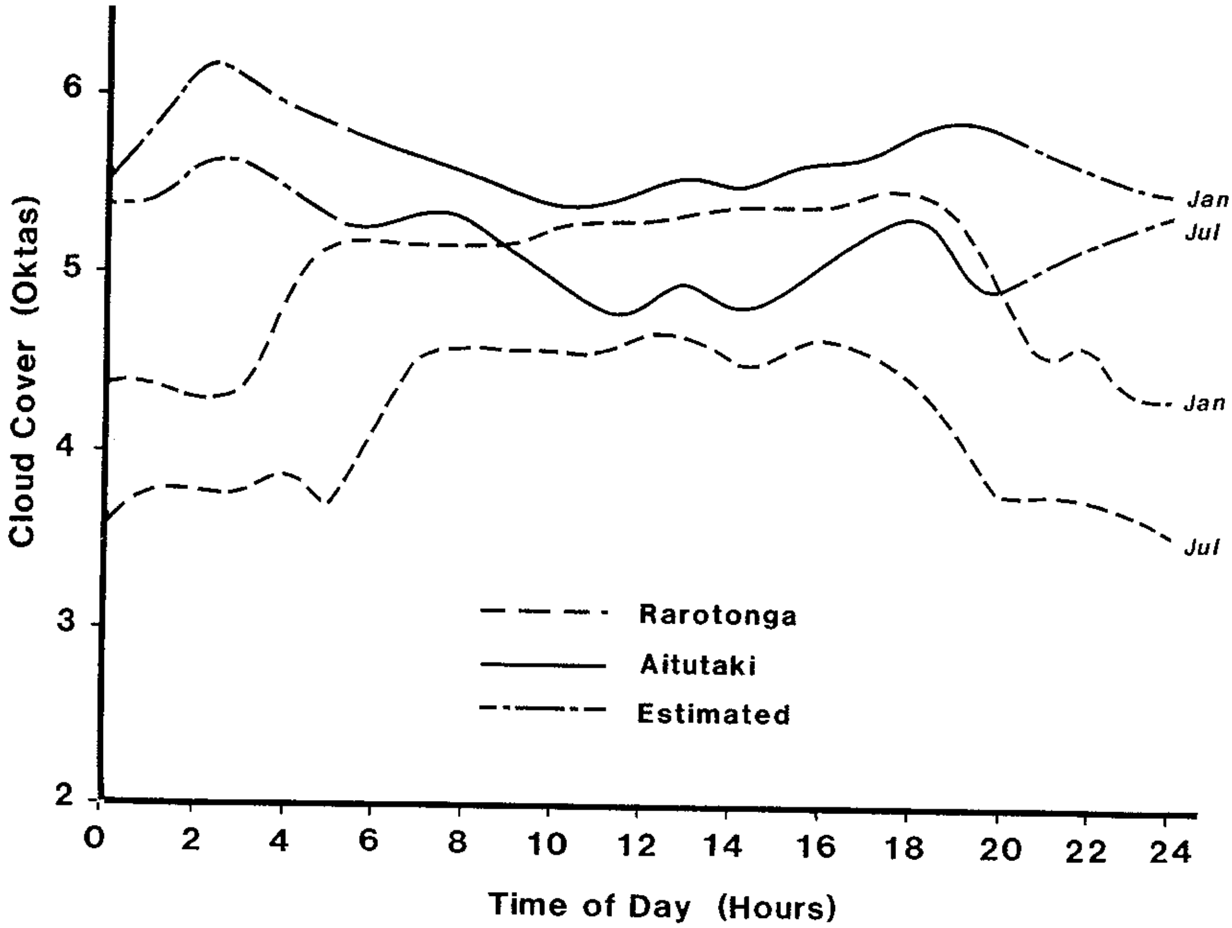

Fig. 25. Diurnal variation of cloud cover at Aitutaki (1975-80) and Rarotonga Airport (1970-80) in January and July

it has been found that clouds increase at night-time due to increased atmospheric instability caused by cloud-top radiational cooling (Ruprecht and Gray, 1976). Cloud cover at Aitutaki shows a minimum during the latter part of the morning, and is consistent with the oceanic environment of this island.

Monthly sunshine totals have been estimated for the Southern Cook Islands using the 9 a.m. cloud cover as an estimate of the mean daily cloud cover. The cloud cover at 9 a.m. is a good estimate of the mean daytime (6 a.m. to 6 p.m.) cloud cover (Table 26 and Fig. 25).

Sunshine was determined from the following empirically derived equation:

$$S = S_o(1 - aC^2)$$

where

S_o = total possible sunshine for the latitude of the location,

C = 9 a.m. cloud amount expressed as a fraction between 0 and 1,

a = a function of latitude (Table 27) found by calibrating stations of the South Pacific between latitudes 10°S and 25°S.

Table 27. Values for the constant a by latitude in the computation of sunshine estimates

Latitude	8	10	12	14	16	18	20	22
Constant a	1.22	1.21	1.20	1.20	1.19	1.18	1.13	1.10

From comparison of the estimated monthly sunshine for Rarotonga Airport with observed sunshine values, the accuracy of the above equation is better than ten percent. The monthly sunshine estimates for the Southern Cook Islands are presented in Table 28. In summer, which is the cloudiest time of the year, the computed sunshine totals represent about 45 to 50 percent of the total possible sunshine . During the dry season, when the sun's elevation is lowest, the sunshine totals represent about 55 to 60 percent of the total possible sunshine.

Table 28. Monthly sunshine (hours) for Southern Cook Islands

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Palmerston	227	173	205	218	194	190	214	226	228	216	219	200
Aitutaki	186	156	165	166	165	179	187	187	189	184	163	172
Mauke	220	185	202	214	196	196	210	217	209	209	203	192
Rarotonga	181	165	180	171	163	160	175	192	177	186	173	182
Rarotonga*	181	178	180	169	159	162	174	179	178	188	179	181
Totokoitu	181	165	180	144	135	148	167	162	164	179	173	182
Mangaia*	165	162	164	154	145	147	159	163	162	171	163	165

* Observed Sunshine data

Solar radiation. Solar radiation comprises direct and diffuse radiation. It varies greatly with latitude, as well as with the amount of cloud cover. Where measurements of radiation are not available, as in the Cook Islands, one of the simplest models used for the estimation of global radiation is the Angstrom correlation relation, given by:

$$Q/Q_o = a + b(n/N)$$

where

- Q = the monthly average daily global radiation
- Q_o = extraterrestrial radiation (Table 29)
- n/N = relative duration of bright sunshine
- a = coefficient depending on the prevailing cloud type
- b = transmission characteristics of a cloud-free atmosphere, mainly the water vapour content and turbidity (Mani and Rangarajan, 1983).

The coefficients a and b for the South-west Pacific oceanic region were computed from Fiji radiation and sunshine data. They were found to be a = 0.306 and b = 0.381. The correlation coefficient was 0.961. The sum (a+b) is 0.687 which is indicative of a moist and turbid atmosphere (Mani and Rangarajan, 1983).

Table 29. Values by month and by latitude of extraterrestrial radiation* ($MJ/m^2/day$)

Lat	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
15°S	41.4	40.4	37.7	33.5	29.4	27.2	28.0	31.3	35.5	39.0	40.8	41.5
20°S	42.4	40.6	36.8	31.7	27.0	24.6	25.5	29.3	34.3	38.8	41.6	42.7
25°S	43.1	40.5	35.7	29.7	24.4	21.8	22.8	27.0	32.8	38.3	42.0	43.7

* Solar constant 1381 W/m^2

Monthly estimates of global radiation are given in Table 30. This table shows highest radiation totals during December or January when the sun is overhead. These months are on average the cloudiest, so there is a high diffuse radiation

Table 30. Monthly global radiation ($MJ/m^2/day$)

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Palmerston	22.1	20.3	19.3	16.8	14.7	13.7	14.6	16.8	19.4	20.5	21.4	21.4
Aitutaki	20.4	19.5	17.7	15.9	13.7	13.2	13.7	15.4	17.8	19.1	20.1	20.6
Mauke	22.0	20.8	19.1	17.4	14.3	13.4	14.0	16.0	18.5	20.2	21.2	21.2
Rarotonga	20.5	20.5	18.3	15.6	12.9	12.0	12.7	14.6	17.1	19.2	20.2	20.6
Totokoitu	20.5	19.8	18.1	14.7	12.1	11.6	12.5	14.0	16.6	18.9	20.1	20.6
Mangaia	19.9	19.7	17.4	14.8	12.3	11.5	12.1	13.9	16.5	18.6	19.6	19.9

component in the total amount. Estimates of diffuse radiation from empirical methods described by Spencer (1982) suggest that the diffuse radiation component is as much as 45 to 50 percent of the total global radiation during the wet season, and about 40 percent in the dry season.

Hail and thunder

Hail is exceedingly rare in the Southern Cook Islands, being reported on only one or two days every 10 years and only during the wet season. By way of an example, there were heavy hail showers on Rarotonga on the evening of 7 February 1980, when a squally and thundery south-easterly airstream prevailed over the Southern Cooks. The hail was confined to the coastal strip from Matavera to Tupapa along the northern coast and along the western coast from Arorangi to Rutaki. Hail stones had an average diameter of about 7 mm.

Table 31 shows the frequency of days of thunder in the Southern Cook Islands. While thunder is likely in any month, between 60 and 65 percent are reported during the wet season. In some months thunder can be heard on up to 7 days.

Table 31. Days of thunder - Southern Cook Islands

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Palmerston Atoll 1972-1980	1.0	1.3	1.2	1.4	1.9	0.3	0.2	0.4	0.3	0.8	0.9	2.1
Aitutaki 1971-1980	2.1	2.9	2.2	2.6	3.6	1.5	0.5	0.5	1.0	1.4	2.3	2.2
Mauke 1971-1980	0.9	0.6	1.5	1.6	1.5	0.5	0.2	0.1	1.0	0.9	1.1	0.8
Rarotonga 1971-1980	1.4	1.3	1.7	1.6	1.6	0.8	0.3	0.6	0.6	1.3	1.0	1.3
Totokoitu 1975-1980	1.4	0.6	0.4			0.2	0.2		0.3	0.2	0.3	0.5
Turoa 1963-1970	0.7	0.2	1.8	0.6	2.2	0.2		1.0	0.4	0.7	1.0	0.3

Lightning is more commonly observed than thunder. The frequency of reported lightning flashes is about twice that of thunder, and in individual months up to 16 days with lightning have been noted.

From an analysis of both hourly and synoptic weather reports, a pronounced diurnal variation exists in the episodes of thunder and lightning. At Aitutaki there is an evening and early-hours maximum when 86 percent of the observations are reported. At Rarotonga, 60 percent happen during the afternoon and evening. A further 25 percent of thunder and lightning events are observed at night, and are most probably out to sea. The maximum number of thunderstorms appear to occur between 8 and 10 p.m., and the minimum from 10 a.m. to noon (Revell, 1984).

Thunderstorm rainfall can be intense. As an example, a series of heavy thunderstorms affected Rarotonga on the afternoon and evening of 10 April 1984. Most of the 143 mm of rain measured at the airport fell between 2 p.m. and midnight. All the island's stations recorded heavy falls.

Evapotranspiration and soil water balance

Evapotranspiration is the combined loss of water by evaporation from the soil and by plant transpiration. In the tropical regions high rates of evapotranspiration are common due to a large amount of available energy (Jackson, 1977). Evapotranspiration is less variable from year to year than is rainfall because of the small variations in the solar radiation component.

Evapotranspiration can be thought of as a response to two climatological 'inputs'; solar radiation and water supply from rainfall (Coulter, 1973). When evapotranspiration is not limited by the supply of water, the rate of loss of water to the atmosphere is at a peak and is known as 'potential evapotranspiration' (PET). There are several methods of calculating PET; the best known is the Penman formulation (Coulter, 1973). Potential evapotranspiration estimates are given in Table 32.

Table 32. Monthly Penman potential evapotranspiration (mm)

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Palmerston	182	156	165	132	118	114	120	140	148	170	168	175
Aitutaki	166	143	139	124	112	105	113	127	138	159	157	165
Mauke	160	135	135	115	95	86	90	108	126	146	150	158
Rarotonga	153	137	131	106	94	84	87	101	119	138	142	154
Totokoitu	145	127	125	97	79	72	77	88	103	125	134	141
Mangaia	144	127	124	98	80	79	82	94	106	128	134	146

The interplay between rainfall and evapotranspiration forms the water balance. When PET exceeds rainfall, soil moisture reserves are utilised until all soil water is used. A deficit then exists. When rainfall exceeds PET, the soil water reserves are recharged up to a maximum storage capacity. Any further

Table 33. Water balance summary - Southern Cook Islands

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Palmerston Atoll (1967-1984)												
DE	12	15	24	2	1	22	29	48	47	74	44	20
RO	71	76	81	73	90	16	1	11	53	24	19	93
FDE	38	31	47	13	19	35	59	71	65	88	69	38
FRO	75	56	53	63	63	35	12	29	29	18	38	75
Aitutaki (1931-1984)												
DE	18	10	4	4	5	12	26	44	57	63	40	21
RO	69	88	81	62	64	18	11	7	5	11	32	76
FDE	32	30	13	11	17	31	60	75	83	88	69	42
FRO	58	79	60	55	62	25	17	17	10	18	31	55
Mauke (1967-1984)												
DE	56	30	33	24	11	14	18	31	51	60	55	55
RO	39	76	39	47	55	30	17	15	21	8	47	49
FDE	71	41	50	33	22	29	41	47	76	76	71	59
FRO	35	47	56	44	44	41	35	24	18	18	29	35
Rarotonga (1948-1984)												
DE	16	7	7	2	1	2	3	2	10	26	31	22
RO	91	73	94	88	84	27	18	38	20	13	22	71
FDE	31	31	17	8	6	6	9	11	28	61	64	47
FRO	64	69	72	72	83	56	37	51	36	19	33	58
Totokoitu (1975-1984)												
DE	13	2	4	1	0	0	0	0	0	2	14	19
RO	104	174	132	179	157	88	96	137	104	89	76	173
FDE	33	22	22	11	0	0	0	0	0	13	13	22
FRO	67	89	78	89	89	88	100	100	75	50	50	67
Mangaia (1967-1984)												
DE	14	3	4	3	1	2	5	2	7	25	26	23
RO	71	107	76	120	115	57	40	52	27	27	39	35
FDE	20	33	27	8	8	15	15	9	27	40	45	45
FRO	50	83	64	83	77	69	54	45	55	30	45	64

Note: Soil moisture capacity 125mm
DE Evapotranspiration deficit (mm)
RO Runoff (mm)
FDE Frequency (percent) of months with deficit
FRO Frequency (percent) of months with runoff

rainfall causes runoff. However, in tropical regions rainfall effectiveness can be substantially reduced because high intensity rainfalls commonly exceed the soil infiltration rates. Subsequent runoff results in soil erosion.

Studies in the Southern Cooks on the amount of water the soil can hold (Jackson, 1981) showed a typical plant rooting depth was 60 to 100 cm, which corresponded to a soil moisture capacity of about 100 to 150 mm. Water balance summaries (Table 33) have been computed for a soil water capacity of 125 mm. Runoff and soil moisture deficits occur all year round. Soil moisture deficits and their frequency of occurrence tend to be greatest in the second half of the year during the dry season. Deficits, like potential evapotranspiration are larger on the islands closer to the Equator.

On the southern side of Rarotonga, Totokoitu has experienced no soil moisture deficits in the dry season during the period of the record. This side of the island is wetter and cloudier than the northern side.

The demand for water by plants in the tropics is high due to the high rates of evapotranspiration. Studies on the water-yield relationships of coconuts cited by Jackson (1977) have shown that an even distribution of rainfall is necessary throughout the year. Tree growth and coconut yields are reduced if there is a well-defined dry season (and therefore soil moisture deficits) in the previous two years. Irrigation during the dry season is therefore beneficial in sustaining crop levels.

Table 34. Annual irrigation requirements (mm) for a given risk

(Water is applied when soil moisture level is 62 mm)

Location	Risk (percent)					
	90	75	50	25	10	HE*
Palmerston	250	385	445	725	870	1041
Aitutaki	245	325	420	525	665	1049
Mauke	225	300	400	810	1075	1324
Rarotonga	100	160	220	280	450	739
Mangaia	10	25	70	225	400	677

* Highest estimate.

Estimates of irrigation requirements (Table 34) for the Southern Cook Islands have been assessed from past climatological data through the use of the water balance and its calculation of the soil moisture deficit. The risk is the number of years in 100 that supplementary water is required. Land is irrigated when the soil moisture level is 50 percent of its field capacity.

6. MARINE CLIMATE OF THE SEAS AROUND THE SOUTHERN COOK ISLANDS

The area of the South Pacific Ocean, in which the Southern Cook Islands lie, is on the southern fringe of the South Sub-tropical Ocean Current (Meteorological Office, 1967). This current flows slowly from the east or north-east at about 0.5 to 1.0 knot. The ocean current is relatively warm, and monthly sea surface temperatures for the islands are displayed in Fig. 26. Average sea temperatures range from 28°C in January and February to 24°C six months later.

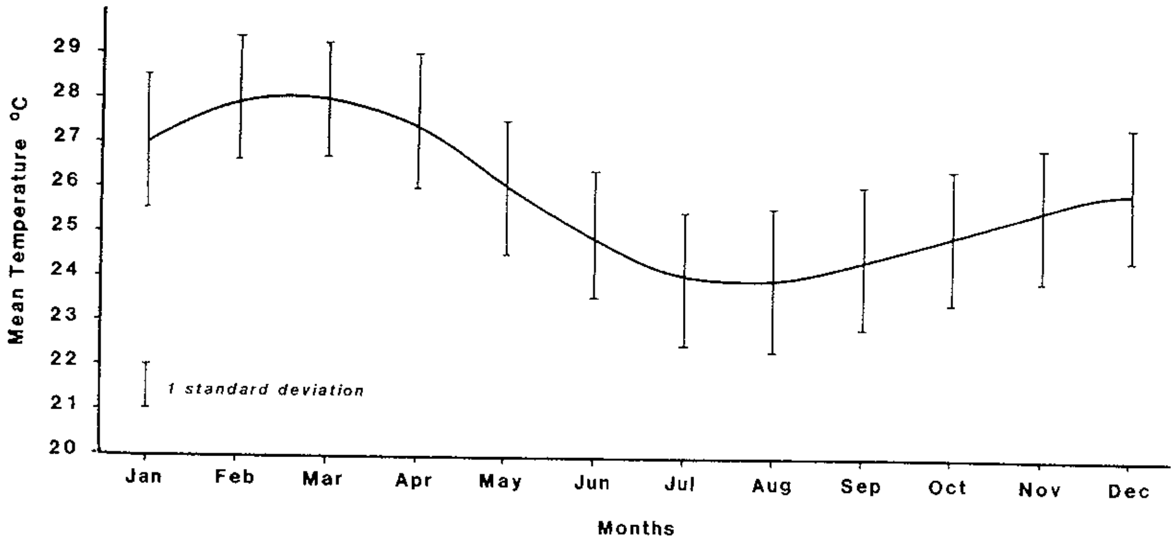

Fig. 26. Sea surface temperatures - Southern Cooks

Table 35 presents a monthly wave analysis for the ocean around the islands. This table, derived from the U.S. Navy Marine Climatic Atlas Series (1979), uses the greatest height of either wind waves or swell present at the time of observation. Over 90 percent of waves are less than 4 metres. Predominant wave directions are from the east or south-east. High waves (over 6 metres) are rare, but they tend to be most frequent in winter. The prevailing direction tends to be east or south-east, but during the cyclone season waves from the north or north-east are also observed, although their frequencies are less than 0.5 percent.

Table 35. Monthly frequencies (percent) of specified wave heights over seas surrounding the Southern Cook Islands

Height Class(m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.0-1.9	55	40	55	40	50	50	45	45	45	50	55	50
2.0-4.0	40	55	40	50	40	45	50	50	45	45	43	45
6.0+	1	1	.5	4	1	4	.5	0	0	1	0	1

On occasion, heavy swells that have been generated thousands of kilometres away can affect the Southern Cook Islands. As an example, late on 26 June 1980, heavy south-west swells caused considerable damage to parts of Rarotonga. A long south-west swell generation area existed between Macquarie Island and the Chatham Islands on 24 June 1980. The fetch area moved slowly north-east during the following three days, and its associated wind field weakened only on 28 June 1980. Swells leaving this fetch area took about 65 hours to reach Rarotonga.

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APPENDIX

The Climate of Rarotonga International Airport

Introduction

Rarotonga International Airport is situated on the north-west side of Rarotonga Island, 7 m above mean sea level, and about 3 km from the town of Avarua. The single paved runway is 2377 m long, and is aligned from 80°-260° magnetic. The approaches to the airport are from over the ocean, and are therefore free from orographic obstructions.

Hourly weather reports are prepared throughout the 24 hours by the Cook Islands Meteorological staff. They are representative of the weather over the airfield and approach areas, but winds of much strength in the south-east quadrant are significantly influenced by turbulent flow over the rugged highlands of the island. Table A1 presents a summary of climatological observations made at Rarotonga Airport.

Surface Winds

Rarotonga, situated in the trade winds zone of the subtropics, is affected by winds which blow predominantly easterly (see Fig. 11 and Table 13). Over 83 percent of wind speeds are less than 16 knots. Easterly winds can be persistent, blowing for days on end.

For speeds in the range 6-20 knots, winds blow 54 percent of the time from between 80°-130°, and 16 percent from 20°-70°. The least likely wind direction is between 260°-310°, the frequency of occurrence being only 5 percent. For speeds over 20 knots, 58 percent are from between 80°-130°, and 12 percent from 320°-10°. Sustained strong winds over 30 knots are very infrequent with 70 percent of these occurrences being in the wet season.

Restrictions on the operation of commercial aircraft are seldom necessary because of high winds or crosswinds. (A crosswind is the component of wind blowing perpendicular to the runway.) An analysis of crosswinds at Rarotonga Airport is given in Table A2. Crosswinds of less than 14 knots occur 97 percent of the time. They exceed 20 knots only 0.3 percent of the time. Nearly 60 percent of crosswinds over 20 knots are during the period November to April, although some of the highest components (over 30 knots) have been measured during the dry season associated with the development of subtropical depressions on quasi-stationary convergence zones. An example occurred during the period 5 to 9 May 1984 when a depression developed just north of Rarotonga. Crosswind components of 35 knots were reported at the height of the storm on 8 May 1984.

Turbulence

Convective turbulence is common all year round due to the presence of cumulus clouds. This type of turbulence is normally accentuated in the wet season, and can be severe when cumulonimbus clouds are embedded in the SPCZ or quasi-stationary frontal systems.

Extremely turbulent conditions are present in tropical cyclones. Turbulent conditions are further enhanced when tropical cyclones pass north of the airport, as southerly airflows cross the highlands to the south-east. These conditions last for no more than 6 to 12 hours.

Frequent wind shear between the surface easterlies and the upper-level westerlies is reported at the airport to be turbulent. It is usually enhanced when the temperature inversion is strong.

Visibility and low cloud

Visibility. Normally visibility is very good apart from the usual reduction during showers.

Low cloud. The airport is seldom affected by low cloud, the main base of the predominant cumulus cloud being about 2000-2500 ft (600-760 m). Cloud bases below 1500 ft (455 m) are reported 2.3 percent of the time, with 40 percent of the low cloud observed in easterly conditions (80 -130) at speeds of less than 16 knots. Due to orographic sheltering in the southerly quadrant (170 -220), there are relatively few events (7 percent of the low cloud observations).

Very low stratus (below 1000 ft or 300 m) commonly forms in situ when it rains, occurring only 0.3 percent of the time. On many occasions, these conditions are reported when the wind is between north-west and east.

During rain, the main nimbostratus cloud base is at 8000-9000 ft (2400-3000 m).

Joint occurrences of low cloud and/or poor visibility. Tables A3 to A6 present the frequency distribution by seasons of selected low cloud and/or poor visibility conditions as a function of wind speed and direction, together with the corresponding wind summary.

The likelihood of low cloud and/or poor visibility occurring simultaneously for specified wind speed and directions is given in tables of joint probability (Tables A7 to A10). While high frequencies of poor flying weather in category A (i.e. cloud below 1500 ft and/or visibility less than 5000 m) occurs in all seasons, the corresponding joint probabilities are generally small. Highest probabilities are however associated with wind directions from between west and north-east, because of the smaller frequency of winds from these directions.

Low cloud and/or poor visibility is most frequent in summer occurring for 3.3 percent of the time. The corresponding values for autumn, winter and spring are 2.5 percent, 2.3 percent and 1.9 percent respectively.

Precipitation. Reduced visibility (less than 5000m), due to convective or synoptic-scale precipitation, is reported 0.3 percent of the time. As Fig. 19 displays there is a distinct rainfall maximum in the middle of the day during the wet season, but in the dry period the majority of rain falls at night.

Visibilities may reduce to 400 m in afternoon summer thunderstorms, and to 3000-5000 m in continuous periods of rainfall.

TABLE A1: AIRPORT CLIMATOLOGICAL SUMMARY

RARUTONGA AIRPORT

LAT. 21 11S LONG. 159 48W HT. 7 M.

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
RAINFALL. MILLIMETRES														
HIGHEST MONTHLY/ANNUAL TOTAL	1930-1980	668	509	667	447	693	268	298	475	268	318	381	653	3022
NORMAL	1941-1970	263	199	255	202	183	113	84	131	112	106	155	231	2034
LOWEST MONTHLY ANNUAL TOTAL	1930-1980	24	42	84	30	29	13	12	13	13	16	9	11	1384
AVERAGE NUMBER OF DAYS WITH RAIN 1.0 MILLIMETRES OR MORE	1948-1980	15	15	16	14	13	9	9	10	10	10	11	14	146
TEMPERATURE. DEGREES CELSIUS														
MEAN MONTHLY/ANNUAL MAXIMUM	1930-1980	30.7	30.8	30.8	30.2	29.2	27.9	27.8	27.6	27.7	28.3	29.0	29.7	31.4
MEAN DAILY MAXIMUM	1930-1980	28.8	29.1	29.0	28.2	26.7	25.7	25.2	24.9	25.3	26.1	27.0	27.8	27.0
NORMAL	1941-1970	25.8	26.1	25.9	25.2	23.7	22.6	21.8	21.8	22.3	23.1	24.1	24.9	23.9
MEAN DAILY MAXIMUM	1930-1980	22.9	23.2	22.7	22.0	20.5	19.3	18.6	18.4	19.1	20.0	21.0	21.9	20.8
MEAN MONTHLY/ANNUAL MINIMUM	1930-1980	19.6	20.4	19.8	18.2	16.2	15.0	13.9	14.2	14.8	16.0	16.7	18.2	12.9
WIND														
AVERAGE NO. OF DAYS WITH GUSTS 34 KNOTS OR MORE	1957-1980	2.4	1.8	1.8	1.9	2.4	2.1	2.1	2.9	2.2	2.3	1.6	1.9	25.4
GUSTS 52 KNOTS OR MORE	1957-1980	0.1	0.2	0.1	.	0.1	.	.	.	0.2	.	.	0.1	0.8
SPECIAL PHENOMENA														
AVERAGE NO. OF DAYS WITH SNOW	1972-1980	.	.	.	.	.	.	.	.	.	.	.	.	.
AVERAGE NO. OF DAYS WITH HAIL	1971-1980	.	.	.	.	.	.	.	.	.	.	0.1	.	0.1
AVERAGE NO. OF DAYS WITH THUNDER	1934-1980	1.4	1.3	1.7	1.6	1.6	0.8	0.3	0.6	0.6	1.3	1.0	1.3	13.5
AVERAGE NO. OF DAYS WITH FOG	1956-1980	.	.	.	.	.	0.1	0.1	.	.	.	0.1	.	0.3
PRESSURE. MILLIBARS														
MEAN MONTHLY/ANNUAL QNH.	1934-1980	1011	1011	1013	1013	1015	1016	1016	1017	1017	1016	1014	1012	1014

TABLE A2:

NZ METEOROLOGICAL SERVICE

STATION RAROTONGA AIRPORT DATA PERIOD 12 1970 TO 12 19

RUNWAY CROSSWIND ANALYSIS DATA FROM 0000 TO 2300 NZST RUNWAY 95/275 T

NUMBER OF OCCASIONS OF CROSSWINDS (KNOTS)

	CALMS	0-5	6-10	11-13	14-15	16-17	18-20	21-25	26-30	>30	TOTALS
JAN	1055	3984	1352	283	137	77	83	34	7		7012
FEB	970	3966	1080	199	62	46	65	38	20	1	6447
MAR	1471	3940	1159	224	117	64	56	30	3	5	7069
APR	1321	3981	1031	190	73	51	22	7			6676
MAY	1032	3824	1523	364	145	56	56	29	7		7036
JUN	966	3406	1623	474	140	62	47	14	1	1	6734
JUL	944	3406	1866	551	173	54	27	10	1	2	7034
AUG	801	4078	1605	423	136	53	34	13	1		7144
SEP	616	4332	1515	302	87	40	26	13	2	1	6934
OCT	728	4511	1361	300	89	37	27	4	2		7059
NOV	834	4230	1320	302	87	29	12	2			6816
DEC	937	4321	1270	292	113	62	26	10	2	3	7036
YEAR	11675	47979	16705	3904	1359	631	481	204	46	13	82997

RAROTONGA **TABLE A4**

PERIOD DECEMBER 1970 - DECEMBER 1980

WIND SUMMARY IN CONDITIONS OF REDUCED CEILING AND VISIBILITY

AUTUMN SEASON (MAR APR MAY)

TOTAL OBSERVATIONS USED 22 076

TABLE A — CRITERIA (CLOUD MORE THAN 4/8 BELOW 1500 FEET) (VISIBILITY LESS THAN 5000 METRES) EITHER OR BOTH

DIR IN 10 DEGREES / SPEED IN KNOTS	36-01	02-03	04-05	06-07	08-09	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	CALM	TOTAL
1 - 5	2	3	2		13	6	4	1	2	1	1		1				1	2		39
6 - 10	8	13	5	11	23	35	12	7	1	8	10		4	4	3	5		4		153
11 - 15	5	6	4	10	28	24	12	4	6	3	3	3	1	4	6	5	7	6		137
16 - 20	2	3	5	3	15	14	12	5	5	1	1	1	3	5	9	11	8	10		113
21 - 25	2	4		4	3	2	2	9	2	1	1	1	2	3	3	5	7	1		52
26 - 30	2	2		1	3		1	2		1			2		1	1	2			18
31 - 35	1																			1
36 - 40																				
OVER 40																				
TOTAL	22	31	16	29	85	81	43	28	16	15	16	5	13	16	22	27	25	23	62	575

TABLE B — CRITERIA (CLOUD MORE THAN 4/8 BELOW 1000 FEET) (VISIBILITY LESS THAN 3000 METRES) EITHER OR BOTH

DIR IN 10 DEGREES / SPEED IN KNOTS	36-01	02-03	04-05	06-07	08-09	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	CALM	TOTAL
1 - 5	1	1	1		1	1		1									1			7
6 - 10				2	4	6	3	3	1	2	2			1		1				25
11 - 15				1	5	5		1	4	1	3	1		2	1	1	1	2		28
16 - 20					5	2	2			1	1		1	2	2	1	2	1		20
21 - 25	1	1		2			2	5	2			1	2		2	2	3			23
26 - 30					1		1						2							4
31 - 35																				
36 - 40																				
OVER 40																				
TOTAL	2	2	1	5	16	14	8	10	7	4	6	2	5	5	5	5	7	3	20	127

TABLE C — CRITERIA (CLOUD MORE THAN 4/8 BELOW 700 FEET) (VISIBILITY LESS THAN 2000 METRES) EITHER OR BOTH

DIR IN 10 DEGREES / SPEED IN KNOTS	36-01	02-03	04-05	06-07	08-09	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	CALM	TOTAL
1 - 5		1	1					1												3
6 - 10					3	3	3	1			1			1						12
11 - 15				1	3	3		1	1	1	1	1		1				1		14
16 - 20					4		2						1		2		1	1		11
21 - 25		1		2			2	1	1			1	2				1			11
26 - 30					1		1													2
31 - 35																				
36 - 40																				
OVER 40																				
TOTAL		2	1	3	11	6	8	4	2	1	2	2	3	2	2		2	2	15	68

TABLE D — WIND SUMMARY (ALL OBSERVATIONS)

DIR IN 10 DEGREES / SPEED IN KNOTS	36-01	02-03	04-05	06-07	08-09	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	CALM	TOTAL
1 - 5	148	177	222	255	445	655	376	201	112	140	101	44	43	62	48	72	66	67		3234
6 - 10	238	399	436	645	1402	1428	830	372	203	246	183	133	133	156	145	136	143	206		7434
11 - 15	161	162	168	258	929	942	523	240	93	87	54	62	113	117	122	149	155	125		4460
16 - 20	75	49	21	36	229	326	196	71	39	20	13	14	34	34	44	71	104	102		1478
21 - 25	16	8	3	4	28	63	23	24	6	2	2	3	5	7	13	13	29	24		273
26 - 30	6	4		1	5	8	6	9	3	2	2	1	2		1	1	6	3		60
31 - 35	1					5												1		7
36 - 40						4	3	2												9
OVER 40							1		1											2
TOTAL	645	799	850	1199	3038	3431	1958	919	457	497	355	257	330	376	373	442	503	528	5119	22076

RAROTONGA **TABLE A6**

PERIOD DECEMBER 1970 - DECEMBER 1980

WIND SUMMARY IN CONDITIONS OF REDUCED CEILING AND VISIBILITY

SPRING SEASON (SEP OCT NOV)

TOTAL OBSERVATIONS USED 21 840

TABLE A

CRITERIA (CLOUD MORE THAN 4/8 BELOW 1500 FEET) ( ) EITHER OR BOTH (VISIBILITY LESS THAN 5000 METRES)

DIR IN 10 DEGREES / SPEED IN KNOTS	36-01	02-03	04-05	06-07	08-09	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	CALM	TOTAL
1 - 5	1	2	3	1	9	5	2	1		1								1		26
6 - 10	5	5	6	8	20	22	11	5	3	5		3	1		1	2	5	1		103
11 - 15	6	11	6	4	21	22	18	12	2	2	2	2	2		3	1	7	4		125
16 - 20	4	5	5	10	18	14	7	1	1	2			1		2	3	7	3		83
21 - 25			1		2	7	1	2		4			1	1				1		20
26 - 30						3	1	1	2	1										8
31 - 35					1		1								1					3
36 - 40					1															1
OVER 40					1															1
TOTAL	16	23	21	23	73	73	41	22	8	15	2	5	5	1	7	6	19	10	26	396

TABLE B

CRITERIA (CLOUD MORE THAN 4/8 BELOW 1000 FEET) ( ) EITHER OR BOTH (VISIBILITY LESS THAN 3000 METRES)

SPEED IN KNOTS	36-01	02-03	04-05	06-07	08-09	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	CALM	TOTAL
1 - 5		2			2	2														6
6 - 10	3	2		2	4	2							1				1	1		16
11 - 15	1		1	1	3	2	2		1			1	1		1		1	1		16
16 - 20				4	1	1	1		1						2	1	3	2		16
21 - 25														1						1
26 - 30																				
31 - 35					1										1					2
36 - 40																				
OVER 40																				
TOTAL	4	4	1	7	11	7	3		2			1	2	1	4	1	5	4	11	68

TABLE C

CRITERIA (CLOUD MORE THAN 4/8 BELOW 700 FEET) ( ) EITHER OR BOTH (VISIBILITY LESS THAN 2000 METRES)

SPEED IN KNOTS	36-01	02-03	04-05	06-07	08-09	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	CALM	TOTAL
1 - 5		2			2	1														5
6 - 10	1	2		2		2											1			8
11 - 15				1		2	2		1									1		7
16 - 20				1		1	1		1							1		1		6
21 - 25														1						1
26 - 30																				
31 - 35															1					1
36 - 40																				
OVER 40																				
TOTAL	1	4		4	2	6	3		2					1	1	1	1	2	4	32

TABLE D

WIND SUMMARY (ALL OBSERVATIONS)

SPEED IN KNOTS	36-01	02-03	04-05	06-07	08-09	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	CALM	TOTAL
1 - 5	77	113	128	169	297	373	349	191	127	131	67	29	28	24	29	22	35	63		2252
6 - 10	196	259	404	588	1373	1353	923	529	292	242	189	126	93	62	46	63	90	103		6931
11 - 15	98	179	186	361	1553	1672	917	304	166	120	76	100	70	33	36	49	112	84		6116
16 - 20	25	33	51	89	814	1057	420	79	37	46	11	13	25	5	15	32	60	35		2847
21 - 25	3	4	2	4	114	166	55	13	6	4	1	3	4	3	3	11	3	2		401
26 - 30	1				19	30	11	4	5	1		1		1		1				74
31 - 35	1				1	2	1								1					6
36 - 40					1	1														2
OVER 40					1	1														2

RAROTONGA **TABLE A3**

PERIOD DECEMBER 1970 - DECEMBER 1980

WIND SUMMARY IN CONDITIONS OF REDUCED CEILING AND VISIBILITY

SUMMER SEASON (DEC JAN FEB)

TOTAL OBSERVATIONS USED 22 412

TABLE A

CRITERIA (CLOUD MORE THAN 4/8 BELOW 1500 FEET) ((VISIBILITY LESS THAN 5000 METRES) EITHER OR BOTH

DIR IN 10 DEGREES / SPEED IN KNOTS	36-01	02-03	04-05	06-07	08-09	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	CALM	TOTAL
1 - 5	2	4	5	1	9	7	1	1	1	4	2		1	1	3			3		45
6 - 10	15	14	13	15	34	15	5	1	3	8	8	1	3	1	1	4	6	8		155
11 - 15	7	11	21	19	44	21	15	1	1	2	7			2	8	13	9	12		193
16 - 20	16	17	21	16	33	13	13	4		4	4	1	1	2	7	11	9	7		179
21 - 25	3	1	7	4	9	6	7	2			1		1	2	1	1	6	5		56
26 - 30	2	1	1		5	7	8	4	2			1			1	1	4	3		40
31 - 35						4	3	1								1	2	1		12
36 - 40						2	4	1					1							8
OVER 40																				
TOTAL	45	48	68	55	134	75	56	15	7	18	22	3	7	8	21	31	36	39	62	750

TABLE B

CRITERIA (CLOUD MORE THAN 4/8 BELOW 1000 FEET) ((VISIBILITY LESS THAN 3000 METRES) EITHER OR BOTH

DIR IN 10 DEGREES / SPEED IN KNOTS	36-01	02-03	04-05	06-07	08-09	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	CALM	TOTAL
1 - 5	1														1			1		3
6 - 10	2	1		4	4	3	1			1	4						1	1		22
11 - 15	3	1	2	4	19	2	2		1		2			1		3		6		46
16 - 20	1	4	5	2	11	1	3	1		3	2				2		1	2		38
21 - 25	2		4	2	5	1	4	1								1		1		21
26 - 30	1	1					1	4							1		3	1		12
31 - 35						1		1								1	2	1		6
36 - 40						1	4						1							6
OVER 40																				
TOTAL	10	7	11	12	39	9	15	7	1	4	8		1	1	4	5	7	13	9	163

TABLE C

CRITERIA (CLOUD MORE THAN 4/8 BELOW 700 FEET) ((VISIBILITY LESS THAN 2000 METRES) EITHER OR BOTH

DIR IN 10 DEGREES / SPEED IN KNOTS	36-01	02-03	04-05	06-07	08-09	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	CALM	TOTAL
1 - 5	1																			1
6 - 10	1			2	4		1				2									10
11 - 15	1		1	2	10	1	1		1		1			1		1		2		22
16 - 20			2	1	3		1	1		1	2						1	1		13
21 - 25	1		2				1											1		5
26 - 30		1						1									2			4
31 - 35						1											1			2
36 - 40						1	1						1							3
OVER 40																				
TOTAL	4	1	5	5	17	3	5	2	1	1	5		1	1		1	4	4	6	66

TABLE D

WIND SUMMARY (ALL OBSERVATIONS)

DIR IN 10 DEGREES / SPEED IN KNOTS	36-01	02-03	04-05	06-07	08-09	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	CALM	TOTAL
1 - 5	81	120	232	295	593	620	252	145	61	79	52	15	27	35	32	48	33	59		2779
6 - 10	272	357	603	1062	1893	1427	572	297	140	140	144	67	78	104	87	109	129	180		7661
11 - 15	193	192	260	463	1510	1031	564	158	72	78	47	54	81	54	55	114	117	143		5186
16 - 20	114	108	91	122	525	417	264	24	6	16	17	1	20	18	34	46	68	87		1978
21 - 25	26	10	19	11	43	54	29	3	1	1	3	7	1	6	10	16	12	29		281
26 - 30	14	4	5	2	17	15	20	8	3	1	3	4	3		3	1	7	11		121
31 - 35	1	1	1		1	8	4	1				1				1	2	2		23
36 - 40	1					4	5	1					1							12
OVER 40												1								1

RAROTONGA **TABLE A6** PERIOD DECEMBER 1970 - DECEMBER 1980

WIND SUMMARY IN CONDITIONS OF REDUCED CEILING AND VISIBILITY

WINTER SEASON (JUN JUL AUG) TOTAL OBSERVATIONS USED 22 079

TABLE A CRITERIA (CLOUD MORE THAN 4/8 BELOW 1500 FEET) EITHER OR BOTH
(VISIBILITY LESS THAN 5000 METRES)

DIR IN 10 DEGREES / SPEED IN KNOTS	36-01	02-03	04-05	06-07	08-09	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	CALM	TOTAL
1 - 5	1	2	1		2	3	2		1	3			2	2		1	1			21
6 - 10	7	6	4	8	11	10	10	14	6	11	6	6	2	7	1	1	1	1		112
11 - 15	2	13	18	11	19	15	13	13	1	11	8	6	2	5	1	3		4		145
16 - 20	4	2	6	6	30	22	12	8	5	7	4	2	2	3	2	1				116
21 - 25	2	1	2	1	13	7	8	5	1	4	1		2	3	2	1				53
26 - 30					6	2	5	2	1	1	1			2	1		1			22
31 - 35					1										1					2
36 - 40									1	2										3
OVER 40																				
TOTAL	16	24	31	26	82	59	50	42	16	39	20	14	10	22	8	7	3	5	28	502

TABLE B CRITERIA (CLOUD MORE THAN 4/8 BELOW 1000 FEET) EITHER OR BOTH
(VISIBILITY LESS THAN 3000 METRES)

SPEED IN KNOTS	36-01	02-03	04-05	06-07	08-09	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	CALM	TOTAL
1 - 5					2								2							4
6 - 10	1	3		1	3	2	1	1	1	3		1								17
11 - 15		3	2		6	1		1		2	3	1	1	1		2		2		25
16 - 20	1		2	2	3	3	1	1	1	2	2	2		1						21
21 - 25					3	2		2	1	4				2						14
26 - 30					1			1									1			3
31 - 35																				
36 - 40										2										2
OVER 40																				
TOTAL	2	6	4	3	18	8	2	6	3	13	5	4	3	4		2	1	2	6	92

TABLE C CRITERIA (CLOUD MORE THAN 4/8 BELOW 700 FEET) EITHER OR BOTH
(VISIBILITY LESS THAN 2000 METRES)

SPEED IN KNOTS	36-01	02-03	04-05	06-07	08-09	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	CALM	TOTAL
1 - 5													1							1
6 - 10	1	3		1	3					2										10
11 - 15		2	2		4	1		1		1	3			1		1		2		18
16 - 20			1		2	1			1	1	2	2								10
21 - 25					1			2		2				2						7
26 - 30								1												1
31 - 35																				
36 - 40										2										2
OVER 40																				
TOTAL	1	5	3	1	10	2		4	1	8	5	2	1	3		1		2	3	52

TABLE D WIND SUMMARY (ALL OBSERVATIONS)

SPEED IN KNOTS	36-01	02-03	04-05	06-07	08-09	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	CALM	TOTAL
1 - 5	70	106	103	124	247	428	321	272	208	214	131	42	32	42	43	52	64	51		2550
6 - 10	241	245	282	486	988	952	920	681	501	509	339	224	155	156	95	132	170	217		7293
11 - 15	150	206	249	291	1183	897	623	401	257	258	211	180	146	134	80	77	121	159		5623
16 - 20	28	46	72	93	580	511	285	122	74	61	43	63	81	67	37	31	30	35		2259
21 - 25	4	4	7	16	95	59	51	20	8	10	3	3	37	13	8	8	8	2		356
26 - 30			1		30	13	12	11	3	1	1	2	11	10	4	4	4			107
31 - 35					2	2	1	1							2					8
36 - 40									1	2						1				4
OVER 40																				
TOTAL	493	607	714	1010	3125	2862	2213	1508	1052	1055	728	514	462	422	269	305	397	464	3879	22079

RAROTONGA TABLE A7 PERIOD DECEMBER 1970 - DECEMBER 1980

JOINT PROBABILITIES IN CONDITIONS OF REDUCED CEILING AND VISIBILITY

NOTE : JOINT PROBABILITY (JP) IS THE PERCENTAGE OCCURRENCE OF REDUCED CEILING AND VISIBILITY FOR A PARTICULAR WIND CATEGORY. 0+ INDICATES A JP BETWEEN 0 AND 0.5.
REFERENCE SHOULD BE MADE TO TABLES A3 A,B,C, OR D FOR ACTUAL OCCURRENCES ON WHICH PERCENTAGES ARE BASED.

SUMMER SEASON (DEC JAN FEB) TOTAL OBSERVATIONS USED 22 412

TABLE A CRITERIA (CLOUD MORE THAN 4/8 BELOW 1500 FEET) ( ) EITHER OR BOTH (VISIBILITY LESS THAN 5000 METRES)

DIR IN 10 DEGREES / SPEED IN KNOTS	36-01	02-03	04-05	06-07	08-09	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	CALM
1 - 5	2	3	2	0+	2	1	0+	1	2	5	4		4	3	9			5	
6 - 10	5	4	2	1	2	1	1	0+	2	6	6	1	4	1	1	4	5	4	
11 - 15	4	6	8	4	3	2	3	1	1	3	15			4	15	11	8	8	
16 - 20	14	16	23	13	6	3	5	17		25	24	100	5	11	21	24	13	8	
21 - 25	12	10	37	36	21	11	24	67			33		100	33	10	6	50	17	
26 - 30	14	25	20		29	47	40	50	67			25			33	100	57	27	
31 - 35						50	75	100								100	100	50	
36 - 40						50	80	100					100						
OVER 40																			
CALM																			1

TABLE B CRITERIA (CLOUD MORE THAN 4/8 BELOW 1000 FEET) ( ) EITHER OR BOTH (VISIBILITY LESS THAN 3000 METRES)

SPEED IN KNOTS	36-01	02-03	04-05	06-07	08-09	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	CALM
1 - 5	1														3			2	
6 - 10	1	0+		0+	0+	0+	0+			1	3						1	1	
11 - 15	2	1	1	1	1	0+	0+		1		4			2		3		4	
16 - 20	1	4	5	2	2	0+	1	4		19	12				6		1	2	
21 - 25	8		21	18	12	2	14	33								6		3	
26 - 30	7	25					5	50							33		43	9	
31 - 35						13		100								100	100	50	
36 - 40						25	80						100						
OVER 40																			
CALM																			0+

TABLE C CRITERIA (CLOUD MORE THAN 4/8 BELOW 700 FEET) ( ) EITHER OR BOTH (VISIBILITY LESS THAN 2000 METRES)

SPEED IN KNOTS	36-01	02-03	04-05	06-07	08-09	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	CALM
1 - 5	1																		
6 - 10	0+			0+	0+		0+				1								
11 - 15	1		0+	0+	1	0+	0+		1		2			2		1		1	
16 - 20			2	1	1		0+	4		6	12						1	1	
21 - 25	4		11				3											3	
26 - 30		25						13									29		
31 - 35						13											50		
36 - 40						25	20						100						

JOINT PROBABILITIES IN CONDITIONS OF REDUCED CEILING AND VISIBILITY

NOTE : JOINT PROBABILITY (JP) IS THE PERCENTAGE OCCURRENCE OF REDUCED CEILING AND VISIBILITY FOR A PARTICULAR WIND CATEGORY. 0+ INDICATES A JP BETWEEN 0 AND 0.5.
REFERENCE SHOULD BE MADE TO TABLES A4 A,B,C, OR D FOR ACTUAL OCCURRENCES ON WHICH PERCENTAGES ARE BASED.

AUTUMN SEASON (MAR APR MAY) TOTAL OBSERVATIONS USED 22 076

TABLE A CRITERIA (CLOUD MORE THAN 4/8 BELOW 1500 FEET) (VISIBILITY LESS THAN 5000 METRES) EITHER OR BOTH

DIR IN 10 DEGREES / SPEED IN KNOTS	36-01	02-03	04-05	06-07	08-09	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	CALM
1 - 5	1	2	1		3	1	1	0+	2	1	1		2				2	3	
6 - 10	3	3	1	2	2	2	1	2	0+	3	5		3	3	2	4		2	
11 - 15	3	4	2	4	3	3	2	2	6	3	6	5	1	3	5	3	5	5	
16 - 20	3	6	24	8	7	4	6	7	13	5	8	7	9	15	20	15	9	10	
21 - 25	13	50		100	11	3	9	38	33	50	50	33	40	43	23	38	24	4	
26 - 30	33	50		100	60		17	22		50			100		100	100	33		
31 - 35	100																		
36 - 40																			
OVER 40																			
CALM																			1

TABLE B CRITERIA (CLOUD MORE THAN 4/8 BELOW 1000 FEET) (VISIBILITY LESS THAN 3000 METRES) EITHER OR BOTH

DIR IN 10 DEGREES / SPEED IN KNOTS	36-01	02-03	04-05	06-07	08-09	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	CALM
1 - 5	1	1	0+		0+	0+		0+									2		
6 - 10				0+	0+	0+	0+	1	0+	1	1			1		1			
11 - 15				0+	1	1		0+	4	1	6	2		2	1	1	1	2	
16 - 20					2	1	1			5	8		3	6	5	1	2	1	
21 - 25	6	13		50			9	21	33			33	40		15	15	10		
26 - 30					20		17						100						
31 - 35																			
36 - 40																			
OVER 40																			
CALM																			0+

TABLE C CRITERIA (CLOUD MORE THAN 4/8 BELOW 700 FEET) (VISIBILITY LESS THAN 2000 METRES) EITHER OR BOTH

DIR IN 10 DEGREES / SPEED IN KNOTS	36-01	02-03	04-05	06-07	08-09	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	CALM
1 - 5		1	0+					0+											
6 - 10					0+	0+	0+	0+			1			1					
11 - 15				0+	0+	0+		0+	1	1	2	2		1				1	
16 - 20					2		1						3		5		1	1	
21 - 25		13		50			9	4	17			33	40				3		
26 - 30					20		17												
31 - 35																			
36 - 40																			
OVER 40																			
CALM																			0+

RAROTONGA **TABLE A9** PERIOD DECEMBER 1970 - DECEMBER 1980

JOINT PROBABILITIES IN CONDITIONS OF REDUCED CEILING AND VISIBILITY

NOTE : JOINT PROBABILITY (JP) IS THE PERCENTAGE OCCURRENCE OF REDUCED CEILING AND VISIBILITY FOR A PARTICULAR WIND CATEGORY. 0+ INDICATES A JP BETWEEN 0 AND 0.5.
REFERENCE SHOULD BE MADE TO TABLES A5 A,B,C, OR D FOR ACTUAL OCCURRENCES ON WHICH PERCENTAGES ARE BASED.

WINTER SEASON (JUN JUL AUG) TOTAL OBSERVATIONS USED 22 079

TABLE A CRITERIA (CLOUD MORE THAN 4/8 BELOW 1500 FEET) ( ) EITHER OR BOTH (VISIBILITY LESS THAN 5000 METRES)

DIR IN 10 DEGREES / SPEED IN KNOTS	36-01	02-03	04-05	06-07	08-09	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	CALM
1 - 5	1	2	1		1	1	1		0+	1			6	5		2	2		
6 - 10	3	2	1	2	1	1	1	2	1	2	2	3	1	4	1	1	1	0+	
11 - 15	1	6	7	4	2	2	2	3	0+	4	4	3	1	4	1	4		3	
16 - 20	14	4	9	6	5	4	4	7	7	11	9	3	2	4	5	3			
21 - 25	50	25	29	6	14	12	16	25	13	40	33		5	23	25	13			
26 - 30					20	15	42	18	33	100	100			20	25		25		
31 - 35					50										50				
36 - 40									100	100									
OVER 40																			
CALM																			1

TABLE B CRITERIA (CLOUD MORE THAN 4/8 BELOW 1000 FEET) ( ) EITHER OR BOTH (VISIBILITY LESS THAN 3000 METRES)

DIR IN 10 DEGREES / SPEED IN KNOTS	36-01	02-03	04-05	06-07	08-09	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	CALM
1 - 5					1								6						
6 - 10	0+	1		0+	0+	0+	0+	0+	0+	1		0+							
11 - 15		1	1		1	0+		0+		1	1	1	1	1		3		1	
16 - 20	4		3	2	1	1	0+	1	1	3	5	3		1					
21 - 25					3	3		10	13	40				15					
26 - 30					3			9									25		
31 - 35																			
36 - 40										100									
OVER 40																			
CALM																			0+

TABLE C CRITERIA (CLOUD MORE THAN 4/8 BELOW 700 FEET) ( ) EITHER OR BOTH (VISIBILITY LESS THAN 2000 METRES)

DIR IN 10 DEGREES / SPEED IN KNOTS	36-01	02-03	04-05	06-07	08-09	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	CALM
1 - 5													3						
6 - 10	0+	1		0+	0+					0+									
11 - 15		1	1		0+	0+		0+		0+	1			1		1		1	
16 - 20			1		0+	0+			1	2	5	3							
21 - 25					1			10		20				15					
26 - 30								9											
31 - 35																			

RAROTONGA TABLE A10 PERIOD DECEMBER 1970 - DECEMBER 1980

JOINT PROBABILITIES IN CONDITIONS OF REDUCED CEILING AND VISIBILITY

NOTE : JOINT PROBABILITY (JP) IS THE PERCENTAGE OCCURRENCE OF REDUCED CEILING AND VISIBILITY FOR A PARTICULAR WIND CATEGORY. 0+ INDICATES A JP BETWEEN 0 AND 0.5.
REFERENCE SHOULD BE MADE TO TABLES A6 A,B,C, OR D FOR ACTUAL OCCURRENCES ON WHICH PERCENTAGES ARE BASED.

SPRING SEASON (SEP OCT NOV) TOTAL OBSERVATIONS USED 21 840

TABLE A CRITERIA (CLOUD MORE THAN 4/8 BELOW 1500 FEET) ( ) EITHER OR BOTH (VISIBILITY LESS THAN 5000 METRES)

DIR IN 10 DEGREES / SPEED IN KNOTS	36-01	02-03	04-05	06-07	08-09	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	CALM
1 - 5	1	2	2	1	3	1	1	1		1								2	
6 - 10	3	2	1	1	1	2	1	1	1	2		2	1		2	3	6	1	
11 - 15	6	6	3	1	1	1	2	4	1	2	3	2	3		9	2	6	5	
16 - 20	15	15	10	11	2	1	2	1	3	4			4		13	9	12	9	
21 - 25			50		2	4	2	15		100			25	33				50	
26 - 30						10	9	25	40	100									
31 - 35					100		100								100				
36 - 40					100														
OVER 40					100														
CALM																			1

TABLE B CRITERIA (CLOUD MORE THAN 4/8 BELOW 1000 FEET) ( ) EITHER OR BOTH (VISIBILITY LESS THAN 3000 METRES)

SPEED IN KNOTS	36-01	02-03	04-05	06-07	08-09	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	CALM
1 - 5		2			1	1													
6 - 10	2	1		0+	0+	0+							1				1	1	
11 - 15	1		1	0+	0+	0+	0+		1			1	1		3		1	1	
16 - 20				4	0+	0+	0+		3						13	3	5	6	
21 - 25														33					
26 - 30																			
31 - 35					100										100				
36 - 40																			
OVER 40																			
CALM																			0+

TABLE C CRITERIA (CLOUD MORE THAN 4/8 BELOW 700 FEET) ( ) EITHER OR BOTH (VISIBILITY LESS THAN 2000 METRES)

SPEED IN KNOTS	36-01	02-03	04-05	06-07	08-09	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	CALM
1 - 5		2			1	0+													
6 - 10	1	1		0+		0+											1		
11 - 15				0+		0+	0+		1									1	
16 - 20				1		0+	0+		3							3		3	
21 - 25														33					
26 - 30																			
31 - 35															100				
36 - 40																			
OVER 40																			
CALM																			0+