THE CLIMATE AND WEATHER

OF

TUVALU

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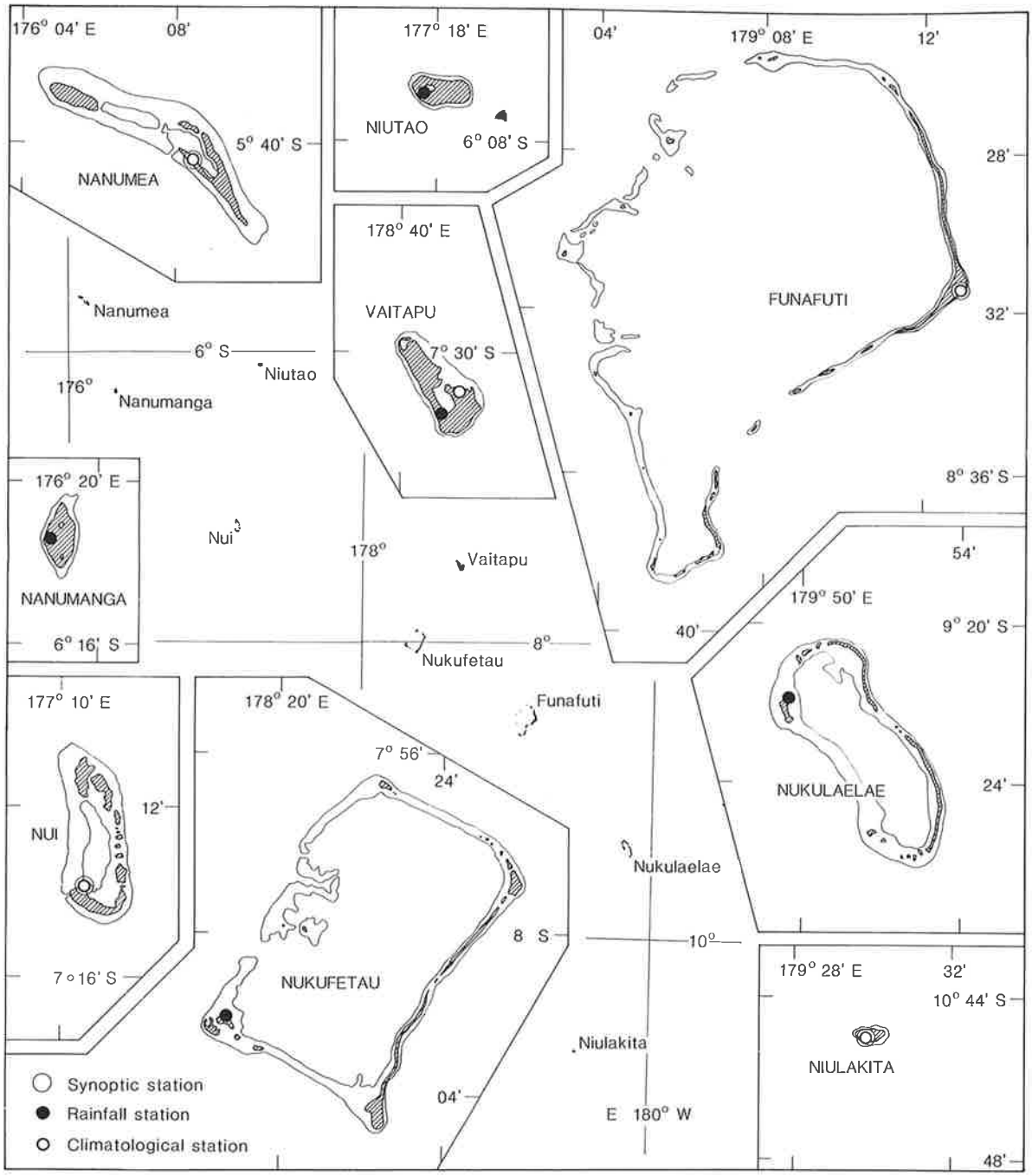

Fig.1(a) Location map

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Note to 188 Series

This publication is the sixth in a series on the climate and weather of specific 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:

(1) Climate and Weather of Niue (published)

(2) Climate and Weather of Southern Cook Islands (published)

(3) Climate and Weather of Northern Cook Islands (published)

(4) Climate and Weather of Tokelau (published)

(5) Climate and Weather of Tonga (published)

(6) Climate and Weather of Tuvalu (published)

(7) Climate and Weather of Western Kiribati

(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).

CONTENTS

THE CLIMATE AND WEATHER OF TUVALU

Summary

Tuvalu lies within the trade wind zone but on the edge of the South-west Pacific equatorial doldrum zone. Prevailing winds are from the easterly quarter and they occur most frequently between June and August. In most years from December to March, winds between west and north usually equal or exceed the easterlies in frequency.

Wind speeds over the surrounding oceans average about 10 knots. Strong winds are not common, being experienced about three percent of the time. Although tropical cyclones occasionally develop in close proximity to Tuvalu, they are most unlikely to become storms.

Rainfall in Tuvalu is high and reliable throughout the year. Sixty percent of the rain falls in the November-April period and it is in this wetter season that most of the heaviest falls are recorded. There is a significant inverse relationship between rainfall and the southern oscillation index, with the southern oscillation leading the rainfall response by several months. However abnormal rainfall anomalies seldom persist for longer than two months.

With the high levels of sunshine, evapotranspiration rates are also high, but in most years precipitation is sufficient to meet these requirements. Soil moisture deficits are most likely in the drier northern atolls.

1. INTRODUCTION

Tuvalu is a group of nine coral atolls or islands located in the South-west Pacific Ocean between 5° and 11°S, and from 176°E - 180°. All are low-lying, none of which rise above 5 metres. The islands and atolls extend over 650 km in a line from Nanumea in the north to Niulakita in the south (Fig. 1). The total land area is about 26 km^2, with the centre of government being at Fongafale on the atoll of Funafuti. The main cultivated food crops are coconuts, bananas, breadfruit, pandanus and taro. Copra is produced for export, but most of the people are engaged in subsistence agriculture and fishing.

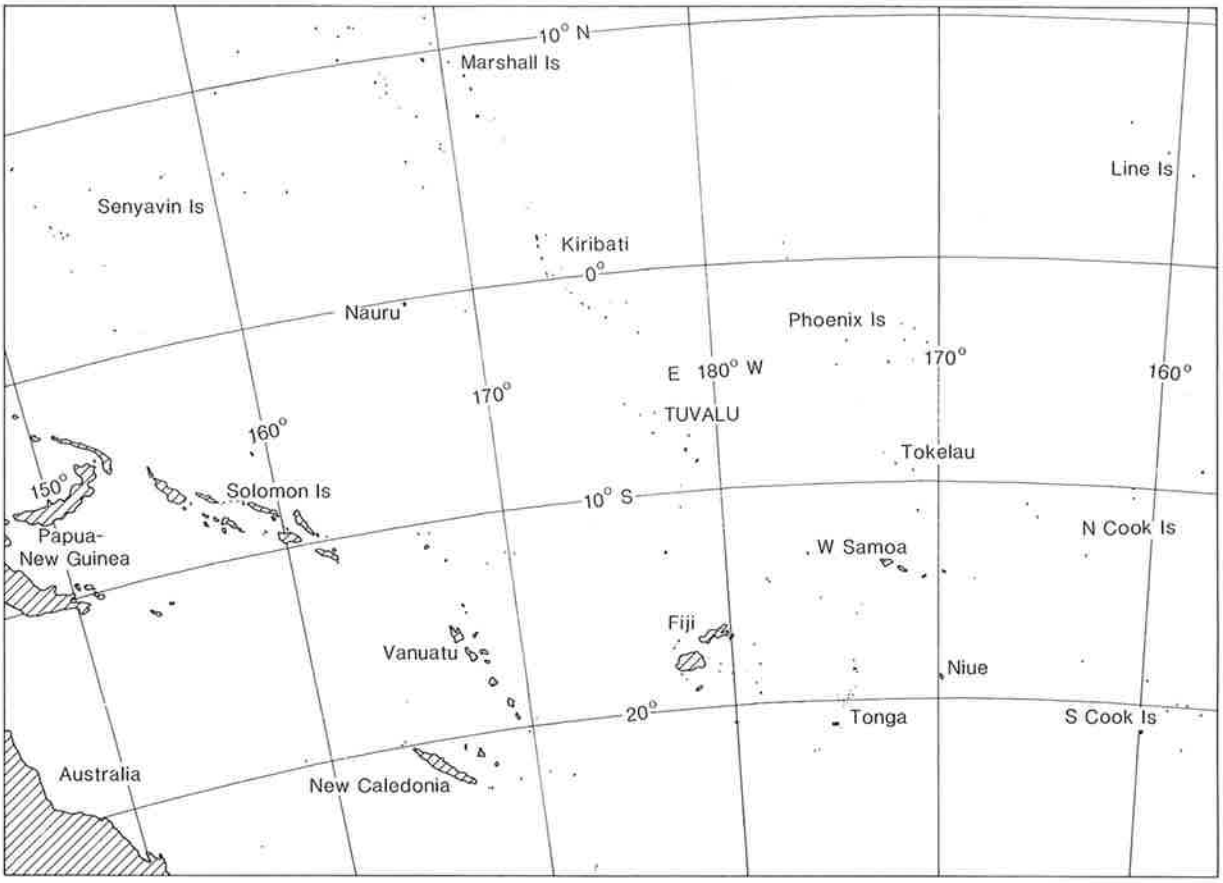

Fig 1 (b) Location of Tuvalu in the Pacific

Meteorological data used in this publication were mostly obtained from the New Zealand Meteorological Service's archives. Rainfall observations made in 1922 at Funafuti are the earliest known weather observations. Table 1 shows some information about the archived meteorological record. Synoptic weather observations are made six-hourly, four times a day beginning at midnight local time (1200 UT). Rainfall observations are made at 9 a.m. (2100 UT), while daily climatological observations are taken either at 6 a.m. (1800 UT) or 9 a.m. (2100 UT).

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

Table 1 The Meteorological Record

Location	* Station Type	Data Period	Remarks
Nanumea	Climat/Synoptic	Jan	Sheltering in sector east via south to north
Niutao	Rainfall	Aug	Site exposure only fair
Wanumanga	Rainfall	Jan	Poor gauge exposure
Nui	Climat/Synoptic	Aug	Sheltering due densely wooded coconut palms
Vaitupu	Rainfall	Jan	Gauge surrounded by trees and buildings
Vaitupu Agmet**	Climat	Aug	excellent exposure
Nukufetau	Rainfall	Jan	Poor gauge exposure
Funafuti**	Climat/Synoptic	Jan	Site well exposed
Nukulaelae	Rainfall	Jan	Exposure good to east and west
Niulakita	Climat/Synoptic	Jan	Site sheltered from trade winds

* Climat: Stations making full climatological observations once daily.
Synoptic: Stations making observations of selected parameters primarily for use in weather analysis and forecasting, several times a day.
Rainfall: Station making daily rainfall observations.
** Climatological observations made at 9 A.M. (2100 UT).

(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 resulting from the eastward migration of anticyclones (Revell, 1981). The intensity of the South Pacific anticyclone influences the strength of the trade winds. Although the trade winds are normally moderate, they tend to be strongest from about May to October when the South Pacific anticyclone is most intense. Wind speeds at these times may reach 25 knots*.

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

A feature of the trade wind region is the frequent presence of temperature inversions between 1500 and 3000 metres. Above the inversion westerly winds predominate with dry subsiding air. The growth of convective clouds to high altitudes is inhibited as cloud tops rarely penetrate far into the inversion zone and showers are usually scattered and light. In the Tuvalu region where trade winds have travelled for great distances from regions of active subsidence, the inversion is generally nonexistent. With the decrease of atmospheric stability convection and heavy showers occur.

(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 five degrees of the Equator, the 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 and into the Coral Sea on the southern fringe of the doldrums. This trough is known regionally as the 'monsoon trough'. The resulting light winds reflect in part alternating periods of easterlies and westerlies. Occasionally the 'monsoon westerlies' can be squally. Although the monsoon westerlies frequently blow as far as the date line, from time to time they spread to the Cook Islands. During the period from May to September the doldrum zone lies principally in the northern hemisphere, and in this period there is no Australian monsoon trough.

The zone between the convergence of the North Pacific and South Pacific trade winds is the intertropical convergence zone (ITCZ). It is characterised by an extensive area of cloud, which fluctuates in intensity over 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 I7CZ is from 3°-10°N in the eastern central Pacific, and from 5°-15°N near America.

(iv) The South Pacific convergence zone

The South Pacific convergence zone (SPCZ) is an important feature of the South-west Pacific. It is an area of convergence between the low latitude easterly trade winds and the higher latitude south-easterly trades. It is a semi-permanent cloud feature of the southern hemisphere (Fig. 2).

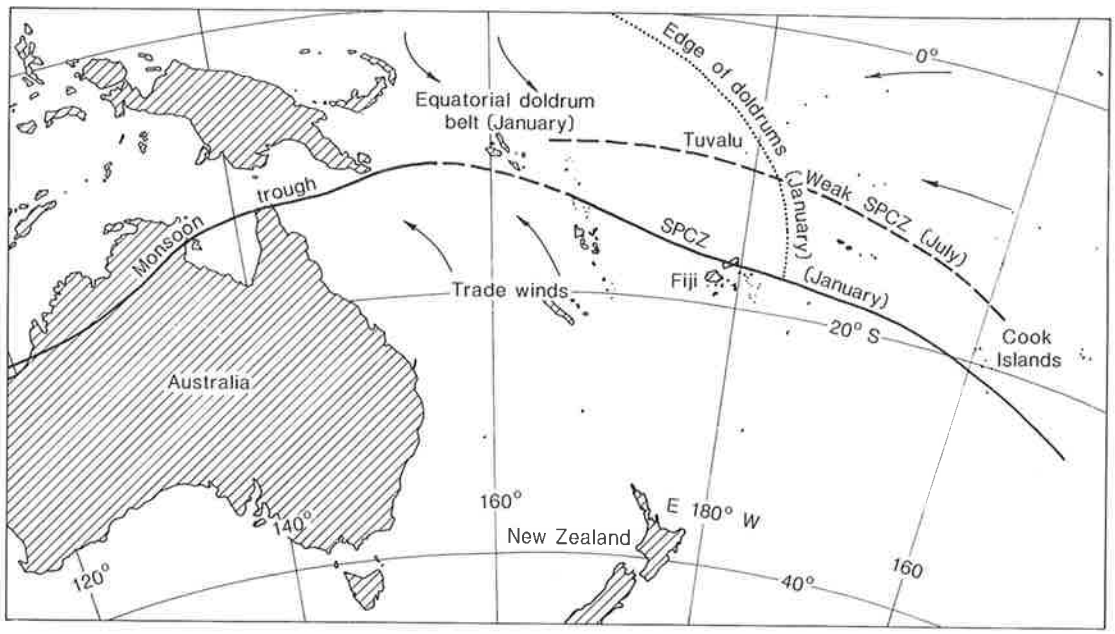

Fig. 2. Mean position of South Pacific convergence zone in January and July. Adapted from Wytrtki and Meyers (1975) and Hessell (1981)

The intensity of the SPCZ varies considerably. From time to time, troughs of low pressure develop on the zone, especially when upper-level westerlies are strong. Their development is accompanied by an increase in the width of the cloud band and a deterioration in the weather (Hill, 1963). Seasonal variation in the location of the SPCZ (Fig. 2) is generally small. During summer (November to April) the SPCZ lies from near Vanuatu and Northern Tonga to the Southern Cook Islands - it is well south of Tuvalu. The western edge of the zone becomes an extension of the monsoon trough of Northern Australia and the Solomon Islands. Although the westerlies associated with the doldrums on the northern side of the SPCZ frequently blow as far as the date line, they also spread further east.

In winter, the SPCZ is frequently very weak or inactive. Its mean position is from near Niulakita, the southernmost island of Tuvalu, to between the Southern Cook Islands and Society Islands (Fig. 2). A broad easterly or south-easterly trade wind flows over the tropical South-west Pacific.

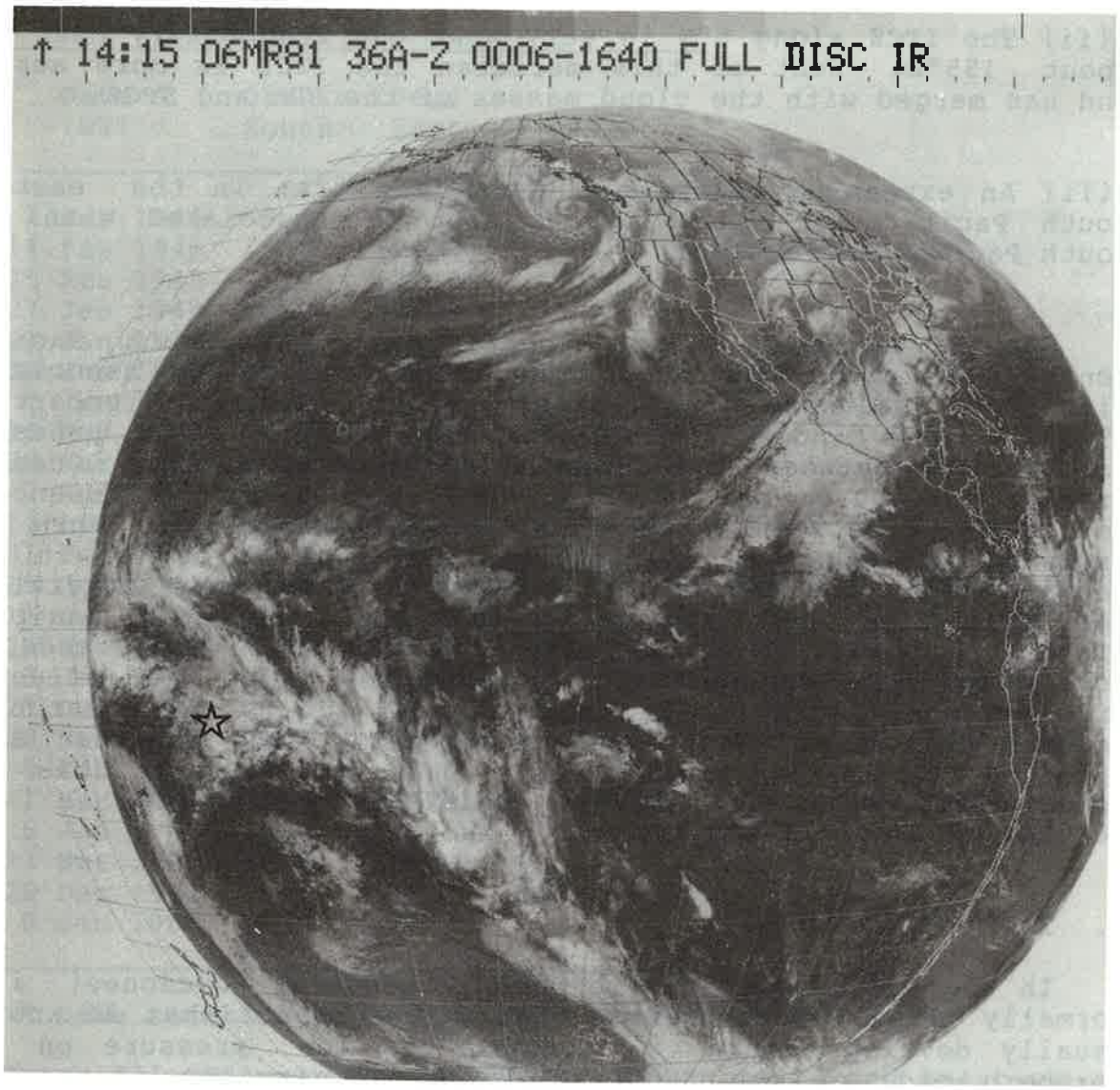

Fig. 3. Satellite view of Pacific Ocean on 6 March 1981. Note SPCZ lying north of mean position. A star marks the general location of Tuvalu.

Figure 3 shows a satellite view of the Pacific Ocean taken on 6 March 1981. This figure shows three important features of the tropical Pacific Ocean circulation.

(i) The extensive cloud band of the SPCZ is lying north of its mean position. Tuvalu lies under an extensive mass of cumulonimbus cloud on the western edge of the photograph.

(ii) The ITCZ along 5°N is very weak and fragmentary east of about 155°W. West of this meridian the ITCZ is more active and has merged with the cloud masses of the EDB and SPCZ.

(iii) An extensive relatively cloud-free area in the eastern South Pacific and along the Equator is associated with the South Pacific Anticyclone.

Spatial variation in the location of the South Pacific convergence zone has also been identified to be associated with the southern oscillation index (SOI) (Trenberth, 1976). This index represents the extent of a pressure oscillation between the Indian and South Pacific Oceans. Trenberth measured the SOI from the normalised differences in pressure between Papeete and Darwin (Australia). When the pressure is high in the Pacific, it tends to be low in the Indian Ocean, and the SOI is positive. Under such conditions the SPCZ lies west and south of its seasonal position (Trenberth, 1976). At the same time the ITCZ also tends to move away from the Equator. Tuvalu comes under the influence of a stronger South Pacific anticyclone, and as the equatorial doldrum belt moves west and north-west, the islands are affected by drier conditions. The SOI clearly has an association with the Tuvalu rainfall variability - see section on Rainfall and the SOI.

3. TROPICAL CYCLONES

In the South-west Pacific Ocean, tropical cyclones(i.e. normally classified as having wind speeds of at least 34 knots) usually develop within a trough of low pressure on the northern side of the SPCZ. Tropical depressions (i.e. wind speeds less than 34 knots) may form all year round, while tropical cyclones (i.e. wind speeds of at least 34 knots) are almost exclusively confined to the months November to April, which in the tropical South Pacific is regarded as the cyclone season. Tropical cyclones occasionally begin to develop close to Tuvalu, mostly south of latitude 9°S (Table 2), but it is very rare for them to become storms while in this area. There have been three known tropical cyclones to result in serious damage to Tuvalu. These occurred on 18 February 1891, 2 January 1958, and 19 October 1972. (This latter one was noteworthy since it occurred outside the normal cyclone season). There was also an unconfirmed report of widespread damage to Tuvalu in November 1957 (Kerr, 1976).

Table 2. Tropical cyclones in the Tuvalu region 1940-1985

Date * (UT)	Origin (Deg) South	East	SOI
4 Feb 1940	9.1	177.8	
14 Feb 1940	9.8	178.8	
25 Feb 1942	9.9	177.9	
27 Jan 1944	10.3	179.8	
21 Jan 1948	9.0	179.0	
22 Feb 1957	10.9	179.1	
1 Jan 1958	8.0	177.0	
28 Nov 1958	9.9	179.5	
29 Mar 1964	10.6	177.0	+ve
7 Apr 1967	11.7	179.1	
12 Dec 1967	10.5	179.5	
31 Feb 1972	10.0	177.5	+ve
19 Oct 1972	7.9	177.1W	
11 Dec 1976	11.5	176.5	
24 Nov 1977	5.9	176.9	
3 Jan 1979	5.1	176.1	
27 Dec 1979	8.0	175.0	
25 Mar 1980	9.5	175.0	
8 Feb 1981	9.0	178.0	
1 Mar 1981	10.5	177.0	
6 Jan 1982	9.0	178.5W	+ve
23 Mar 1983	10.0	179.0	
26 Dec 1984	9.1	178.2	
8 Jan 1985	11.0	180.0	

* Date refers to the time when first observed.

Note. All SOI values negative except those marked positive

Since 1940 there have been 23 occasions when tropical cyclones began to develop in the Tuvalu region. The table shows that nearly all developed when the SOI was negative. Revell and Goulter (1985) noted a close relationship between the origins of tropical cyclones and the SOI. The mean origin point of South-west Pacific tropical cyclones was north-east of the median position of 14°S 170°E for negative SOI, and south-west for positive SOI.

4. CLIMATE ELEMENTS

Wind

Tuvalu lies within the trade wind zone of the South-west Pacific and on the edge of the austral summer equatorial doldrum belt. (Fig. 2, 4). Predominant surface winds are from between northeast and southeast for about 55 to 65 percent of the time, but seasonal differences do exist (Table 3). East to south-east winds are most frequent between June and August, varying from about 60 percent of the time in the northern atolls of Nanumea and Nui, to over 75 percent on Funafuti and Niulakita. These wind directions are more than twice as frequent during the period from May to October, than at other times of the year. During this period, the doldrum zone lies predominantly in the

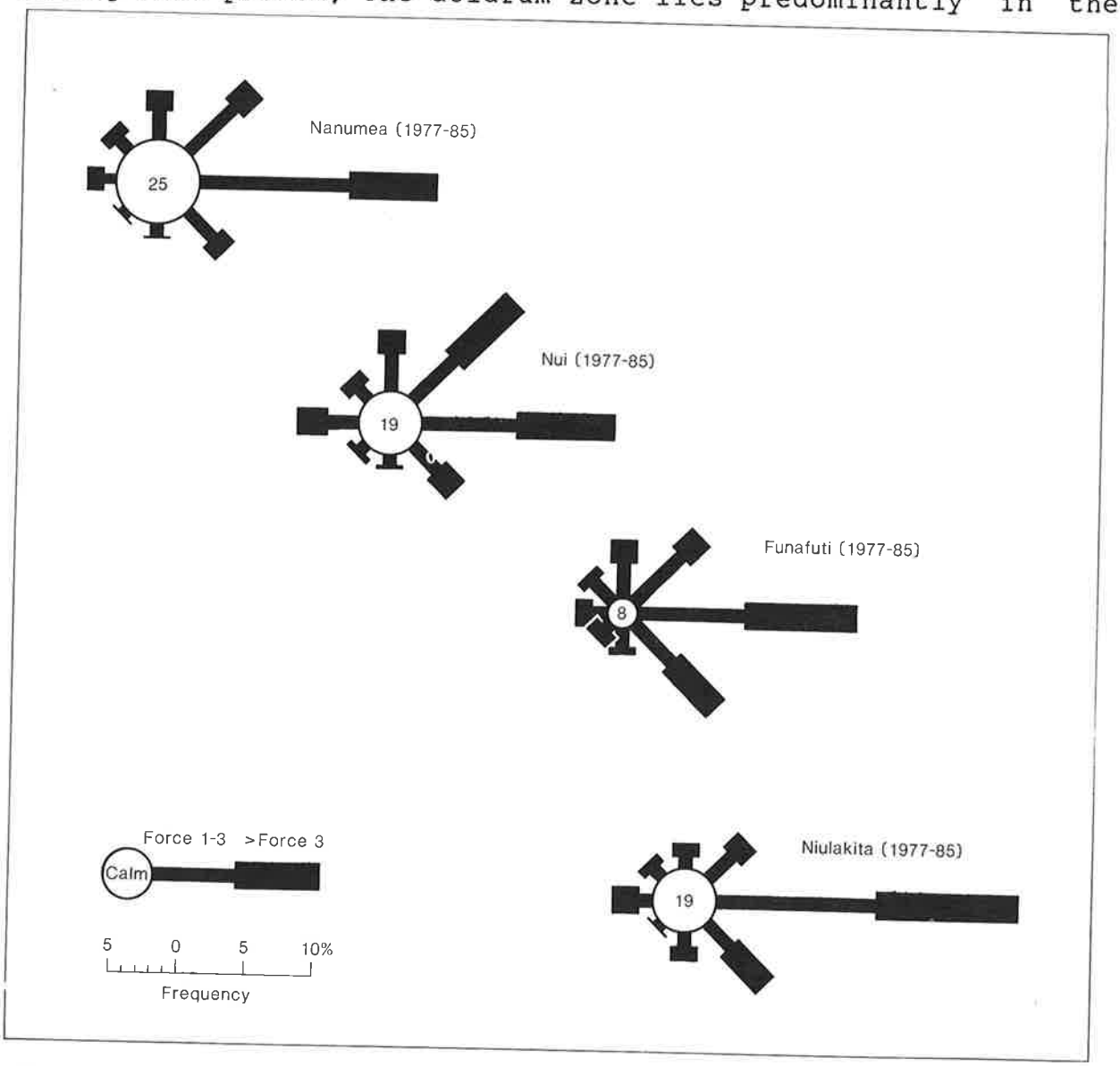

Fig. 4. Mean annual wind roses for Tuvalu . All observations are taken at 6 am except Funafuti which is recorded at 9 am.

Table 3. Seasonal wind frequencies (percent) and mean speeds (knots)

		Dec Jan Feb	Mar Apr May	Jun Jul Aug	Sep Oct Nov	Wetter	Drier	Annual
(a) Nanumea (6 a.m.) 1977-85								
Dir	N	13.8	7.7	1.8	4.8	11.9	2.3	7.0
(percent)	NE	14.1	14.3	9.7	10.7	17.1	10.3	13.6
	E	19.1	33.9	47.5	37.8	23.8	45.5	34.9
	SE	3.0	6.5	13.7	10.5	4.9	11.8	8.5
	S	2.1	0.7	2.0	2.4	1.7	1.9	1.8
	SW	1.6	0.2	0.5	1.2	1.0	0.8	0.9
	W	10.0	5.5	0.1	2.4	8.3	0.8	4.5
	NW	10.0	3.0	0.6	2.8	7.4	0.9	4.1
	Calm	25.6	28.2	24.2	21.5	23.9	25.8	24.9
Mean speed		8.3	7.2	7.8	7.7	7.9	7.5	7.7
Percent over 22 knots		4.1	1.5	1.7	1.2	2.9	1.3	2.1
(b) Nui (6 a.m.) 1977-1975								
Dir	N	14.6	9.3	3.2	8.2	13.2	4.6	8.8
(percent)	NE	16.9	13.4	15.8	18.0	16.8	15.3	16.0
	E	9.1	27.0	46.8	29.9	14.7	41.3	28.3
	SE	2.8	7.2	15.0	11.4	3.7	14.3	9.1
	S	2.2	2.0	2.1	2.8	2.4	2.2	2.3
	SW	3.5	1.7	0.5	0.7	2.6	0.6	1.6
	W	24.6	11.9	0.5	5.9	19.5	2.2	10.7
	NW	10.5	4.3	0.7	2.9	8.0	1.3	4.6
	Calm	15.7	23.0	15.5	20.2	19.0	18.2	18.6
Mean speed		9.8	8.1	9.9	8.2	9.0	9.0	9.0
Percent over 22 knots		3.5	1.9	4.5	1.3	3.0	2.7	2.8
(c) Vaitupu Agricultural (9 a.m.) 1981-1985								
Dir	N	29.3	22.1	9.9	15.6	28.3	10.6	19.2
(percent)	NE	20.2	22.7	24.3	27.7	21.8	25.7	23.8
	E	11.3	23.6	36.3	31.8	14.3	36.6	25.8
	SE	2.9	3.2	7.1	5.1	2.2	6.9	4.6
	S	5.1	8.4	12.5	9.2	5.3	12.0	8.7
	SW	4.9	7.1	5.6	4.6	6.5	4.5	5.4
	W	12.6	9.0	4.2	5.2	12.2	3.4	7.7
	NW	12.4	2.9	0.3	1.2	8.4	0.4	4.3
	Calm	11.3	0.9	0.0	0.0	1.1	0.0	0.5
Mean speed		8.0	6.6	7.6	7.8	7.4	7.8	7.6
percent over 22 knots		0.7	0.0	1.1	0.9	0.5	0.9	0.7

		Dec Jan Feb	Mar Apr May	Jun Jul Aug	Sep Oct Nov	Wetter	Drier	Annual
(d) Funafuti (9 a.m.) 1977-85								
Dir	N	16.0	9.1	2.2	7.8	14.2	3.5	8.7
(percent)	NE	17.0	13.2	10.0	16.1	16.8	11.4	14.1
	E	13.8	32.2	44.3	38.7	19.6	44.5	32.3
	SE	7.5	14.3	32.2	19.0	9.3	27.0	18.3
	S	4.8	3.5	3.6	3.8	4.4	3.5	3.9
	SW	4.8	2.2	0.8	1.8	3.8	1.0	2.4
	W	12.4	6.0	0.5	2.0	9.6	0.9	5.2
	NW	13.8	9.2	0.7	3.0	12.1	1.7	6.8
	Calm	10.0	10.3	5.7	7.2	10.2	6.4	8.3
Mean speed		9.4	8.8	11.9	9.5	8.9	10.9	9.9
Percent over 22 knots		2.7	2.0	6.3	2.6	2.3	4.5	3.4
(e) Niulakita (6 a.m.) 1977-1985)								
Dir	N	7.6	4.0	1.4	2.2	6.0	1.6	3.7
(percent)	NE	9.3	11.3	5.5	7.1	10.2	6.5	8.2
	E	17.9	38.9	65.3	54.3	26.0	61.8	44.7
	SE	6.5	6.4	15.5	12.5	6.3	14.1	10.4
	S	6.1	3.5	1.9	3.4	4.9	2.6	3.7
	SW	4.7	1.5	0.0	0.8	3.2	0.3	1.7
	W	13.6	6.4	0.3	1.4	10.2	0.7	5.2
	NW	9.6	3.0	0.2	0.4	6.5	0.2	3.2
	Calm	24.7	24.9	10.0	17.8	26.7	12.3	19.2
Mean speed		8.1	7.9	10.6	8.4	7.7	9.8	8.8
Percent over 22 knots		3.5	2.5	3.6	1.1	2.9	2.5	2.7

Note: Wetter period is from November to April and the drier period is from May to October.

northern hemisphere, and the trade winds blow largely undisturbed over the tropical South-west Pacific.

From December to May, and particularly between December and February, north and west winds associated with the doldrum belt/monsoon trough account for 35 to 45 percent of the wind; equalling or exceeding the frequencies of winds from the easterly quadrant. In about March or April there is a marked in the monsoon winds together with a sharp increase in the frequency of trade winds.

The frequency in which the wind blows within 40 degrees of the most frequent direction is called the wind constancy.

During March to August, the modal direction is 090°, and the constancy varies from about 45 percent in March to nearly 80 percent in July. From December to February, while 300° is the most frequent direction, the wind constancy is 30 percent. From September to November, 120° is the modal wind direction, and the constancy is about 65 percent.

The annual frequency of surface wind directions over the period 1973 to 1984 at Nanumea and Funafuti were correlated with an annual mean value of the SOI. Correlation coefficients are presented in Table 4. The table shows that while the SOI is positively associated with north-east winds, and to a lesser extent easterlies, it is also inversely related with south or south-west winds. This means that when the value of the SOI is low (i.e. negative), Funafuti and Nanumea are both likely to have above average frequencies of south and south-west winds, while there is a marked reduction in north-east and east winds.

During 1982, and a major El Nino episode, the SOI reached a record negative value, causing the frequency of south and south-west winds at Nanumea and Funafuti to be about three times and twice as frequent respectively. During this period both east and north-east winds reduced by about 35 percent at Nanumea and by 10 percent at Funafuti.

Table 4 also shows a strong inverse relationship at Nanumea between the SOI and calm conditions, but at Funafuti, there is a small non-significant positive correlation.

Table 4. Correlation between the SOI and wind direction frequency. Correlations over ± 0.53 are significant at the five percent level

Direction	Namuea	Funafuti
N	-0.08	0.02
NE	0.84	0.76
E	0.43	0.45
SE	0.42	0.20
S	-0.52	-0.86
SW	-0.55	-0.65
W	-0.13	-0.12
NW	-0.37	-0.12
Calm	-0.78	0.13

Monthly mean wind speeds, based on synoptic weather reports made several times daily are shown in Table 5. Buildings and trees surrounding the meteorological sites affect the wind speeds recorded. Oceanic winds around Tuvalu (see

section 5.1) average about 9.8 knots. Wind speeds on the atolls and island are slightly less; Nanumea probably being some 20 percent lighter than at sea. However seasonal winds (Table 3) indicate that the northern atolls of Nanumea and Nui have relatively uniform speeds all year round, but at Funafuti and Niulakita, there is a distinct maximum from June to September.

Table 5. Mean monthly wind speeds (knots)

Location	Jan	Feb	mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Nui	10	11	10	8	8	10	11	11	9	8	8	10	9.4
Funafuti	8	9	10	8	9	11	12	12	11	8	7	8	9.4
Niulakita	7	9	9	5	8	10	11	11	10	8	6	7	8.4
Nanumea	8	9	9	7	6	8	7	8	8	7	8	8	7.9

While winds over 22 knots occur between two and four percent of the time (Table 3), gale force winds (those having mean speeds over 33 knots) are relatively rare. On Funafuti, where there is an instrumental record, 13 gale episodes have been measured between 1978 and 1983; an average of two gales per year. Nearly 80 percent of all gales occurred with west or north-west winds during the South Pacific cyclone season, November to April.

Wind gust data for Funafuti shows that gusts over 33 knots are measured on 50-60 days each year. One extreme gust of 73 knots from the south-east was measured on 22 August 1984. A gust of at least this magnitude has a frequency of occurrence of about once every 25-35 years.

Diurnal variation of wind speed over the islands is given in Fig. 5. The maximum occurs in the middle of the day, resulting from an augmentation of the trade winds by a local sea-breeze regime. A wind speed minimum occurs at night-time.

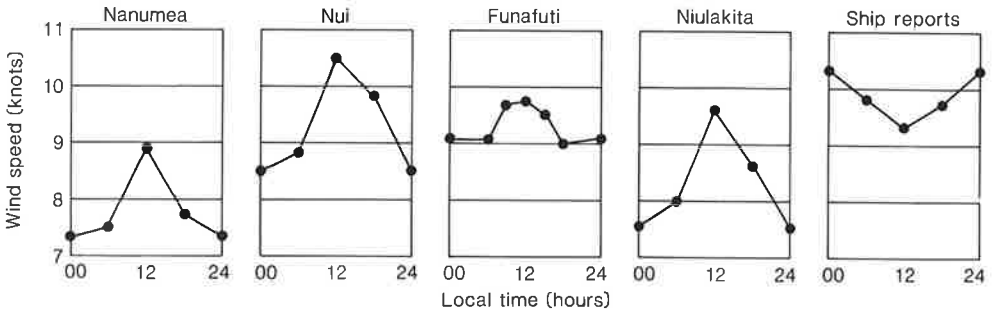

Fig. 5. Diurnal variation of wind. (Based on synoptic weather reports over period 1978-1985. However ship reports are over period 1951-1980)

The range of variation is between 5 and 15 percent of the mean speed.

In contrast, over the oceans, night-time winds are stronger than the daytime ones. This feature is typical of the trade wind regimes of the Pacific Ocean (Riehl et. al., 1951).

Knowledge of the characteristics of wind throughout the Pacific have grown in importance with the increasing awareness of the uses of wind as a resource, especially in the area of wind energy production. The potential of a location as an energy source is dependent on the prevailing mean wind speed and distribution since wind power is since wind power is proportional to the cube of the wind speed. From a theoretical or fitted distribution of wind speeds, another important wind energy consideration can be assessed; that is, the time at which the wind will blow at any given speed or between a specified range.

Table 6. Wind energy potential for Tuvalu

Loocation	V_m	Wind energy* kWh/m^2/yr	Hours per year between 6-30 knots
Nanumea	7.9	680	5912
Nui	9.4	1154	6635
Funafuti	9.4	1154	6635
Niulakita	8.4	821	6187
Ocean+	9.8	1305	6783

* Assumes a Weibull distribution with a shape factor of 2. Characteristic wind speed is 11 percent greater than V_m(Swift-Hook, 1979).

\+ Ocean refers to are 2.5 -12.5°S, 172°E-180°.

Annual wind energy potential for Tuvalu is given in Table 6. The total potential between 6 and 30 knots over the oceanic region is 1305 kWh/m^2/year which is nearly 50 percent larger than the estimates for the sheltered Nanumea site, but only 12 percent greater than at Nui and Funafuti.

Rainfall

Annual, seasonal and monthly rainfalls. Tuvalu lies to the east and north of the maximum rainfall region of the tropical South Pacific Ocean, in an area associated with both the cloud and convergent zones of the SPCZ and the Austral summer doldrum belt. Tuvalu tends to have considerably more rainfall than island groups further north (e.g. Kiribati) and south (e.g. Figi and Tonga). The annual rainfall