WAVE CLIMATE OF TUVALU

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1. Introduction

The South Pacific Applied Geoscience Commission (SOPAC) acting through its Secretariat in Suva, Fiji, embarked on a wave data collection program in 1987 with the aim to map the ocean wave climate off the shores of several South Pacific island nations. The principal application of the wave data was seen to be the mapping of the wave energy resource of the islands needed to study the feasibility of developing wave power as a future energy source.

In the present report data from the wave measurement programme recorded by a Waverider buoy moored off the eastern coast of Funafuti atoll in the Tuvalu group are combined with satellite altimetric data and island wind measurements in building up a picture of the climatology of ocean waves in the area. Wave data from special events such as tropical cyclones and energetic swells are highlighted. Influence of the El-Niño Southern Oscillation phenomenon on the wave climate is also discussed.

Companion reports describing the ocean wave climate of the Cook Islands, Western Samoa, Fiji, Vanuatu and Tonga are also available. Further, a report has been produced discussing region-wide differences in the wave climate, entitled The Wave Climate of the South West Pacific (Barstow and Haug, 1994a) also giving further details on the various data sources used, in particular, the GEOSAT satellite altimeter data. It is recommended that readers should acquaint themselves with this report first before reading the present one.

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2. Some Basics

The ocean waves we are concerned with here are those waves generated by wind as opposed to tsunamis (or tidal waves) which are generated by subterranean seismic activity or landslide and the tides caused by the gravitational attraction of the moon and sun on the earth. In the South Pacific ocean wind waves are always present, it never being perfectly calm, and the energy involved is obvious to anyone at the coast as wave after wave dissipates on the coast. Ocean waves have a typical range of wave periods from 2 secs. (short wind waves) to 25 secs. (long swell).

The generation of ocean waves in response to wind depends both on the wind speed, the fetch or distance over which the wind blows and the duration of the wind in a given direction. A shift in wind direction leads to new waves growing in the new direction. There is, however, a limit to the growth of wind waves for a given wind speed. If the wind blows long enough over a long enough fetch the waves reach the so-called fully developed state.

Storm waves once created are known to attenuate very slowly and can travel many days across the ocean before dissipating on distant shores. Ocean waves are known as swell away from their generation area. The classic studies of ocean swell propagation were carried out in the Pacific during the early 1960s (e.g., Snodgrass et al, 1966) confirming the prediction of the linear wave theory that predicts that ocean waves travel across the ocean with a speed which increases with increasing wave period or wavelength. In a storm area waves of a range of wave periods are generated. When this spectrum of waves leaves the storm area, the longer waves travel faster, so that an observer at a distant point will detect the longer period swell waves first.

In reality, at a given location on the shore of a Pacific island, waves may be present arising from several different wind systems which may include local trade winds, storms in the southern ocean or northern Pacific, and, occasionally, from tropical cyclones. The exposure of the actual location is also very important, so that a location on the northern coast of an island will only experience swell from the northern hemisphere due to the island sheltering the location from southerly swell. It is, therefore, important to have information on the variability of oceanic winds on different time scales in both the local area and the source areas for swell in order to understand the variability of the wave climate. This is discussed in the next section.

3. Oceanic Winds

3.1 General Description

A good overview of the wind climate of Tuvalu is to be found in the New Zealand Meteorological Service's publication the Climate and Weather of Tuvalu (Thompson, 1986).

Another useful reference is Harrison and Luther (1990) who present climatological monthly mean winds from 33 island stations in the Pacific. The data were quality controlled by comparing neighbouring stations and long term averages from ship observations near to the islands. Generally, agreement is very good with differences generally no more than about 1 m/s in speed and 10 degs. in direction. We are grateful to Harrison for providing us with his long term climatological means. These statistics are reproduced for the 4 island stations in the Tuvalu group which have been analysed (Funafuti, Nanumea, Niulakita and Nui) in Fig. 1.

Time series of wind speed and direction were obtained in digitised form from New Zealand's National Institute of Water and Atmospheric Research Ltd. (NIWA) for Funafuti Airport (1 m.a.s.l.) for the period December 1948 to February 1993.

In the Tuvalu group, winds in the sector north east to south east occur about 60% of the time. According to Harrison and Luther (1990) the largest annual variability on the zonal (east-west) wind component in the South Pacific occurs close to Funafuti. Also the meridional variability is largest between 5 and 10°S. This means that there is a relatively large inter-seasonal change in the winds around the Tuvalu group. During the winter months (May to September) east to south east winds are most frequent (about 75% of the time at Funafuti) whereas, during November to March, winds with a northerly component are most frequent. Westerlies are also quite common at this time of year associated either with cyclone activity further south or the monsoon trough. Wind speed tends to be up to 1 m/s higher during the winter. The more variable winds during the summer can be seen in the statistics of Fig. 1 or the time series plots from Funafuti in Appendix A.

The Tuvalu group is also influenced by the El-NiÃo Southern Oscillation. The Southern Oscillation Index (SOI) describes the well known pressure oscillation between the western part of the South Pacific, represented by Tahiti and the eastern part (Darwin in Australia), and is intimately related to the El-Niño phenomenon. When air pressure is relatively high at Darwin the SOI is negative. A time series of the SOI is shown from 1980 to the end of 1992 in Fig. 2. The major 1983 event is clearly seen as well as more moderate events in 1987 and a rare two year event in 1991-2. These negative SOI episodes occur about every 4-5 years on average. In El-Niño years, when the SOI is negative, the Tuvalu group tends to experience higher south to south west winds while easterlies are less common. The effect on the zonal wind by El-Niño events is strongest in September-December (Harrison and Luther, 1990).

Island name: FUNAFUTI N Latitude: -8.52 E Longitude: 179.22

Monthly climatology and standard deviation in M/S
Generated from daily average observations from 01 Jan, 1949 to 31 Dec, 1980

Month	U	Stddev	V	Stddev	Speed	Stddev
Jan	0.23	4.36	-1.95	2.54	4.72	2.64
Feb	-0.64	3.91	-2.07	2.64	4.66	2.28
Mar	-1.57	3.59	-1.58	2.41	4.36	2.15
Apr	-2.55	3.15	-0.36	2.24	4.16	2.07
May	-3.80	2.54	0.47	1.98	4.54	2.10
Jun	-4.69	2.56	0.85	1.83	5.22	2.32
Jul	-5.11	2.40	1.22	2.05	5.67	2.34
Aug	-5.33	2.37	1.31	2.05	5.85	2.39
Sep	-4.70	2.44	0.86	2.17	5.31	2.31
Oct	-3.41	2.56	-0.02	2.23	4.39	1.99
Nov	-2.13	2.90	-0.79	2.87	4.22	2.00
Dec	-0.74	3.65	-1.30	2.83	4.38	2.07

Island name: NANUMEA N Latitude: -5.65 E Longitude: 176.13

Monthly climatology and standard deviation in M/S
Generated from daily average observations from 01 Mar, 1949 to 31 Dec, 1980

Month	U	Stddev	V	Stddev	Speed	Stddev
Jan	-0.72	4.53	-2.18	2.68	5.20	2.44
Feb	-2.18	3.70	-1.92	2.38	4.83	2.12
Mar	-3.08	2.88	-1.42	2.30	4.60	1.96
Apr	-3.15	2.76	-0.40	2.13	4.27	2.00
May	-3.53	2.38	0.07	2.01	4.30	1.92
Jun	-3.86	2.31	0.30	1.98	4.49	2.02
Jul	-4.05	2.13	0.67	2.07	4.67	1.95
Aug	-4.26	2.18	0.45	1.84	4.72	2.06
Sep	-3.86	2.39	0.18	2.11	4.56	2.07
Oct	-3.18	2.57	-0.61	2.20	4.27	1.92
Nov	-2.26	2.73	-1.43	2.35	4.10	1.83
Dec	-1.23	3.90	-1.79	2.39	4.50	2.31

Island name: NIULAKITA N Latitude: -10.75 E Longitude: 179.50

Monthly climatology and standard deviation in M/S
Generated from daily average observations from 02 Apr, 1949 to 30 Nov, 1980

Month	U	Stddev	V	Stddev	Speed	Stddev
Jan	-0.28	3.73	-1.18	2.99	4.21	2.56
Feb	-0.30	3.73	-1.28	2.75	4.20	2.36
Mar	-0.77	3.68	-1.15	2.16	3.92	2.18
Apr	-2.04	3.16	-0.61	2.34	3.83	2.30
May	-3.35	2.76	0.08	1.76	4.12	2.24
Jun	-4.40	2.45	0.25	1.80	4.82	2.31
Jul	-4.48	2.46	0.71	1.99	4.99	2.39
Aug	-4.61	2.40	0.67	2.04	5.09	2.39
Sep	-4.06	2.26	0.33	1.70	4.47	2.16
Oct	-3.29	2.72	0.18	2.03	4.14	2.28
Nov	-2.39	2.86	-0.27	2.16	3.80	2.05
Dec	-0.94	3.13	-0.84	2.64	3.68	2.18

Island name: NUI N Latitude: -7.23 E Longitude: 177.15

Monthly climatology and standard deviation in M/S
Generated from daily average observations from 28 Feb, 1949 to 31 Dec, 1980

Month	U	Stddev	V	Stddev	Speed	Stddev
Jan	0.44	5.02	-1.49	2.90	5.47	2.46
Feb	-1.07	4.52	-2.05	2.50	5.24	2.14
Mar	-2.18	3.77	-1.89	2.34	4.89	2.00
Apr	-2.77	3.43	-0.73	2.24	4.59	1.98
May	-3.64	2.62	-0.20	1.92	4.52	1.85
Jun	-4.32	2.43	-0.03	1.90	4.92	1.99
Jul	-4.63	2.37	0.33	1.94	5.19	2.00
Aug	-4.87	2.16	0.13	1.94	5.32	1.95
Sep	-4.28	2.22	-0.14	1.97	4.86	1.89
Oct	-3.30	2.92	-0.72	2.20	4.62	1.84
Nov	-1.99	3.37	-1.25	2.56	4.46	1.88
Dec	-0.57	4.40	-1.41	2.62	4.88	2.16

Fig.1 Climatological statistics for winds in the ***Tuvalu group (courtesy of Ed Harrison, Pacific Marine Environmental Laboratory in Seattle). U is the zonal (E-W) component velocity and V the meridional (N-S) component velocity***

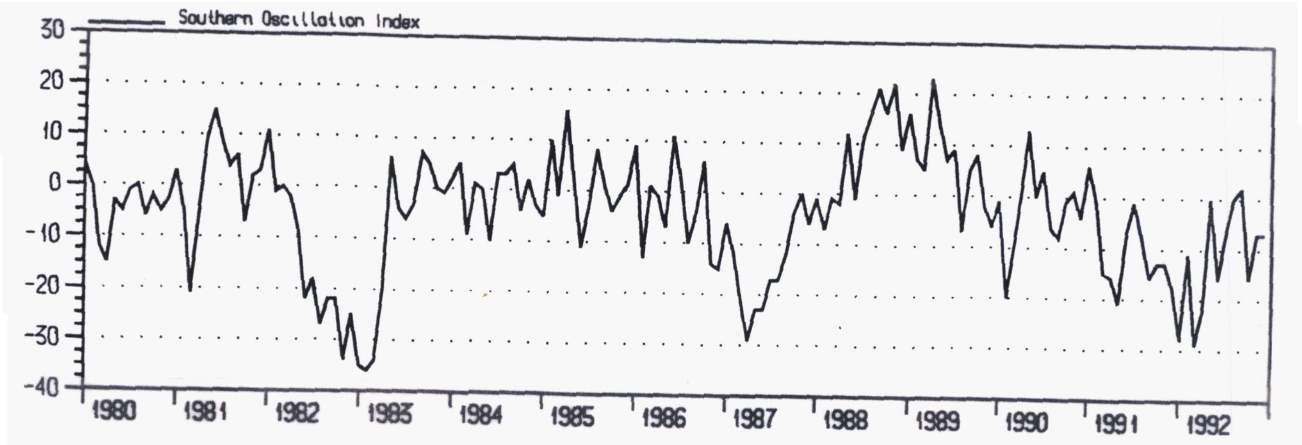


Fig. 2 Time series of the Southern Oscillation index from 1980 to 1992

Tropical cyclones occur infrequently in the Tuvalu group although they can cause widespread damage when they do occur. According to Thompson (1987) there are 3 known cyclones causing damage in Tuvalu, notably Cyclone Bebe in October 1972. More recently Cyclone Val on 5th December 1991 caused wind damage at Funafuti and three other atolls. Also in December 1992 a cyclone caused some damage.

3.2 Representativity of the measurement period

It is important to describe the temporal representativity of the wave measurement period (May 1990 - April 1992) with respect to the long term climatology. In other words, can the period for which wave measurements exist be considered to be representative for long term conditions as far as local winds (and hence wind seas) are concerned. This has been assessed by computing monthly mean wind statistics for 1990-92 and comparing with the long term conditions. In Fig. 3 are shown time series of monthly averaged wind speed and zonal and meridional component velocities (as in Fig. 1). The measured values at Funafuti are shown by the solid line and the long term climatology is given by the dashed line. The most important departure from the long term climatology in the wave measurement period at Tuvalu is the November 1991 to March 1992 period when the winds were more southerly and westerly than normal. This is associated with the 1991-2 El-Niño (see Fig. 1). As noted earlier, these conditions are typical of El-Niño years. Wind speeds were not significantly different from normal, however. Wind speeds were, however, a little higher than normal in 1990.

3.3 Winds in the source region for swell

The temporal representativity of the measurement period with respect to storm activity in the main area of ocean swell in the Tuvalu group islands, i.e., the Northern Hemisphere high latitudes during the winter and the Southern Ocean area, is somewhat more difficult to assess due to sparsity of wind and wave observations in both areas. It is probably not of major importance to the inter-annual variability of the wave climate in the Tuvalu group, as they lie far from the source regions, wind seas being more important. This aspect is not considered further here.

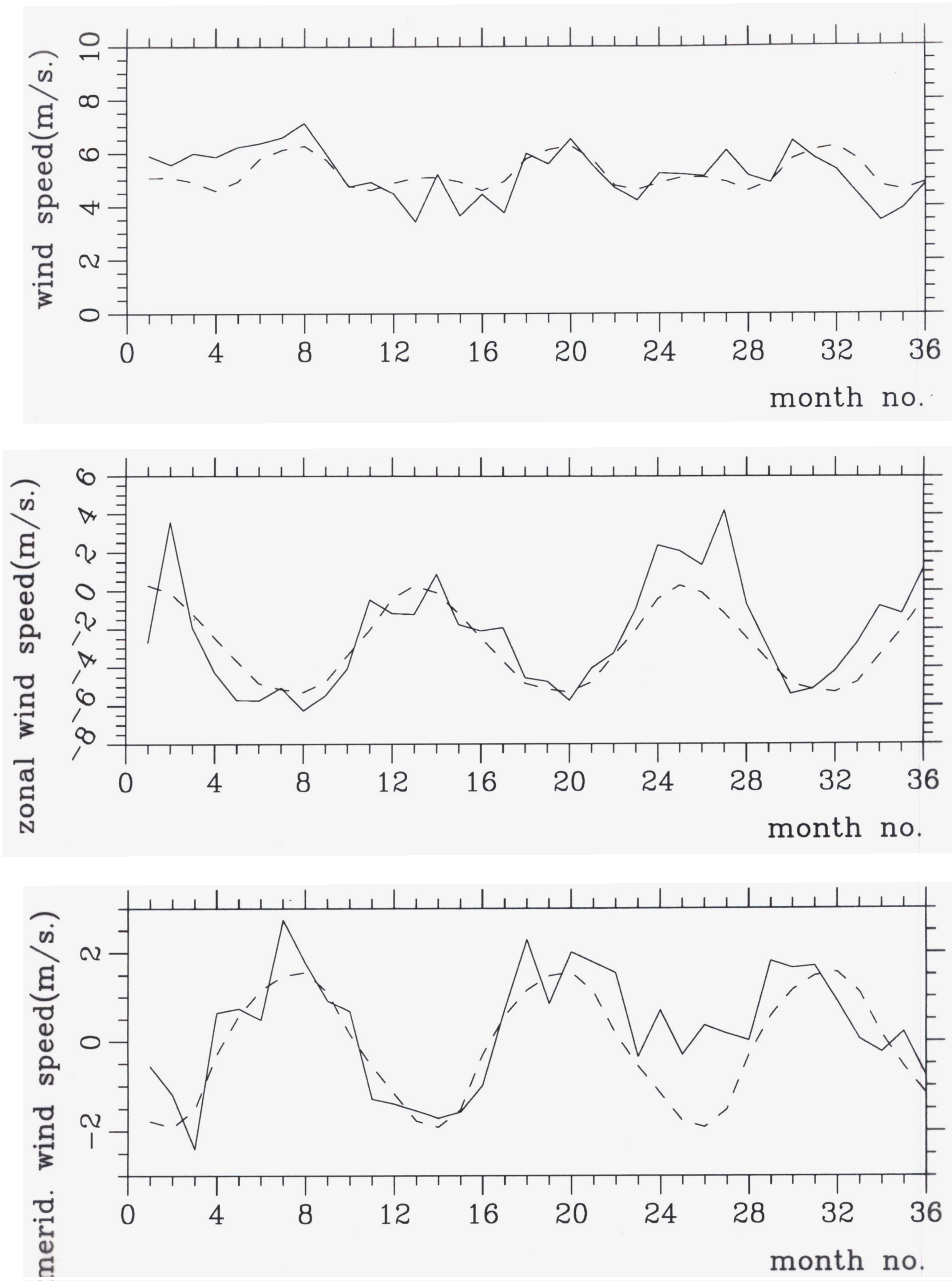


Fig.* 3** ***Comparison of mean monthly a) wind speed, b) zonal and c) meridional velocity components from the Rarotonga wind measurements (solid line) against the long term climatology (dotted line); for Funafuti Airport.

4. Ocean Waves

4.1 Buoy Measurements

Wave measurements were carried out off the eastern coast of Funafuti Atoll (Fig. 4) between May 1990 and April 1992 with a Waverider buoy. Full details of the measurements and the data analysis together with comprehensive statistics can be found in the data reports (Barstow and Olsen, 1992; Olsen and Selanger, 1993).

Time series of selected wave parameters for the duration of the measurement period are to be found in Appendix A. Wind speed and direction measurements from Funafuti Airport are also plotted. A brief definition of the various wave parameters are given below:

S(f): Wave spectrum (m^2s). Based on a 17 min. registration of the wave elevation relative to mean water level. The wave spectrum is computed using the Fast Fourier Transform over the frequency range $f = 0.025$ to 0.5 Hz (wave period, $T = 1/f$).

Hm0: Significant wave height (m). This is numerically close to the classical definition of significant wave height which is the height of the $^1/_3$ highest waves during the 17 min. measurement period. Hm0 is computed from the wave spectrum as follows:

$$Hm0 = 4\left(\int S(f)df\right)^{\frac{1}{2}}$$

Tp: Peak wave period (s). This is the wave period at which the wave spectrum attains its maximum value.

Tm-10: Energy period (s). There are many definitions of wave period. Tm-10 tends to be somewhat higher than Tm02. It is computed as follows:

$$Tm\text{-}10 = m_{-1} / m_0$$

where

$$m_n = \int S(f) f^n df$$

Tm-10 is used in the computation of wave power.

Tm02: Mean wave period (s).

$$Tm02 = \sqrt{m_0 / m_2}$$

J_T: Wave power (kW/m)

$$J_T = 0.49\, Hm0^2\, Tm\text{-}10$$

Hmax: Maximum wave height (m). Maximum wave height is the height of the highest single wave during a wave record. It is typically 1.4 - 1.6 times the significant wave height for 17 min wave records. In the wave measurement project single wave data were not collected.

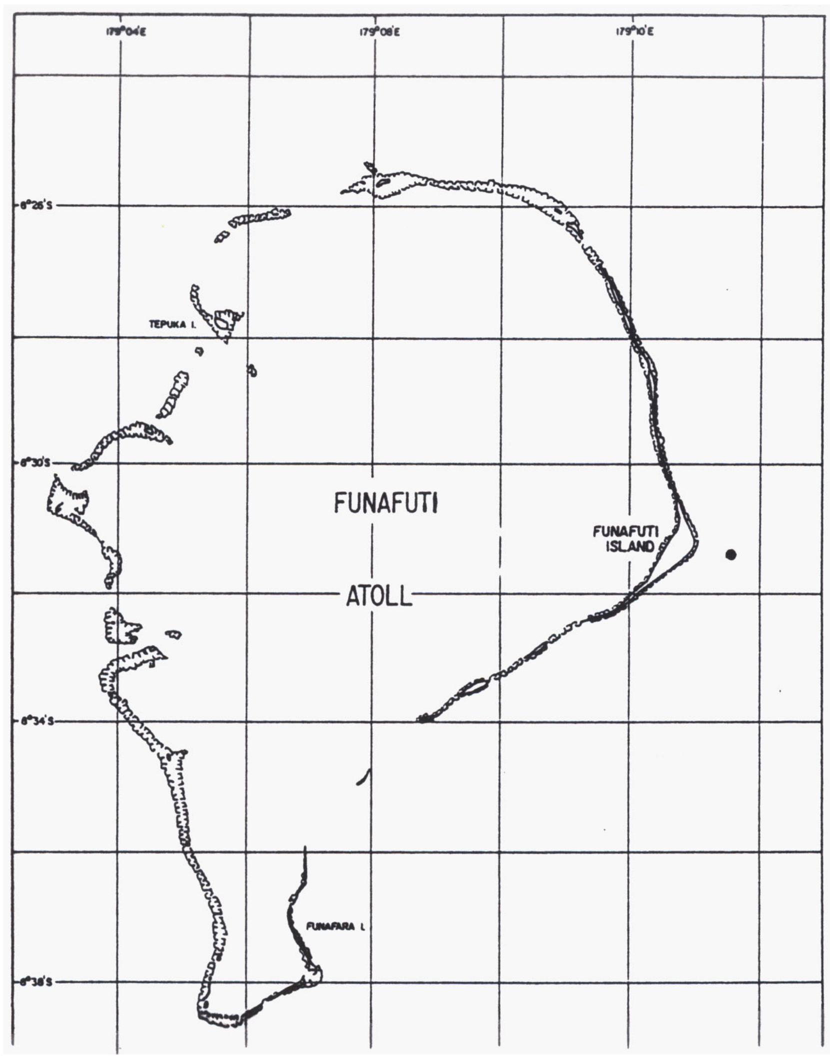


Fig. 4 Wave measurement location at Funafuti, Tuvalu

4.2 Ocean Wave Statistics

The monthly variation of various wave parameters measured by the Waverider at Funafuti are shown in Fig. 5. Note that the number of records (Fig. 5.d) are not equally distributed through the year. However, each month has at least data from one year available but mostly 2 years.

Significant wave height does not vary much over the year at the Waverider location, the monthly average lying mostly between 1.6 and 1.9 m. August seems, however, to have an anomalously high level at 2.1 m. This value is based on one month of data (August 1991). Examination of data elsewhere in the South Pacific does not indicate unusually high levels of swell in that month. The time series of wave height and wind speed (Appendix A) for Funafuti indicates that the waves increase in response to two bursts of fairly high easterly winds on 3 occasions during the month, with very low wind speeds in between. The wind is also steady from the east for most of the month. This is the direction which the buoy is best exposed to (see discussion below). The monthly mean wind speed is not anomalous, however (Fig. 3).

The mean wave period (Fig. 5.b) does show a marked seasonal cycle with low wave periods in the winter months (about **8.5** secs.) compared to about **10** secs. during November to March. This is presumably due to the greater influence of northerly swell at Tuvalu which occurs during the summer (northern hemisphere winter). This also helps to explain the fact that despite higher winds in the winter the waves are not significantly higher, i.e., northerly swell compensates for the lower winds in summer.

In Fig. **6** is shown the frequency distribution of the peak wave period, Tp. The peak in the wave spectrum is most frequently around **10** secs., and with a significant proportion of swell dominated spectra (Tp > 10 secs.). During winter, Tp is more often less than **10** secs. than in summer, confirming again the influence of swell from the north.

Analysis of the GEOSAT satellite altimeter data for the South Pacific (see Barstow and Haug, **1994a** for more details on these satellite measurements of waves and winds) confirms little variation in the offshore wave height in the Tuvalu group throughout the year, averaging about 2 m. The month to month variation of significant wave height is shown in Fig. **7** for both GEOSAT data averaged over an open ocean area close to Funafuti and the Waverider measurements. In general, the satellite wave heights are a little higher than for the buoy. This is probably due to the buoy being somewhat sheltered from the west, energy from that sector not then being detected by the buoy.

A comparison of the wave heights during **1987** which was a moderate El-Niño year with **1988** when the SOI was positive shows significantly higher waves in the El-Niño year. This can be easily seen in Fig. **7** as the monthly means are typically over 2 m in **1987** and under 2 m in **1988.** The annual average wind speed at Funafuti was **6.7** m/s in **1987** and **5.7** m/s in **1988,** with particularly high anomalies in southerly wind speeds during the winter months of **1987.**

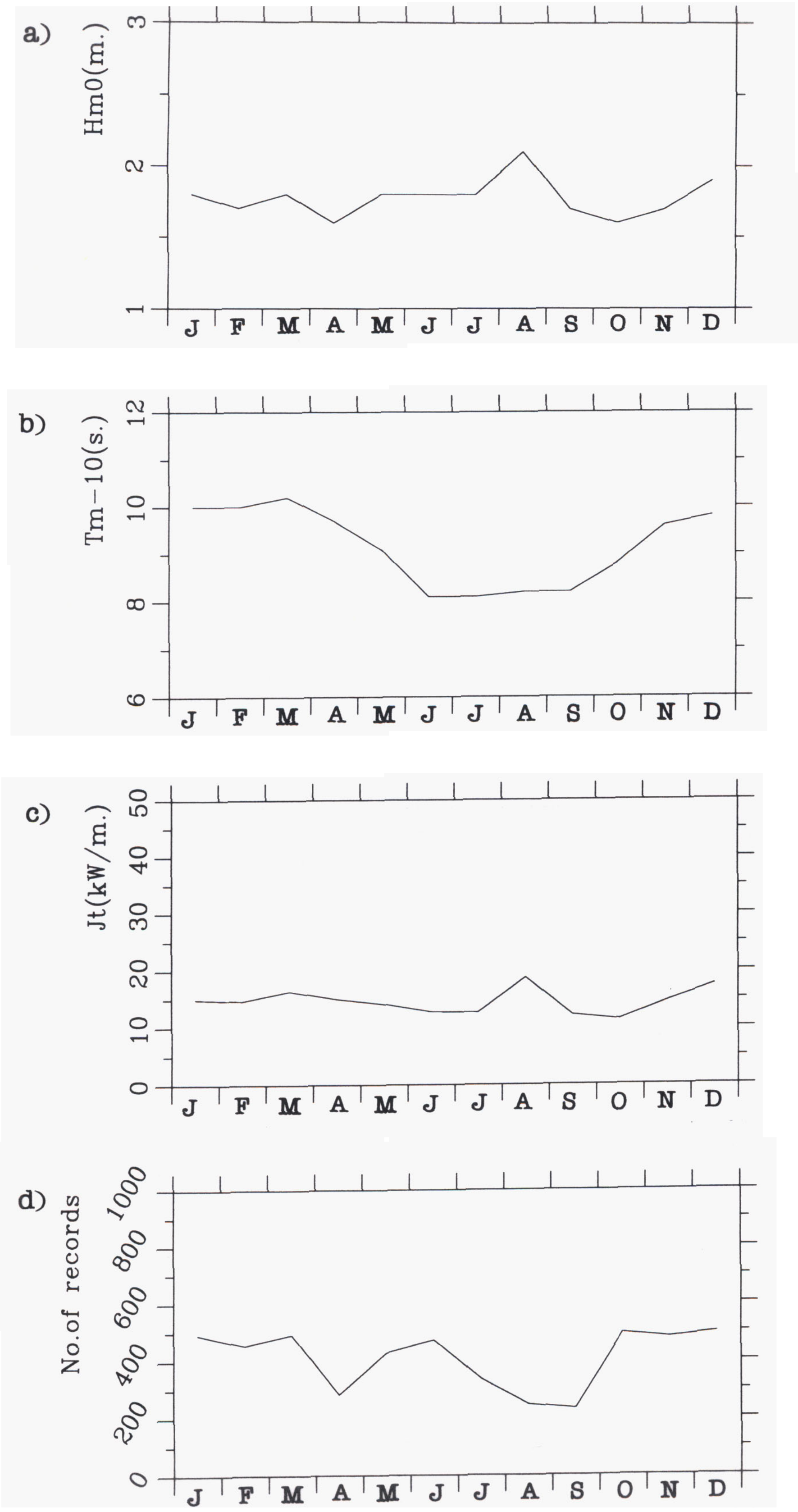


Fig. 5 ***Annual varlatlon of a) Slgnlflcant wave helght, Hm0, b) Energy Perlod, Tm-10, c)Wave Power, J_T and d) Number of wave records for the Waverider measurements at Funafuti Atoll.***

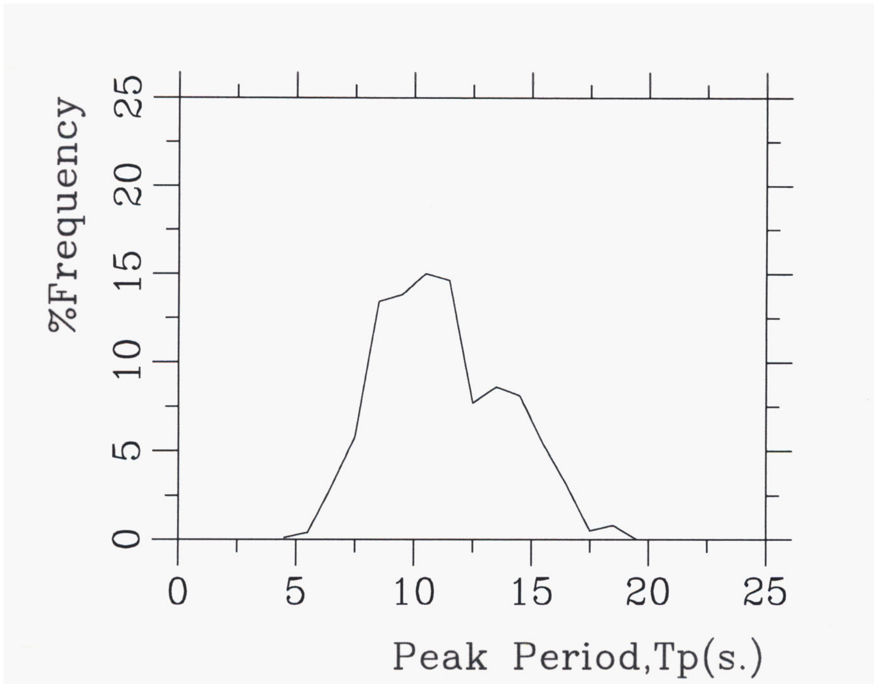


Fig. 6 ***Frequency distribution of the peak wave period, Tp, for the Waverider measurements at Funafuti.***

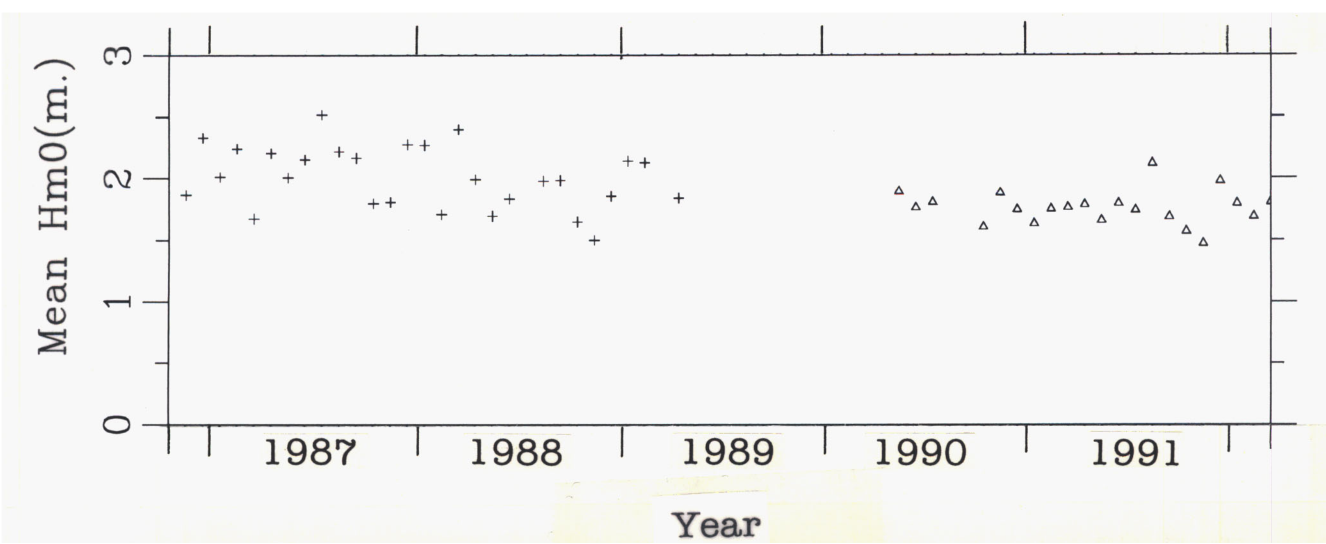


Fig. 7 ***Monthiy mean significant wave heights (m) for GEOSAT (crosses) and the Waverider buoy at Funafuti (triangies).***

Fig. 5.c shows the variation of wave power at the buoy location throughout the year. As wave periods are higher during the summer months there is a slightly higher wave power level during that time of the year. Again, August is anomalous for reasons described above. Wave power levels vary typically from about 12 to 17 kW/m. It should be stressed, however, that these are not coastal values. Not all energy experienced by the buoy will arrive on the coast adjacent to the buoy. The wave direction is critical in a determination of the wave energy at a given location on the coast. Directional wave measurements have not been made at Tuvalu. However, it is probable that the principal directions are south easterly to northerly for the wind seas and northerly or southerly for the swell. It is probable, therefore, that the easternmost tip of Funafuti Island is the best exposed to the ocean wave power. The north eastern shores are also quite well exposed.

The importance of wave direction on the coastal wave climate is illustrated by Barstow and Patiale (1992) who compare the difference in the wave climate at the buoy and the location on the south east coast of Funafuti where long term visual observations of wave heights had been carried out. Although the offshore buoy measurements show negligible variation of wave heights with season, the visual observations indicated a strong seasonality with higher waves in the winter when the dominant wind direction is south easterly. During the summer the site in question is sheltered from the more northerly wind seas and northerly swells that prevail at that time of the year, although the buoy which is less than 1 km offshore is exposed to these same northerlies.

The wave climate is not likely to be significantly different at other islands in the Tuvalu group although there is a slight trend towards lower wave heights towards the north-west of the group which is more sheltered to northerly swell due to the presence of the Western Kiribati group further north.

5. Special Events

In this section, wave data are presented for a number of special events. We first consider wave data from tropical cyclones affecting the Tuvalu group. No cyclone caused wave conditions significantly higher than normal during the Waverider measurement period, the only noticeable effects being increased swells from the south. The highest significant wave height recorded occurred in late November 1990 at 3.4 m. This was probably due to swell arriving from a storm in the North Pacific at the same time as swell from Cyclone Sina which moved south-eastward past Fiji on 27th. The GEOSAT satellite altimeter data base (1986-1989), however, contains a number of higher wave height records due to tropical storms. These are described in the following.

5.1 Tropical Cyclone Uma

On 8th February 1987, significant wave height exceeded 5 m to the west of the Tuvalu group at about 10°S, 172°E as a result of Tropical Cyclone Uma further south. This storm is described in more detail in the report in this series 'The Wave Climate of Vanuatu" (Barstow and Haug, 1994b).

5.2 Tropical Depression, December 1987

On 23rd December 1987 another record of 5 m was recorded close to Funafuti. A tropical depression was located at that time at about 14OS, 177.5°E and winds at Funafuti were near gale force (15 m/s) and westerly. The wave heights measured by the satellite along ground tracks in the sea area near to Tuvalu are shown in Fig. 8.

5.3 Tropical Cyclone Anne

The next high wave event due to cyclone activity was tropical cyclone Anne which developed into one of the most intense cyclones in recent years (Kishore, 1988). It passed over Tuvalu during its developing stage. The storm passed to the north of Funafuti where 20 m/s (strong gale force) winds were recorded. Unfortunately no satellite data is available from the Tuvalu group during the passage of Anne but one track in Western Kiribati has wave heights of 5 m already on the 5th indicating strong winds before the cyclone developed.

Wave heights exceeding 10 m were later registered in the Vanuatu group (Barstow and Haug, 1994b).

5.4 Tropical Cyclone Val

Cyclone Val devastated Western Samoa during several days in early December 1991. The storm formed in the first couple of days of December to the south west of Funafuti and on the 4th - 5th December strong winds caused some damage at Funafuti and several other atolls in the Tuvalu group. As the storm intensified as it approached Samoa, high seas moved out of the immediate storm area later to be detected as swell at Tuvalu. These features can be seen quite clearly from the series of wave spectra in Fig. 9. On the 4th at 0900 UTC the local wind sea peaks in response to the local high winds. On the 5th at 1800 UTC a fairly broad band swell centred at about 0.07 Hz starts to arrive from Val and continues to do so over the next few days. Wave spectra are generally double peaked as local winds remain relatively strong and south westerly. Weather charts for 5th - 8th December are shown in Fig. 10.

5.5 Swell Events

Very high damaging swells can occur on occasion in the Tuvalu group. There is one notable event on record. Matthews (1971) demonstrates that damage caused on the northern shores of South Pacific Islands in December 1969 was due to an unusually intense storm in the North Pacific, the swell travelling over 7000 km before dissipating its energy over a wide area of the South Pacific from Tuvalu to Tahiti. A report was received from Funafuti of much larger swell than normal in the lagoon during this event.

5.5.1 Long period swells in January 1991

We give a brief description here of this swell event which was detected at all stations in the South Pacific.

During the period 19th - 21st January 1991, long swells were detected at all SOPAC's stations operating in the South Pacific at that time. Peak period, Tp, reaches 20 secs. at various times at all stations (Fig. 11). This seems to have been a result of swells arriving both out of the south and north at about the same time. Simultaneous wave spectra for the 19th - 21st January are presented for all stations in Fig. 12. Long period wave energy can be seen to increase at Tongatapu late on the 19th, the spectral peak at about 0.05 Hz (20 secs.) increasing gradually over the next few hours, dominating the wave spectrum after about 0600 UTC on the 20th. A secondary swell was also present peaking at about 0.07 Hz for the same period. Long swell energy seems also to increase late on the 19th at Vanuatu, following a similar sequence as at Tongatapu. Similarly, a secondary swell is present at Vanuatu. Western Samoa begins to feel the swell somewhat later on the 20th, the swell first dominating the spectrum at about 0300 UTC on the 21st, with again a secondary swell present.

Finally, the Tuvalu Waverider starts recording long swells at about 0600 on the 20th, becoming dominant at about 0300 on the 21st. This swell has probably a different source as there is no time delay between the swell arrival at Samoa and Tuvalu. The Tuvalu swell probably derives from a powerful storm (down to 950 hPa central pressure) which had been present over the previous days in the North Pacific.

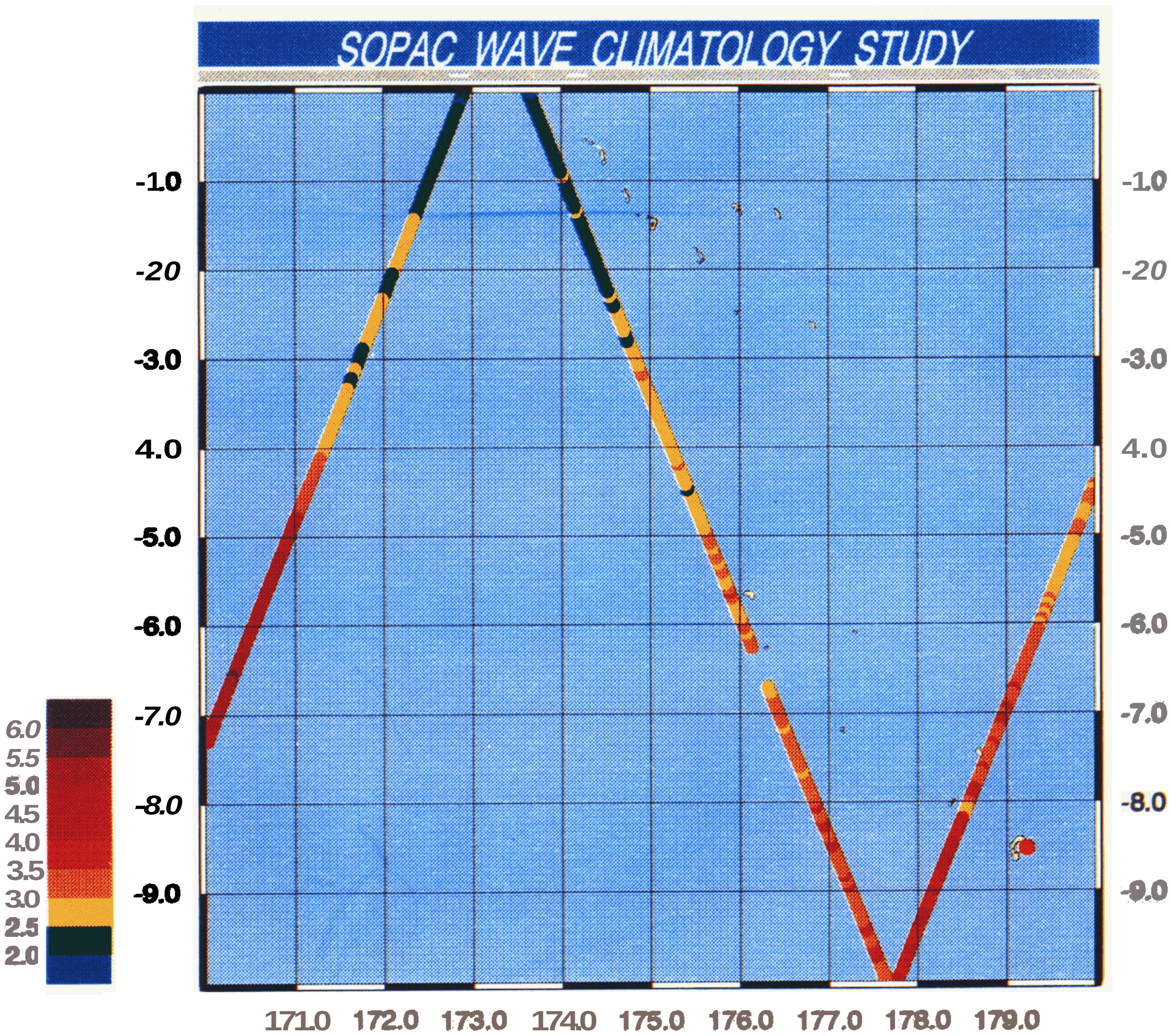
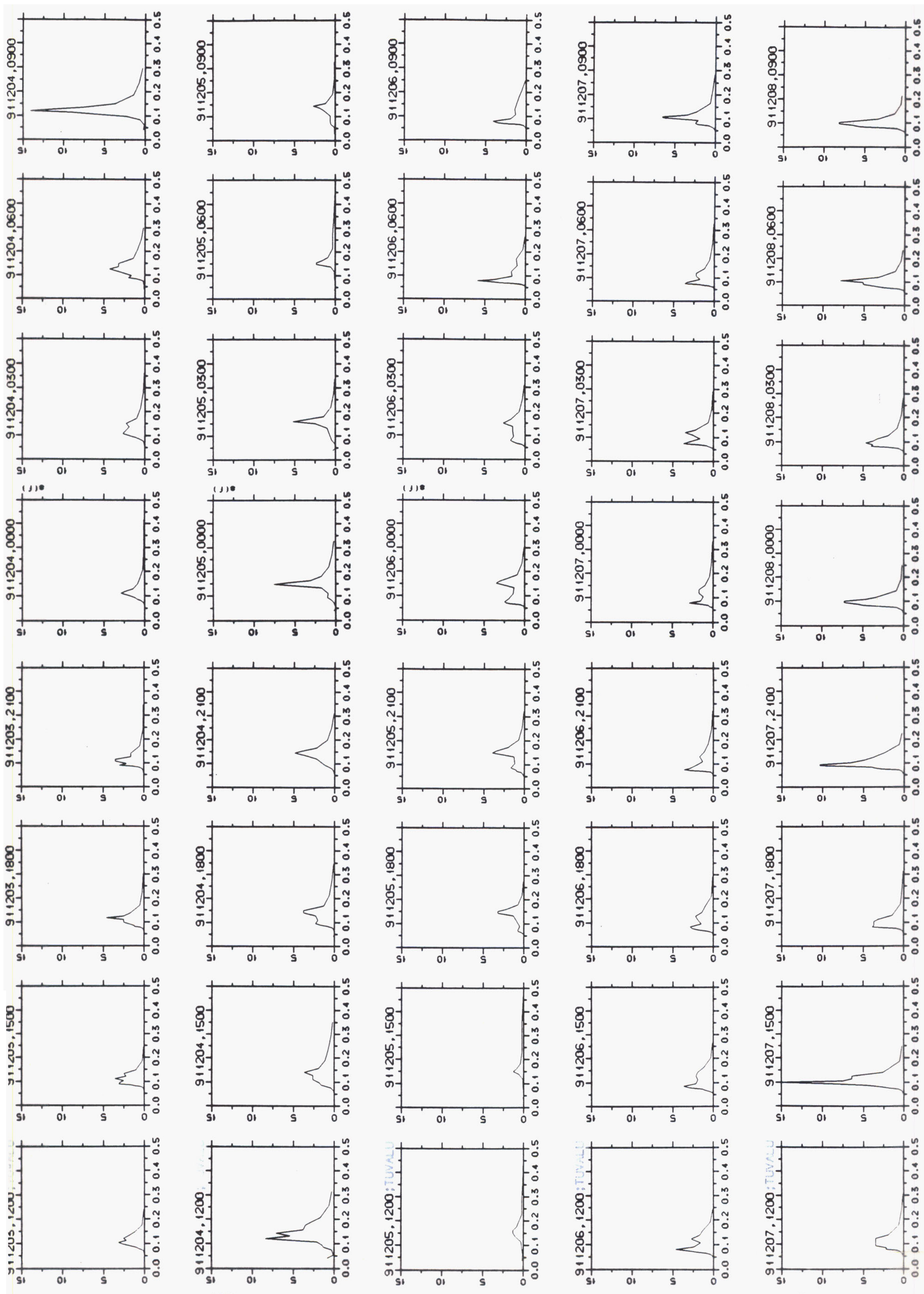


***Fig. 8** Colour coded significant wave heights (m) from the GEOSAT altimeter during 23rd - 25th December 1987 when 5 m seas were recorded close to Funafuti. The buoy location is indicated by a red circle.*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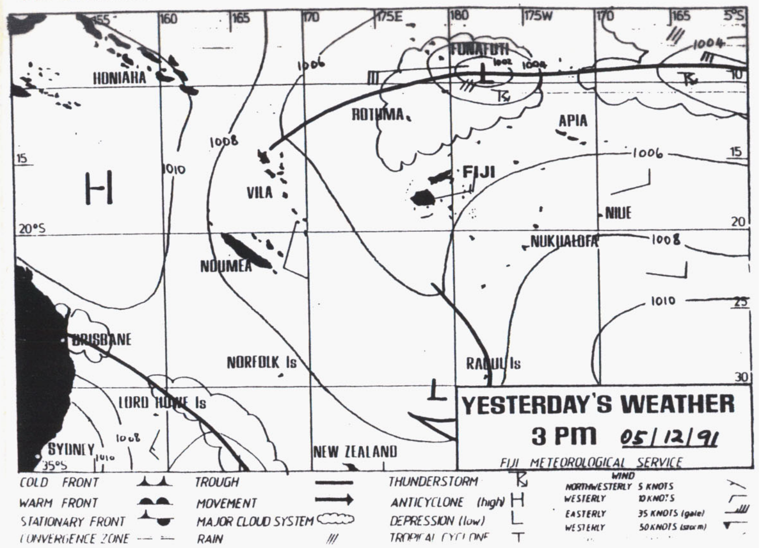

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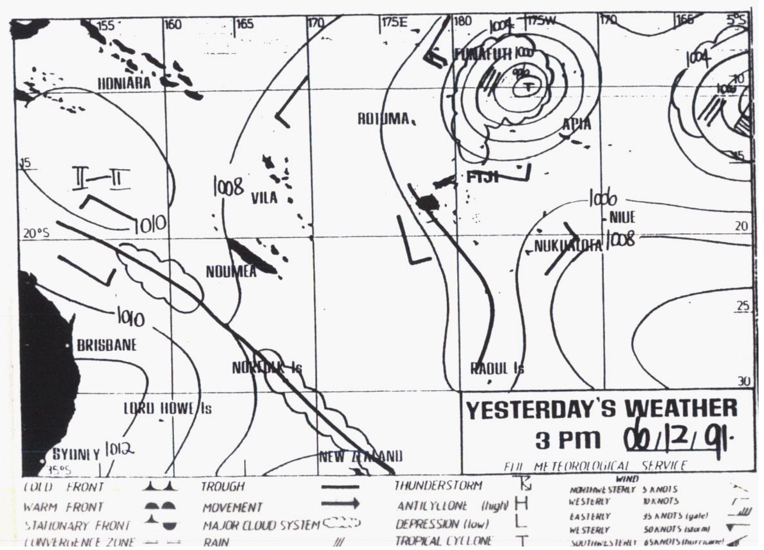
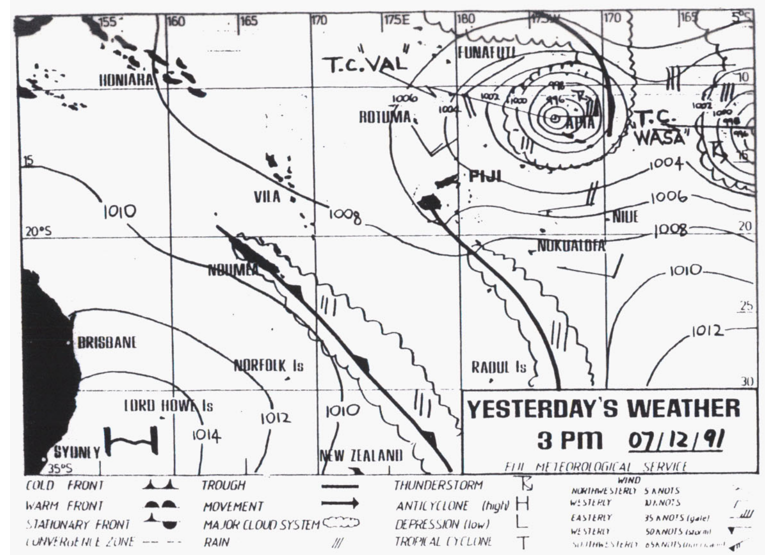


7th December



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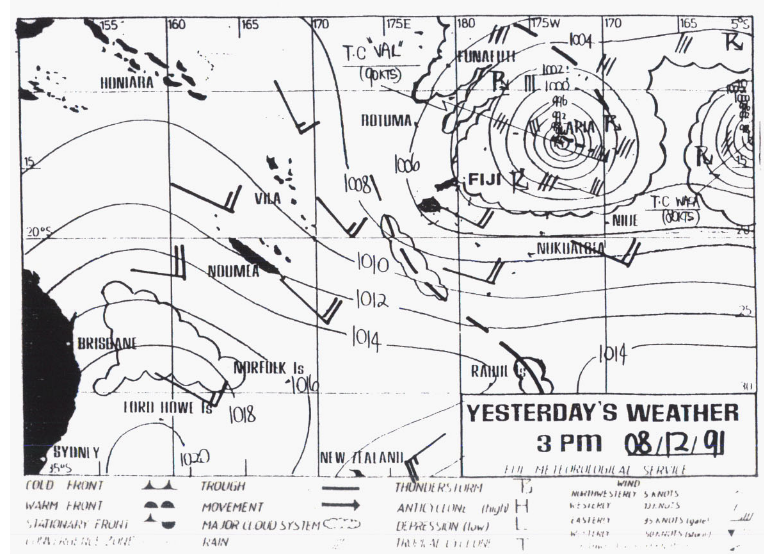

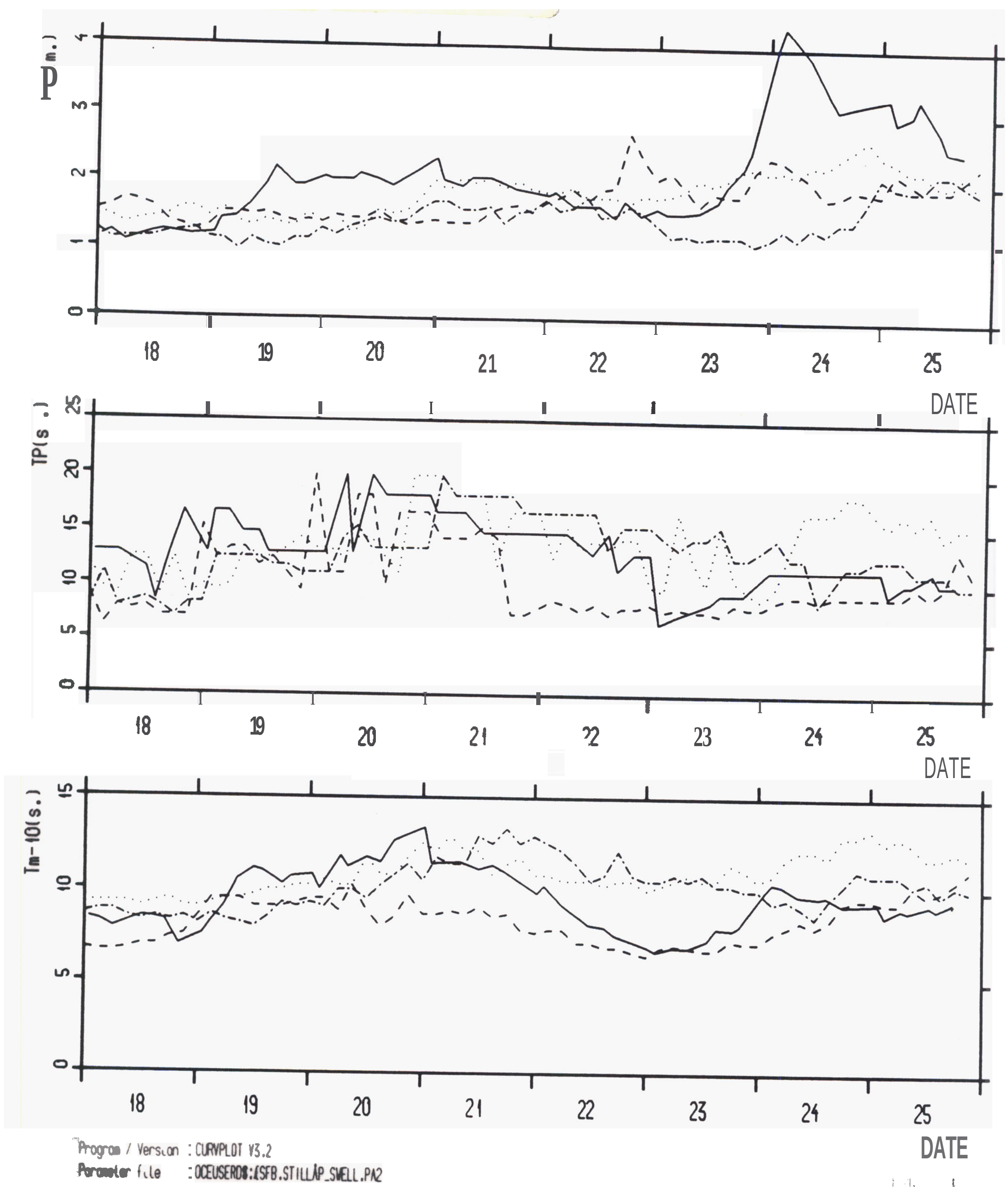

Fig. 11 Time series of Hm0, Tp and Tm-10 at Tongatapu (———), Tuvalu (• • • •), Vanuatu (- - - -) and Western Samoa (–•–•–•–) for 18th - 25th January 1991.

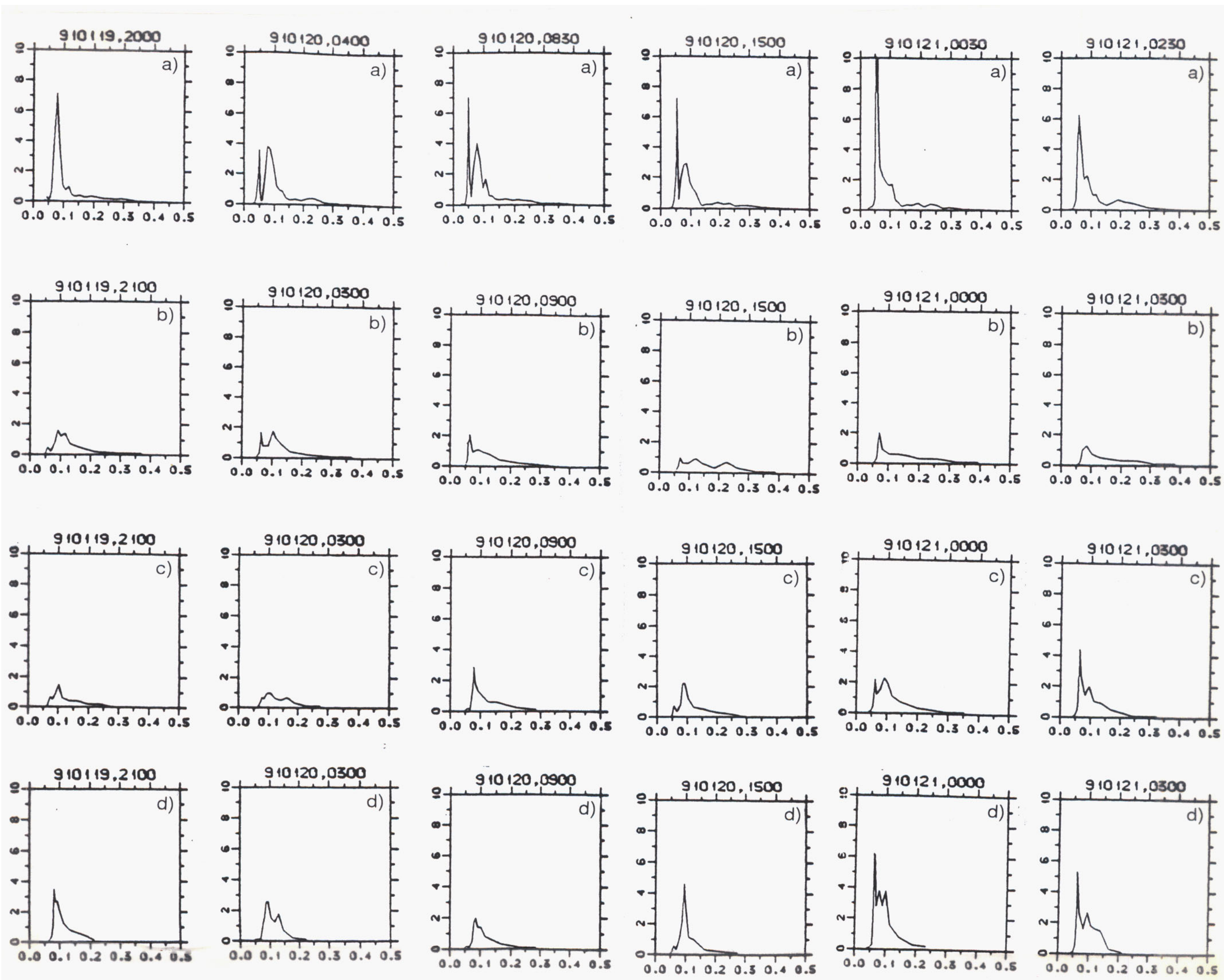

Fig. 12 Simultaneous wave spectra for a) Tongatapu, b) Vanuatu, c) Western Samoa and d) Tuvalu during the January 1991 swell event.

6. Conclusions

The purpose of SOPAC's wave data collection programme has been to map the wave energy resource of several South Pacific island nations including Tuvalu.

The data confirms that the Tuvalu group are endowed with a relatively high resource of the same order of magnitude as an area on the south coast of Java where a wave power development project is underway.

Although wave power levels are on average not as high as the higher northern latitudes, e.g., European Atlantic coastlines, the resource is considerably more steady. In fact, both buoy and satellite measurements do not reveal any discernible variation in wave heights through the year

Although average wave heights are remarkably steady in the Tuvalu group (no other island group studied can boast such a steady offshore resource), the directional character off the waves is extremely variable through the year. Wind seas tend to be east to south-east during winter, whereas north-easterlies are most frequent during summer. Swells are relatively common from the north during summer whilst swells from south occur all year but tend to be more frequent in winter. Therefore, hidden behind an apparently relatively invariant wave climate is a complex regime of crossing wave trains.

As far as wave power is concerned, although initial indications were that Tuvalu should have a steady, reliable resource, the strong seasonal directionality in the ocean wave climate leads to a relatively large seasonal variability in the coastal wave climate depending on the directional exposure of the coastline. This has been confirmed by a comparison of visual measurements on the coast with the buoy data.

A positive aspect of the wave climate for wave power development is that high cyclone driven seas are uncommon, particularly in the north of the group. Thus, extreme design wave forces are likely to be significantly less here than further south in the South Pacific region. The most favourable location for a wave power plant, as far as the highest resource is concerned, is the easternmost tip of Funafuti, but north-eastern and south-eastern shores are also wave rich environments.

The wave power resource of the islands is of a similar magnitude as Funafuti particularly on east facing coasts.

Although the offshore resource is stable throughout the year in the Tuvalu group at about 15 kW/m, there is considerable variability in wave power levels on other time scales from minutes to years. The tendency for high single waves to appear in groups leads to wave energy varying strongly on the time scale of minutes. There is also variability, on the time scale of days and weeks, in the swell component associated with the passage of storms further south and for wind seas due to trade wind variability. On the longest time scale, the El-Niño Southern Oscillation phenomenon may potentially have a significant impact on coastal wave energy levels due to anomalies in trade wind directions and, possible variability in swell in some years. In El-Niño years Tuvalu tends to experience higher south to south-westerlies at the expenses of easterlies.

Due to the fact that tropical cyclones tend to be in their early stages in the area of Tuvalu, high winds and waves are uncommon. In fact, after two years of measurements the highest significant wave height measured was only **3.4** m. Two records of ***5*** m significant wave height were measured by the GEOSAT, satellite, however, in 1987 associated with tropical storms to the south.

The foundations have been lain in this project for estimates to be made of the wave energy resource at any location in the Tonga group. The data will also be useful with respect to coastal defence, harbour design and improved wave forecasting. Various points need to be stressed to the potential user of this data. First, there are large gradients in the wave conditions in the neighbourhood of the islands and as such the wave measurements should be considered to be site specific. The length of the record is also short compared to the dominant El-Niño Southern Oscillation climate cycle and the data cannot necessarily be considered to be representative for the long term. Finally, wave direction measurements elsewhere in the region have confirmed that wave directions provided by the UK Met. Office global wave model, which is probably the best source of such data, are not entirely satisfactory due to systematic underestimation of swell heights. Information on wave direction is crucial for the estimation of the coastal wave climate.

In the final section we give recommendations as to how the wave climate can be estimated away from the measurement site and what future work would be beneficial. All data collected in this project have been installed at the SOPAC Secretariat in Suva, Fiji.

7. Recommendations

In the course of this project, in addition to the wave measurements and wave climatology work, a number of training workshops have been held for nations of several countries including Tuvalu. At the present time, in-country knowledge of ocean waves, wave power technology and Waverider buoy operation and maintenance exists. Some wave measuring equipment is also available in the region. In order to maximise the benefits from this training activity it is imperative to continue to the next natural stage of carrying out site specific assessments for wave power. In fact, the Fiji Ministry of Energy has already set up its own wave power programme to look at the wave power potential at 3 or 4 sites in the Fijian Archipelago where energy requirements are presently covered by fossil fuels. It is recommended that Tuvalu follows a similar procedure. This is described in the following.

Short term measurements (3-6 months) could be made using a Directional Waverider at the offshore measurement location, simultaneously with Waverider measurements as close to each of the chosen sites as possible. This data can then be used to construct a long term wave climate at the site in question using calibrated global wave model data, coastal wave modelling and available satellite data.

It is also recommended that SOPAC produces a regionwide brochure describing the results of the wave climate program with emphasis on the wave energy resource, the state-of-the-art of wave power technology internationally, and the potential in the South Pacific. This document would then be invaluable both as an information source within the countries themselves and to attract foreign companies involved in wave power to the region.

It has been pointed out earlier in this report that the length of the measurement series is relatively short compared to the El-Niño/Southern Oscillation cycle, which may have quite a large effect on the inter-annual variability of the wave climate. It is therefore considered to be worthwhile to extend the data base compiled at SOPAC with the ongoing satellite measurements from the ERS-1 and Topex/Poseidon satellites which followed GEOSAT which is widely used in this report. These data will also be useful directly to SOPAC in their coastal science projects. Cyclone data are, in particular, often captured by the satellites.

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Appendix A

Time series plots of wave and wind parameters; 1987 - 92

Hm0:	Significant wave height (m)
Wind Speed:	Measurements from Funafuti Aero (m/s), 7 m.a.s..l.
Tp:	Spectral peak wave period (s)
Tm-10:	Energy (wave) period (s)
Tm02:	Mean wave period (s)
Wind Direction:	Measurements from Funafuti Aero (m/s), 7 m.a.s.l. (degs. from which)