THE CLIMATE AND WEATHER

OF

WESTERN KIRIBATI

S.M. Burgess

New Zealand Meteorological Service
Wellington, New Zealand

The climate and weather of Western Kiribati

S M Burgess

N.Z. Met. Serv. Misc. Publ. 188(7)
ISSN 0110-6937

UDC 551/582 (968.2)

New Zealand Meteorological Service
PO Box 722
Wellington

CONTENTS

Note to 188 Series

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

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	(published)
188(4)	Climate and Weather of Tokelau	(published)
188(5)	Climate and Weather of Tonga	(published)
188(6)	Climate and Weather of Tuvalu	(published)
188(7)	Climate and Weather of Western Kiribati	(published)
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 WESTERN KIRIBATI

Summary

Western Kiribati's weather is governed chiefly by the seasonal movements of the intertropical convergence zone (ITCZ) and the equatorial doldrum belt (EDB).

Winds between north-east and south-east prevail throughout the year. During the drier months of the year (June to November) south-easterlies are more frequent than usual, while winds between north and east prevail during the wetter part of the year, from December to May. Winds are usually light and gales are rare. Strong winds are more frequent from between north-west and south-west and winds from these directions are usually associated with squally showery conditions.

Annual rainfall is not particularly high, except in the most northern islands of Butaritari and Makin. Monthly rainfalls are high from December through to May due to the presence of the ITCZ. Monthly and annual rainfall variability is large. Dry and wet periods may persist for several months.

Temperatures are constantly high with little annual variation. Together with high humidities this can often create uncomfortable conditions.

Sunshine hours are high throughout the year, especially between June and November when the mean cloud amount at most stations is only three to four octas.

1. INTRODUCTION

Three main island groups make up the republic of Kiribati, the Gilberts, Phoenix and Line Islands. There are 33 islands altogether, ten of which are coral atolls lying in the Pacific ocean between latitudes 5°N and 5°S, and longitudes 167°E-155°W (Fig.1). The total land area is only 710 square kilometres while the islands cover 5 million square kilometres. The islands are mainly flat rising no more than 4 m above sea level, except for Banaba, (formerly Ocean Island) which is an uplifted atoll 2 to 3 km across which rises to 81 m above sea level.

Tarawa is the most populated island in the Kiribati group with a population of approximately 20,000 people (DSIR, 1981).

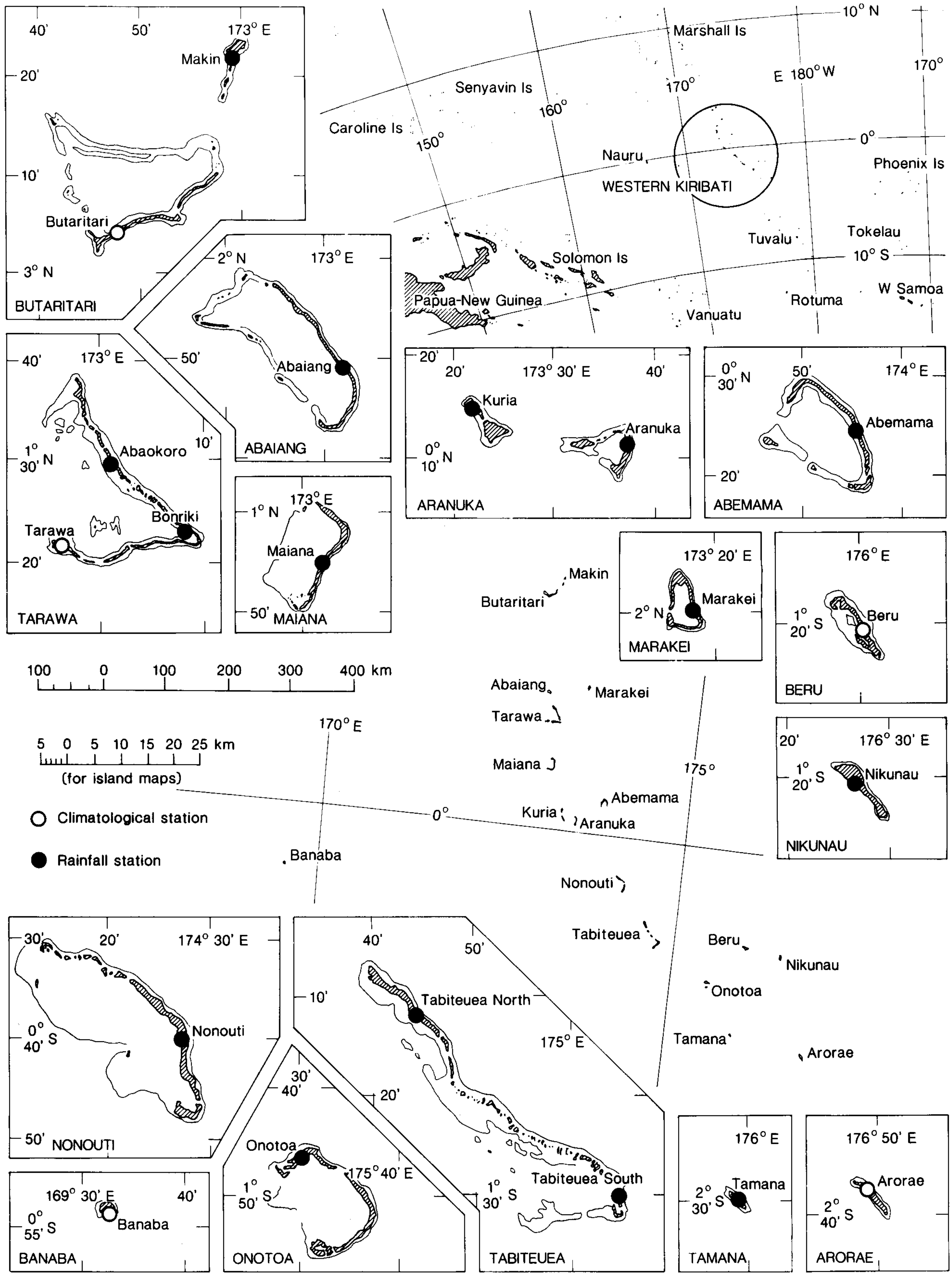


Fig. 1. Location of Western Kiribati and other stations in the group

The soils are very porous, consisting mainly of coral and sand. The soil layer is also thin, and little can be grown except bobai (taro), coconuts, and pandanus (Stirling,1978).

This climatology does not include the Phoenix or Line Island groups of Kiribati, which are east of 180°, hence the title 'The Climate of Western Kiribati' is used. The data used in this publication, when not otherwise indicated were obtained from the New Zealand Meteorological Service's archives. At present the Meteorological Service has twenty stations recording meteorological data in Western Kiribati. Of these only five make full daily climatological observations which include wind speed and direction, rainfall and temperature, and just three of these include barometric pressure. The remaining stations record only daily rainfall (Table 1). The earliest climatological observations began in 1903 at Banaba, 1907 at Abaiang, and in 1946 at Tarawa.

Table 1. Meteorological sites in Western Kiribati

Station index no	Name	Data period year began	Height (metres)	Remarks on site exposure
J60101	Little Makin	1977	3	Fair, sheltered W-S-E by trees
J60100	Butaritari*	1947	2	Poor, due to nearby trees
J60400	Marakei	1954	3	Fair, surrounded by trees
J60700	Abaiang	1907	3	Fair, sheltered to NE
J61001	Abaokoro	1977	2	Good
J61002	Bonriki	1982	3	Good
J61000	Tarawa*	1946	2	Good, coconut palms up to 15 m NW-NE
J61300	Maiana	1955	3	Good.
J61500	Abemama	1948	3	Fair, building NE-SE-SW
J61600	Kuria	1955	3	Good, sheltered NE-SE
J61700	Aranuka	1955	3	Good, sheltered to SW
J62000	Nonouti	1955	3	Very good

J53300	Banaba*	1903	66	Good, well exposed to prevailing w winds, sunshine recorder shaded by bush at angle 4° at sunrise and set
J62100	Tabiteuea N.	1958	3	Fair, sheltered by trees
J62400	Nikunau	1955	3	Fair
J62300	Beru*	1947	2	Fair, much enclosed to N and S due to trees up to 15 m. Casts doubt on representation of wind speed and direction
J62200	Tabiteuea S.	1960	3	Good
J62500	Onotoa	1953	3	Good, building to SE
J62600	Tamana	1950	3	Fair, sheltered by building NE-SE
J62900	Arorae*	1950	7	Poor, very enclosed by trees, outlook very limited, repre-sentativeness of wind rather doubtful

* = observations include wind speed and direction, rainfall and temperature

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 shorter time-scales, the time-averaged state is characterised by four main features. These are:

(i) The subtropical high pressure zone

This is a belt of high pressure which spans the South Pacific and is centred on the latitudes 25° to 30°S. Within this zone in the eastern South Pacific is a large semi-permanent anticyclone located at 90° to 100°W. On the western margin of the belt of high pressure, anticyclones move eastwards into the Pacific region from the Australia-Tasman Sea. A belt of high pressure centred on latitudes 25° to 30°N also spans the North Pacific Ocean.

(ii) Trade winds

On the equatoral sides of these high pressure belts there is an extensive region where the winds blow consistently from the same general direction. These "trade winds" blow from the easterly quarter. They have a mean strength of 10 kn, but may occasionally reach 25 to 30 kn*.

(iii) The equatorial doldrum belt and intertropical convergence zone

The equatorial doldrum belt is a region of relatively light winds that is present throughout the year in the Western Pacific Ocean. This belt lies within 5° of the equator and is in general an area of high rainfall and great seasonal variability (Revell,1981). The resultant winds are light and reflect in part the alternating periods of easterlies and westerlies (Thompson,1985).

From December through to February the EDB is furthest south and there is usually a trough of low pressure which extends from Northern Australia and into the Coral sea on the southern fringe of the doldrums. This trough is known as the "Monsoon trough".

The monsoon westerlies usually produce a few days of squally unsettled weather, followed by a fine spell. These contrasting conditions are sometimes referred to as the disturbed and undisturbed monsoon. In some years the monsoon westerlies are frequent in Kiribati while in other years they may occur on only a few days.

From June to August the doldrum zone lies principally in the Northern hemisphere, and the Australian monsoon trough is absent.

In the zone between the convergence of the North and South Pacific trade winds, lies the intertropical convergence zone, an extensive area of cloud and showers caused by the ascent of air, although the intensity fluctuates with time. The ITCZ follows the passage of the sun, with a lag of about three to four months (Wyrtki and Meyers, 1975) and varies in width from 30 to 500 km (Fig.2.). The ITCZ normally lies just to the north of Kiribati at approximately 5°N, and is usually 'broken' (i e. the cloud band is often not continuous) in the vicinity of 170°E, where it merges with the EDB.

* One knot equals 0.515 m/s or 1.85 km/h.

(iv) The South Pacific convergence zone (SPCZ)

The SPCZ is an area of convergence between the equatorial easterly winds and the higher latitude south-easterlies. It is area of cyclonic wind shear, and is a semi-permanent feature in the southern hemisphere. The SPCZ usually extends from Tuvalu to the Austral Islands in the east.

Because this zone is usually located between 200 to 700 km south of the equator, it has no real effect on the climate of Kiribati. Weather conditions are governed mainly by the movement of the EDB and the ITCZ. Figs. 3 and 4 show typical circulation of the south-west Pacific.

Effect of the southern oscillation index (SOI) on the ITCZ

The southern oscillation index was discovered by a British climatologist (Sir Gilbert Walker) in 1932. He noticed that when surface pressures were anomalously high in the Indonesian region, they were also correspondingly low in the South Pacific and vice versa (Ward, 1983). Trenberth's index of the southern oscillation is used here and is defined as the difference between Tahiti and Darwin pressures, normalised by subtracting the monthly mean pressure difference then dividing by the monthly mean standard deviation of the pressure difference (units are standard deviations) (Gordon, 1985).

When the averaged SOI for the year is negative, the ITCZ moves closer to the equator and the cloudy EDB tends to move southwards. At Kiribati, surface winds are then more frequent from south-west through north-west to north-east, and there are heavier and prolonged falls of rain. When the average SOI for the year is positive, dry easterlies are more predominant than usual.

Tropical cyclones

Tropical cyclones rarely form within 5° of the equator as the Coriolis force is close to zero. There are often also zones of strong vertical wind shear. For this reason there are no records of tropical cyclones having occurred in Kiribati, although gale force* west to north-west winds do sometimes occur when cyclonic systems are developing to the south.

* Mean speed greater than 33 kn

3. CLIMATIC ELEMENTS

Wind

North-easterly or easterly winds are the most common. Easterlies are dominant throughout the year but north-easterlies have a high frequency from December through to May, when the ITCZ tends to be closest to Kiribati. South-easterlies are most frequent between June and November.

The occurrence of winds between north-west and south-west is also of special interest because of their effect on the rainfall regime.

Observations of both wind direction and speed are made daily at 6 am at both Butaritari and Beru, and at 9 am at Tarawa, Banaba, and Arorae. Tarawa is the only climatological station in Kiribati which has an anemometer, and it is therefore the most reliable station for wind data. The exposure of the climatological sites at Butartari, Beru, and Arorae is restricted by the close proximity of coconut palms and breadfruit trees, some being 15 m in height. As the wind at these stations is also estimated, the representativeness of the wind observations may be rather doubtful.

Wind constancy. Wind constancy values are defined as being the percentage of observations in which the wind direction is within 40° of the most frequent direction. For Tarawa, based on hourly observations, this value is high (Table 2).

Wind constancy is least from September through to February. From September to November/December winds between north-west and south-west reach their highest frequency, while from December to February winds between north and east prevail.

Table 2. Most frequent wind directions and wind constancy values for Tarawa (1978-82), based on hourly observations

	Direction (deg)	Frequency (per cent)	Constancy value
Sep-Nov	090	12	49
Dec-Feb	090	11	51
Mar-May	090	14	60
Jun-Aug	090	14	56
Year	090	13	54

Seasonal variation of winds. While winds between north-east and south-east prevail throughout Kiribati (frequency 55-75 per cent), seasonal differences of winds are governed largely by the position of the ITCZ and EDB.

During the wetter part of the year (December to May) wind directions are often more variable, and winds between north and east are more frequent than usual as the ITCZ and EDB are at their furthest point south. North-easterlies prevail on the northern side of the ITCZ while more variable winds occur in the EDB.

During the drier part of the year (June to November) both the ITCZ and the EDB are situated to the north of the islands and south-easterlies are more frequent. Table 3 shows monthly wind frequencies at Tarawa and Fig. 3 shows the seasonal variation of surface winds over Western Kiribati.

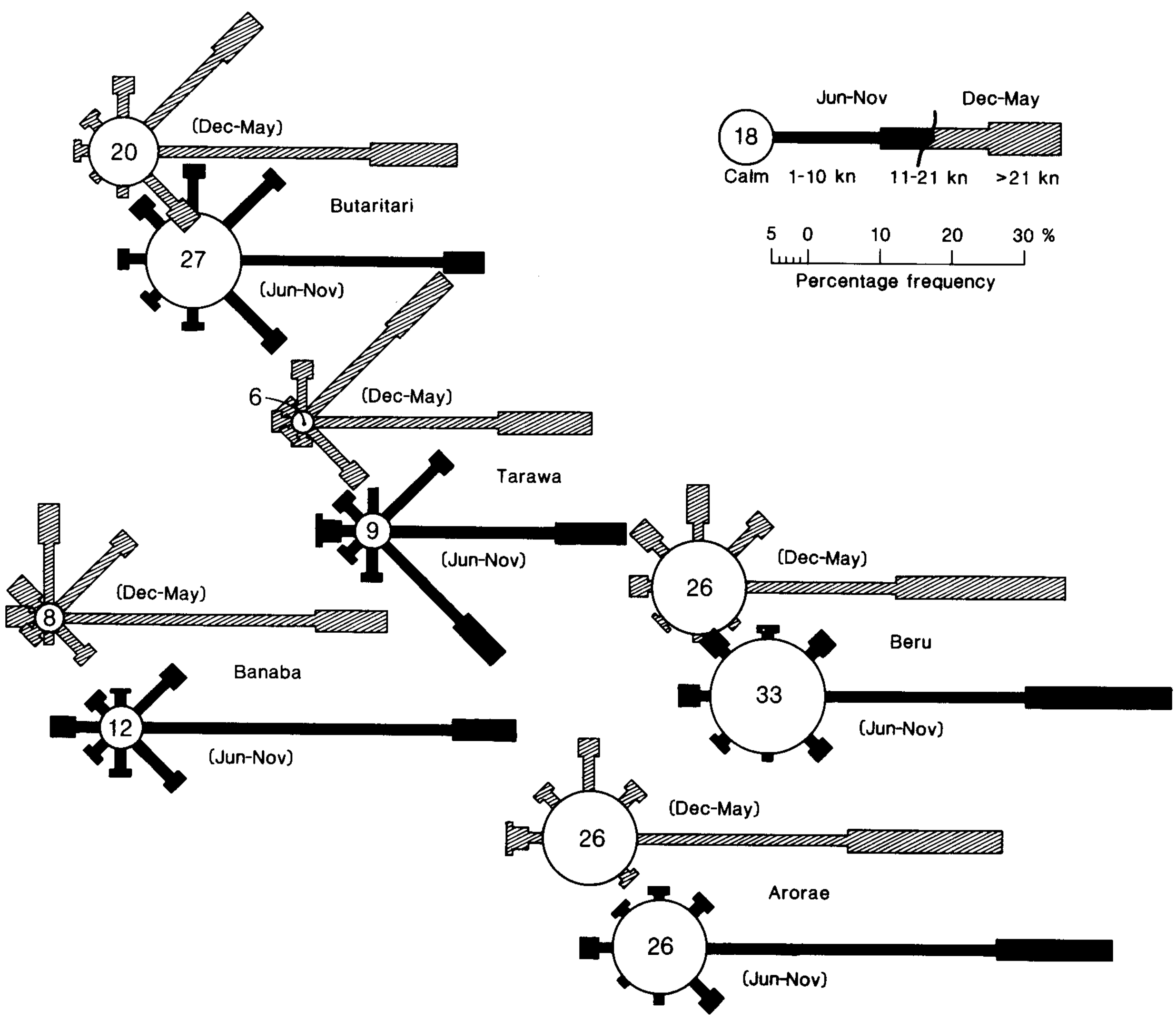


Fig. 3. Seasonal wind roses for Western Kiribati (1977-84), based on 9 a.m. observations

Table 3. Monthly wind frequencies (percentage) for Tarawa (1978-83) (based on hourly observations)

	N	NE	E	SE	S	SW	W	NW	Calm
Jan	14	32	34	6	1	2	1	2	8
Feb	11	43	30	4	1	1	1	1	8
Mar	12	30	34	10	1	2	2	41	5
Apr	9	26	42	7	2	1	2	4	7
May	7	19	42	12	4	2	2	3	9
Jun	6	15	42	15	5	1	2	3	11
Jul	4	12	34	16	4	5	8	4	13
Aug	3	6	35	17	6	4	6	6	17
Sep	2	6	36	18	4	5	13	6	10
Oct	4	8	26	14	8	7	11	6	16
Nov	4	12	31	17	5	3	11	8	9
Dec	12	26	23	9	4	2	4	6	14
Year	7	20	34	12	4	3	5	4	11

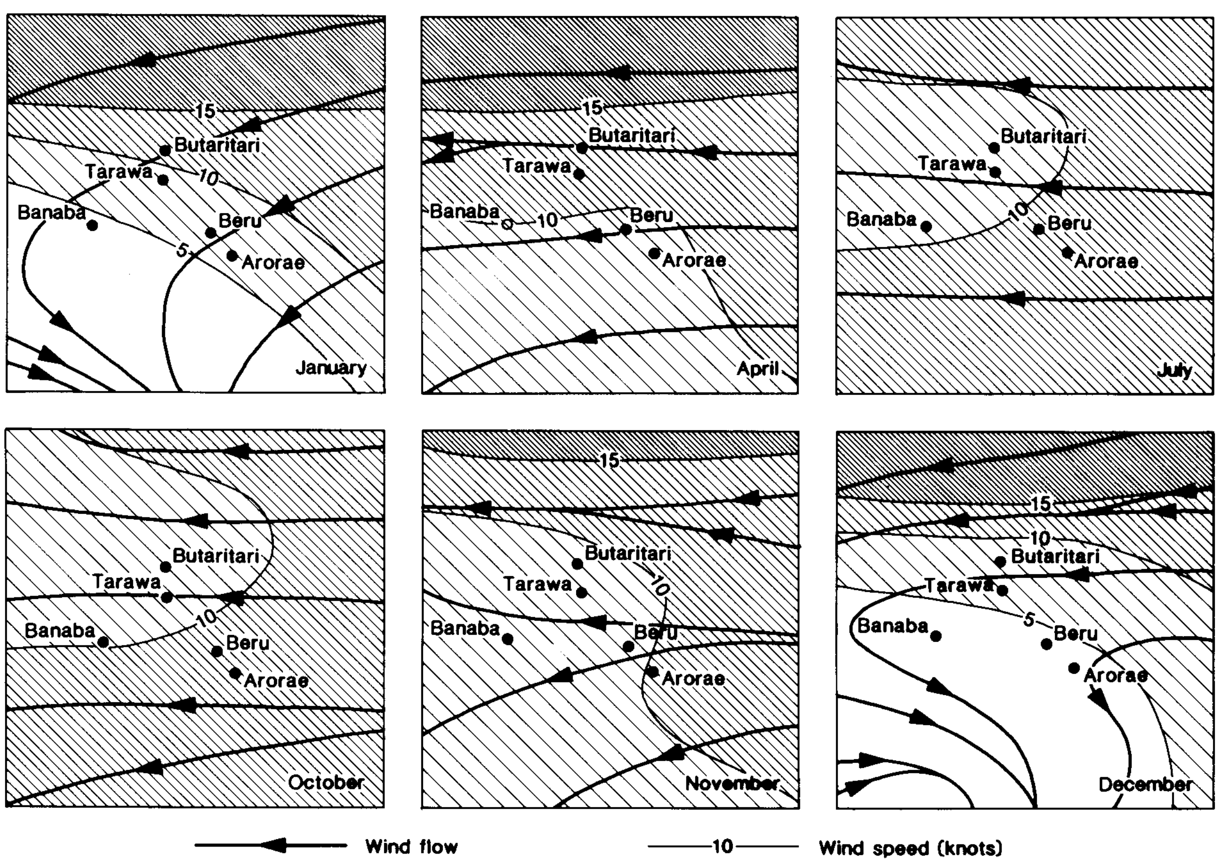


Fig. 4. Profiles of the mean wind flow over Western Kiribati for January, April, July, October, November, and December (adapted from Sadler,1970)

Fig. 4 shows profiles of the mean wind flow over Western Kiribati for different months of the year. From June to November the prevailing easterlies are generally divergent, while from November through to May they show more convergence. This is very marked between November and December when there is an increase in rainfall throughout the island group.

Easterlies. Winds between north-east and south-east average 50-65 per cent when they are at their minimum frequency, and from 60-85 per cent when they are most frequent. Their frequency varies throughout the year but is usually least from September to November/December to the north of the equator, and from November to January to the south of the equator when north-west to south-west winds are at their maximum.

Easterlies and the SOI. The annual frequency of easterlies varies from year to year in phase with the SOI, from 25 to 75 per cent (Fig.5). When the average SOI for the year has a positive value the easterlies are in nearly all cases more frequent than usual. With negative values they are less frequent; winds having a relatively high frequency from south-west through north-west to north-east.

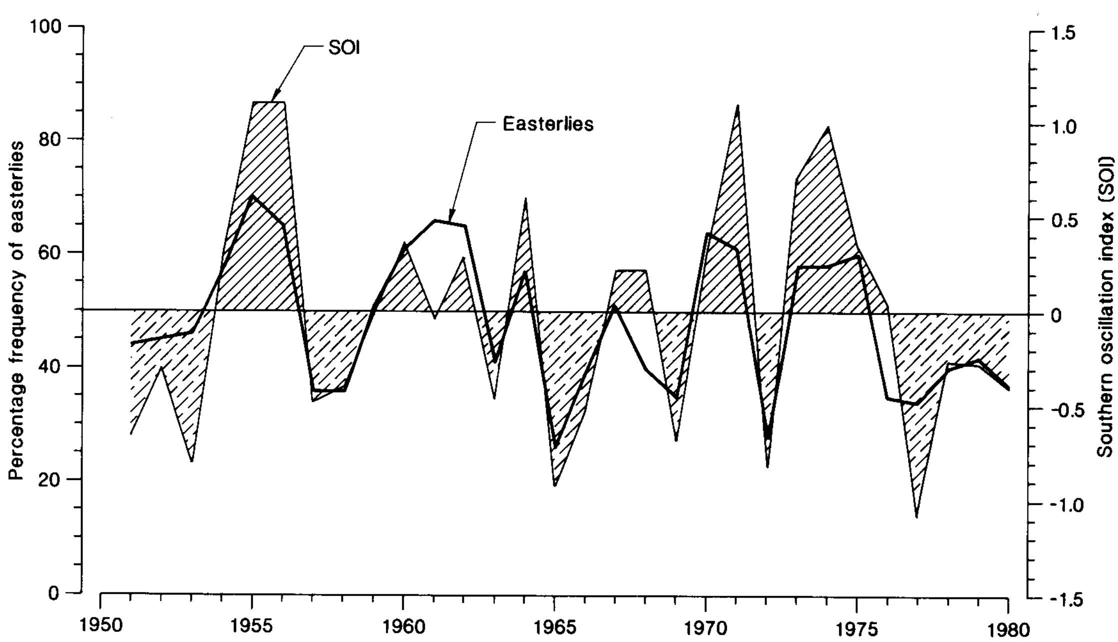


Fig. 5. Annual frequency of easterlies and SOI values for Tarawa (1951-80)

The correlation between the SOI and annual frequency of easterlies is 0.82 . This is extremely significant at a level beyond 99.9 per cent. The regression equation for the data from 1951-80 is y = 16.9x + 49.2, where x is the average SOI for the year and y represents the annual frequency of easterlies expressed as a percentage. When the annual SOI is high, i.e. + 1.0 then easterlies for that year would have a frequency of approximately 66 per cent, while if it is low, i.e. -1.0 the frequency would be about 32 per cent.

<u>North-easterlies and South-easterlies</u>. These winds have a large effect on the rainfall regime. North-easterlies are associated with the increase in monthly rainfall for the wetter part of the year from December through to May. The change to more frequent north-easterlies in December is generally quite marked. North-easterlies usually prevail on the northern side of the ITCZ and bring showery conditions and high rainfalls.

A change to frequent south-easterlies (Table 4) occurs in different months, being April in Arorae where the dry season is longer, June at Tarawa, July at Banaba, and in August at Butaritari. South-easterlies usually bring dry sunny weather.

Table 4. Percentage frequencies of north-easterlies and south-easterlies, (1977-84) based on observations made at 6 a.m.*, and 9 a.m.

Month	Butaritari* NE/SE	Tarawa NE/SE	Bananba NE/SE	Beru* NE/SE	Arorae NE/SE
Jan	24 / 11	30 / 12	15 / 3	9 / 0	6 / 1
Feb	24 / 9	32 / 12	13 / 6	10 / 1	5 / 2
Mar	23 / 13	34 / 9	17 / 3	8 / 0	4 / 0
Apr	18 / 7	20 / 13	12 / 4	6 / 3	2 / 6
May	14 / 10	22 / 14	15 / 8	4 / 1	4 / 4
Jun	15 / 8	17 / 21	12 / 5	3 / 2	4 / 3
Jul	8 / 7	17 / 20	6 / 6	3 / 1	2 / 5
Aug	9 / 11	8 / 23	6 / 12	5 / 5	2 / 5
Sep	8 / 10	10 / 25	7 / 6	2 / 4	4 / 5
Oct	10 / 11	10 / 25	10 / 10	4 / 5	5 / 6
Nov	6 / 15	12 / 23	10 / 11	11 / 1	6 / 4
Dec	20 / 6	24 / 12	14 / 7	7 / 2	4 / 3
Year	15 / 10	20 / 17	11 / 7	6 / 2	4 / 4

Westerlies. Winds between north-west and south-west are usually associated with the north-west monsoon, and their frequency varies out of phase with the SOI. In some years they may not occur while in other years they may be evident in all months.

Winds between north-west and south-west have an average frequency of 7 to 11 per cent. They usually increase in frequency from July, to reach a maximum during November/December (Table 5). The mean monthly rainfall is at its minimum from September to November when they are most frequent. Although they are associated with the north-west monsoon and bring most of the rainfall during these months, their frequency of occurrence is relatively low.

Winds between north-west and south-west are at their minimum during May, north of the equator and in June to the south of the equator. Their frequency drops sharply from November to December to the north of the equator. This is also associated with an increase in rainfalls and more frequent north-easterlies in December, and is due to the southwards movement of the ITCZ. South of the equator the frequency of winds between north-west and south-west drops markedly from December to January.

Table 5. Frequency (per cent) of winds between north-west and south-west, (1977-84) based on observations made at 6 a.m.*, and 9 a.m.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Butaritari*	2	1	2	1	1	3	14	10	15	13	15	8	7
Tarawa	6	3	6	4	3	8	12	12	16	17	17	13	10
Banaba	9	8	15	12	5	3	9	9	13	17	19	19	11
Beru*	13	10	10	6	4	4	7	7	12	12	16	28	11
Arorae	9	6	8	4	4	1	2	3	9	9	13	18	7

Winds between north-west and south-west are usually associated with broken altocumulus and scattered cumulus cloud, with showers and squally conditions followed by a brief fine period.

Wind speed. Mean wind speeds average 5.7 kn from June to August (July being the least windy month for most of the islands), and 7-10 kn from December to February (Table 6). There is no significant geographical variation of the surface wind strength over the islands, mainly because of the vast ocean area and no high land areas. Because of the restricted exposure of the climatological sites at Butaritari, Beru, and Arorae, actual mean wind speeds may be greater than those listed.

Table 6. Mean monthly wind speeds (kn) at 6 a.m.*, and 9 a.m., (July 1978-May 1983)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Butaritari*	8	8	8	7	6	6	5	5	6	6	7	7	7
Tarawa	9	10	10	9	9	7	7	7	9	9	9	8	9
Banaba	7	8	8	7	7	6	6	6	8	8	8	7	7
Beru*	9	9	9	8	7	7	7	7	7	7	8	9	8
Arorae	8	8	8	7	6	6	5	6	8	7	8	8	7

During May and June mean wind speeds rarely exceed 15 kn. Strong winds, 22-27 kn are not common and only occur two or three days each year. Winds of near gale force or greater strength (at least 28 kn) occur on average only one day per year.

The maximum gust recorded from the anemometer at the Tarawa meteorological office was 52 kn from 280° on November 18th 1982. However, the anemograph was only installed in 1979. The strongest winds recorded at Banaba were those estimated by a meteorological observer on the 22nd and 25th of February 1911, being Beaufort force 10 (48-55 kn) from the south-west and west respectively.

South-easterly and north-easterly winds are generally about the same strength (4-10 kn), but at Banaba north-easterlies are usually stronger (7-10 kn) than south-easterlies (4-6 kn).

On most of the islands 60 to 80 per cent of strong winds or greater are between north-west and south-west. Strong winds seldom occur from June through to August. The frequency of calms is relatively high, being 20 per cent between June and November, and 15 per cent between December and May. These are estimates based on 9 a.m. surface wind observations.

As Tarawa is the only station with an anemometer, wind records are more reliable there, and calms at 9 a.m. have a frequency of 9 per cent between June and November, and 6 per cent from December through to May.

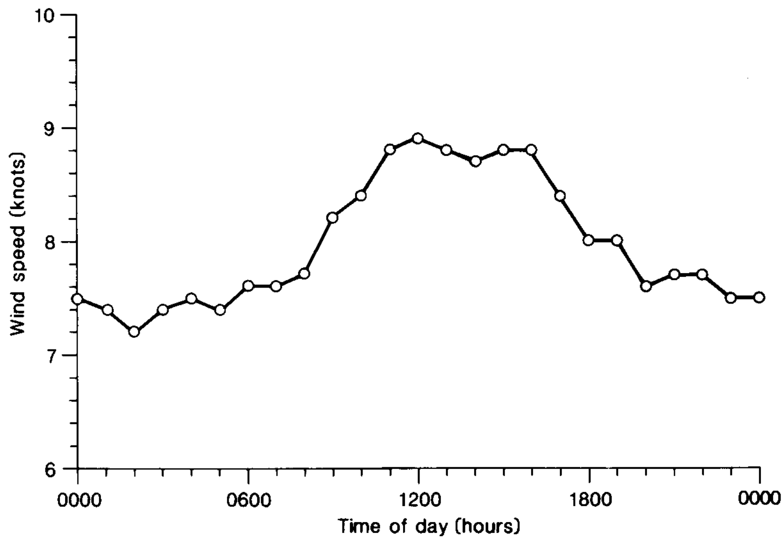


Fig. 6. Mean hourly wind speed at Tarawa (1979-82)

Diurnal variation of wind. At Tarawa the diurnal variation of wind speed is very small. It is usually least windy at about 2 am and most windy in the early afternoon (Fig. 6). The prevailing wind direction has little variation throughout the day. However, from September to November winds from between 110-130° are more frequent during the afternoon than at other times of the day when the prevailing wind is usually between 080-100°. Winds are more variable during the afternoons.

Rainfall and Wind Direction. Table 7(a) shows wind frequencies at Tarawa for drier and wetter than normal years. Table 7(b) represents wind frequencies for November when winds between north-west and south-west have their highest frequency. This analysis shows that easterlies and south-easterlies are more frequent than usual in the drier years. In drier than normal years winds between north-west and south-west are rare. Light winds are much more frequent in the wetter years, with a decrease in the frequency of easterlies and more winds from south-west through north-west to north-east.

Table 7(a). Wind frequencies at 9 a.m. and rainfall at Tarawa for drier and wetter than normal years

	Wind direction									Average
	N	NE	E	SE	S	SW	W	NW	Calm	Rainfall
1951-80 (17 years) Drier than normal years (per cent)	2	11	58	16	2	0	1	1	9	1353mm
1951-80 (13 years) Wetter than Normal years (per cent)	6	15	37	10	4	2	4	3	19	2835mm
Normal	4	13	48	13	3	1	2	2	14	1991mm

Table 7(b). Wind frequencies at 9 a.m. and rainfall at Tarawa for drier and wetter than normal Novembers

	Wind direction									Average
	N	NE	E	SE	S	SW	W	NW	Calm	Rainfall
1951-80 (19 years) Drier than normal years (per cent)	3	10	48	23	3	0	0	0	13	39 mm
1951-80 (11 years) Wetter than Normal years (per cent)	9	9	25	12	6	6	12	6	15	246mm
Normal	3	9	38	19	6	3	6	3	13	115mm

Tables 8 and 9 show the percentage of rainfall and its frequency for different wind directions in January and October, normally the wettest and driest months respectively.

Most of the rainfall (52 per cent) between December and May comes from winds between north and east. Winds between north-west and south-west are much less frequent during these months, but when they do occur they often bring heavier rainfall than winds between north and east.

During the drier months of the year (June to November) the ITCZ has little effect on the weather and most of the rainfall (47 per cent) comes with winds between south and west.

Table 8. Wind direction and rainfall data for Tarawa, based on hourly observations (Januaries 1979-83)

	Wind direction								
	N	NE	E	SE	S	SW	W	NW	Calm
Wind Frequency (per cent)	14	32	34	6	1	2	1	2	8
Total rainfall (mm)	98	140	220	45	19	57	99	52	158
Obs. with rain	45	7	90	21	11	24	18	10	46
Total obs.	487	1185	1280	198	21	66	42	21	270
Percentage of monthly rainfall	11	16	24	5	2	7	11	6	18
Rainfall frequency (percentage)	9	7	7	11	52	36	43	48	17

Table 9. Wind direction and rainfall data for Tarawa, based on hourly observations (Octobers 1978-83)

	Wind direction								
	N	NE	E	SE	S	SW	W	NW	Calm
Wind frequency (per cent)	4	8	26	14	8	7	11	6	16
Total rainfall (mm)	25	73	78	75	99	82	129	20	79
Obs. with rain	9	13	33	19	27	21	45	21	16
Total obs.	136	298	947	490	278	248	398	210	554
Percentage of monthly rainfall	4	11	12	11	15	12	20	3	12
Rainfall frequency (percentage)	7	4	4	4	10	9	11	10	3

Wind Energy. Because average wind speeds are low, power generation using wind is not viable. The annual average wind energy density for the region based on ship reports is approximately 140 to 160 Watts per square metre at 15 m above mean sea level (Schroeder and Hori,1982).

Rainfall

Rainfall in the tropics has large annual and seasonal variability. High rates of evaporation and the characteristics of tropical rainfall can pose particular problems. Rainfall is markedly seasonal in character and is probably the most important factor influencing agriculture (Jackson,1977). At certain times of the year some areas may have excessive rainfall leading to high surface runoff, while at other times the availability of water may be greatly reduced causing serious drought and crop failure. Kiribati has no rivers or lakes so rainfall is of vital importance. Rainwater is stored in tanks and fresh water can be obtained from underground wells, but when prolonged dry spells occur these supplies can become low (DSIR,1981).

Rainfall intensities tend to be high and rainfall is usually localised. Most of the tropical rain results from convection in cumulus and cumulonimbus clouds. Air masses are very warm and humid and large amounts of rain may fall in a very short time.

Annual Seasonal and Monthly Rainfalls. There is a large variation in mean annual rainfalls over Kiribati. A notable zone of lower rainfall (less than 1500 mm per annum) exists near the equator and extends eastwards from 170°E (Fig. 7a). The islands of Butaritari and Makin, only 350 km to the north of Tarawa have much higher annual rainfalls, in the vicinity of 3000 mm.

Although the islands of Butaritari and Makin can expect substantial rainfalls in nearly all years, the other islands of the group are subject to abnormally dry years (Table 10). High annual rainfalls are associated with low values of the averaged SOI for the year while low rainfalls occur when the SOI is high.

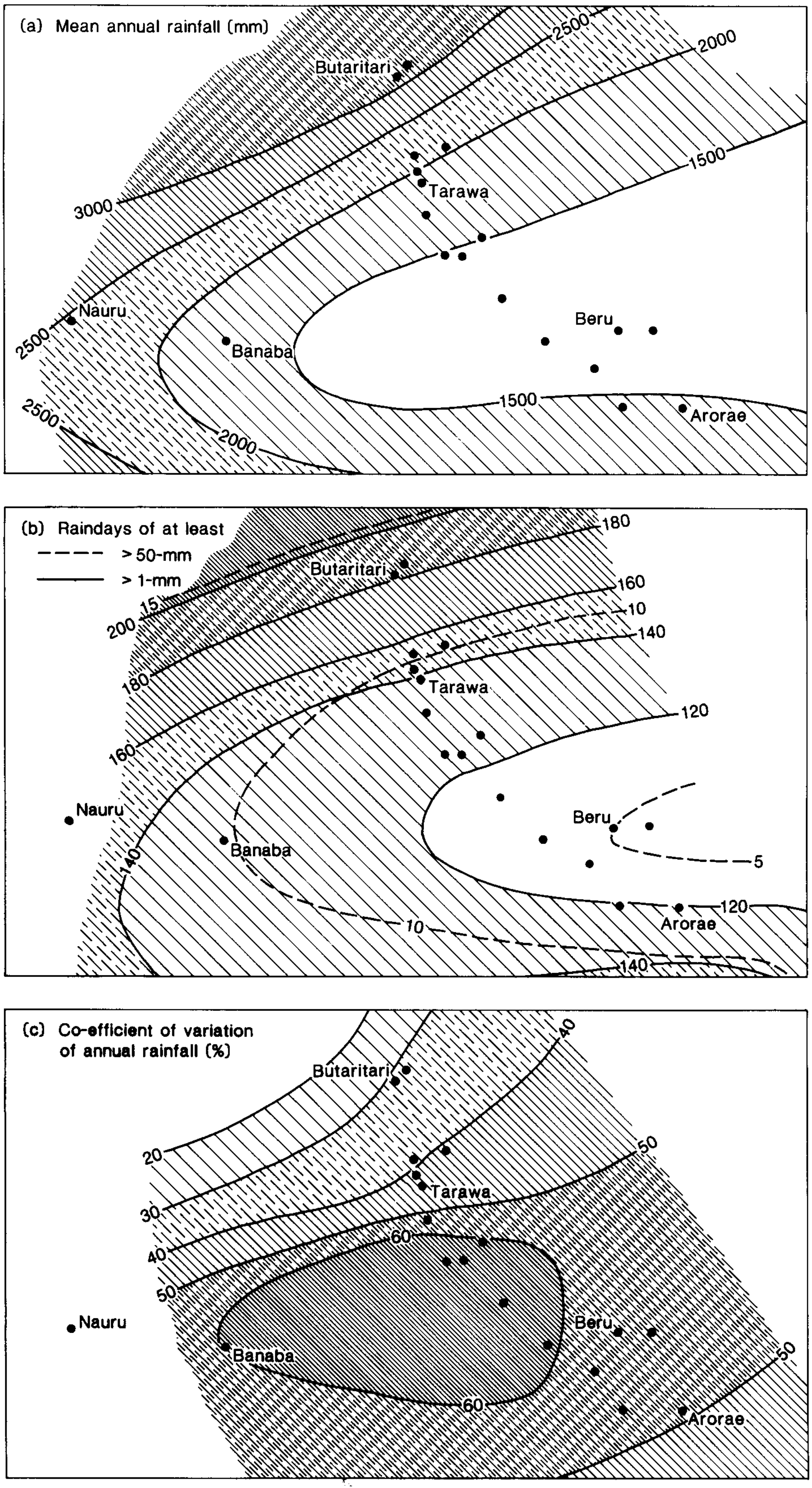
Table 10. Record annual rainfalls (mm)

Station	Period	Annual rainfall highest	/ year	SOI	Annual rainfall lowest	/ year	SOI
Butaritari	1945-84	4365	1959	0	1447	1950	16
Tarawa	1947-84	3452	1972	-8	395	1950	16
Banaba	1905-84	4448	1919	-1	362	1917	2
Beru	1945-84	3085	1972	-8	247	1950	16
Arorae	1951-84	3100	1972	-8	375	1962	2

The period of lowest mean monthly rainfalls generally begins in February in Beru and Arorae in the south, and in April in Tarawa and Banaba where it is slightly shorter. In Butaritari the low rainfall period usually begins much later in August.

Throughout the islands there is a marked change in mean monthly rainfall towards the end of the year. December's rainfall is often 100 per cent greater than that of November. All the islands have a slight secondary rainfall maxima in July.

Fig. 7. (a) Selected features of annual rainfall over Western Kiribati (1951-80).



(b) Average annual raindays of at least 1.0 and 50.0 mm

(c) Coefficient of variation of annual rainfall (per cent) over Western Kiribati.

The driest months are generally September and October (Table 11),and the wettest month is in January except for the islands of Butaritari and Makin where rainfall is highest during March. Over all of the islands 60 to 65 per cent of the annual rainfall occurs between December and May, and 35 to 40 per cent of the annual rainfall is received during June to November (Table 12).

Table 11. Monthly and Annual Rainfall (mm) 1951-80,

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Butaritari	291	334	380	337	297	264	278	220	163	158	204	301	3227
Tarawa	304	227	234	172	137	132	149	116	113	99	114	194	1991
Banaba	271	226	172	144	114	103	118	101	89	110	108	215	1771
Abemama	221	189	135	138	85	101	119	96	88	81	96	184	1533
Beru	205	127	101	99	91	84	113	100	72	68	83	147	1290
Arorae	232	139	114	148	124	93	132	108	98	73	97	192	1550

Table 12. Percentage of Rainfall for December to May, and June to November (1951-80)

Station	percentage of rainfall Dec-May	Jun-Nov
Butaritari	60	40
Tarawa	64	36
Banaba	64	36
Beru	60	40
Arorae	61	39

Raindays. The average number of raindays with rainfalls of 1.0 mm or more has a similar geographical variation to that of the mean annual rainfalls, in that the number of raindays are greatest to the north (Fig. 7b).

In general, raindays of at least 1.0 mm are fairly evenly spread throughout the year (10 to 12 per month), being greater in Butaritari and Makin, except for the months September to November when only 6 to 9 days per month occur. There is a notable increase in December, when the number of days with this amount of rainfall range from 14 to 18 days. Days with falls of at least 50.0 mm are not uncommon (Table 13). At Banaba 8 out of the 10 days per annum when rainfalls of this nature occur, are between December and May.

Table 13. Average annual number of raindays of at least 5.00 mm

Station	Period	Dec-May	Jun-Nov
Butaritari	1945-83	7.8	4.3
Tarawa	1946-83	6.1	2.6
Banaba	1971-83	7.7	2.3
Beru	1945-83	3.3	2.4
Arorae	1971-83	5.6	2.5

Rainfall variability and reliability. Rainfall variability (or coefficient of variation) is defined as the ratio of the standard deviation to the annual mean. It is usually expressed as a percentage. Annual rainfall variability for Western Kiribati is approximately 50 per cent for most of the islands (Fig. 7c). Butaritari is an exception and has an annual variability of only 24 per cent, where substantial rainfall can be relied upon throughout the year. The annual variability is greatest near Nonouti in the dry zone (65 per cent per annum), where for 9 months of the year it is over 100 per cent.

Monthly variability of rainfall is high in the islands which receive less than 1500 mm per annum. The monthly rainfall variability often exceeds 100 per cent resulting in rainfalls which are very much higher, or lower, than normal. It is greatest between September and November (Fig.12.), and there is a sharp decrease in December.

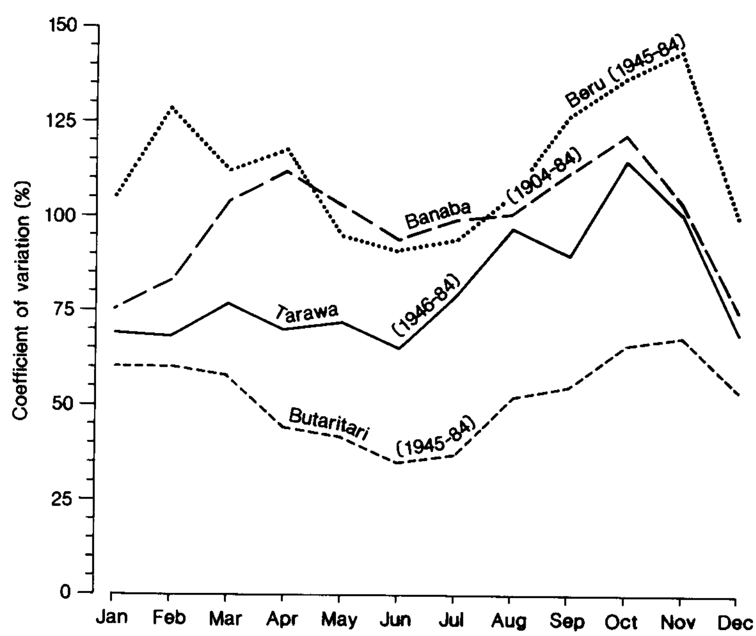


Fig. 8. Co-efficient of variation of monthly rainfall (per cent)

The 10 and 90 percentile values (Fig.13) together with the maximum and minimum values show further the large monthly variability. For example, at Tarawa in October the 90 percentile values show that one October in every ten will have a rainfall of greater or equal to 308 mm, and the 10 percentile value shows that one October in every ten will be likely to have a total of 4 mm or less.

The greatest amount of rain recorded in Western Kiribati in one month was 1240 mm during April 1966, at Little Makin Island. The second highest, 914 mm, was in January 1931 at Banaba. The heaviest rainfalls of any duration are most likely in January and February, and are very much greater in intensity than heavy falls which occur between April and November.

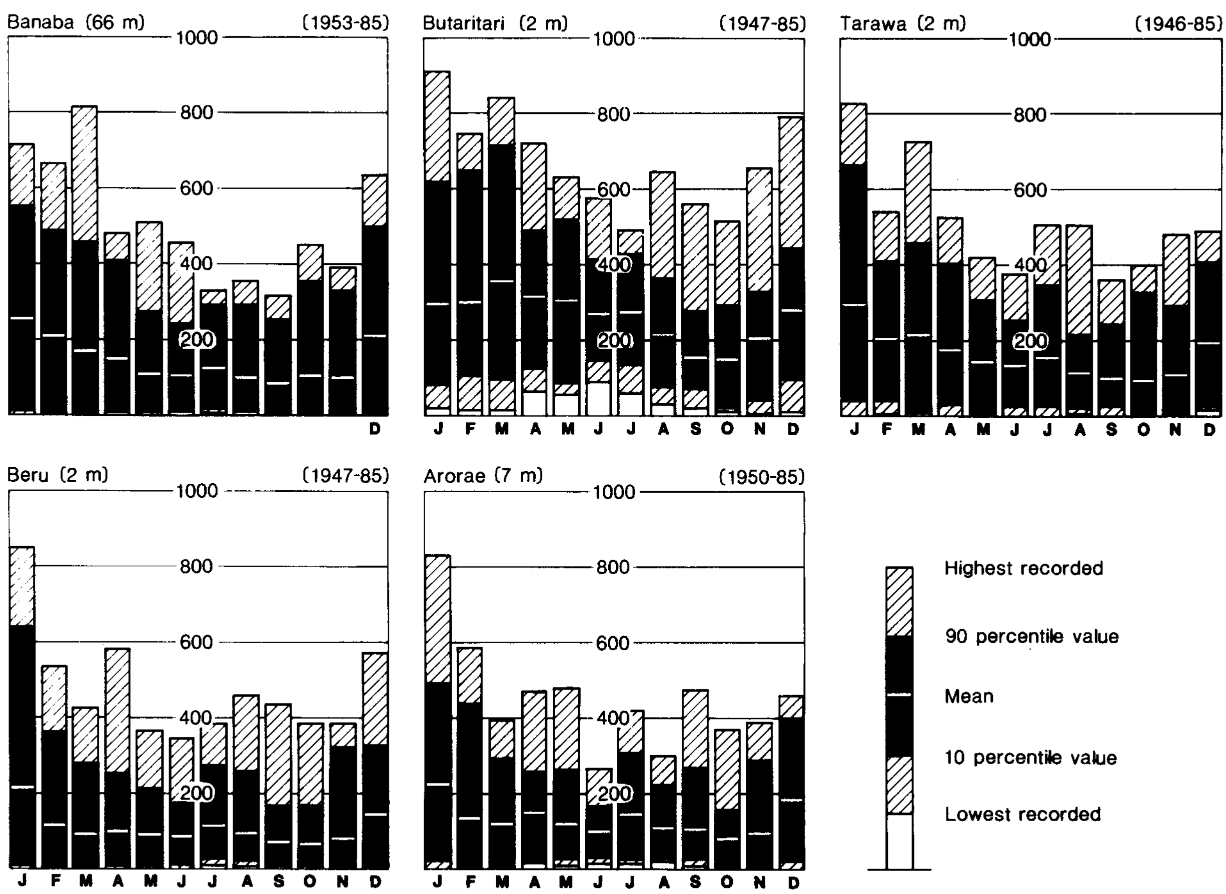


Fig. 9. Monthly variation of rainfall

<u>The SOI and its effect on wet and dry years at Tarawa.</u> When annual rainfall departures from normal are compared with the average SOI (as shown in section 2) for each year it is found that there is a very good correlation between the two. For the period from 1951-80 the correlation co-efficient was -0.83. This is significant at the 0.1 per cent level.

Rainfall is usually above normal in cases when the SOI is negative, and below normal when the SOI is positive (Fig. 10), thus varying out of phase with the SOI. The regression equation for the data is y = -61.1x + 99.0, where x represents the average monthly SOI for the year and y represents the percentage of normal of the annual rainfall. If the SOI is high, i.e. + 1.0 the annual rainfall for the year would be approximately 38 per cent of normal, while if it was low, i.e. -1.0 then the annual rainfall would be about 160 per cent of normal.

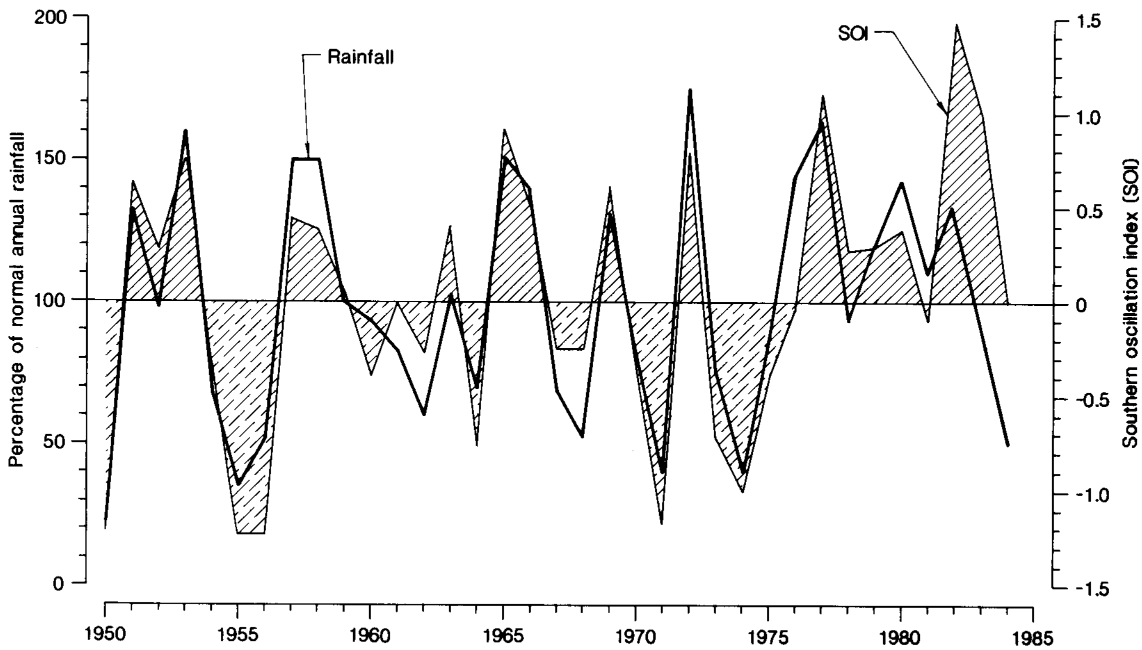


Fig. 10. Annual rainfall and SOI values for Tarawa (1951-80)

From month to month the association between the SOI and the monthly percentage of rainfall is not so marked. The correlation coefficient for monthly values of the SOI and rainfalls from 1951-1984 was -0.525. The correlation is at its maximum when the rainfall lags the SOI by zero to one month. This means that the SOI and rainfall are both sharply coupled, and their fluctuation takes place almost simultaneously.

In some cases with low values of SOI the monthly rainfall was well below average. In all cases of very high monthly values of the SOI of at least + 2.0 the monthly rainfalls have been well below normal.

Abnormal rainfall. Abnormal rainfall is defined as a departure from normal of at least 50 per cent (Seelye, 1950). Tarawa rainfall records from 1946 to 1984 show that abnormally wet and dry months tend to be persistent and that abnormally dry periods are more frequent than wet periods.

In the northernmost islands of Butaritari and Makin, rainfall is more reliable. Periods of abnormally high rainfall are more frequent than those of low rainfall and are of lesser duration (Table 14).

Table 14. Frequency of run lengths of abnormally wet and dry periods

Duration Months	Tarawa (1946-84) Wet periods	Dry periods	Butaritari (1945-84) Wet periods	Dry periods
1	20	27	46	24
2	8	15	13	2
3	7	5	2	3
4	5	5	nil	5
5	5	nil	nil	nil
6	1	1	nil	2
7	nil	3	nil	nil
8	nil	nil		
9	nil	2		
10	nil	1		
11	nil	nil		
12	nil	1		
Total	48	60	61	36

Persistence of wet and dry months. From August 1949 to September 1984, 64 per cent of months had below normal rainfall at Tarawa. Of these the average number of consecutive drier and wetter than normal months was 3 and 2 respectively. It should be noted that periods of extreme rainfall can last beyond a year. Drier than normal periods persisted for up to 20 consecutive months in the period between August 1949 to March 1951 (average SOI 0.9), and the longest persistence of wet months was 11, from June 1965 to April 1966 (average SOI -1.2). During the dry period only 39 per cent of the average rainfall fell, while in the wetter period 192 per cent fell, averaging 319 mm per month.

<u>Periods of low rainfall</u>. A drought is defined as a period of more than fourteen days without rain. A dry period is a period of more than fourteen days with less than 1 mm of rain daily. The variation in occurrence of drought and dry spells is greater than usual over the island group, especially as the distance from the northernmost to the southernmost islands is only 750 km and is over the ocean. Table 15 presents the longest recorded periods of low rainfall in Western Kiribati.

In Butaritari the lowest rainfall in any single month was 7mm, recorded in November 1973. Only one period of drought has occurred in the 40 years since rainfall records began there, and this was for only 15 days in October 1978. The longest dry spell has been a period of only 23 days.

In the southern islands from Banaba to Nikunau dry periods are much more frequent and of longer duration. They are most likely in September, October and November, but can occur at any time of the year. A period of 97 days without rain occurred at Beru Island from 31 December 1973 to 6 April 1974, and the longest period, 122 days with less than 1 mm of rain per day was at the same station.

Table 15. The longest recorded spells of low rainfall in Western Kiribati

Station	Drought days	Period	Dry spell days	Period
Beru	97	31/12/73 - 06/04/74	122	06/12/73 - 06/04/74
Onotoa	96	01/01/74 - 06/04/74	96	01/01/74 - 06/04/74
Banaba	89	21/10/73 - 17/01/74	104	21/10/73 - 01/02/74
Arorae	83	24/12/73 - 16/03/74	97	23/12/73 - 29/03/74
Aranuka	53	14/02/71 - 07/04/71	97	01/01/71 - 07/04/71
Abemama	50	17/02/71 - 07/04/71	51	16/02/71 - 07/04/71
Maiana	48	20/08/79 - 06/10/79	52	15/02/71 - 07/04/71
Tarawa	38	29/09/78 - 05/11/78	60	29/09/78 - 27/11/78
Butaritari	15	01/10/78 - 15/10/78	23	05/10/73 - 01/02/74

At Tarawa there have been 7 periods between 1946 and 1984 when the total rainfall for two consecutive months has been less than 15 mm; these are shown in Table 16.

Table 16. Two month periods at Tarawa with less than 15mm rainfall (1947-84)

Months	Year	Rainfall (mm)
Feb, Mar	1950	8
Oct, Nov	1955	13
Apr, May	1968	4
Sep, Oct	1970	5
Jul, Aug	1973	14
Mar, Apr	1974	13
Oct, Nov	1975	6

Diurnal rainfall. The diurnal rainfall pattern for Tarawa (Fig. 11) shows a maximum of rainfall during the early hours of the morning and a minimum between 8 am and noon; this is a feature of most small low lying tropical islands. An analysis of hourly rainfall data for Tarawa showed that 54 per cent of the rain fell between the night' hours of 8 p.m. to 8 a.m. This regime is caused by night-time convection which is the result of a steepened lapse rate as the upper troposphere is cooled by radiation losses, mainly from the tops of clouds, while the lower layers of the atmosphere remain warm by close contact with the sea surface (Nieuwolt, 1977). This effect would be greatest near dawn. During the day direct absorption of solar radiation heats up the lower layers of the troposphere faster than the sea surface. This creates stability at low levels and a minimum of rainfall occurs (Nieuwolt, 1977).

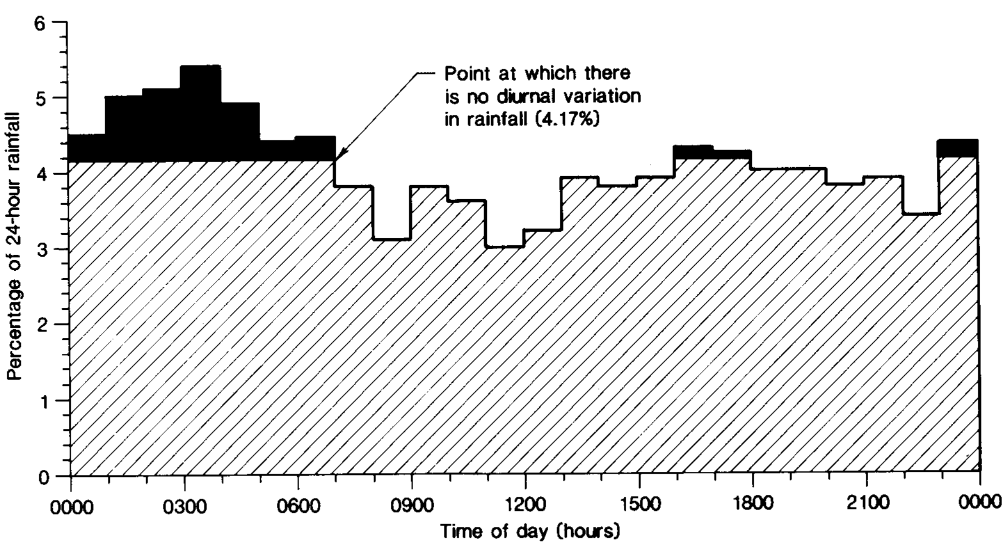


Fig. 11. Diurnal variation of rainfall at Tarawa (based on 23 years of observations between 1951 and 1984)

Short term rainfalls. As maximum daily rainfalls are measured between fixed hours (9 a.m. to 9 a.m.), the ratio of maximum 24 hour rainfall to maximum one-day rainfall may vary from year to year. The average value of this ratio was found to be 1.14 (Coulter and Hessell, 1980). This is the factor by which the calculated daily rainfalls, for the selected return periods of ten and fifty years were multiplied to produce the figures in Table 17. A return period of ten years represents the average interval between the years which contain 24 hour rainfalls of at least the amount shown.

Table 17. Extreme maximum, mean annual maximum 24 hour rainfalls, mm,(9 a.m.-9 a.m.) and return period rainfall for 10 and 50 years (Hessell and Ereckson., 1980., Coulter, 1980)

Station	Period	Extreme maximum	Mean annual maximum	V per cent	R10	R50
Little Makin	1955-75	237	143	32	218	290
Butaritari	1971-80	354	172	39	296	412
Marakei	1954-74	202	103	44	177	248
Abaiang	1950-73	217	118	33	181	240
Tarawa	1946-80	222	134	41	219	301
Maiana	1954-76	173	111	27	158	204
Abemama	1945-75	264	124	42	206	285
Kuria	1955-76	282	114	55	216	315
Aranuka	1954-73	165	102	51	187	268
Nonouti	1953-75	167	95	36	150	202
Banaba	1953-76	246	109	52	200	287
Beru	1971-80	198	132	43	236	334
Nikunau	1953-76	175	86	40	141	194
Onotoa	1953-76	190	97	36	153	207
Arorae	1971-80	206	130	39	223	310

V = variability per cent, of annual maximum
R10 / R50 = average interval of 10 years / 50 years between the years which contain 24 hour augmented rainfalls of at least the amount shown

Maximum one and two-day rainfalls (Table 18) at most stations show a marked difference between March and April and October/November or November/December. At most of the islands maximum one-day rainfalls range between 200 to 250 mm.

Table 18. Maximum 24 and 48 hour rainfalls, mm, (9 a.m. - 9 a.m.),

Station	Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Butaritari	24hr	296	135	136	90	108	77	93	94	64	96	77	192	296
1971-80	48hr	354	252	229	139	155	109	128	110	80	127	142	230	354
Tarawa	24hr	202	222	189	183	149	83	117	111	80	80	160	115	222
1946-80	48hr	240	233	300	201	179	105	125	126	88	116	216	172	300
Banaba	24hr	246	225	186	94	89	96	62	97	102	105	58	110	246
1971-80	48hr	257	241	246	109	139	112	84	118	138	130	108	161	257
Beru	24hr	191	137	156	82	198	73	75	82	95	91	58	93	198
1971-80	48hr	231	157	199	141	205	108	92	93	123	100	98	169	231
Arorae	24hr	94	115	114	68	76	70	84	67	154	64	206	146	206
1971-80	48hr	144	154	214	106	117	86	97	72	157	84	206	16	214

Banaba and Tarawa are the only stations where reliable short term duration records are available from an automatic raingauge. Maximum short term rainfalls are possibly greater in the areas that have higher annual rainfalls, such as Butaritari and Makin Island, and lesser in the drier zone near Beru Island.

Heavy short duration rainfalls are very common due to the convectional type clouds and large moisture capacity of the air. Totals of 20 to 25 mm in one hour are common in the period from December to March (Table 19).

Out of 101 observations at Tarawa from 1971 to 1984 (when the 24 hour 9 a.m. - 9 a.m. rainfalls were at least 50 mm), 58 per cent of the rainfalls of at least 50 mm occurred when winds were between north-east and south-east, and 21 per cent when winds were between north-west and south-west.

Table 19. Maximum rainfalls (mm) for short durations

Time	Tarawa	Banaba
10 min	28	21
30 min	51	55
1 hour	88	102
2 hour	102	123

Hourly observations of rainfall at Tarawa from 1969-84 show that the average intensity of rainfall is 6.7 mm per hour. This is classified as 'heavy', and on average rain falls for only 3.4 per cent of the time. The average daily rainfall of at least 0.1 mm and average duration at Tarawa are listed in Table 20.

Table 20. Duration of rainfall and daily amounts for Tarawa, using hourly data for rainfall and days of duration of at least 0.1 mm (1969-84), based on an average intensity of 6.7 mm per hour

Tarawa	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average duration per month (hours)	46	34	35	26	21	20	22	17	17	15	17	29	299
Average rainfall per rainday (mm)	18	16	14	10	9	9	9	8	10	10	11	13	11

Evapotranspiration and water balance

Evapotranspiration. Evaporation takes place over water and land areas when soils and rocks or the vegetation cover are wet after recent precipitation, or when the ground water is reasonably close to the surface (Nieuwolt, 1977). Transpiration is the process by which water from vegetation is transferred into the atmosphere in the form of vapour (WMO, 1984). Evapotranspiration is the amount of water which is transferred from the soil to the atmosphere by evaporation and plant transpiration (WMO, 1984). These figures are high in the tropics because of the large capacity of the air to hold water vapour and the large amount of heat for evaporation and transpiration (solar radiation) and convection.

Evaporation pans indicate the potential evapotranspiration expressed in units of water depth (WMO, 1984). Because of their small evaporating surface they often indicate higher values, and a correction factor of 0.73 is required to make them comparable with areas of open water (N.Z. Met. Serv., 1982).

Evaporation rates are high in March and September (Table 21) when the sun reaches its highest elevation at noon, and lowest in June, with a secondary minima in December.

At Tarawa the pan evaporation exceeds the rainfall from April to November and the annual pan evaporation is also higher than the annual rainfall.

Table 21. Mean monthly and annual pan evaporation (mm), at Tarawa (1981-86)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
205	201	218	191	183	167	174	204	208	212	193	188	2344

Annual pan evaporation varies only slightly in the geographical location of Kiribati, averaging between 2300 to 2500 mm. This gives an average daily evaporation of 6 to 7 mm per day.

<u>Water Balance</u>. Water balance studies give a general overview of the water conditions in an area. All of the Western Kiribati islands have at least six months or more when the potential evapotranspiration exceeds the monthly rainfall, except for those to the north of Tarawa where there are only two or three months from September to November.

In the dry months when rainfall is less than the potential evaporation, actual evaporation equals rainfall (Fig. 12). In the wetter months where rainfall exceeds the potential evaporation, this allows the soil moisture to recharge followed by utilisation in succeeding dry months (Jackson, 1977).

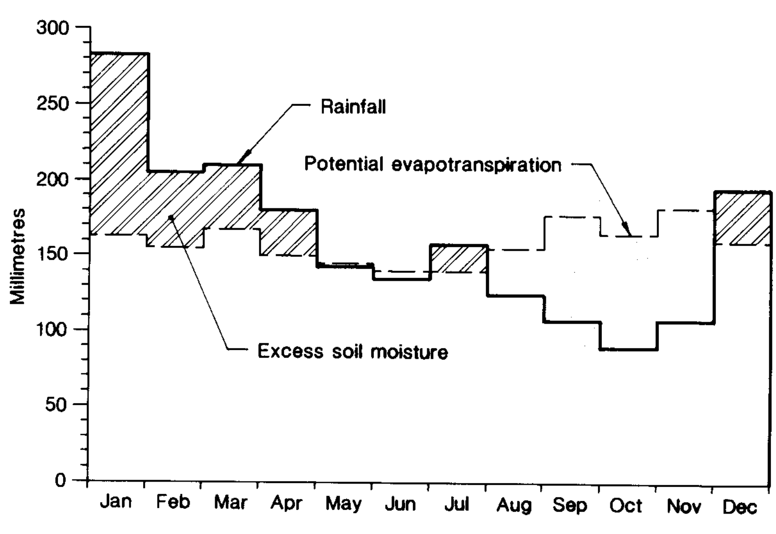


Fig. 12. Tarawa water balance for a soil moisture capacity of 140 mm

At most of the islands from September through to November, for a soil with an available water capacity of 140 mm (representative of coral soils) there are more than 50 to 60 days when on average the soil moisture deficit is less than fifty per cent (75 mm). Such reductions of soil moisture are rare at any time during the year at Butaritari. Mean monthly water balance statistics are given in table 22.

Table 22. Monthly water balance summary (available soil capacity 140 mm)

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Butaritari 1945-85	PE	163	156	169	149	150	142	143	157	181	173	175	158	1916
	RR	275	268	341	281	291	296	280	225	134	146	201	296	3034
	WPD	20	11	10	7	4	1	0	7	15	47	38	4	164
	ND	4	2	2	1	1	0	0	2	3	10	7	1	33
	RO	135	114	186	128	140	145	141	99	16	33	33	110	1280
	NR	5	5	7	6	6	7	8	6	2	1	2	5	60
Tarawa 1947-85	PE	164	154	72	152	149	142	144	156	179	170	178	158	1918
	RR	284	202	214	179	145	136	160	124	104	90	110	194	1942
	WPD	33	29	39	31	32	33	31	47	83	94	92	49	593
	ND	7	6	8	7	7	8	8	11	16	18	17	11	124
	RO	137	83	87	58	37	33	45	34	19	22	19	45	619
	NR	5	3	4	3	2	2	2	2	1	1	1	2	28
Bananba 1971-85	PE	160	153	172	150	149	141	143	156	184	178	180	161	1927
	RR	272	219	213	161	122	129	151	130	89	125	113	253	1977
	WPD	33	38	55	56	49	33	33	53	92	87	83	51	663
	ND	7	7	11	13	12	8	8	11	16	16	15	11	135
	RO	141	116	110	76	24	7	32	44	21	13	25	86	695
	NR	5	4	4	3	1	1	2	2	1	1	2	3	29
Beru 1945-85	PE	172	164	177	158	158	148	151	165	187	179	183	167	2009
	RR	167	108	93	93	110	115	122	118	83	79	67	189	1344
	WPD	68	80	98	74	68	60	71	77	111	114	128	69	1018
	ND	14	14	19	16	16	14	16	16	20	21	22	13	201
	RO	63	38	19	11	11	21	40	35	21	16	11	64	350
	NR	2	2	1	1	0	1	2	1	1	1	1	2	15

Arorae	PE	172	161	175	153	155	144	142	161	190	178	186	165	1982
1971-85	RR	225	154	167	182	126	120	166	119	142	89	111	252	1853
	WPD	39	55	63	22	36	40	34	44	74	90	120	39	656
	ND	7	10	12	5	8	10	9	9	13	17	21	8	129
	RO	105	70	52	44	21	14	43	10	44	18	22	86	529
	NR	4	3	2	2	1	1	2	1	2	1	1	4	24

PE = potential evapotranspiration (mm)
RR = mean monthly rainfall (mm)
WPD = wilting point deficit (mm)
ND = days of deficit
RO = runoff (mm)
NR = days of runoff

Sunshine and solar radiation

Sunshine. Campbell-Stokes sunshine recorders are located at both Banaba and Tarawa. The sunshine records for both stations cover only a short period, and these statistics are shown in Table 23.

At Tarawa 304 hours of sunshine were recorded in both July 1978 and August 1981. This is equal to 86 and 87 per cent respectively, of the total sunshine possible during these months. At both sites sunshine hours have a monthly variation from average of 20 to 30 per cent, and an annual variation of about 10 per cent.

Table 23. Average monthly and annual hours of sunshine for Banaba

Location 1977-84	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Maximum	206	267	260	255	253	245	280	283	278	286	257	243	2356
Average	169	184	176	182	218	191	194	223	221	226	194	156	2334
Minimum	141	129	119	120	163	138	115	152	171	153	117	99	2026
Average as percentage of possible	48	59	50	54	62	56	55	64	65	64	57	44	57

Tarawa 1977-84													
Maximum	268	261	277	243	279	279	304	304	281	290	275	249	3144
Average	196	191	194	201	228	208	234	242	254	258	234	182	2622
Minimum	128	127	123	135	136	171	127	174	206	193	159	115	2323
Average as percentage of possible	56	61	55	59	65	61	66	69	74	74	69	51	64

Estimates from cloud cover. Annual sunshine hours (Table 24) have been estimated using mean monthly cloud amounts from satellite observations (Sadler, Oda and Kilonsky, 1976).

The estimated values are only approximate and can only give an indication of the annual sunshine. Cloud cover estimates appear to underestimate the sunshine by about 10 per cent, and the values listed have therefore been adjusted by this amount. Both Beru and Arorae are more likely to have a greater or equal amount of sunshine than Tarawa (2700 and 2600 hours respectively), as mean cloud amounts are less.

Table 24. Annual sunshine, estimated from mean cloud amounts

	Annual sunshine (hours)	Percentage of possible	Actual cloud cover (octas)
Butaritari	2270	55	4.0
Tarawa	2622 *	63	3.6
Banaba	2334 *	56	3.7
Beru	2560	62	3.5
Arorae	2500	61	3.6

* Actual means (1977-84)

Sunshine hours are high, generally being above 55 per cent of the total possible for all the islands of the Kiribati group. Annual sunshine hours are estimated to range between 2200 and 2700 hours out of a possible 4135 hours.

Hours of sunshine are least in the northern islands of Butaritari and Makin, and are greatest near the equator, east of 177°E. The sunniest months are August, September and October, while the least sunshine occurs from December to February. There is a marked increase in cloudiness in December which has the least sunshine for any month throughout the region.

Solar Radiation. Solar radiation has been measured with an Eppley pyranometer at Tarawa meteorological office since 1979. The average length of daylight hours remains between 11.75 and 12.25 hours per day throughout the year. This contributes to the rather uniform distribution of solar radiation throughout the year. As the sun reaches its highest elevation at noon during March and September, the highest values of solar radiation are received in these months. Solar radiation is least in July and December when the sun does not pass directly overhead. The data for Tarawa (Table 25) gives an indication of daily amounts for the island group.

Table 25. Mean daily values of solar radiation (0.1 MegaJoules/square metre) at Tarawa 1979-84

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean	207	214	214	201	198	193	191	208	243	225	234	200	211

Temperatures.

In the equatorial tropics there is no cold season and no sharp temperature changes occur. This generally means very small seasonal temperature differences. The slight maxima of incoming solar radiation around the equinoxes is not reflected in the temperature curve, which is influenced more by other factors (Nieuwolt, 1977). On atolls irregularities in temperature are small because the sea temperature is almost constant throughout the year.

The mean annual temperature range throughout Kiribati is only 0.3 to 0.7°C. Mean temperatures are recorded as being slightly higher in the southern islands of Beru and Arorae. This may be caused by the poor instrument exposure rather than lesser mean cloudiness, as both Beru and Arorae are in enclosed areas.

On days with less than 2 hours of sunshine daily maximum temperatures are usually 1 to 2°C lower than average. The average daily minimum temperature is 25°C (Fig. 13) and temperatures below 23°C are rare. The lowest minimum temperature recorded was 18.9°C at Butaritari. Day-time maximum temperatures are high, averaging between 31 to 33°C, but seldom rise above 34°C.

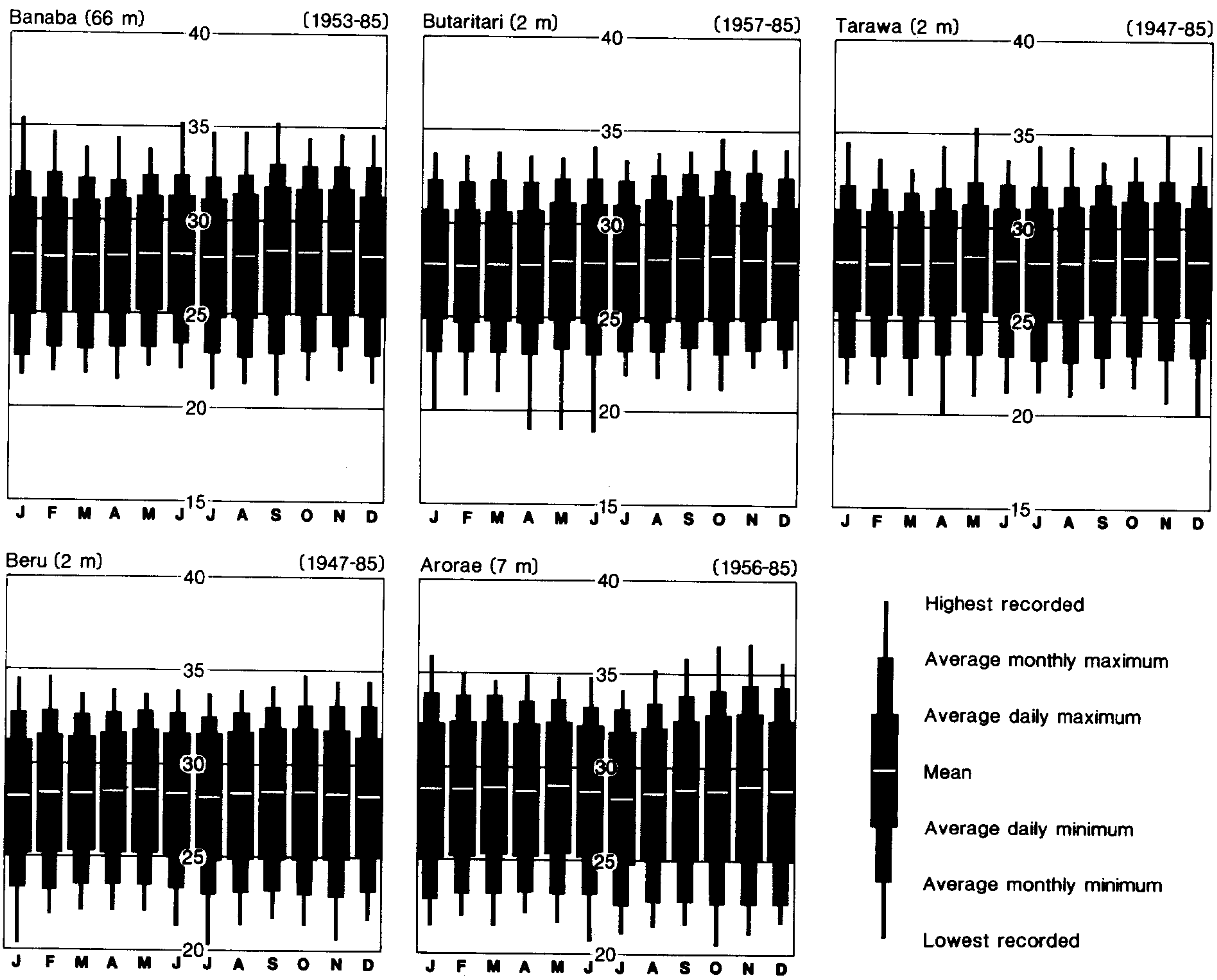


Fig. 13. Monthly temperature variation

Diurnal Variation. The mean daily temperature range averages between 6 to 7°C. Temperatures are lowest at about 6 a.m. The daily maximum temperature is reached between 1 and 2 p.m. (Fig. 13). Temperatures drop by only 1 to 2°C after sunset during the night . On occasions night time temperatures remain as high as 28 or 29°C.

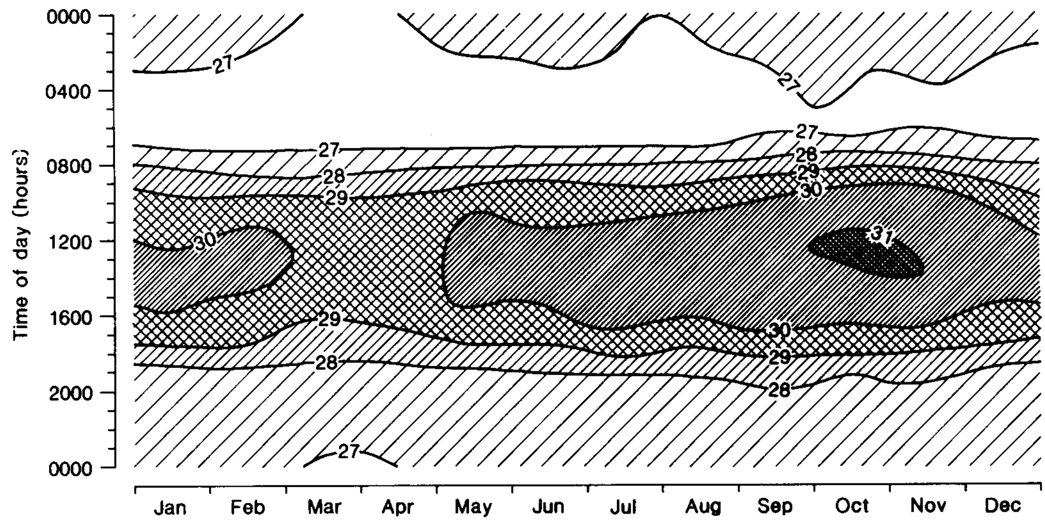


Fig. 14. Diurnal and seasonal variation of temperature for Tarawa (°C), July 1978 - May 1981

Relative humidity.

Mean relative humidity values are constantly high over all of the Kiribati Islands, ranging from 75 to 85 per cent throughout the year. Low values of humidity below 55 per cent are seldom experienced. The lowest humidities occur in the driest months of the year from September to November, and the higher values between December and May. The annual range is small, being only 4 to 7 per cent. The islands in the dry zone tend to have slightly lower average humidities (Table 26). Diurnal variation is larger than the annual variation, being about 15 per cent. The humidity is greatest just before sunrise. From December to June, during the night from 11 p.m. to 7 a.m., the humidity is often greater than 85 per cent.

Table 26. Mean monthly relative humidity (24 hours) 1977-84

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Butaritari	82	81	82	82	80	82	82	79	78	78	80	80	80
Tarawa	82	82	84	84	83	82	80	79	77	78	79	82	81
Banaba	82	82	82	83	83	83	82	80	79	79	80	82	82
Beru	80	77	77	77	76	77	77	76	74	75	76	77	76
Arorae	79	79	79	81	79	81	82	78	77	77	75	78	79

The temperature humidity index. The temperature humidity index (THI) gives an indication of the physiological temperature based on the actual temperature and the relative humidity, i.e. it expresses thermal stress in degrees of temperature.

The equation used is: $THI = 0.8t + (RH.t/500)$

where t is the air temperature in °C and RH the relative humidity (Nieuwold, 1977).

The critical value, when most people are uncomfortably hot is 26°C, although in the tropics higher values may be tolerated because of more frequent exposure to thermal stress. THI data for Tarawa shows that throughout the year the weather is uncomfortably hot if there is no adequate ventilation (Fig. 15). It should be noted that the THI does not take into account the effects of air movement or other parameters that may influence comfort such as radiation and rainfall.

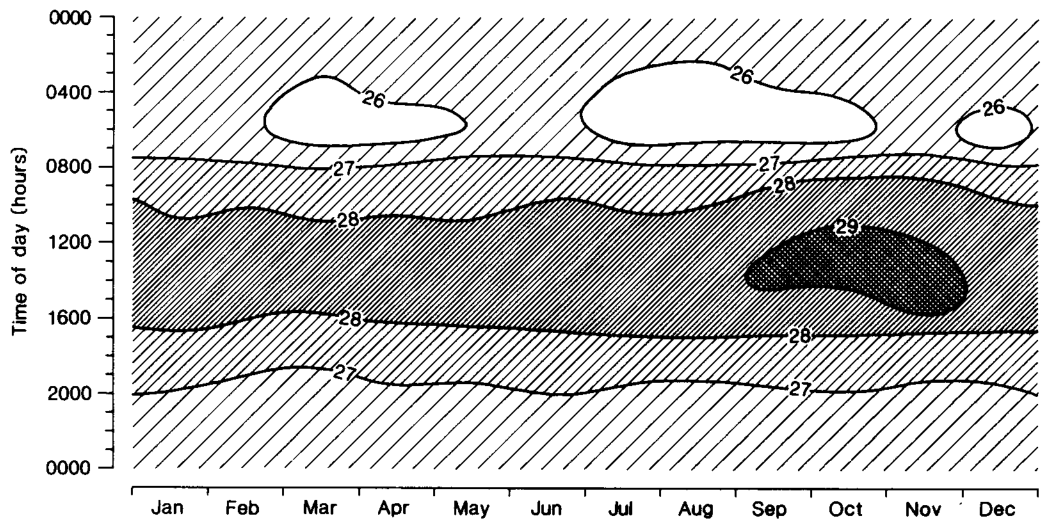


Fig. 15. Temperature humidity index values (°C) for Tarawa (July 1978 to May 1981)

Mean sea level pressure.

Mean sea level pressures are recorded at Tarawa, Arorae and Banaba, and have an annual variation of approximately 3 hPa (Table 27). The highest recorded mean sea level pressures during three years of observations from 1977-80 were 1014.4 and 1014.9 hPa for Tarawa and Arorae respectively, and the lowest was 1004.0 hPa for both stations.

Pressure has a diurnal variation of about 3 hPa with maximums at 9 a.m. and 9 p.m. and minima at 3 a.m. and 3 p.m. Pressures are slightly higher in the northern islands from December to April, coinciding with the wetter months of the year, and lower to the north for the rest of the year.

Table 27. Mean sea level pressures, hPa (1977-80)

Location	Jan	Feb	Mar	Apr	May	Jun
Tarawa	1008.6	1009.5	1009.3	1009.9	1010.1	1009.8
Arorae	1008.4	1009.3	1009.3	1009.8	1010.2	1010.0

Location	Jul	Aug	Sep	Oct	Nov	Dec	Year
Tarawa	1009.8	1010.2	1010.6	1010.2	1009.2	1008.8	1009.7
Arorae	1009.9	1010.3	1010.8	1010.5	1009.3	1008.5	1009.7

Thunderstorms

As most of Kiribati is situated in an area of relatively low rainfall (1500-2000 mm per annum) the frequency of thunderstorms is not great, especially when compared to island groups with higher annual rainfall such as Tuvalu, Tokelau, and Fiji (Table 28). The observations from Tarawa are probably more reliable than those at Butaritari, where the annual rainfall is higher and more thunderstorm activity is likely.

Table 28. Average annual number of thunderstorms

Station	Period	No.
Tarawa	1947-80	10
Nui	1965-80	20
Funafuti	1947-80	30
Nandi	1972-80	39

Table 29. Average number of thunderstorms per month

Location Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Butaritari 1957-80	0.7	0.7	0.3	0.5	0.4	1.2	1.5	0.6	0.4	0.5	0.3	0.5	7.6
Tarawa 1947-80	1.4	1.0	0.7	0.4	0.4	0.8	1.3	1.1	0.6	0.5	0.5	1.1	9.8
Banaba 1953-80	0.1	0.2	0.0	0.1	0.1	0.2	0.3	0.3	0.2	0.2	0.4	0.6	2.7
Beru 1971-80	0.8	0.8	0.4	0.4	0.2	0.5	1.0	1.0	0.1	0.6	0.5	0.9	7.2
Arorae 1956-80	0.9	0.5	0.2	0.6	0.6	0.4	0.8	0.7	0.4	0.5	0.5	0.9	7.0

4. MARINE CLIMATE

Over the sea the sky is often not as cloudy in the afternoons as it is over land areas. Cloudiness tends to increase during the night because of increased instability caused by cloud top radiative cooling.

Sea Temperatures

In this region the mean sea temperature obtained from ship reports (U.S.Navy, 1979) is almost constant throughout the year (Table 30), and has a standard deviation of approximately 1°C. Sea temperatures can range from 24°C to 32°C.

Table 30. Mean monthly sea temperatures (°C) for the region 5-9°, 170-174°E

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
28.5	28.0	28.0	28.2	28.0	28.2	28.3	28.6	29.0	29.0	28.8	28.5	28.4

Waves

High seas in this region are very rare, as winds seldom exceed gale force. When the sea is rough large waves do not reach land as most of the islands are atolls, protected by their surrounding coral reefs.

Most waves in the open sea, in the region 5-9°N, 170-174°E come from directions between north-east and south-east, ranging from 68 per cent in February to 32 per cent in September. In January and February waves are more frequent from the north-east, but in other months the prevailing direction is easterly.

Wave heights of at least 3.5 m in the open sea have a frequency of approximately 4 per cent from October to March, and 1 per cent from April to September. High seas with wave heights of at least 6 m have not been observed.

5. ACKNOWLEDGEMENTS

I would like to thank the Meteorological Service staff of Kiribati whose daily climatological observations have made this publication possible. I am also grateful to Mr D. McIntyre, officer in charge at the Tarawa meteorological office, for his comments on this climatology, and Mr U. Koniteti and Mr G. Smith for the local knowledge which they gave.

References

Coulter, J.D., 1980. Extreme One-day Rainfalls in Tuvalu and Kiribati. Fiji Met. Serv. Tech. Note no. 12.

Coulter, J.D., and Hessell, J.W.D., 1980. The Frequency of High Intensity Rainfalls in New Zealand, Part II Point estimates. N.Z. Met. Serv. Misc. Publ, no. 162.

DSIR., 1981. Pacific Island Water Resources, N.Z. DSIR South Pacific Tech. Inventory 2.

Gordon, N., 1985. The Southern Oscillation. A New Zealand Perspective. Journal of the Royal Society of New Zealand, Vol.15, no. 2, 1985, pp 137-155.

Hessell, J.W.D. and Ereckson, B.C., 1980. Depth-Duration -Frequency Tables based on daily rainfalls. N.Z. Met. Serv. Misc. Publ. no. 162. (Suppl.1) to the Frequency of High Intensity Rainfalls in New Zealand : Part II N.Z. Met. Serv. Misc. Publ, no. 162.

Jackson, I.J., 1977. Climate Water and Agriculture in the Tropics. Longman, London.

N.Z. Met. Serv., 1982. Meteorological Observations for 1982. Pacific Island Stations. N.Z. Met. Serv. Misc. Publ, no. 176.

N.Z. Met. Serv., 1983. Percentiles and Extremes of Atmospheric Pressure at Sea Level: Stations in New Zealand, the Pacific Islands and Antarctica. N.Z. Met. Serv. Misc. Publ, no. 179.

N.Z. Met. Serv., 1981. Rainfall normals for New Zealand 1951-80. N.Z. Met. Serv. Misc. Publ, no. 185.

N.Z. Met. Serv., 1981. Summaries of Climatological Observations to 1980. N.Z. Met. Serv. Misc. Publ, no. 177.

Nieuwolt, S., 1977. Tropical Climatology An introduction to the climates of the low latitudes. J.Wiley and Sons, Chichester.

Revell, C., 1981. Tropical Cyclones in the South West Pacific. N.Z. Met. Serv. Misc. Publ, no. 170.

Sadler, J., 1970. Mean Cloudiness, Gradient Level Wind Charts over the Tropics. University of Hawaii. A.W.S. Technical report 215 Vol.2.

Sadler, J.C., Oda, l., and Kilonsky, B.J., 1976. Pacific Ocean Cloudiness from Satellite Observations. Dept. of Meteorology University of Hawaii. UHMET-76-01, Oct, 1976.

Schroeder, T.A., Hori, A.M., 1982. Wind Energy Assessment for the Western Pacific Based on Ship Reports. Dept. of Meteorology University of Hawaii, Honolulu. UHMET-82-05.

Seelye, C.J., 1950. Rainfall and its Variability over the Central and South-West Pacific. N.Z. Met. Office Note, no. 35.

Steiner, J.T., 1980. The Climate of the South-West Pacific Region. N.Z. Met. Serv. Misc. Publ, no. 166.

Stirling, I.F., 1978. Atlas of the South Pacific. N.Z. DSIR N.Z. Map Series 295 first edition, Govt.Printer, Wellington N.Z.

Thompson, C., 1986. The Climate of the Northern Cook Islands. N.Z. Met. Serv. Misc. Publ, no. 188(3)

U.S.Navy, 1979. U.S. Navy Marine Climatic Atlas of the World. Vol.V. South Pacific Ocean. NAVAIR 50-IC-532. U.S. Govt. Printing Office, Washington D.C. 20402

Ward, G., 1983. The Southern Oscillation Index and its Effects on New Zealand Weather. N.Z. Agricultural Science Review N.Z. Met. Serv. Met. Office Note, no. 133.

World Meteorological Organization, 1984. Glossary of terms used in Agrometeorology (provisional simplified edition) CAgm Report, no. 21, Geneva.

Wyrtki, K. and Meyers, G., 1975. The Trade Wind field over the Pacific Ocean Part II. University of Hawaii. Inst. of Geophysics. HIG-75-2.

Government Printing Office 1987

79095E— 87 PTK