

THE CLIMATE AND WEATHER  
OF  
TONGA

C. S. Thompson

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N.Z. Met. Serv. Misc. Publ. 188(5)  
ISSN 0110-6937

UDC 551.582 (961.2)

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New Zealand Meteorological Service  
PO Box 722  
Wellington

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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 | (published) |
| 188(4) | Climate and Weather of Tokelau               | (published) |
| 188(5) | Climate and Weather of Tonga                 | (published) |
| 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 TONGA

### Summary

The Kingdom of Tonga lies within the trade wind zone of the South Pacific. While winds speeds over the ocean surrounding Tonga average 12 to 13 knots, speeds within the various groups are reduced due to sheltering effects by orography, vegetation and buildings. Strong winds are not common except in tropical cyclone passages. Although on average just over one tropical cyclone each year strikes Tonga, 40 percent of seasons are cyclone free.

The rainfall regime of Tonga shows a pronounced wet season from November to April when about two-thirds of the annual amount falls, and a dry season (May to October). Rainfall is highly variable from year to year reflecting the sporadic nature of the intensity and amount of rainfall. However, periods of abnormally low or high rainfall persisting for more than three months are exceedingly rare.

High evaporative water demand by vegetation and crops, and the variable nature of the rainfall, creates soil moisture deficits at any time of the year, and especially during the dry season. Irrigation of crops would be beneficial during periods of soil deficit.

### 1. INTRODUCTION

The Kingdom of Tonga, is situated in the South Pacific Ocean, and includes all the islands between the latitudes from 15°S to 23.5°S and between the longitudes from 173°W to 177°W. Of the total surface area of about 0.7 million square kilometres within this zone, the total land area is just 699 square kilometres (Franco, et al 1982). There are about 170 islands of which only 36 are inhabited.

Tonga includes three main island groupings; the Tongatapu group, the Ha'apai group, and the Vava'u group. There are also several outlying islands. The largest and most populous island is Tongatapu (260 km<sup>2</sup>). Nuku'alofa, on Tongatapu, is the capital and principal urban area of Tonga. Most of the islands are of coral with an overlying fertile soil developed from volcanic ash (Carter, 1984). The highest point of Tonga is an extinct volcano, Kao, rising to 1030 metres, in the Ha'apai group. Apart from 'Eua (rising to 330 metres), south-east of Tongatapu, there are no other distinct

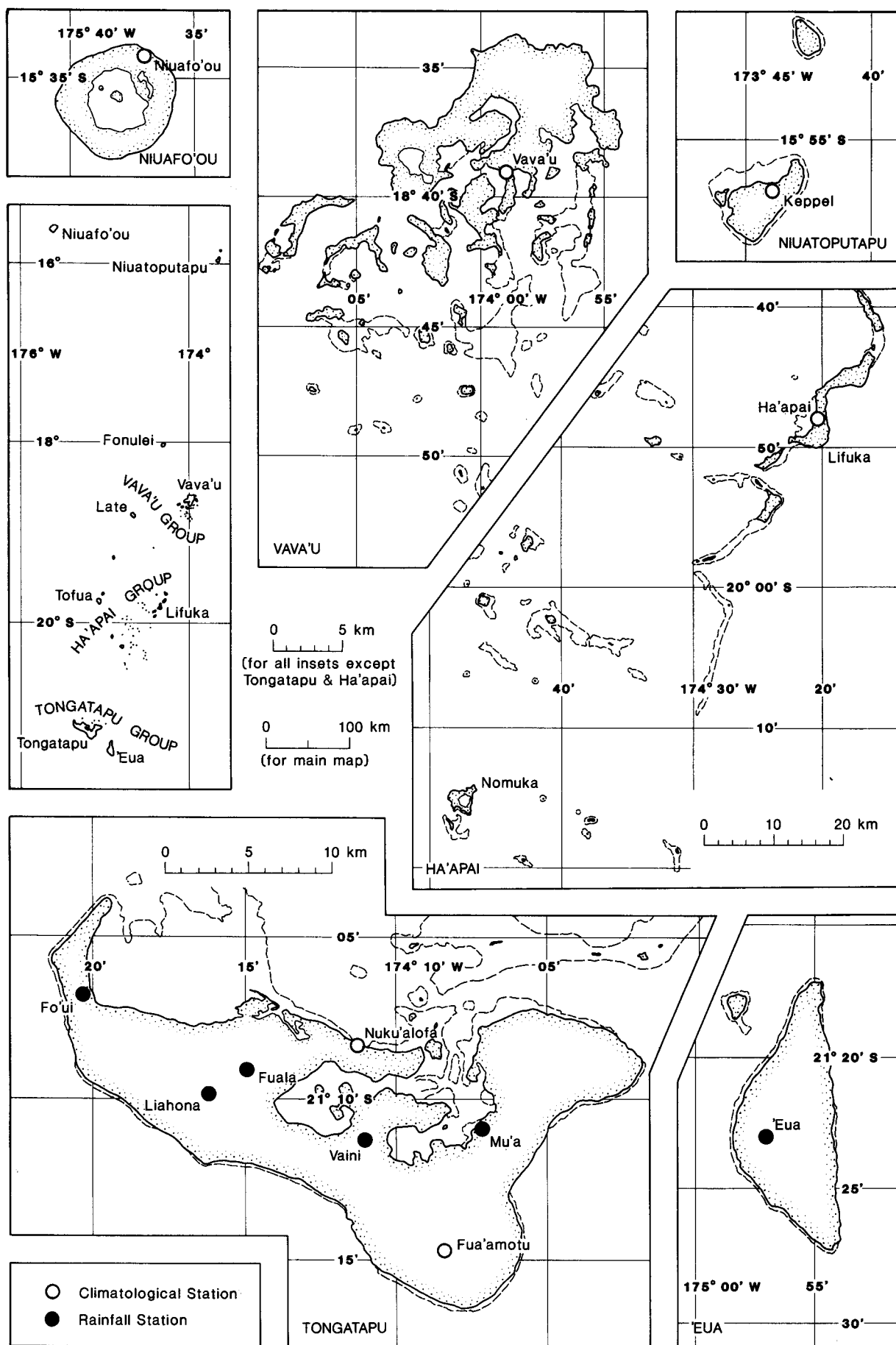


Fig. 1. Location map

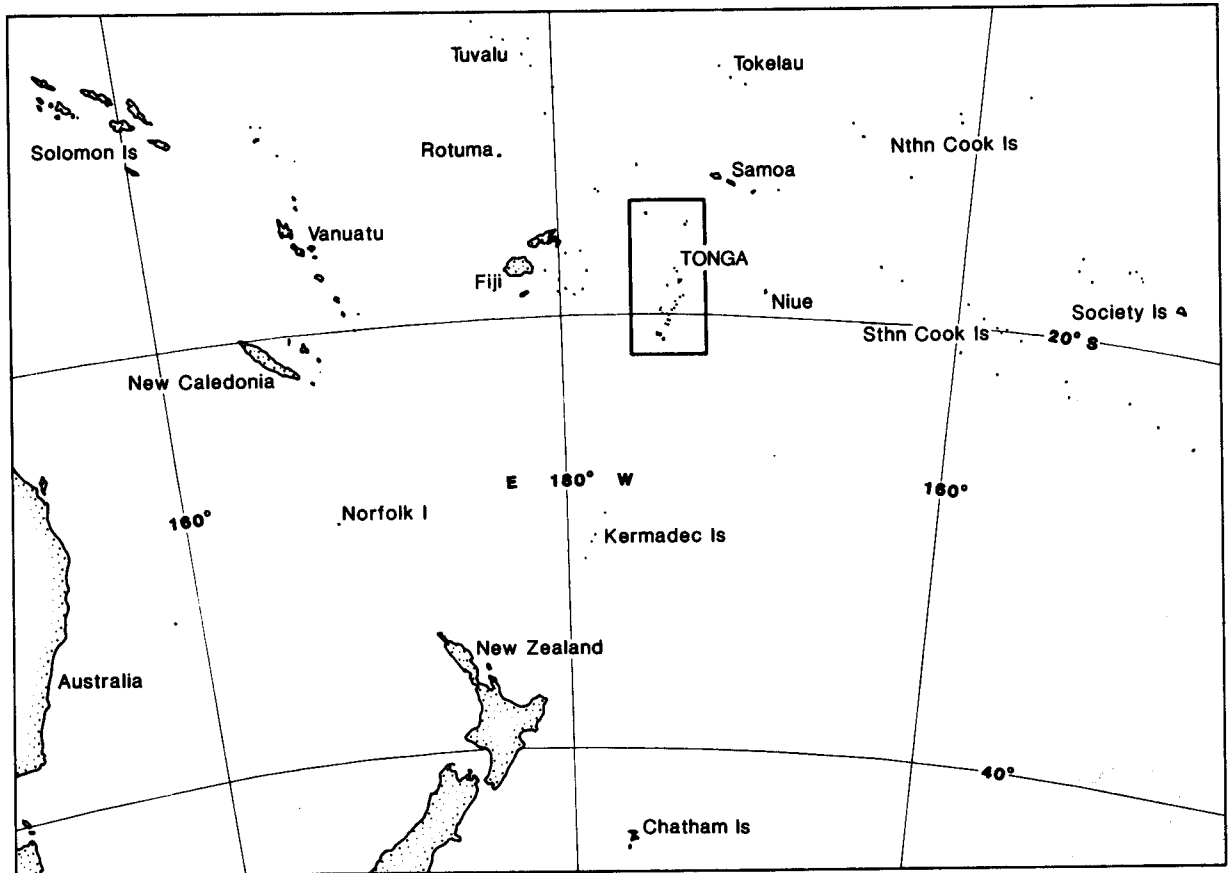


Fig. 1(b). Location map

mountains, although on Vava'u hills rise to between 150 and 300 metres. The remainder of the Tongan islands form a chain of recently formed volcanic islands, some of which contain active volcanoes.

The data used in this publication, when not otherwise indicated, were obtained from the New Zealand Meteorological Service's archives. Weather observations were first taken at Nuku'alofa between 1881 and 1891 and again since 1924. On Vava'u, there were observations between 1894 and 1908, and again from 1927. Table 1 presents information on the meteorological record for Tonga held on computer archive by the New Zealand Meteorological Service. Climatological and rainfall observations are made daily at 7 a.m., except at Fua'amotu Airport, Nuku'alofa and 'Eua where the observations are made at 10 a.m.

For the purposes of this publication, Tonga will be divided into two zones; Northern Tonga and Southern Tonga. All those islands and atolls north of 19°S constitute Northern Tonga.

Table 1. The meteorological record

| Location                 | Ht(m) | Data period           | Station type*  | Remarks                                  |
|--------------------------|-------|-----------------------|----------------|--|
| Niuafu'ou                | 60    | Jan 1971-0            | Climate/synop. | Wind may be affected by orography        |
| Keppel<br>(Niuatoputapu) | 2     | Jan 1947-             | Climate/synop. | Wind influenced by hills to the south    |
| Vava'u                   | 9     | Jan 1947-             | Climate/synop. | Wind possibly affected by orography      |
| Ha'apai                  | 2     | Jan 1947-             | Climate/synop. |  |
| Nuku'alofa               | 2     | Jan 1947-             | Climate/synop. | Wind affected by nearby buildings        |
| Kolovai                  | 5     | Jul 1980-<br>Feb 1983 | Rainfall       | Good exposure                            |
| Liahona                  | 9     | Jul 1980-             | Rainfall       | Good exposure                            |
| Fuala                    | 20    | Apr 1981-             | Rainfall       | Exposure satisfactory                    |
| Mu'a                     | 10    | Jul 1980-             | Rainfall       | Good exposure                            |
| Fo'ui                    | 7     | Feb 1983-             | Rainfall       | Exposure satisfactory                    |
| Fua'amotu                | 38    | Dec 1979-             | Climate        | Rainfall records exist between 1945-1951 |
| Vaini                    | 23    | Aug 1980-             | Climate        | Excellent exposure                       |
| 'Eua                     | 110   | Mar 1983-             | Climate        | Good exposure                            |

\* Climate: Stations making full climatological observations once daily.

Synoptic: Stations making observations of selected parameters primarily for use in weather analysis and forecasting, several times daily.

Rainfall: Stations making daily rainfall observations.

## 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) near 90-100°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 resulting from the eastward migration of anticyclones (Revell, 1981). Between the South Pacific anticyclone to the east and the migratory one is a region of convergence, the South Pacific convergence zone. The intensity of the anticyclones influence wind speeds in the trades. Although trade wind strengths are normally moderate, the trades tend to be strongest during the period from about May to October when the South Pacific anticyclone is most intense. Winds speeds may reach 25 to 30 knots at times.

A feature of trade winds is the frequent presence of temperature inversions between 1500 and 3000m. The height of the inversion varies seasonally, being near the upper limit in the wet season, and the lower one during the dry season. In the presence of the inversion the growth of convective clouds to high altitudes is inhibited and showers become less likely. In unsettled periods the inversion is absent.

(iii) Equatorial doldrum belt

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 degrees 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, a trough of low pressure (monsoon trough) extends from Northern Australia to the Coral Sea on the southern fringe of the doldrums. The resultant light winds reflect in part alternating periods of easterlies and westerlies. The 'monsoon westerlies' are occasionally squally. Although the monsoon westerlies frequently blow as far as the date line, they reach Northern Tonga most summers, and on occasions blow as far as the Cook Islands. During the winter season, the doldrum zone lies principally in the northern hemisphere, and the Australian monsoon trough is absent. East or south-east trade winds predominate over Tonga.

(iv) The South Pacific convergence zone (SPCZ)

The South Pacific convergence zone (SPCZ) is an area of convergence between the low latitude easterly trade 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 (Fig. 2). It is an important feature of the tropical South Pacific to which the long-term rainfall distribution, as displayed by Seelye (1950) and Hessell (1981), is ascribed.

The intensity of the SPCZ can vary considerably (Trenberth, 1976). From time to time, troughs of low pressure or depressions 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).

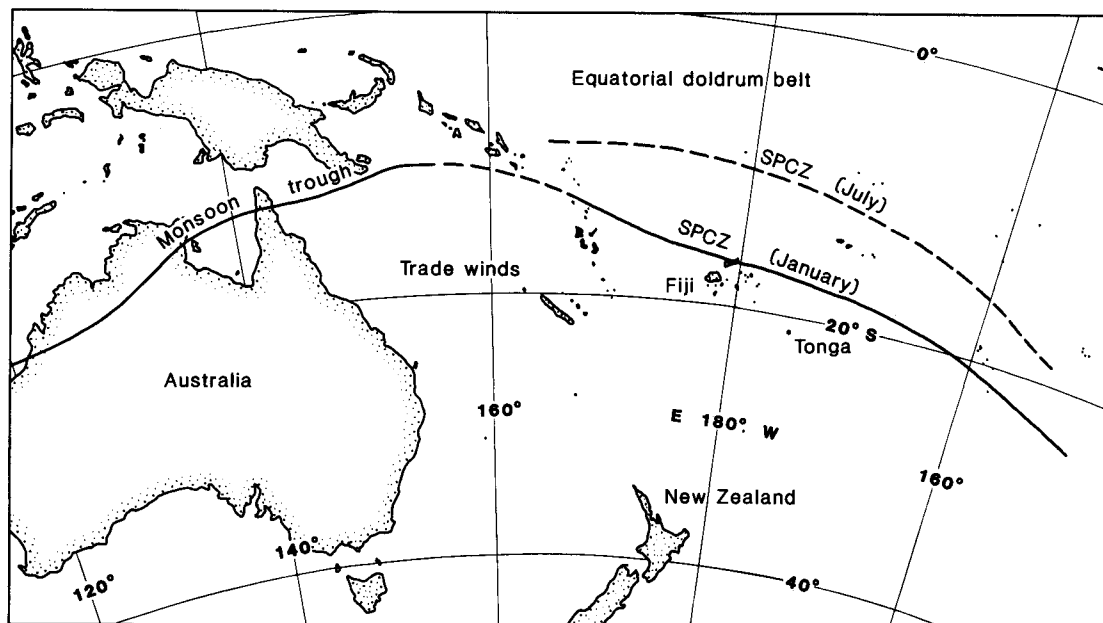


Fig. 2. Mean position of South Pacific convergence zone in January and July. Adapted from Wyrтки and Meyers (1975) and Hessel (1981)

There is generally small seasonal variation in the location of the SPCZ. During summer the SPCZ lies from near Vanuatu to midway between Western Samoa and Northern Tonga to the Southern Cook Islands (Fig. 2). 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 do on occasions spread further east.

In winter, the SPCZ is occasionally very weak or inactive. Its mean position is from near Tuvalu to between the Southern Cook Islands and Society Islands (Fig. 2), but well north of Tonga. A broad settled easterly or south-easterly trade wind flows over the tropical south-west Pacific.

Spatial variation in the location of the South Pacific convergence zone has been identified by Trenberth (1976) to be associated with the southern oscillation. The southern oscillation, represented by an index the SOI, measures the extent of a pressure oscillation between the Indian and South Pacific Oceans. Trenberth measured the SOI from the normalised

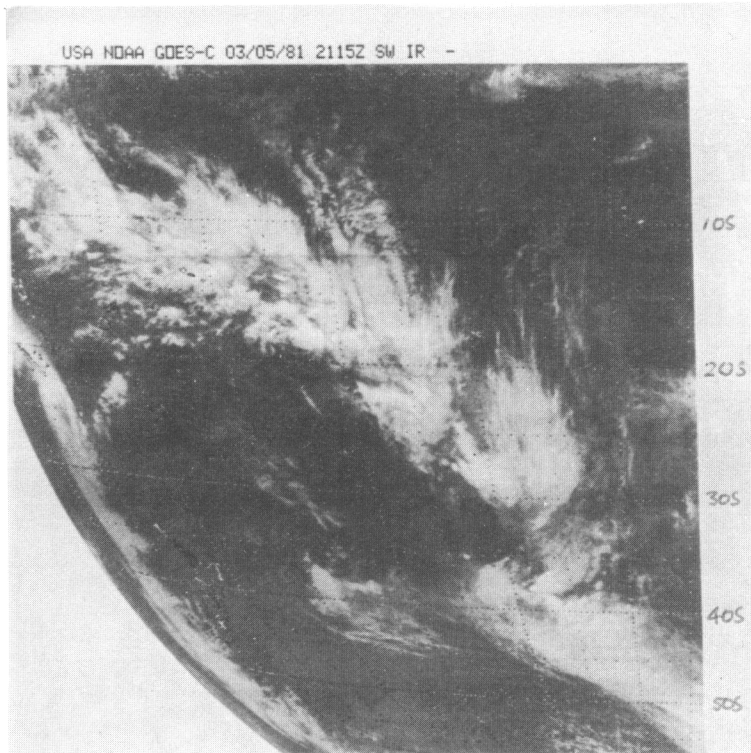


Fig. 3. Satellite view of South Pacific convergence zone on 6 March 1981

differences in pressure between Papeete (Tahiti) and Darwin (Australia). The southern oscillation index is reasonably persistent from one month to the next, although the persistence is least in the period March to May. These are the transition months resulting in a phase change of the southern oscillation (Trenberth, 1984).

Figure 3 presents a satellite picture of an active SPCZ taken at a time when the SOI was in a negative phase. Typically of negative SOI conditions the SPCZ lies north of its usual position (Trenberth, 1976). On the northern and eastern side of the SPCZ is the almost cloud free zone associated with the ridge of high pressure which extends from the anticyclone of the eastern South Pacific. Tonga lies to the south of the SPCZ, but the northern island of the kingdom are covered by clusters of cumulonimbus clouds.

### 3. TROPICAL CYCLONES

Tropical cyclones are normally classified in terms of the wind speeds associated with them. Table 2 shows a classification of tropical disturbances in terms of the wind speed. Although tropical cyclonic disturbances may occur all year round, tropical cyclones are principally confined to the

wet season from November to the following April, which is also called the cyclone season.

Table 2. Classification of tropical cyclonic circulations

| Cyclone intensity   | Speed range (knots)* |
|---------------------|----------------------|
| Tropical depression | <34                  |
| Tropical cyclone    | 34+                  |
| gale                | 34 - 47              |
| storm               | 48 - 63              |
| hurricane           | 64+                  |

In the South-West Pacific, tropical cyclones frequently form on the northern side of the SPCZ where cyclonic shear is greatest. Another favourable condition for formation is an ocean temperature of at least 26-27°C (Gabites, 1963). Between November 1939 and April 1985 there have been 17 cyclones affecting the whole of Tonga. Forty-one cyclones affected only Northern Tonga and there have been 38 in Southern Tonga.

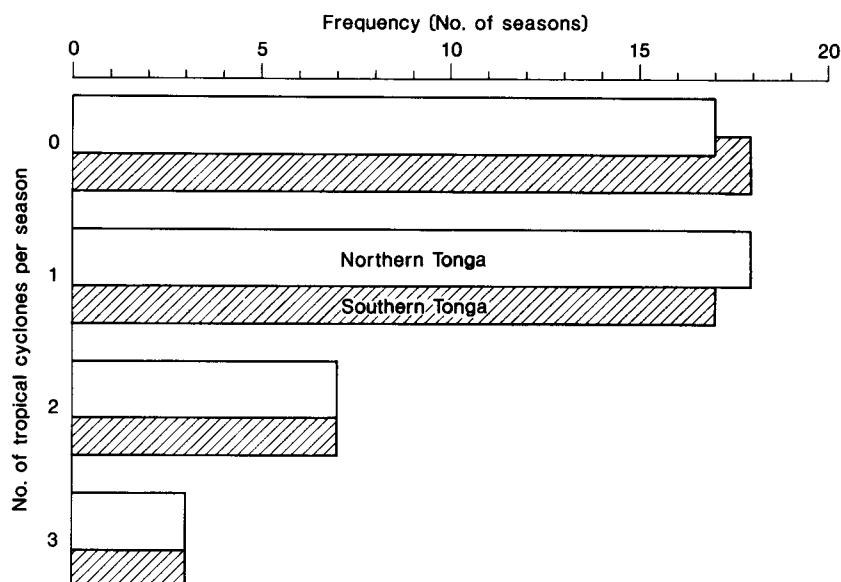


Fig. 4. Number of tropical cyclones affecting Northern Tonga (N) and Southern Tonga (S) in a season (1939/40 - 1984/85)

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

Further details of major tropical cyclones prior to 1939 may be found in Kerr (1976).

Since the advent of weather surveillance by satellites, to the New Zealand Meteorological Service, in 1969, there have been an average of 1.3 cyclones per year in each of Northern and Southern Tonga; a cyclone has influenced the entire group about once every two years. These frequencies are greater than those derived for the longer period. They suggest either that prior to the satellite era some cyclones were not recognised as such or that there has been an increase in cyclone frequency, probably the former.

Some indication of the interseasonal variability in the frequency of cyclones is given in Fig. 4. Sixteen seasons in Northern Tonga and 19 in Southern Tonga have been cyclone free,

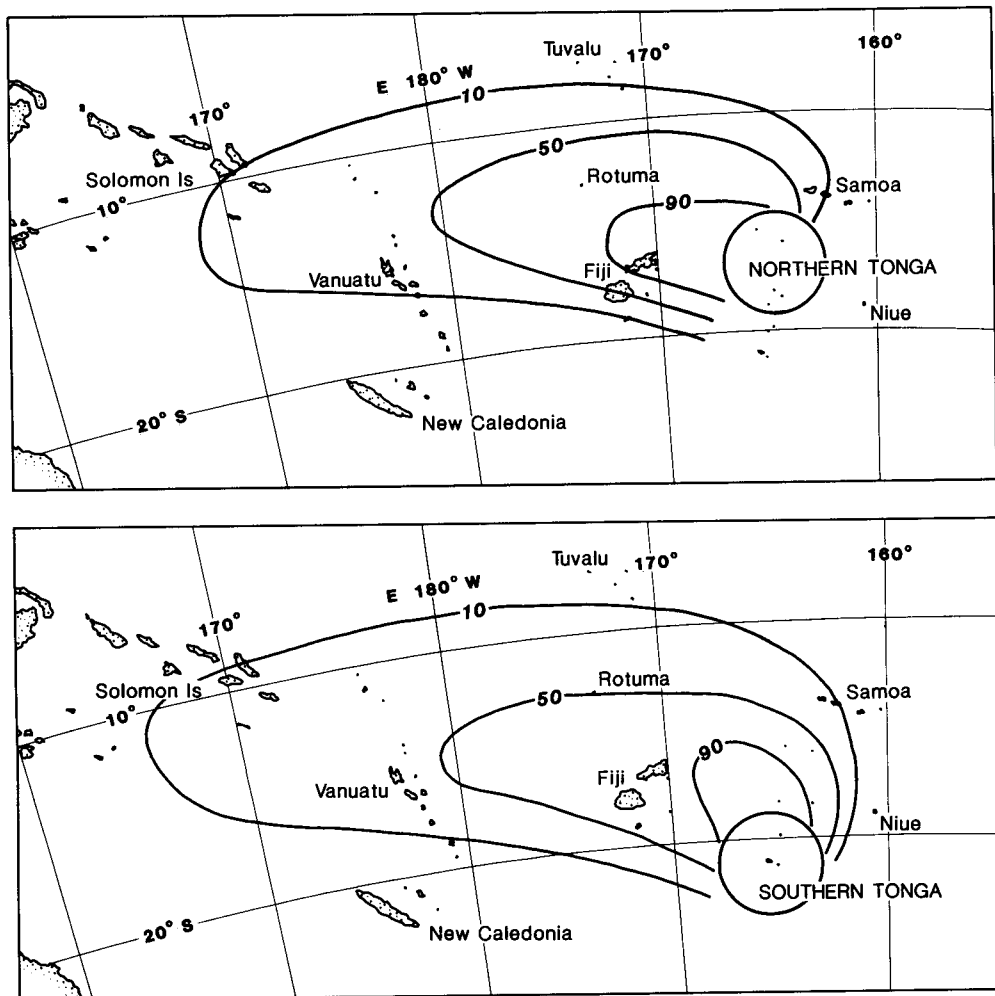


Fig. 5. Probability of a tropical cyclone once identified, subsequently affecting (a) Northern Tonga, and (b) Southern Tonga (based on data since 1969)

and there have been only three occasions in both the north and south when there were three in a single season.

Three tropical cyclones in a single season in Northern Tonga occurred in the 1949/1950, 1970/1971, and 1973/1974 seasons. In Southern Tonga they occurred in 1969/1970, 1977/1978 and 1980/1981. In five of the above six seasons the SOI was negative. Revell and Goulter (1985) have shown that the median location of South Pacific tropical cyclones is at 14°S 170°E. In negative SOI seasons, tropical cyclones tended to form north-east of the median position, but to the south-west for positive SOI. In seasons when three cyclones have affected Tonga, the average origin point lay close to the median latitude, but between the median longitude and 180°.

Figure 5 indicates the probability of a tropical cyclone being first identified in a particular location and subsequently affecting either Northern Tonga (Fig. 5a) or Southern Tonga (Fig. 5b). The shape of the isolines of equal probability indicates that tropical cyclones affecting Tonga mostly travel in an east to south-east direction.

#### Case Study: Tropical Cyclone 'Isaac' 27 February-5 March 1982

Tropical cyclone Isaac was a major hurricane that affected the whole of Tonga. Major hurricanes, defined by Revell (1982) as those with wind speeds over 90 knots, are infrequent in the South-west Pacific; only four have been recorded in the period from 1969 to 1979. Isaac is an example of a small, yet very intense tropical cyclone which caused widespread property damage and resulted in loss of life.

Isaac was first identified as a trough of low pressure within the South Pacific Convergence Zone during 27 February 1982 about 300 km south-west of Tokelau. As it moved south-eastward it intensified, reaching gale force at 1200 UT (Universal Time) the following day. At this stage Isaac lay 180 km east of Samoa. Isaac then began to move south-west, and during the evening of the 1st of March reached hurricane intensity as it continued to deepen. Continuing to move steadily south-west, Isaac passed over the island group of Ha'apai at about 1800 UT on the second and passed within 25 km west of Tongatapu in the early afternoon local time (0045 UT) on the 3rd of March 1982. Nuku'alofa reported a maximum wind gust of 92 knots from the north-north-east, and a lowest pressure of 976 hPa (Reddy, 1983). A copy of the barogram for Nuku'alofa is given in Fig. 6. Fua'amotu Airport reported gusts to 80 knots and a maximum sustained 10 minute wind speed of 54 knots. An estimate of the lowest central pressure was computed using the Atkinson and Holliday (1975) relationship as being about 965 to 970 hPa.

The south-westward movement of the tropical cyclone continued until about 1200 UT on the 3rd of March, by which time it was about 200 km south-west of Tongatapu, after which it

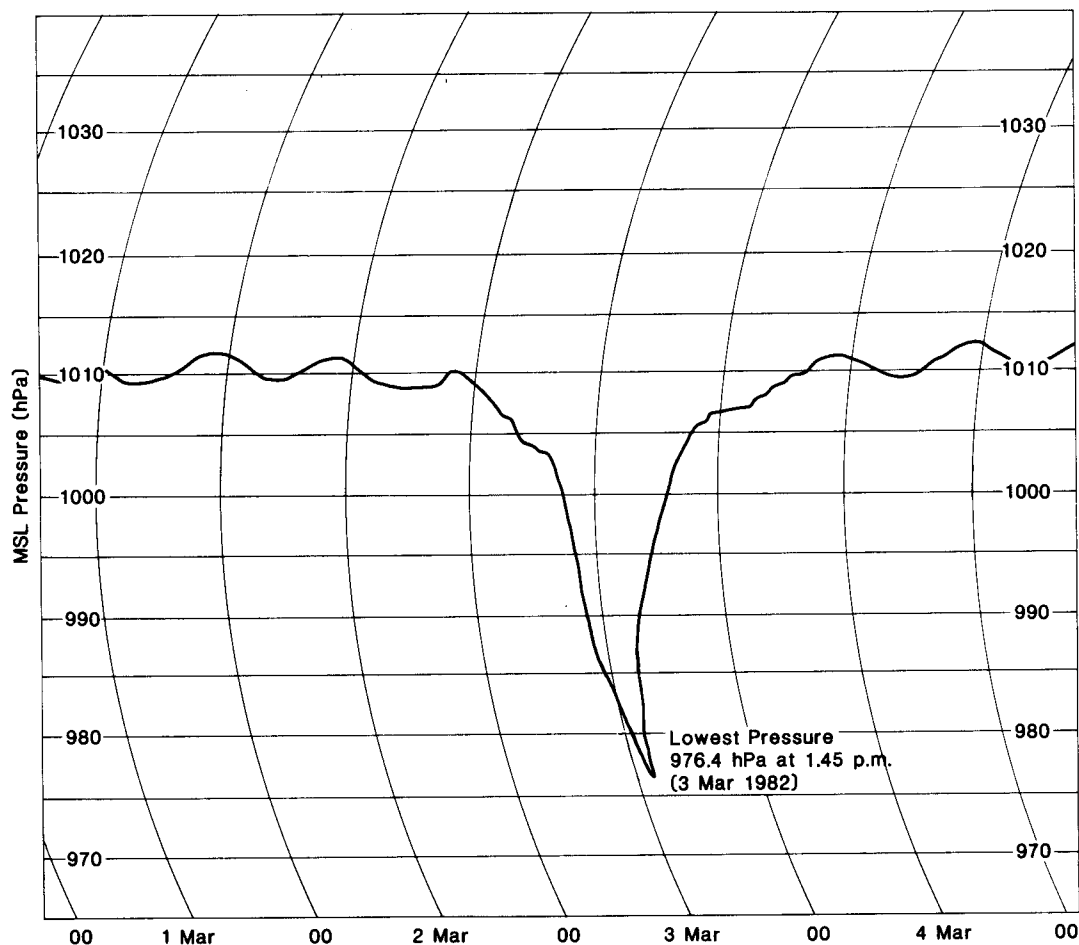


Fig. 6. Nuku'alofa barogram trace during the passage of tropical cyclone Isaac

recurved to the south-east and began to weaken. Figure 7 shows the passage of Isaac together with its attained intensity (Revell, 1985 pers. comm.) The cyclone moved at a fairly constant speed of 12 knots throughout its entire life. As a consequence, the hurricane force winds affected the island groupings for only a relatively short period of time (Reddy, 1983).

Figure 8 gives a sequence of daily satellite pictures from 27 February to 3 March 1982 during the lifetime of tropical cyclone Isaac. The photographs show Isaac as a relatively small and intense cyclone with its mean diameter being on average about 400 km. It caused immense losses to both property and crops through wind and flooding. On Tongatapu 20,000 people were left homeless. The estimated value of property loss and damage was estimated at \$T10 million (\$NZ12 million) (Tonga Chronicle, 12 March 1983). The value of lost crops was put at \$T8.7 million (\$NZ10.5 million); 90 percent of the island's

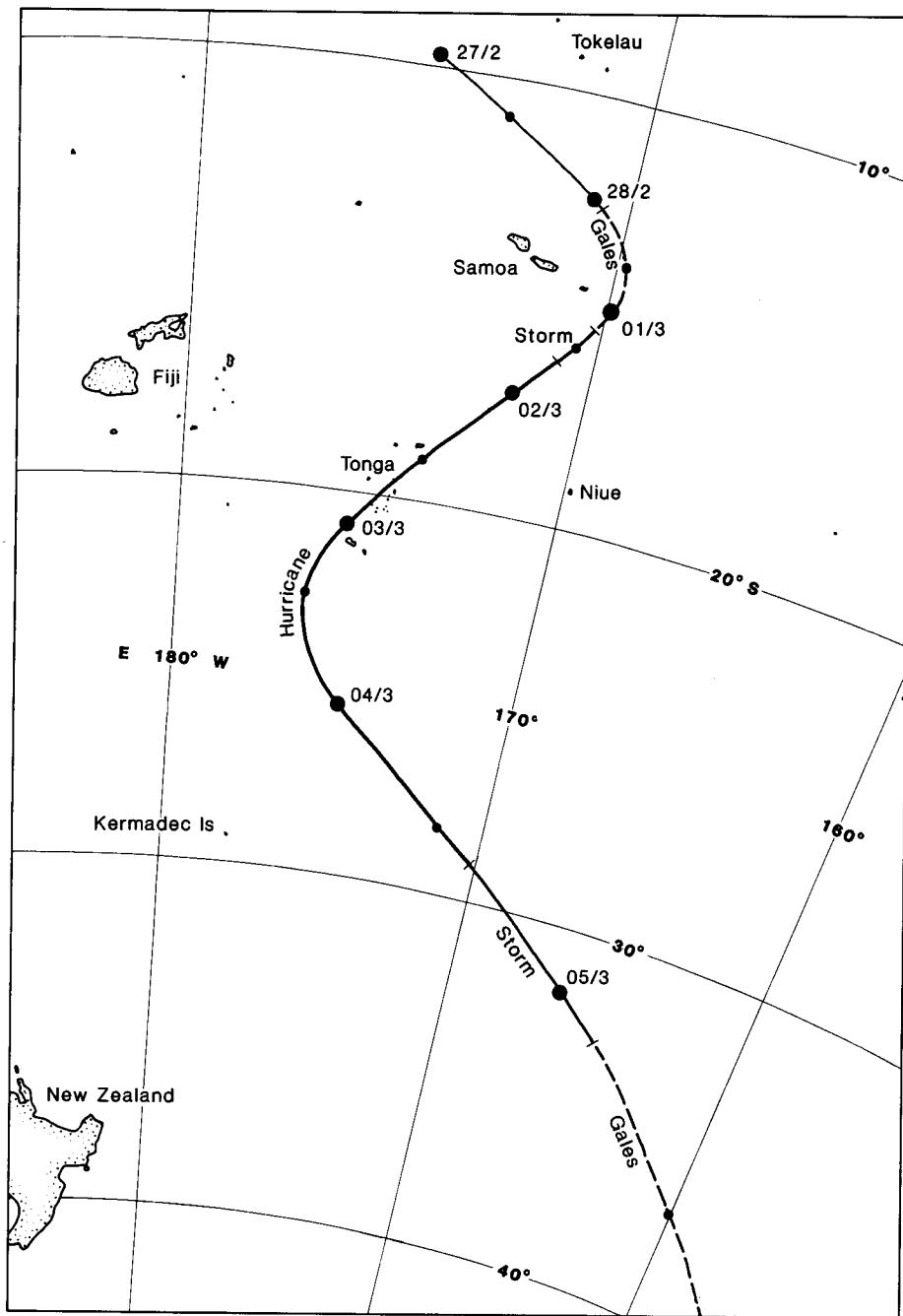


Fig. 7. Track of tropical cyclone Isaac from 29th February to 5 March 1982. Bars on track indicate positions every 12 hours

agricultural income. The accompanying storm surge swept several hundreds of metres inland. In the Ha'apai group 90 percent of buildings were swept away by the wind.

Comparing this storm with previous ones, the only other hurricane to cause a comparable loss to Tonga occurred in March 1961 (Kerr, 1976). However it does appear that Isaac resulted in greater damage than the 1961 storm.

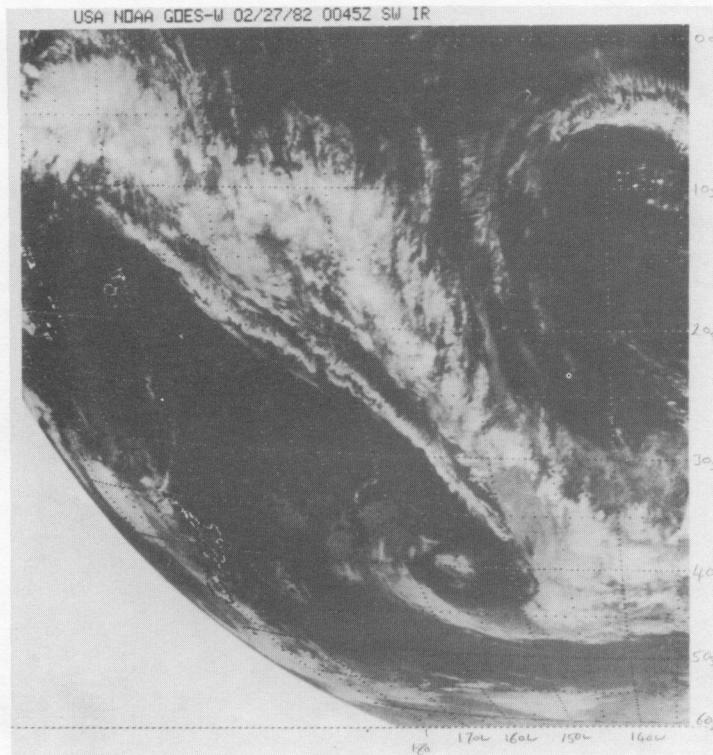


Fig. 8(a) Satellite view of South-West Pacific region on 27th February 1982. Formation stage of tropical cyclone Isaac



Fig. 8(b) Satellite view of South-West Pacific region on 28th February 1982. Tropical cyclone Isaac situated at  $12^{\circ}\text{S } 171^{\circ}\text{W}$



Fig. 8(c) Satellite view of South-West Pacific region on 1st March 1982. Tropical cyclone Isaac situated at 15°S 170°W



Fig. 8(d) Satellite view of South-West Pacific region on 2nd March 1982. Tropical cyclone Isaac situated at 17°S 172°W

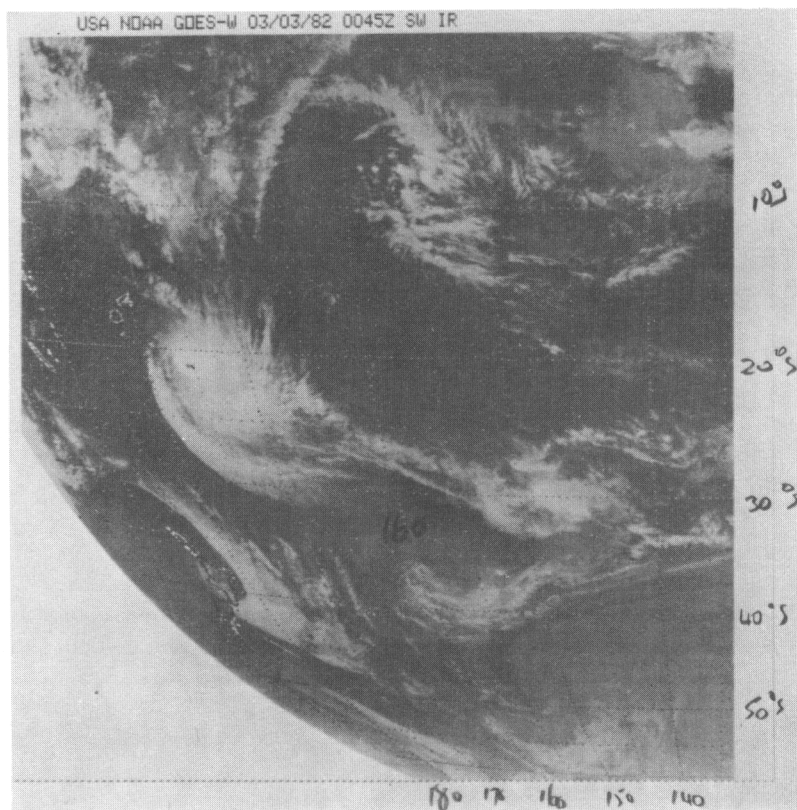


Fig. 8(e) Satellite view of South-West Pacific region on 3rd March 1982 as Isaac passed near Tongatapu

#### 4. EXTRA-TROPICAL INFLUENCES ON TROPICAL WEATHER

At any time of the year middle latitude cold fronts may enter the trade wind region and become quasi-stationary (Hutchings, 1961). The fronts tend to lie in a west-north-west to east-south-east direction. The weather of the tropical portions of fronts is normally a broad band of showers or rain. Middle latitude fronts eventually merge with the SPCZ and can display characteristics typical of convergence and frontal zones.

The mixed characteristic of the SPCZ is most noticeable during the dry season, when troughs of low pressure or sub-tropical depressions develop on the zone in association with low latitude jet streams. Their development is accompanied by an increase in the width of the cloud band and a further deterioration in the weather. The extensive altostratus cloud sheet and widespread rain forms downstream of the amplifying upper level trough of low pressure in the region of ascending motion associated with the equatorward entrance of the jet stream (Hill, 1963).

Figure 9 shows a satellite picture for 2 May 1985, of a quasi-stationary frontal zone lying just to the south of Tonga and Fiji. There is also an extensive area of cumulonimbus cloud between New Caledonia and Vanuatu, from which a shallow

sub-tropical depression had developed late on 2 May 1985. The depression subsequently moved eastwards along latitude 20°S, bringing high winds and rain to Southern Tonga on the 4th and 5th of May.

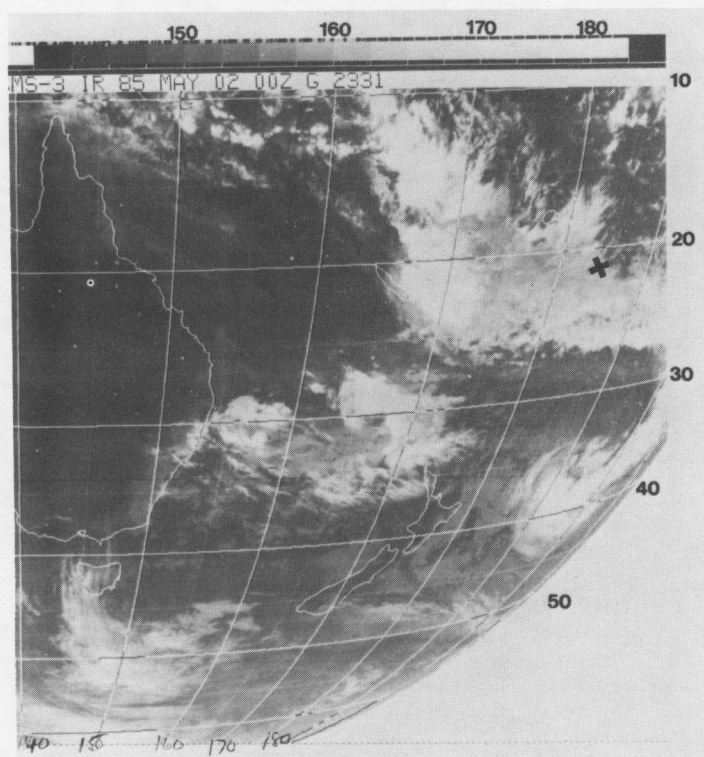


Fig. 9. Satellite view of South-West Pacific on 2 May 1985. A quasi-stationary frontal zone lies south of Fiji and Tongatapu (marked by an x). An extensive area of cumulonimbus clouds lies just east of New Caledonia out of which a sub-tropical depression formed.

## 5. CLIMATIC ELEMENTS

### Wind

The Kingdom of Tonga lies within the extensive trade wind zone of the South Pacific Ocean. Typically known as the south-east trades, they show remarkable constancy of direction and speed. While winds from the easterly quadrant blow for about 65 to 75 percent of the time, there are however seasonal differences (Table 3 and Fig. 10). In Northern Tonga easterlies and south-easterlies have their highest frequencies during the period May to October, when the trade winds are typically strongest. During this period trade winds may persist for weeks at a time (Revell, 1981). In Southern Tonga there is a tendency for little variation of the east or south-east winds throughout the year.

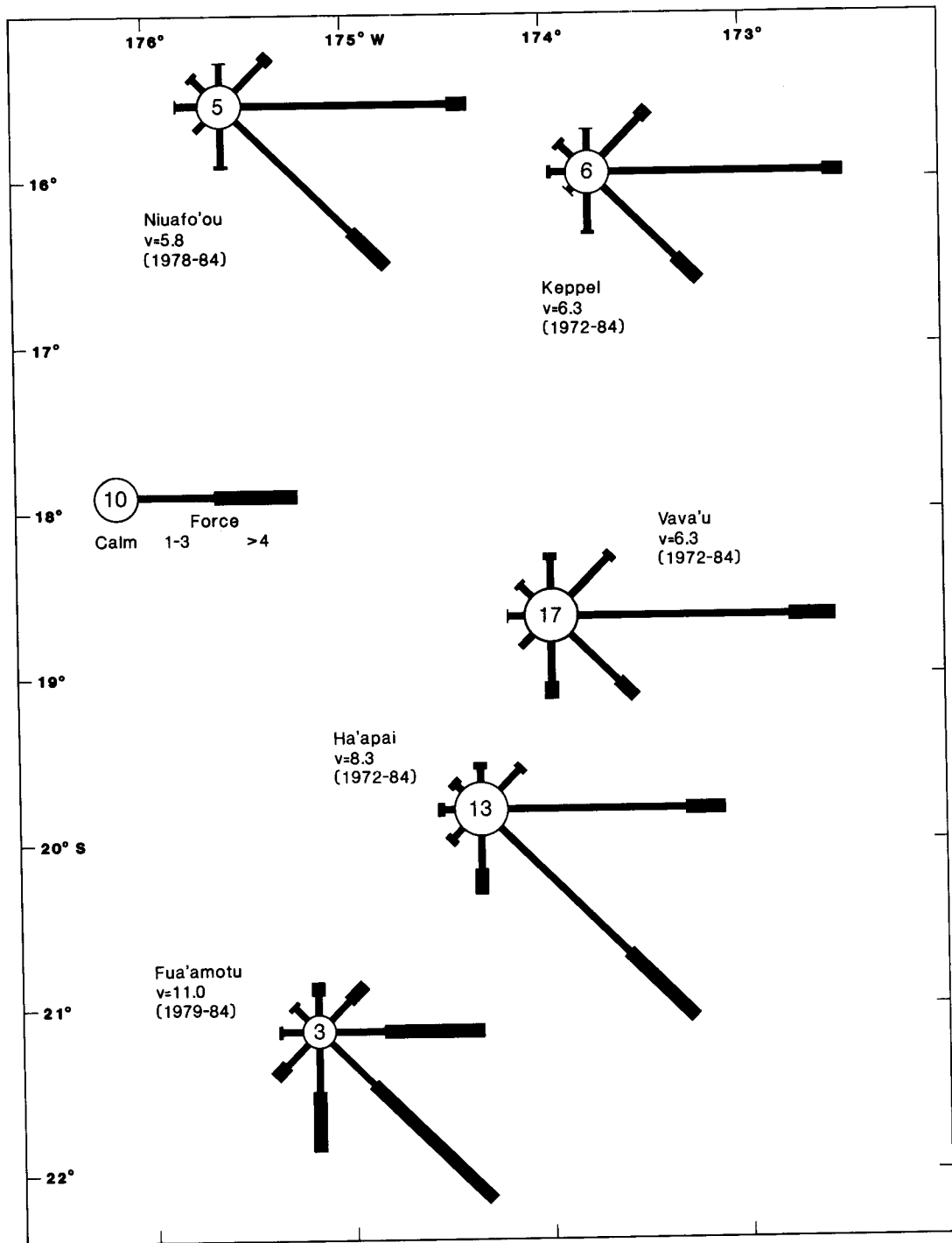


Fig. 10. Mean annual wind roses for Tonga  
 Percentages of wind from various directions  
 Observations made at 7 a.m. except at Fua'amotu  
 which are made at 10 a.m

From November to April, when the SPCZ generally lies over or near Northern Tonga, Southern Tonga still remains in the east to south-east trade wind zone. Northern Tonga on the other hand

Table 3. Wind direction frequencies (percent)

| Niuafu'ou (7 a.m.) |         |         |          | Keppel (7 a.m.) |         |         |          |
|--------------------|---------|---------|----------|-----------------|---------|---------|----------|
| Dir                | Nov-Apr | May-Oct | Combined | Dir             | Nov-Apr | May-Oct | Combined |
| N                  | 6.7     | 2.4     | 4.6      | N               | 7.7     | 3.6     | 5.6      |
| NE                 | 8.5     | 5.0     | 6.8      | NE              | 10.9    | 8.3     | 9.6      |
| E                  | 34.0    | 36.1    | 35.0     | E               | 43.5    | 51.1    | 47.4     |
| SE                 | 23.3    | 41.0    | 31.9     | SE              | 14.8    | 25.0    | 20.0     |
| S                  | 5.9     | 6.4     | 6.1      | S               | 3.9     | 4.3     | 4.1      |
| SW                 | 3.3     | 0.5     | 1.9      | SW              | 2.1     | 0.4     | 1.3      |
| W                  | 5.0     | 1.7     | 3.4      | W               | 4.1     | 1.5     | 2.7      |
| NW                 | 8.6     | 1.8     | 5.3      | NW              | 6.2     | 0.7     | 3.4      |
| Calm               | 4.8     | 5.1     | 5.0      | Calm            | 6.9     | 5.1     | 5.9      |

| Vava'u (7 a.m.) |         |         |          | Ha'apai (7 a.m.) |         |         |          |
|-----------------|---------|---------|----------|------------------|---------|---------|----------|
| Dir             | Nov-Apr | May-Oct | Combined | Dir              | Nov-Apr | May-Oct | Combined |
| N               | 5.2     | 4.7     | 4.9      | N                | 3.3     | 2.1     | 2.7      |
| NE              | 11.0    | 9.2     | 10.1     | NE               | 4.7     | 3.1     | 3.9      |
| E               | 40.2    | 39.1    | 39.7     | E                | 29.4    | 22.9    | 26.1     |
| SE              | 8.4     | 17.7    | 13.0     | SE               | 39.8    | 42.3    | 41.0     |
| S               | 4.5     | 12.5    | 8.5      | S                | 5.3     | 9.7     | 7.5      |
| SW              | 2.2     | 1.4     | 1.8      | SW               | 1.8     | 3.0     | 2.4      |
| W               | 3.2     | 1.5     | 2.4      | W                | 2.3     | 1.5     | 1.9      |
| NW              | 3.3     | 1.4     | 2.3      | NW               | 2.3     | 1.5     | 1.9      |
| Calm            | 22.0    | 12.5    | 17.2     | Calm             | 11.1    | 13.8    | 12.5     |

| Nuku'alofa (10 a.m.) |         |         |          | Fua'amotu (10 a.m.) |         |         |          |
|----------------------|---------|---------|----------|---------------------|---------|---------|----------|
| Dir                  | Nov-Apr | May-Oct | Combined | Dir                 | Nov-Apr | May-Oct | Combined |
| N                    | 5.7     | 5.4     | 5.5      | N                   | 3.8     | 4.2     | 4.0      |
| NE                   | 13.5    | 8.5     | 11.0     | NE                  | 7.8     | 6.9     | 7.4      |
| E                    | 34.4    | 21.7    | 27.9     | E                   | 26.7    | 20.2    | 23.5     |
| SE                   | 27.6    | 31.4    | 29.5     | SE                  | 35.1    | 32.2    | 33.7     |
| S                    | 9.7     | 18.4    | 14.1     | S                   | 13.5    | 17.7    | 15.6     |
| SW                   | 2.0     | 4.0     | 3.0      | SW                  | 5.3     | 8.9     | 7.1      |
| W                    | 1.8     | 4.6     | 3.2      | W                   | 1.9     | 4.5     | 3.2      |
| NW                   | 2.6     | 2.0     | 2.3      | NW                  | 2.4     | 3.1     | 2.7      |
| Calm                 | 2.8     | 4.1     | 3.5      | Calm                | 3.6     | 2.2     | 2.9      |

is affected by increased frequencies of northerlies, and 'monsoon' winds from the north and north-west become more prominent. Although their frequencies are reduced, east and south-east winds are still the dominant directions.

Table 4. Mean wind speeds (knots)

| Location   | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Niuafu'ou  | 5   | 5   | 5   | 4   | 6   | 6   | 7   | 7   | 7   | 6   | 6   | 6   |
| Keppel     | 5   | 5   | 5   | 4   | 7   | 7   | 7   | 7   | 7   | 7   | 7   | 6   |
| Vava'u     | 5   | 5   | 5   | 5   | 7   | 7   | 8   | 8   | 7   | 7   | 8   | 6   |
| Ha'apai    | 8   | 8   | 8   | 6   | 9   | 8   | 9   | 9   | 8   | 9   | 10  | 9   |
| Nuku'alofa | 10  | 9   | 9   | 7   | 8   | 8   | 8   | 8   | 9   | 9   | 10  | 9   |
| Fua'amotu* | 9   | 9   | 10  | 7   | 9   | 8   | 8   | 10  | 10  | 10  | 11  | 10  |

\* Wind speeds derived from an instrumental record.

Mean monthly wind speeds are presented in Table 4. The mean values have been derived from Beaufort wind scale estimates taken at the climatological observing time with the exception of Fua'amotu, where a short instrumental record exists. Winds on Niuafu'ou, Keppel and Vava'u are most likely underestimated being affected by the orography of these locations. Mean wind speeds from May to October in Northern Tonga are stronger than at other times of the year. In Southern Tonga and especially on Tongatapu, mean speeds tend to be stronger during the November to April period which is coincident with the tropical cyclone season.

The seasonal frequency of fresh to strong winds (Beaufort force four and above) are shown in Table 5. Northern Tongan locations show there is almost twice the frequency of high winds in the dry season (i.e. May to October) than at other times. The windiest month is usually July or August. In Southern Tonga November to December is commonly the windiest time of the year, but the frequency of fresh to strong winds is similar in both seasons.

Table 5. Frequency (percent) of winds Beaufort force 4 and above

| Location   | May-Oct | Nov-Apr | Combined | Windiest Month | Least Windy |
|------------|---------|---------|----------|----------------|-------------|
| Niuafu'ou  | 13.6    | 7.9     | 10.6     | July 15.6      | April 2.9   |
| Keppel     | 20.5    | 11.8    | 16.2     | July 23.6      | April 2.5   |
| Vava'u     | 20.6    | 10.2    | 15.4     | Aug. 30.2      | Jan. 5.3    |
| Ha'apai    | 28.1    | 24.5    | 26.3     | July 31.9      | April 13.6  |
| Nuku'alofa | 27.8    | 32.1    | 29.9     | Nov. 42.4      | April 18.4  |
| Fua'amotu  | 54.8    | 59.0    | 57.0     | Dec. 70.4      | April 38.7  |

Gale force winds (at least Beaufort Force 8) are mostly reported when tropical cyclones pass through the Tongan group between November and April. Gales have been reported at other times, but most of these were in the nature of squalls associated with winds from between west and north-west.

Wind gust data exists for Fua'amotu Airport. Gusts over 33 knots are measured on about 14 days every year. A hurricane wind gust for Tonga with a 50-year return period is about 105 knots (Reid, 1985, pers. comm.).

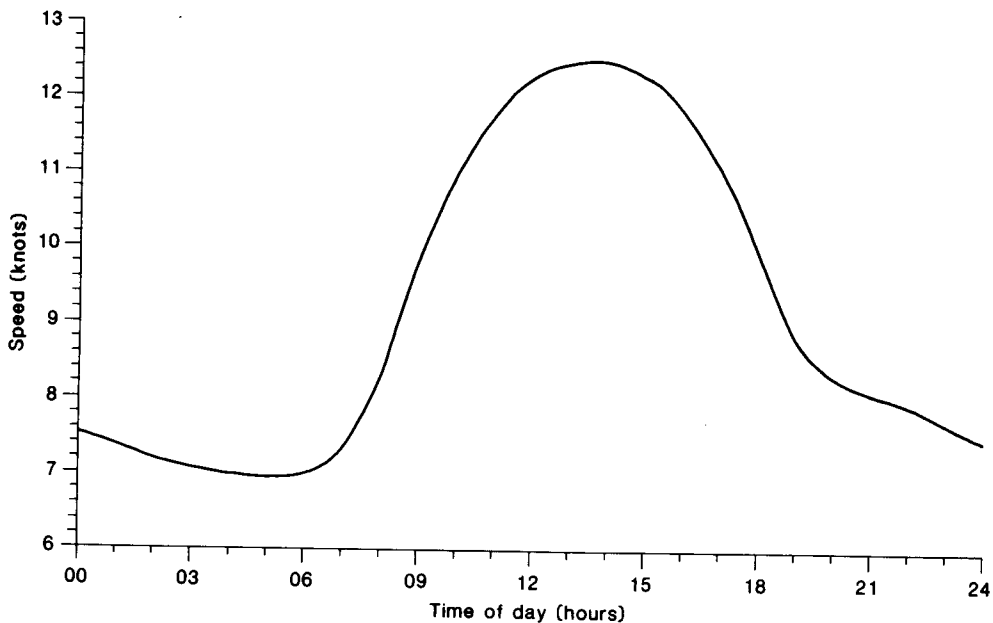


Fig. 11. Diurnal variation of wind speed at Fua'amotu, Tonga, 1980 - 1983

The diurnal variation of wind speed at Fua'amotu Airport is given in Fig. 11. There is a maximum wind speed in the early afternoon when temperatures are highest and atmospheric stability least, but the night-time reduction in wind results from the decrease in the land - sea temperature contrast. The range of the diurnal variation is quite large, being about 50 percent of the mean speed. Calm conditions are a maximum at night, occurring 21 percent of the time, but are rare during the afternoons being reported on just one percent of occasions. Data on diurnal variation elsewhere in Tonga is not available.

Wind Power. Wind is an ever present resource which is a result of interactions between the large scale weather patterns and the orographic characteristics of a particular location. An analysis of wind data can be used to assess the potential of a site for wind energy generation.

A Weibull distribution is frequently used in fitting observed wind speed distributions. From observations the standard wind speed  $c$  (Weibull scale parameter) is that speed which is exceeded for 36.8 percent of the time (Swift-Hook, 1979). For a range of Weibull shape parameters  $k$ , the mean speed and the standard speed are closely related. In this study a value of  $k=2$  has been adopted, since the accuracy of  $c$  is better than two percent for values of  $k$  in the range from 1.5 to 3 (Swift-Hook, 1979).

One approach in assessing a location's potential for wind power is with the aid of velocity-duration curves based on a theoretical Weibull distribution (Fig. 12). Starting with the highest speeds, the velocity-duration curve accumulates for a known mean speed, the number of hours in a year that the wind blows in excess of a certain speed. For a mean speed of six knots, the average number of hours per year the wind is likely to blow between six and 30 knots is 4425 hours. For a mean speed of 10 knots the value is 6850 hours.

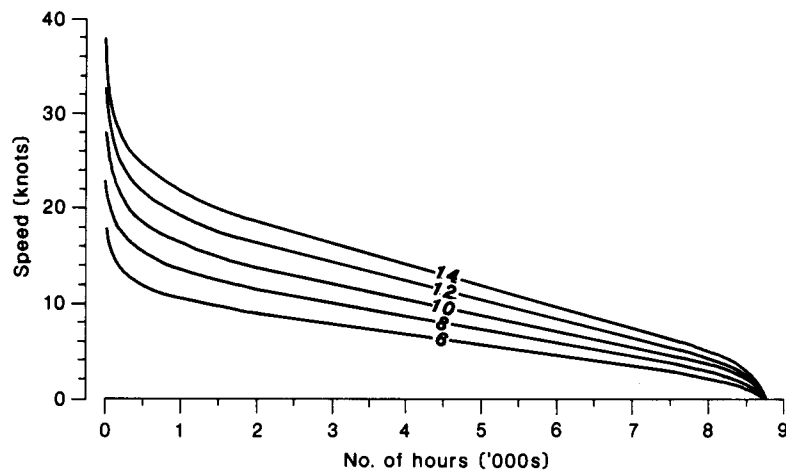


Fig. 12. Speed-duration diagram for various mean speeds (Derived from a Weibull distribution with a shape factor of 2.)

Wind power is proportional to the cube of the wind speed. At a speed of one knot the total cumulative wind power available in one hour is  $8.82 \times 10^{-5}$  kwh/m<sup>2</sup>. Estimates of available wind power between 6 and 30 knots for locations in Tonga are displayed in Table 6. An estimate of the mean wind was made assuming that the 7 a.m. wind observation was made at the time when the winds were at a diurnal minimum. It was further assumed that the mean speed was about 10 percent higher than the minimum speed ( as Thompson 1986 noted was the case on small islands in the the Northern Cooks). Table 6 shows that Tongatapu has greatest wind energy potential because of the higher mean speeds. Fua'amotu with 1082 kwh/m<sup>2</sup> has over twice as much power available each year from the wind as is available at the meteorological sites on Keppel Island and Vava'u.

Table 6. Wind power estimates\* for Tonga

| Location   | V <sub>m</sub> | C    | Wind power<br>kwh/m <sup>2</sup> /yr | Hours per year<br>between 6 and 30 kn |
|------------|----------------|------|--------------------------------------|---------------------------------------|
| Niuafou'ou | 6.4            | 7.0  | 350                                  | 4810                                  |
| Keppel     | 7.0            | 7.7  | 465                                  | 5305                                  |
| Vava'u     | 7.0            | 7.7  | 465                                  | 5305                                  |
| Ha'apai    | 9.1            | 10.0 | 1045                                 | 6515                                  |
| Nuku'alofa | 8.5            | 9.4  | 850                                  | 6235                                  |
| Fua'amotu  | 9.2            | 10.2 | 1080                                 | 6555                                  |
| Ocean+     | 12.8           | 14.2 | 2650                                 | 7455                                  |

\* Assumes a Weibull distribution with a shape factor of 2.

+ Ocean refers to the area, 15-23°S, 171-177°W, surrounding Tonga.

### Rainfall

Annual, seasonal and monthly rainfalls. In tropical and sub-tropical regions, rainfall varies greatly in both time and space. Rainfall in such regions is perhaps the most important climatic variable from the human viewpoint (Jackson, 1977). Extreme climatic fluctuations persisting for months and even years can have a dramatic impact on the economies as well as the lives of the inhabitants of an affected region.

Table 7. Seasonal distribution of rainfall

| Location   | Season |     | Percent of annual total |     |
|------------|--------|-----|-------------------------|-----|
|            | wet    | dry | wet                     | dry |
|            | (mm)   |     | season                  |     |
| Niuafou'ou | 1575   | 947 | 62                      | 38  |
| Keppel     | 1529   | 822 | 65                      | 35  |
| Ha'apai    | 1214   | 591 | 67                      | 33  |
| Vava'u     | 1555   | 757 | 67                      | 33  |
| Nuku'alofa | 1138   | 676 | 63                      | 37  |

There is a marked seasonality in the Tongan rainfall. There are two main seasons; a wet season from November to April and a dry season from May to October. Table 7 presents the

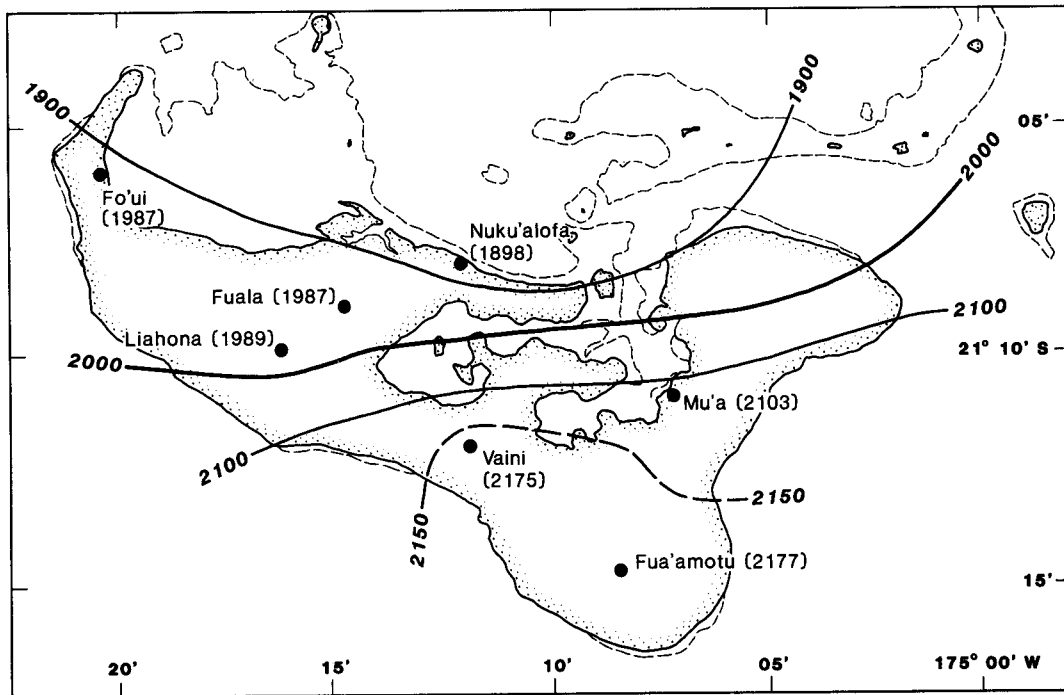


Fig. 13. Mean annual rainfall (1951-1980) on Tongatapu

seasonal distribution for areas in Tonga. About 65 percent of the rain falls during the wet season. Rainfall seasonality is most marked on the Ha'apai and Vava'u island groups.

In Tonga, precipitation results from convective processes, from tropical cyclones and from rain associated with the cloud sheets of the subtropical jet-stream. While convective rainfall occurs all year round and is most pronounced during during the warm wet season, the organised large scale precipitation is usually prevalent during the cooler dry part of the year.

The spatial variation of monthly and annual rainfall over Tonga is shown in Table 8. It can be seen that the northernmost islands which come under the influence of the SPCZ have highest rainfalls.

The Ha'apai group of islands lies in a relatively dry zone of Tonga, between the region of influence associated with the SPCZ over Northern Tonga, and rainfall associated with the upper air jet-stream and other extra-tropical weather features. However, the volcanic islands of Kao and Tofua receive considerably more rainfall than elsewhere in the group due to orographic enhancement of rainfall (Fifita, 1985; pers. comm.). Both island summits are frequently covered by cloud.

Figure 13 shows the spatial variation of rainfall on Tongatapu. The south-eastern side of the island is slightly wetter than elsewhere.

Table 8. Rainfall normals 1951-1980

| Location   | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year |
|------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
| Niuafo'ou  | 287 | 246 | 244 | 254 | 189 | 81  | 139 | 121 | 150 | 160 | 246 | 260 | 2377 |
| Keppel     | 276 | 233 | 297 | 253 | 153 | 123 | 118 | 90  | 147 | 189 | 230 | 229 | 2338 |
| Vava'u     | 285 | 260 | 364 | 227 | 136 | 105 | 122 | 116 | 132 | 144 | 180 | 185 | 2255 |
| Ha'apai    | 206 | 199 | 253 | 288 | 95  | 74  | 90  | 112 | 105 | 104 | 133 | 152 | 1710 |
| Nuku'alofa | 217 | 247 | 256 | 184 | 101 | 91  | 93  | 116 | 138 | 157 | 136 | 152 | 1888 |
| Kolovai    | 249 | 311 | 303 | 148 | 130 | 91  | 112 | 103 | 120 | 101 | 119 | 130 | 1917 |
| Liahona    | 223 | 267 | 290 | 169 | 111 | 92  | 115 | 117 | 165 | 156 | 131 | 163 | 1989 |
| Fuala      | 230 | 246 | 271 | 186 | 110 | 102 | 112 | 119 | 121 | 186 | 149 | 155 | 1987 |
| Mu'a       | 226 | 301 | 272 | 189 | 151 | 103 | 104 | 119 | 156 | 150 | 148 | 184 | 2103 |
| Vaini      | 267 | 342 | 275 | 221 | 111 | 95  | 85  | 110 | 151 | 155 | 162 | 201 | 2175 |
| Fua'amotu  | 248 | 318 | 256 | 205 | 128 | 109 | 97  | 126 | 174 | 178 | 151 | 187 | 2177 |

On the island of 'Eua, just south-east of Tongatapu, rainfall measurements have been taken since 1983 at the Government sawmill at Vaitaki. 'Eua is wetter than Tongatapu

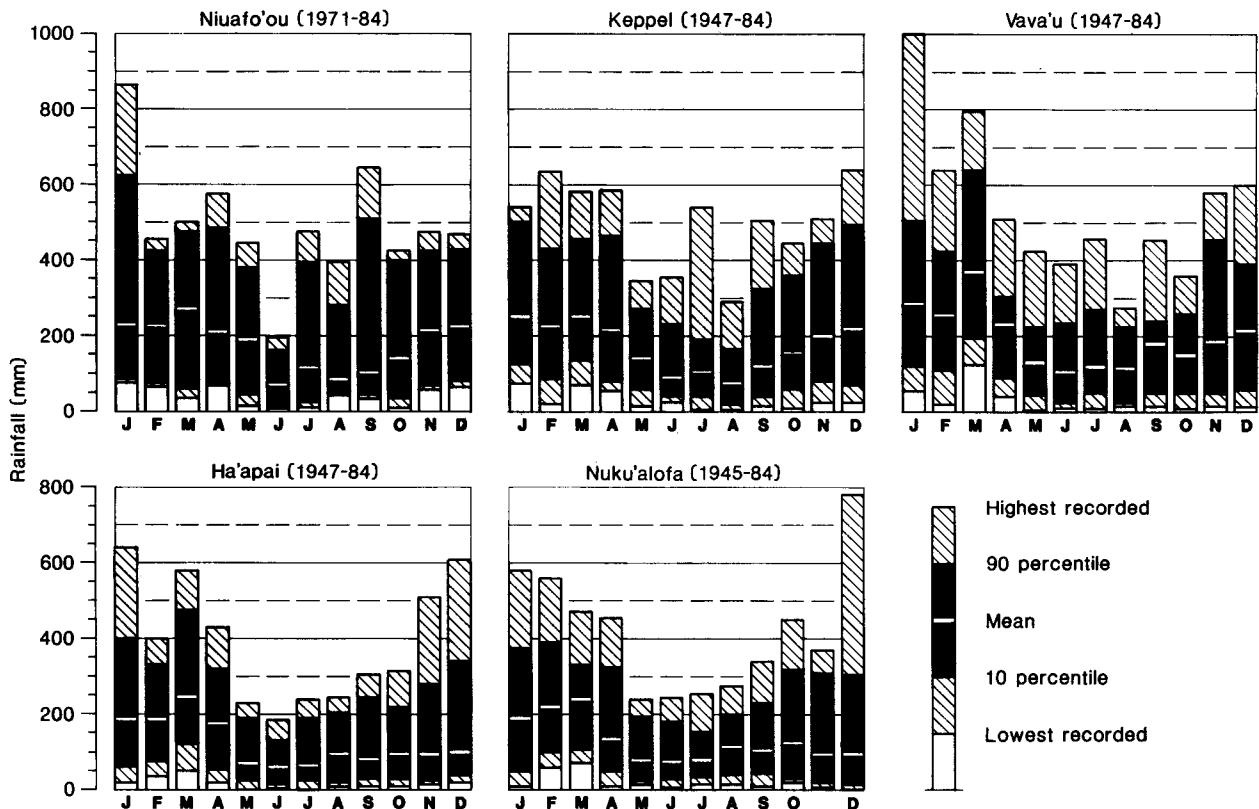


Fig. 14. Rainfall statistics - Tonga

(Fifita and Havea, 1985; pers. comm.). A preliminary analysis of rainfall data suggests that Vaitaki probably receives up to about 25 percent more rainfall than does Fua'amotu Airport.

Actual monthly rainfalls show large variation from year to year (Table 9 and Fig. 14). The coefficient of variation statistic in Table 9 indicates that rainfall is just as variable in the wet season as it is in the dry season. Rainfall statistics are shown diagrammatically in Fig. 14. As an example of how to interpret this figure, the 90 percentile rainfall for March at Niufo'ou is 488 mm. This means that one year in ten rainfall can be expected to be above this amount. Similarly the 10 percentile rainfall of 48 mm on Niufo'ou will not be exceeded in one year in ten.

Table 9. Monthly rainfall extremes and coefficient of variation (CV) for Tonga

|                   | Jan  | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|-------------------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| <b>Niufo'ou</b>   |      |     |     |     |     |     |     |     |     |     |     |     |
| Highest           | 865  | 456 | 497 | 573 | 445 | 197 | 474 | 204 | 646 | 424 | 476 | 471 |
| Lowest            | 77   | 65  | 37  | 69  | 15  | 11  | 8   | 47  | 33  | 12  | 60  | 113 |
| CV*               | 76   | 53  | 65  | 62  | 63  | 76  | 88  | 57  | 91  | 78  | 52  | 47  |
| <b>Keppel</b>     |      |     |     |     |     |     |     |     |     |     |     |     |
| Highest           | 537  | 636 | 580 | 588 | 347 | 355 | 542 | 293 | 507 | 449 | 511 | 648 |
| Lowest            | 72   | 20  | 68  | 52  | 13  | 24  | 4   | 5   | 13  | 9   | 23  | 41  |
| CV                | 48   | 55  | 48  | 59  | 51  | 69  | 74  | 74  | 78  | 64  | 58  | 64  |
| <b>Vava'u</b>     |      |     |     |     |     |     |     |     |     |     |     |     |
| Highest           | 1009 | 642 | 799 | 509 | 425 | 393 | 467 | 273 | 456 | 359 | 581 | 604 |
| Lowest            | 50   | 15  | 126 | 42  | 7   | 9   | 11  | 12  | 12  | 11  | 12  | 14  |
| CV                | 70   | 52  | 45  | 50  | 68  | 82  | 82  | 62  | 66  | 60  | 83  | 73  |
| <b>Ha'apai</b>    |      |     |     |     |     |     |     |     |     |     |     |     |
| Highest           | 649  | 403 | 593 | 436 | 233 | 187 | 238 | 245 | 308 | 316 | 512 | 613 |
| Lowest            | 15   | 35  | 53  | 31  | 0   | 5   | 2   | 1   | 7   | 6   | 11  | 14  |
| CV                | 62   | 49  | 45  | 54  | 68  | 67  | 67  | 64  | 77  | 70  | 90  | 90  |
| <b>Nuku'alofa</b> |      |     |     |     |     |     |     |     |     |     |     |     |
| Highest           | 582  | 564 | 469 | 458 | 241 | 243 | 259 | 273 | 341 | 452 | 368 | 783 |
| Lowest            | 10   | 61  | 71  | 9   | 17  | 7   | 18  | 17  | 11  | 17  | 6   | 3   |
| CV                | 65   | 51  | 37  | 63  | 62  | 72  | 60  | 58  | 63  | 81  | 87  | 109 |

\* CV is the ratio of the monthly standard deviation to the monthly mean expressed as a percentage.

Rainfall deciles for consecutive months can be used to identify the extent of a risk to an area of very dry or wet conditions. In Fig. 15 deciles are presented for six and 12 consecutive months. As an example of how to interpret this figure, the 50 percentile (median) at Ha'apai in a six month period commencing in March is 853 mm of rainfall. In 10 percent of all six-month periods there will be at least 1093 mm of rainfall.

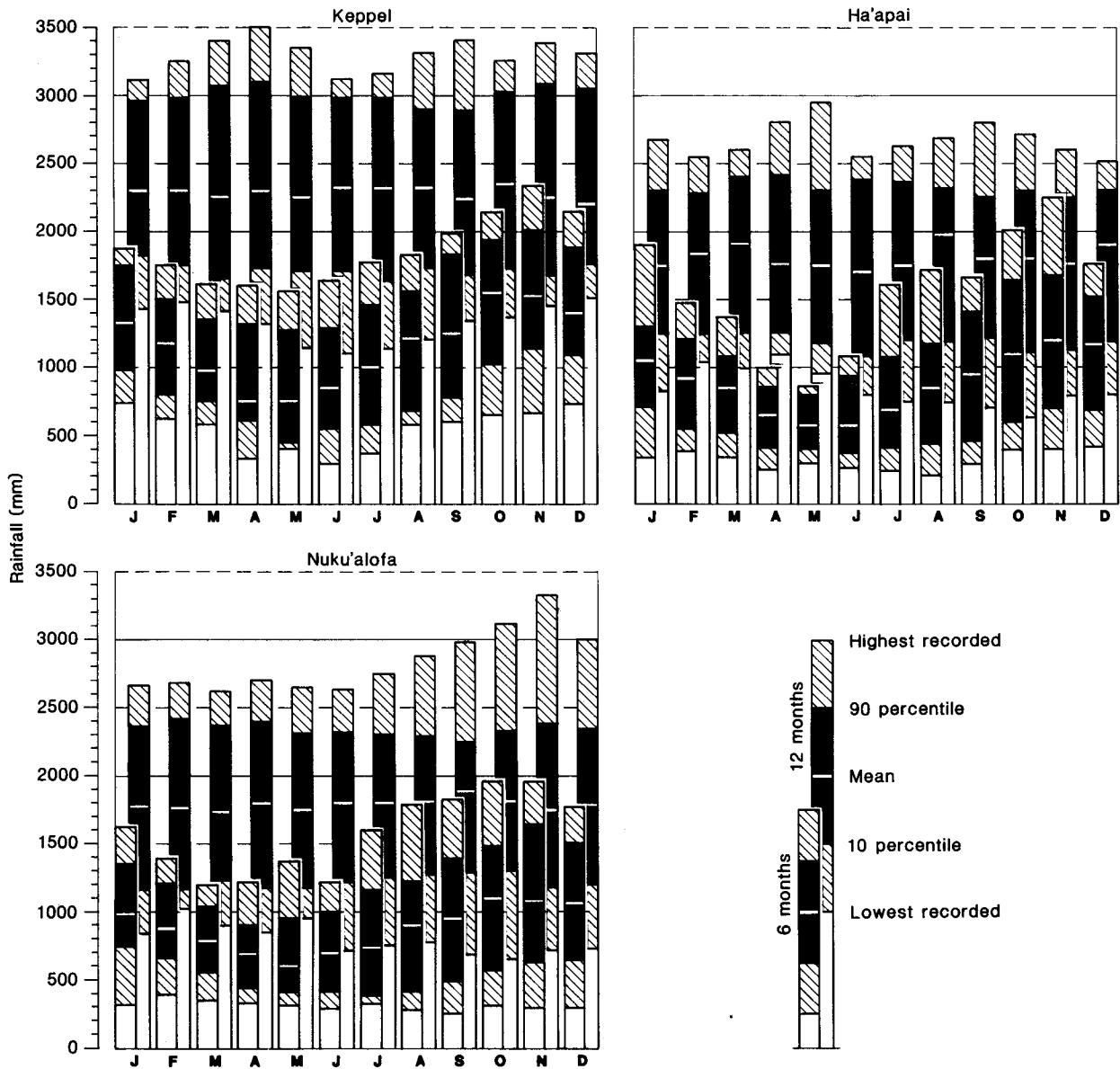


Fig. 15. Rainfall deciles for Tonga for 6 and 12 consecutive months. The month shown in the figure is the start month

The probability of receiving a specified amount of rainfall every year can be used to estimate the reliability of the rainfall. Table 10 gives the probabilities of receiving at least 2000 mm and 2500 mm a year in at least four out of five successive years. This table also indicates the probabilities that two successive years will record less than the above thresholds. At Keppel there is a 10 percent chance of 2500 mm falling in four out of five years, but a negligible chance at Nuku'alofa. The corresponding probabilities for two successive dry years are 34 and 90 percent respectively.

Table 10. Rainfall probabilities - Tonga

| Location   | Percent probability of receiving at least 2000 mm per year | Percent probability of receiving at least 2000 mm in 4 out of 5 successive years | Percent probability of 2 successive years receiving less than 2000 mm |
|------------|--|--|---|
| Keppel     | 68   | 48   | 10  |
| Vava'u     | 63   | 40   | 13  |
| Ha'apai    | 39   | 8  | 38  |
| Nuku'alofa | 32   | 4  | 47  |

| Location   | Percent probability of receiving at least 2500 mm per year | Percent probability of receiving at least 2500 mm in 4 out of 5 successive years | Percent probability of 2 successive years receiving less than 2500 mm |
|------------|--|--|---|
| Keppel     | 42   | 10   | 34  |
| Vava'u     | 39   | 8  | 37  |
| Ha'apai    | 3  | 0  | 94  |
| Nuku'alofa | 5  | 0  | 90  |

Raindays, rainfall persistence and diurnal variation. The frequency of days with rainfall above specified thresholds is given in Table 11. Of days with more than 0.1 mm, 55 to 60 percent occur during the wet season. There are more heavier falls of rain in the wet season than in the dry (Table 11(d)) contributing to the rainfall maximum of this season.

Table 12 shows that frequencies of days with rain vary markedly from season to season and from year to year, reflecting

Table 11. Days with rain - Tonga

|                            | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|----------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| (a) above 0.1 mm threshold |     |     |     |     |     |     |     |     |     |     |     |     |
| Niuafo'ou                  | 19  | 19  | 17  | 18  | 13  | 12  | 12  | 14  | 13  | 13  | 17  | 17  |
| Keppel                     | 22  | 18  | 21  | 17  | 17  | 15  | 13  | 13  | 16  | 15  | 17  | 18  |
| Vava'u                     | 17  | 18  | 19  | 14  | 12  | 9   | 11  | 12  | 12  | 12  | 12  | 14  |
| Ha'apai                    | 14  | 14  | 16  | 12  | 9   | 8   | 10  | 10  | 9   | 9   | 9   | 10  |
| Nuku'alofa                 | 17  | 17  | 20  | 15  | 15  | 14  | 11  | 13  | 11  | 12  | 13  | 13  |
| (b) above 1 mm threshold   |     |     |     |     |     |     |     |     |     |     |     |     |
| Niuafo'ou                  | 18  | 18  | 15  | 16  | 11  | 9   | 9   | 10  | 10  | 10  | 15  | 14  |
| Keppel                     | 19  | 17  | 18  | 14  | 14  | 11  | 10  | 9   | 12  | 12  | 15  | 15  |
| Vava'u                     | 16  | 17  | 17  | 13  | 11  | 7   | 9   | 10  | 10  | 10  | 11  | 13  |
| Ha'apai                    | 12  | 13  | 14  | 11  | 8   | 7   | 6   | 8   | 9   | 7   | 8   | 9   |
| Nuku'alofa                 | 13  | 13  | 16  | 11  | 11  | 8   | 8   | 9   | 8   | 8   | 9   | 9   |
| (c) above 5 mm threshold   |     |     |     |     |     |     |     |     |     |     |     |     |
| Niuafo'ou                  | 10  | 11  | 9   | 11  | 8   | 5   | 4   | 5   | 5   | 6   | 9   | 8   |
| Keppel                     | 11  | 11  | 11  | 8   | 6   | 5   | 5   | 4   | 7   | 6   | 8   | 9   |
| Vava'u                     | 10  | 12  | 12  | 9   | 7   | 4   | 5   | 7   | 6   | 6   | 7   | 8   |
| Ha'apai                    | 8   | 8   | 10  | 7   | 4   | 3   | 4   | 5   | 6   | 3   | 4   | 6   |
| Nuku'alofa                 | 7   | 8   | 9   | 6   | 5   | 3   | 4   | 5   | 5   | 5   | 5   | 5   |
| (d) above 20 mm threshold  |     |     |     |     |     |     |     |     |     |     |     |     |
| Niuafo'ou                  | 4   | 5   | 3   | 4   | 3   | 1   | 2   | 1   | 2   | 3   | 3   | 3   |
| Keppel                     | 4   | 4   | 4   | 4   | 2   | 2   | 2   | 1   | 3   | 3   | 4   | 4   |
| Vava'u                     | 4   | 5   | 5   | 3   | 2   | 1   | 2   | 3   | 2   | 1   | 3   | 3   |
| Ha'apai                    | 3   | 3   | 4   | 3   | 1   | 1   | 2   | 2   | 3   | 2   | 2   | 3   |
| Nuku'alofa                 | 3   | 3   | 3   | 3   | 2   | 1   | 1   | 2   | 2   | 2   | 2   | 2   |

Table 12. Extremes in annual numbers of days with rain, and coefficient of variation (CV)

|            | Raindays |     |    |        |     |    |        |     |    |         |     |    |
|------------|----------|-----|----|--------|-----|----|--------|-----|----|---------|-----|----|
|            | 0.1 mm   |     |    | 1.0 mm |     |    | 5.0 mm |     |    | 20.0 mm |     |    |
|            | High     | Low | CV | High   | Low | CV | High   | Low | CV | High    | Low | CV |
| Keppel     | 239      | 195 | 7  | 202    | 152 | 10 | 129    | 68  | 18 | 44      | 17  | 24 |
| Vava'u     | 205      | 107 | 18 | 178    | 106 | 15 | 119    | 59  | 18 | 44      | 18  | 24 |
| Ha'apai    | 179      | 93  | 25 | 150    | 86  | 23 | 90     | 38  | 30 | 42      | 15  | 42 |
| Nuku'alofa | 199      | 137 | 11 | 148    | 80  | 16 | 88     | 39  | 24 | 38      | 9   | 38 |

the considerable interannual variation in the frequency and intensity of meso-scale and synoptic scale disturbances. The coefficient of variation increases as the threshold value increases (Table 12), but the variation is greatest in the drier Southern Tonga zone.

The persistence of rainfall over several consecutive days is given in Table 13. For example at Vava'u, 53 percent of all days have no rainfall. However, for 14-day periods there is a one percent chance there will be no rainfall, but there is a 23 percent probability that the total rainfall will be between 50 and 100 mm.

Table 13. Persistence of rainfall - Tonga  
(i.e. Percent of n-days with various amounts of rain)

| n-Days<br>Amount | Keppel |    |    |    |    |    | Vava'u |    |    |    |    |    |
|------------------|--------|----|----|----|----|----|--------|----|----|----|----|----|
|                  | 1      | 3  | 5  | 7  | 14 | 30 | 1      | 3  | 5  | 7  | 14 | 30 |
| Nil              | 50     | 23 | 11 | 6  | 1  | 0  | 53     | 25 | 12 | 7  | 1  | 0  |
| 0.1 - 5mm        | 25     | 25 | 19 | 14 | 4  | 0  | 24     | 26 | 22 | 16 | 5  | 0  |
| 5.1 -10mm        | 8      | 12 | 8  | 10 | 5  | 1  | 8      | 11 | 11 | 11 | 6  | 1  |
| 10.1-15mm        | 4      | 8  | 12 | 8  | 5  | 1  | 4      | 7  | 8  | 8  | 5  | 2  |
| 15.1-25mm        | 6      | 9  | 11 | 12 | 8  | 2  | 5      | 9  | 11 | 11 | 9  | 2  |
| 25.1-50mm        | 5      | 12 | 16 | 19 | 18 | 7  | 4      | 11 | 16 | 19 | 18 | 9  |
| 50.1-100mm       | 2      | 8  | 13 | 18 | 24 | 18 | 2      | 8  | 13 | 17 | 23 | 21 |
| 100.1-150mm      | 0      | 2  | 5  | 8  | 17 | 17 | 0      | 2  | 4  | 7  | 14 | 15 |
| over 150mm       | 0      | 1  | 3  | 5  | 18 | 55 | 0      | 1  | 3  | 6  | 18 | 50 |
| over 200mm       | -      | -  | -  | -  | 10 | 39 | -      | -  | -  | -  | 10 | 36 |
| over 300mm       | -      | -  | -  | -  | 3  | 18 | -      | -  | -  | -  | 4  | 19 |
| over 500mm       | -      | -  | -  | -  | 0  | 3  | -      | -  | -  | -  | 0  | 4  |

| n-Days<br>Amount | Ha'apai |    |    |    |    |    | Nuku'alofa |    |    |    |    |    |
|------------------|---------|----|----|----|----|----|------------|----|----|----|----|----|
|                  | 1       | 3  | 5  | 7  | 14 | 30 | 1          | 3  | 5  | 7  | 14 | 30 |
| Nil              | 65      | 39 | 23 | 15 | 4  | 1  | 53         | 24 | 12 | 6  | 1  | 0  |
| 0.1 - 5mm        | 17      | 22 | 21 | 18 | 8  | 1  | 29         | 35 | 31 | 25 | 7  | 0  |
| 5.1 -10mm        | 8       | 10 | 12 | 12 | 8  | 2  | 6          | 10 | 12 | 40 | 9  | 1  |
| 10.1-15mm        | 3       | 5  | 6  | 7  | 6  | 2  | 3          | 6  | 7  | 8  | 6  | 1  |
| 15.1-25mm        | 4       | 7  | 9  | 10 | 10 | 4  | 4          | 7  | 9  | 11 | 12 | 4  |
| 25.1-50mm        | 4       | 10 | 13 | 16 | 19 | 10 | 4          | 9  | 13 | 15 | 17 | 11 |
| 50.1-100mm       | 2       | 6  | 11 | 20 | 24 | 25 | 2          | 6  | 11 | 15 | 25 | 24 |
| 100.1-150mm      | 0       | 2  | 3  | 5  | 11 | 17 | 0          | 2  | 2  | 4  | 10 | 17 |
| over 150mm       | 0       | 1  | 2  | 3  | 11 | 38 | 0          | 1  | 2  | 4  | 13 | 39 |
| over 200mm       | -       | -  | -  | -  | 6  | 24 | -          | -  | -  | -  | 6  | 27 |
| over 300mm       | -       | -  | -  | -  | 2  | 10 | -          | -  | -  | -  | 1  | 8  |
| over 500mm       | -       | -  | -  | -  | 0  | 1  | -          | -  | -  | -  | 0  | 1  |

Hourly observations of rainfall amounts are available only for Fua'amotu Airport and since 1980. The diurnal variation for wet and dry seasons is given in Fig. 16. Average hourly rainfall amounts have been expressed as a percentage of the 24-hourly total. Figure 16 shows that although there is a considerable amount of random fluctuation, there do appear to be seasonal differences. In the wet season a rainfall maximum exists during the middle of the afternoon and a relative minimum during the early hours of the morning. During the dry season

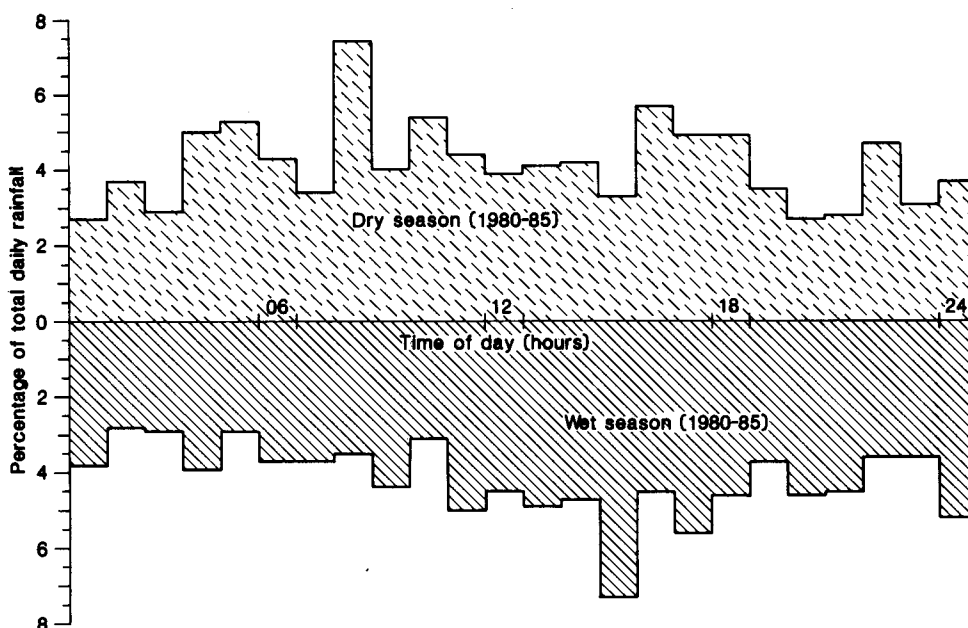


Fig. 16. Diurnal variation of rainfall at Fua'amotu Airport, 1980 - 1985

there appears to be an early morning maximum, with possibly another one in the late afternoon. However it should be noted the analysis is based on a short record.

The 8 a.m. peak during the the dry season is a reflection of a single intense rain storm on 30 May 1982 when 114mm was recorded between 8 and 9 a.m. Such an amount is likely to occur on average about once every five to ten years.

Extreme short period rainfalls. Assessing the frequency of intense short duration rainfalls can be made using depth-duration-frequency tables (Table 14). This type of analysis has been derived from annual maximum rainfall measured at a fixed time over one, two, and three-day periods. A least squares regression (Coulter and Hessell, 1980) determined the amount of rain that could be expected for a given return period. The results were adjusted to provide 24, 48 and 72-hour estimates of rainfall for various return periods using factors given by Coulter an Hessell (1980), since rainfall measured at fixed time intervals rarely indicated the true maximum amounts for indicated durations (WMO, 1983).

Table 14 can be interpreted as follows. At Nuku'alofa a fall of at least 330 mm in 48 hours can be expected to be measured on average once every 20 years. Highest recorded one, two and three-day rainfalls together with the estimated return-periods are presented in Table 15.

Table 14. Depth (mm)-duration (hrs)-frequency (per year)

| Return Period |      | 2yr | 5yr | 10yr | 20yr | 50yr |
|---------------|------|-----|-----|------|------|------|
| Keppel        | 24hr | 147 | 191 | 221  | 250  | 287  |
|               | 48hr | 178 | 228 | 262  | 294  | 335  |
|               | 72hr | 204 | 260 | 298  | 334  | 381  |
| Ha'apai       | 24hr | 148 | 214 | 258  | 300  | 355  |
|               | 48hr | 176 | 243 | 289  | 334  | 392  |
|               | 72hr | 187 | 265 | 317  | 366  | 430  |
| Nuku'alofa    | 24hr | 142 | 219 | 269  | 318  | 381  |
|               | 48hr | 153 | 230 | 281  | 330  | 393  |
|               | 72hr | 174 | 265 | 326  | 385  | 460  |

Table 15. Highest one, two, three-day rainfalls (mm)

| No. of days | 1             | 2   | 3   | Approx. return period (yrs) |    |    |
|-------------|---------------|-----|-----|-----------------------------|----|----|
|             | Rainfall (mm) |     |     | 1                           | 2  | 3  |
| Keppel      | 269           | 278 | 313 | 35                          | 15 | 13 |
| Ha'apai     | 228           | 249 | 289 | 7                           | 7  | 7  |
| Nuku'alofa  | 229           | 271 | 351 | 5                           | 9  | 14 |

Table 16. Mean maximum one, two, three-day rainfalls (mm)

|            | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| One-day    |     |     |     |     |     |     |     |     |     |     |     |     |
| Keppel     | 69  | 58  | 69  | 67  | 53  | 45  | 43  | 29  | 49  | 65  | 66  | 64  |
| Ha'apai    | 47  | 69  | 75  | 78  | 47  | 33  | 37  | 54  | 46  | 47  | 49  | 63  |
| Nuku'alofa | 44  | 52  | 69  | 57  | 47  | 43  | 39  | 45  | 53  | 75  | 52  | 55  |
| Two-day    |     |     |     |     |     |     |     |     |     |     |     |     |
| Keppel     | 94  | 80  | 99  | 86  | 70  | 58  | 52  | 37  | 62  | 82  | 87  | 90  |
| Ha'apai    | 68  | 88  | 97  | 98  | 52  | 39  | 48  | 72  | 61  | 57  | 63  | 82  |
| Nuku'alofa | 61  | 71  | 87  | 70  | 54  | 52  | 48  | 59  | 68  | 89  | 65  | 66  |
| Three-day  |     |     |     |     |     |     |     |     |     |     |     |     |
| Keppel     | 116 | 95  | 117 | 104 | 79  | 66  | 62  | 42  | 69  | 88  | 99  | 101 |
| Ha'apai    | 78  | 101 | 114 | 108 | 56  | 41  | 52  | 81  | 65  | 62  | 72  | 91  |
| Nuku'alofa | 74  | 85  | 99  | 79  | 60  | 54  | 51  | 63  | 74  | 103 | 79  | 72  |

Table 16 gives the mean monthly maximum one, two and three-day falls. There is a tendency for the largest falls of rain to occur during the wet season. This table also indicates that although on average the two and three-day rainfalls will be generally less than the one-day fall, it is also possible to have, in individual three-day periods, two days of light rain followed by a heavy one on the third day.

Dry spells. Dry spells reflect an anomalous and sometimes persistent pattern in the general circulation of the atmosphere. A dry spell can be defined as a period of 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. Statistics of dry conditions over Tonga are presented in Table 17. The average length of dry and very dry conditions is about 21 days. The majority of these conditions are observed during the dry season, but especially in the latter part of the season.

Table 17. Dry and very dry spells - Tonga

| Location               | Number per decade | Mean and max. length (days) | Predominant season |
|------------------------|-------------------|-----------------------------|--------------------|
| <u>Dry spells</u>      |                   |                             |                    |
| Keppel                 | 10                | 21 38                       | Late dry           |
| Ha'apai                | 24                | 22 46                       | Dry                |
| Nuku'alofa             | 18                | 19 30                       | Late dry           |
| <u>Very dry spells</u> |                   |                             |                    |
| Keppel                 | 5                 | 21 36                       | Late dry           |
| Ha'apai                | 18                | 21 45                       | Dry                |
| Nuku'alofa             | 7                 | 18 27                       | Late dry           |

Persistence of abnormal monthly rain. Abnormal monthly rainfall is defined as a departure of at least 50 percent from the average monthly amount. Persistence of such rainfall is quite common in the tropics especially in the South Pacific equatorial dry zone. Table 18 gives an indication of the frequency of abnormal rainfall in Tonga. Each abnormal period of rainfall is the maximum number of consecutive months of either high or low rainfall. For example on Ha'apai, a three month high rainfall period occurs on average about 8 times each century. Such an event is not also included in the table as two two-month or three one-month events.

From Table 18 it can be seen that periods of high or low rainfall of at least three months are rare. Keppel, which is the closest Tongan island to the sphere of influence of the SPCZ, does not experience long periods of high or low rainfall.

Table 18. Average number of runs per decade of the stated maximum number of consecutive months, each with abnormal rainfall

| Max. no. consecutive months<br>each with<br>over 150 percent of average. |   |   |   |   |   |  | Max no. consecutive months<br>each with<br>less than 50 percent of average. |     |     |     |   |     |      |     |     |     |     |     |     |     |
|--|---|---|---|---|---|--|---|-----|-----|-----|---|-----|------|-----|-----|-----|-----|-----|-----|-----|
| 1  | 2 | 3 | 4 | 5 | 6 |  | 1   | 2   | 3   | 4   | 5 | 6   | 7    | 8   |     |     |     |     |     |     |
| (a) Keppel (1947-1985)   |   |   |   |   |   |  | 12.6  | 3.7 | 0.3 | -   | - | -   | 13.4 | 2.6 | 1.3 | 0.3 | -   | -   | -   | -   |
| (b) Vava'u (1947-1985)   |   |   |   |   |   |  | 15.0  | 2.6 | 1.1 | -   | - | -   | 13.4 | 3.9 | 0.8 | 0.3 | 0.3 | 0.3 | -   | -   |
| (c) Ha'apai (1947-1985)  |   |   |   |   |   |  | 17.4  | 2.6 | 0.8 | 0.3 | - | -   | 13.9 | 4.2 | 1.1 | 0.3 | 0.3 | -   | 0.3 | -   |
| (d) Nuku'alofa (1945-1985)   |   |   |   |   |   |  | 14.2  | 2.7 | 0.3 | -   | - | 0.3 | 14.7 | 2.7 | 1.3 | 0.5 | 0.5 | -   | -   | 0.3 |

Table 19. Expected number of runs per decade of stated number of consecutive months, each month with abnormal rainfall

| Max. no. consecutive months<br>each with<br>over 150 percent of average. |   |   |   |   |   |  | Max no. consecutive months<br>each with<br>less than 50 percent of average. |     |     |     |    |    |      |     |     |     |     |    |    |    |
|--|---|---|---|---|---|--|---|-----|-----|-----|----|----|------|-----|-----|-----|-----|----|----|----|
| 1  | 2 | 3 | 4 | 5 | 6 |  | 1   | 2   | 3   | 4   | 5  | 6  | 7    | 8   |     |     |     |    |    |    |
| (a) Keppel   |   |   |   |   |   |  | 17.2  | 3.0 | 0.5 | -   | -  | -  | 19.0 | 3.7 | 0.7 | 0.1 | -   | -  | -  | -  |
| (b) Vava'u   |   |   |   |   |   |  | 19.0  | 3.7 | 0.7 | -   | -  | -  | 21.5 | 5.0 | 1.2 | 0.2 | 0.1 | 0* | -  | -  |
| (c) Ha'apai  |   |   |   |   |   |  | 20.4  | 4.4 | 1.0 | 0.2 | -  | -  | 22.7 | 5.8 | 1.4 | 0.4 | 0.1 | 0* | 0* | -  |
| (d) Nuku'alofa   |   |   |   |   |   |  | 18.1  | 3.4 | 0.6 | 0.1 | 0* | 0* | 22.9 | 5.9 | 1.6 | 0.4 | 0.1 | 0* | 0* | 0* |

\* Frequency less than 0.05.

The other island groups in Tonga tend to have more dry periods than wet ones. On Nuku'alofa there was an 8 month period from October 1982 to May 1983 when only 357 mm of rain was measured.

The persistence of abnormal periods of rainfall are associated with anomalous tropical circulation patterns. Table 19 presents expected number of runs per decade for the same locations as in Table 18. Table 19 has been derived from a geometric model of run lengths, assuming complete randomness. Departures between observed and expected run lengths can identify the extent of persistence of any abnormal rainfall period. Combining data from the four locations into one pooled result for both observed and expected frequencies, persistence of the observed run lengths in Tonga was tested for non-randomness with the chi-square test. Both wet and dry abnormal rainfall periods were significant; dry periods being very persistent. The 8 month dry period at Nuku'alofa is clearly a non-random event. Normal expectation from the geometric run length model is less than 0.05. It was also associated with the 1982/1983 low/wet southern oscillation episode.

Table 20 illustrates a possible relationship between periods of abnormal rains lasting for at least three months over Tonga and the southern oscillation Index. In compiling this table, the SOI was averaged over the same length of the rainfall period. The results presented in Table 20 were tested for significance using the chi-square test, under the assumption that there is no association between the SOI and abnormal rainfall. The value of chi was 8.5 for two degrees of freedom, and is significant at the 95 percent level. This table therefore indicates that low rainfall periods are likely to be associated with a negative SOI, while during high rainfall periods, the SOI is likely to be positive.

Table 20. Abnormal rainfall periods of at least three months and the index of the southern oscillation averaged over the corresponding period

| Frequency percent of abnormal rainfall |      |      |
|--|------|------|
| Mean SOI                               | High | Low  |
| SOI $\geq$ 0.5                         | 45.5 | 13.8 |
| -0.5 < SOI < 0.5                       | 36.4 | 20.7 |
| SOI $\leq$ -0.5                        | 18.2 | 65.5 |
| No. of cases                           | 11   | 29   |

### Air temperatures

While tropical air temperatures remain high all year round with little seasonal variation, diurnal variations can be relatively large by comparison. Tropical temperatures also show some dependence upon latitude; in the Kingdom of Tonga mean annual temperatures vary from about 26°C at Niuafou'ou and Keppel to 23°C on Tongatapu. Temperature variations throughout the year are presented in Fig. 17 for a number of Tongan locations. This figure shows some increase in the daily and seasonal variations with increasing latitude. Keppel has an average daily range of 6°C, and a seasonal variation in the mean temperatures of 2°C. Nuku'alofa has corresponding values of just over 6°C and 5°C respectively. Daily maximum and minimum temperatures are highest generally in February, and least in July or August; about two months after the sun reaches the solstices.

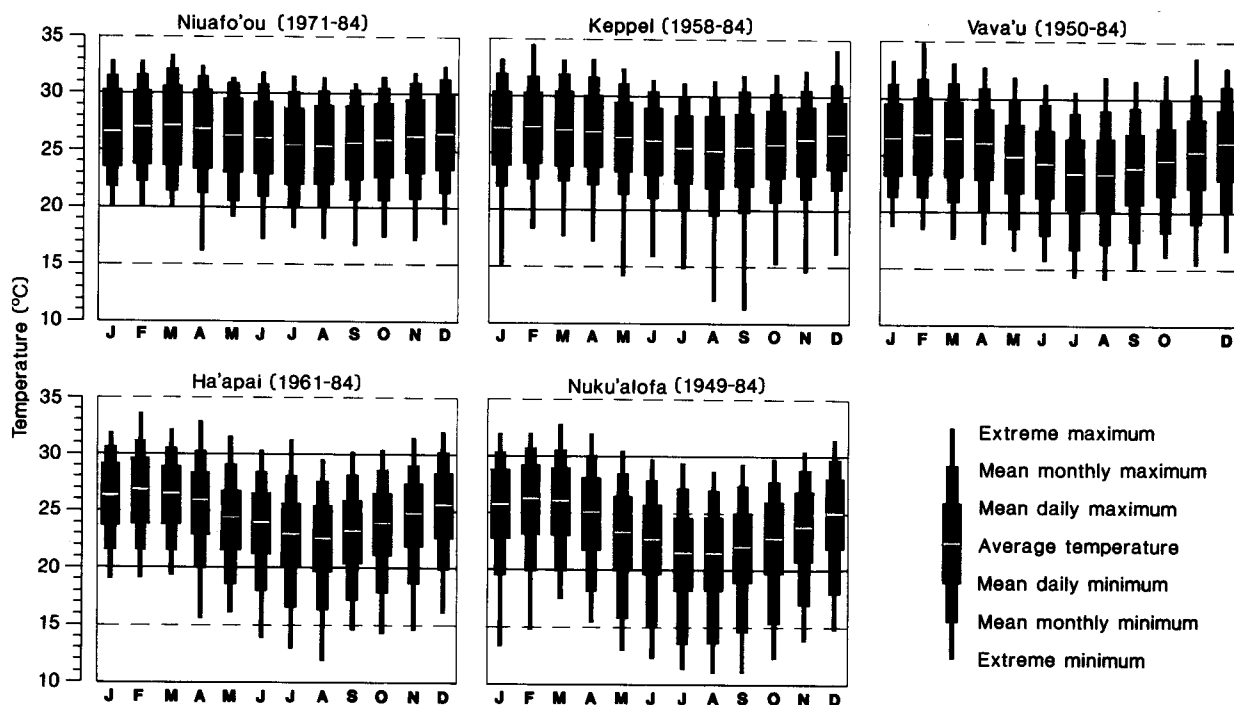


Fig. 17. Temperature statistics for Tonga

Table 21 presents 10, 50 and 90 percentile values for the mean daily maximum, mean daily minimum and the mean temperature. The mean temperature is the mid-point between the maximum and minimum temperatures (i.e.,  $[T_{\max} + T_{\min}]/2$ ). At Ha'apai, for example, in nine years out of ten, (the 10 percentile), the mean daily maximum temperature in December will be at least 27.5°C. In one year in ten, (the 90 percentile), will the mean daily maximum during December exceed 29.5°C. Eighty percent of all Decembers will expect a mean daily maximum temperature of between 29.5°C and 27.5°C.

Table 21. Percentiles of monthly temperature (°C)

|  | Jan  | Feb  | Mar  | Apr  | May  | Jun  | Jul  | Aug  | Sep  | Oct  | Nov  | Dec  |
|--|------|------|------|------|------|------|------|------|------|------|------|------|
| (a) Mean Daily Maximum                         |      |      |      |      |      |      |      |      |      |      |      |      |
| Keppel   |      |      |      |      |      |      |      |      |      |      |      |      |
| 90 percentile                                  | 30.9 | 31.4 | 31.6 | 31.1 | 30.1 | 29.9 | 29.2 | 29.2 | 29.4 | 30.0 | 30.3 | 30.8 |
| Median   | 30.3 | 30.4 | 30.6 | 30.2 | 29.5 | 29.0 | 28.4 | 28.4 | 28.8 | 29.0 | 29.4 | 29.9 |
| 10 percentile                                  | 29.7 | 29.4 | 29.6 | 29.3 | 28.9 | 28.1 | 27.6 | 27.6 | 28.2 | 28.1 | 28.5 | 29.0 |
| Vava'u   |      |      |      |      |      |      |      |      |      |      |      |      |
| 90 percentile                                  | 30.8 | 31.1 | 30.9 | 30.1 | 28.9 | 28.4 | 27.5 | 27.6 | 28.0 | 28.7 | 29.5 | 30.2 |
| Median   | 29.8 | 30.2 | 29.9 | 29.3 | 28.0 | 27.4 | 26.5 | 26.6 | 27.1 | 27.6 | 28.5 | 29.2 |
| 10 percentile                                  | 28.8 | 29.3 | 28.9 | 28.5 | 27.1 | 26.4 | 25.5 | 25.6 | 26.2 | 26.4 | 27.5 | 28.2 |
| Ha'apai  |      |      |      |      |      |      |      |      |      |      |      |      |
| 90 percentile                                  | 30.2 | 30.7 | 30.2 | 29.7 | 28.1 | 27.7 | 26.9 | 26.7 | 27.2 | 28.0 | 28.8 | 29.5 |
| Median   | 29.3 | 29.8 | 29.4 | 28.8 | 27.2 | 26.7 | 25.7 | 25.5 | 26.0 | 26.6 | 27.6 | 28.5 |
| 10 percentile                                  | 28.4 | 28.9 | 28.6 | 27.9 | 26.3 | 25.7 | 24.5 | 24.4 | 24.8 | 25.2 | 26.4 | 27.5 |
| Nuku'alofa                                     |      |      |      |      |      |      |      |      |      |      |      |      |
| 90 percentile                                  | 29.7 | 30.1 | 29.5 | 28.7 | 27.1 | 26.5 | 25.5 | 25.5 | 25.9 | 26.8 | 27.9 | 29.1 |
| Median   | 28.9 | 29.3 | 29.0 | 28.2 | 26.6 | 25.7 | 24.6 | 24.6 | 25.0 | 25.8 | 27.0 | 28.2 |
| 10 percentile                                  | 28.1 | 28.5 | 28.5 | 27.7 | 26.1 | 24.9 | 23.7 | 23.7 | 24.1 | 24.8 | 26.1 | 27.3 |
| (b) Mean Temperature ( $T_{max} + T_{min}$ )/2 |      |      |      |      |      |      |      |      |      |      |      |      |
| Keppel   |      |      |      |      |      |      |      |      |      |      |      |      |
| 90 percentile                                  | 27.9 | 28.3 | 28.1 | 27.6 | 27.0 | 26.9 | 26.2 | 26.0 | 26.4 | 26.7 | 27.0 | 27.5 |
| Median   | 27.3 | 27.4 | 27.2 | 27.0 | 26.5 | 26.1 | 25.6 | 25.5 | 25.8 | 26.1 | 26.4 | 26.9 |
| 10 percentile                                  | 26.7 | 26.5 | 26.3 | 26.4 | 26.0 | 25.3 | 25.0 | 25.0 | 25.2 | 25.5 | 25.8 | 26.3 |
| Vava'u   |      |      |      |      |      |      |      |      |      |      |      |      |
| 90 percentile                                  | 27.5 | 27.8 | 27.5 | 26.7 | 25.6 | 25.2 | 24.0 | 23.9 | 24.8 | 25.5 | 26.3 | 26.7 |
| Median   | 26.7 | 26.9 | 26.6 | 26.1 | 25.1 | 24.4 | 23.4 | 23.3 | 23.9 | 24.6 | 25.4 | 26.1 |
| 10 percentile                                  | 25.9 | 26.0 | 25.7 | 25.5 | 24.4 | 23.6 | 22.8 | 22.7 | 23.0 | 23.7 | 24.5 | 25.5 |
| Ha'apai  |      |      |      |      |      |      |      |      |      |      |      |      |
| 90 percentile                                  | 27.0 | 27.7 | 27.1 | 26.4 | 25.3 | 24.8 | 23.9 | 23.6 | 24.2 | 25.2 | 25.8 | 26.5 |
| Median   | 26.4 | 26.9 | 26.6 | 25.9 | 24.5 | 24.0 | 23.0 | 22.6 | 23.2 | 23.9 | 24.8 | 25.6 |
| 10 percentile                                  | 25.8 | 26.1 | 26.1 | 25.4 | 23.7 | 23.2 | 22.1 | 21.6 | 22.2 | 22.6 | 23.8 | 24.7 |
| Nuku'alofa                                     |      |      |      |      |      |      |      |      |      |      |      |      |
| 90 percentile                                  | 26.7 | 27.2 | 26.7 | 25.6 | 24.1 | 23.5 | 22.4 | 22.1 | 23.0 | 23.8 | 24.9 | 25.9 |
| Median   | 25.9 | 26.3 | 26.1 | 25.0 | 23.3 | 22.5 | 21.4 | 21.3 | 21.8 | 22.6 | 23.7 | 25.0 |
| 10 percentile                                  | 25.1 | 25.4 | 22.5 | 24.4 | 22.5 | 21.5 | 20.4 | 20.5 | 20.6 | 21.4 | 22.5 | 24.1 |

Table 21.

|                        | Jan  | Feb  | Mar  | Apr  | May  | Jun  | Jul  | Aug  | Sep  | Oct  | Nov  | Dec  |
|------------------------|------|------|------|------|------|------|------|------|------|------|------|------|
| (c) Mean Daily Minimum |      |      |      |      |      |      |      |      |      |      |      |      |
| Keppel                 |      |      |      |      |      |      |      |      |      |      |      |      |
| 90 percentile          | 25.1 | 25.2 | 25.1 | 25.1 | 24.4 | 24.1 | 23.5 | 23.2 | 23.7 | 23.9 | 24.3 | 24.8 |
| Median                 | 24.3 | 24.2 | 23.9 | 23.9 | 23.4 | 23.3 | 22.6 | 22.6 | 22.8 | 23.3 | 23.5 | 24.0 |
| 10 percentile          | 23.5 | 23.2 | 22.7 | 22.7 | 22.4 | 22.5 | 21.7 | 22.0 | 21.9 | 22.7 | 22.7 | 23.2 |
| Vava'u                 |      |      |      |      |      |      |      |      |      |      |      |      |
| 90 percentile          | 24.3 | 24.5 | 24.2 | 23.9 | 22.8 | 22.3 | 21.1 | 21.0 | 22.1 | 22.7 | 23.5 | 23.7 |
| Median                 | 23.4 | 23.5 | 23.2 | 22.9 | 21.8 | 21.3 | 20.3 | 20.0 | 20.8 | 21.5 | 22.3 | 22.9 |
| 10 percentile          | 22.5 | 22.5 | 22.2 | 21.9 | 20.8 | 20.3 | 19.5 | 19.0 | 19.6 | 20.3 | 21.1 | 22.1 |
| Ha'apai                |      |      |      |      |      |      |      |      |      |      |      |      |
| 90 percentile          | 24.4 | 24.9 | 24.6 | 24.2 | 23.0 | 22.6 | 21.6 | 21.2 | 21.6 | 22.4 | 23.0 | 23.8 |
| Median                 | 23.6 | 23.9 | 23.8 | 22.8 | 21.7 | 21.3 | 20.1 | 19.7 | 20.3 | 21.1 | 22.0 | 22.8 |
| 10 percentile          | 22.8 | 22.9 | 23.0 | 21.4 | 20.4 | 20.0 | 18.6 | 18.2 | 19.0 | 19.8 | 21.0 | 21.8 |
| Nuku'alofa             |      |      |      |      |      |      |      |      |      |      |      |      |
| 90 percentile          | 24.0 | 24.5 | 23.9 | 23.0 | 21.2 | 20.7 | 19.1 | 19.0 | 20.1 | 20.8 | 22.0 | 23.0 |
| Median                 | 22.8 | 23.2 | 23.1 | 21.8 | 20.0 | 19.3 | 17.9 | 18.0 | 18.6 | 19.4 | 20.6 | 21.8 |
| 10 percentile          | 21.6 | 21.9 | 22.3 | 20.6 | 18.8 | 17.9 | 16.6 | 17.0 | 17.1 | 18.0 | 19.2 | 20.6 |

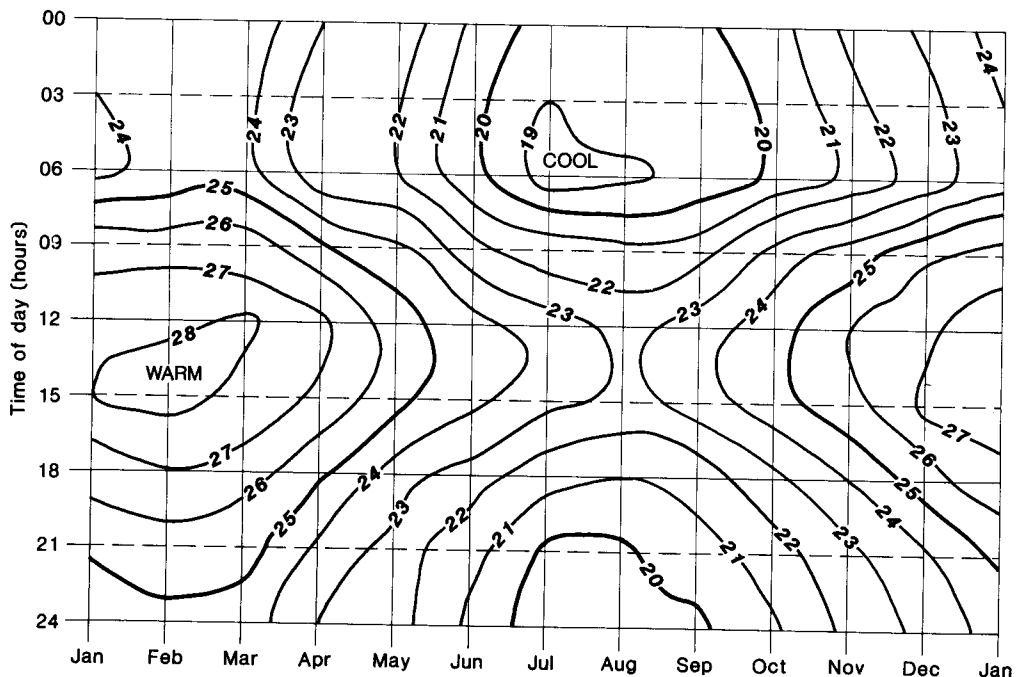


Fig. 18. Diurnal and seasonal temperature variations (°C) at Fua'amotu Airport, 1980 - 1983

Figure 18 shows an alternative way of displaying the combination of diurnal and seasonal variations for Fua'amotu Airport. The diurnal cycle (the abscissa in Fig. 18) show highest temperatures near the middle of the day and lowest temperatures during the early hours of the morning prior to sunrise. The seasonal cycle is highlighted by highest temperatures during January and February, and lowest in July and August.

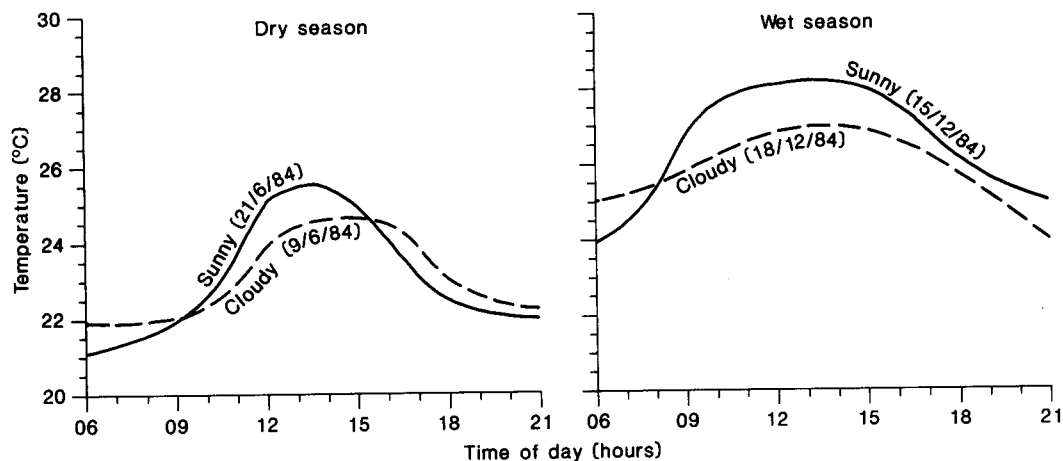


Fig. 19. Temperature variations on sunny and cloudy days at Fua'amotu Airport

The extent of the diurnal variation on any particular day is related to changes in cloud cover (Fig. 19) and also to the wind speed. Daytime temperature variations are generally largest when global radiation levels are high.

The highest recorded temperature was 35.0°C on Vava'u on 10 February 1979. Maximum temperatures in excess of 33°C are seldom measured. They have never been recorded at Nuku'alofa, but occur one day every two or three years on Niuafu'ou, Keppel and Vava'u, and one day every 10 years on Ha'apai.

The lowest recorded temperature in Tonga has been recorded has been 10.6°C on 4 September 1951. Temperatures below 15°C are measured during the dry season. On Keppel and Niuafu'ou the frequency is one day every three or four years, but elsewhere low temperatures occur on about one to two days every year.

### Sunshine

Sunshine measurements in Tonga began in 1979 at Fua'amotu Airport, and in 1984 at Vaini Experimental Farm. To date Fua'amotu averages 2146 hours of bright sunshine each year. At other locations on Tonga, sunshine has never been recorded. However, as cloud cover directly affects the amount of sunshine reaching the earth, reasonable estimates of

the spatial and temporal variation can be made from observations of cloud cover.

Sadler, Oda, and Kilonsky (1976) assessed the cloudiness of the Pacific Ocean using satellite observations of cloud cover over the period from 1965 to 1973. They prepared monthly maps of cloud cover for 2.5° latitude-longitude 'squares'. Table 22 shows average monthly cloud cover for the island groups in Tonga.

Table 22. Average cloud cover (percent) over selected 2.5° latitude-longitude squares

| Location  | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Niuafo'ou | 58  | 56  | 49  | 54  | 51  | 50  | 55  | 52  | 53  | 57  | 53  | 57  |
| Keppel    | 57  | 55  | 49  | 54  | 51  | 48  | 52  | 51  | 51  | 55  | 52  | 57  |
| Vava'u    | 56  | 53  | 52  | 54  | 52  | 53  | 57  | 56  | 56  | 57  | 53  | 57  |
| Ha'apai   | 56  | 53  | 52  | 54  | 52  | 53  | 57  | 56  | 56  | 57  | 53  | 57  |
| Tongatapu | 55  | 53  | 57  | 54  | 56  | 56  | 58  | 56  | 59  | 59  | 52  | 56  |
| Ata       | 55  | 53  | 57  | 54  | 56  | 57  | 58  | 56  | 59  | 59  | 51  | 56  |

Source. Sadler, Oda and Kilonsky (1976).

Comparing Sadler et al.'s estimates of cloud cover with known sunshine data for several South-west Pacific locations, it was found that their estimates were on average about 10 percent too high. The presence of cirriform cloud, which does not appreciably reduce the amount of bright sunshine could account for the under-estimates of bright sunshine. Table 23 presents estimates of monthly sunshine hours for Tonga, based on adjusted cloud data. Sunshine is fairly uniform throughout the Kingdom of Tonga at 2100 to 2200 hours each year. This represents about 50 to 55 percent of the total possible sunshine.

Table 23. Estimates of monthly sunshine (hours)

| Location  | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
| Niuafo'ou | 185 | 170 | 203 | 203 | 172 | 182 | 177 | 183 | 179 | 181 | 191 | 190 | 2193 |
| Keppel    | 190 | 173 | 203 | 172 | 182 | 184 | 177 | 186 | 186 | 189 | 196 | 191 | 2229 |
| Vava'u    | 196 | 178 | 192 | 171 | 176 | 164 | 161 | 171 | 172 | 182 | 194 | 193 | 2150 |
| Ha'apai   | 197 | 178 | 192 | 170 | 175 | 163 | 160 | 170 | 172 | 183 | 196 | 195 | 2151 |
| Tongatapu | 201 | 179 | 178 | 170 | 165 | 156 | 156 | 169 | 162 | 176 | 200 | 200 | 2125 |
| Ata       | 203 | 180 | 178 | 169 | 164 | 151 | 155 | 168 | 161 | 176 | 205 | 201 | 2111 |

### Thunderstorms

Thunderstorms are of considerable importance in tropical regions, in that they can provide a large proportion of the rainfall. Both thunder and lightning are observed in thunderstorms; lightning being more readily reported. On Tongatapu, lightning is reported on average on 20 days each year at Nuku'alofa, and 26 days at Fua'amotu. Seventy-five percent of all lightning-days occur in the wet season. A pronounced diurnal variation in lightning episodes exists. Sixty percent of observed lightning occurs during the evening and night-time, with a further 25 percent during the afternoon.

The frequency of occurrence of days of lightning varies considerably from year to year. At Nuku'alofa, the 10 percentile level is 7 days, and the 90 and 98 percentiles are 37 and 52 days of lightning a year. For Fua'amotu, the corresponding values are 8, 48, and 69 days respectively. At Nuku'alofa the 98 percentile level is 52. This means that at least 52 days of lightning in a single year will be observed on the average once in 50 years. Fifty-four days of lightning were recorded at Nuku'alofa in 1977.

Although other locations in Tonga do report lightning-days, it is suspected that many episodes (especially at night-time) have passed unnoticed. For example Keppel reports just six days of lightning each year, and both Vava'u and Ha'apai three days each year.

### Moisture in the atmosphere

The high water content of the tropical atmosphere is influenced by the warm airmasses of the tropics and by the presence of sea temperatures that generally exceed air temperatures.

Table 24. Mean monthly vapour pressure (hPa)

| Location   | Jan  | Feb  | Mar  | Apr  | May  | Jun  | Jul  | Aug  | Sep  | Oct  | Nov  | Dec  |
|------------|------|------|------|------|------|------|------|------|------|------|------|------|
| Niufo'ou   | 29.5 | 29.7 | 29.4 | 28.9 | 27.4 | 26.7 | 24.6 | 25.1 | 25.9 | 26.9 | 28.5 | 28.6 |
| Keppel     | 29.7 | 31.2 | 29.8 | 29.8 | 28.5 | 26.9 | 24.8 | 25.0 | 25.6 | 26.9 | 27.8 | 28.6 |
| Vava'u     | 27.9 | 28.8 | 27.9 | 26.9 | 24.4 | 23.5 | 21.7 | 22.0 | 23.7 | 23.6 | 25.4 | 26.8 |
| Ha'apai    | 27.7 | 28.3 | 27.6 | 26.5 | 24.2 | 23.2 | 20.5 | 20.7 | 21.5 | 22.8 | 24.4 | 26.1 |
| Nuku'alofa | 27.8 | 29.3 | 28.5 | 26.2 | 23.7 | 22.7 | 19.8 | 20.1 | 20.8 | 21.2 | 23.0 | 26.2 |
| Fua'amotu  | 27.5 | 29.2 | 28.2 | 26.1 | 27.7 | 21.4 | 19.4 | 19.4 | 20.4 | 20.0 | 22.8 | 25.1 |

Atmospheric moisture is commonly measured in terms of vapour pressure and relative humidity. Table 24 gives mean vapour pressures for Tonga. Vapour pressure shows little

variation from year to year. It varies from five to 10 percent about its mean value. There is a latitudinal variation in vapour pressure similar to the temperature variation. The seasonal variation follows both the variation in air and sea temperatures.

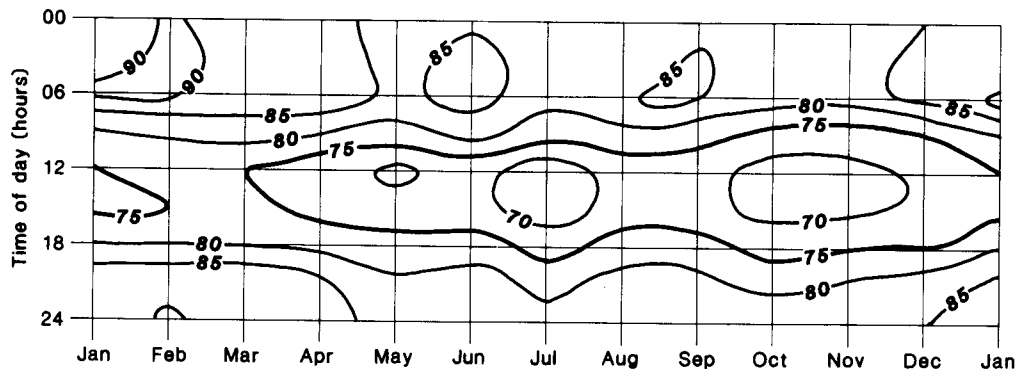


Fig. 20. Diurnal and monthly variation of relative humidity at Fua'amotu Airport, 1980 -1983

The diurnal and seasonal variation of relative humidity at Fua'amotu Airport is displayed in Fig. 20. The diurnal variation of relative humidity throughout the year is fairly constant with the lowest humidities in the early afternoon coinciding with the time of highest temperatures.

### Effective temperature

The temperature experienced by human beings depends on a number of factors of which humidity, air movement and temperature are important. A number of indices have been proposed to assess human comfort in warm humid conditions. Effective temperature (ET) is one such index, and is defined as the temperature of a still, saturated atmosphere which would induce the same sensation of comfort as that caused by the actual conditions of temperature, humidity and air movement. It should be realised the ET excludes consideration of solar radiation and precipitation. It can not be considered as a complete definition of physiological comfort which may also be dependent on clothing, and experience of particular conditions.

Human comfort varies considerably with climate. Finkelstein (1971) adopted a critical ET comfort range for the South-west Pacific of between 21-24°C. The Diurnal and seasonal variation of ET at Fua'amotu is given in Fig. 21. Highest effective temperature values are in the afternoons from January to April, but the mean critical value of 21°C is seldom attained because of the relative windiness of Fua'amotu.

However, in the more northern islands of Tonga where air temperatures are slightly higher than on Tongatapu, and where winds are apparently less values of ET will be greater. Consequently some human discomfort is likely to be felt especially from January to April.

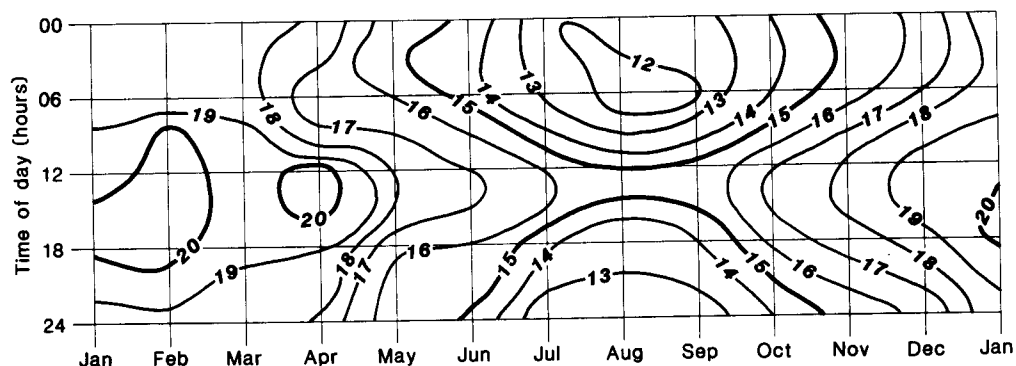


Fig. 21. Diurnal and monthly variation of Effective Temperature at Fua'amotu Airport, 1980 -1983

#### Evapotranspiration and soil water balance

Evapotranspiration is the combined effect of evaporation from the land or ocean surface, and transpiration from plants. It is a response to the sun's energy and to the water supply derived principally from rainfall. When evapotranspiration is not limited by the lack of rainfall, the loss of water to the atmosphere is at a maximum, and is known as Potential Evapotranspiration ( $ET_{max}$ ). Penman ET estimates are given in Table 25.

Table 25. Estimate of Penman potential evapotranspiration (mm/month)

| Location   | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Niuafo'ou  | 144 | 133 | 141 | 114 | 110 | 99  | 106 | 118 | 129 | 140 | 142 | 150 |
| Keppel     | 149 | 130 | 138 | 112 | 108 | 99  | 106 | 116 | 129 | 143 | 148 | 152 |
| Vava'u     | 151 | 134 | 135 | 112 | 103 | 90  | 99  | 108 | 117 | 142 | 151 | 159 |
| Ha'apai    | 161 | 144 | 145 | 113 | 103 | 89  | 101 | 109 | 121 | 145 | 156 | 161 |
| Nuku'alofa | 164 | 137 | 139 | 108 | 89  | 77  | 85  | 96  | 116 | 144 | 152 | 154 |

Comparing Table 25 with the table of rainfall normals (Table 8) shows that there is sufficient precipitation nearly all year round to meet the total evapotranspiration requirements. June and July are the months when

evapotranspiration exceeds rainfall. Such an interaction between rainfall and evapotranspiration forms the basis of the soil water balance. When ET exceeds rainfall, water held in the soil is released until all the soil water is used. A deficit then exists. Soil water is replaced when rainfall exceeds ET, and if the soil becomes saturated runoff occurs.

For the range of soil types in Tonga, the available water content (AWC) of the soil varies between about 90 and 160 mm (Wilson and Beecroft, 1985; Wilde and Hewitt, 1983). Water

Table 26. Water balance summary - Tonga

|                   | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|-------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| <b>Niuafo'ou</b>  |     |     |     |     |     |     |     |     |     |     |     |     |
| DE                | 22  | 8   | 10  | 6   | 10  | 23  | 24  | 18  | 21  | 28  | 30  | 15  |
| RO                | 133 | 87  | 97  | 114 | 112 | 19  | 62  | 27  | 63  | 54  | 91  | 63  |
| FDE               | 33  | 11  | 20  | 20  | 27  | 30  | 50  | 36  | 46  | 62  | 50  | 27  |
| FRO               | 56  | 78  | 70  | 60  | 73  | 50  | 60  | 36  | 38  | 23  | 58  | 55  |
| <b>Keppel</b>     |     |     |     |     |     |     |     |     |     |     |     |     |
| DE                | 5   | 2   | 3   | 0   | 0   | 3   | 7   | 20  | 20  | 22  | 11  | 10  |
| RO                | 122 | 111 | 154 | 124 | 69  | 36  | 30  | 13  | 23  | 56  | 68  | 92  |
| FDE               | 24  | 6   | 6   | 6   | 0   | 12  | 24  | 39  | 52  | 50  | 37  | 17  |
| FRO               | 82  | 72  | 85  | 81  | 72  | 39  | 41  | 27  | 27  | 44  | 57  | 69  |
| <b>Vava'u</b>     |     |     |     |     |     |     |     |     |     |     |     |     |
| DE                | 9   | 4   | 1   | 0   | 0   | 5   | 7   | 11  | 13  | 27  | 30  | 29  |
| RO                | 133 | 114 | 231 | 121 | 56  | 32  | 30  | 20  | 24  | 28  | 57  | 78  |
| FDE               | 26  | 11  | 3   | 3   | 0   | 19  | 27  | 30  | 35  | 51  | 54  | 44  |
| FRO               | 60  | 76  | 95  | 86  | 68  | 38  | 32  | 30  | 38  | 43  | 46  | 47  |
| <b>Ha'apai</b>    |     |     |     |     |     |     |     |     |     |     |     |     |
| DE                | 52  | 22  | 5   | 4   | 10  | 15  | 25  | 21  | 11  | 48  | 54  | 47  |
| RO                | 22  | 78  | 88  | 79  | 33  | 3   | 7   | 22  | 18  | 15  | 42  | 45  |
| FDE               | 64  | 45  | 25  | 8   | 25  | 42  | 42  | 33  | 31  | 62  | 62  | 75  |
| FRO               | 36  | 73  | 67  | 75  | 42  | 8   | 25  | 25  | 31  | 23  | 23  | 25  |
| <b>Nuku'alofa</b> |     |     |     |     |     |     |     |     |     |     |     |     |
| DE                | 49  | 20  | 10  | 7   | 7   | 7   | 6   | 6   | 18  | 33  | 47  | 40  |
| RO                | 29  | 72  | 59  | 75  | 42  | 20  | 12  | 40  | 40  | 59  | 39  | 52  |
| FDE               | 69  | 46  | 23  | 7   | 20  | 19  | 31  | 25  | 44  | 56  | 50  | 53  |
| FRO               | 38  | 54  | 62  | 67  | 53  | 38  | 44  | 44  | 56  | 38  | 38  | 20  |

Available water capacity 130 mm

DE Water deficiency in soil (mm)

RO Runoff (mm)

FDE Frequency (percent) of months with deficit

FRO Frequency (percent) of months with runoff

balance summaries (Table 26) have been computed for a mid-range AWC of 130 mm.

Runoff and soil moisture deficit occur all year round. The amount of runoff tends to be largest in the wet season, and soil water deficits during the dry, particularly during the latter part of the season. The frequency of years in which at least 200 mm of soil water deficiency exists is between 20 and 50 percent, with the highest occurrences in the drier zone of Southern Tonga.

The demand for water by plants in the tropics is high due to high rates of evapotranspiration. In regions where there is a well defined dry season, as occurs in Tonga, irrigation during such times would be beneficial in sustaining crop yields. Estimates of irrigation requirements for Tonga are given in Table 27. This table is based on the application of irrigation when the soil moisture level falls to 50 percent of its nominal available capacity. The risk in the table is the number of years in 100 that a certain amount of irrigation water is needed. For example, on Vava'u, supplementary water through irrigation will exceed 465 mm on average about once in 10 years, or 10 percent of the time. However, actual irrigation requirements will clearly depend on the prevalent soil types throughout the Kingdom of Tonga.

Table 27. Annual irrigation requirement (mm) for a given risk (Available water capacity is 130 mm)

Water is applied when soil moisture level reaches 65 mm.

|            | Risk (percent) |     |     |     |     | HE* | No. obs. |
|------------|----------------|-----|-----|-----|-----|-----|----------|
|            | 90             | 75  | 50  | 25  | 10  |     |          |
| Keppel     | 70             | 95  | 160 | 295 | 370 | 565 | 29       |
| Vava'u     | 80             | 145 | 205 | 320 | 465 | 570 | 35       |
| Ha'apai    | 85             | 195 | 410 | 620 | 730 | 805 | 8        |
| Nuku'alofa | 130            | 175 | 315 | 390 | 565 | 800 | 13       |

\* Highest estimate determined from the data.

## 6. MARINE CLIMATE

Weather and sea state observations from ship reports during the period 1951 to 1980 in the area from 15° S-23° S, and from 171°W-177°W, were used to construct the tables and figure in this section. These data were obtained not only from the New Zealand Meteorological Service's archives, but also from data

supplied by the Royal Netherlands Meteorological Institute (KNMI) and the Climatic Centre of the National Oceanographic and Atmospheric Administration (NOAA). A total of over 10500 ship observations were available.

### Marine winds

Wind blow from the east and south-east for 61 percent of the time (Table 28). However, during the dry season, the frequency of such directions is somewhat higher, as is the mean wind speed. Wind speeds over 27 knots occur for just over two percent of the time. The majority of these strong winds are from the east or south-east. However in the wet season, there is a relatively high proportion of strong winds from the west and north-west, associated with not only tropical cyclones, but also with squally monsoon weather.

Table 28. Seasonal wind data over the oceans surrounding Tonga (1951-1980)

|                              | Dec<br>Jan<br>Feb | Mar<br>Apr<br>May | Jun<br>Jul<br>Aug | Sep<br>Oct<br>Nov | Wet  | Dry  | Annual |
|------------------------------|-------------------|-------------------|-------------------|-------------------|------|------|--------|
| Speed (kn)                   | 11.9              | 12.2              | 13.4              | 13.6              | 12.1 | 13.4 | 12.8   |
| Dir                          |                   |                   |                   |                   |      |      |        |
| (percent)                    |                   |                   |                   |                   |      |      |        |
| N                            | 8.5               | 6.5               | 3.3               | 3.7               | 7.4  | 3.6  | 5.5    |
| NE                           | 13.4              | 10.0              | 9.0               | 8.0               | 11.7 | 8.4  | 10.1   |
| E                            | 30.4              | 30.8              | 29.9              | 31.9              | 31.0 | 30.6 | 30.8   |
| SE                           | 24.7              | 29.1              | 33.6              | 35.8              | 27.2 | 34.6 | 30.8   |
| S                            | 6.6               | 7.5               | 12.2              | 10.8              | 7.2  | 11.4 | 9.3    |
| SW                           | 3.3               | 3.4               | 5.2               | 3.8               | 3.2  | 4.6  | 3.9    |
| W                            | 3.8               | 3.3               | 3.0               | 2.1               | 3.7  | 2.3  | 3.0    |
| NW                           | 6.2               | 6.0               | 2.4               | 2.3               | 5.7  | 2.7  | 4.2    |
| Calm                         | 3.1               | 3.4               | 1.4               | 1.7               | 3.0  | 1.8  | 2.4    |
| Percent speeds<br>over 27 kn | 2.4               | 2.6               | 2.1               | 2.1               | 2.6  | 2.1  | 2.3    |

### Sea and swell

Table 29 presents a monthly frequency analysis of wind waves and swell. Waves and swell are measured and coded to the nearest half metre. Nearly all reported waves and swells are less than three metres. Between 60 and 70 percent of waves are less than 1.5 metres, and most of the reported swells are between 1.5 and 2.5 metres. The predominant waves and swells come from the east or south-east, but during the dry season swells from the south and south-west arrive. These have been generated in the Tasman Sea or in the oceans to the south of Australia.

Table 29. Wind wave and swell analysis for the Tongan Oceanic region

|                                       | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| (a) Frequency (percent) of wind waves |     |     |     |     |     |     |     |     |     |     |     |     |
| Class Height (m)                      |     |     |     |     |     |     |     |     |     |     |     |     |
| 0 -1.0                                | 73  | 72  | 73  | 75  | 64  | 62  | 64  | 59  | 63  | 55  | 57  | 67  |
| 1.5 -2.5                              | 25  | 26  | 25  | 23  | 32  | 36  | 33  | 38  | 33  | 38  | 37  | 31  |
| over 6.5                              | -   | -   | 0*  | -   | -   | -   | -   | -   | -   | -   | 0   | 0   |
| (b) Frequency (percent) of swells     |     |     |     |     |     |     |     |     |     |     |     |     |
| Class Height (m)                      |     |     |     |     |     |     |     |     |     |     |     |     |
| 0 -1.0                                | 23  | 29  | 24  | 27  | 16  | 18  | 16  | 17  | 18  | 17  | 17  | 23  |
| 1.5 -2.5                              | 58  | 59  | 61  | 56  | 64  | 64  | 64  | 67  | 66  | 65  | 65  | 63  |
| over 6.5                              | 0   | -   | 0   | 0   | -   | 1   | 0   | -   | 0   | -   | -   | -   |

\* 0 denotes occurrences less than 0.5 percent.

### Sea temperatures

Monthly sea surface temperatures are given in Fig. 22. The mean annual temperature is 26.6°C and the annual range is 3.2°C. Sea surface temperatures are highest during February and March and least some six months later. Interannual variation is small; being five to eight percent of the mean temperature. Some of this variation is also due to the size of ocean surrounding the kingdom of Tonga.

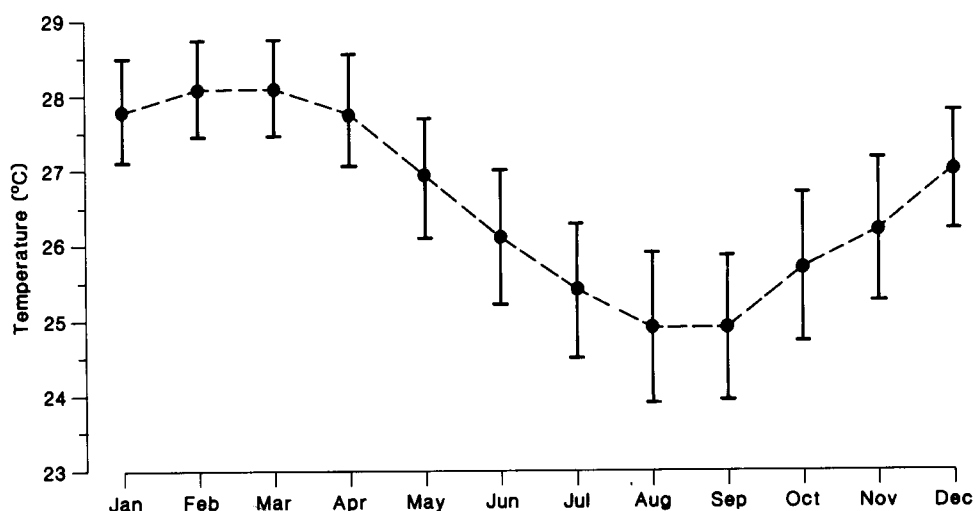


Fig. 22. Sea surface temperatures in Tongan oceanic region (Region is 15°-23°S, 171°-174°W)

Comparing mean air temperatures (Fig. 14) for Tonga with the sea temperatures (Fig. 22) indicates that the variations throughout the year are in phase with each other, and that sea temperatures are usually higher all year round than the air temperatures.

## 7. ACKNOWLEDGEMENTS

I am grateful for the comments and suggestions made by the staff of the Tongan Meteorological Service, especially Messrs P. Havea, and L. Fifita. Mr C. Hayward drafted the diagrams.

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## APPENDIX

The Climate of Fua'amotu International AirportIntroduction

Fua'amotu airport is situated on the south-eastern side of Tongatapu, 38 m above sea level and about 13 km from Nuku'alofa, the capital of Tonga. The airport has two runways. The main sealed runway is 2130 m long and is aligned from 110° to 290° magnetic. There is also a grass runway which is aligned from 170° to 350° magnetic. The approaches to Fua'amotu airport are free of orographic obstruction as the land surrounding the airport is all flat and is covered by bush or coconut plantations.

Weather reports are prepared daily by staff of the Tongan Meteorological Service. Observations are made hourly between 1 a.m. and 8 p.m. local time, but during the remaining hours instrument readings are taken from autographic charts. Because of the flatness of the surrounding countryside, there are no readily available cloud height marks. However, weather reports are generally representative of conditions over the airfield and its approaches.

Surface winds

Tongatapu, situated in the trade wind zone of the South Pacific Ocean, is affected by light to moderate winds which predominantly blow from the east or south-east (Table 3). Ninety percent of all winds at Fua'amotu airport are less than 16 knots. For speeds in the range 6 to 20 knots, winds blow 51 percent of the time from between 110° and 160°, and 22 percent from 050° to 110°. The least likely wind direction is from 290° to 340° when the frequency of occurrence is just 2 percent. For speeds over 20 knots, 65 percent blow from between 080° and 130°, with a further 22 percent of winds directions between 020° and 070°.

Sustained strong winds over 30 knots are very rare. They have nearly all occurred during the wet season and were associated with the passage of tropical cyclones. Consequently the restrictions in the operation of commercial aircraft, due to high winds, seldom occurs.

Restrictions due to crosswind components rarely affect aircraft operations. (A crosswind is the component of wind blowing perpendicular to the runway). Analysis of crosswinds at Fua'amotu Airport are presented in Table A1. On the main runway, 11/29, crosswinds of less than 14 knots occur 98 percent of the time. During the daytime this runway can be utilised for 96 percent of the time, and at night-time 99 percent.

Table A1. Runway crosswind analysis for Fua'amotu Airport, derived from hourly data, 1980 - 1983

(a) Runway 11/29 (125°/305°T)

| Crosswind<br>(knots) | Number of occasions of crosswinds |      |      |      |      |      |      |      |      |      |      |      |
|----------------------|-----------------------------------|------|------|------|------|------|------|------|------|------|------|------|
|                      | Jan                               | Feb  | Mar  | Apr  | May  | Jun  | Jul  | Aug  | Sep  | Oct  | Nov  | Dec  |
| Calm                 | 204                               | 252  | 272  | 407  | 216  | 292  | 388  | 240  | 231  | 198  | 123  | 155  |
| 0-5                  | 1461                              | 996  | 1254 | 1148 | 1186 | 648  | 1013 | 1042 | 1128 | 1091 | 1327 | 1400 |
| 6-10                 | 468                               | 489  | 459  | 485  | 662  | 397  | 588  | 661  | 521  | 650  | 603  | 543  |
| 11-13                | 71                                | 161  | 121  | 90   | 135  | 59   | 176  | 192  | 162  | 211  | 68   | 92   |
| 14-15                | 7                                 | 51   | 39   | 9    | 16   | 17   | 33   | 56   | 51   | 48   | 17   | 33   |
| 16-17                | 4                                 | 23   | 33   | 1    | 3    | 8    | 17   | 19   | 27   | 13   | 3    | 5    |
| 18-20                | 2                                 | 18   | 10   | -    | 1    | 8    | 6    | 6    | 12   | 2    | -    | -    |
| 21-25                | -                                 | 4    | 2    | 1    | -    | -    | 2    | 1    | 4    | -    | -    | -    |
| 26-30                | -                                 | -    | 4    | -    | -    | -    | -    | -    | -    | -    | -    | -    |
| 30                   | -                                 | -    | 12   | -    | 1    | -    | -    | -    | -    | -    | -    | -    |
| Total                | 2217                              | 1994 | 2206 | 2141 | 2220 | 1429 | 2223 | 2217 | 2136 | 2213 | 2141 | 2228 |

(b) Runway 17/35 (185°/05°T)

| Crosswind<br>(knots) | Number of occasions of crosswinds |      |      |      |      |      |      |      |      |      |      |      |
|----------------------|-----------------------------------|------|------|------|------|------|------|------|------|------|------|------|
|                      | Jan                               | Feb  | Mar  | Apr  | May  | Jun  | Jul  | Aug  | Sep  | Oct  | Nov  | Dec  |
| Calm                 | 204                               | 252  | 272  | 407  | 216  | 292  | 388  | 240  | 231  | 198  | 123  | 155  |
| 0-5                  | 547                               | 664  | 630  | 1055 | 729  | 518  | 1014 | 816  | 765  | 759  | 528  | 602  |
| 6-10                 | 849                               | 662  | 502  | 502  | 834  | 366  | 496  | 768  | 682  | 699  | 707  | 761  |
| 11-13                | 397                               | 262  | 336  | 137  | 327  | 160  | 171  | 280  | 260  | 342  | 432  | 423  |
| 14-15                | 153                               | 95   | 186  | 32   | 69   | 66   | 75   | 61   | 127  | 153  | 215  | 209  |
| 16-17                | 47                                | 31   | 111  | 7    | 25   | 21   | 48   | 23   | 44   | 44   | 83   | 55   |
| 18-20                | 18                                | 25   | 116  | 1    | 15   | 5    | 22   | 23   | 23   | 17   | 48   | 22   |
| 21-25                | 2                                 | 3    | 41   | -    | 4    | 1    | 9    | 6    | 3    | 1    | 5    | 1    |
| 26-30                | -                                 | -    | 4    | -    | -    | -    | -    | -    | 1    | -    | -    | -    |
| 30                   | -                                 | -    | 8    | -    | 1    | -    | -    | -    | -    | -    | -    | -    |
| Total                | 2217                              | 1994 | 2206 | 2141 | 2220 | 1429 | 2223 | 2217 | 2136 | 2213 | 2141 | 2228 |

Crosswinds exceed 20 knots 0.4 percent of the time. Nearly three-quarters of all crosswinds over 20 knots are during the wet season.

Crosswinds, on the grass secondary runway 17°/35°, are less than 14 knots for 91 percent of the time, and over 20 knots for 0.4 percent of the time. This runway can be used in crosswinds up to 13 knots for 88 percent of occasions during the daytime, and 94 percent of the time during the night.

#### Turbulence

Convective turbulence associated with cumulus clouds is

common all year round, but is normally slight. However severe turbulence is generated in and near the vicinity of isolated cumulonimbus clouds, and also in quasi-stationary frontal systems which have embedded cumulonimbus clouds.

Extreme turbulence associated with high wind speeds is present in tropical cyclones. Such conditions at Fua'amotu Airport seldom last for more than 12 to 18 hours.

### Visibility and low cloud

Visibility. Visibility is normally very good apart from reductions during precipitation. Visibility reductions to less than 5000 m occur just 0.5 percent of the time, mostly due to convective showers and other organised large-scale weather features.

Because 21 percent of night-time winds at Fua'amotu become calm, shallow radiation fog or mist forms in-situ for one or two hours on about six days each year. Fog rarely persists after 7 a.m.

Low cloud. Fua'amotu Airport is occasionally affected by low cloud, the main base of the predominant cumulus cloud being about 1800 to 2000 ft (550 to 600m). Low cloud below 1500ft (455m) affects the airport for about 4 percent of the time, with 48 percent of the observed low cloud occurring in easterly or south-easterly winds. There is no apparent diurnal variation in the frequency of low cloud, although it does appear that low cloud is slightly more prevalent during the dry season than in the wet one (Table A2).

Very low stratus (below 1000 ft or 300 m) usually forms in-situ when it rains, and occurs for about 1.5 percent of the time. Nearly 65 percent of occurrences of low stratus form when the wind is between 080° and 190°.

During conditions of rainfall, the main altostratus/nimbostratus cloud base is commonly at 8000 to 10000 ft (2400 to 3000m).

### Joint occurrences of low cloud and/or poor visibility

Tables A3 to A6 present the frequency distributions by three-monthly periods 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 for specified wind speed and directions are given in tables of joint probability (Table A7 to A10).

Low cloud and/or poor visibility in category A (i.e. cloud less than 1500 ft and/or visibility below 5000 m) is most frequent during the months from June to November when these conditions are reported for five percent of the time. During

the other months of the year, poor conditions occur for about four percent of the time. Occurrences of poor flying weather are most likely to occur when the wind direction is from between 080° to about 170°. However, their joint probabilities are generally small.

### Precipitation

Visibility reduction in convective showers and rainfall from organised features is normally slight, unless the precipitation is particularly heavy or prolonged, when it can lower to less than 10 km. However, visibilities may reduce to about 500 m in thunderstorms passing directly over the airfield.

Table A2. Hourly occurrences of reduced ceiling at Fua'amotu Airport  
Ceiling criterion: More than 4 oktas below 1500 ft (455 m).

| Time of<br>day<br>(hr) | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total | Obs.<br>used |
|------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------|--------------|
| 0000                   | -   | -   | 2   | -   | -   | -   | 1   | -   | 1   | 1   | -   | -   | 5     | 143          |
| 0100                   | 5   | 6   | 8   | -   | 3   | -   | 2   | 5   | 3   | 3   | 2   | 2   | 39    | 1065         |
| 0200                   | 3   | 3   | 6   | -   | 1   | 1   | 2   | 6   | 2   | 4   | 1   | 2   | 31    | 1065         |
| 0300                   | 5   | 3   | 3   | -   | 2   | 1   | 3   | 6   | 5   | 3   | 1   | 5   | 37    | 1065         |
| 0400                   | 1   | 2   | 7   | -   | 2   | 2   | 3   | 3   | 5   | 2   | -   | 2   | 29    | 1065         |
| 0500                   | 1   | 2   | 4   | -   | 1   | 2   | 1   | 2   | 2   | 2   | 1   | 2   | 20    | 1065         |
| 0600                   | 1   | 4   | 5   | 1   | 2   | 4   | 1   | 2   | 3   | 1   | 2   | -   | 26    | 1065         |
| 0700                   | 2   | 6   | 7   | 2   | 2   | 1   | 5   | 5   | 6   | 2   | 1   | 1   | 40    | 1065         |
| 0800                   | 4   | 4   | 5   | 2   | 1   | 2   | 2   | 4   | 6   | 2   | 3   | -   | 35    | 1065         |
| 0900                   | 3   | 6   | 4   | -   | 5   | 1   | 4   | 0   | 6   | 4   | 3   | 1   | 47    | 1065         |
| 1000                   | 6   | 4   | 6   | -   | 4   | 3   | 4   | 7   | 6   | 3   | 3   | 2   | 48    | 1065         |
| 1100                   | 5   | 3   | 6   | 1   | 4   | 4   | 4   | 5   | 7   | 3   | 3   | 2   | 47    | 1065         |
| 1200                   | 7   | 4   | 5   | -   | 3   | 4   | 3   | 4   | 7   | 2   | 5   | -   | 44    | 1065         |
| 1300                   | 7   | 2   | 5   | 1   | 3   | 5   | 2   | 6   | 6   | 2   | 5   | 1   | 45    | 1065         |
| 1400                   | 7   | 4   | 4   | 2   | 2   | 2   | 3   | 5   | 8   | 2   | 3   | 1   | 43    | 1065         |
| 1500                   | 3   | 6   | 6   | 2   | 2   | 3   | 4   | 3   | 6   | 1   | 1   | 2   | 39    | 1065         |
| 1600                   | 4   | 4   | 6   | 2   | 2   | 2   | 3   | 6   | 5   | 3   | 3   | 2   | 42    | 1065         |
| 1700                   | 6   | 4   | 5   | 1   | 3   | 2   | 3   | 7   | 5   | 4   | 4   | 1   | 45    | 1065         |
| 1800                   | 4   | 5   | 6   | 2   | 4   | 4   | 1   | 6   | 4   | 3   | 2   | 2   | 43    | 1065         |
| 1900                   | 3   | 5   | 8   | 2   | 3   | 3   | 2   | 6   | 6   | 3   | 2   | 2   | 45    | 1064         |
| 2000                   | -   | 1   | 3   | -   | -   | -   | -   | -   | -   | -   | -   | -   | 4     | 66           |
| 2100                   | -   | 1   | 3   | -   | -   | -   | -   | -   | -   | -   | -   | -   | 4     | 74           |
| 2200                   | -   | -   | 2   | -   | -   | -   | -   | -   | -   | -   | -   | -   | 2     | 86           |
| 2300                   | -   | -   | 1   | -   | -   | -   | 1   | -   | 1   | -   | -   | -   | 3     | 120          |
| Total                  | 177 | 79  | 117 | 18  | 49  | 46  | 54  | 98  | 100 | 50  | 45  | 40  | 763   |              |

#### Observations used

1832 1612 1810 1723 1802 1140 1851 1858 1777 1777 1712 1829 20723

TABLE A3. WIND SUMMARY IN CONDITIONS OF REDUCED CEILING AND VISIBILITY, FUA'AMOTU AIRPOPT, 1980-1983.  
SEASON: DEC, JAN, FEB.

| A3.A              |  | (CLOUD MORE THAN 4/8 BELOW 1500 FEET) |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
|-------------------|--|---------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----------------|-------|------|-------|
| CRITERIA          |  | (VISIBILITY LESS THAN 5000 METRES)    |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       | EITHER OR BOTH |       |      |       |
| DIR IN 10 DEGREES |  | 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 |
| SPEED IN KNOTS    |  |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| 1 - 5             |  |                                       |       | 2     |       | 1     | 2     | 1     |       |       |       |       |       |       |       |       |       |                | 1     |      | 7     |
| 6 - 10            |  | 2                                     | 6     | 3     | 7     | 7     | 1     | 1     | 3     | 3     |       |       | 2     |       |       |       |       | 1              | 3     |      | 39    |
| 11 - 15           |  | 12                                    | 13    | 10    | 5     | 6     | 4     | 6     | 4     | 4     |       |       |       | 1     |       |       |       |                | 7     |      | 73    |
| 16 - 20           |  | 1                                     | 7     | 6     | 2     | 4     | 4     | 4     | 2     | 9     | 3     |       |       |       | 1     |       |       |                | 1     |      | 43    |
| 21 - 25           |  |                                       | 1     |       | 1     | 2     | 1     | 4     | 3     | 2     |       |       |       |       |       |       |       |                | 1     |      | 14    |
| 26 - 30           |  |                                       |       |       |       |       |       |       |       | 1     |       |       |       |       |       |       |       |                |       |      | 1     |
| 31 - 35           |  |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| OVER 35           |  |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| TOTAL             |  | 15                                    | 29    | 19    | 15    | 20    | 12    | 16    | 12    | 19    | 3     |       | 2     | 1     |       | 1     |       | 1              | 12    | 20   | 197   |
| A3.B              |  | (CLOUD MORE THAN 4/8 BELOW 1000 FEET) |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| CRITERIA          |  | (VISIBILITY LESS THAN 3000 METRES)    |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       | EITHER OR BOTH |       |      |       |
| DIR IN 10 DEGREES |  | 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 |
| SPEED IN KNOTS    |  |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| 1 - 5             |  |                                       |       |       |       | 1     | 1     | 1     |       |       |       |       |       |       |       |       |       |                |       |      | 3     |
| 6 - 10            |  | 2                                     | 1     | 1     | 1     | 3     |       |       |       | 1     |       |       |       |       |       |       |       | 1              | 3     |      | 13    |
| 11 - 15           |  | 3                                     | 3     | 6     | 1     |       |       | 5     | 1     | 2     |       |       |       |       |       | 1     |       |                | 4     |      | 26    |
| 16 - 20           |  | 1                                     | 6     | 4     |       |       | 1     | 3     | 1     | 2     | 2     |       |       |       |       |       |       |                | 1     |      | 21    |
| 21 - 25           |  |                                       | 1     |       |       | 2     | 1     | 4     | 3     | 1     |       |       |       |       |       |       |       |                |       |      | 12    |
| 26 - 30           |  |                                       |       |       |       |       |       |       |       | 1     |       |       |       |       |       |       |       |                |       |      | 1     |
| 31 - 35           |  |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| OVER 35           |  |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| TOTAL             |  | 6                                     | 11    | 11    | 2     | 6     | 3     | 13    | 5     | 7     | 2     |       |       |       |       | 1     |       | 1              | 8     | 10   | 86    |
| A3.C              |  | (CLOUD MORE THAN 4/8 BELOW 700 FEET)  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| CRITERIA          |  | (VISIBILITY LESS THAN 2000 METRES)    |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       | EITHER OR BOTH |       |      |       |
| DIR IN 10 DEGREES |  | 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 |
| SPEED IN KNOTS    |  |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| 1 - 5             |  |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| 6 - 10            |  |                                       |       |       |       | 1     |       |       |       |       |       |       |       |       |       |       |       |                |       |      | 1     |
| 11 - 15           |  | 1                                     | 1     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      | 2     |
| 16 - 20           |  |                                       | 1     |       |       |       |       |       |       |       | 1     |       |       |       |       |       |       |                | 1     |      | 3     |
| 21 - 25           |  |                                       |       |       |       |       | 1     | 1     | 2     | 1     |       |       |       |       |       |       |       |                |       |      | 5     |
| 26 - 30           |  |                                       |       |       |       |       |       |       |       | 1     |       |       |       |       |       |       |       |                |       |      | 1     |
| 31 - 35           |  |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| OVER 35           |  |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| TOTAL             |  | 1                                     | 2     |       |       | 1     | 1     | 1     | 2     | 2     | 1     |       |       |       |       |       |       |                | 1     | 4    | 16    |
| A3.D              |  | WIND SUMMARY (ALL OBSERVATIONS)       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| DIR IN 10 DEGREES |  | 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 |
| SPEED IN KNOTS    |  |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| 1 - 5             |  | 15                                    | 19    | 38    | 33    | 65    | 72    | 81    | 82    | 34    | 16    | 14    | 9     | 11    | 4     | 3     | 13    | 11             | 16    |      | 536   |
| 6 - 10            |  | 36                                    | 49    | 56    | 114   | 211   | 285   | 331   | 282   | 135   | 81    | 47    | 32    | 19    | 3     | 15    | 4     | 10             | 19    |      | 1729  |
| 11 - 15           |  | 24                                    | 42    | 46    | 162   | 210   | 436   | 486   | 298   | 147   | 59    | 30    | 20    | 18    | 9     | 3     | 5     | 18             |       |      | 2022  |
| 16 - 20           |  | 5                                     | 12    | 11    | 22    | 51    | 144   | 115   | 78    | 41    | 11    | 1     | 3     | 3     | 1     |       |       | 2              | 4     |      | 504   |
| 21 - 25           |  |                                       | 1     | 2     | 3     | 1     | 7     | 3     | 3     |       |       |       |       |       |       |       |       |                |       |      | 26    |
| 26 - 30           |  |                                       |       |       |       |       |       |       | 1     |       |       |       |       |       |       |       |       |                |       |      | 1     |
| 31 - 35           |  |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| OVER 35           |  |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| TOTAL             |  | 80                                    | 123   | 153   | 337   | 540   | 938   | 1020  | 743   | 361   | 167   | 92    | 64    | 51    | 17    | 27    | 20    | 28             | 57    | 454  | 5272  |

TABLE A4. WIND SUMMARY IN CONDITIONS OF REDUCED CEILING AND VISIBILITY, FUA'AMOTU AIRPORT, 1980-1983.  
SEASON: MAR, APR, MAY.

|                   |  | (CLOUD MORE THAN 4/8 BELOW 1500 FEET) |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
|-------------------|--|---------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----------------|-------|------|-------|
| A4.A              |  | CRITERIA ( )                          |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       | EITHER OR BOTH |       |      |       |
|                   |  | (VISIBILITY LESS THAN 5000 METRES )   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| DIR IN 10 DEGREES |  | 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 |
| SPEED IN KNOTS    |  |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| 1 - 5             |  |                                       | 1     |       | 1     |       |       |       | 1     |       |       | 3     |       |       | 2     |       |       | 2              |       |      | 10    |
| 6 - 10            |  | 3                                     | 6     | 3     | 1     | 3     |       | 1     | 2     | 3     | 4     | 3     |       |       |       |       |       | 1              |       |      | 30    |
| 11 - 15           |  | 5                                     | 8     | 4     |       | 11    | 9     | 6     | 7     | 3     | 1     |       | 1     |       | 1     |       |       | 1              |       |      | 57    |
| 16 - 20           |  | 2                                     | 6     | 2     |       | 11    | 5     | 4     | 3     | 4     | 1     |       |       |       |       | 1     |       |                | 2     |      | 41    |
| 21 - 25           |  |                                       |       |       | 2     | 4     | 6     | 1     | 4     |       |       |       |       |       |       |       |       |                | 1     |      | 18    |
| 26 - 30           |  | 1                                     | 3     |       |       | 1     |       |       |       |       |       |       |       |       |       |       |       |                |       |      | 5     |
| 31 - 35           |  |                                       |       | 3     |       |       |       | 3     |       |       |       |       |       |       |       |       |       |                |       |      | 6     |
| OVER 35           |  |                                       |       | 3     | 2     | 2     | 3     |       |       | 1     |       |       |       |       |       |       |       | 4              | 3     | 18   | 11    |
| TOTAL             |  | 11                                    | 24    | 15    | 6     | 32    | 23    | 15    | 17    | 11    | 6     | 6     | 1     |       | 3     | 1     |       | 4              | 3     | 18   | 196   |
|                   |  | (CLOUD MORE THAN 4/8 BELOW 1000 FEET) |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| A4.B              |  | CRITERIA ( )                          |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       | EITHER OR BOTH |       |      |       |
|                   |  | (VISIBILITY LESS THAN 3000 METRES )   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| DIR IN 10 DEGREES |  | 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 |
| SPEED IN KNOTS    |  |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| 1 - 5             |  |                                       |       |       |       |       |       |       |       |       |       | 1     |       |       | 1     |       |       | 2              |       |      | 4     |
| 6 - 10            |  |                                       |       |       |       | 2     |       |       |       |       |       |       |       |       |       |       |       |                |       |      | 2     |
| 11 - 15           |  |                                       | 3     | 3     |       | 3     | 4     | 3     |       |       |       |       |       |       |       |       |       |                |       |      | 16    |
| 16 - 20           |  |                                       |       |       |       | 8     | 1     | 3     | 2     | 3     | 1     |       |       |       |       | 1     |       |                |       |      | 19    |
| 21 - 25           |  |                                       |       |       |       | 1     | 2     | 1     | 4     |       |       |       |       |       |       |       |       |                | 1     |      | 9     |
| 26 - 30           |  | 1                                     | 2     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      | 3     |
| 31 - 35           |  |                                       |       | 2     |       |       |       | 3     |       |       |       |       |       |       |       |       |       |                |       |      | 5     |
| OVER 35           |  |                                       |       | 3     | 2     | 2     | 3     |       |       | 1     |       |       |       |       |       |       |       | 2              | 1     | 12   | 11    |
| TOTAL             |  | 1                                     | 5     | 8     | 2     | 16    | 10    | 10    | 6     | 4     | 1     | 1     |       |       | 1     | 1     |       | 2              | 1     | 12   | 81    |
|                   |  | (CLOUD MORE THAN 4/8 BELOW 700 FEET)  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| A4.C              |  | CRITERIA ( )                          |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       | EITHER OR BOTH |       |      |       |
|                   |  | (VISIBILITY LESS THAN 2000 METRES )   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| DIR IN 10 DEGREES |  | 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 |
| SPEED IN KNOTS    |  |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| 1 - 5             |  |                                       |       |       |       |       |       |       |       |       |       | 1     |       |       |       |       |       |                |       |      | 1     |
| 6 - 10            |  |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| 11 - 15           |  |                                       |       | 1     |       | 2     |       | 1     |       |       |       |       |       |       |       |       |       |                |       |      | 5     |
| 16 - 20           |  |                                       |       |       |       | 3     | 1     | 1     |       | 1     | 1     |       |       |       |       | 1     |       |                |       |      | 8     |
| 21 - 25           |  |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                | 1     |      | 1     |
| 26 - 30           |  | 1                                     | 2     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      | 3     |
| 31 - 35           |  |                                       |       | 2     |       |       |       | 3     |       |       |       |       |       |       |       |       |       |                |       |      | 5     |
| OVER 35           |  |                                       |       | 3     | 2     | 2     | 3     |       |       | 1     |       |       |       |       |       |       |       |                |       |      | 11    |
| TOTAL             |  | 1                                     | 2     | 6     | 2     | 7     | 4     | 5     |       | 2     | 1     | 1     |       |       |       | 1     |       |                | 1     | 10   | 43    |
| A4.D              |  | WIND SUMMARY (ALL OBSERVATIONS)       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| DIR IN 10 DEGREES |  | 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 |
| SPEED IN KNOTS    |  |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| 1 - 5             |  | 15                                    | 15    | 41    | 36    | 75    | 57    | 81    | 87    | 96    | 65    | 48    | 32    | 20    | 20    | 9     | 7     | 8              | 4     |      | 716   |
| 6 - 10            |  | 26                                    | 49    | 39    | 78    | 151   | 157   | 273   | 269   | 230   | 150   | 94    | 73    | 51    | 47    | 10    | 15    | 10             | 17    |      | 1739  |
| 11 - 15           |  | 24                                    | 24    | 19    | 90    | 83    | 254   | 411   | 279   | 172   | 110   | 52    | 27    | 18    | 26    | 14    | 7     | 11             | 11    |      | 1639  |
| 16 - 20           |  | 11                                    | 8     | 3     | 14    | 59    | 116   | 109   | 101   | 54    | 12    |       | 1     | 3     | 4     | 4     | 1     | 3              | 5     |      | 508   |
| 21 - 25           |  | 1                                     |       |       | 5     | 14    | 22    | 2     | 5     | 1     |       |       |       |       |       |       |       | 2              | 1     |      | 53    |
| 26 - 30           |  | 1                                     | 4     |       |       | 1     | 2     | 1     |       |       |       |       |       |       |       |       |       |                |       |      | 9     |
| 31 - 35           |  |                                       | 3     | 3     |       |       | 1     | 1     |       |       |       |       |       |       |       |       |       |                |       |      | 10    |
| OVER 35           |  |                                       |       | 3     | 2     | 2     | 3     |       |       | 1     |       |       |       |       |       |       |       |                |       |      | 11    |
| TOTAL             |  | 78                                    | 103   | 108   | 225   | 385   | 612   | 880   | 741   | 554   | 337   | 194   | 133   | 92    | 97    | 37    | 30    | 34             | 37    | 657  | 5334  |

TABLE A5. WIND SUMMARY IN CONDITIONS OF REDUCED CEILING AND VISIBILITY, FUA'AMOTU AIRPORT, 1980-1983.  
SEASON: JUN, JUL, AUG.

|                   |  | (CLOUD MORE THAN 4/8 BELOW 1500 FEET)       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
|-------------------|--|---|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----------------|-------|------|-------|
| A5.A              |  | CRITERIA (VISIBILITY LESS THAN 5000 METRES) |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       | EITHER OR BOTH |       |      |       |
| DIR IN 10 DEGREES |  | 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 |
| SPEED IN KNOTS    |  |   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| 1 - 5             |  | 3   | 1     | 1     |       | 1     |       |       | 5     | 1     |       |       |       |       |       |       |       |                |       |      |       |
| 6 - 10            |  | 4   | 5     | 2     |       | 4     | 2     | 7     | 3     | 1     |       | 1     | 2     |       | 4     |       |       | 2              | 6     |      | 12    |
| 11 - 15           |  | 2   | 3     | 3     |       | 9     | 7     | 12    | 4     | 4     | 2     | 2     | 4     | 2     | 4     | 4     | 4     | 2              | 8     |      | 43    |
| 16 - 20           |  | 3   | 4     | 3     | 5     | 7     | 9     | 7     | 4     | 3     | 5     | 1     |       | 2     |       | 2     | 1     | 2              | 8     |      | 76    |
| 21 - 25           |  | 1   |       |       |       | 2     | 2     |       | 1     | 1     | 1     |       |       |       | 1     |       |       |                | 2     |      | 58    |
| 26 - 30           |  |   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      | 9     |
| 31 - 35           |  |   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| OVER 35           |  |   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| TOTAL             |  | 13  | 13    | 9     | 5     | 23    | 20    | 26    | 17    | 10    | 8     | 4     | 6     | 4     | 9     | 6     | 5     | 4              | 16    | 38   | 236   |
| A5.B              |  | (CLOUD MORE THAN 4/8 BELOW 1000 FEET)       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| A5.B              |  | CRITERIA (VISIBILITY LESS THAN 3000 METRES) |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       | EITHER OR BOTH |       |      |       |
| DIR IN 10 DEGREES |  | 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 |
| SPEED IN KNOTS    |  |   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| 1 - 5             |  | 1   |       |       |       | 1     |       |       | 1     |       |       |       |       |       |       |       |       |                |       |      | 3     |
| 6 - 10            |  | 3   | 2     |       |       | 3     |       |       | 1     | 1     |       |       | 1     |       | 2     |       |       |                | 2     |      | 15    |
| 11 - 15           |  | 1   | 2     | 1     |       | 8     | 2     | 6     | 1     | 2     |       | 1     | 3     |       | 1     |       | 1     |                | 4     |      | 33    |
| 16 - 20           |  | 1   | 3     | 1     | 4     | 6     | 8     | 1     | 2     | 2     | 1     | 1     |       |       |       |       |       |                |       |      | 30    |
| 21 - 25           |  |   |       |       |       |       | 2     |       | 1     | 1     | 1     |       |       |       | 1     |       |       |                |       |      | 6     |
| 26 - 30           |  |   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| 31 - 35           |  |   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| OVER 35           |  |   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| TOTAL             |  | 6   | 7     | 2     | 4     | 18    | 12    | 7     | 6     | 6     | 2     | 2     | 4     |       | 4     |       | 1     |                | 6     | 33   | 120   |
| A5.C              |  | (CLOUD MORE THAN 4/8 BELOW 700 FEET)        |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| A5.C              |  | CRITERIA (VISIBILITY LESS THAN 2000 METRES) |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       | EITHER OR BOTH |       |      |       |
| DIR IN 10 DEGREES |  | 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 |
| SPEED IN KNOTS    |  |   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| 1 - 5             |  | 1   |       |       |       | 1     |       |       |       |       |       |       |       |       |       |       |       |                |       |      | 2     |
| 6 - 10            |  |   | 1     |       |       | 3     |       |       |       |       |       |       |       |       |       |       |       |                |       |      | 4     |
| 11 - 15           |  | 1   | 1     | 1     |       | 2     | 1     | 2     |       |       |       |       | 1     |       |       |       |       |                | 2     |      | 11    |
| 16 - 20           |  | 1   | 1     |       | 2     | 4     | 3     | 1     |       |       |       | 1     |       |       |       |       |       |                |       |      | 14    |
| 21 - 25           |  |   |       |       |       |       |       |       | 1     | 1     |       |       |       |       | 1     |       |       |                |       |      | 3     |
| 26 - 30           |  |   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| 31 - 35           |  |   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| OVER 35           |  |   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| TOTAL             |  | 3   | 3     | 1     | 2     | 10    | 4     | 3     | 2     | 1     |       | 1     | 1     |       | 1     |       |       |                | 2     | 23   | 57    |
| A5.D              |  | WIND SUMMARY (ALL OBSERVATIONS)             |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| DIR IN 10 DEGREES |  | 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 |
| SPEED IN KNOTS    |  |   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| 1 - 5             |  | 28  | 25    | 31    | 35    | 67    | 51    | 73    | 67    | 64    | 75    | 29    | 29    | 27    | 18    | 7     | 6     | 10             | 9     |      | 651   |
| 6 - 10            |  | 53  | 47    | 46    | 89    | 146   | 101   | 161   | 153   | 147   | 160   | 127   | 89    | 71    | 53    | 18    | 22    | 26             | 43    |      | 1555  |
| 11 - 15           |  | 32  | 27    | 23    | 63    | 111   | 122   | 231   | 304   | 125   | 137   | 95    | 64    | 40    | 31    | 24    | 23    | 12             | 33    |      | 1497  |
| 16 - 20           |  | 17  | 19    | 8     | 11    | 26    | 66    | 80    | 73    | 42    | 27    | 8     | 7     | 4     | 3     | 8     | 4     | 1              | 7     |      | 411   |
| 21 - 25           |  | 1   | 1     |       |       | 5     | 8     | 2     | 1     | 1     | 2     |       | 2     |       | 2     |       |       |                |       |      | 25    |
| 26 - 30           |  |   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| 31 - 35           |  |   |       |       |       |       |       | 1     |       |       |       |       |       |       |       |       |       |                |       |      | 1     |
| OVER 35           |  |   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |       |
| TOTAL             |  | 131   | 119   | 108   | 198   | 355   | 351   | 548   | 598   | 379   | 401   | 259   | 191   | 142   | 107   | 57    | 55    | 49             | 92    | 702  | 4846  |

TABLE A6. WIND SUMMARY IN CONDITIONS OF REDUCED CEILING AND VISIBILITY, FUA'AMOTU AIRPORT, 1980-1983.  
SEASON: SEP, OCT, NOV.

| A6.A              |       | (CLOUD MORE THAN 4/8 BELOW 1500 FEET) |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       | EITHER OR BOTH |       |
|-------------------|-------|---------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----------------|-------|
| CRITERIA          |       | (VISIBILITY LESS THAN 5000 METRES)    |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |
| DIR IN 10 DEGREES | 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 |
| SPEED IN KNOTS    |       |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |
| 1 - 5             | 2     | 2                                     | 1     | 1     | 1     |       |       | 1     | 1     |       |       |       | 1     |       | 1     |       |       |       |                | 11    |
| 6 - 10            | 2     | 4                                     | 2     | 2     | 9     | 8     | 12    | 10    | 6     | 3     |       | 2     | 2     | 1     |       | 1     |       |       |                | 64    |
| 11 - 15           | 2     | 1                                     | 2     | 5     | 13    | 16    | 12    | 15    | 10    | 17    |       | 1     |       | 2     |       | 1     | 1     |       |                | 98    |
| 16 - 20           |       | 1                                     | 1     |       | 1     | 5     | 4     | 3     | 2     | 2     | 1     | 1     | 1     | 1     |       |       |       |       |                | 23    |
| 21 - 25           |       |                                       | 1     |       |       | 3     | 1     | 2     |       |       |       |       |       |       |       |       |       |       |                | 7     |
| 26 - 30           |       |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |
| 31 - 35           |       |                                       |       |       |       |       |       | 1     |       |       |       |       |       |       |       |       |       |       |                | 1     |
| OVER 35           |       |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |
| TOTAL             | 6     | 8                                     | 7     | 8     | 24    | 32    | 29    | 32    | 19    | 22    | 1     | 4     | 4     | 4     | 1     | 2     | 1     |       | 51             | 255   |
| A6.B              |       | (CLOUD MORE THAN 4/8 BELOW 1000 FEET) |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       | EITHER OR BOTH |       |
| CRITERIA          |       | (VISIBILITY LESS THAN 3000 METRES)    |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |
| DIR IN 10 DEGREES | 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 |
| SPEED IN KNOTS    |       |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |
| 1 - 5             | 2     | 1                                     |       | 1     |       |       |       |       | 1     |       |       |       | 1     |       | 1     |       |       |       |                | 7     |
| 6 - 10            |       | 2                                     |       | 1     | 5     | 5     | 4     | 8     | 3     |       |       | 2     | 2     | 1     |       | 1     |       |       |                | 34    |
| 11 - 15           | 2     | 1                                     | 2     |       | 4     | 8     | 4     | 5     | 3     | 10    |       | 1     |       | 1     |       | 1     |       |       |                | 42    |
| 16 - 20           |       | 1                                     | 1     |       |       | 2     | 2     | 3     | 2     | 2     | 1     |       |       | 1     |       |       |       |       |                | 15    |
| 21 - 25           |       |                                       | 1     |       |       | 3     | 1     | 2     |       |       |       |       |       |       |       |       |       |       |                | 7     |
| 26 - 30           |       |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |
| 31 - 35           |       |                                       |       |       |       |       |       | 1     |       |       |       |       |       |       |       |       |       |       |                | 1     |
| OVER 35           |       |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |
| TOTAL             | 4     | 5                                     | 4     | 2     | 9     | 18    | 11    | 19    | 9     | 12    | 1     | 3     | 3     | 3     | 1     | 2     |       |       | 45             | 151   |
| A6.C              |       | (CLOUD MORE THAN 4/8 BELOW 700 FEET)  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       | EITHER OR BOTH |       |
| CRITERIA          |       | (VISIBILITY LESS THAN 2000 METRES)    |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |
| DIR IN 10 DEGREES | 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 |
| SPEED IN KNOTS    |       |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |
| 1 - 5             |       | 1                                     |       |       |       |       |       |       | 1     |       |       |       | 1     |       | 1     |       |       |       |                | 4     |
| 6 - 10            |       | 2                                     |       | 1     | 2     | 3     | 1     |       | 1     |       |       | 2     | 1     | 1     |       |       |       |       |                | 14    |
| 11 - 15           |       |                                       | 1     |       | 2     | 1     | 1     | 1     | 1     | 2     |       |       |       |       |       |       |       |       |                | 9     |
| 16 - 20           |       |                                       |       |       |       | 2     | 2     |       |       | 1     | 1     |       |       |       |       |       |       |       |                | 6     |
| 21 - 25           |       |                                       |       |       |       | 2     |       |       |       |       |       |       |       |       |       |       |       |       |                | 2     |
| 26 - 30           |       |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |
| 31 - 35           |       |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |
| OVER 35           |       |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |
| TOTAL             |       | 3                                     | 1     | 1     | 4     | 8     | 4     | 1     | 3     | 3     | 1     | 2     | 2     | 1     | 1     |       |       |       | 38             | 73    |
| A6.D              |       | WIND SUMMARY (ALL OBSERVATIONS)       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |
| DIR IN 10 DEGREES | 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 |
| SPEED IN KNOTS    |       |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |
| 1 - 5             | 8     | 8                                     | 5     | 23    | 29    | 40    | 52    | 61    | 66    | 38    | 32    | 9     | 7     | 7     | 1     | 2     | 7     | 6     |                | 401   |
| 6 - 10            | 26    | 24                                    | 23    | 92    | 177   | 178   | 258   | 291   | 220   | 124   | 83    | 45    | 31    | 20    | 13    | 10    | 2     | 3     |                | 1620  |
| 11 - 15           | 15    | 14                                    | 23    | 111   | 206   | 387   | 478   | 334   | 227   | 139   | 89    | 61    | 32    | 13    | 8     | 3     | 3     | 3     |                | 2146  |
| 16 - 20           | 13    | 23                                    | 14    | 36    | 42    | 153   | 162   | 70    | 71    | 29    | 15    | 8     | 6     | 5     |       | 1     | 2     |       |                | 650   |
| 21 - 25           |       | 1                                     | 4     | 1     | 1     | 9     | 11    | 3     |       |       |       |       |       |       |       |       |       |       |                | 30    |
| 26 - 30           |       |                                       |       |       |       | 1     |       |       |       |       |       |       |       |       |       |       |       |       |                | 1     |
| 31 - 35           |       |                                       |       |       |       |       |       | 1     |       |       |       |       |       |       |       |       |       |       |                | 1     |
| OVER 35           |       |                                       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |
| TOTAL             | 62    | 70                                    | 69    | 263   | 455   | 768   | 961   | 760   | 584   | 330   | 219   | 123   | 76    | 45    | 22    | 16    | 14    | 12    | 416            | 5265  |

TABLE A7. JOINT PROBABILITIES (JP) IN CONDITIONS OF REDUCED CEILING AND VISIBILITY AT FUA'AMOTU AIRPORT, 1980-1983.  
 NOTE: JP IS THE PERCENTAGE OCCURRENCE OF REDUCED CEILING AND VISIBILITY FOR A PARTICULAR WIND CATEGORY.  
 A 0+ INDICATES A JP BETWEEN 0 AND 0.5 PERCENT.

SEASON: DEC, JAN, FEB.

| A7.A              |  | CRITERIA (CLOUD MORE THAN 4/8 BELOW 1500 FEET)<br>(VISIBILITY LESS THAN 5000 METRES) |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       | EITHER OR BOTH |       |      |
|-------------------|--|--|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----------------|-------|------|
| DIR IN 10 DEGREES |  | 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 |
| SPEED IN KNOTS    |  |  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |
| 1 - 5             |  |  | 11    |       |       | 2     | 3     | 1     |       |       |       |       |       |       |       |       |       |                |       |      |
| 6 - 10            |  | 6  | 12    |       |       | 3     | 0+    | 0+    | 1     | 2     |       |       |       |       |       |       |       |                |       | 6    |
| 11 - 15           |  | 50   | 31    | 22    | 3     | 3     | 1     | 1     | 1     | 3     |       |       | 6     |       |       |       |       |                | 10    | 16   |
| 16 - 20           |  | 20   | 58    | 55    | 9     | 8     | 3     | 3     | 3     | 22    |       |       |       | 6     |       | 11    |       |                |       | 39   |
| 21 - 25           |  |  |       |       | 17    | 67    | 100   | 57    | 100   | 67    |       |       |       |       |       |       |       |                |       | 25   |
| 26 - 30           |  |  |       |       |       |       |       |       |       | 100   |       |       |       |       |       |       |       |                |       |      |
| 31 - 35           |  |  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |
| OVER 35           |  |  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |
| CALM              |  |  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |
|                   |  |  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       | 4    |

| A7.B              |  | CRITERIA (CLOUD MORE THAN 4/8 BELOW 1000 FEET)<br>(VISIBILITY LESS THAN 3000 METRES) |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       | EITHER OR BOTH |       |      |
|-------------------|--|--|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----------------|-------|------|
| DIR IN 10 DEGREES |  | 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 |
| SPEED IN KNOTS    |  |  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |
| 1 - 5             |  |  |       |       |       | 2     | 1     | 1     |       |       |       |       |       |       |       |       |       |                |       |      |
| 6 - 10            |  | 6  | 2     | 2     | 1     | 1     |       |       |       | 1     |       |       |       |       |       |       |       |                |       |      |
| 11 - 15           |  | 13   | 7     | 13    | 1     |       |       | 1     | 0+    | 1     |       |       |       |       |       |       |       |                | 10    | 16   |
| 16 - 20           |  | 20   | 50    | 36    |       |       | 1     | 3     | 1     | 5     |       |       |       |       |       | 11    |       |                |       | 22   |
| 21 - 25           |  |  |       |       |       | 67    | 100   | 57    | 100   | 33    |       | 18    |       |       |       |       |       |                |       | 25   |
| 26 - 30           |  |  |       |       |       |       |       |       |       | 100   |       |       |       |       |       |       |       |                |       |      |
| 31 - 35           |  |  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |
| OVER 35           |  |  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |
| CALM              |  |  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |
|                   |  |  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       | 2    |

| A7.C              |  | CRITERIA (CLOUD MORE THAN 4/8 BELOW 700 FEET)<br>(VISIBILITY LESS THAN 2000 METRES) |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       | EITHER OR BOTH |       |      |
|-------------------|--|---|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----------------|-------|------|
| DIR IN 10 DEGREES |  | 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 |
| SPEED IN KNOTS    |  |   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |
| 1 - 5             |  |   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |
| 6 - 10            |  |   |       |       |       | 0+    |       |       |       |       |       |       |       |       |       |       |       |                |       |      |
| 11 - 15           |  | 4   | 2     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |
| 16 - 20           |  |   | 8     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |
| 21 - 25           |  |   |       |       |       |       | 100   | 14    | 67    | 33    |       | 9     |       |       |       |       |       |                |       | 25   |
| 26 - 30           |  |   |       |       |       |       |       |       |       | 100   |       |       |       |       |       |       |       |                |       |      |
| 31 - 35           |  |   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |
| OVER 35           |  |   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |
| CALM              |  |   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |      |
|                   |  |   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       | 1    |

TABLE A8. JOINT PROBABILITIES (JP) IN CONDITIONS OF REDUCED CEILING AND VISIBILITY AT FUA'AMOTU AIRPORT, 1980-1983.  
 NOTE: JP IS THE PERCENTAGE OCCURRENCE OF REDUCED CEILING AND VISIBILITY FOR A PARTICULAR WIND CATEGORY.  
 A 0+ INDICATES A JP BETWEEN 0 AND 0.5 PERCENT.

SEASON: MAR, APR, MAY.

| A8.A              |  | CRITERIA (CLOUD MORE THAN 4/8 BELOW 1500 FEET) |       |       |       |       |       |       |       |       |       |       |       |       |       | EITHER OR BOTH |       |       |       |      |
|-------------------|--|--|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----------------|-------|-------|-------|------|
|                   |  | (VISIBILITY LESS THAN 5000 METRES)             |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |       |       |      |
| DIR IN 10 DEGREES |  | 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 |
| SPEED IN KNOTS    |  |  |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |       |       |      |
| 1 - 5             |  |  | 7     |       | 3     |       |       |       | 1     |       |       | 6     |       |       | 10    |                |       |       | 25    |      |
| 6 - 10            |  | 12   | 12    | 8     | 1     | 2     |       | 0+    | 1     | 1     | 3     | 3     |       |       |       |                |       | 10    |       |      |
| 11 - 15           |  | 21   | 33    | 21    |       | 13    | 4     | 1     | 3     | 2     | 1     |       |       | 4     | 4     |                |       | 9     |       | 40   |
| 16 - 20           |  | 18   | 75    | 67    |       | 19    | 4     | 4     | 3     | 7     | 8     |       |       |       |       | 25             |       |       |       | 100  |
| 21 - 25           |  |  |       |       | 40    | 29    | 27    | 50    | 80    |       |       |       |       |       |       |                |       |       |       |      |
| 26 - 30           |  | 100  | 75    |       |       | 100   |       |       |       |       |       |       |       |       |       |                |       |       |       |      |
| 31 - 35           |  |  |       | 100   |       |       |       | 100   |       |       |       |       |       |       |       |                |       |       |       |      |
| OVER 35           |  |  |       | 100   | 100   | 100   |       | 100   |       |       |       |       |       |       |       |                |       |       |       |      |
| CALM              |  |  |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |       |       | 3    |

| A8.B              |  | CRITERIA (CLOUD MORE THAN 4/8 BELOW 1000 FEET) |       |       |       |       |       |       |       |       |       |       |       |       |       | EITHER OR BOTH |       |       |       |      |
|-------------------|--|--|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----------------|-------|-------|-------|------|
|                   |  | (VISIBILITY LESS THAN 3000 METRES)             |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |       |       |      |
| DIR IN 10 DEGREES |  | 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 |
| SPEED IN KNOTS    |  |  |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |       |       |      |
| 1 - 5             |  |  |       |       |       |       |       |       |       |       |       | 2     |       |       | 5     |                |       |       | 25    |      |
| 6 - 10            |  |  |       |       |       | 1     |       |       |       |       |       |       |       |       |       |                |       |       |       |      |
| 11 - 15           |  |  | 13    | 16    |       | 4     | 2     | 1     |       |       |       |       |       |       |       | 25             |       |       |       |      |
| 16 - 20           |  |  |       |       |       | 14    | 1     | 3     | 2     | 6     | 8     |       |       |       |       |                |       |       |       | 100  |
| 21 - 25           |  |  |       |       |       | 7     | 9     | 50    | 80    |       |       |       |       |       |       |                |       |       |       |      |
| 26 - 30           |  | 100  | 50    |       |       |       |       |       |       |       |       |       |       |       |       |                |       |       |       |      |
| 31 - 35           |  |  |       | 67    |       |       |       | 100   |       |       |       |       |       |       |       |                |       |       |       |      |
| OVER 35           |  |  |       | 100   | 100   | 100   | 100   |       |       | 100   |       |       |       |       |       |                |       |       |       |      |
| CALM              |  |  |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |       |       | 2    |

| A8.C              |  | CRITERIA (CLOUD MORE THAN 4/8 BELOW 700 FEET) |       |       |       |       |       |       |       |       |       |       |       |       |       | EITHER OR BOTH |       |       |       |      |
|-------------------|--|---|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----------------|-------|-------|-------|------|
|                   |  | (VISIBILITY LESS THAN 2000 METRES)            |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |       |       |      |
| DIR IN 10 DEGREES |  | 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 |
| SPEED IN KNOTS    |  |   |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |       |       |      |
| 1 - 5             |  |   |       |       |       |       |       |       |       |       |       | 2     |       |       |       |                |       |       |       |      |
| 6 - 10            |  |   |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |       |       |      |
| 11 - 15           |  |   |       | 5     |       | 2     |       | 0+    |       |       |       |       |       |       |       | 25             |       |       |       |      |
| 16 - 20           |  |   |       |       |       | 5     | 1     | 1     |       | 2     | 8     |       |       |       |       |                |       |       |       | 100  |
| 21 - 25           |  |   |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |       |       |      |
| 26 - 30           |  | 100   | 50    |       |       |       |       |       |       |       |       |       |       |       |       |                |       |       |       |      |
| 31 - 35           |  |   |       | 67    |       |       |       | 100   |       |       |       |       |       |       |       |                |       |       |       |      |
| OVER 35           |  |   |       | 100   | 100   | 100   | 100   |       |       | 100   |       |       |       |       |       |                |       |       |       |      |
| CALM              |  |   |       |       |       |       |       |       |       |       |       |       |       |       |       |                |       |       |       | 2    |

TABLE A9. JOINT PROBABILITIES (JP) IN CONDITIONS OF REDUCED CEILING AND VISIBILITY AT FUA'AMOTU AIRPORT, 1980-1983.  
 NOTE: JP IS THE PERCENTAGE OCCURRENCE OF REDUCED CEILING AND VISIBILITY FOR A PARTICULAR WIND CATEGORY.  
 A 0+ INDICATES A JP BETWEEN 0 AND 0.5 PERCENT.

SEASON: JUN, JUL, AUG.

A9.A

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

| DIR IN 10 DEGREES | 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 |
|-------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------|
| SPEED IN KNOTS    |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |      |
| 1 - 5             | 11    | 4     | 3     |       | 1     |       |       | 7     | 2     |       |       |       |       |       |       |       |       |       |      |
| 6 - 10            | 8     | 11    | 4     |       | 3     | 2     | 4     | 2     | 1     |       |       | 2     |       |       |       |       |       |       |      |
| 11 - 15           | 6     | 11    | 13    |       | 8     | 6     | 5     | 1     | 3     | 1     | 2     | 6     | 5     | 8     | 17    | 17    | 8     | 14    |      |
| 16 - 20           | 18    | 21    | 38    | 45    | 27    | 14    | 9     | 5     | 7     | 19    | 13    |       | 50    | 13    | 25    | 25    | 17    | 24    |      |
| 21 - 25           | 100   |       |       |       | 40    | 25    |       | 100   | 100   | 50    |       |       |       | 50    |       |       |       | 29    |      |
| 26 - 30           |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |      |
| 31 - 35           |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |      |
| OVER 35           |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |      |
| CALM              |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       | 5    |

A9.B

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

| DIR IN 10 DEGREES | 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 |
|-------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------|
| SPEED IN KNOTS    |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |      |
| 1 - 5             | 4     |       |       |       | 1     |       |       | 1     |       |       |       |       |       |       |       |       |       |       |      |
| 6 - 10            | 6     | 4     |       |       | 2     |       |       | 1     | 1     |       |       | 1     |       | 4     |       |       |       |       |      |
| 11 - 15           | 3     | 7     | 4     |       | 7     | 2     | 3     | 0+    | 2     |       |       | 5     |       | 3     |       | 4     |       | 5     |      |
| 16 - 20           | 6     | 16    | 13    | 36    | 23    | 12    | 1     | 3     | 5     | 4     | 13    |       |       |       |       |       |       | 12    |      |
| 21 - 25           |       |       |       |       |       | 25    |       | 100   | 100   | 50    |       |       |       | 50    |       |       |       |       |      |
| 26 - 30           |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |      |
| 31 - 35           |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |      |
| OVER 35           |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |      |
| CALM              |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       | 5    |

A9.C

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

| DIR IN 10 DEGREES | 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 |
|-------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------|
| SPEED IN KNOTS    |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |      |
| 1 - 5             | 4     |       |       |       | 1     |       |       |       |       |       |       |       |       |       |       |       |       |       |      |
| 6 - 10            |       | 2     |       |       | 2     |       |       |       |       |       |       |       |       |       |       |       |       |       |      |
| 11 - 15           | 3     | 4     | 4     |       | 2     | 1     | 1     |       |       |       |       |       |       |       |       |       |       | 6     |      |
| 16 - 20           | 6     | 5     |       | 18    | 15    | 5     | 1     | 1     |       |       |       | 13    |       |       |       |       |       |       |      |
| 21 - 25           |       |       |       |       |       |       |       | 100   | 100   |       |       |       |       |       |       |       |       |       |      |
| 26 - 30           |       |       |       |       |       |       |       |       |       |       |       |       |       | 50    |       |       |       |       |      |
| 31 - 35           |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |      |
| OVER 35           |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |      |
| CALM              |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       | 3    |

TABLE A10. JOINT PROBABILITIES (JP) IN CONDITIONS OF REDUCED CEILING AND VISIBILITY AT FUA'AMOTU AIRPORT, 1980-1983.  
 NOTE: JP IS THE PERCENTAGE OCCURRENCE OF REDUCED CEILING AND VISIBILITY FOR A PARTICULAR WIND CATEGORY.  
 A 0+ INDICATES A JP BETWEEN 0 AND 0.5 PERCENT.

SEASON: SEP, OCT, NOV.

| A10.A             | CRITERIA (CLOUD MORE THAN 4/8 BELOW 1500 FEET) |       |       |       |       |       |       |       |       |       |       |       |       |       | EITHER OR BOTH | CALM |       |       |       |
|-------------------|--|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----------------|------|-------|-------|-------|
|                   | 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 |
| DIR IN 10 DEGREES |  |       |       |       |       |       |       |       |       |       |       |       |       |       |                |      |       |       |       |
| SPEED IN KNOTS    |  |       |       |       |       |       |       |       |       |       |       |       |       |       |                |      |       |       |       |
| 1 - 5             | 25   | 25    | 20    | 4     | 3     |       |       | 2     | 2     |       |       |       | 14    |       | 100            |      |       |       |       |
| 6 - 10            | 8  | 17    | 9     | 2     | 5     | 4     | 5     | 3     | 3     | 2     |       | 4     | 6     | 5     |                | 10   |       |       |       |
| 11 - 15           | 13   | 7     | 9     | 5     | 6     | 4     | 3     | 4     | 4     | 12    |       | 2     |       | 15    |                | 33   | 33    |       |       |
| 16 - 20           |  | 4     | 7     |       | 2     | 3     | 2     | 4     | 3     | 7     | 7     | 13    | 17    | 20    |                |      |       |       |       |
| 21 - 25           |  |       | 25    |       |       | 33    | 9     | 67    |       |       |       |       |       |       |                |      |       |       |       |
| 26 - 30           |  |       |       |       |       |       |       |       | 100   |       |       |       |       |       |                |      |       |       |       |
| 31 - 35           |  |       |       |       |       |       |       |       |       |       |       |       |       |       |                |      |       |       | 12    |
| OVER 35           |  |       |       |       |       |       |       |       |       |       |       |       |       |       |                |      |       |       |       |
| CALM              |  |       |       |       |       |       |       |       |       |       |       |       |       |       |                |      |       |       |       |
| A10.B             | CRITERIA (CLOUD MORE THAN 4/8 BELOW 1000 FEET) |       |       |       |       |       |       |       |       |       |       |       |       |       | EITHER OR BOTH | CALM |       |       |       |
|                   | 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 |
| DIR IN 10 DEGREES |  |       |       |       |       |       |       |       |       |       |       |       |       |       |                |      |       |       |       |
| SPEED IN KNOTS    |  |       |       |       |       |       |       |       |       |       |       |       |       |       |                |      |       |       |       |
| 1 - 5             | 25   | 13    |       | 4     |       |       |       | 2     | 2     |       |       |       | 14    |       | 100            |      |       |       |       |
| 6 - 10            |  | 8     |       | 1     | 3     | 3     | 2     | 3     | 1     |       |       | 4     | 6     | 5     |                | 10   |       |       |       |
| 11 - 15           | 13   | 7     | 9     |       | 2     | 2     | 1     | 1     | 1     | 7     |       | 2     |       | 8     |                | 33   |       |       |       |
| 16 - 20           |  | 4     | 7     |       |       | 1     | 1     | 4     | 3     | 7     | 7     |       |       | 20    |                |      |       |       |       |
| 21 - 25           |  |       | 25    |       |       | 33    | 9     | 67    |       |       |       |       |       |       |                |      |       |       |       |
| 26 - 30           |  |       |       |       |       |       |       |       | 100   |       |       |       |       |       |                |      |       |       |       |
| 31 - 35           |  |       |       |       |       |       |       |       |       |       |       |       |       |       |                |      |       |       | 11    |
| OVER 35           |  |       |       |       |       |       |       |       |       |       |       |       |       |       |                |      |       |       |       |
| CALM              |  |       |       |       |       |       |       |       |       |       |       |       |       |       |                |      |       |       |       |
| A10.C             | CRITERIA (CLOUD MORE THAN 4/8 BELOW 700 FEET)  |       |       |       |       |       |       |       |       |       |       |       |       |       | EITHER OR BOTH | CALM |       |       |       |
|                   | 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 |
| DIR IN 10 DEGREES |  |       |       |       |       |       |       |       |       |       |       |       |       |       |                |      |       |       |       |
| SPEED IN KNOTS    |  |       |       |       |       |       |       |       |       |       |       |       |       |       |                |      |       |       |       |
| 1 - 5             |  | 13    |       |       | 1     | 1     | 2     | 0+    |       | 2     |       |       | 14    |       | 100            |      |       |       |       |
| 6 - 10            |  | 8     |       |       |       |       | 0+    | 0+    | 0+    | 0+    |       | 4     | 3     | 5     |                |      |       |       |       |
| 11 - 15           |  |       | 4     |       | 1     | 0+    | 0+    | 0+    | 0+    | 1     |       |       |       |       |                |      |       |       |       |
| 16 - 20           |  |       |       |       |       | 1     | 1     |       |       | 3     | 7     |       |       |       |                |      |       |       |       |
| 21 - 25           |  |       |       |       |       |       | 22    |       |       |       |       |       |       |       |                |      |       |       |       |
| 26 - 30           |  |       |       |       |       |       |       |       |       |       |       |       |       |       |                |      |       |       |       |
| 31 - 35           |  |       |       |       |       |       |       |       |       |       |       |       |       |       |                |      |       |       | 9     |
| OVER 35           |  |       |       |       |       |       |       |       |       |       |       |       |       |       |                |      |       |       |       |
| CALM              |  |       |       |       |       |       |       |       |       |       |       |       |       |       |                |      |       |       |       |