Pacific Country Report

Sea Level & Climate: *Their Present State*

Papua New Guinea

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.

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

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Executive Summary

● A SEAFRAME gauge was installed in Manus Island, Papua New Guinea, in September 1994. 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 +17.3 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.

● Variations in monthly mean sea level are dominated by seasonal cycles and by the effect of the 1997/1998 El Niño. The seasonal cycle shows a peak early in the year

● Variations in monthly mean air and water temperatures are likewise dominated by seasonal cycles and by the effect of the 1997/1998 El Niño.

● Manus Island is protected from tropical cyclones by virtue of its proximity to the equator. However, a tsunami caused numerous deaths and widespread devastation near Aitape on the northern mainland.

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Feedback

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 in Manus Island, in September 1994. Aside from a ten month interval when the wharf was being refurbished, 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.

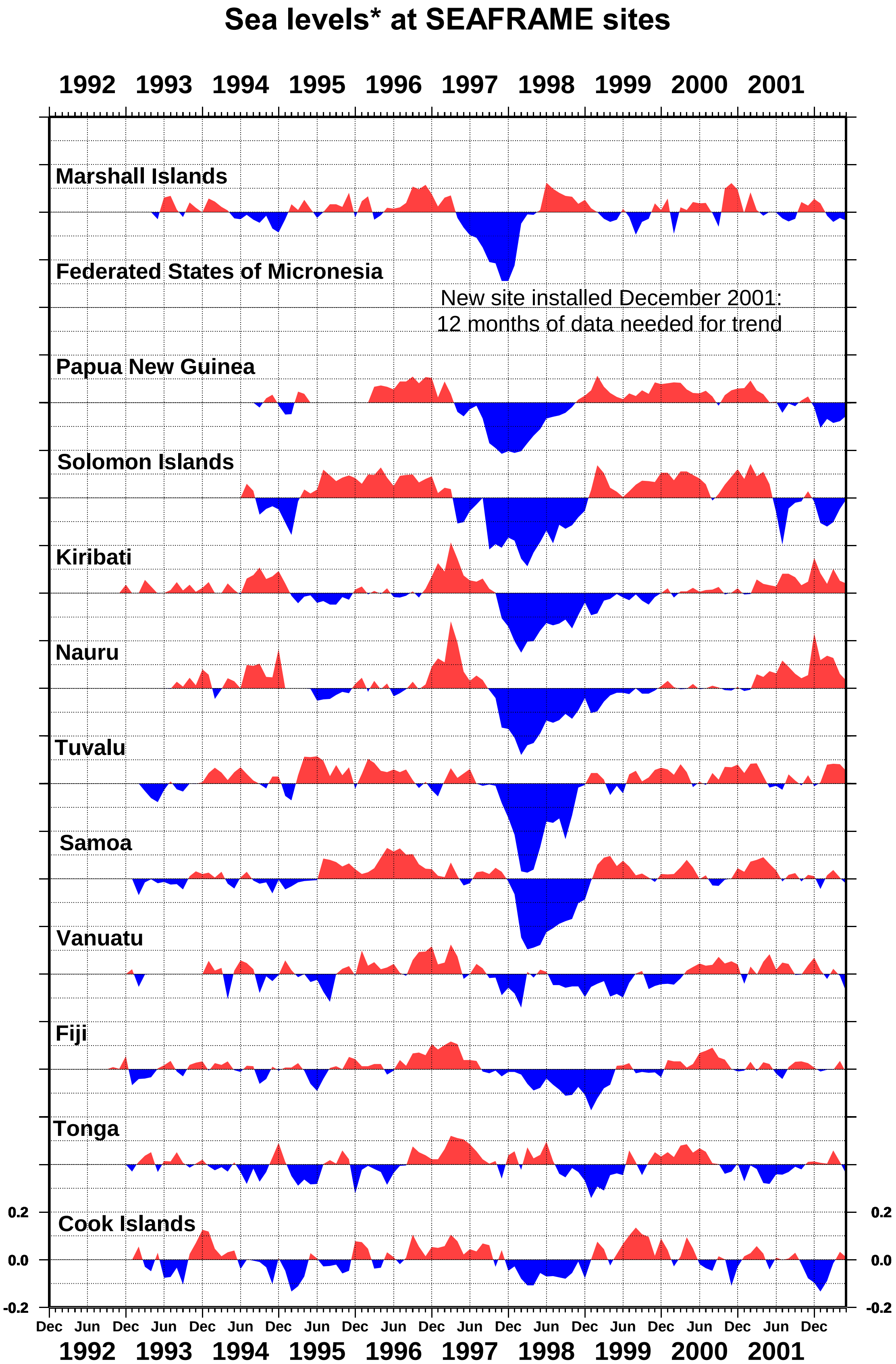
Regional Overview

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

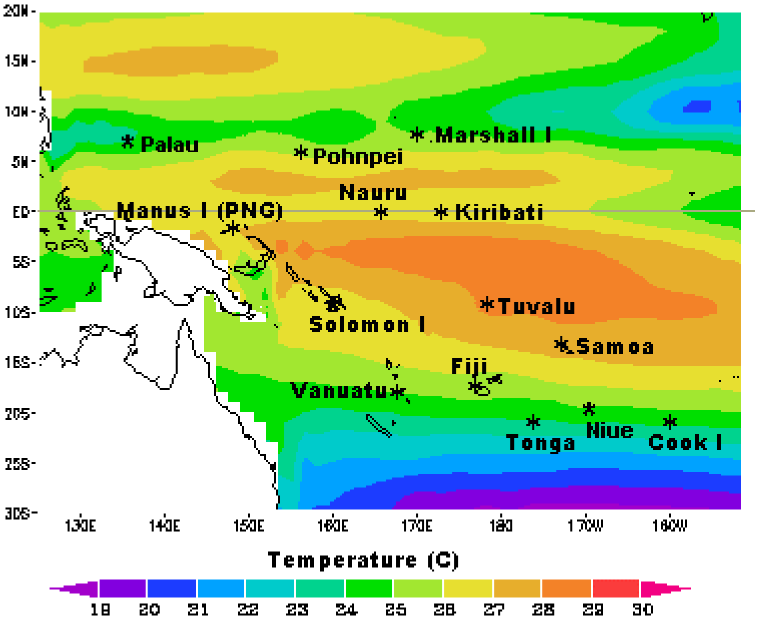
The most striking oceanic and climate fluctuations in the equatorial region are not the seasonal, but interannual changes associated with El Niño. These affect virtually every aspect of the system, including sea level, winds, precipitation, and air and water temperature. Referring to the plot below, 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.



* 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.

Mean Surface Water Temperature

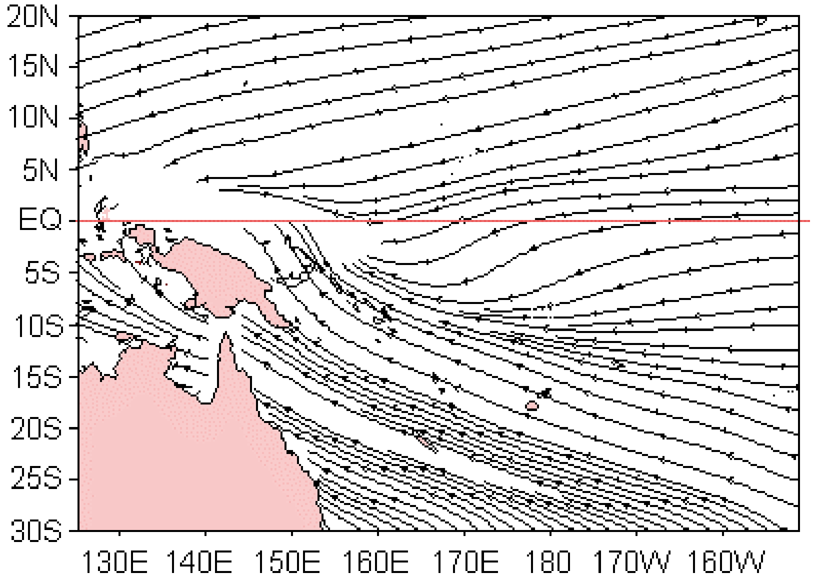


Note the warm temperatures in the STCZ and just north of the equator.

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.

Streamlines of Mean Surface Wind



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

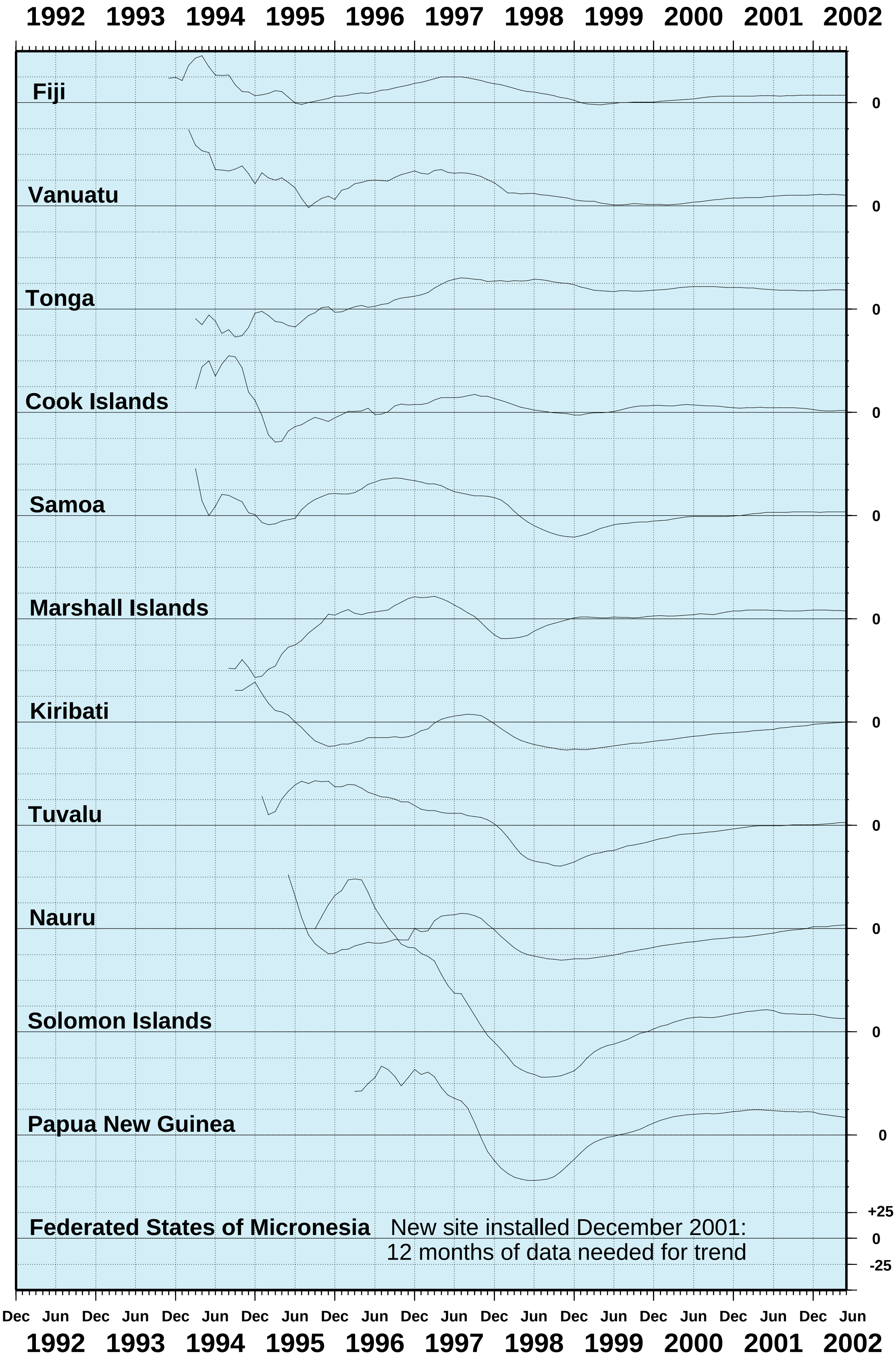
With the great diversity in climatic environments, vertical land movement and ocean variability, one might expect that that the sea level trends measured at different stations over the limited period for which tide gauge data has been collected may also vary. That this is indeed the case is demonstrated 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

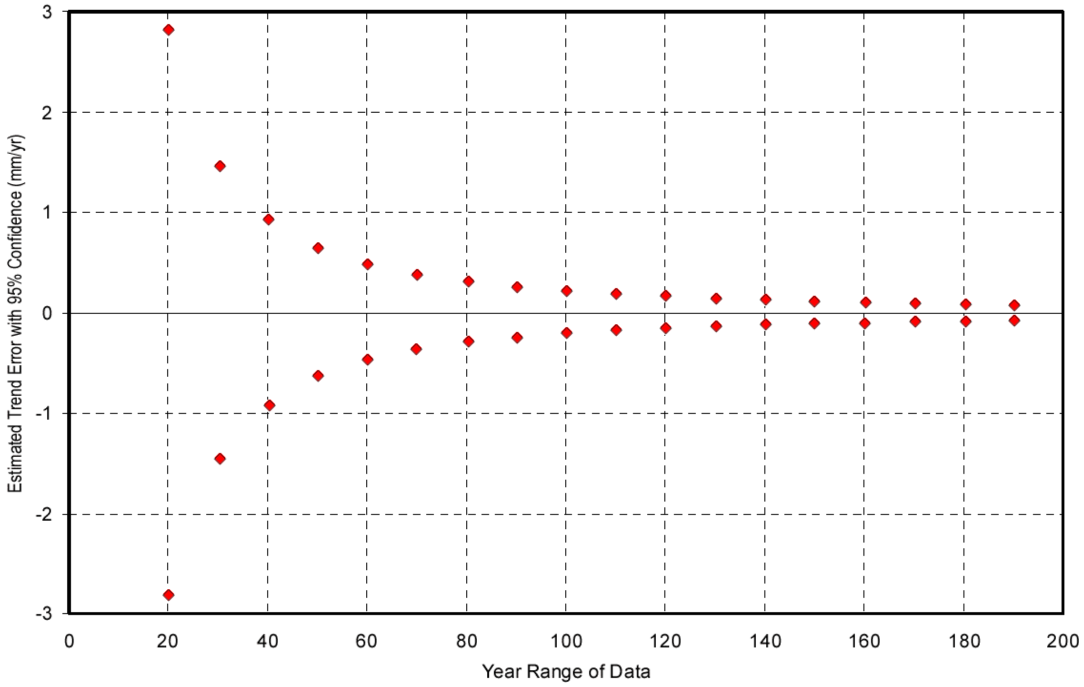
The following plot depicts the evolution of the short term sea level trends, at SEAFRAME stations, from one year after installation to the present. Please note that the trendlines have not yet stabilised.

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 – Papua New Guinea

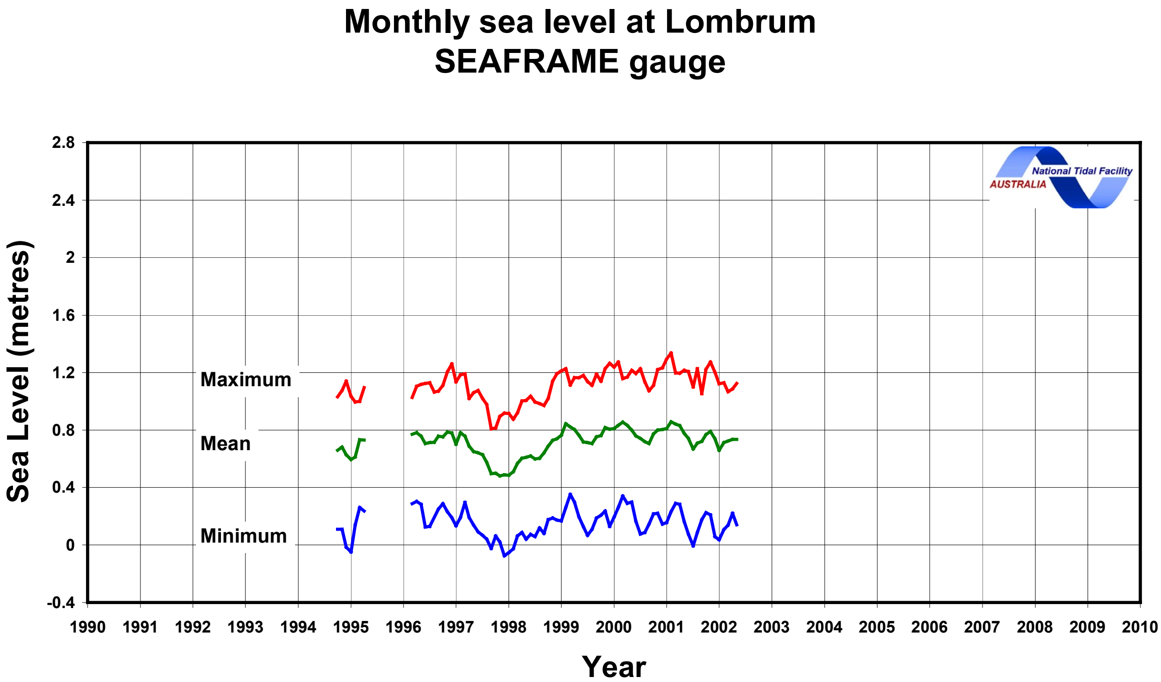
Short-term sea level trend

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 over six years of Manus Island data, a rate of +17.3 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. Later, due to the 1997/1998 El Niño when sea level fell 20 cm below average, the trend actually went negative, and remained so for the next year or more. Only in mid-1999 did the trend return to positive values. 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.

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. Like many of the SEAFRAME sites, sea level at Manus Island experienced a dramatic decrease in 1998 as a result of El Niño. Manus Island is very close to the equator, where El Niño signals are most pronounced.

By inspection of the monthly maxima (red curve) it appears that Manus Island experiences highest sea levels near the start of the year. At mid-year, the highest sea levels are typically about 10 cm less than when at the maximum. However, this pattern does not occur every year, and the seasonal cycle is particularly disrupted during the El Niño.

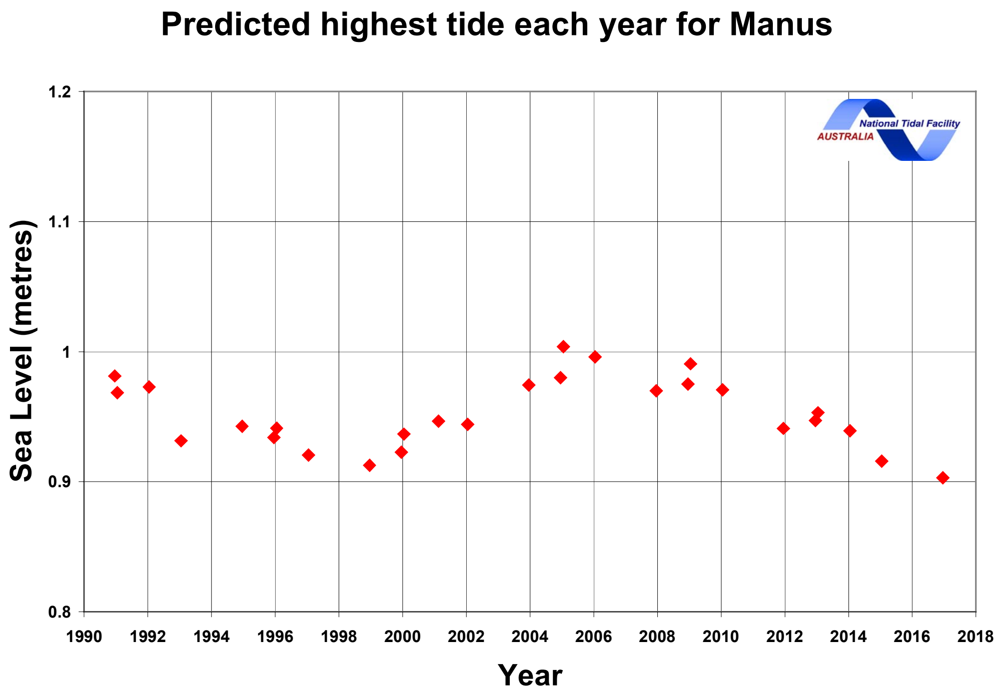


Historical Sea Level Trend Assessment

A number of tide gauges have operated for various periods of time around PNG. Most of these were installed in the mid-1980s, but a gauge at Rabaul began in 1966. Unfortunately, tectonic activity in the Rabaul region, and the shortness of the other records, has resulted in a situation where none of these gauges add meaningful information about the interannual and longer term sea levels.

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 (1.00 m) over the period 1990 to 2016 was reached at 15:36 Local Time on 10 January 2005.

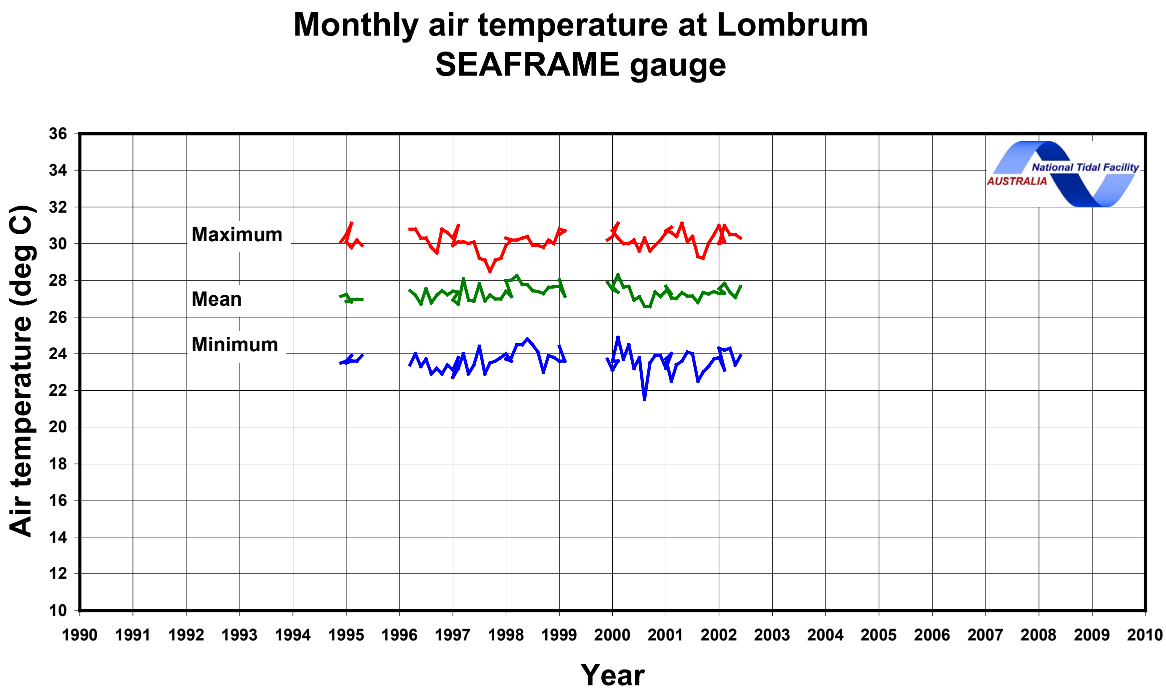


Monthly mean air temperature, water temperature, and atmospheric pressure

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.

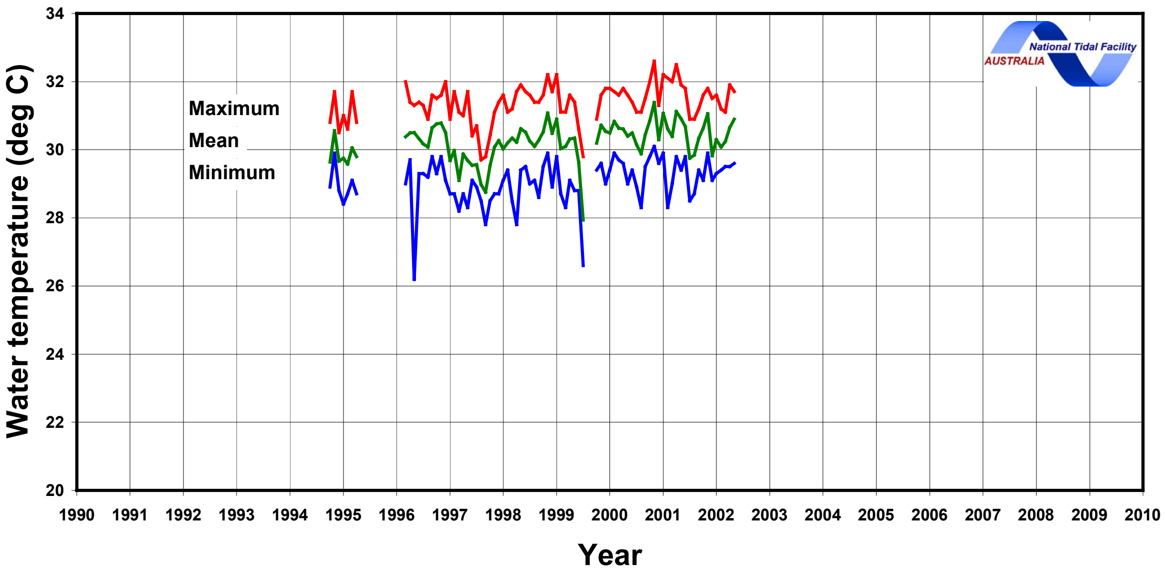
Compared to the sites further from the equator, Manus Island, PNG, undergoes much less seasonal temperature variation. However, the summertime highs are normally recorded in December, January, or February, during the northwest monsoon. The minimum air temperature of 21.5°C was reached on 20 July 2000, and a maximum of 31.1°C was reached on 15 December 1994.

The mean monthly air temperature does not show a clear response to the 1997/1998 El Niño, but during the early stages (mid-1997) the monthly maximum air temperature fell sharply.



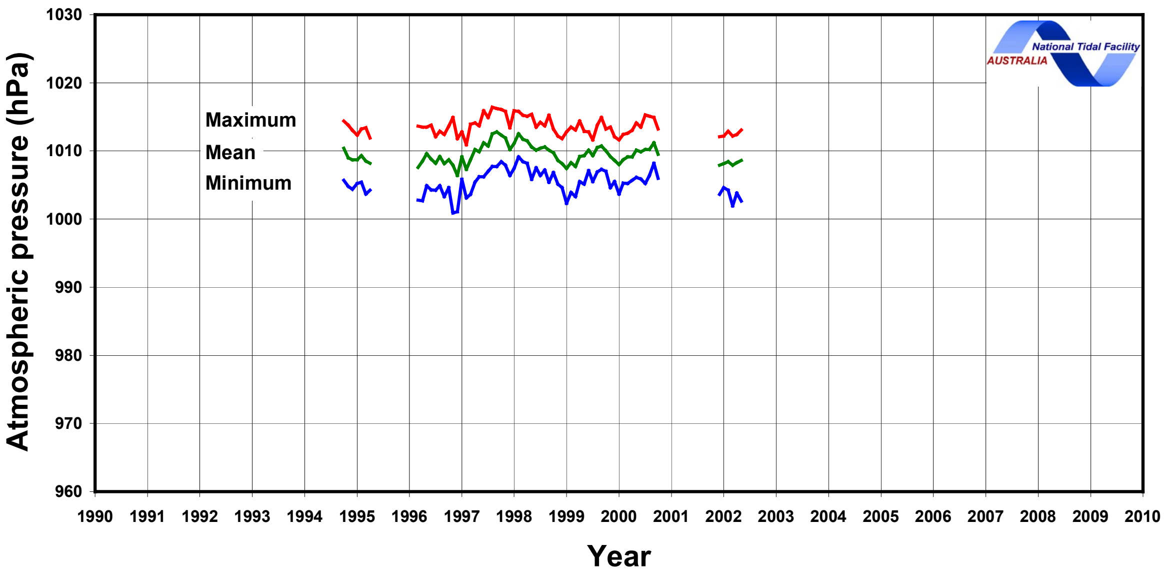
At this location, a region of strong western boundary currents, it is difficult to pick out a seasonal cycle of water temperature in the SEAFRAME records. Mean water temperatures of about 2° below normal during the 1997/1998 El Niño were recorded, as the result of the well-known re-distribution of heat that occurs during these events. Two episodes of low water temperatures occurred at Lombrum, in May 1996 and again in July/August of 1999. The air temperatures at these times appear to have remained normal. Their cause is uncertain, but may be the result of unusual ocean currents entering the harbour. Over the entire period (1995-2002), the mean water temperature was 30.2°C. The highest recorded water temperature was 32.6°C in November 2000, and the minimum was 26.1°C in August 1999.

Monthly water temperature at Lombrum 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). For example, looking at the monthly sea level plot, we see there was a small peak in sea level at the start of 1999, which coincides with a dip in atmospheric pressure. The lowest barometric pressure occurred on 4 November 1996.

Monthly atmospheric pressure at Lombrum SEAFRAME gauge



Extreme Events

Manus Isaland, PNG, being within 3° of the equator, is not subject to cyclones. However, in the period since installation, PNG was hit by a tsunami with tragic consequences for the local people. This occurred on 17 July, 1998, near Aitape, PNG.

Tsunami records

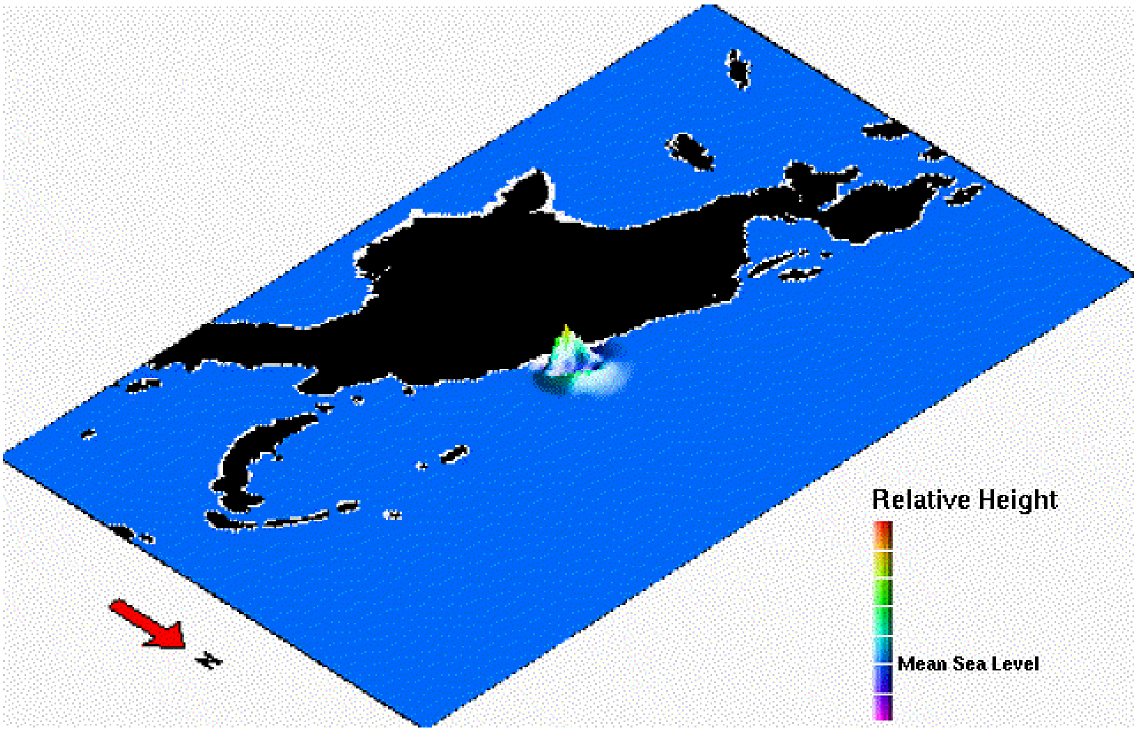
A tsunami can be defined as "A wave usually generated by seismic activity. Also called seismic sea wave, or, incorrectly, a *tidal wave*. Barely discernible in the open ocean, their amplitude may increase to over ten metres in the shallow coastal regions. Tsunamis are most common in the Pacific Ocean."

The Aitape tsunami followed an arthquake which occurred about 15 km offshore in about 1500 metres water depth. It is thought that the earthquake triggered an underwater landslide which in turn produced the tsunami. When the tsunami reached the coast, it built up in height. The following account is largely based on the United Nations Disaster Assessment (UNDAC) Team Mission report, written shortly after the event.

At approximately 1930 local time on Friday 17 July 1998 an earthquake of magnitude 7 on the Richter Scale occurred just off the north-west coast of Papua New Guinea some 35 km north-west of Sissano Lagoon. Although the tremor was felt over a large area, no direct earthquake damage has been reported. However, approximately 10 minutes after the tremor, the first of three 7 to 10 metre tsunami waves came ashore in Sandaun Province. Although the tsunami was experienced along 50 km of the coast west of the regional centre of Aitape, the worst affected area was a 25 km strip from Sissano to Malol. The coastline consists of low beaches, 3 to 4 metres high, and up to 100 metres wide, protecting extensive inland lagoons and waterways. The tsunamis, which struck at high speed shortly after dark, appear to have penetrated up to 1 km inland to an average distance of about 0.5 km. Where the water and debris crossed into lagoons, the penetration was deeper. The water receded quickly. The main impact area now presents a picture of almost total destruction, being stripped of all buildings and habitation and all vegetation except surviving mature coconut trees. Vegetation and house debris is still visible on or below the surface while the inland boundaries of all lagoons and waterways are lined with a thick layer of debris. No accurate census of the affected area has been carried out recently but extrapolation of the 1990 census, the best available, indicates that approximately 9,000 people lived in the affected villages. Casualty figures indicate that there are more than 2,100 dead, 668 with major injuries that required attention from regional and visiting hospital teams and many more with minor injuries treated by mobile medical teams. 500 or more people are missing.

There are still bodies in the lagoons and inland debris zones but the difficulties of finding and retrieving them, their condition, and the presence of crocodiles led to the search being abandoned. Sissano Lagoon has been declared a no-go area for health and cultural reasons. Most casualties appear to have been caused when people were battered by debris as they were swept away by the wave. Large numbers of bone fractures, lacerations and soft tissue injuries occurred. A number of people also suffered pneumonia after salt-water inhalation. Many of the casualties were children. A number of coastal villages, from Sissano to Malol, were completely destroyed. Others were partially destroyed and isolated housing damage was experienced even to the east of Aitape. The tsunami destroyed three schools, a health sub-centre, a health aid post, a number of mission buildings and churches as well as the government administration centre at Sissano. Two bridges on the road between Aitape and Malol were destroyed or damaged. Few crops were damaged, as food gardens are inland. Coastal vegetation inundated by the tsunamis may not survive, although the coconut trees that were not knocked down will. Secondary impacts to-date have been confined to salt water contamination of wells in some surviving coastal villages and coliform contamination of coastal lagoons and waterways. No epidemics have been reported either at the coast or among those affected by the disaster. No increase in malaria cases has occurred. The disaster has had an economic impact as copra production will be reduced to some degree by the destruction of coconut trees. Fishing income may also be reduced by local concerns about the safety of fish caught in the affected zone and by the restrictions placed on transit of boats through the lagoons to the open sea. Survivors immediately began local rescue operations and were gradually joined by church workers, police and provincial officials from Saturday 18 July. Commercial helicopter operators and mining companies also deployed resources to the area. Search and rescue operations continued until survival was considered impossible. Recovery and burial or cremation of bodies continued until the state of bodies began to make this impractical. An area around Sissano Lagoon in which most bodies seem to be lying was declared a no-go area on 23 July. Private individuals, non-government organisations (NGOs) community groups, churches, business and commercial agencies and other provincial governments all contributed. Within Sandaun Province, volunteers performed a wide variety of tasks from loading and unloading aircraft to feeding casualties in hospitals. International Response. Although this was not the largest of events on an international scale and confined to a small and clearly defined area, its rarity, the lack of warning and the circumstances caught the imagination and sympathy of the world.

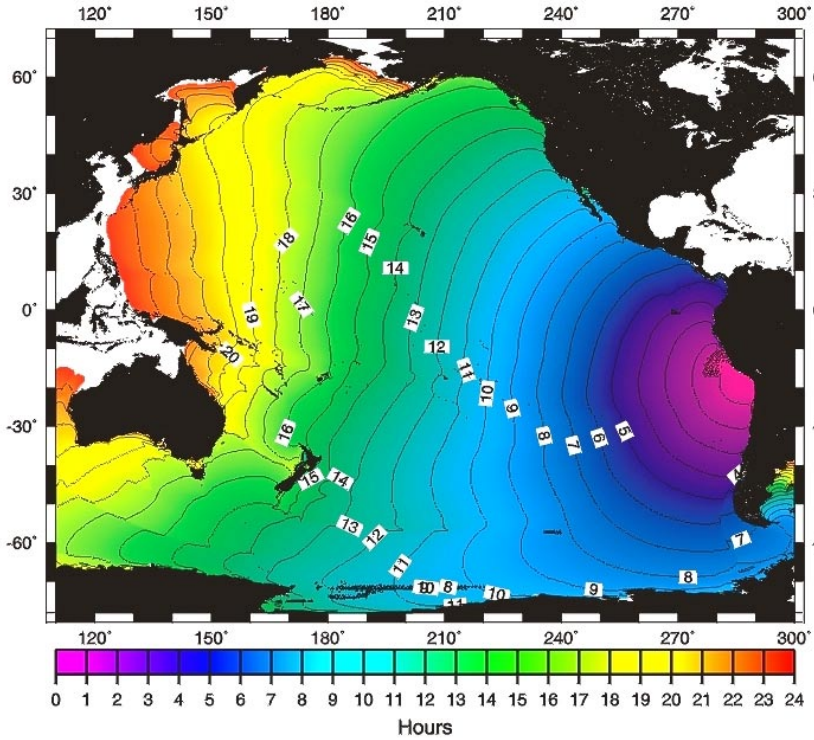
17 July 1998 PNG Tsunami



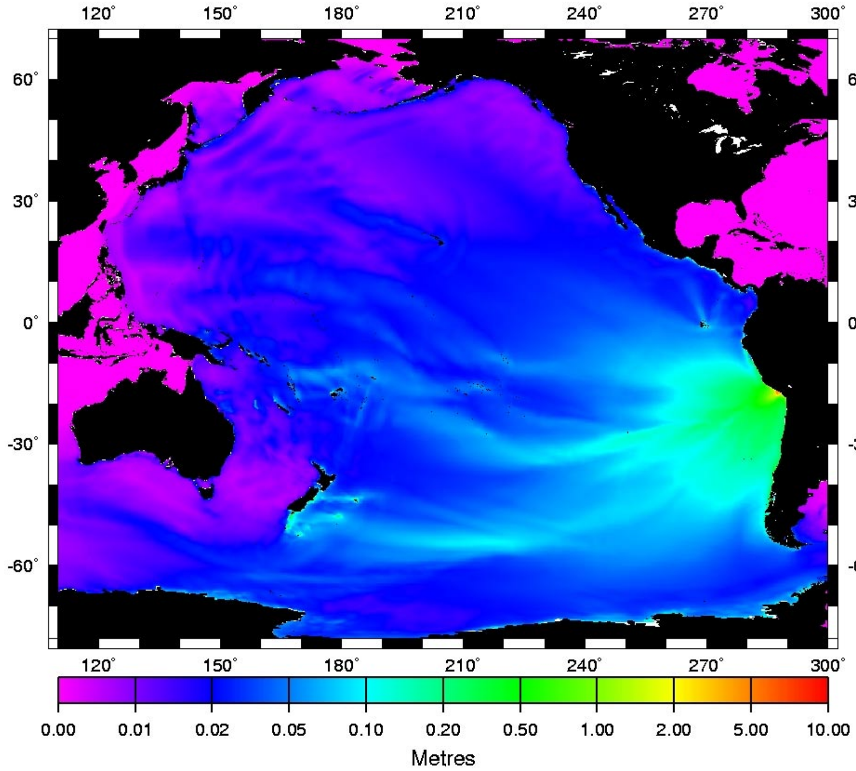
Sissano Lagoon, site of devastation from 17 July 1998 PNG Tsunami

Obviously, PNG is vulnerable to 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



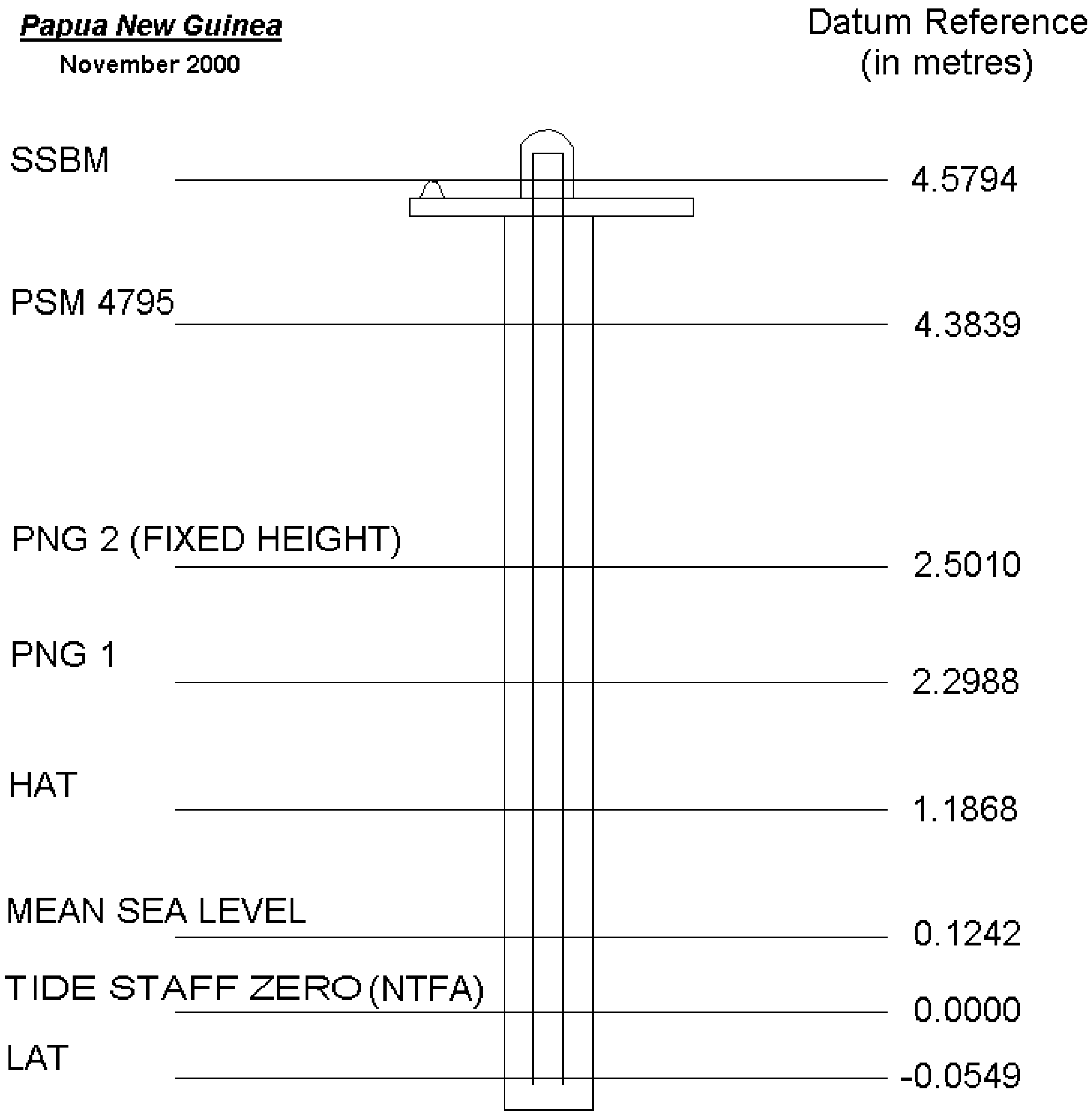
Tsunami Wave due to Peru Earthquake (simulated magnitude)



Definition of Datum and other Geodetic Levels at Manus Island, PNG

Newcomers to the study of sea level are confronted by bewildering references to "Chart Datum", "Tide Staff Zero", and other specialised terms. Frequently asked 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 needed 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 relation 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 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 depths.

Mean Sea Level (MSL) in the figure is the average recorded level at the gauge over an extended period. MSL at Lombrum was 0.1242 metres above the SEAFRAME zero level.

Lowest Astronomical Tide, or “LAT”, is based purely on tidal predictions over a 19 year period. In this case, LAT is -0.0549 metres, meaning that 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. Likewise, the sea level would rise to +1.1868 metres (HAT) once in the same interval.