# Pacific Country Report

## Sea Level & Climate:
## *Their Present State*

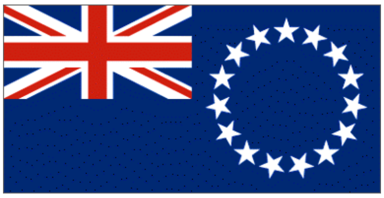
### *Cook Islands*

**June 2002**

This project is sponsored by the Australian Agency for International Development (AusAID), managed by Australian Marine Science and Technology Ltd (AMSAT), and supported by NTF Australia at the Flinders University of South Australia.

# Disclaimer

**PACIFIC COUNTRY REPORT**
**ON**
**SEA LEVEL & CLIMATE: THEIR PRESENT STATE**



**COOK ISLANDS**

**June 2002**

## Executive Summary


● A SEAFRAME gauge was installed in Rarotonga, Cook Islands, in February 1993. It records sea level, air and water temperature, atmospheric pressure, wind speed and direction. It is one of an array designed to monitor changes in sea level and climate in the Pacific.

● This report summarises the findings to date, and places them in a regional and historical context.

● The sea level trend to date is +1.9 mm/year (as compared to a global average of 1-2 mm/year) but the magnitude of the trend continues to vary widely from month to month as the data set grows. Nearby gauges, with longer records but less precision and datum control, show trends of +3.80 and +0.89 mm/year.

● Variations in monthly mean sea level are affected by the 1997/1998 El Niño, with a moderate seasonal cycle.

● Variations in monthly mean air and water temperature are likewise affected by the 1997/1998 El Niño, with pronounced seasonal cycles.

● In 1997 a tropical cyclone devastated a number of outer islands. Shortly thereafter another cyclone caused high sea levels and flooding at Rarotonga.

● The tsunami caused by the Peru earthquake of June 2001, which registered strongly on many Pacific SEAFRAME gauges, registered about 15 cm peak-to-trough at Rarotonga.

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# Feedback

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Dear Pacific Island Government Representative

Welcome to the first **Pacific Country Report**, containing a summary of the sea level, climate, oceanography and extreme events for each of the twelve SEAFRAME monitoring sites, plus Palau and Niue. We intend to produce them to coincide with the Forum Meetings.

Your feedback is essential to ensure that improvements are made, that what is important to **you** is addressed and explained. Your feedback will help guide the frequency of publishing and distribution. We invite you to give us both positive and negative feedback (your comments will remain confidential) because what might be obvious to you might be overlooked by scientists.

**You can tear out this page, jot notes on it, and mail or fax it to us at the address above. Or you can email comments to us. A few words is all we need.**

1-Did you find it informative?

2-What significant information have we omitted?

3-Would you like to see additional emphasis on any topic? If so, what?

4-Would you like more explanation on any topic? If so, what?

5-Any other suggestions or constructive criticism?

Name (optional)

Country

**Thank you for your time!**

## Introduction

As part of the AusAID-sponsored South Pacific Sea Level and Climate Monitoring Project ("Pacific Project") for the FORUM region, in response to concerns raised by its member countries over the potential impacts of an enhanced Greenhouse Effect on climate and sea levels in the South Pacific region, a **SEAFRAME** (**Sea** Level **F**ine **R**esolution **A**coustic **M**easuring **E**quipment) gauge was installed at Avatiu Harbour, Rarotonga, Cook Islands, in February, 1993. The gauge has been returning high resolution, good scientific quality data since installation.

SEAFRAME gauges not only measure sea level by two independent means, but also a number of "ancillary" variables - air and water temperatures, wind speed, wind direction and atmospheric pressure. There is an associated programme of levelling to first order, to determine shifts in the vertical of the sea level sensors due to local land movement. Continuous GPS measurements are now also being made to determine the vertical movement of the land with respect to the International Terrestrial Reference Frame.

When change in sea level is measured with a tide gauge over a number of years one cannot be sure whether the sea is rising or the land is sinking. Tide gauges measure relative sea level change, i.e., the change in sea level relative to the tide gauge, which is connected to the land. To local people, the relative sea level change is of paramount importance. Vertical movement of the land can have a number of causes, e.g. island uplift, compaction of sediment or withdrawal of ground water. From the standpoint of global change it is imperative to establish absolute sea level change, i.e. sea level referenced to the centre of the Earth which is to say in the terrestrial reference frame. In order to accomplish this the vertical land movement and in particular the rate at which the land moves must be measured separately. This is the reason for the addition of CGPS near the tide gauges.

## Regional Overview

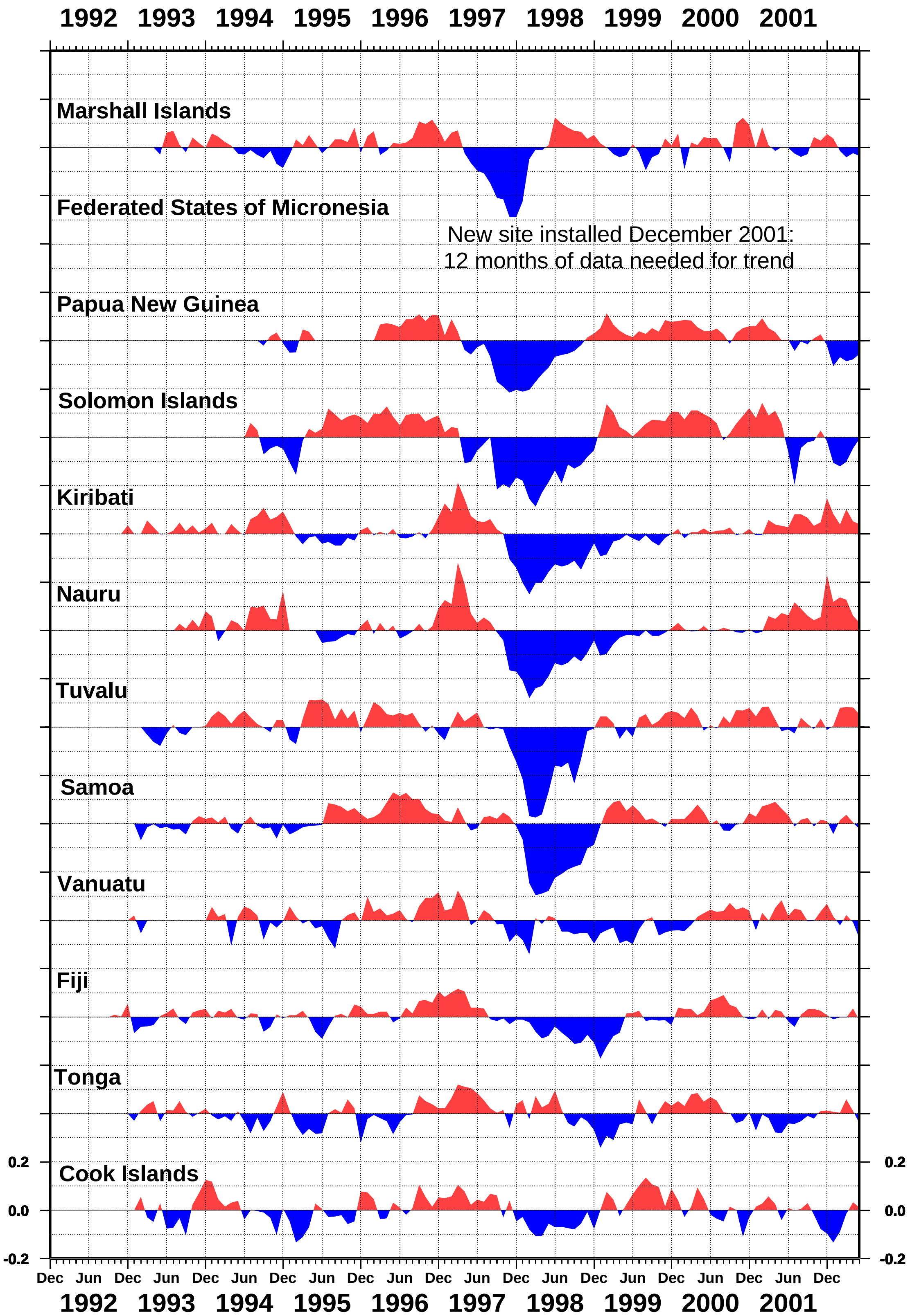
Variations in sea level and atmosphere are inextricably linked. For example, to understand why the sea level at Tuvalu undergoes a much larger annual fluctuation than at Samoa, we must study the seasonal shifts of the trade winds. On the other hand, the climate of the Pacific Island region is entirely ocean-dependent. When the warm waters of the western equatorial Pacific flow east during El Niño, the rainfall, in a sense, goes with them, leaving the islands in the west in drought.

Compared to higher latitudes, air temperatures in the tropics vary little throughout the year. Of the SEAFRAME sites, the most extreme changes are naturally experienced by those furthest from the equator – the Cook Islands (at 21°S) recorded the lowest temperature, 13.1°C, in August 1998. The Cook Islands regularly fall to 16°C while Tonga (also at 21°S) regularly falls to 18°C in winter (July/August).

| SEAFRAME location | Minimum recorded air temperature (°C) | Maximum recorded air temperature (°C) |
|---|---|---|
| Cook Islands | 13.1 | 32.0 |
| Tonga | 16.0 | 31.4 |
| Fiji (Lautoka) | 16.6 | 33.4 |
| Vanuatu | 16.5 | 33.3 |
| Samoa | 18.7 | 32.1 |
| Tuvalu | 22.8 | 31.6 |
| Kiribati | 22.4 | 32.9 |
| Nauru | 22.4 | 32.4 |
| Solomon Islands | 20.1 | 34.5 |
| Papua New Guinea | 21.5 | 31.1 |
| Marshall Islands | 20.5 | 31.9 |

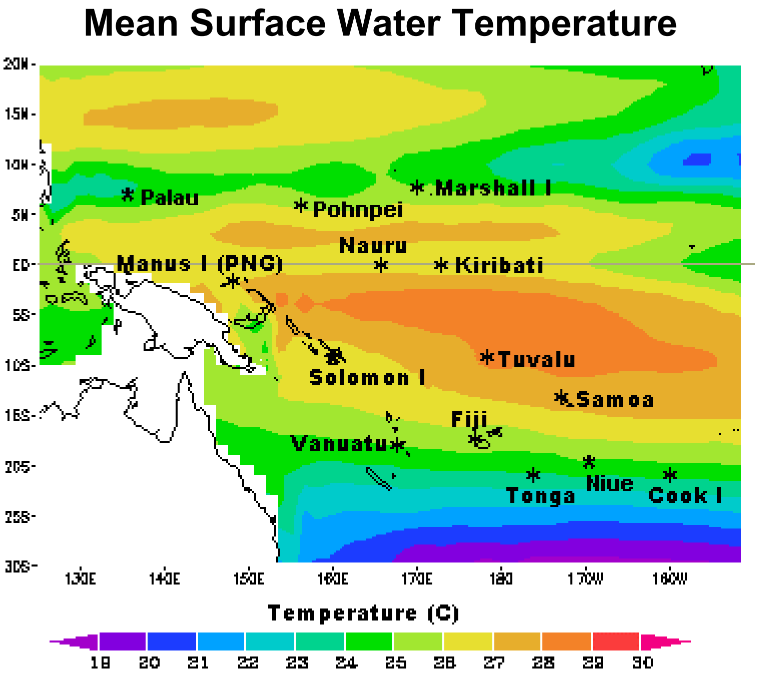
The most striking oceanic and climate fluctuations in the equatorial region are not the seasonal, but interannual changes associated with El Niño. These affect virtually every aspect of the system, including sea level, winds, precipitation, and air and water temperature. Referring to the plot below, we see that at most SEAFRAME sites, the lowest recorded sea levels appear during the 1997/1998 El Niño. The most dramatic effects were observed at the Marshall Islands, PNG, Nauru, Tuvalu and Kiribati, and along a band extending southeastward from PNG to Samoa. The latter band corresponds to a zone meteorologists call the "Sub-Tropical Convergence Zone" or STCZ. In the figure below, we see the effect of the 1997/1998 El Niño on all SEAFRAME stations.

# Sea levels* at SEAFRAME sites




* Plotted values are sea level "anomalies" (tides and trend removed from data).

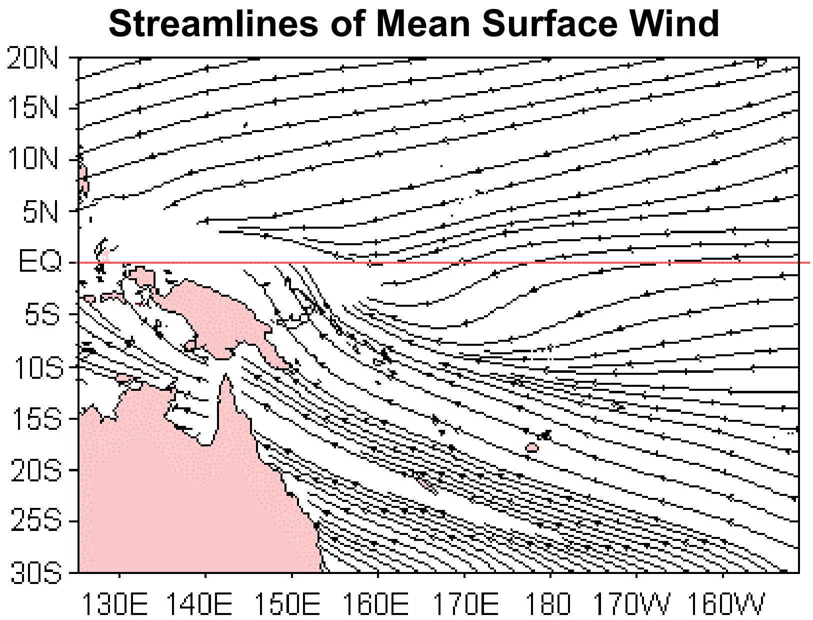
Most Pacific Islanders are very aware that the sea level is controlled by many factors, some periodic (likes the tides), some brief but violent (like cyclones), and some prolonged (like El Niño), because of the direct effect the changes have upon their lives. The effects vary widely across the region. Along the Melanesian archipelago, from Manus Island to Vanuatu, tides are predominantly diurnal, or once daily, while elsewhere the tide tends to have two highs and two lows each day. Cyclones, which are fueled by heat stored in the upper ocean, tend to occur in the hottest month. They do not occur within 5° of the equator due to the weakness of the "Coriolis Force", a rather subtle effect of the earth's rotation. El Niño's impact on sea level is mostly felt along the STCZ, because of changes in the strength and position of the Trade Winds, which have a direct bearing on sea level, and along the equator, due to related changes in ocean currents. Outside these regions, sea levels are influenced by El Niño, but to a far lesser degree.




Note the warm temperatures in the STCZ and just north of the equator.

The convergence of the Trade Winds along the STCZ has the effect of deepening the warm upper layer of the ocean, which affects the seasonal sea level. Tuvalu, which is in the heart of the STCZ, normally experiences higher-than-average sea levels early each year when this effect is at its peak. At Samoa, the convergence is weaker, and the seasonal variation of sea level is far less, despite the fact that the water temperature recorded by the gauge varies in a similar fashion. The interaction of wind, solar heating of the oceanic upper layer, and sea level, is quite complex and frequently leads to unexpected consequences.

The plot **Streamlines of Mean Surface Wind** shows how the region is dominated by easterly trade winds. In the Southern Hemisphere the Trades blow to the northwest and in the Northern Hemisphere they blow to the southwest. The streamlines converge, or crowd together, along the STCZ.




Much of the Melanesian subregion is also influenced by the Southeast Asian Monsoon. The strength and timing varies considerably, but at Manus Island (PNG), for example, the NW monsoon season (winds from the northwest) runs from November to March, while the SE monsoon brings wind (also known as the Southeast Trade Winds) from May to October. Unlike many monsoon-dominated areas, the rainfall at Manus Island is distributed evenly throughout the year (in normal years).

### *Mean Sea Level Trends and their Confidence Intervals*

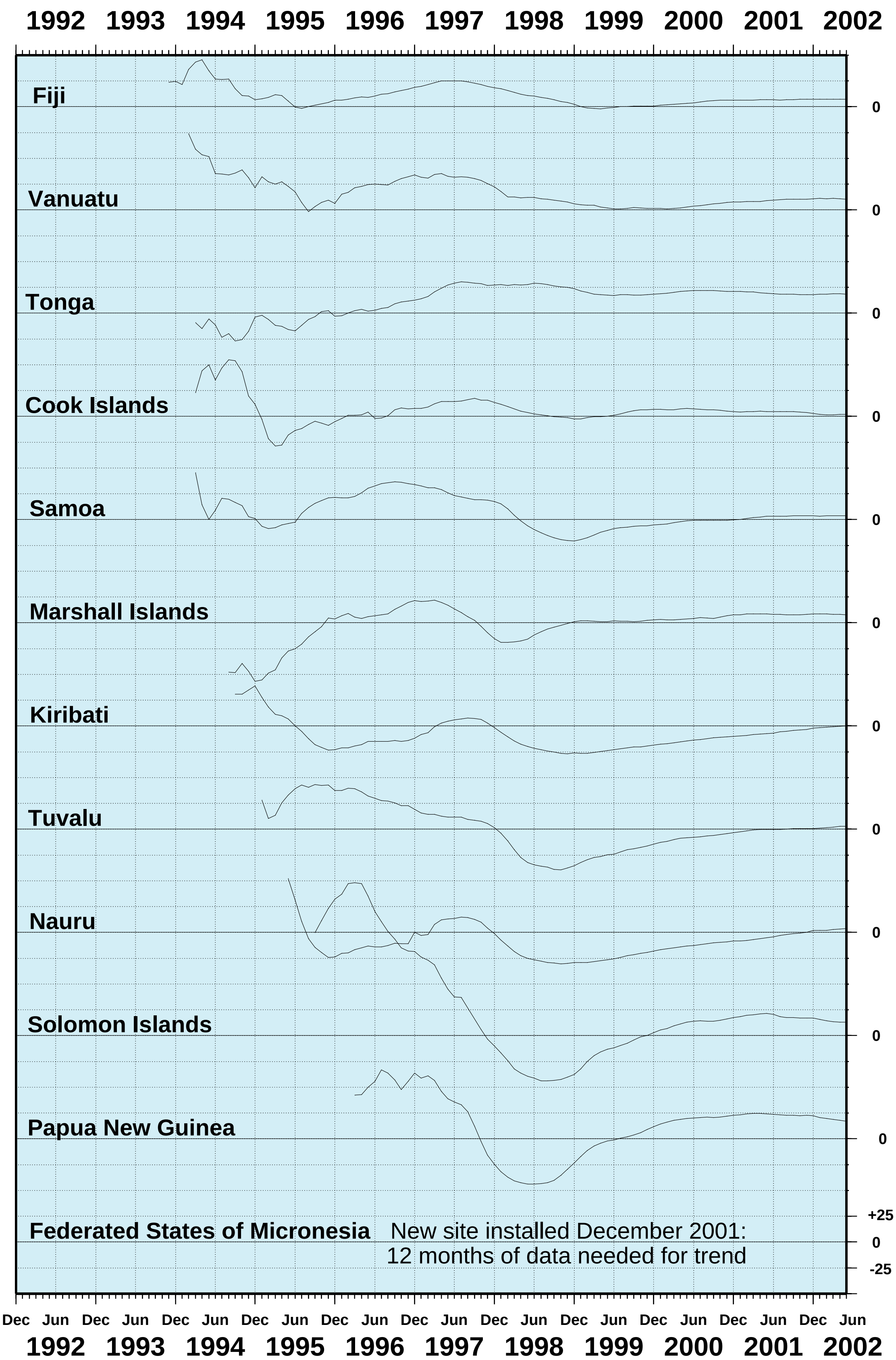
With the great diversity in climatic environments, vertical land movement and ocean variability, one might expect that that the sea level trends measured at different stations over the limited period for which tide gauge data has been collected may also vary. That this is indeed the case is demonstrated by the following table, which contains the relative sea level trends from all the regional stations for which at least 25 years of hourly data was available.

| Location | Country | Years of data | Trend (mm/year) | Standard Deviation mm/year |
|---|---|---|---|---|
| Pago Pago | U S Trust | 49.7 | +1.43 | 1.5 |
| Rarotonga | Cook Is | 22.2 | +3.80 | 3.7 |
| Penrhyn | Cook Is | 21.6 | +0.89 | 3.4 |
| Pohnpei | F S of Micronesia | 26.9 | +0.42 | 3.7 |
| Kapingamarangi | F S of Micronesia | 19.9 | -1.04 | 4.7 |
| Truk | F S of Micronesia | 27.6 | +1.79 | 3.3 |
| Guam | U S Trust | 50.1 | +0.37 | 1.9 |
| Yap | F S of Micronesia | 30.9 | -0.20 | 3.6 |
| Suva | Fiji | 24.8 | +3.99 | 3.0 |
| Christmas | Rep of Kiribati | 40.3 | -0.68 | 2.2 |
| Kanton | Rep of Kiribati | 45.0 | +0.26 | 1.5 |
| Fanning | Rep of Kiribati | 16.8 | +2.17 | 5.1 |
| Tarawa | Rep of Kiribati | 23.6 | -2.24 | 3.6 |
| Majuro | Rep of Marshall Is | 30.8 | +2.79 | 2.6 |
| Enewetok | Rep of Marshall Is | 24.5 | +1.18 | 3.3 |
| Kwajalein | Rep of Marshall Is | 54.4 | +1.13 | 1.3 |
| Nauru | Rep of Nauru | 24.2 | -2.03 | 4.2 |
| Malakal | Rep of Palau | 30.1 | +0.64 | 4.0 |
| Honiara | Solomon Is | 24.5 | -2.21 | 4.8 |
| Nuku'alofa | Tonga | 9.4 | +4.90 | 7.2 |
| Funafuti | Tuvalu | 21.6 | +0.92 | 5.1 |
| Port Vila | Vanuatu | 11.3 | +6.21 | 6.8 |

Mean trend: 1.11 mm/year (all data)    Mean trend of data > 25 years: 0.8 mm/year
Data from University of Hawaii as at June 2002

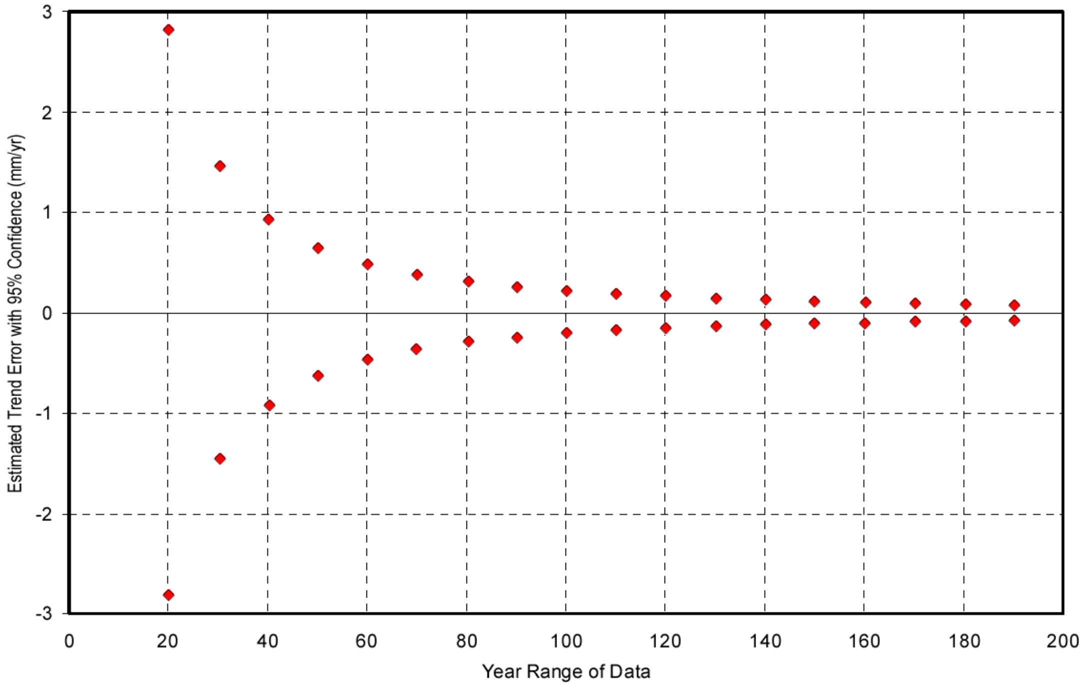
The following plot depicts the evolution of the short term sea level trends, at SEAFRAME stations, from one year after installation to the present. Please note that the trendlines have not yet stabilised.

# Short Term Sea Level Trends (mm/year)



The expected width of the 95% confidence interval (±1.96 times the standard error) as a function of data length based on the relationship for all National Oceanographic and Atmospheric Administration (NOAA) gauges with a data record of at least 25 years are shown in the figure below. A confidence interval or precision of 1 mm/year should be obtainable at most stations with 50-60 years of data on average, providing there is no acceleration in sea level change, vertical motion of the tide gauge, or abrupt shifts in trend due to tectonic events. In the figure, the 95% confidence intervals are plotted as a function of the year range of data, based on NOAA tide gauges with at least 25 years of record[1].

95% Confidence Intervals for Linear Mean Sea Level trends (mm/year)




This overview was intended to provide an introduction to the Pacific Islands regional climate, in particular those aspects that are related to sea level. This is an area of active research, and many elements, such as interdecadal oscillations, are only beginning to be appreciated. The individual country reports give greater detail on the variations experienced at the twelve SEAFRAME sites in the Pacific.

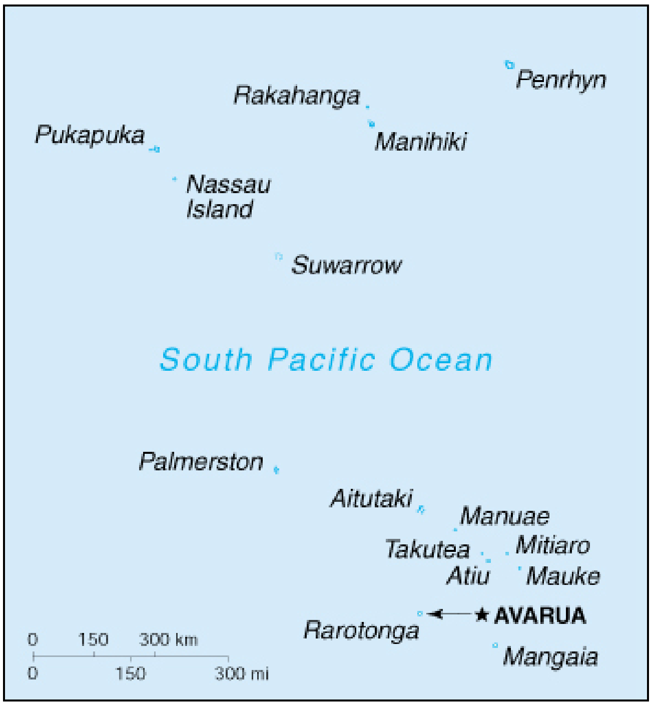
1. Zervas, C. (2001) Sea Level Variations of the United States 1854-1999. NOAA, USA.

## Project findings to date - Cook Islands

### *Short-term sea level trend*

A fundamental goal of the Project is to establish the rate of sea level change. It has been recognised since the beginning that this would require several decades of continuous, high quality data. However, in response to increasing requests from the region for information regarding the trends as they gradually emerge from the background "noise", combined with concern that less experienced users might attempt to fit a trend line to the data without properly accounting for processes such as seasonality that can bias the result, the preliminary findings are now being provided. These are given in the form of plots (see **Short Term Sea Level Trends** above) which show how the trend develops as more data becomes available. We caution against drawing conclusions prematurely.

As at June 2002, based on the short-term sea level rise analyses performed by the National Tidal Facility Australia of the approximately nine years of Rarotonga data, a rate of +1.9 mm per year has been observed (as compared to the global average, published by the IPCC, of around 1 or 2 mm per year). The Short Term Sea Level Trends plot shows how the trend estimate has varied over time, and because the data set is still relatively short, still varies considerably from month to month. In the early years, the trend appeared to indicate an enormous rate of sea level rise. During the 1997/1998 El Niño, when sea level fell 10 cm below average (once seasonal factors were subtracted), the trend actually went negative, and remained near zero for about a year. We see that it is still far too early to deduce a long-term trend (or even whether it will be positive of negative) from this data.

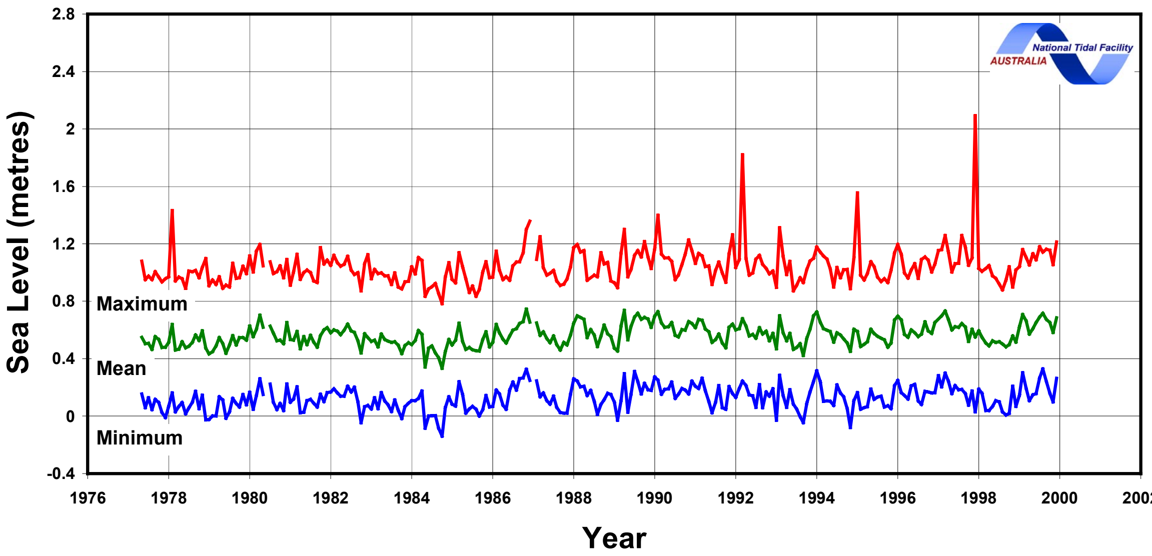


### *Historical Sea Level Trend Assessment*

Longer sea level records are available at the Cook Islands, from tide gauges at Rarotonga and Penrhyn, which each operated for about 22 years. The University of Hawaii (UH) data exhibits a sea level rise of **+3.80 and +0.89 mm/year** respectively over the interval. The gauge was designed to monitor the variability caused by El Niño and shorter- term oceanic fluctuations, for which the high level of precision and datum control demanded by the determination of sea level trend were not required. Hence, even with over twenty years of data at each site, the trend can not be established without sizeable uncertainties.

The sea level data recorded since installation is summarised in the following plot. The middle curve (green) represents the monthly mean sea level. The upper and lower curves show the highest and lowest values recorded each month.

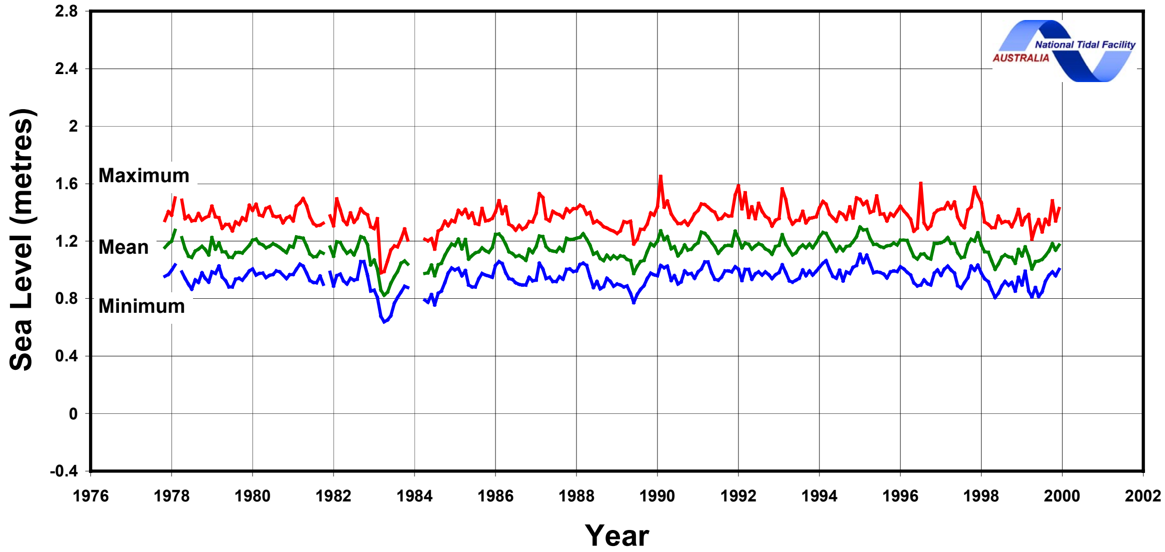
**Monthly sea level at Rarotonga**
**University of Hawaii data**



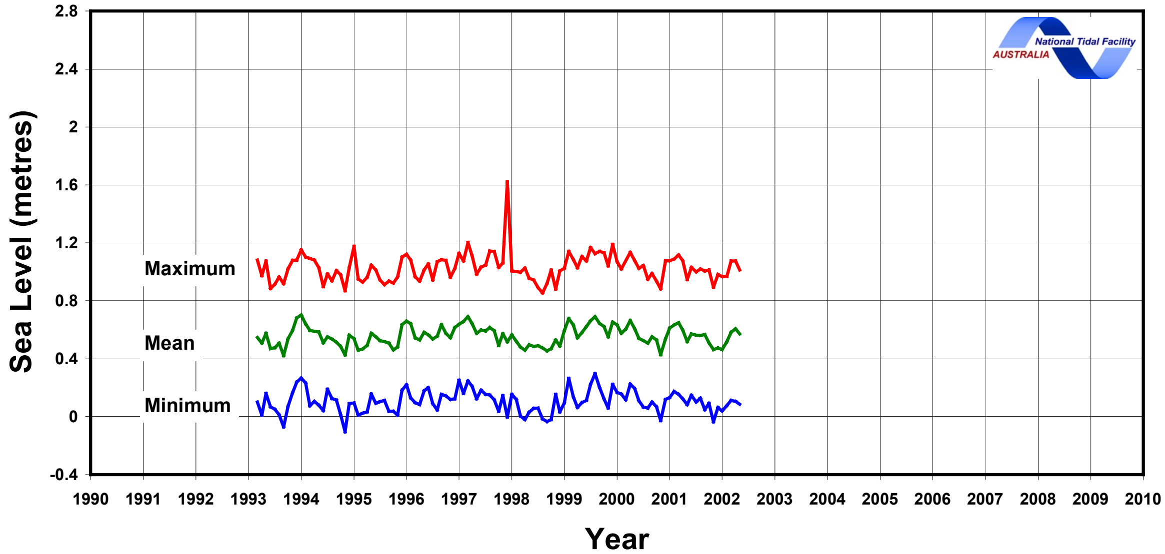

Unlike many of the SEAFRAME sites, sea level at Avatiu Harbour, Rarotonga did not experience a dramatic decrease in 1998 as a result of El Niño, although (once seasonal effects are subtracted from the data) there was a fall of about 20 cm between early 1997 and early 1998. Rarotonga is relatively far from the equator, where El Niño signals are most pronounced.

By inspection of the monthly maxima (red curve) it appears that the Cook Islands, like Tonga and Tuvalu, experiences highest sea levels near the start of the year. At mid-year, the highest sea levels are typically about 20-30 cm less than when at the maximum.

## Monthly sea level at Penrhyn
## University of Hawaii data



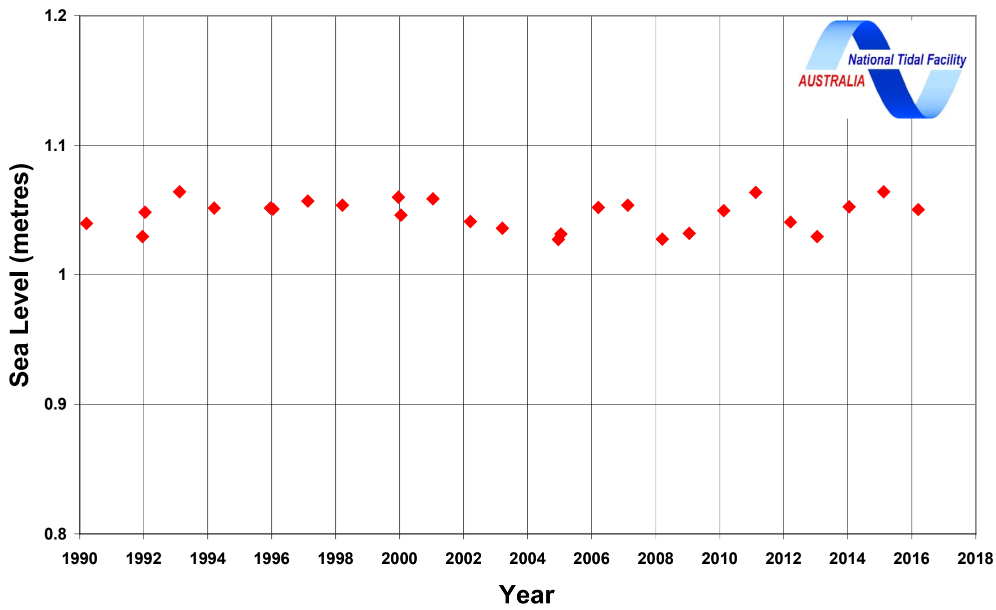

## Monthly sea level at Rarotonga
## SEAFRAME gauge



*__Predicted highest astronomical tide__*

The component of sea level that is predictable due to the influence of the Sun and the Moon and some seasonal effects allow us to calculate the highest predictable level each year. It is primarily due to the ellipticity of the orbit of the Earth around the Sun, and that of the the Moon around the Earth resulting in a point at which the Earth is closest to the Sun, combined with a spring tide in the usual 28 day orbit of the Moon around the Earth. The figure shows that the highest predicted level (1.06 m) over the period 1990 to 2016 was reached at 12:19 Local Time on 10 February 1993

**Predicted highest tide each year for Rarotonga**

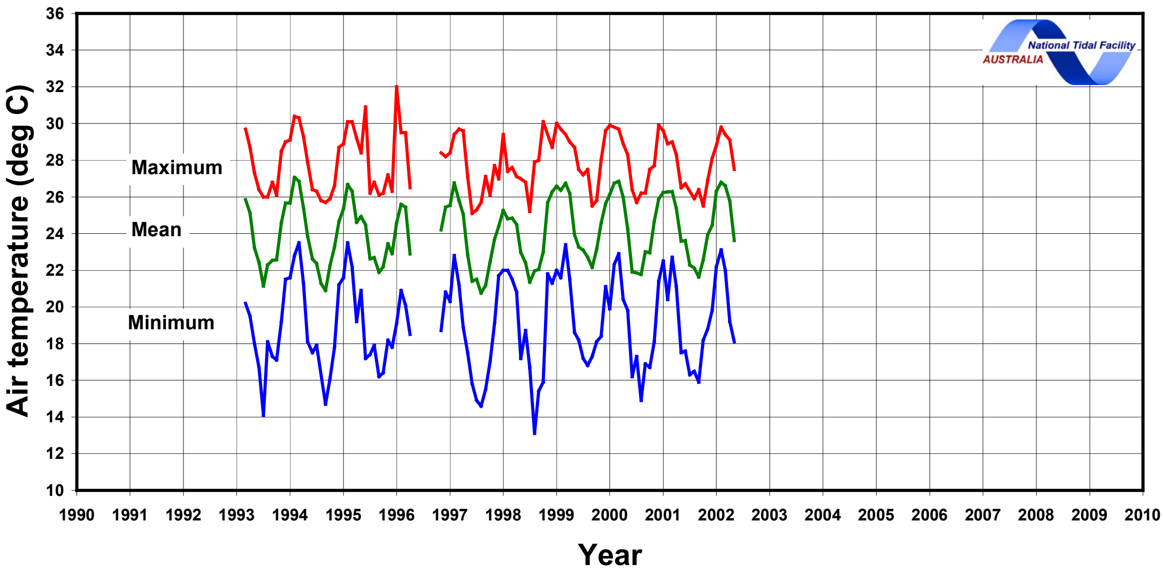



*__Monthly mean air temperature, water temperature, and atmospheric pressure__*

The data summarised in the following three plots follows the same format as the preceeding sea level plot: the middle curve (green) represents the monthly mean, and the upper and lower curves show the highest and lowest values recorded each month.

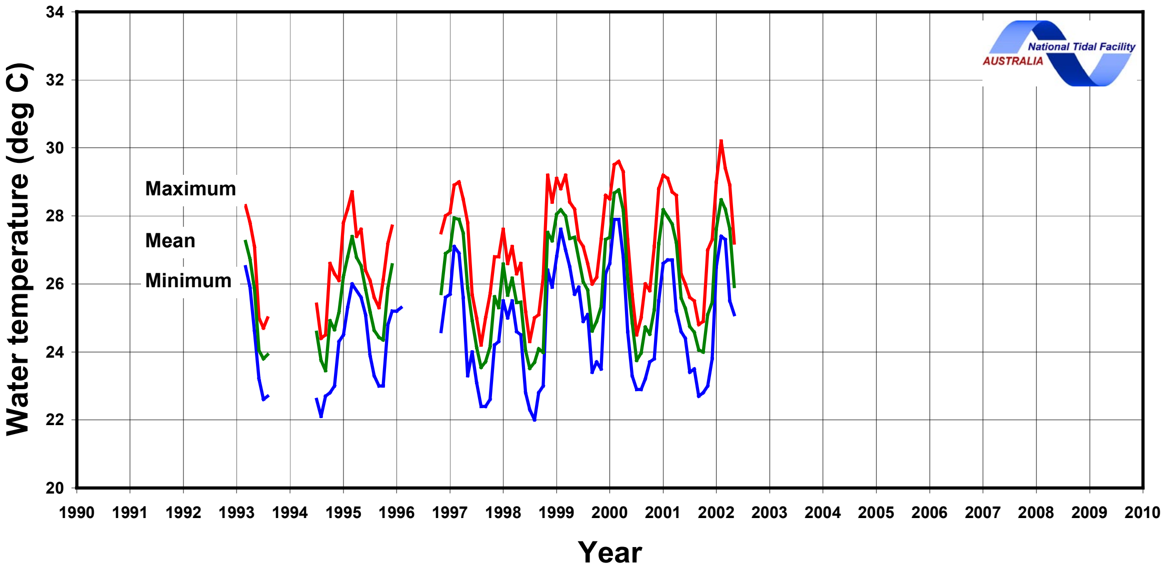
Compared to the more tropical sites, Rarotonga undergoes much greater seasonal temperature variations. The summertime highs are normally recorded in January or February. The minimum air temperature of 13.1°C was reached in August 1998, and a maximum of 32°C was reached in January 1996.

## Monthly air temperature at Rarotonga SEAFRAME gauge

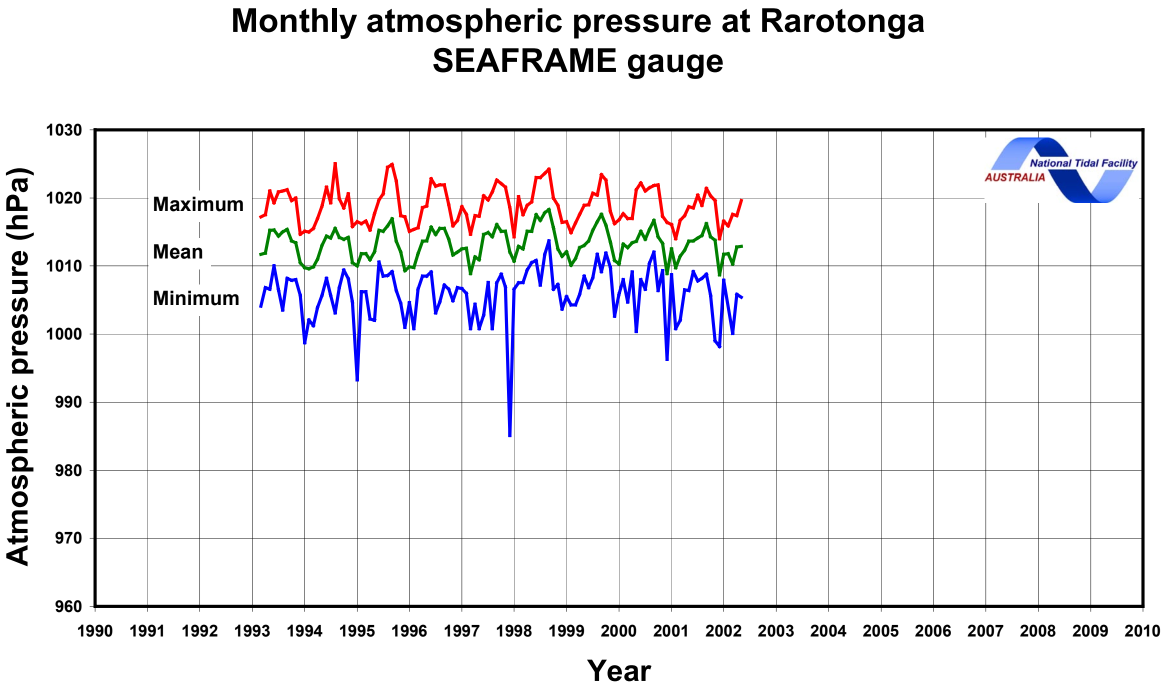



Water temperature also undergoes seasonal oscillations, which are virtually in phase with those of air temperature. Interestingly, in several years the maxima in air and water temperature come a month or two after the sea level maxima.

## Monthly water temperature at Rarotonga SEAFRAME gauge



The sea level also responds to changes in barometric pressure. As a rule of thumb, a 1 hPa fall in the barometer, if sustained over a day or more, produces a 1 cm rise in the local sea level (within the area beneath the low pressure system). The seasonal (summertime) high sea levels at Rarotonga are highly correlated with low barometric pressure systems. This is particularly the case for the very low pressure events (cyclones), most of which coincide with the highest sea levels for the year (since summer is also cyclone season). The lowest barometric pressure occurred during Cyclone Pam, in December 1997.



**Extreme Events**

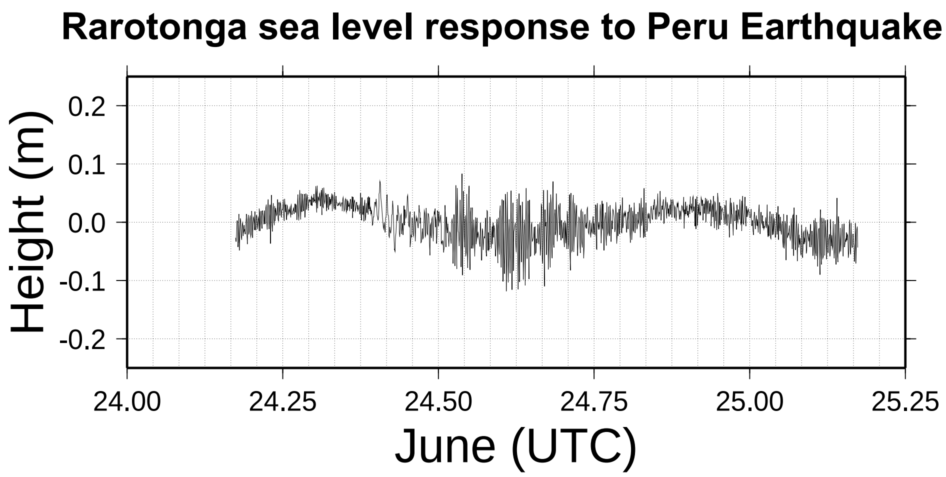
### *Tropical Cyclones*

In October/November 1997, one of the worst cyclones of the century for the Pacific region struck the northern Cook Islands. This was Cyclone Martin, which brought high winds and mountainous seas to Pukapuka, Manihiki, and Ranahanga atolls, and sadly caused a number of deaths along with great destruction. The cyclone barely affected the island of Rarotonga, which is located 1200 km south. However, six weeks later, on 9 December 1997, Cyclone Pam did pass close to Rarotonga. Low pressures and high winds caused a storm surge which flooded low-lying areas. Maximum winds recorded by the SEAFRAME were over 50 knots (92 km/hr).

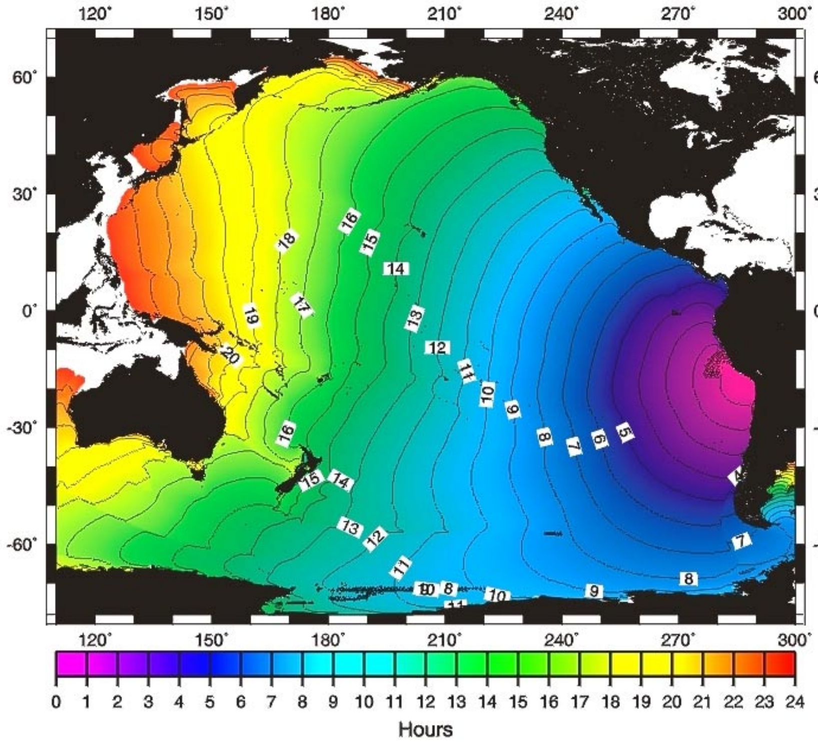
### *Tsunami records*

A tsunami can be defined as "A wave usually generated by seismic activity. Also called seismic sea wave, or, incorrectly, a *tidal wave*. Barely discernible in the open ocean, their amplitude may increase to over ten metres in the shallow coastal regions. Tsunamis are most common in the Pacific Ocean."

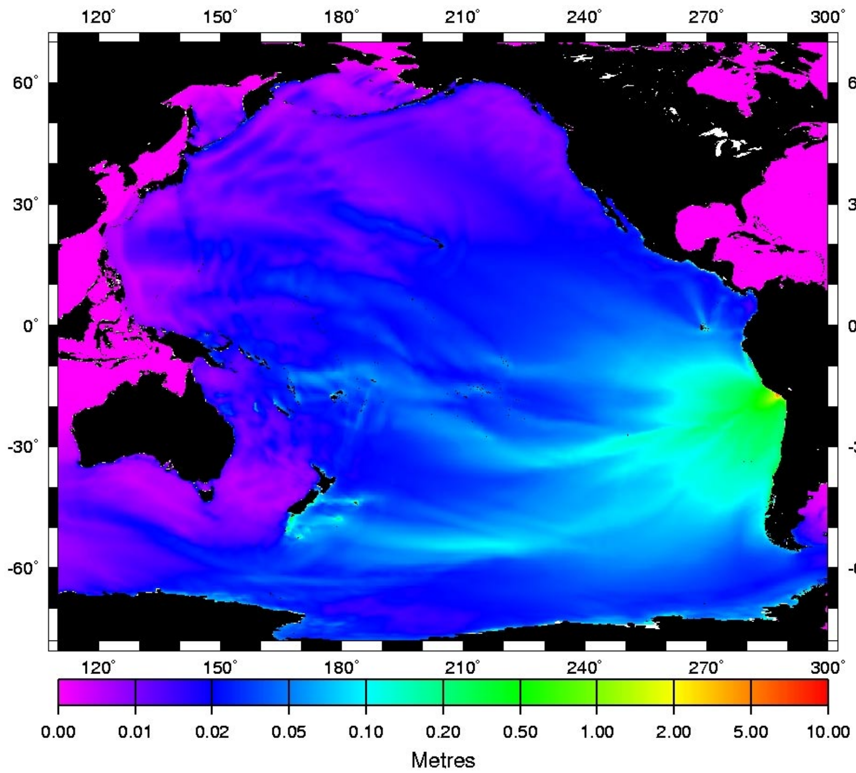
In June 2001 a tsunami was generated by an earthquake near Peru. The tsunami was detected at a number of SEAFRAME sites, with peak-to-trough amplitudes of over 20 cm at Lautoka, for example. At Rarotonga the amplitude was about 15 cm. Despite recent history, Tonga is not immune from potential problems should there be a large tsunami-generating undersea earthquake in the vicinity. The following plots show how, many hours after the initial earthquake, tsunamis can generate large disturbances in coastal locations.



## Travel Times for Tsunami Wave from Peru Earthquake



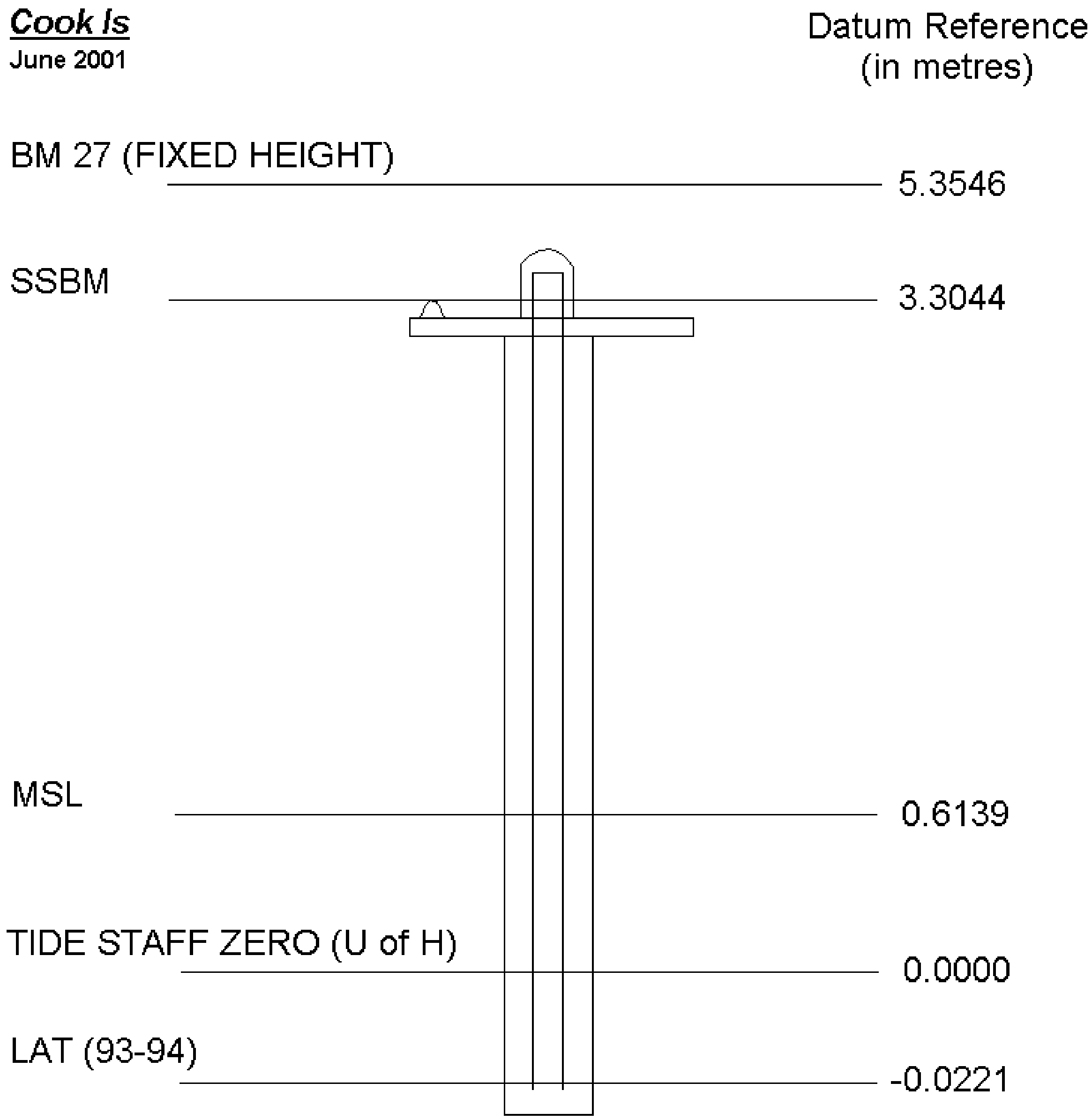

## Tsunami Wave due to Peru Earthquake (simulated magnitude)



## Definition of Datum and other Geodetic Levels at Rarotonga, Cook Islands

Newcomers to the study of sea level are confronted by bewildering references to “Chart Datum”, “Tide Staff Zero”, and other specialised terms. Frequent questions are, “how do NTFA sea levels relate to the depths on the marine chart?” and “how do the UH sea levels relate to NTFA’s?”.

Regular surveys to a set of coastal benchmarks are essential. If a SEAFRAME gauge or the wharf to which it fixed were to be damaged and need replacement, the survey history would enable the data record to be “spliced across” the gap, thereby preserving the entire invaluable record from start to finish.



The word “datum” in reference to tide gauges and nautical charts means a reference level. Similarly, when you measure the height of a child, your datum is the floor on which the child stands.

“Sea levels” in the NTFA data are normally reported relative to “Chart Datum” (CD), thus enabling users to relate the NTFA data (such as shown in the figure above) directly to depth soundings shown on marine charts – if the NTFA sea level is +1.5 metres, an additional 1.5 metres of water may be added to the chart sounding. Unfortunately, at Rarotonga the original benchmark used for the marine surveys is unrecoverable, so it is not possible to place CD on this chart. In the absence of a known CD, NTFA has chosen to refer sea level to the older UH datum, or “Tide Staff Zero” (TSZ). With this choice, the Mean Sea Level of either data set is close (though not necessarily identical).

Mean Sea Level (MSL) in the figure is the average recorded level over a period of time. The MSL at Rarotonga is 0.6139 metres above TSZ.

Lowest Astronomical Tide, or “LAT”, is based purely on tidal predictions over a 19 year period. In this case, LAT is -0.0221 metres below TSZ. If the sea level were controlled by tides alone, the sea level reported by NTFA would drop to this level just once in 19 years.