THE CLIMATE AND WEATHER

OF

WESTERN SAMOA

Stuart M. Burgess

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S.M. Burgess

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New Zealand Meteorological Service
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Series List

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

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

THE CLIMATE AND WEATHER OF WESTERN SAMOA

Summary

The climate of Western Samoa is dominated by the south-easterly trade winds and the South Pacific Convergence Zone (SPCZ). There is a dry season, April to September, and a rainy season, October to March when the convergence zone is at its most active.

Tropical cyclones affect the area at times and temperatures are consistently warm. The warm, humid conditions cause some discomfort, but are often moderated by the wind.

During the drier part of the year the climate of Samoa is dominated by the easterly to south-easterly trade winds. The SPCZ lies over the region during most of the year, but is especially active during the wetter months.

1 INTRODUCTION

Western Samoa is an independent state and a member of the Commonwealth. It is located in the South Pacific Ocean between latitudes 13° and 14°S and longitudes 171° and 173°W (Fig. 1). There are two large mountainous islands: Savai'i (1820 km^2) and Upolu (1113 km^2), and six small islets (Fig. 2) (Stirling, 1978). Savai'i and Upolu are surrounded by a coral reef, which is broken in many places. Most of the land within eight km of the coast is flat or undulating country, but the eastern region of Upolu near Lemafa is steep. Both Savai'i and Upolu have mountainous, volcanic interiors. Mt. Silsili rises to 1858 m on Savai'i, while the highest point on Upolu rises to 1113 m (Carter, 1984).

The soils are volcanic, consisting mainly of basaltic rock and some of the cones are still active. An eruption occurred on Savai'i in 1902 and another between 1905 and 1911. The lava from the 1905 eruption covered an area of 150 km^2. Upland soils are not generally used for cultivation.

Although the soils are mainly stony and leached a wide range of crops can be grown: these include taro, kumara, yams, coconut, cocoa, bananas, copra and breadfruit. Some land is also used for grazing beef and for forestry.

The population of both islands was just over 156,000 in 1981. Settlement is almost entirely along the coast. In 1981 Upolu had approximately 108,000 people, and Savai'i 49,000. The capital city, Apia, is located on the northern side of Upolu and had a population of 31,000 (Carter, 1984). The major airfield is located at Faleolo, near the western end of the north coast of Upolu.

The data used in this publication, where not otherwise indicated, were obtained from the New Zealand Meteorological Service's archives. At present the Meteorological Office at Apia receives data from nine stations which make daily climatological observations. These observations include wind, rainfall, and temperature. The remaining stations record only daily rainfall (Table 1). Rainfall has also been measured at a large number of other sites in Western Samoa for short periods, by such agencies as the electricity department (for use in hydro development schemes), the forestry department and also by schools. The earliest climatological observations began at Apia in 1890, but since 1902 observations have been made at the Apia Observatory. Meteorological observations also began later at both Satupa'itea and Fagamalo, during 1924. There is a lack of stations in the central areas of Savai'i and in some cases the data lack continuity and cover only a relatively short period of time.

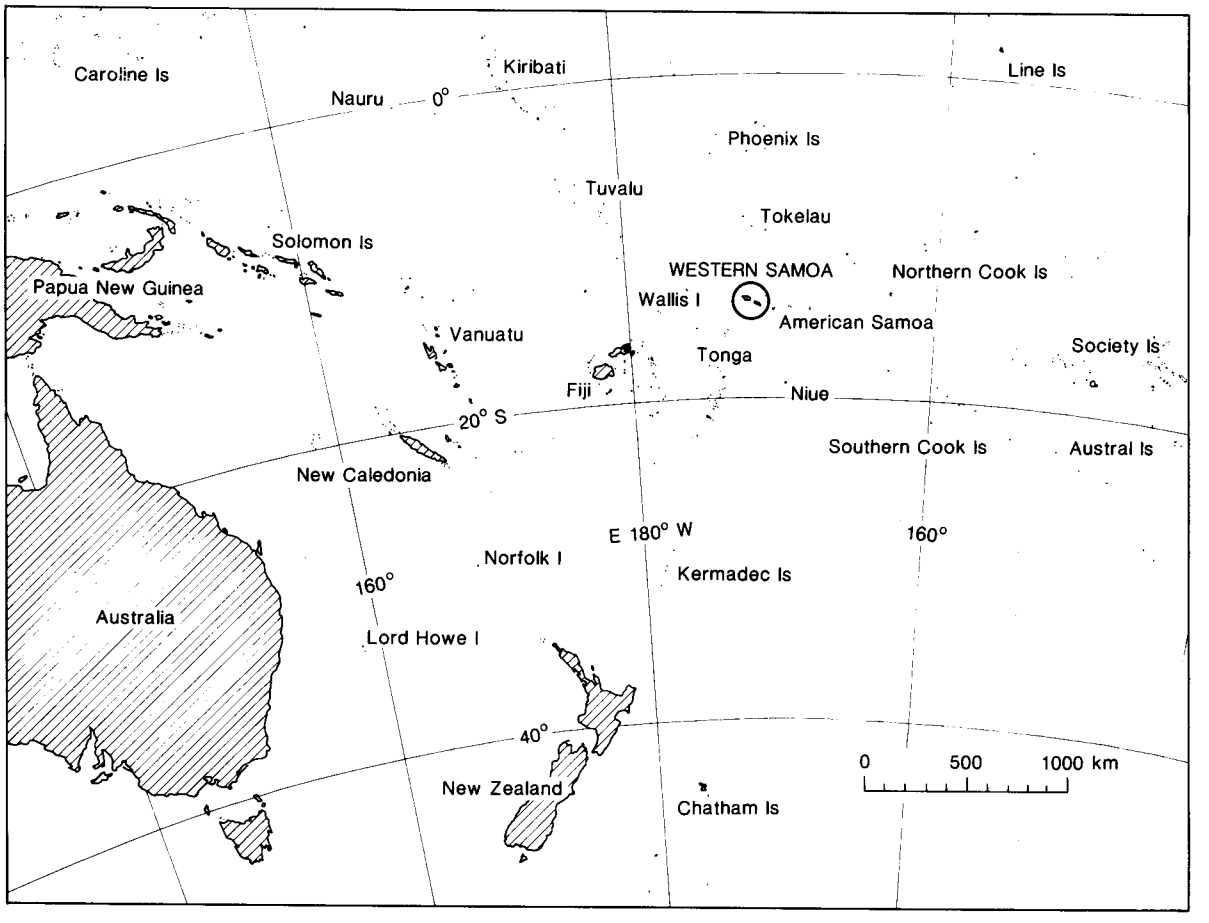

Figure 1 Location of Western Samoa in the South-west Pacific Ocean

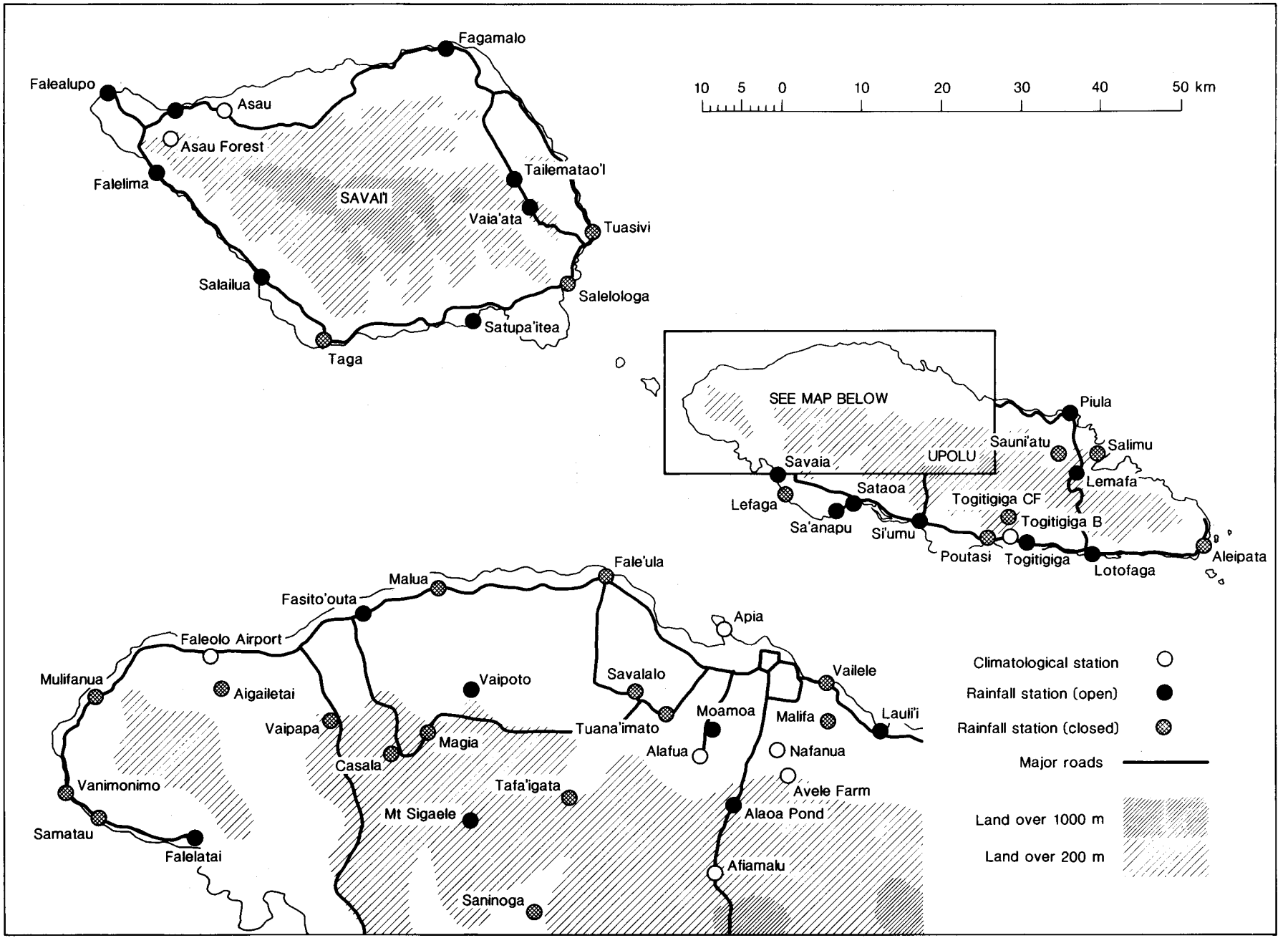

Figure 2 Map of Western Samoa showing station localities.

Table 1 Meteorological Sites in Western Samoa
P = Present

Climate stations

Station Name and Height	Index no. and Data period	Remarks on site exposure
Faleolo Airport 4 m	J75900 (1970-P)	A large tar sealed apron is located about 15 m to the east, in front of the terminal building. In easterly winds this could influence temperatures measured during daylight hours. The general exposure is good.
Apia 2 m	J76200 (1890-P)	Sheltered by hills E-S-W, otherwise exposure is good.
Alafua 65 m	J76201 (1968-P)	Some sheltering from the west, otherwise exposure is satisfactory.
Nafanua 128 m	J76202 (1965-79)	Exposure is fair, some banana trees 128 m to the south and a building to the north-west.
Avele Farm 213 m	J76203 (1964-86)	Exposure very good.
Afiamalu 796 m	J76204 (1967-P)	Located on land sloping downwards to the north. Exposure to the north-west and south restricted by tropical vegetation.
Togitigiga B. 148 m	J76205 (1973-75,77)	----
Asau 4 m	J76000 (1968-P)	----
Asau Forest 328 m	J76001 (1977-P)	----

Rainfall stations

Fasito'outa 20 m	J75901 (1980-P)	Falelatai 27 m	J75902 (1970-P)
Savaia 3 m	J75903 (1970-P)	Falelima 3 m	J76002 (1980-P)
Falealupo 5 m	J76003 (1967-P)	Salailua 3 m	J76004 (1949-P)
Satupa'itea 6 m	J76005 (1924-P)	Fagamalo 3 m	J76006 (1924-P)
Tailematao'l 250 m*	J76007 (1980-P)	Vaia'ata 200 m*	J76008 (1983-P)
Lauli'i 5 m	J76206 (1970-86)	Moamoa 200 m*	J76207 (1963-P)
Lemafa 473 m	J76208 (1975-P)	Sataoa 15 m	J76209 (1970-P)
Togitigiga CF 250 m*	J76210 (1978-P)	Lotofaga 9 m	J76211 (1934-P)
Togitigiga 30 m	J76212 (1975-76)	Togitigiga 100 m*	J76213 (1969-73)
Alaoa Pond 300 m*	J76214 (1957-P)		

* Approximate height above sea level.

2 GENERAL CIRCULATION IN THE WESTERN SAMOAN AREA

The main factors affecting the weather in the area are:

(i) The sub-tropical high pressure zone. This is a belt of high pressure which spans the South Pacific and is centred on latitudes 25^{o} to 30^{o}S. Within this zone in the eastern South Pacific is a large semi-permanent anticyclone. On the western margin of the belt of high pressure, anticyclones move eastwards into the Pacific Ocean from the Australia-Tasman Sea area.

(ii) Trade winds. On the northern side of the high pressure belt there is an extensive region where the winds blow consistently from the same general direction. These 'trade winds', have a strong influence on Western Samoa's climate. They are explained by the direct tropical

circulation - the Hadley cell, and the longitudinal circulation of air having upward motion over the continents and downward motion over the oceans - the Walker cell. The Hadley Cell is marked by ascending air in low latitudes, a poleward flow of air aloft, and an accumulation of air in the regions of the sub-tropical high pressure zone. The return low level current are the Trade winds, and in this region they blow from between east and south-east.

There is normally a temperature inversion associated with the trade winds, above which cloud tops rarely penetrate and showers become less likely. This inversion is often absent in the Western Pacific, especially over Western Samoa due to the presence of the South Pacific Convergence Zone, and during disturbed periods. Scattered showers are likely on the windward sides of mountainous islands, and clouds are often aligned in bands parallel to the wind direction.

(iii) The South Pacific convergence zone (SPCZ). The SPCZ is an area between the south-easterly trade winds and the current which originates in the semi-permanent anticyclones of the South-east Pacific. Part of the current flows as a north-easterly on the northern side of the SPCZ. Western Samoa's climate is greatly influenced by the position of the SPCZ, which varies both in its intensity and location. The SPCZ is frequently continuous with mid-latitude frontal bands.

During the Southern Hemisphere summer (December to February) the SPCZ usually lies between Samoa and Fiji (Fig. 3). In the winter (June to August) it is normally to the north-east of Samoa (Fig 3), often weak and sometimes does not exist. In this situation, a broad undisturbed east to south-east flow prevails over the island group (Steiner, 1980). The SPCZ is associated with a trough of low pressure in the mean sea level pressure pattern. The pressure often falls in areas around the SPCZ so that a closed isobar depression develops. When this occurs the SPCZ usually expands in width and becomes very active (Steiner, 1980). When situated over Western Samoa, it brings unsettled weather with rain or showers.

(iv) Effect of the Southern Oscillation on the SPCZ. The Southern Oscillation was discovered by British climatologist Sir Gilbert Walker, in 1932. He noticed that when surface pressures were unusually high in the Indonesian region, they were correspondingly low in the South Pacific, and vice versa (Ward, 1983). The Southern Oscillation Index, (SOI), was defined by Trenberth (1976) as the normalised pressure difference between Tahiti and Darwin. When the SOI is negative, the position of the SPCZ is further north of Western Samoa than is usual, and there is a decrease in the

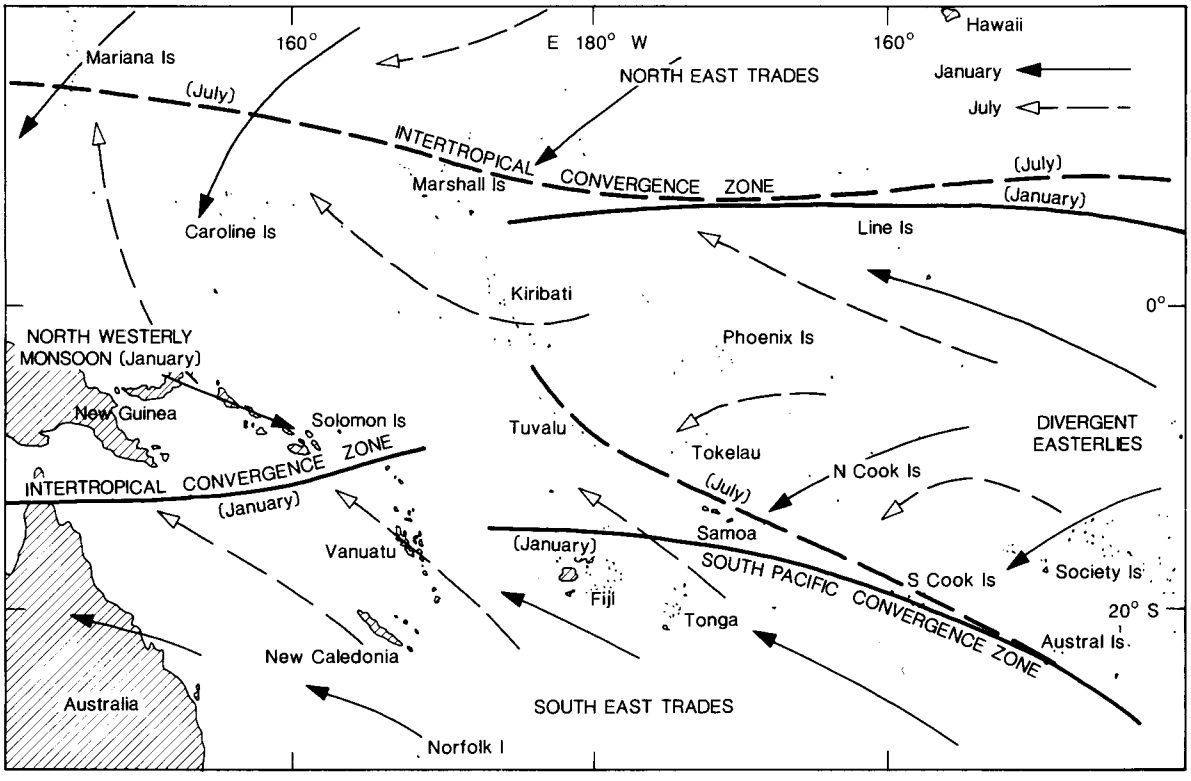

Figure 3 Typical Southern hemisphere summer (January) and winter (July) circulation of the South-west Pacific Ocean (from Steiner, 1980)

rainfall. When the SOI is positive the SPCZ is often over the island group, and heavier and more prolonged periods of rainfall are likely to occur.

3 TROPICAL CYCLONES

Tropical cyclones are classified in terms of the maximum sustained wind strength in the cyclonic circulation. In the Pacific they usually have a diameter of 500-900 km, and a central mean sea level pressure of 980-990 hPa. When the mean speeds are from 63-87 km/hr*, the circulations are classified as gales. Storms have a mean speed of 88-117 km/hr, and anything over 117 km/hr is described as a hurricane.

* one kilometre per hour (km/hr) is equal to 0.54 knots.

Conditions are most favourable for the development of tropical cyclones between November and April. In these months the convergence zones are active, and warm, moist air ascends over ocean surfaces. Sea surface temperatures are at least 27°C. Cyclones usually form between latitudes 10° and 15°S.

Of the many minor depressions which develop over the tropical ocean, only a few develop into major cyclonic storms or hurricanes. The frequency of occurrence (1941 to 1978) in the Western Samoa region, of a severe tropical storm ie. with a sustained wind speed of over 88 km/hr, was approximately one in every ten years (Kerr, 1976, Revell, 1981).

In some tropical cyclones the seas and the resultant danger to shipping, especially in the anchorage off Apia, are more serious than the winds. This applies to the historic storm of 16 March 1889, in which three American warships were lost off Apia. The episode is described in some detail by R.L. Stevenson in 'The Hurricane,' part of 'A Footnote to History' in 'Vailima Papers'.

The frequency of destructive storms is less than in Fiji and Rarotonga because many are not yet fully developed in Samoa's lower latitudes. One of the most severe tropical cyclones during the period November 1939 to April 1969 occurred in January 1966. At 1 a.m.* on 29 January the storm was centred about 100 km south-west of Wallis Island. In the next 24 hours it moved eastwards, passing to the south of Western Samoa. The maximum sustained wind speed was 111 km/hr, recorded at Mulinu'u near Apia, with a peak gust of 152 km/hr from 310 at 8 p.m. Gale force winds were experienced at Apia from 3 p.m. on the 29th to 3 a.m. on the 30th. The lowest pressure recorded at Apia was 987 hPa. Wind strengths no doubt varied with exposure, and hurricane force winds were probably experienced in other parts of the islands. The damage caused was severe, and the banana industry was temporarily wiped out. There was a very serious loss in copra, cocoa and breadfruit production. Ten people were killed, mostly by falling trees, and the total cost of the damage was estimated to be NZ$6 million. In Apia 222 millimetres of rain fell in the 48 hours to 9 a.m., on the 30th.

* Times noted in the text are Local Standard Time in Western Samoa. Western Samoa is 23 hours behind New Zealand Standard Time. i.e. 1 p.m. LST 29 Jan = midday NZST 30 Jan = midnight GMT 29 Jan.

4 CLIMATIC ELEMENTS

Wind

Regular observations of both wind speed and direction are made daily at 9 a.m. at Apia, Asau, Faleolo Airport, Alafua, Nafanua, Avele Farm and Afiamalu. Observations were made at Togitigiga B. from 1973 to 1977. A Munro anemometer and anemograph are situated at Faleolo Airport, and a Dines pressure tube anemometer at Apia. These instrument records are the most reliable sources of wind data. All of the other observations are estimates; the wind speed being based on the subjective Beaufort scale of wind force.

The exposure of most of the sites is good (see Table 1 for details). The surface wind flow over the islands is predominantly between north-east and south-east. Winds from this sector have a frequency (at 9 a.m.), ranging from 45 to 75 percent. North-westerlies and south-westerlies are infrequent, occurring only 5 percent of the time.

The northern sides of the islands are sheltered by hills from winds from the southern quadrant, so the frequency of southerlies is lower than on the southern sides of the islands. At Afiamalu and Nafanua the exposure may be affected somewhat by trees to the north-west and to the south.

The prevailing low level easterlies usually extend to between 1,800 and 3,000 m above mean sea level throughout the year, with frequencies of 55 percent at 450 m, 47 percent at 900 m, and 34 percent at 1,800 m.

Wind and the SOI. The SPCZ is located further to the south than usual when the averaged SOI for the year is positive. This means that the frequency of winds from between north and north-east is likely to be greater than usual. It was noted in a recent study (Saifaleupolu,1985) that winds from west through north to east were more frequent than usual at 1.5 km above mean sea level, and that winds from east through south to west were more frequent than usual at 12 km, when the SOI was positive.

There was a complete reversal, with winds from east through south to west being more frequent than usual at 1.5 km, with a negative SOI. Analysis of surface wind direction at Apia and Faleolo for the period 1969 to 1983 showed that the annual frequency of winds between north-east and south-east and the SOI had correlations of 0.66 and 0.64 respectively, being significant at the 99 percent level. This means that winds are more frequent from these directions when the mean annual value of the SOI is higher than usual. Analysis of annual surface wind speed anomalies and the SOI (Saifaleupolu, 1985) from 1941-84 showed that there was only a very weak correlation at Apia of 0.13 .

Seasonal variation of wind. Seasonal differences are governed mainly by the position of the SPCZ relative to Western Samoa. During the wetter part of the year the SPCZ is located to the south of Samoa, and the mean wind flow at the surface is easterly. Winds from west to north-west have a low frequency throughout the year, but occur more often in these months than during the drier part of the year.

Table 2. Mean monthly wind frequencies (percent) in Western Samoa

Dry = April to September
Wet = October to March

Asau
1971-82, ht. 4 m
(2646 observations at 9 a.m.)

direction	wet	dry	year
N 340-020	5	3	4
NE 030-060	7	9	8
E 070-110	73	73	73
SE 120-150	2	2	2
S 160-200	1	1	1
SW 210-240	0	0	0
W 250-290	3	3	3
NW 300-330	3	2	3
Calm	6	7	6
mean speed (km/hr) (24 hours, 1979-83)			9

Faleolo Airport
1971-83, ht. 4 m
(3954 observations at 9 a.m.

direction	wet	dry	year
N 340-020	13	4	8
NE 030-060	25	13	19
E 070-110	26	31	28
SE 120-150	4	7	6
S 160-200	2	2	2
SW 210-240	3	1	2
W 250-290	2	1	2
NW 300-330	4	1	3
Calm	21	40	30
mean speed (km/hr) (24 hours, 1976-78)			9

Afiamalu
1971-83, ht. 706 m
(2646 observations at 9 a.m.)

direction	wet	dry	year
N 340-020	8	4	6
NE 030-060	19	14	16
E 070-110	28	35	32
SE 120-150	3	4	4
S 160-200	2	3	2
SW 210-240	1	1	1
W 250-290	2	0	1
NW 300-330	3	1	2
Calm	34	38	36
mean speed (km/hr) 24 hours (1979-83)			11

Togitigiga B.
1973-77, ht. 148 m
(1444 observations at 9 a.m.)

direction	wet	dry	year
N 340-020	6	10	8
NE 030-060	12	14	13
E 070-110	37	38	37
SE 120-150	15	11	13
S 160-200	7	10	8
SW 210-240	2	2	2
W 250-290	4	1	3
NW 300-330	3	2	3
Calm	14	12	13

Apia
1979-83, ht. 2m
(34360 observations, 24 hours)

direction	wet	dry	year	mean speeds (km/hr) wet	dry	year
N 340-020	4	3	31	11	9	9
NE 030-060	9	6	7	13	15	15
E 070-110	24	32	28	15	20	19
SE 120-150	12	21	17	7	9	9
S 160-200	9	18	14	4	4	4
SW 210-240	4	4	4	6	4	6
W 250-290	3	1	2	2	9	6
NW 300-330	4	2	3	13	7	11
Calm	31	13	22			
mean speed (km/hr)	7	11	9			

Reports from ships in the region 12-15}S,170-174}W,
1951-80, (2644 observations, 24 hours)

direction	wet	dry	year	mean speeds (km/hr) wet	dry	year
N 340-020	10	3	6	22	15	19
NE 030-060	13	9	11	19	17	19
E 070-110	32	41	36	20	24	22
SE 120-150	21	33	27	24	26	24
S 160-200	5	6	6	17	20	19
SW 210-240	2	1	1	13	19	17
W 250-290	5	2	4	26	15	20
NW 300-330	9	3	6	24	19	22
Calm	3	2	3			
mean speed (km/hr)	20	22	22			

At Faleolo, which is one of the most exposed sites, there is a noticeable seasonal variation in surface wind direction. Northerlies are almost three times as frequent between October and March, and north-easterlies are twice as frequent than during the drier part of the year (Table 2). At Apia, which also has good exposure, the seasonal differences in surface wind direction are also noticeable, although northerly and north-easterly winds are less frequent than at Faleolo.

During the dry season winds on Savai'i and Upolu blow from between east and south-east, south-easterlies being more frequent on the southern coasts because of the greater exposure there. The only site on the southern side of Western Samoa for which records of wind direction are

available is at Togitigiga. Observations cover a period of just four years. If there is any explanation for the differences in wind frequencies and their variability throughout the year over the sea and on the southern coast, it could be due to local wind flows, and/or the rather short period of observations at Togitigiga.

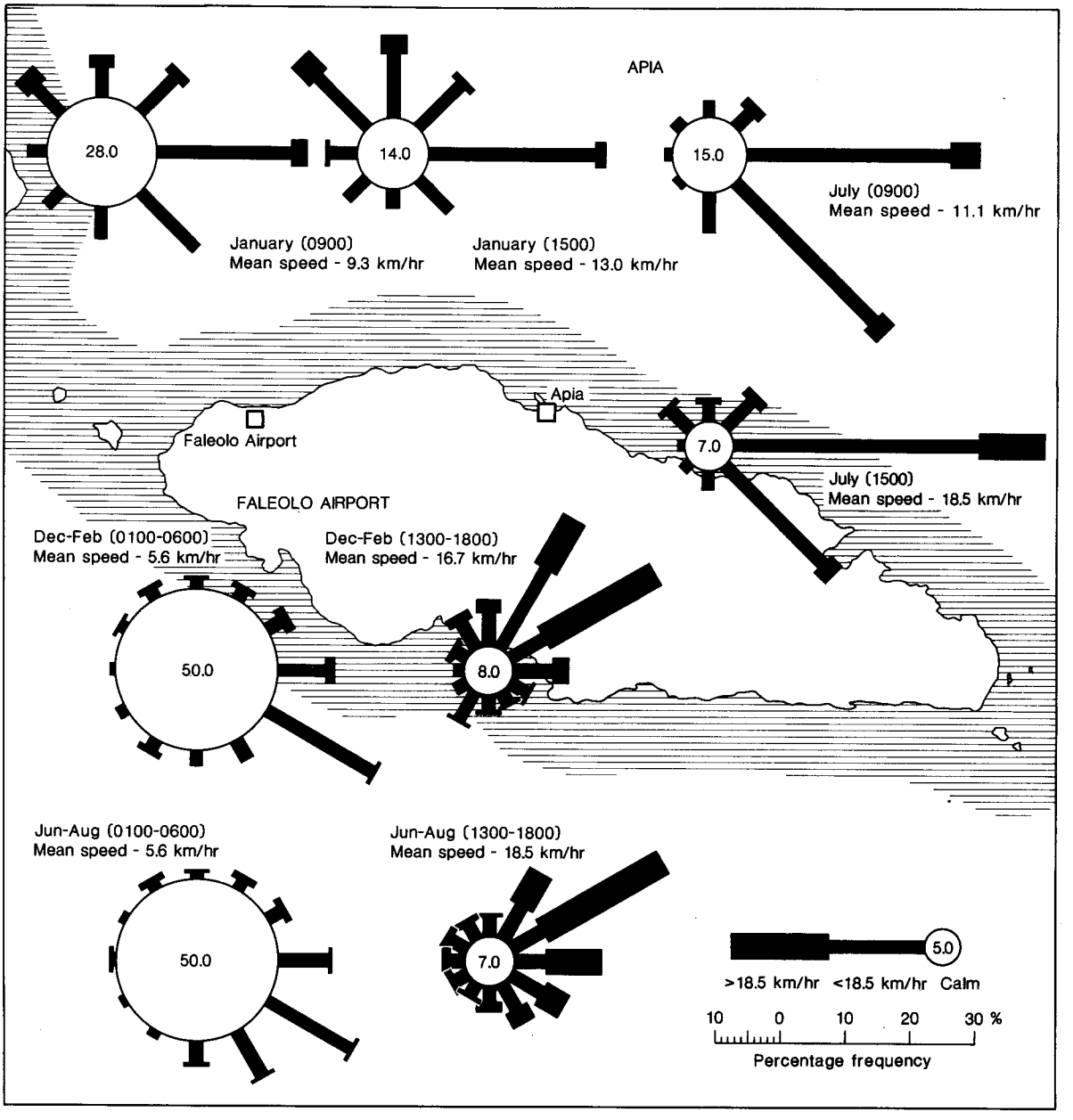

Figure 4 Diurnal variation of wind at Faleolo Airport (1976-77) and Apia (1979).

Diurnal variation of wind. As Savai'i and Upolu are large islands, surface heating influences the wind direction and speed during the day. With diurnal heating there is usually a light sea breeze. This causes the northern coasts to have a larger frequency of north-easterlies during the day time. For example at Faleolo Airport (Fig. 4), between 11 a.m. and 4 p.m. the wind is most frequently from the north-east with an average speed of 18.5 km/hr. North-west and north-easterlies are more common during the daylight hours than at night. On the southern coasts the sea breeze effect results in a higher frequency of south-easterlies than elsewhere. (Steiner,1980). A light south-easterly land breeze often prevails during the night on the northern side of the islands (and north-easterly on the southern side). This is noticeable at Apia (Fig. 4). At Faleolo Airport a light east to south-easterly breeze prevails on most nights. There is a large diurnal variation of wind speed in Western Samoa, it being about 100 percent of the mean daily wind speed at both Apia and Faleolo. The mean speed at Apia ranges from 4 to 6 km/hr

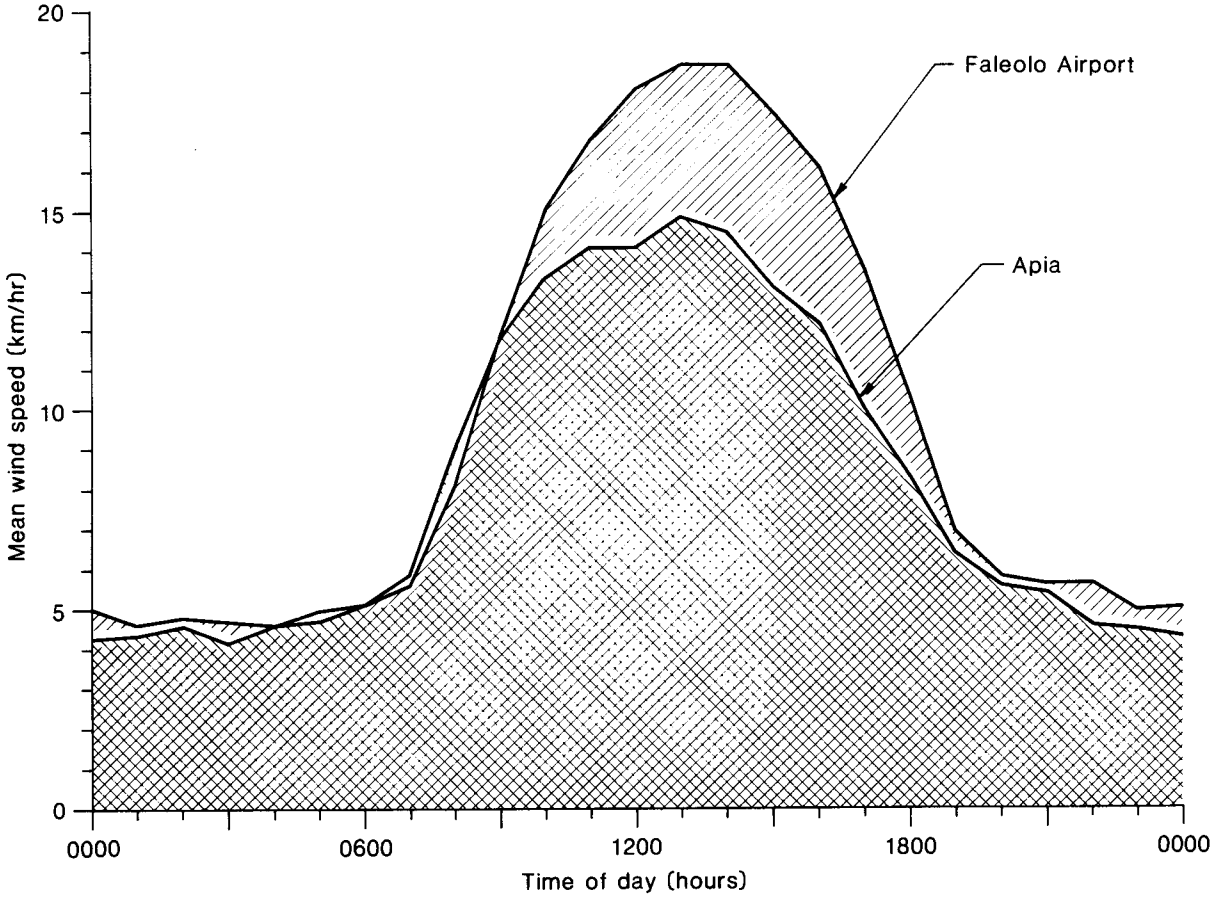

Figure 5 Mean wind speed (km/hr) at Apia, (1982) and Faleolo Airport, (1976-77).

in the early hours of the morning (Fig. 5) to 15 km/hr in the afternoon. The frequency of calms is large at night (Table 3): 55 percent at 1 a.m. (LST). Wind speeds exceed 19 km/hr at Faleolo Airport between 5 p.m. and 4 a.m., on average, for only 6 percent of the time.

Table 3 Diurnal variation of wind speed (percent) at Faleolo Airport (1976-77)

	calm	1-10	11-20	21-37	38-55	56-75	mean speed (km/hr)
Night	54	27	15	4	0	0	6
Morning	30	25	25	19	1	0	11
Afternoon	9	18	32	40	1	0	19
Evening	43	31	19	7	0	0	9
Average	33	25	23	18	1	0	11

Night = 0100-0600 LST Afternoon = 1300-1800 LST
Morning = 0700-1200 LST Evening = 1900-2400 LST

Mean speeds. Cup anemometers have been installed at a number of sites in Western Samoa, but the records generally cover short periods. Mean wind speeds vary from 7 to 19 km/hr. The mean strength of the wind is only

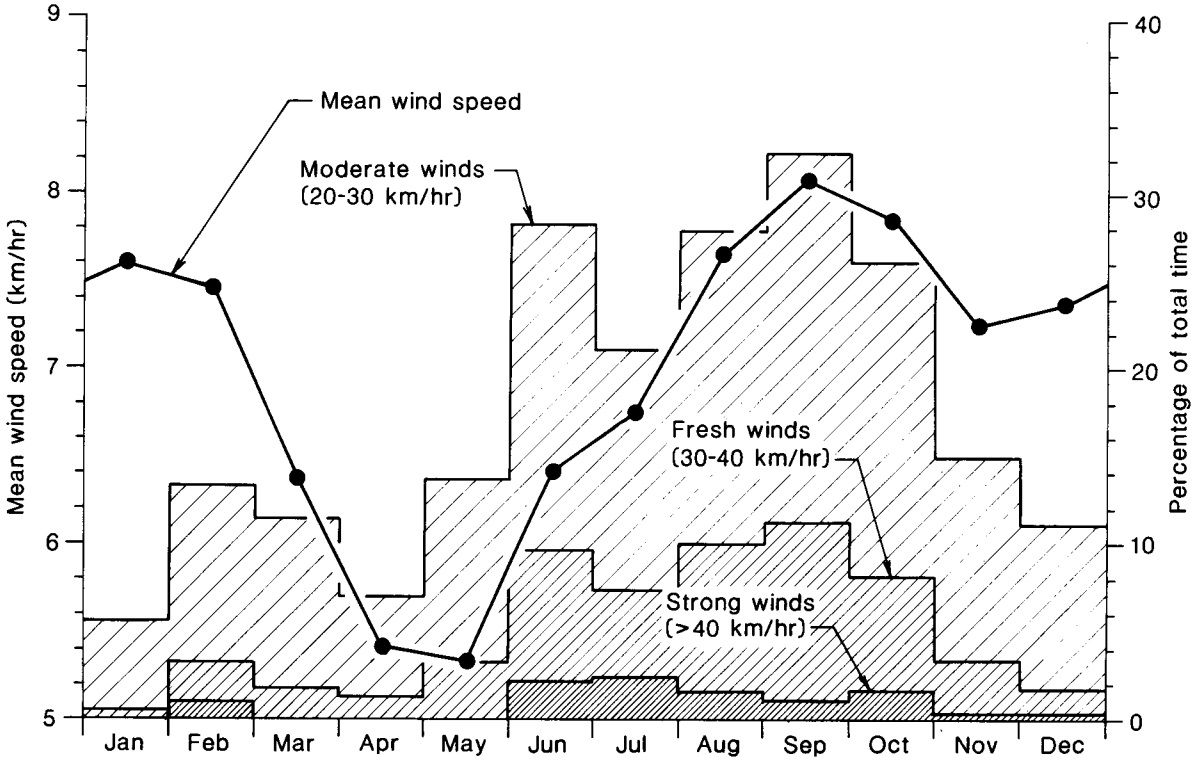

Figure 6. Monthly variation of wind speed (km/hr), Apia (1979-83).

slightly greater at Afiamalu (706 m above msl) than at lower sites. Mean wind speeds at Apia (Fig. 6) are slightly higher between June and October than in other months, and are lower from March to May. Strong winds (greater than 40 km/hr) from between south-west and south-east are uncommon on the northern side of the islands, mainly due to the sheltering by the hills in that sector. Gales are infrequent, even at higher altitudes such as Afiamalu. Most gales arise from cyclonic activity and are of short duration, occurring on average only once a year at Apia.

Wind Energy. Because the mean wind speeds are low, power generation from the wind is not viable in Western Samoa. The annual average wind power density for most coastal areas in Western Samoa is approximately 50 to 100 Watts per square metre. This figure is much higher at sea, averaging 250 to 300 Watts per square metre, based on wind data from ships in the region 12-15^{o}S, 170-174^{o}W.

Rainfall.

Rainfall is probably the most important factor influencing agriculture, and it has a marked seasonal variation (Jackson, 1977). At certain times of the year some areas have excessive rainfall leading to high surface runoff and leaching in soils. Intensities tend to be high and rainfall is often localised, sometimes causing flooding in low lying areas. Most of the tropical rain results from convection in cumulus clouds. There are no records of hail having occurred in Western Samoa.

Annual and seasonal rainfall. Western Samoa lies within a broad region of high annual rainfall (3000-3500 mm) in the South Pacific ocean. This zone extends from Samoa to the Solomon Islands and is closely associated with the SPCZ.

Western Samoa's rainfall is greatly influenced by the orography, as the normal increase in rainfall with height is modified in elevated areas which are exposed to the prevailing winds. This is apparent at Lemafa in the north-east of Upolu. Lemafa is situated at the top of a steep gully, 325 m above sea level. The prevailing north-easterly winds are often forced up the gully, resulting in high intensity rainfalls and large annual totals.

Rainfall has been measured at a large number of sites throughout Western Samoa, many since the early 1970's. Rainfall statistics from 23 of these sites have been selected for use in this climatology because of the length and reliability of the data record. The mean January, July and annual rainfalls (Figs. 7, 8 and 9), have been calculated from statistics from those stations which have reliable records for at least five years, and by an intercomparison with Apia's rainfall record from 1951 to 1980, and other nearby stations.

There are few rainfall sites in the highlands of Savai'i and the rainfall for this region is only estimated. Annual rainfall ranges from 2100 to 2300 mm in the north-western lowland regions of both islands, to over 4000 mm per annum (Fig. 8) over the eastern half of Upolu island, which is most exposed to the prevailing winds. Rainfall for the highland region of Savai'i Island has been estimated using a regression, based on rainfall statistics for fifteen stations on Upolu Island. These give a

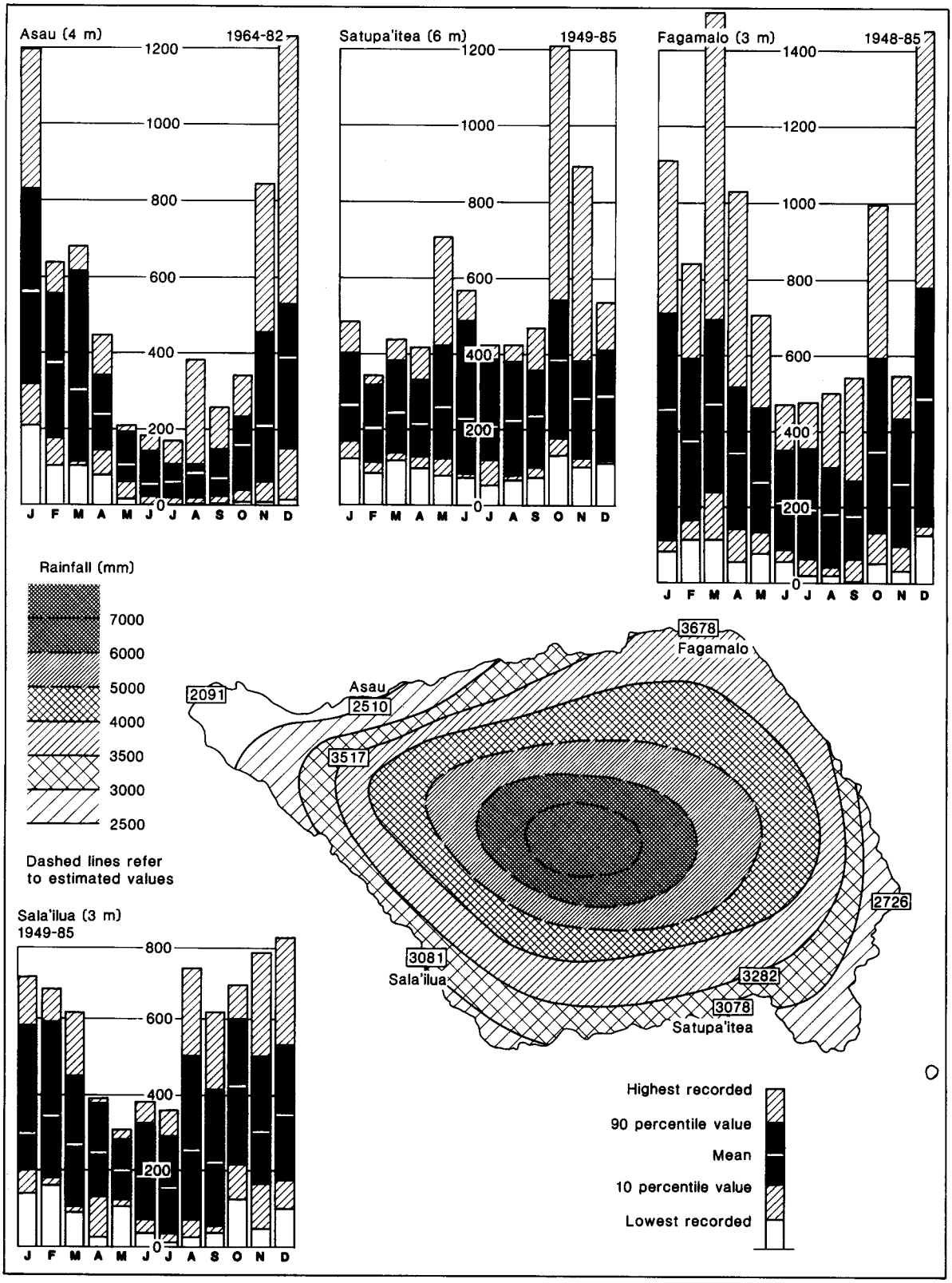

Figure 7. Mean annual rainfall (mm) over Savai'i (1951-80) and the monthly variation of rainfall at selected stations.

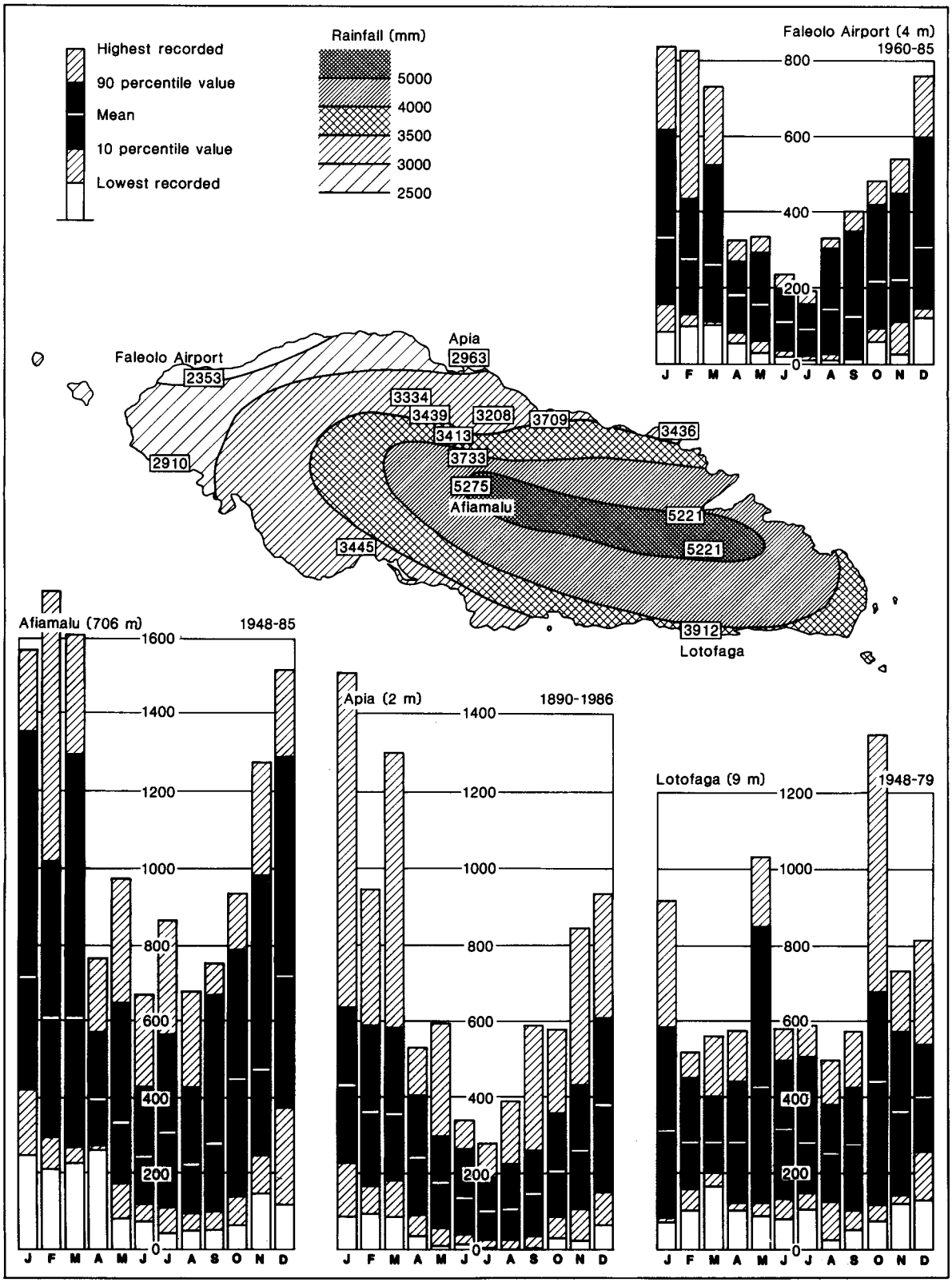

Figure 8. Mean annual rainfall (mm) over Upolu (1951-80) and the monthly variation of rainfall at selected stations.

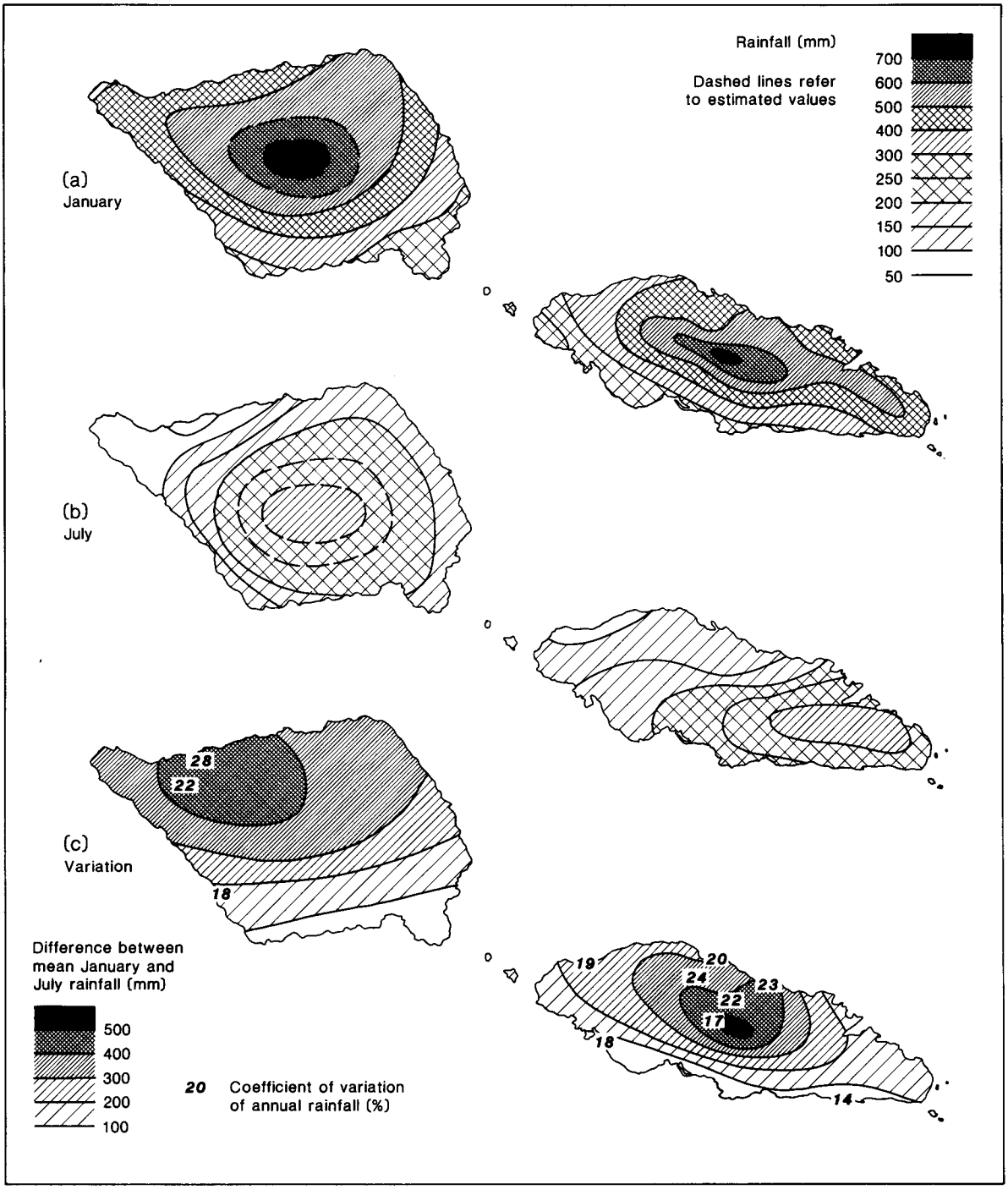

Figure 9. Mean annual rainfall (mm) for (a) January, (b) July and (c) the difference between January and July rainfall over Western Samoa.

mean increase in total annual rainfall of approximately 300 mm per 100 m in height above sea level, but this may vary considerably in different parts of the islands. The increase in amount of rainfall with altitude is less in the drier months than the wet months. Annual rainfall is highest along the central ridge of Upolu Island (over 5000 mm) and in the centre of Savai'i Island (approximately 7000 mm). The lower annual rainfall in the north-west of both islands is due to the sheltering by the mountainous

Most of the annual rainfall occurs from October to March. North-easterly winds are more prevalent then, and tend to force the warm moist air up the northern sides of the hills resulting in higher rainfalls in the north. (Fig. 9a).

In Savai'i, approximately 70 to 75 percent of the annual rainfall is received in north-western regions from October to March; in the south 55 to 65 percent, and in the north-east 65 to 70 percent. In Upolu the north-western regions receive approximately 70 percent, and the north-east 55 percent of their total annual rainfall from October to March. In the south of the island there is little contrast between each season and the rainfall from October to March is only 50 to 55 percent of the annual total.

January is normally the wettest month of the year, except for stations on the southern side of both islands, and those east of Piula. In these areas monthly rainfall totals are generally highest during October and November.

The dry season (April to September) is almost the same as the period when ship's reports show the greater predominence of east to south-easterly winds (May to October). During this time of year the north-western regions of the islands are sheltered and rainfall there is considerably lower (Fig. 9c) than that between October and May. The mean January rainfall at Asau meteorological station is 459 mm, and in July it is only 43 mm. July is normally the driest month of the year. Table 4 lists normal monthly and annual rainfall for various regions of Samoa.

Variation of rainfall. Rainfall variability (or coefficient of variation, C.V.) is defined as the ratio of the standard deviation to the annual mean. It is usually expressed as a percentage. Substantial rainfall can be expected in all years and annual variability is small, ranging from approximately 15 percent in the south and east of both islands, to 20 to 25 percent in the northern regions near the coast. Figure 9(c) shows the annual C.V. of rainfall, together with the difference between the mean January and July rainfall over Western Samoa.

Seasonal variability is high on the northern side of both islands. Figures 7 and 8 show monthly variation of rainfall in various parts of Western Samoa, together with extreme values. In the south of Savai'i and Upolu there is little or no seasonal variation.

Periods of low rainfall. A very dry spell may be defined as a period of more than fourteen consecutive days without rain. A dry spell is a period of more than fourteen days with less than 1mm of rain on every day. Long periods of dry weather seldom occur in Western Samoa. The longest periods of very dry conditions occur in the north and north-western lowlands, and the coastal regions of the islands. The longest very dry spell was 38 days at Asau, in 1975. Table 5 lists the duration of very dry and dry spells for various places. Periods of drought are seldom likely to occur in the south-eastern regions of Upolu.

Table 4. Normal monthly and annual rainfall, mm (1951-80)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
North-west Savai'i													
Faleolupo	392	231	306	159	88	69	62	90	63	177	206	248	2091
Asau	459	355	373	219	85	71	43	92	55	154	197	407	2510
Asau Forest	518	427	486	472	133	100	86	111	75	226	497	386	3517
North-east Savai'i													
Fagamalo	521	376	428	279	238	224	164	167	189	321	317	454	3678
Tuasivi	294	229	290	216	191	137	152	149	176	274	319	299	2726
South-west Savai'i													
Salailua	316	300	237	247	173	166	146	220	234	394	374	274	3081
South-east Savai'i													
Palauli	279	206	236	206	252	230	220	265	318	403	379	288	3282
Satupa'itea	262	193	221	193	236	216	206	249	298	378	356	270	3078
North-west Upolu													
Faleolo	322	266	268	172	158	109	83	157	122	220	204	272	2353
Apia	410	319	376	237	166	151	122	122	163	252	275	370	2963
Nafanua	479	374	449	227	157	183	115	128	145	270	261	450	3238
Moamoa	519	370	485	275	203	137	118	146	159	274	279	474	3439
Alafua	495	410	462	269	196	150	119	145	148	247	269	424	3334
Avele Farm	457	454	465	209	223	169	116	118	161	283	333	425	3413
Alaoa	585	462	474	299	236	175	136	152	158	309	284	463	3733
Upolu Highlands													
Afiamalu	720	626	674	400	300	273	204	245	265	450	537	581	5275
North-east Upolu													
Laulii	568	427	428	244	206	228	123	177	192	320	381	415	3709
Piula	386	367	344	230	248	182	218	217	216	324	323	381	3436
Lemafa	561	401	325	294	287	325	310	348	439	621	581	523	5221
South-west Upolu													
Falelatai	246	286	371	287	278	173	131	151	143	282	294	268	2910
Sataoa	294	250	336	366	240	211	206	286	341	348	362	205	3445
South-east Upolu													
Lotofaga	314	280	276	267	386	278	255	304	417	424	389	322	3912
Vaipu	469	454	543	407	444	305	341	331	364	542	519	502	5221

Table 5. Periods of low rainfall

Station	drought		dry spell		data
period		period		period	
	days		days		
Asau	38	17/06/75-24/07/75	45	12/08/76-25/09/76	1968-82
Avele Farm	30	10/08/74-08/09/76	30	10/08/74-08/09/74	1968-77
Asau Forest	26	21/09/82-16/10/82	26	21/09/82-16/10/82	1977-82
Nafanua	25	17/07/77-10/08/77	39	17/07/77-24/08/77	1919-79
Apia	24	16/07/77-08/08/77	34	17/07/83-19/08/83	1963-84
Afiamalu	21	08/09/69-28/09/69	21	08/09/69-28/09/69	1968-81
Faleolo	20	20/07/77-08/08/77	29	22/08/77-10/09/77	1969-82
Alafua	19	09/09/69-27/09/69	19	09/09/69-27/09/69	1969-81

Raindays. The average number of raindays, with rainfalls exceeding various threshold amounts, has a similar geographical variation to that of the annual and monthly rainfalls throughout Western Samoa. The greatest number of days with rain occur in the highlands of both islands and in the east of Upolu. These regions record mean annual rainfalls in excess of 4000 mm per annum.

Table 6 lists the average number of days with rainfall of at least 0.1, 5, 40, and 60 mm for various places. On the northern side of the islands the number of raindays in January is three times that of those in July. The number of raindays per month is more evenly spread throughout the year in the south-eastern regions. Days with at least 60 mm of rain are quite common, having a frequency of about 10 to 14 days per year in most coastal areas, but considerably higher inland.

The Southern Oscillation and its effect on rainfall at Apia. When the annual rainfall departures from normal for Apia were compared with the average SOI for each year, it was found that there was a correlation between the two (Fig. 10). For the period 1951 to 1980 the correlation coeficient was 0.54 which is significant at the 99 percent level. Statistics showed that both the annual rainfall and the average SOI for the year were either both higher or both lower than normal for 22 of the years (73 percent) and both opposite for 8 years (27 percent). The regression equation for the data is $y = 17.8x + 100.7$, where x represents the average SOI for the year and y represents the percentage of normal (1951-80) of the annual rainfall. For example if the SOI is high, ie +1.0, the total rainfall for the year would be 119 percent of normal, while if it is low, ie. -1.0, the annual rainfall would be 83 percent of normal.

Extreme rainfall. The highest annual rainfall at a station with continuous reliable records was recorded at Afiamalu, and was 9359 mm in 1949 (SOI 0.2). The lowest rainfall in a year was 982 mm, recorded at Mulifanua in 1918. Other extremes are listed in Table 7.

Table 6. Raindays of at least 0.1, 5, 40 and 60 mm

Asau met.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1968-82													
0.1 mm	20	15	14	10	8	5	6	7	6	11	12	15	126
5 mm	15	11	10	7	4	3	3	4	3	7	7	11	85
40 mm	5	2	2	2	1	0	0	0	0	1	2	4	19
60 mm	3	1	1	1	0	0	0	0	0	0	1	2	9

Asau Forest	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1977-82													
0.1 mm	23	19	22	15	13	8	8	12	10	15	17	15	190
5 mm	18	12	17	9	9	3	4	7	5	10	12	10	116
40 mm	5	4	4	2	0	0	1	1	0	2	2	3	24
60 mm	3	3	2	1	0	0	0	0	0	0	1	1	11

Faleolo	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1968-82													
0.1 mm	22	18	19	16	15	13	11	11	12	17	17	19	190
5 mm	13	11	11	9	7	5	5	4	6	10	9	11	101
40 mm	3	2	2	1	1	0	0	1	1	1	1	2	15
60 mm	1	1	1	0	0	0	0	1	1	1	1	1	8

Apia	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1960-85													
0.1 mm	23	21	23	19	16	16	14	14	15	19	18	21	215
5 mm	15	12	14	9	8	7	6	5	7	9	10	13	115
40 mm	3	2	2	1	1	1	1	1	1	2	2	3	20
60 mm	1	1	1	1	0	0	0	0	1	1	1	2	9

Afiamalu	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1968-82													
0.1 mm	27	24	25	23	21	18	17	17	18	22	22	24	257
5 mm	19	16	14	15	10	7	8	8	9	12	14	16	148
40 mm	7	5	4	3	2	1	2	1	2	3	4	5	39
60 mm	3	4	2	1	1	0	1	1	1	2	3	3	22

Togitigiga B	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1970-75													
0.1 mm	25	18	23	19	25	22	21	18	20	19	22	25	249
5 mm	18	15	13	13	15	15	9	8	6	12	16	15	152
40 mm	5	2	1	3	3	3	2	2	0	2	3	2	27
60 mm	4	1	0	2	2	1	1	1	0	1	1	2	17

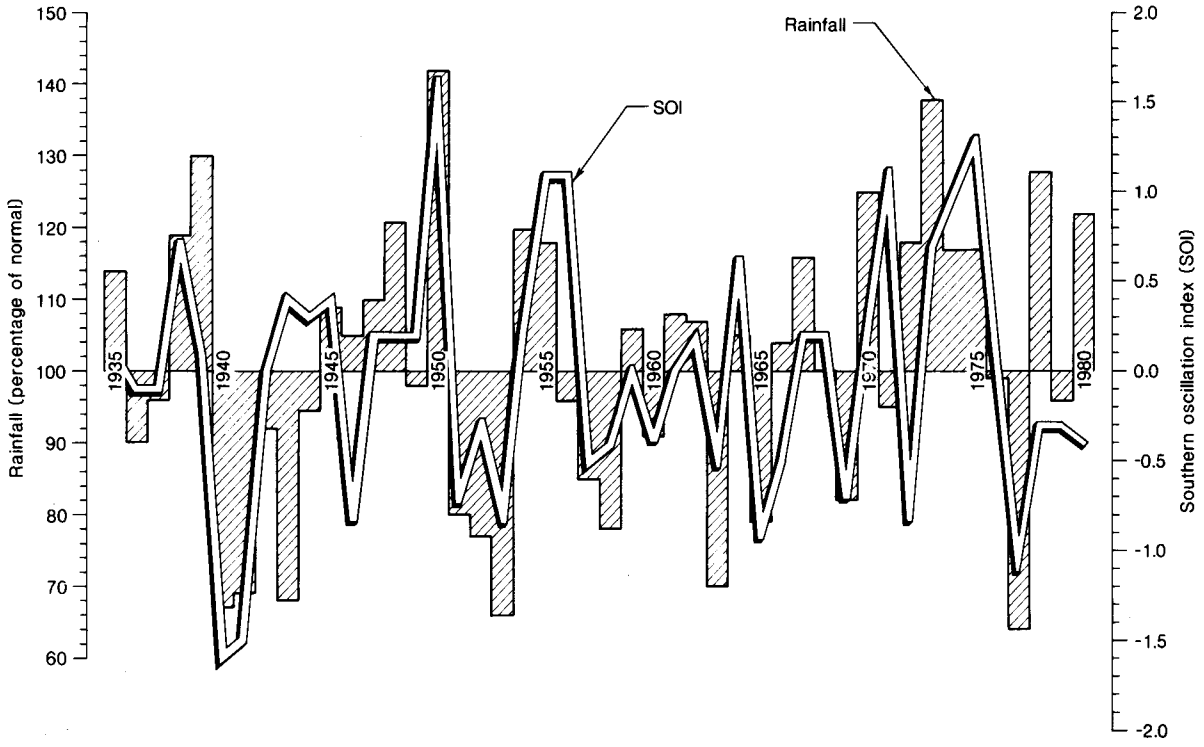

Figure 10. Annual rainfall percentage of normal, and SOI value for Apia (1935-80)

Table 7. Extreme annual rainfall (mm)

Station	maximum	/ year	minimum	/ year	data period
Faleolo Airport	3112	1972	1691	1977	1970-82
Asau	4205	1973	1939	1979	1970-79
Apia	4387	1908	1764	1905	1890-1980
Alafua	6548	1933	2513	1941	1932-80
Afiamalu	6627	1978	4334	1977	1970-80

Table 8 lists the probability of annual rainfall being within various thresholds at Apia.

Table 8. Probability (percentage) of annual rainfall at Apia, 1890-1984

Annual rainfall, mm	probability
4500	1
4000-4999	3
3500-3999	11
3000-3499	33
2500-2999	25
2000-2499	20
1500-1999	8
<1500	<<1

Short term rainfalls. As daily rainfalls are measured between fixed hours (9 a.m. - 9 a.m.) the ratio of maximum 24-hour rainfall to maximum one-day rainfall may vary from year to year. An average value of this ratio of 1.14 was used by Coulter and Hessell (1980) based on an earlier study of Robertson (1963) for New Zealand rainfall stations. Verification of this augmentation factor for Pacific Island rainfall regimes is not yet available. This is the factor by which the calculated daily rainfalls for the selected return periods of ten and fifty years were multiplied by to produce Table 9. A return period of ten years represents the average interval in years which contain 24-hour rainfalls of at least the amount shown.

Table 9. Augmented maximum recorded one-day rainfall, mean of augmented annual maximum one-day rainfalls, (mm) (9 a.m. - 9 a.m.) and return period rainfall for 10 and 50 years (Hessell and Ereckson, 1980, Coulter and Hessell, 1980)

Station Name	Period	Extreme Maximum	Mean Annual Maximum	V%	R10	R50
Faleolo Airport	1968-80	271	143	42	249	349
Apia	1967-80	270	183	21	250	313
Alafua	1968-80	464	224	53	439	641
Afiamalu	1968-80	334	234	20	319	401

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

Daily rainfall is measured at 9a.m. each day. Maximum recorded rainfall in the 24 and 48 hours to 9 a.m. for five stations are listed in Table 10. The greatest rainfalls recorded were 671 mm in the 24 hours to 9 a.m, on 16 January 1939, and 1334 mm in the 48 hours to 9 a.m, on 16 January 1939 at Tapatapao (335 m).

Table 10. Maximum (a) 1-day and (b) 2-day rainfalls, (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Faleolo Airport a.	130	238	98	148	87	86	74	223	95	116	121	168	238
(1968-82)b.	259	295	129	231	142	101	74	294	154	188	229	326	326
Asau a.	171	183	149	258	111	97	47	164	56	115	158	212	258
(1968-82)b.	303	465	221	330	126	102	57	224	63	140	188	370	465
Apia a.	237	224	192	118	150	120	76	105	177	118	186	170	237
(1960-84)b.	303	335	233	209	156	178	113	156	195	154	317	282	335
Alafua a.	331	314	407	168	130	109	71	137	151	133	305	155	407
(1968-82)b.	499	513	407	256	143	118	79	198	183	217	308	305	513
Afiamalu a.	251	277	238	240	165	209	196	108	122	201	293	228	293
(1968-82)b.	480	461	441	321	209	288	340	172	155	283	582	450	582

Table 11. Greatest daily rainfall. Apia (1890-1984, missing 1908 and 1920)

Month	mm	Year	Month	mm	Year
Jan	507	1931	Jul	77	1924
Feb	247	1923	Aug	205	1892
Mar	263	1923	Sep	177	1980
Apr	243	1913	Oct	160	1939
May	198	1937	Nov	253	1932
Jun	175	1931	Dec	260	1916

Table 12. Extreme hourly rainfall, Apia (1932-64)

Month	mm	Year	Month	mm	Year	
Jan	85	1939	Jul	46	1950	mean annual
Feb	39	1937	Aug	53	1955	maximum = 51 mm
Mar	74	1934	Sep	65	1932	standard deviation
Apr	37	1957	Oct	55	1947	= 15 mm
May	52	1961	Nov	78	1932	
Jun	46	1954	Dec	77	1949	

Maximum short term rainfalls vary in their intensity throughout the year, generally being lower between June and August and greatest from December to February. Annual maximum 24-hour rainfalls average 160 mm in coastal regions to over 200 mm in the hills. At Alafua, a 24 hour rainfall of 641 mm has a calculated return period of 50 years. Table 11 lists the greatest daily rainfalls at Apia since records began in 1890.

Due to cumulus build up, high intensity rainfalls of short duration are common in Western Samoa.

The average intensity of the rainfall at Apia for a period of two years was 9 mm per hour, with rainfall having occurred about 4 percent of the time.

Diurnal variation of rainfall at Apia. A study of diurnal rainfall on tropical Pacific Islands was made by Finkelstein (1964) for Apia Observatory. Over a fourteen year period this did not show any appreciable diurnal variation for the months May to October (Fig. 11). From November to April there was a noticable minimum which occurred between 10 a .m. and 1 p.m., and a maximum between 5 and 8 p.m., possibly due to afternoon heating causing an increase in convectional rainfall at this time of year.

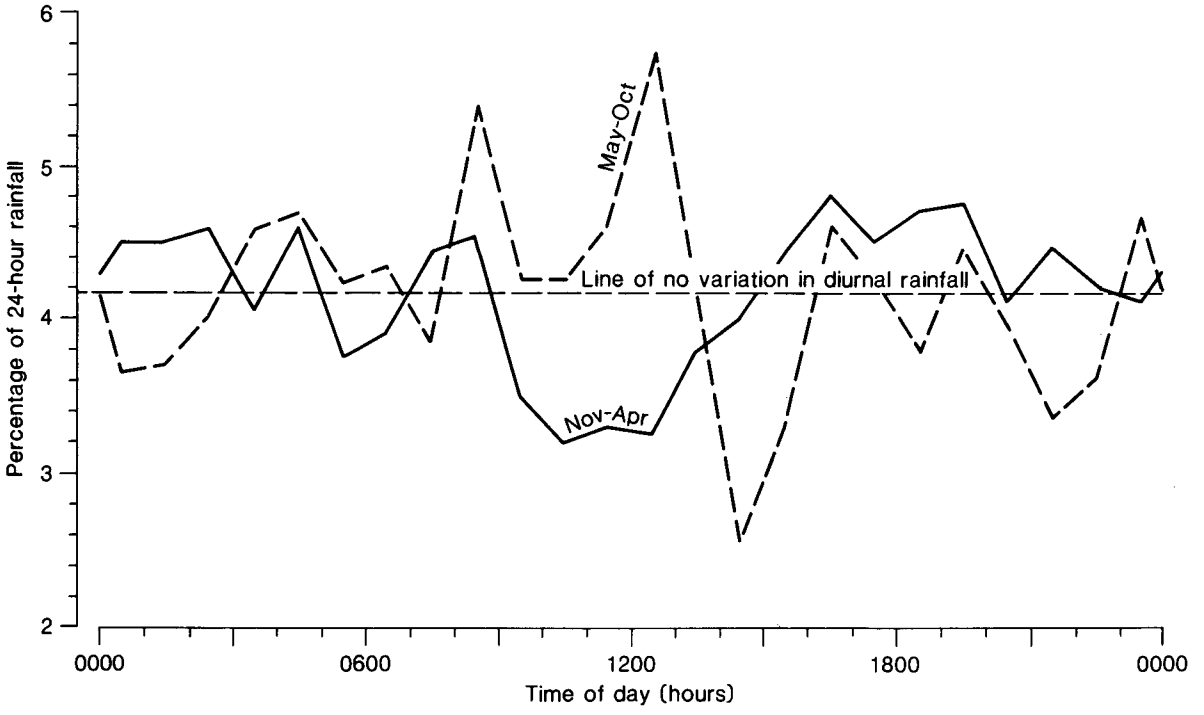

Figure 11. Diurnal variation of rainfall at Apia (from Finkelstein, 1964)

Evaporation and water balance

Evaporation. Evaporation takes place over water and land areas when soils, rocks or vegetation are wet after recent precipitation, or when ground water is close to the surface (Nieuwolt, 1977). Transpiration is the process by which water from vegetation is transferred into the atmosphere in the form of vapour (WMO, 1984). Evapotranspiration is the amount of water which is transferred from the soil to the atmosphere by evaporation and by plant transpiration (WMO, 1984). Pan evaporimeters

are located at Apia, Alafua and Afiamalu. Apia is the only site which has reliable records of pan evaporation for a ten year period. Evaporation varies only slightly during the year (Table 13). The lower elevation of the sun accounts for the minimum during June, while the higher rates of evaporation during September and October are due to higher elevation of the sun and also the higher mean wind speed. Evaporation is lower during November and December than September and October because of an increase in cloudiness during these months. Estimates of annual pan evaporation for Alafua and Afiamalu have been made based on actual values and an intercomparison with statistics from Apia.

Table 13. Raised pan evaporation, (mm), (1975-84). Correction factor to open-water is 0.73

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Apia	155	144	152	139	127	121	126	146	162	167	150	157	1746
Alafua													1450
Afiamalu													1000

Water Balance. Virtually every village has roof catchment areas and tanks to collect rainfall. Three quarters of both islands have a piped water supply, from which water is available about half the time. Water is also available from wells, stream intakes and springs (Dale, 1981).

Water balance studies give a general overview of the water conditions in an area, and summaries have been computed using daily rainfall and potential evapotranspiration for Asau, Faleolo, Apia and Afiamalu (Table 14). The values of potential evapotranspiration have been calculated using solar radiation, sunshine, temperature, wind, and vapour pressure statistics. These show that potential evapotranspiration is higher than the average monthly rainfall for six months of the the year at Asau, with soil moisture deficits of 60 to 70 mm from July to October. The lowland and coastal region of north-west Savai'i is the only area in Western Samoa with such high soil mositure deficits. Over the remainder of Savai'i and Upolu a prolonged soil moisture deficit of this nature is uncommon. In other northern lowland and coastal regions of both islands there are only one to two months when evapotranspiration exceeds the monthly rainfall. In the southern regions and the highlands a soil moisture deficit of 70 mm is rare, as average monthly rainfalls are high throughout the year (Fig. 12).

When looking at water balance statistics it must be noted that the average monthly rainfall does not take into account the variability of monthly totals from year to year. Table 14 also lists the likelihood of months with a deficit and/or runoff for soils with an available water capacity of 75, 100 and 125 mm.

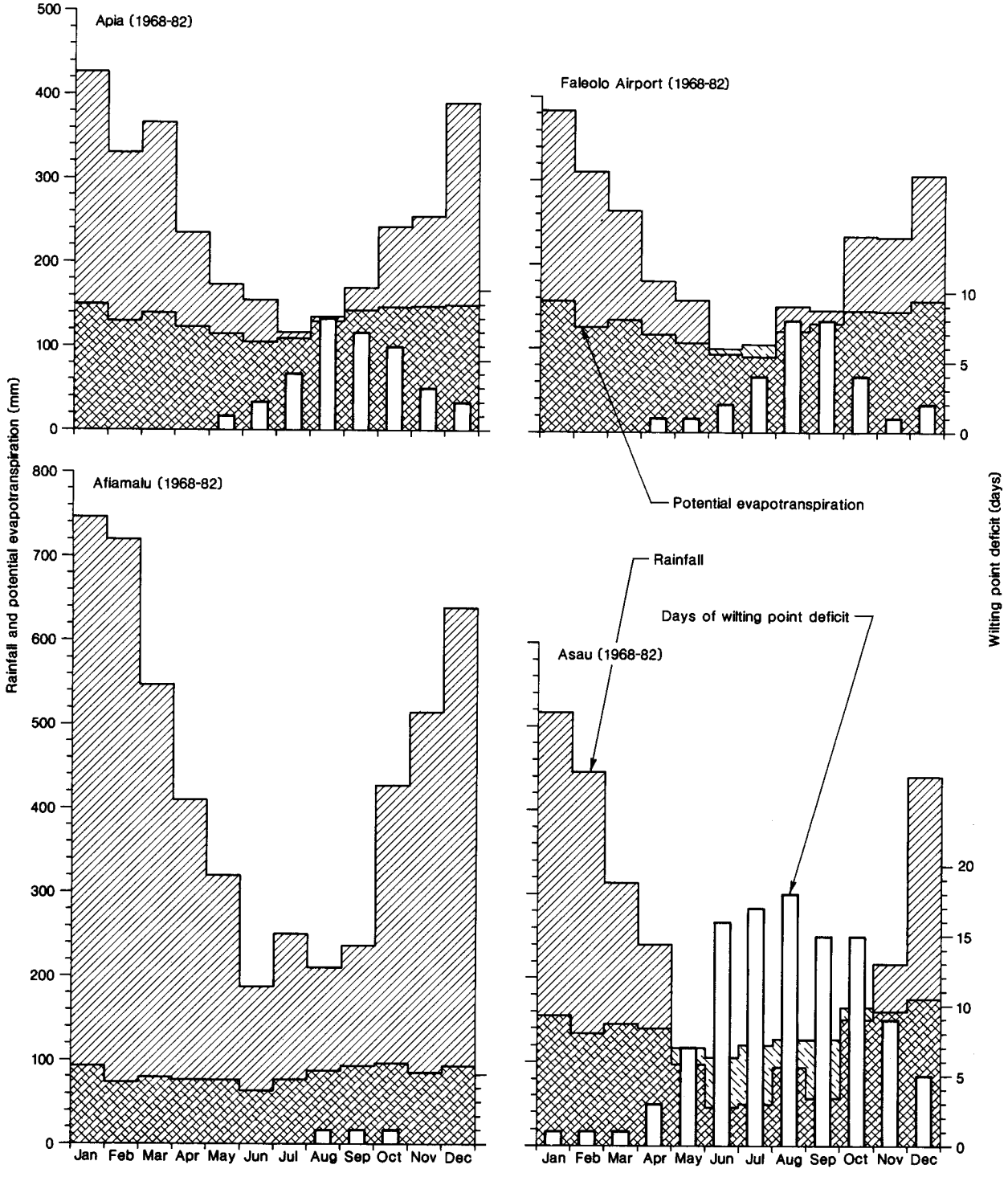

Figure 12. Water balance for soils with available water capacity of 75 mm for Apia, Faleolo Airport, Afiamalu and Asau.

Table 14. Water balance summaries for Western Samoa Available water capacity = 75, 100 and 125 mm

PE = potential evapotranspiration (mm)
RR = mean monthly rainfall (mm)
WPD = wilting point deficit (mm)
RO = runoff runoff
ND = No. days deficit
NR = No. days runoff

Asau 1968-82
Averages-millimetres/month, days/month

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
AWC = 75 mm													
PE	156	132	145	140	118	105	120	126	127	164	160	176	1669
RR	517	444	313	240	98	45	51	93	55	151	218	440	2665
WPD	4	6	5	14	22	51	61	70	59	70	45	26	433
ND	1	1	1	3	7	16	17	18	15	15	9	5	108
RO	348	326	167	128	20	6	0	21	1	31	109	269	1426
NR	8	9	6	3	1	0	0	1	0	1	3	6	38
Frequency- % of months													
WPD	33	20	45	60	60	100	100	92	100	92	75	67	100
RO	100	90	82	70	50	20	0	17	15	50	42	83	100
AWC = 100 mm													
WPD	2	1	2	7	13	40	54	70	56	69	39	23	376
ND	1	0	1	2	4	12	15	18	14	15	8	5	95
RO	338	326	161	126	15	4	0	18	0	19	104	258	1369
NR	8	9	5	3	1	0	0	0	0	1	3	6	36
Frequency- % of months													
WPD	11	20	27	20	50	70	91	92	100	92	75	58	100
RO	100	90	73	70	50	20	0	8	0	42	42	75	100
AWC = 125 mm													
WPD	2	0	0	4	3	32	50	69	60	65	32	23	340
ND	1	0	0	1	1	10	14	18	15	14	7	5	86
RO	329	326	159	123	11	3	0	19	0	9	109	249	1337
NR	8	9	5	3	1	0	0	1	0	1	3	6	37
Frequency- % of months													
WPD	11	0	0	10	20	50	80	90	91	91	55	50	100
RO	100	90	73	70	50	20	0	10	0	36	36	75	100

Faleolo Airport 1968-82
Averages - millimetres/month, days/month

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
AWC = 75 mm													
PE	156	124	133	117	106	100	105	120	130	145	144	157	1537
RR	382	311	264	180	158	93	91	155	148	233	232	308	2555
WPD	2	0	1	3	3	5	12	26	31	16	5	6	110
ND	0	0	0	1	1	2	4	8	8	4	1	2	31
RO	221	188	133	65	68	18	1	56	51	82	93	154	1130
NR	8	7	7	5	4	1	0	2	2	4	5	5	50
Frequency- % of months													
WPD	14	0	13	7	13	33	60	60	67	47	13	33	93
RO	93	100	93	87	80	33	13	53	53	60	87	87	100
AWC = 100 mm													
WPD	0	0	0	1	2	2	5	21	26	15	5	4	81
ND	0	0	0	0	1	1	2	6	7	4	1	1	23
RO	217	179	132	65	68	17	0	49	50	76	88	150	1091
NR	8	7	7	5	4	1	0	1	2	4	4	5	48
Frequency- % of months													
WPD	0	0	0	7	7	13	47	40	53	40	13	13	79
RO	93	100	93	87	80	27	0	53	47	60	80	80	100
AWC = 125 mm													
WPD	0	0	0	0	2	0	1	15	24	13	5	3	63
ND	0	0	0	0	1	0	0	5	6	3	1	1	17
RO	215	179	132	65	68	17	0	46	48	72	83	148	1073
NR	8	7	7	5	4	1	0	1	2	4	4	5	48
Frequency- % of months													
WPD	0	0	0	0	7	0	7	33	40	27	13	13	57
RO	93	100	93	87	80	27	0	40	47	53	73	80	100

Apia 1960-86
Averages - millimetres/month, days/month

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
AWC = 75 mm													
PE	151	130	139	123	114	104	110	127	142	147	148	149	1584
RR	428	331	367	236	173	156	117	135	170	242	255	390	3000
WPD	1	2	0	1	2	5	12	27	29	23	11	9	122
ND	0	0	0	0	1	2	4	8	7	6	3	2	33
RO	268	205	224	127	68	61	23	42	52	105	120	243	1538
NR	11	9	10	6	4	3	2	2	2	4	5	9	67
Frequency- % of months													
WPD	12	4	4	4	16	36	38	60	65	38	36	25	86
RO	100	100	96	84	80	72	46	56	69	62	84	83	100
AWC = 100 mm													
WPD	1	1	0	0	1	2	9	20	23	22	9	8	96
ND	0	0	0	0	0	1	3	5	6	6	2	2	25
RO	264	205	222	127	67	59	23	37	48	101	116	241	1510
NR	11	9	10	6	4	3	2	2	2	4	5	9	67
Frequency- % of months													
WPD	12	4	0	4	4	12	23	44	44	35	28	21	73
RO	100	96	96	84	80	68	46	52	56	62	76	83	100
AWC = 125 mm													
WPD	1	0	0	0	0	0	5	13	22	21	8	6	76
ND	0	0	0	0	0	0	2	4	5	5	2	2	20
RO	259	205	222	127	66	59	24	34	45	96	115	238	1490
NR	11	9	10	6	4	3	2	2	2	4	5	9	67
Frequency- % of months													
WPD	12	0	0	0	4	0	24	32	36	32	24	21	59
RO	100	96	96	84	80	68	44	44	52	60	72	79	100

Afiamalu 1968-82
Averages - millimetres/month, days/month

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
AWC = 75 mm													
PE	94	72	81	74	75	63	74	87	92	96	85	92	985
RR	747	721	547	410	321	187	250	209	237	430	514	641	5214
WPD	0	0	0	0	0	0	0	1	3	2	0	0	6
ND	0	0	0	0	0	0	0	1	1	1	0	0	3
RO	652	652	466	336	252	124	180	132	151	317	430	547	4239
NR	19	18	16	16	12	7	8	6	7	11	15	17	152
Frequency- % of months													
WPD	0	0	0	0	0	0	0	14	13	7	0	0	27
RO	100	100	100	100	100	92	100	86	80	93	100	100	100
AWC = 100 mm													
WPD	0	0	0	0	0	0	0	0	1	0	0	0	1
ND	0	0	0	0	0	0	0	0	1	0	0	0	1
RO	652	652	466	336	252	124	180	132	151	314	428	547	4234
NR	19	18	16	16	12	7	8	6	7	11	15	17	152
Frequency- % of months													
WPD	0	0	0	0	0	0	0	0	7	7	0	0	18
RO	100	100	100	100	100	92	100	86	80	93	100	100	100
AWC = 125 mm													
WPD	0	0	0	0	0	0	0	0	0	0	0	0	0
ND	0	0	0	0	0	0	0	0	0	0	0	0	0
RO	652	652	466	336	252	124	180	132	151	313	428	547	4233
NR	19	18	16	16	12	7	8	6	7	10	15	17	151
Frequency- % of months													
WPD	0	0	0	0	0	0	0	0	0	0	0	0	0
RO	100	100	100	100	100	92	100	86	80	93	100	100	100

Though the average rainfall in January and February is very high at Asau, a soil moisture deficit of 75 mm occurs in 33 percent of the time in January, and 20 percent of the time in February. These statistics show that a lack of sufficient soil moisture for crops and agriculture is not a potential problem in Western Samoa, except, at times in north-western lowland and coastal regions of Savai'i. For places like Afiamalu in the highlands there is a surplus of soil moisture throughout the year.

Sunshine

Sunshine recorders in Western Samoa. A Campbell-Stokes sunshine recorder has been in use at the Apia Observatory since 1930; recordings have also been made at both Avele Farm and Afiamalu for short periods. Sunshine statistics for Apia for the period 1961 to 1984 are listed below (Table 15).

Estimates from cloud cover. Cloud amounts are often greater in the hills than in lowland and coastal areas. It is also cloudier in those areas which are exposed to the prevailing wind. Mean monthly cloudiness has been observed at a small number of stations, mostly on the northern side of the islands, and these show that much of this region is affected by cloudy conditions with cloud amounts averaging five oktas (one okta is equivalent to a total of one eigth cloud cover) (Table 16).

Annual sunshine hours have been estimated for these stations using the mean monthly cloud amounts at 9 a.m. A comparison between the mean cloudiness at 9 a.m. and total monthly sunshine at Apia over twenty years showed that cloud cover estimates appeared to underestimate sunshine by approximately 14 percent. The estimated values (Table 17) therefore only give an indication of the annual sunshine. Where actual sunshine or solar radiation records have been available these have been used in place of mean cloudiness.

Table 15. Average monthly sunshine, Apia (1961-80)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Maximum	213	248	237	255	255	242	254	283	270	280	244	218	2508
Average	163	154	174	178	195	198	210	218	218	190	182	164	2244
Minimum	109	99	57	115	148	139	166	176	144	121	98	62	2011
Percentage of possible	43	46	48	53	57	61	62	63	63	51	50	43	53
Possible sunshine at site*	382	337	362	339	340	324	337	346	345	369	367	384	4232

* Possible sunshine at the site is calculated as the time difference between sunrise and sunset, minus 30 minutes, summed for the days in each month in the year

Table 16. Mean monthly cloudiness (oktas) at 9 a.m. in Western Samoa

Station	Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Asau	1976-82	5.8	5.6	5.3	4.4	4.5	4.3	3.7	4.2	4.9	4.6	5.0	5.2	4.8
Forest	1977-83	5.8	5.4	5.5	4.6	4.2	3.6	4.0	4.2	5.1	5.9	5.6	5.9	5.0
Faleolo	1976-83	5.8	5.8	5.6	5.3	5.0	4.5	4.5	4.6	4.7	5.2	5.4	5.7	5.2
Apia	1976-83	5.8	5.6	5.3	4.5	4.8	4.4	4.3	4.6	4.5	4.9	5.3	5.5	5.0
Afiamalu	1976-83	6.5	5.9	5.7	5.0	5.4	4.7	4.9	4.9	5.5	6.0	6.1	6.0	5.6
Viapu*	1976-83	6.4	6.3	5.9	5.9	5.5	5.5	5.4	5.5	5.5	6.2	6.1	6.5	5.9

* estimated from solar radiation

The cloudiest regions are the highlands of both islands and the south-east of Upolu, and high totals of annual sunshine probably occur in the north-western lowlands of Savai'i. July and August are generally the sunniest months of the year on the northern sides of the islands, but it is probably cloudier on the southern side of the islands during these months, as rainfall totals there are higher. There is a maximimum in mean cloudiness from December to February in the north of the islands, when north to north-eastlies are predominant. In the south of both islands October and November are probably the cloudiest months as then mean monthly rainfall totals are often highest.

Table 17. Mean annual sunshine (hours), (1961-80) in Western Samoa

Station	Annual sunshine	Percentage of total possible
Asau Met.	2330 c	55
Asau Forest	2240 c	53
Faleolo Airport	2120 c	50
Apia	2240 s	53
Avele Farm	2010 s	47
Vaipu	1770 r	42
Afiamalu	1760 r	42

c = estimates using mean cloudiness
s = " " actual sunshine
r = " " solar radiation

Diurnal variation of sunshine at Apia. Hourly statistics of sunshine for Apia in 1980 (Fig. 13) show that on average the sunniest part of the day for any time of the year occurs between

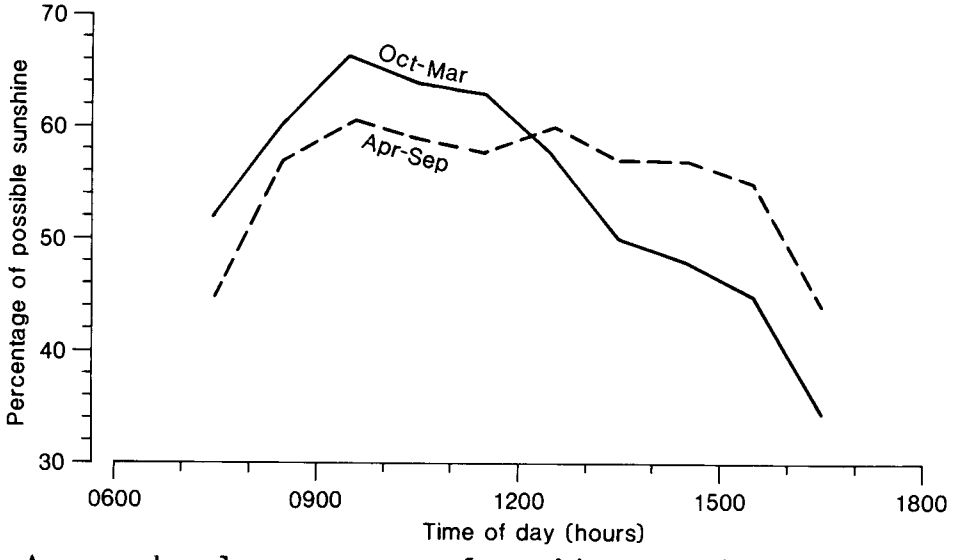

Figure 13. Average hourly percentage of sunshine at Apia, 1980

9 and 10 a.m. During the drier part of the year there is no noticable difference between the amount of sunshine in the morning and that in the afternoons. In the wetter months, when the sun reaches its highest elevation, the afternoons are cloudier, with significantly less sunshine than during the mornings. On average the cloudiest time of day during the wet season is between 4 and 5 p.m. This corresponds well with the study on diurnal variation of rainfall by Finkelstein (1964), showing a maximum during the late afternoon and early evening (refer Figure 11).

Solar Radiation

Daily global solar radiation was measured at Mulinu'u, Apia from 1941 to 1982 using an Epply Pyheliometer. There is only a small variation in the length of day from sunrise to sunset throughout the year in Western Samoa ranging from a maximum of 12 hrs 55 mins in December, to a minimum of 11 hrs 40 mins in June. This annual variation is reflected in the mean daily solar radiation, which is lowest in June and July (especially so at Vaipu, due to cloudiness from the prevailing east to south-easterlies) and greatest between September and November.

Values of mean daily global solar radiation (Table 18) are highest between September and March (the sun being directly overhead at noon during late October and in February). Global solar radiation has also been recorded at both Vaipu (1975-77) and Afiamalu (1973-77). An intercomparison of the statistics from these two sites was made with those for Apia so that long term values could be derived.

Table 18. Mean daily solar radiation (0.1 Megajoules/square metre) for Apia, Vaipu and Afiamalu (1941-77)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Apia	209	199	198	187	170	162	168	189	212	209	216	204	194
Vaipu	175	162	169	149	135	123	129	141	155	151	168	167	148
Afiamalu	157	140	145	144	135	129	138	156	165	164	153	157	152

Temperatures

In the tropics there is no cold season and sharp temperature changes do not occur, therefore, there are very small seasonal temperature differences. Because of the vast expanse of warm ocean in which Western Samoa lies, irregularities in temperature are small because the sea temperature is almost constant through-out the year. The annual range in temperature is only 1 to 2°C throughout the islands, the mean daily temperature being about 26 or 27°C at sea level and 22°C at 700 m, decreasing at a rate of approximately 6.5°C per 1000 metres. Figure 14 shows the mean daily temperature over Western Samoa. The warmest month of the year is usually February or March, and the coolest is August.

The highest recorded temperature up to December 1985 was 36.5°C, and this was recorded in December 1977 at Asau. The most reliable lowest minimum air temperature on record was 11.1°C at Afiamalu in September 1977. Cooler temperatures can be expected at higher altitudes, as the mean daily minimum temperature in July at 1800 m is estimated to be about 11°C. Temperatures above 30°C have not been recorded at Afiamalu in any month.

Diurnal Variation. The mean daily temperature range averages between 6 and 8°C in January and 7 and 9°C during July in most places, and is greatest in the north-west of Savai'i at Asau where it has a range of 9°C during January and 11°C in July. In lowland coastal areas daily minimum temperatures average 22 to 23°C, and temperatures below 18°C are rare.

Daytime maximum temperatures are high, averaging 30 to 32°C, but seldom rising above 34°C. Temperatures are lowest at about 5 a.m. and the maximum afternoon temperature is usually reached at about 1 p.m. (Fig. 15). On occasions, night-time temperatures do remain as high as 27 or 28°C.

Relative humidity

Mean values of relative humidity range from an average annual value of 75 percent at Faleolo Airport and Asau in the north-west, 80 percent in other lowland and coastal regions, and up to 90 percent in the highlands. The annual variation is small being only about 6 percent. Relative humidities are lower in August and September, and highest in January and February (Table 19). Values of relative humidity below 60 percent are rare.

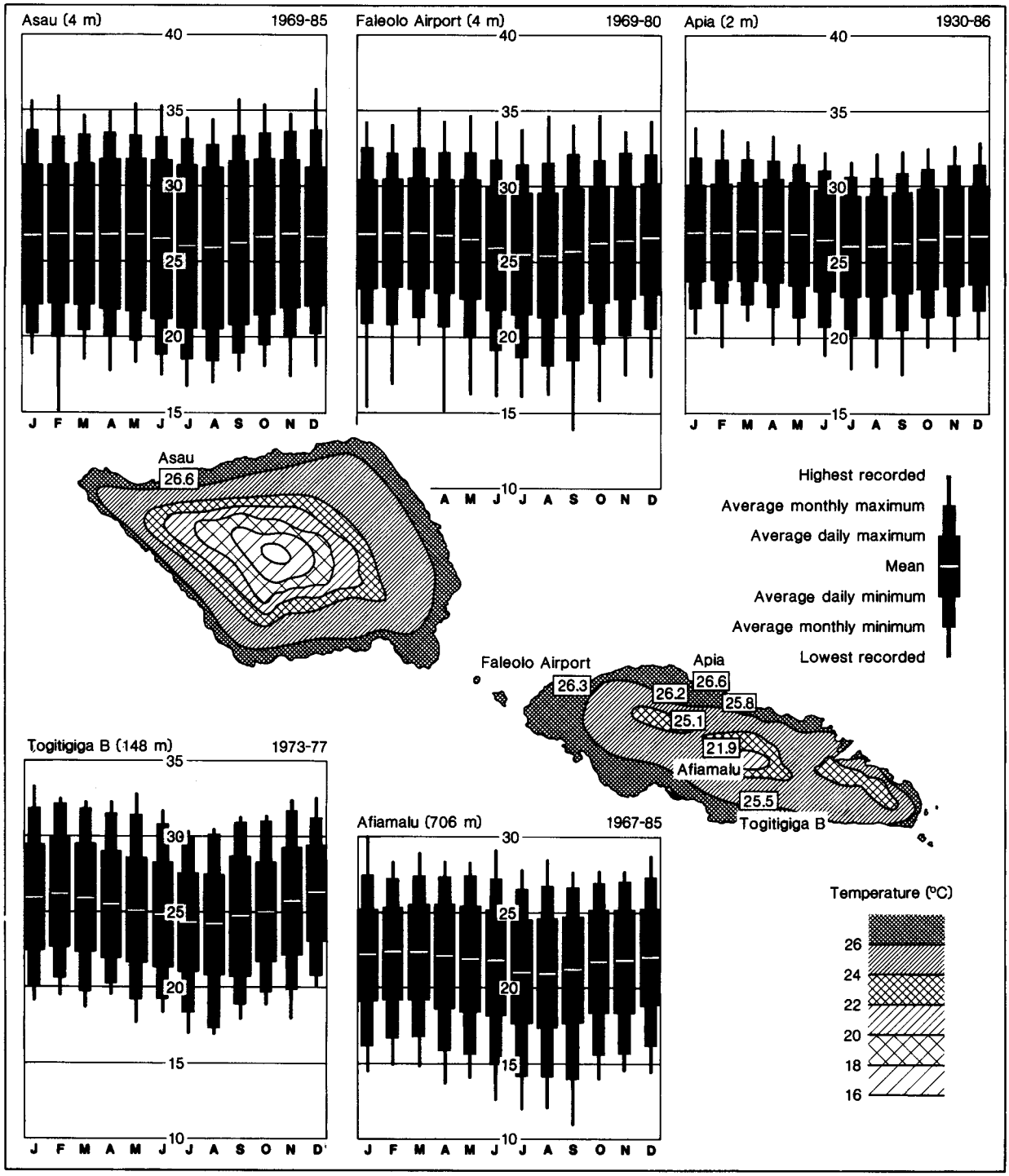

Figure 14. Mean daily temperature (^{o}C) over Western Samoa, 1951-80 and the monthly variation of temperature at selected stations.

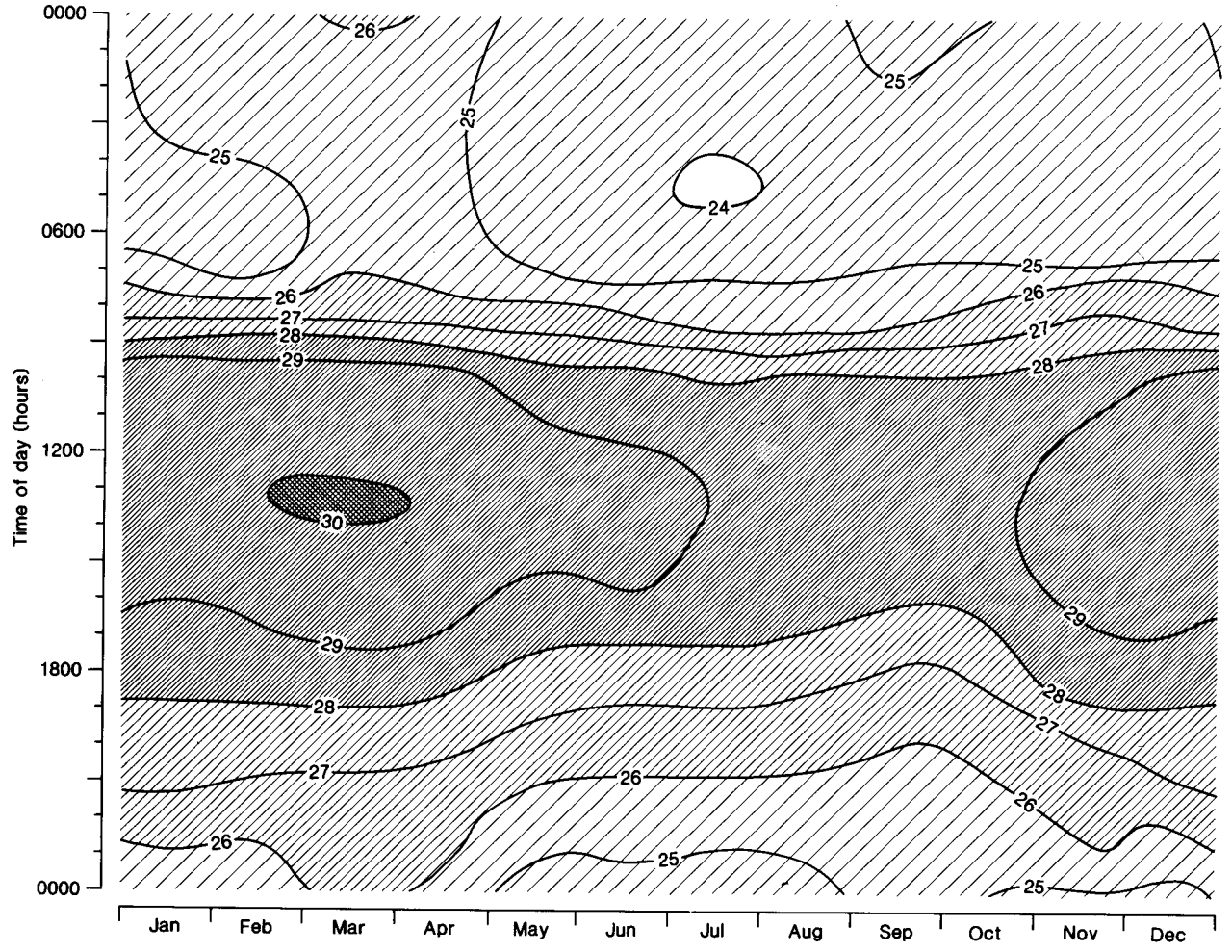

Figure 15. Seasonal and diurnal variation of temperature (^{o}C) at Apia (LST), 1980

Table 19. Mean monthly relative humidity (percent), at 9 a.m.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Faleolo	79	77	78	76	75	76	74	72	72	73	76	76	75
Asau Met.	77	75	77	75	76	77	76	75	75	74	76	76	76
Apia	81	82	81	80	80	79	78	77	76	77	78	79	79
Alafua	84	83	83	85	83	84	80	78	77	76	80	82	81
Afiamalu	92	91	91	87	87	88	88	86	87	88	90	89	89
Togitigiga*	83	82	81	81	80	79	79	78	77	78	79	80	80

* = estimated

The humidity is usually greatest just before sunrise, and lowest between 1 and 2 p.m. The average diurnal range at Apia is 15 percent throughout the year. Most nights are humid, with relative humidities over 90 percent between midnight and 6 a.m.

Temperature humidity index

The temperature humidity index (THI) gives an indication of the physiological temperature based on the actual temperature and the relative humidity, ie. it expresses thermal stress in degrees of temperature. The equation used is: THI = 0.8T + (RH.T/500), where T is the air temperature (^{o}C) and RH the relative humidity (Nieuwold, 1977).

The critical value when most people are uncomfortably hot is 26^{o}C, although in the tropics higher values may be tolerated due to more frequent exposure to thermal stress. It should be noted that the THI does not take into account the effects of air movement (which provides a decrease in discomfort) or of other parameters such as radiation and rainfall. The average annual THI for Apia and Faleolo is 25^{o}C. This rises to over 26^{o}C from 10 a.m. through to 6 p.m., (Fig. 16) making most

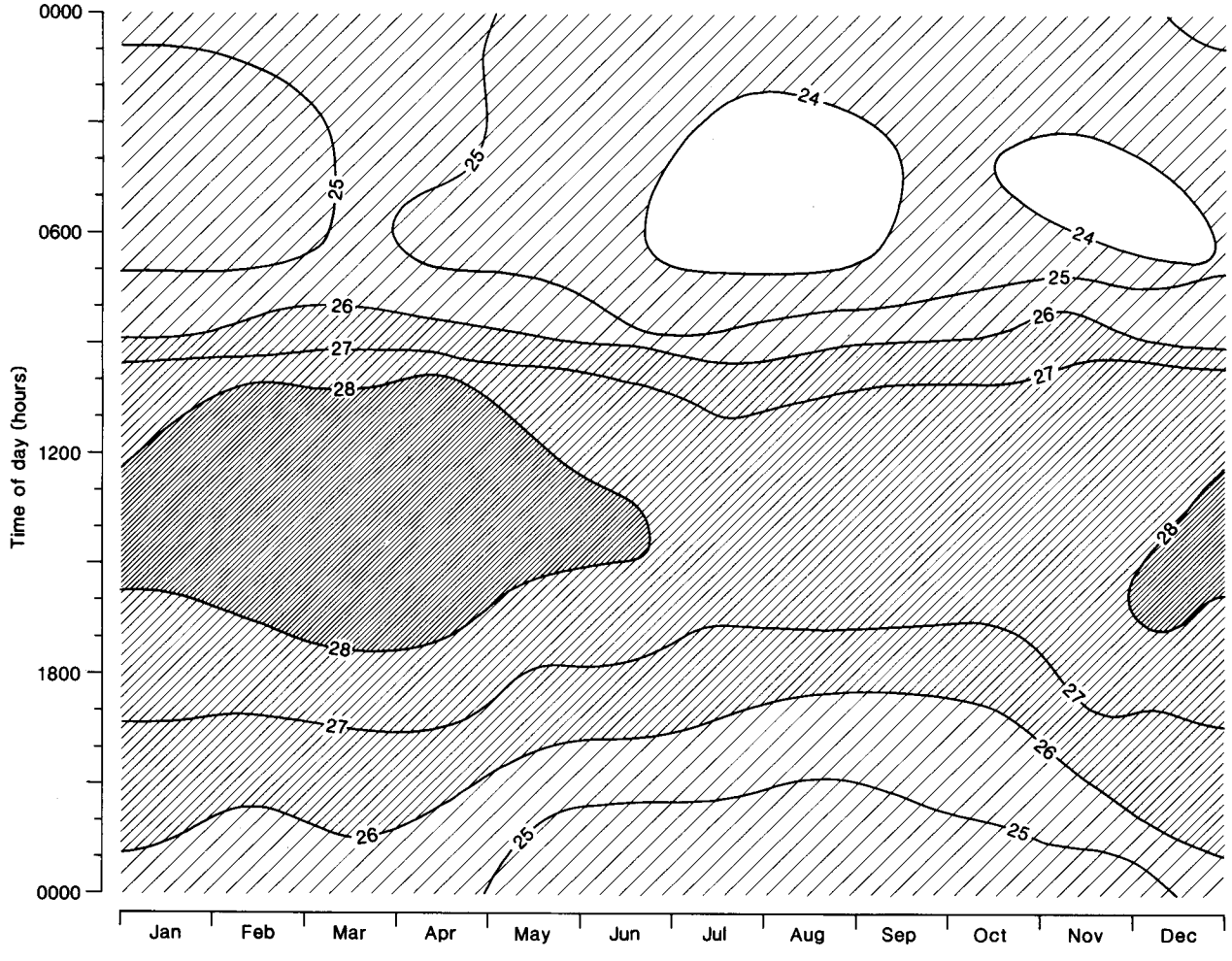

Figure 16. Seasonal and diurnal variation of the THI (^{o}C) at Apia (LST), 1980

afternoons uncomfortably hot if there is no adequate ventilation, especially in the lowland regions. The discomfort experienced at Apia is generally least during August and September, when mean temperatures are lower and mean wind speeds higher than at other times of the year.

Mean Sea Level Pressure

Mean sea level pressure is recorded at both Apia and Faleolo Airport. Pressures are normally highest between July and September when the anticyclones in the South-west Pacific tend to travel eastwards at their lowest latitudes (and the South Pacific anticyclone is also at its most intense stage). They are least in December and January (Table 20). Mean sea level pressures rarely lie outside the range 1007 to 1016 hPa and have a diurnal variation of 2 to 3 hPa.

Table 20. Means and extremes of mean sea level pressure (hPa), from daily observations made at 10am (LST), Apia, 1972-80

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Min	995	1001	1005	1006	1008	1008	1009	1008	1009	1007	1004	1000	995
Mean	1009	1010	1011	1011	1012	1013	1013	1014	1014	1013	1011	1009	1012
Max	1015	1015	1016	1015	1017	1017	1018	1018	1017	1017	1016	1015	1018

Special Phenomena

Thunderstorms. Observations from Apia show that thunder-storm frequency is high, averaging sixty per year (Table 21). They are twice as common between October and March as they are at other times of the year. At present Apia is the only station for which reliable reports of their occurrence are available.

Table 21. Average monthly occurence of thunder, Apia (1930-84)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
6.2	6.5	7.1	7.0	5.5	2.9	1.5	1.6	2.1	5.3	6.9	7.2	59.8

Waterspouts. There has only been one report of a waterspout which was sighted on 27 January 1971. It was located offshore to the north-west of Asau.

5 SEA CLIMATE SUMMARY OF WESTERN SAMOA

East to south-east winds prevail over the sea area around Western Samoa, being most frequent between May and July. North-west to north-easterly winds are noticeably more frequent between November and April, (Fig. 17). Westerlies to north-westerlies are also markedly more common in these months, as most of the cyclonic disturbances that develop at this time tend to pass to the south-west of Western Samoa.

There is no noticable diurnal variation in wind velocity over the sea. Wind frequencies from ships' reports during the period 1951 to 1980 showed that the mean daily wind speed was 22 km/hr, being approximately twice the strength of the wind speed over the land. Over the sea the sky is often not as cloudy during the afternoons as it is over land areas. Cloudiness tends to increase during the night due to more active instability caused by radiative cooling of the cloud tops.

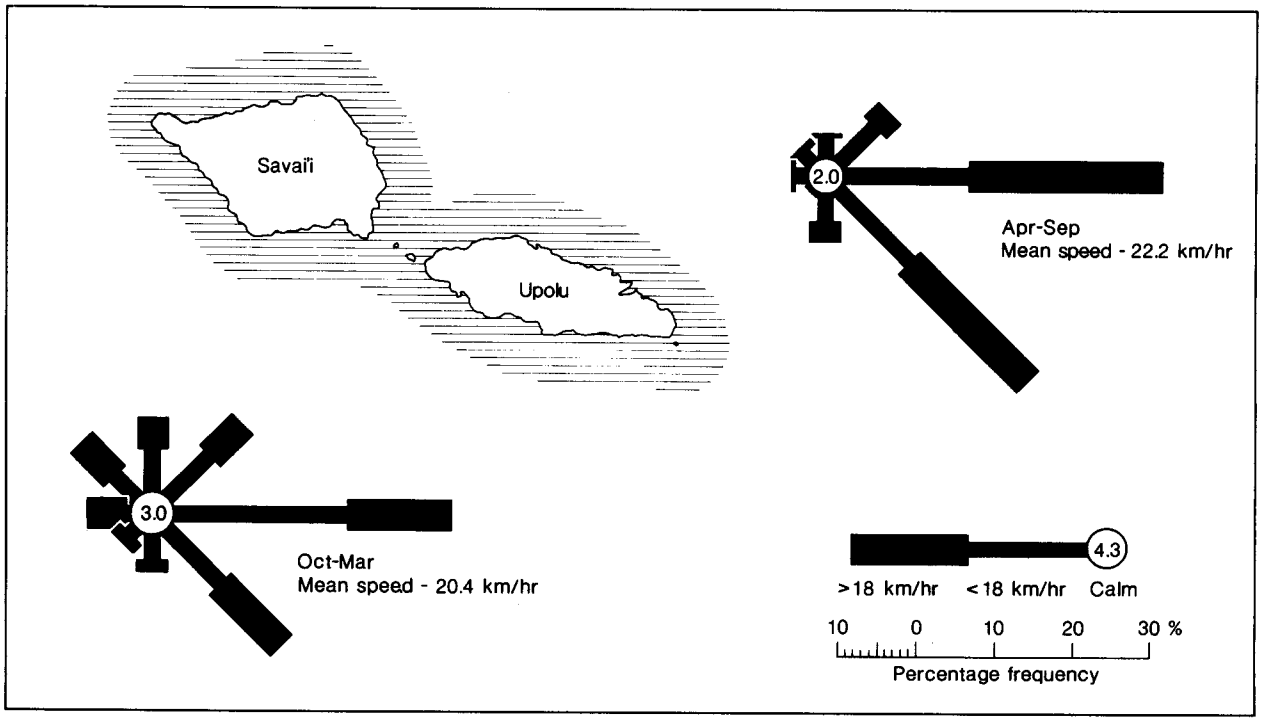

Figure 17. Seasonal variation of wind at sea (from ships reports in the region 12-15°S, 170-174°W, 1951-80)

Sea Temperatures. In the region 12-15°S and 170-174°W the mean sea surface temperatures have been obtained from ships reports. These show only a slight annual variation of 2°C (Table 22), being highest in March and lowest in August and September, with a mean monthly standard deviation of 1°C.

Table 22. Mean monthly sea surface temperatures (^{o}C) for the region 12-15^{o}S, 170-174^{o}W

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
29.1	29.1	29.3	29.2	29.0	28.5	27.9	27.5	27.5	28.1	28.3	28.7	28.5

Waves. High seas seldom occur in this region, as sustained mean wind speeds rarely exceed gale force. When the sea is rough, large waves do not often reach land as the island group is surrounded by a coral reef, broken in places. 55 percent of the waves come from directions between east and south-east. Waves from other directions are more frequent from

December to February than at other times. Statistics show that on average 2 percent of the wave heights are between 3 and 6 m, but that their frequencies increase to 5 percent between December and February. There are few reports of wave heights having exceeded 7 m. Wave heights of at least 3 m are more common when there are strong winds from west through to north.

6 BRIEF CLIMATOLOGY OF FALEOLO AIRPORT

Introduction. Faleolo Airport is located on Upolu Island, near the western end of the northern coast (24 km to the west of Apia). The airport is sited on a strip of relatively flat land, the coast forming its northern boundary. The outlook from the airport is completely unobstructed between west-northwest through north, to east. The land slopes steadily upwards towards a ridge of hills rising 500 to 600 m to the south-east of the airport. Two of the more prominent landmarks near the airport are; Mt. Tafua Upolu, 640 m high located 6 km to the south-east, and Mt. Lauti, 460 m high located 5.4 km to the south-east, but west of Mt. Tafua Upolu. The airport has one runway; the western end (approx. 1700 m in length) has been overlaid and the shape changed to a centre high point in place of the previous north sloping one slope runway. The runway lies due east-west and has a new section extending 1000 m eastward. The total runway length is 2700 m and the highest point is 17.6 m above mean sea level, at the western end.

Location of anemometer. A munro anemograph is located in the control tower building at the airport, and hourly weather observations are made almost daily between 7 a.m. and 8 p.m. by flight service staff. The anemometer (from which data has been used for this climatology) was located 122 m to the south of the old part of the runway and 110 m to the north of the air traffic control tower. A new anemometer has recently been installed (June 1986) and is located 1100 m to the west of the air traffic control tower and 100 m to the north of the runway, on a small piece of reclaimed land.

Surface wind and turbulence. On the southern side of the airport there are extensive coconut plantations on ground which slopes steadily upwards towards the hills. Because of the high ground in this area there may be a tendency for light low level winds to flow parallel to these hills rather than to flow across them. It should be noted that there is often a north-easterly sea breeze (mean speed 19 km/hr) during the daylight hours at the airport. At night winds are frequently light easterly or south-easterlies). Surface winds between east-southeast through south to

west-northwest are not usually as strong as winds from other directions, due to sheltering by the hills. The most severe winds are associated with tropical disturbances which pass over, or in the vicinity of Western Samoa. Sustained gale force winds seldom occur and wind gusts over 90 km/hr are rare. When the general windflow over Upolu Island is south-easterly, the wind may be deflected around the western coastline, through the strait, and then come into Faleolo as a south-westerly. It has been noted by pilots that turbulence often occurs in these conditions. Mechanical turbulence sometimes occurs over the coconut plantations, and is reported to be worst at the south-west end of the airfield.

Visibility and low cloud. There are no significant local sources of dust and smoke that reduce visibility. Reduced visibility is therefore associated with heavy rain; fog is extremely rare and low cloud and poor visibility are infrequent. Conditions with visiblity less than or equal to 7 km and/or more than 4 eighths of cloud below 450 m, based on two years observations, occurred about 1 percent of the time. Cloud base (covering more than 4 eighths of the sky) below 300 m occurs less than 1 percent of the time. These conditions are most common between October and March, with winds between north-west and north-east. They often occur when there is a convergence zone over Samoa. In south-easterly conditions the frequency of low cloud and poor visibilty is likely to be higher on the southern side of Upolu Island than on the northern side.

7 ACKNOWLEDGEMENTS

I would like to thank the Meteorological Office staff and observers in Western Samoa for the observations which have been made over the years, without which this climatology would not have been possible. I also thank the meteorological staff at Apia for their approval of this climatology for publication. Thanks also to S.W. Goulter for his help with the rainfall and sunshine statistics, and to J. Finkelstein for comments on the text.

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