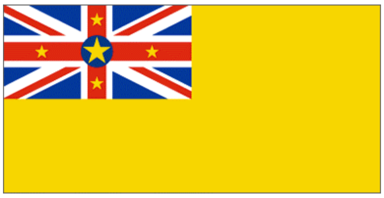
Pacific Country Report

Sea Level & Climate:
Their Present State

Niue

December 2008

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



NIUE

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Executive Summary

- SEAFRAME gauges have been installed in a number of Pacific Island locations, beginning in 1992. They record sea level, air and water temperature, atmospheric pressure, wind speed and direction. They form an array designed to monitor changes in sea level and climate in the Pacific.

- No SEAFRAME gauge has yet been installed at Niue.

- This report summarises the findings to date, based on available regional and historical data for Niue.

- The nearest sea level gauge with a long term record (but less precision and datum control than the SEAFRAME gauges), shows a trend of +2.1 mm/year (as compared to a global long-term average trend of 1-2 mm/year).

- Variations in monthly mean sea level include a moderate seasonal cycle and were affected by the 1997/1998 El Niño.

- Variations in monthly mean air and water temperature include pronounced seasonal cycles and were likewise affected by the 1997/1998 El Niño.

- Tropical Cyclone Heta passed Niue as a category 5 cyclone in January 2004 and caused severe devastation.

- The tsunami caused by the Vanuatu earthquake of 26 November 1999, which registered strongly on many Pacific SEAFRAME gauges, registered about 15 cm at a now-inoperative Pacific Tsunami Warning Center gauge at Niue.

Contents

1. 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, **SEAFRAME** (**Sea** Level **F**ine **R**esolution **A**coustic **M**easuring **E**quipment) gauges have been installed in twelve forum countries. This report provides background information regarding sea level and climate in the region of Niue based on available data.

As far as could be determined by this study, the only pre-existent climate monitoring based at Niue is the data collection from the local meteorological office. A tsunami-warning gauge (similar to a tide gauge) was installed at one time, but is no longer operative.

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 vertical movement of the sea level sensors due to local land movement. Continuous Global Positioning System (CGPS) 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 rate at which the land moves must be measured separately. This is the reason for the addition of CGPS near the tide gauges.

2. Regional Overview

2.1. Regional Climate and Oceanography

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.

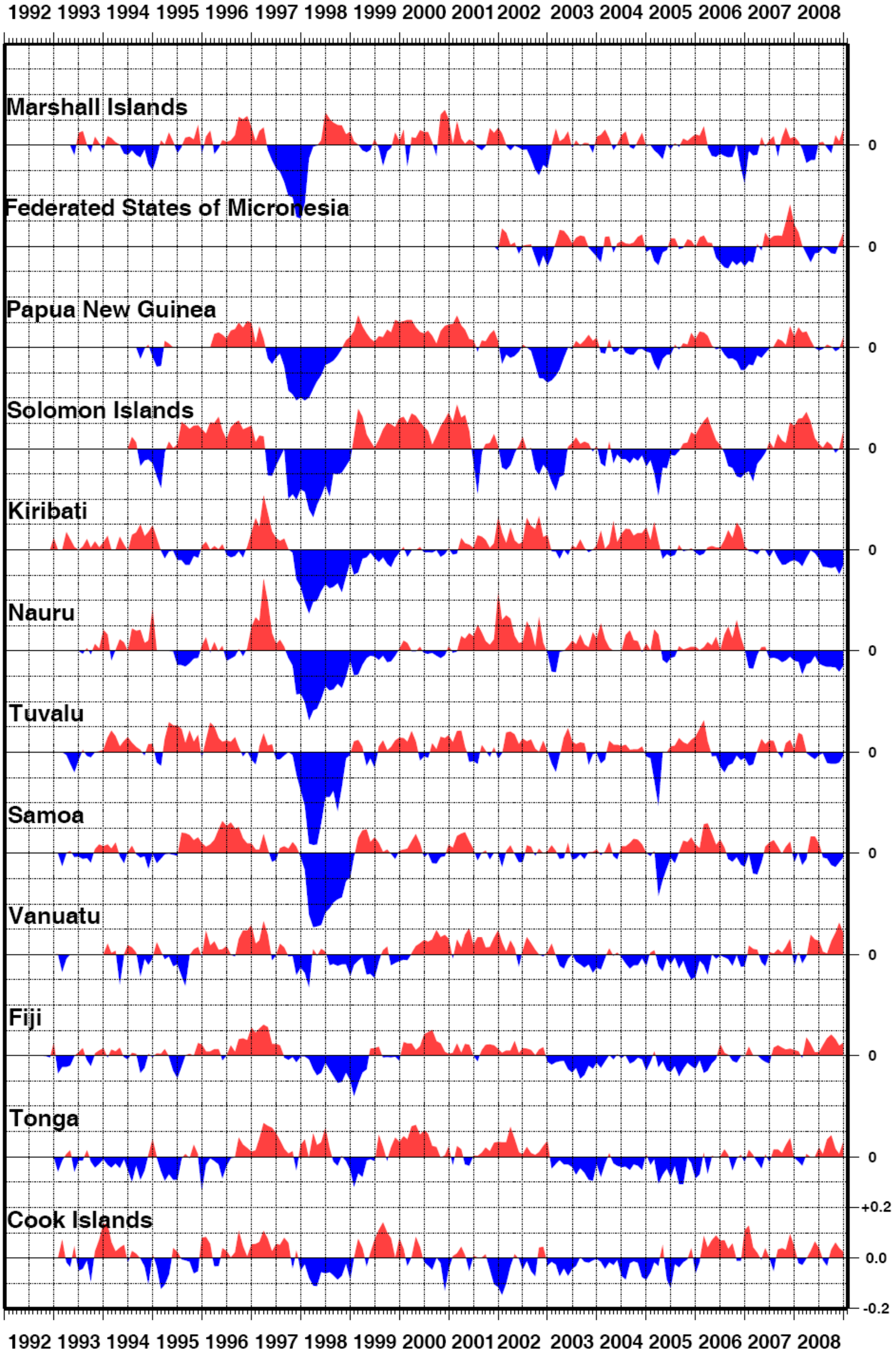
Compared to higher latitudes, air temperatures in the tropics vary little throughout the year. Of the SEAFRAME sites, those furthest from the equator naturally experience the most extreme changes – the Cook Islands (at 21°S) recorded the lowest temperature, 13.1°C, in August 1998. The Cook Islands regularly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

Table 1. Range in air temperatures observed at SEAFRAME stations

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	33.8
Vanuatu	15.2	33.3
Samoa	18.7	32.3
Tuvalu	22.8	33.7
Kiribati	22.4	32.9
Nauru	22.4	33.0
Solomon Islands	20.1	34.5
Papua New Guinea	21.5	31.8
Marshall Islands	20.9	32.1
FSM	22.6	31.8

The most striking oceanic and climatic 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 Figure 1, 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 “South Pacific Convergence Zone” or SPCZ (sometimes called the “Sub-Tropical Convergence Zone”, or STCZ).

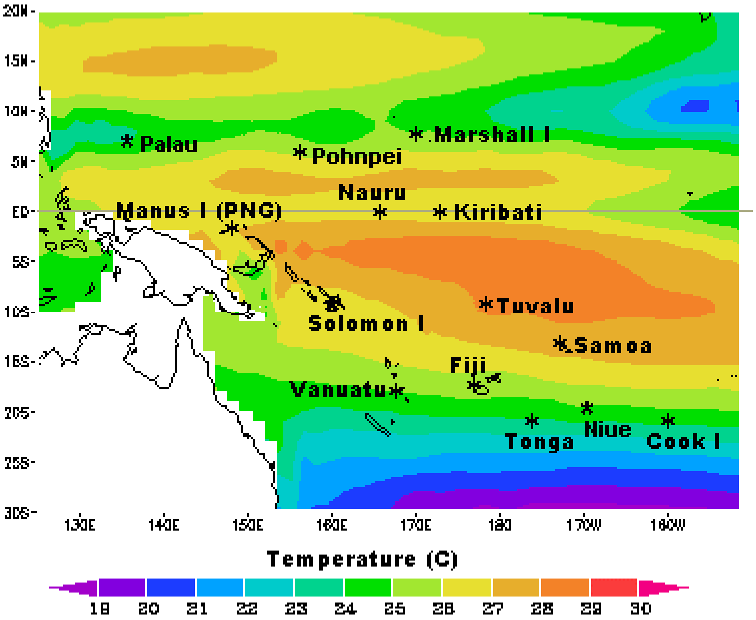
Figure 1. Sea level anomalies* at SEAFRAME sites



* Sea level "anomalies" have had tides, seasonal cycles and trend removed from the sea level observations.

Most Pacific Islanders are very aware that the sea level is controlled by many factors, some periodic (like 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 months. 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 SPCZ, 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.

Figure 2. Mean surface water temperature

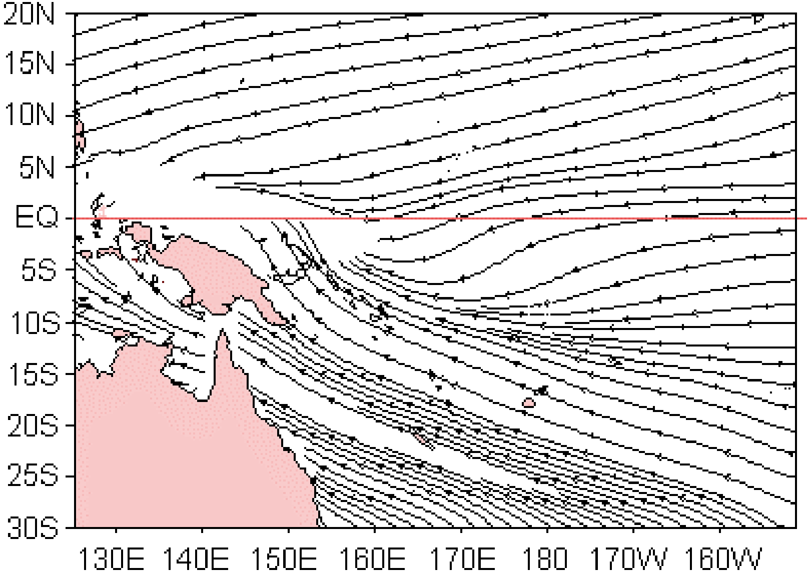


Note the warm temperatures in the SPCZ and just north of the equator.

The convergence of the Trade Winds along the SPCZ 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 SPCZ, 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 Streamlines of Mean Surface Wind (Figure 3) show 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 SPCZ.

Figure 3. Streamlines of mean surface wind



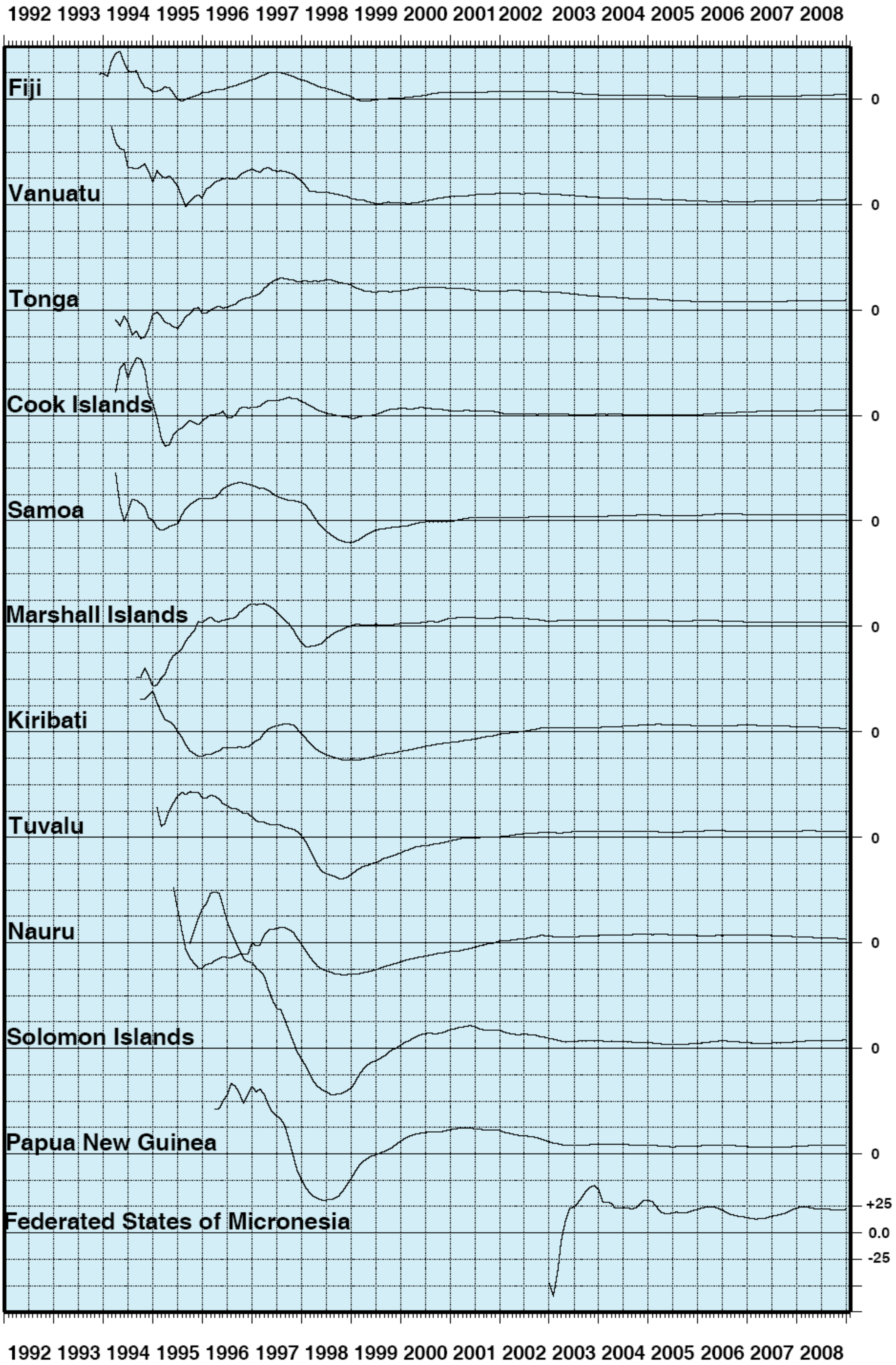
Much of the Melanesian subregion is also influenced by the Southeast Asian Monsoon. The strength and timing varies considerably, but at Manus Island (PNG), for example, the NW monsoon season (winds from the northwest) runs from November to March, while the SE monsoon brings wind (also known as the Southeast 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).

2.2. Sea Level Datasets from SEAFRAME stations

A key objective of the South Pacific Sea Level and Climate Monitoring Project (SPSLCMP) is to provide an accurate long-term sea level record. SEAFRAME stations were installed from 1992 onwards to provide precise relative sea level measurements. The SEAFRAMES undergo regular calibration and maintenance and are levelled against a network of land-based benchmarks to maintain vertical datum control. The SEAFRAME observations are transmitted hourly via satellite and are processed using specific quality control procedures.

The project's data collection program has been operating for a relatively short term and therefore the sea level trends are still prone to the effects of shorter-term ocean variability (such as El Niño and decadal oscillations). As the data sets increase in length, the trend estimates will begin to reflect longer-term change rather than short-term fluctuations. Figure 4 shows how the sea level trends from SEAFRAME stations have evolved from one year after installation to the present. These trends will continue to stabilise for many more years, as is demonstrated by Figure 6.

Figure 4. Evolution of relative sea level trends (mm/year) at SEAFRAME stations. The trends continue to stabilise as the lengths of records increase.



2.2.1 Vertical datum control of SEAFRAME sensors

Precise levelling of the height of the SEAFRAME sea level sensor relative to an array of land-based benchmarks is undertaken periodically, preferably every eighteen months. The precision to which the survey must be performed is dependent on the distance K_m (km) between the SEAFRAME sensor benchmark and the primary tide gauge benchmark (TGBM) and forms part of the project's design specifications.

The precise levelling program enables the vertical stability of the SEAFRAME stations to be monitored. Referencing the sea levels to land is especially important if the SEAFRAME needs to be replaced or relocated, or is displaced by a boat or a storm. The rates of vertical movement of the gauges relative to the TGBM (determined by fitting a straight line to the survey results) that are contributing to the observed sea level trends are listed in Table 2. Substantial subsidence of the tide gauge at Samoa is occurring at a rate of -1.0 mm/year. Subsidence is also occurring at Marshall Islands. The tide gauges at Cook Islands and Fiji are rising with respect to the tide gauge benchmark. The rates of vertical tide gauge movement are used to correct observed rates of relative sea level change.

Table 2. Distance (km), required survey precision (mm), number of surveys and the rate of vertical movement of the SEAFRAME relative to the TGBM.

Location	**K_m (km)**	**$\pm 2\sqrt{K_m}$ (mm)**	**Number of Surveys**	**Vertical movement (mm/year)**
Cook Is	0.491	1.4	8	+0.3
FSM	0.115	0.7	2	-0.4
Fiji	0.522	1.4	8	+0.5
Kiribati	0.835	1.8	9	+0.1
Marshall Is	0.327	1.1	8	-0.6
Nauru	0.120	0.7	9	+0.2
PNG	0.474	1.4	7	-0.1
Samoa	0.519	1.4	8	-1.0
Solomon Is	0.394	1.3	4	-0.4
Tonga	0.456	1.4	8	-0.7
Tuvalu	0.592	1.5	8	-0.1
Vanuatu	1.557	2.5	7	+0.1

Continuous Geographical Positioning Systems (CGPS) stations have also been installed on all of the islands where SEAFRAME gauges are located. The purpose of the CGPS program is to close the final link in establishing vertical datum control – that is, to determine whether the island or coastal region as a whole is moving vertically with respect to the International Terrestrial Reference Frame. Early estimates of the rates of vertical movement are being calculated by Geosciences Australia but continued monitoring is necessary before meaningful results emerge from the CGPS time series data. The latest CGPS information for the project is available from Geosciences Australia at
http://www.ga.gov.au/geodesy/slm/spslcmp/

2.2.2. Inverted barometric pressure effect

Atmospheric pressure is another parameter that can potentially influence relative sea level rise. Known as the inverted barometer effect, if a 1 hPa fall in barometric pressure is sustained over a day or more, a 1 cm rise is produced in the local sea level (within the area beneath the low pressure system). Trends in barometric pressure over a period of time will cause changes in relative sea level. A 1 hPa/year decrease (increase) in barometric pressure for example will cause a 10 mm/year increase (decrease) in relative sea level.

Estimates of the contribution to relative sea level trends by the inverted barometric pressure effect at all SEAFRAME sites over the period of the project are listed in Table 3. The estimates are mostly positive, which means relative sea level trends are being overestimated without taking the barometric pressure effect into consideration.

Table 3. Recent short-term barometric pressure trends expressed as equivalent sea level rise in mm/year based upon SEAFRAME data to December 2008.

Location	**Installed**	**Barometric Pressure Contribution to Sea Level Trend (mm/yr)**
Cook Is	19/02/1993	-0.1
FSM	17/12/2001	-0.8
Fiji	23/10/1992	0.9
Kiribati	02/12/1992	0.4
Marshall Is	07/05/1993	0.1
Nauru	07/07/1993	0.5
PNG	28/09/1994	1.6
Samoa	26/02/1993	0.1
Solomon Is	28/07/1994	-0.3
Tonga	21/01/1993	0.6
Tuvalu	02/03/1993	0.3
Vanuatu	15/01/1993	1.1

*The trend at FSM is from a comparatively short series and therefore varies considerably.

2.2.3. Combined net rate of relative sea level trends

The effects of the vertical movement of the tide gauge platform and the inverse barometer effect are removed from the observed rates of relative sea level change and presented in Table 4 and Figure 5. The net sea level trends are positive at all sites, which indicates sea level in the region has risen over the duration of the project. The sea level rise has not been geographically uniform, but rather there exists a spatial pattern that is in agreement with observations taken by satellite altimeters over a similar timeframe. The changes between neighbouring stations are reasonably smooth and are due to regional oceanographic and geodynamic factors rather than poor data quality. The sea level trend at FSM is comparatively large because it is derived from a comparatively short record. The net sea level trend at Tonga is large in comparison to its neighbouring sites (Cook Islands and Fiji), which could possibly be due to vertical motion of the island, but the CGPS record there is still too short (since February 2002) for this motion to be reliably quantified.

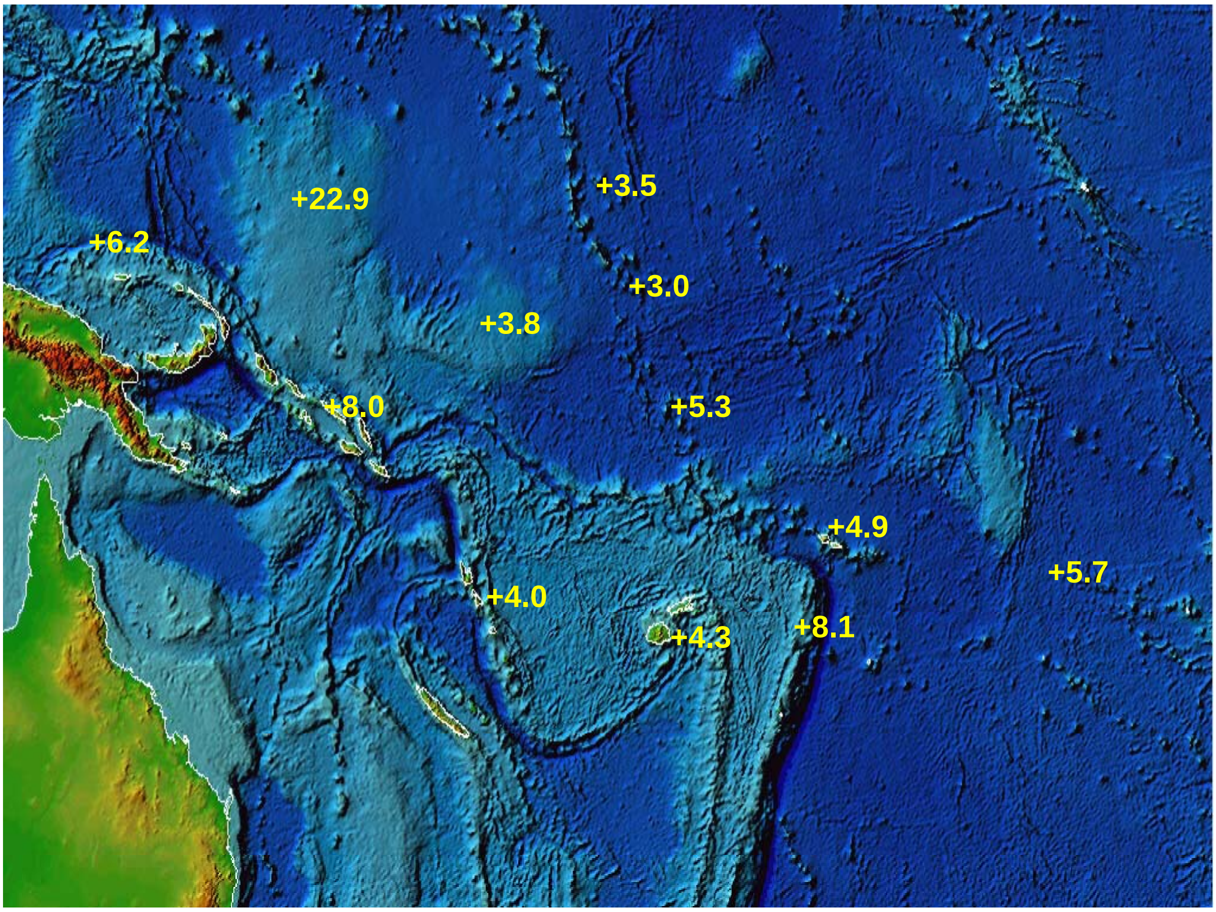
Table 4. The net relative sea level trend estimates as at December 2008 after the inverted barometric pressure effect and vertical movements in the observing platform are taken into account.

Location	**Installed**	**Sea Level Trend (mm/yr)**	**Barometric Pressure Contribution (mm/yr)**	**Vertical Tide Gauge Movement Contribution* (mm/yr)**	**Net Sea Level Trend (mm/yr)**
Cook Is	19/02/1993	5.3	-0.1	-0.3	5.7
FSM**	17/12/2001	22.5	-0.8	0.4	22.9
Fiji	23/10/1992	4.7	0.9	-0.5	4.3
Kiribati	02/12/1992	3.3	0.4	-0.1	3.0
Marshall Is	07/05/1993	4.2	0.1	+0.6	3.5
Nauru	07/07/1993	4.1	0.5	-0.2	3.8
PNG	28/09/1994	7.9	1.6	+0.1	6.2
Samoa	26/02/1993	6.0	0.1	+1.0	4.9
Solomon Is	28/07/1994	8.1	-0.3	+0.4	8.0
Tonga	21/01/1993	9.4	0.6	+0.7	8.1
Tuvalu	02/03/1993	5.7	0.3	+0.1	5.3
Vanuatu	15/01/1993	5.0	1.1	-0.1	4.0

*The contribution is the inverse rate of vertical tide gauge movement

** The sea level trend at FSM is derived from a comparatively short data record.

Figure 5. Map of region showing net relative sea level trends (in mm/year) after subtracting the effects of the vertical movement of the platform and the inverse barometric pressure effect, utilising all the data collected since the start of the project up to the end of December 2008.

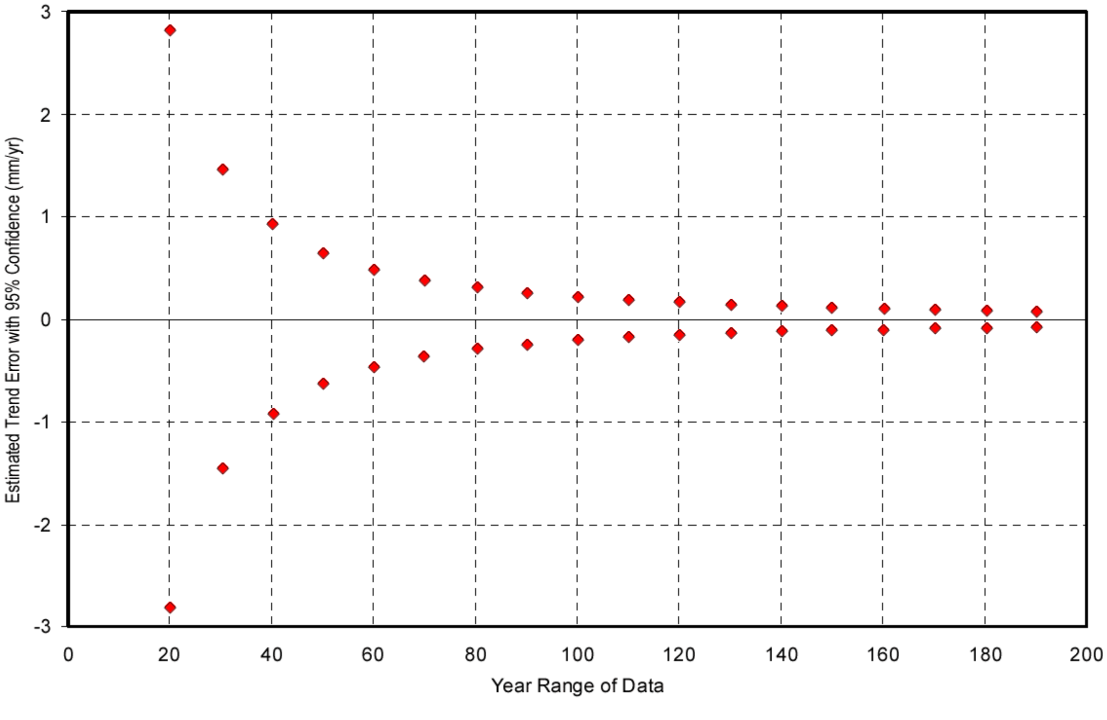


2.3. Sea Level Datasets from Additional Stations

Additional sea level data sets for the Pacific Forum Region are available from the Joint Archive for Sea Level (JASL). This archive was established in 1987 to supplement the University of Hawaii Sea Level Centre data holdings with contributions from other agencies. The research quality datasets available from the JASL may be accessed online at http://uhslc.soest.hawaii.edu/uhslc/jasl.html

Sea level in the Pacific Forum region undergoes large inter-annual and decadal variations due to dynamic oceanographic and climatic effects such as El Niño. Such variability or 'noise' affects estimates of the underlying long-term trend. In general, more precise sea level trend estimates are obtained from longer sea level records as is shown in Figure 6. Sea level records of less than 25 years are thought to be too short for obtaining reliable sea level trend estimates. 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.

Figure 6. 95% Confidence Intervals for linear mean sea level trends (mm/year) plotted as a function of the year range of data. Based on NOAA tide gauges with at least 25 years of record[1].



The annual mean sea levels and relative sea level trends for the additional JASL sea level data sets are shown in Figure 7. The datasets are of different lengths covering different periods of time, and therefore different periods of climatic and sea level change. Many of the datasets are too short to provide reliable trend estimates. At some islands there are multiple sea level records, but joining them together can be problematic. They are archived separately on the Joint Archive for Sea Level because

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

they either originate from different tide gauge locations or they have unrelated tide gauge datums.

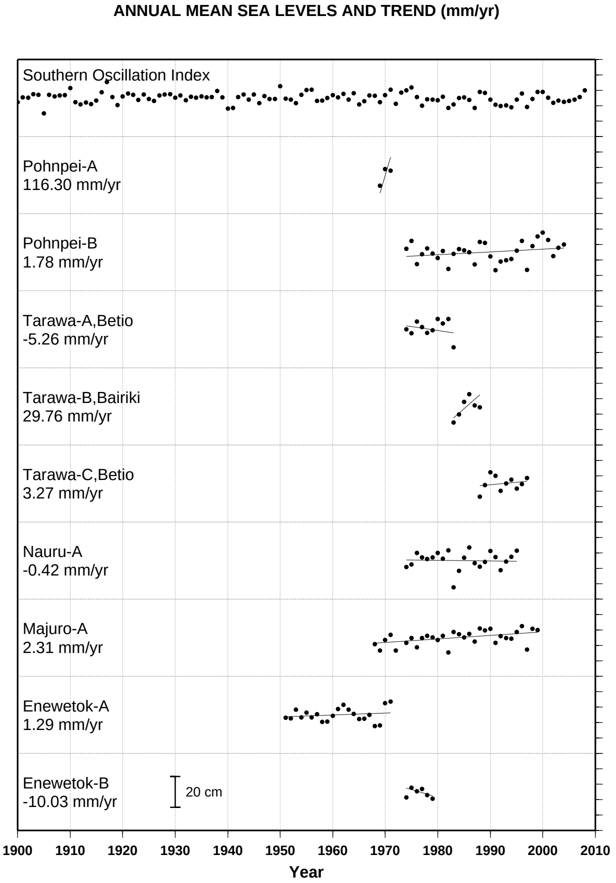
Diverse climatic and oceanographic environments are found within the Pacific Islands region. Different rates of vertical land movement are likely at different stations. Many of the historical tide gauges were designed to monitor tides and sea level variability caused by El Niño and shorter-term oceanic fluctuations rather than long-term sea level change and lack the required level of instrumental precision and vertical datum control. All of these factors potentially affect the rates of relative sea level change that are listed in Table 5. The overall mean trend from stations with more than 25 years of data is 1.3 mm/year.

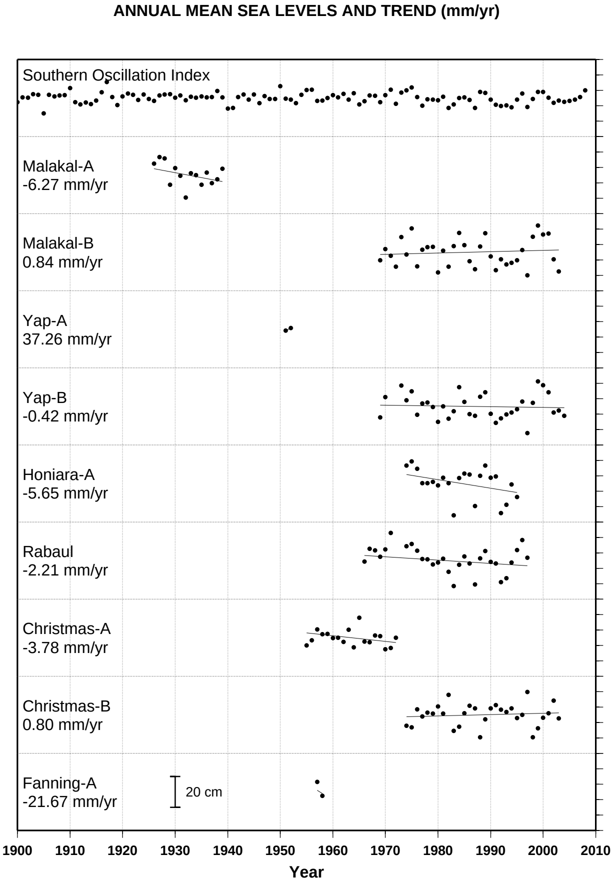
Table 5. Sea level trends for Pacific Forum Stations on the Joint Archive for Sea Level Data Holdings as at December 2008.

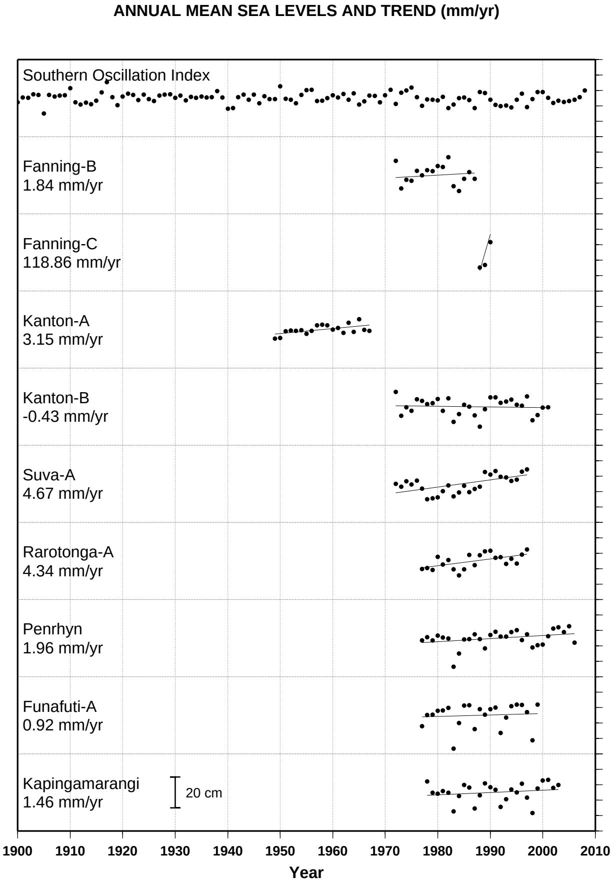
JASL	STATION	COUNTRY	START DATE	END DATE	SPAN (years)	TREND (mm/yr)
001a	Pohnpei-A	Fd St Micronesia	1-Jan-69	31-Dec-71	3	116.3
001b	**Pohnpei-B**	**Fd St Micronesia**	**1-Jan-74**	**31-Dec-04**	**31**	**1.8**
002a	Tarawa-A,Betio	Rep. of Kiribati	1-Jan-74	31-Dec-83	10	-5.3
002b	Tarawa-B,Bairiki	Rep. of Kiribati	1-Jan-83	31-Dec-88	6	29.8
002c	Tarawa-C,Betio	Rep. of Kiribati	1-Jan-88	31-Dec-97	10	3.3
004a	Nauru-A	Rep. of Nauru	1-Jan-74	31-Dec-95	22	-0.4
005a	**Majuro-A**	**Rep. Marshall I.**	**1-Jan-68**	**31-Dec-99**	**32**	**2.3**
006a	Enewetok-A	Rep. Marshall I.	1-Jan-51	31-Dec-71	21	1.3
006b	Enewetok-B	Rep. Marshall I.	1-Jan-74	31-Dec-79	6	-10.0
007a	Malakal-A	Rep. of Belau	1-Jan-26	31-Dec-39	14	-6.3
007b	**Malakal-B**	**Rep. of Belau**	**1-Jan-69**	**31-Dec-03**	**35**	**0.8**
008a	Yap-A	Fd St Micronesia	1-Jan-51	31-Dec-52	2	37.3
008b	**Yap-B**	**Fd St Micronesia**	**1-Jan-69**	**31-Dec-04**	**36**	**-0.4**
009a	Honiara-A	Solomon Islands	1-Jan-74	31-Dec-95	22	-5.7
010a	**Rabaul**	**Papua New Guinea**	**1-Jan-66**	**31-Dec-97**	**32**	**-2.2**
011a	Christmas-A	Rep. of Kiribati	1-Jan-55	31-Dec-72	18	-3.8
011b	**Christmas-B**	**Rep. of Kiribati**	**1-Jan-74**	**31-Dec-03**	**30**	**0.8**
012a	Fanning-A	Rep. of Kiribati	1-Jan-57	31-Dec-58	2	-21.7
012b	Fanning-B	Rep. of Kiribati	1-Jan-72	31-Dec-87	16	1.8
012c	Fanning-C	Rep. of Kiribati	1-Jan-88	31-Dec-90	3	118.9
013a	Kanton-A	Rep. of Kiribati	1-Jan-49	31-Dec-67	19	3.2
013b	**Kanton-B**	**Rep. of Kiribati**	**1-Jan-72**	**31-Dec-01**	**30**	**-0.4**
018a	**Suva-A**	**Fiji**	**1-Jan-72**	**31-Dec-97**	**26**	**4.7**
023a	Rarotonga-A	Cook Islands	1-Jan-77	31-Dec-97	21	4.3
024a	**Penrhyn**	**Cook Islands**	**1-Jan-77**	**31-Dec-06**	**30**	**2.0**
025a	Funafuti-A	Tuvalu	1-Jan-77	31-Dec-99	23	0.9
029a	**Kapingamarangi**	**Fd St Micronesia**	**1-Jan-78**	**31-Dec-03**	**26**	**1.5**
046a	Port Vila-A	Vanuatu	1-Jan-77	31-Dec-82	6	13.6
053a	**Guam**	**USA Trust**	**1-Jan-48**	**31-Dec-08**	**61**	**1.3**
054a	**Truk**	**Fd St Micronesia**	**1-Jan-63**	**31-Dec-91**	**29**	**1.8**
055a	**Kwajalein**	**Rep. Marshall I.**	**1-Jan-46**	**31-Dec-08**	**63**	**1.7**
056a	**Pago Pago**	**USA Trust**	**1-Jan-48**	**31-Dec-08**	**61**	**2.1**

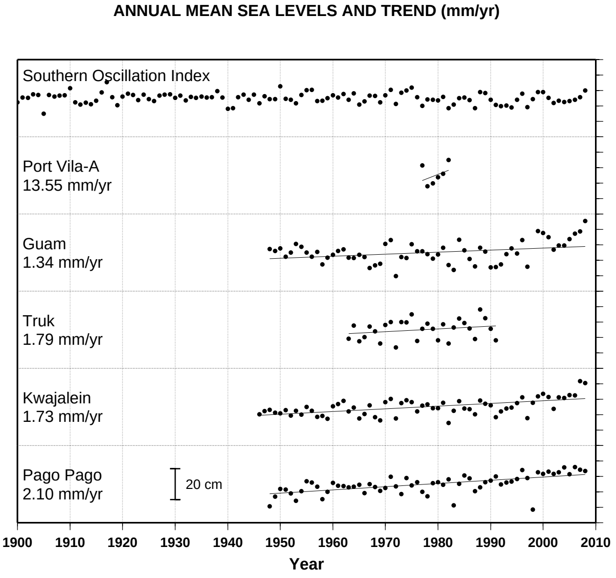
The mean trend for datasets that span more than 25 years (bold font) is 1.3 mm/yr.
Data from JASL as at June 2009

Figure 7. Annual mean sea levels and linear sea level trends (mm/year) for additional stations on the Joint Archive for Sea Level.


ANNUAL MEAN SEA LEVELS AND TREND (mm/yr)


ANNUAL MEAN SEA LEVELS AND TREND (mm/yr)


ANNUAL MEAN SEA LEVELS AND TREND (mm/yr)


ANNUAL MEAN SEA LEVELS AND TREND (mm/yr)

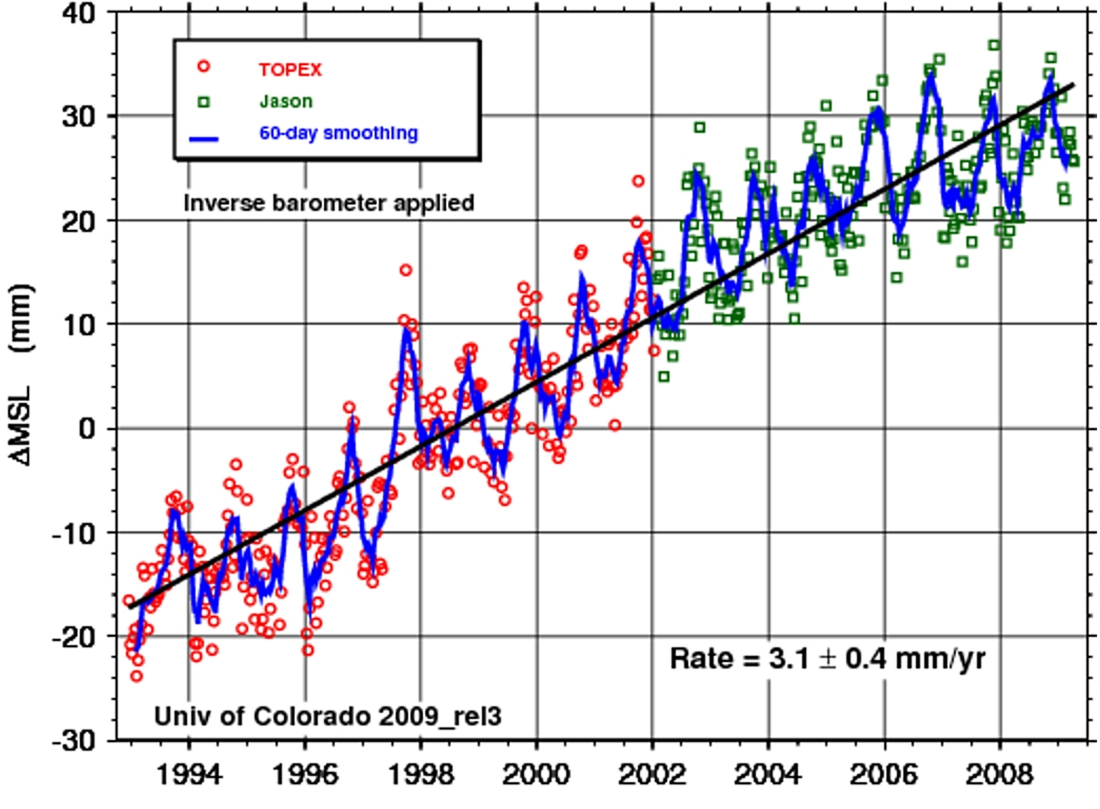
2.4. Satellite Altimetry

Satellite altimetry is technology that allows the height of the sea surface to be measured from satellites orbiting the earth. Satellites altimeters such as Topex/Poseidon and the follow-up mission Jason1 have provided a global record of sea level beginning in late 1992. Although the time interval between successive sea level measurements of the same position on earth is 10 days, the spatial coverage is particularly useful for mapping sea surface anomalies and monitoring development of basin scale events such as El Niño.

Satellite altimeters have an accuracy of several centimetres in the deep ocean, but are known to be inaccurate in shallow coastal regions. As such they cannot replace in-situ tide gauges. Tide gauges are needed to calibrate the satellite altimeters and provide accurate and more frequent sea level measurements in specific locations where reliable tide predictions and real time monitoring of extreme sea levels is of prime importance.

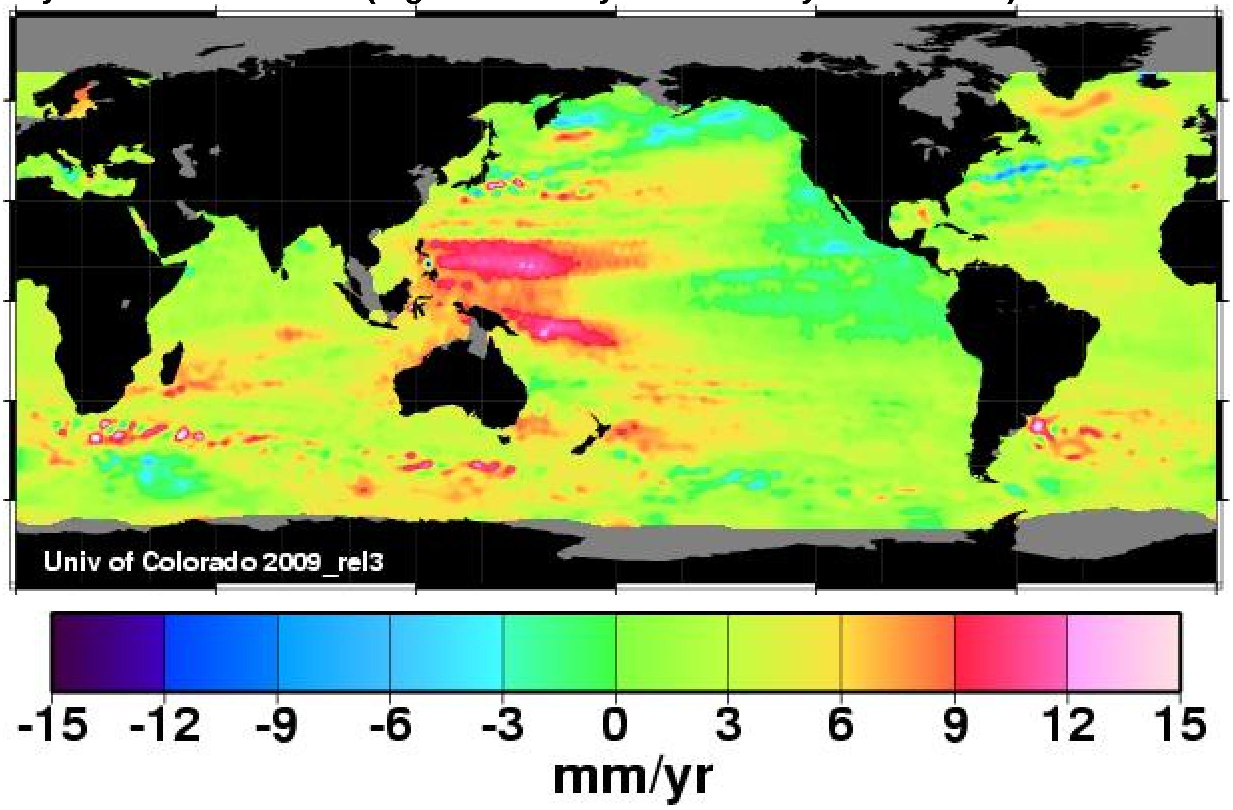
Information about global sea level change derived from satellite altimeters is available from the University of Colorado at http://sealevel.colorado.edu/.
Sea level data collected by Topex/Poseidon and Jason show that global mean sea level has risen at a rate of 3.1 +/- 0.4 mm/yr since late 1992 (Figure 8).

Figure 8. Global Mean Sea Level Change Measured By Satellite Altimeters between 1993 and 2008. (Figure Courtesy Of University Of Colorado)



However global mean sea level change during this time has not been geographically uniform (Figure 9) and continued monitoring is necessary. For example, sea level has risen at relatively high rates in the southwest Pacific region and has fallen in the northeast Pacific, illustrating basin-wide decadal variability in the Pacific Ocean. The satellite altimetry data has a similar length of record to the South Pacific Sea Level Monitoring Project SEAFRAME stations. The sea level trends from SEAFRAME stations (Table 4) are mostly higher than the global average rate shown in Figure 8, but this is consistent with the map of regional sea level trends shown in Figure 9.

Figure 9. Regional Rates of Sea Level Change from 1992 to 2008 as measured by satellite altimeters. (Figure courtesy of University of Colorado)



This section has provided an overview of aspects of the climate and sea level of the South Pacific Sea Level and Climate Monitoring Project region as a whole. The following section provides further details of project findings to date that are relevant to Niue.

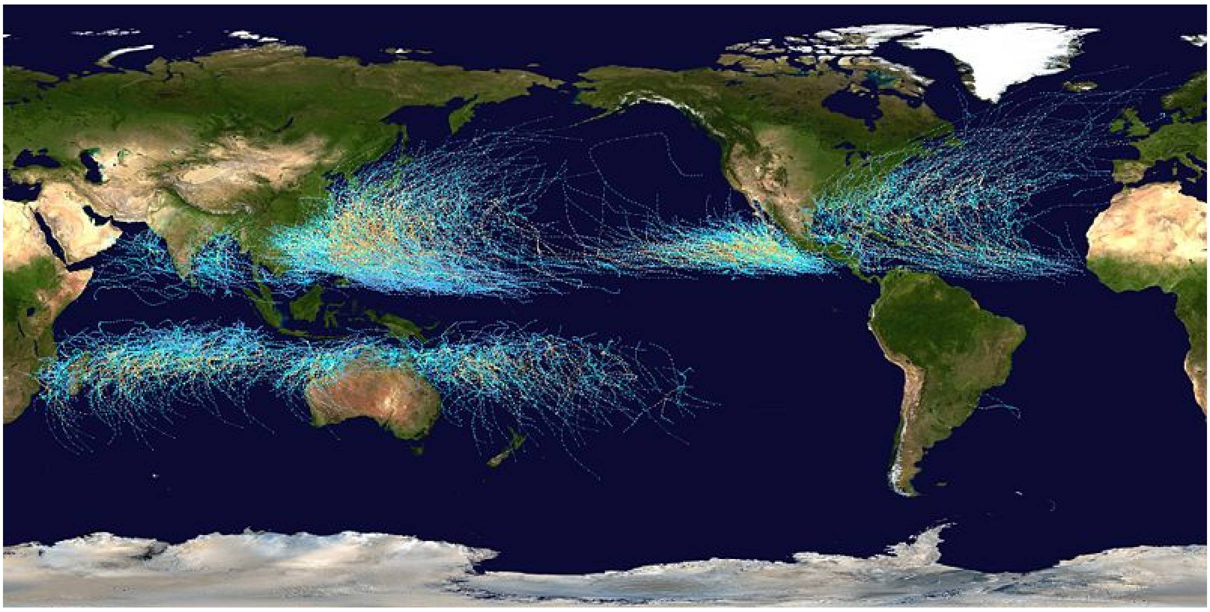
3. Project findings to date - Niue

3.1. Extreme Events

3.1.1. Tropical Cyclones

Niue is situated in the southwest Pacific in an area that experiences tropical cyclones (Figure 10).

Figure 10. Global Tropical Cyclone Tracks between 1985 and 2005 (Figure courtesy of Wikipedia)



On average, Niue is struck by one severe Tropical Cyclone per decade. On 5-6 January 2004, Niue was devastated by destructive hurricane-force winds and extremely high sea waves associated with Tropical Cyclone Heta. The meteorological station on Niue recorded wind gusts of over 150 knots before the instrumentation failed. Flooding of clifftop areas 40 m above sea level was reported. Samoa and Tonga were also affected, but it was the extensive and severe damage of Niue that was reported to be the worst in living memory.

Figure 11. Satellite Image of Cyclone Heta as it passed Nuie

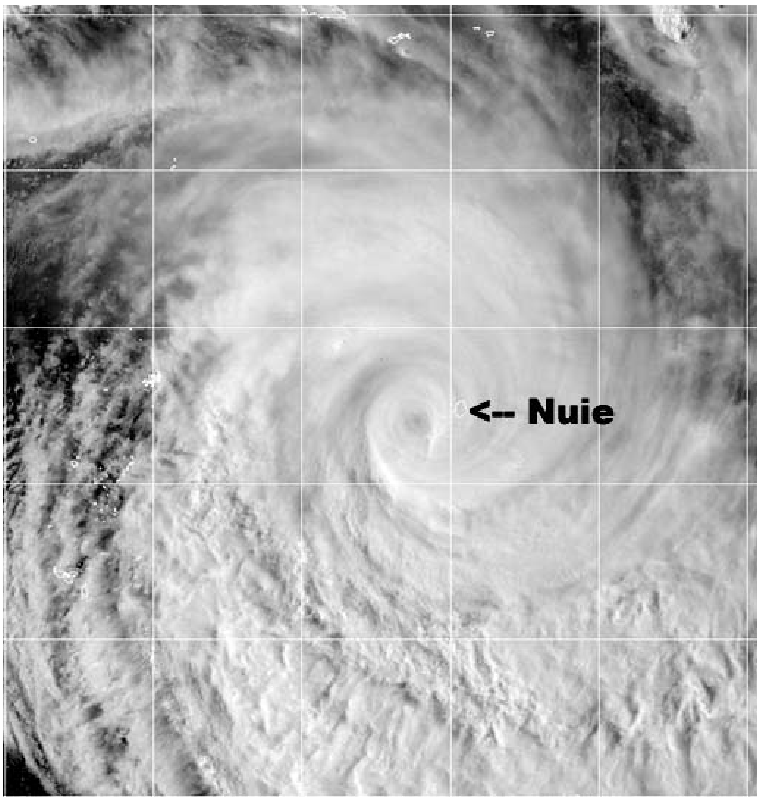
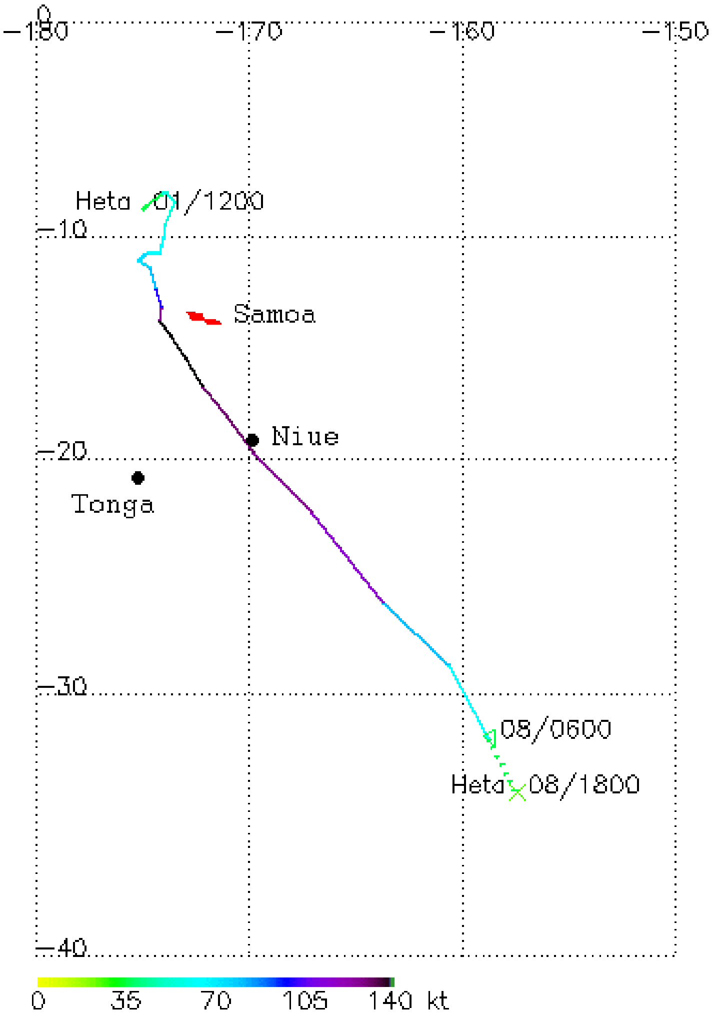


Figure 12. Track of Tropical Cyclone Heta, January 2004



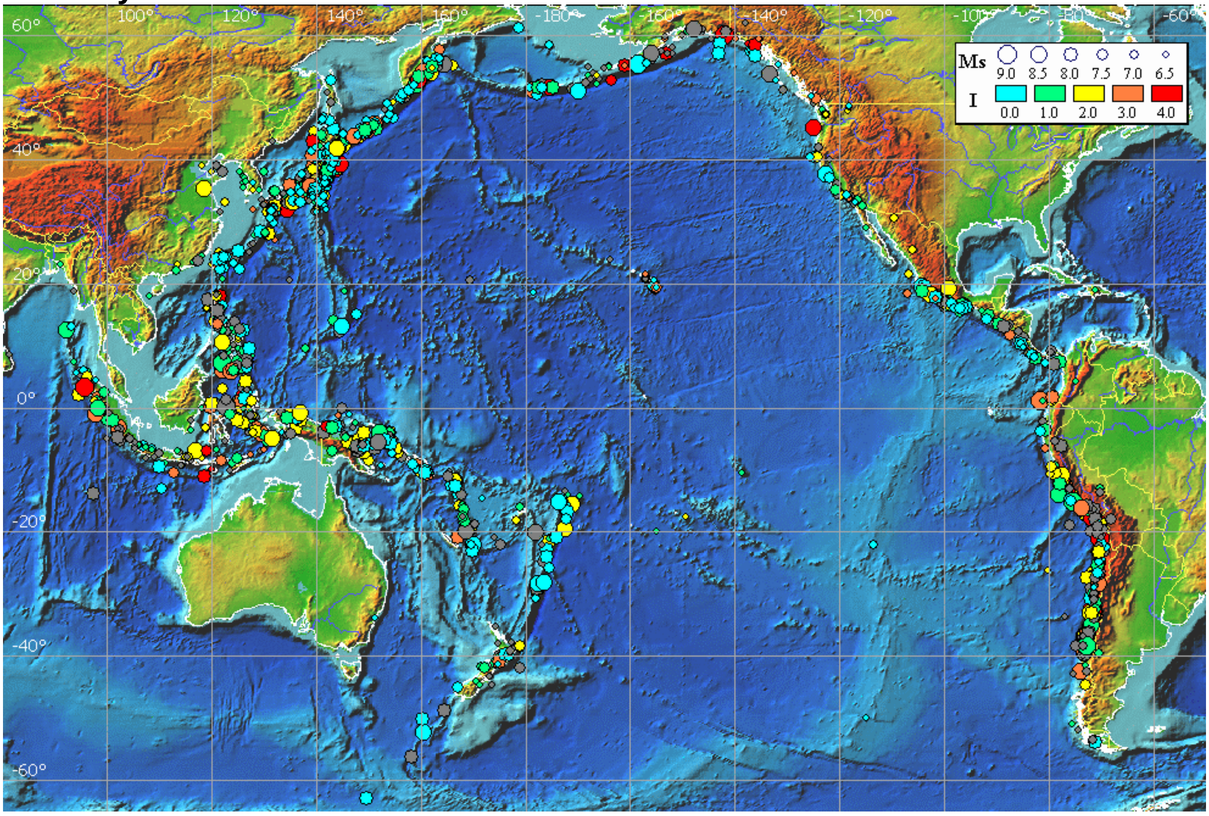
Prior to TC Heta, the most destructive cyclone in recent times was TC Ofa, on 4-5 February, 1990. Cyclone Ofa caused far greater devastation in the Samoan Islands and Tokelau, as Niue's high cliffs gave protection from the high waves. Nevertheless, substantial damage was done. Winds were reported to 107 knots, damaging trees and crops. Extensive damage was also done to the hospital and a hotel, both of which had to be evacuated. Most residents of South Alofi town were also evacuated, and the access road to the wharf and a derrick crane were washed away by huge waves. Wave damage was reported as high as twenty metres above normal sea level.

3.1.2. Tsunamis

A tsunami is a series of waves generated by an impulsive disturbance such as an undersea earthquake, coastal or submarine landslide, volcanic eruption, or asteroid impact. Tsunamis are most commonly generated along tectonic plate margins where earthquakes and volcanoes are found. Due to their association with seismic events tsunamis are also referred to as *seismic sea waves*. The term *tidal wave* is incorrect, as tsunamis have nothing to do with gravitational tide generating forces. Tsunami waves may be barely discernible in the open ocean but as they propagate into shallow coastal waters their size may increase significantly.

Figure 13 shows the sources of historical tsunami events listed in the *Integrated Tsunami Database for the Pacific and the Eastern Indian Ocean*[1]. A number of tsunamis have been generated in the South Pacific Sea Level and Climate Monitoring Project region. The SEAFRAME tide gauge network provides important real time tsunami monitoring capability in the region and contributes toward the tsunami warning system for the Pacific Ocean.

Figure 13. Historical Tsunami Events in the Pacific and Eastern Indian Ocean. Circle size indicates earthquake magnitude and colour indicates tsunami intensity.



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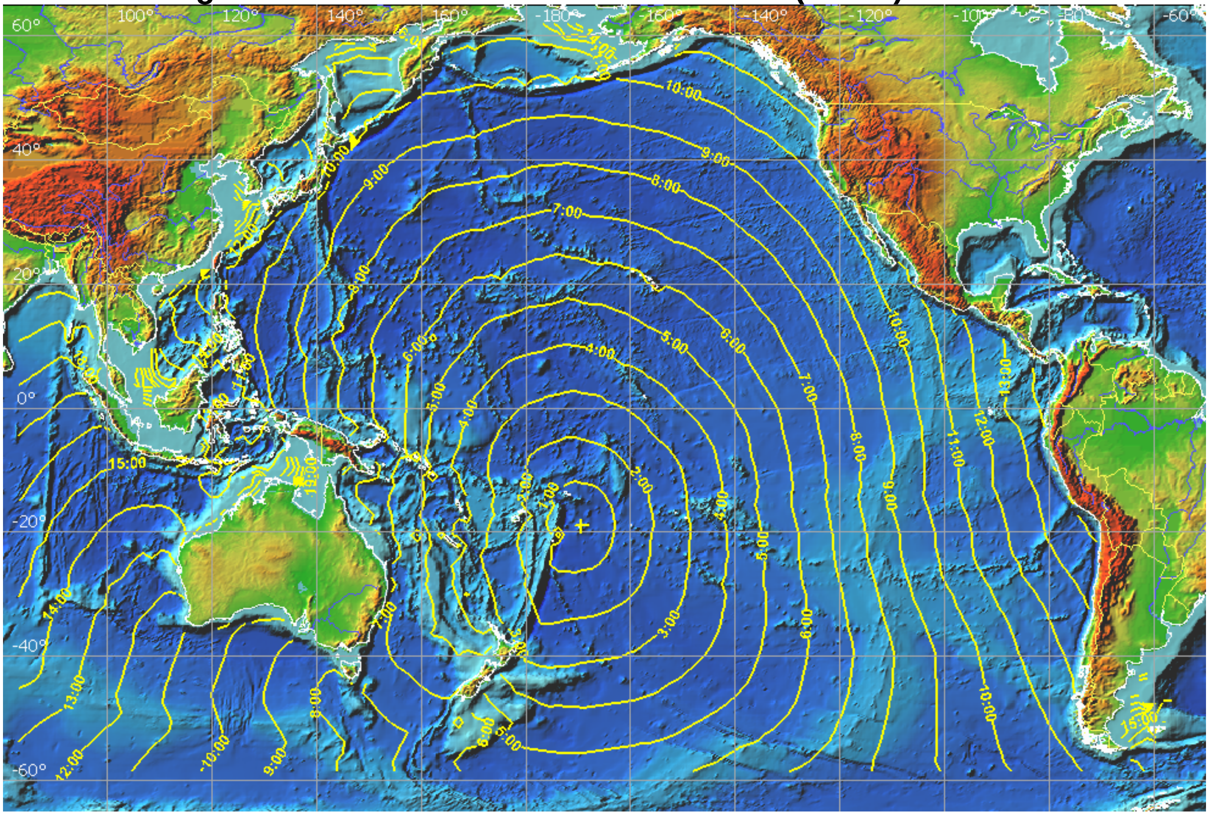
[1] ITDB/PAC (2004) Integrated Tsunami Database for the Pacific, Version 5.12 of December 31, 2004. CD-ROM, Tsunami Laboratory, ICMMG SD RAS, Novosibirsk, Russia.

The historical record reveals few reported observations of tsunamis at Niue. Tsunamis have been reported from sources including Tonga and Vanuatu. Figure 14 shows the inverse tsunami travel time chart for Niue. This chart may be used to provide an estimate of the time taken for a tsunami to arrive at Niue from any source location.

Figure 14. Inverse Tsunami Travel Times (hours) for Niue.



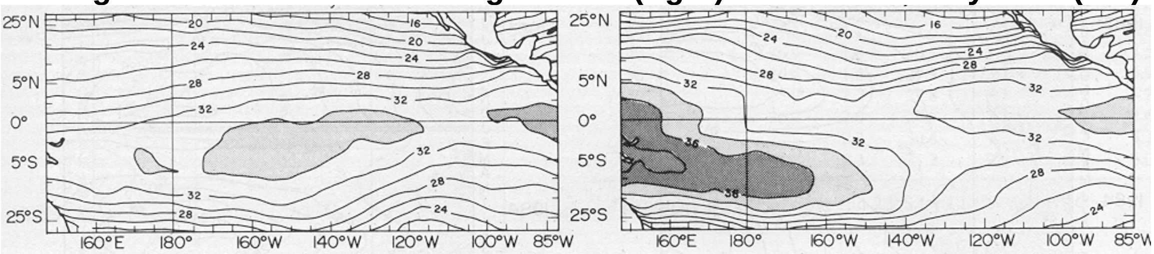
3.2. The Climate and Oceanography of Niue

Niue is a single, isolated, raised coralline platform at 19° S, 170°W. The island has a land area of 259 sq km and a maximum height of 65 m above sea level.

Located in the southeast trade winds zone, at the edge of the tropical cyclone belt, Niue experiences an average of one severe cyclone per decade. Otherwise, it has a tropical climate with two distinct seasons; a warm wet season from November to March and a cooler, less wet season from April to November. Over the past thirty years, rainfall averaged 2047 mm per year and the mean temperature was 24.7°C.

The location of Niue is shown in Figure 2 (Mean Surface Water temperature) on a background of sea surface temperature. The temperatures were obtained as averages over weekly values for a six-year period. A broad "warm pool" can be seen northeast of Papua New Guinea. Tongues of warm water extend eastward and southeastward from the warm pool. These two tongues follow along special lines known to meteorologists as the Inter-Tropical Convergence Zone (ITCZ) and Sub-Tropical Convergence Zone (STCZ), respectively. Niue is located near the southern boundary of the STCZ. The convergence zones are so-named because the near-surface winds tend to converge along these lines. Where convergence occurs, the air rises, carrying with it water vapour that condenses to form cloud bands. Thus, the ITCZ and STCZ are visible as regions of relatively high cloudiness. Their positions shift somewhat with the seasons, but an even greater shift occurs during El Niño events.

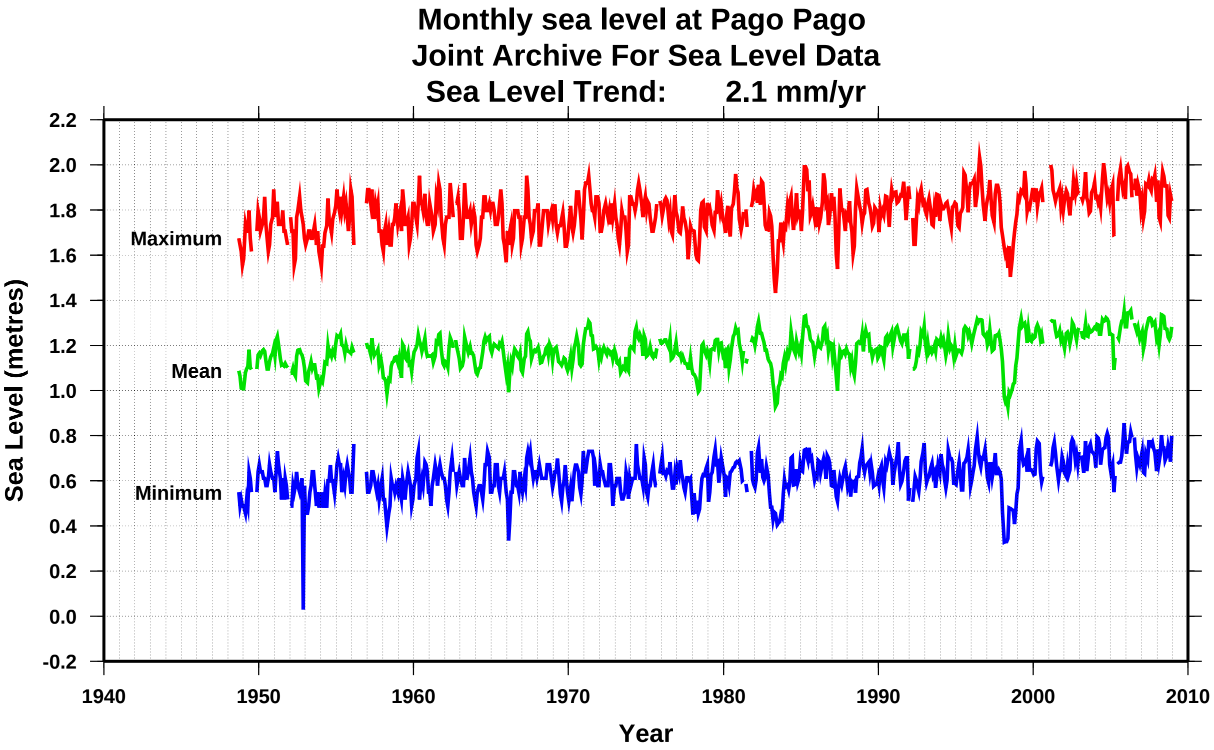
Figure 15. Cloudiness during El Niño (right) and immediately after (left)



3.3. Sea level records and trend

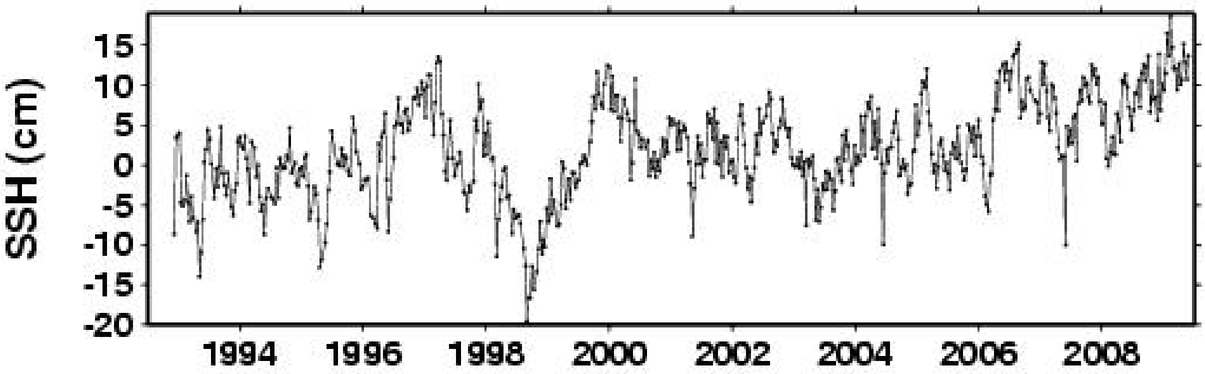
A sea level record at Pago Pago, American Samoa in close proximity to Niue is available from the Joint Archive for Sea Level. The monthly mean data for this 61-year record are shown in Figure 16. The relative sea level trend is +2.1 mm/year. By comparison, the Intergovernmental Panel on Climate Change (IPCC) in its Fourth Assessment Report (IPCC AR4, 2007) estimates that global average long-term sea level rise over the last hundred years was of the order of 1 to 2 mm/yr.

Figure 16



Data from the Topex/Poseidon satellite altimeter and its follow-on mission Jason1 can also be used to supplement sea level estimates for “low-frequency” variations. Satellite altimetry sea levels for a location near to Niue are shown in Figure 17. The sample interval (repeat time for satellite) is about ten days. Of particular interest is the response to the 1997/1998 El Niño when sea level fell by around 20cm.

Figure 17. Sea Surface Height (SSH) from Satellite (Figure courtesy of University of Colorado)



3.4. 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. The highest astronomical tide is the highest sea level that can be predicted under any combination of astronomical conditions, including the proximity of the earth to the sun and the moon. Figure 18 shows that the highest predicted level (1.02 m) over the period 1990 to 2016 is at 20:48 Local Time on 14 December 2016.

Figure 18

Predicted highest tide each year for Niue

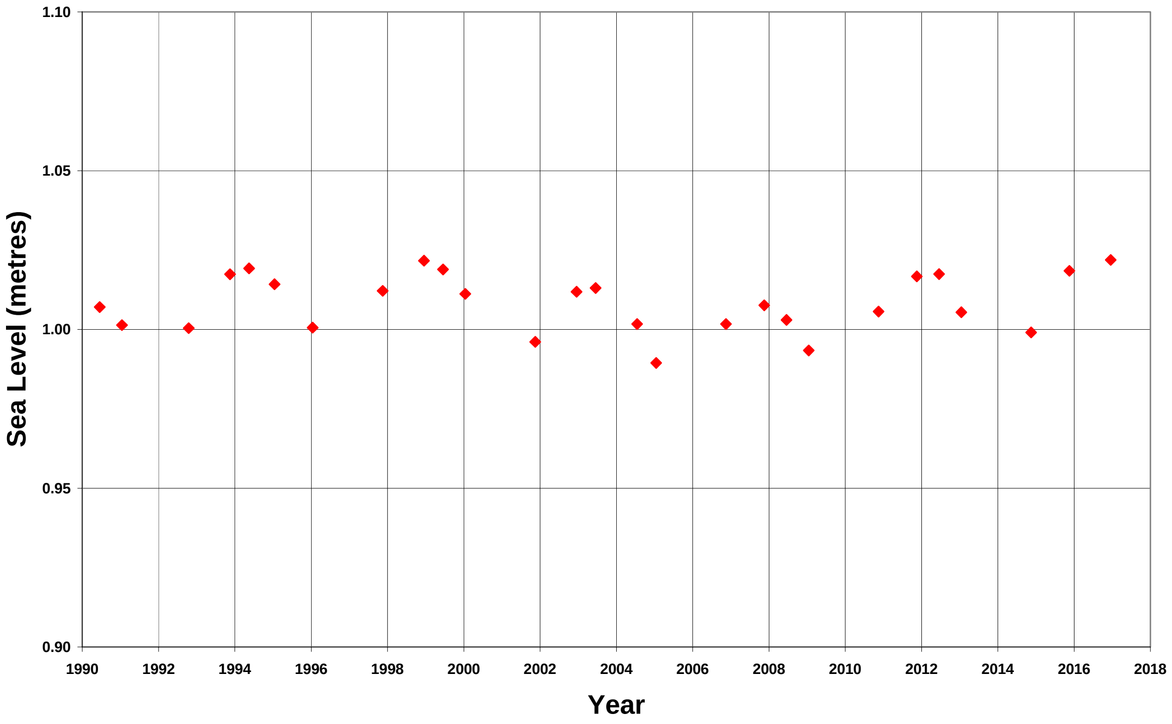
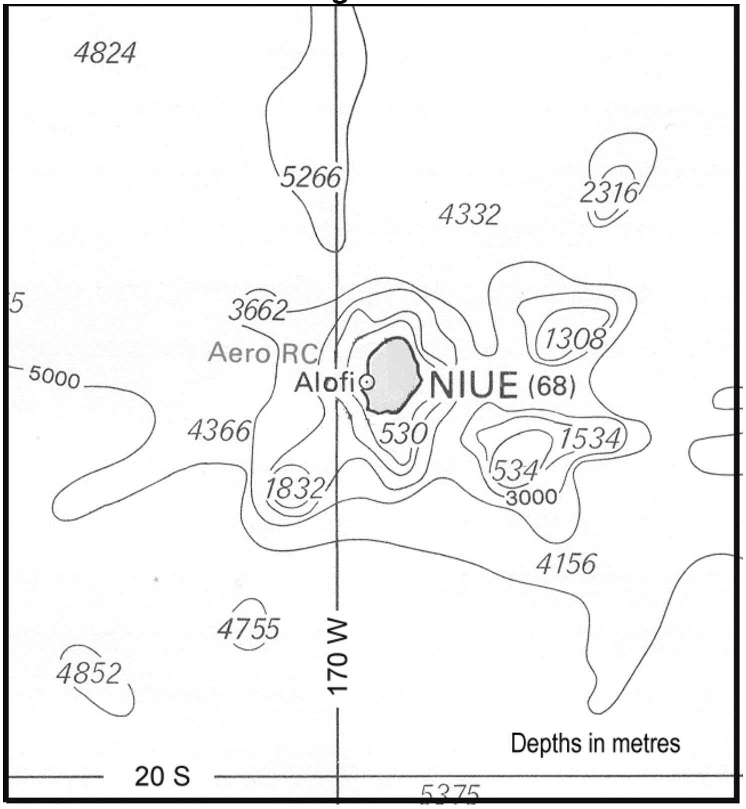


Figure 19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2316
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Alofi
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1308
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170 W
4852
Depths in metres
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