Pacific Country Report

Sea Level & Climate:
Their Present State

Kiribati

June 2004

Disclaimer

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

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Executive Summary

- A SEAFRAME gauge was installed in Betio, Tarawa, Kiribati, in December 1992. 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 +5.5 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. Accounting for the geodetic survey results and inverted barometric pressure effect, the trend is +5.0 mm/year. Nearby gauges, with longer records but less precision and datum control, show trends of –0.68 and +0.27 mm/year.

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

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

- The equatorial location of Tarawa means that it is not subject to tropical cyclones.

- The tsunami caused by the Peru earthquake of June 2001, which registered strongly on many Pacific SEAFRAME gauges, was negligible at Tarawa.

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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, a **SEAFRAME** (**Sea** Level **F**ine **R**esolution **A**coustic **M**easuring **E**quipment) gauge was installed in Betio, Tarawa, Kiribati, in December, 1992. 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 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 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.

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.

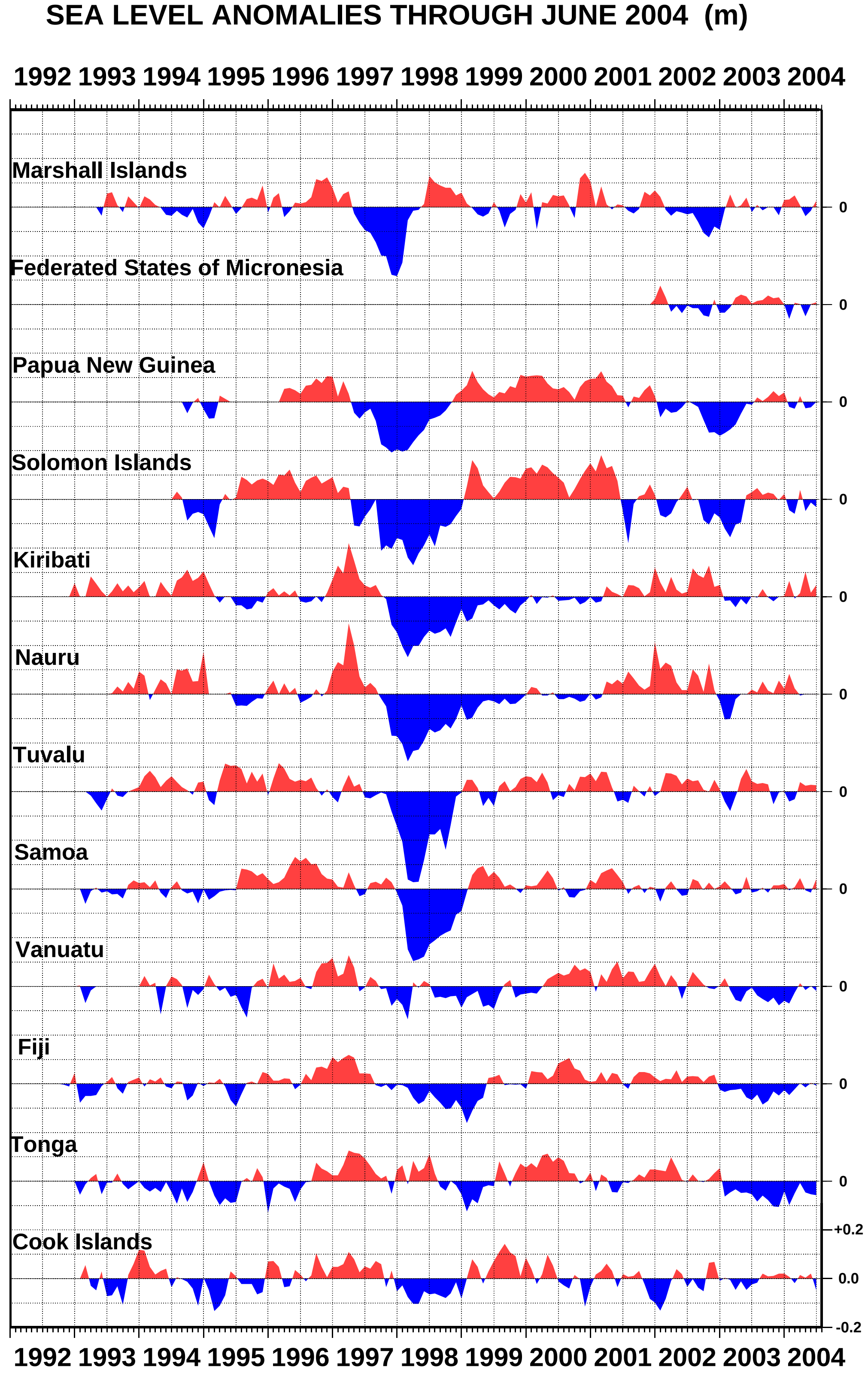
Compared to higher latitudes, air temperatures in the tropics vary little throughout the year. Of the SEAFRAME sites, the most extreme changes are naturally experienced by those furthest from the equator – the Cook Islands (at 21°S) recorded the lowest temperature, 13.1°C, in August 1998. The Cook Islands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

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	33.4
Vanuatu	16.5	33.3
Samoa	18.7	32.3
Tuvalu	22.8	32.6
Kiribati	22.4	32.9
Nauru	22.4	32.5
Solomon Islands	20.1	34.5
Papua New Guinea	21.5	31.8
Marshall Islands	20.0	31.9
FSM	23.0	31.3

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 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). In Figure 1, we see the effect of the 1997/1998 El Niño on all SEAFRAME stations.

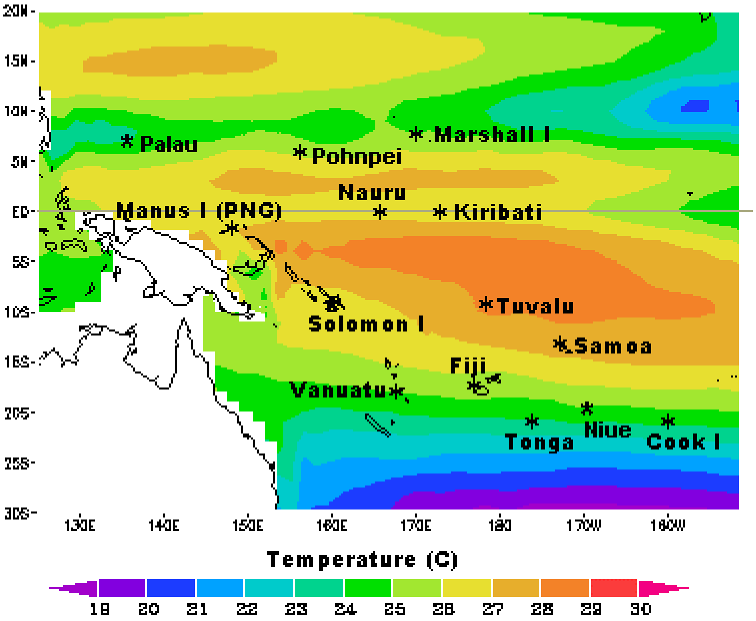
Figure 1. Sea level anomalies* at SEAFRAME sites



* 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 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 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

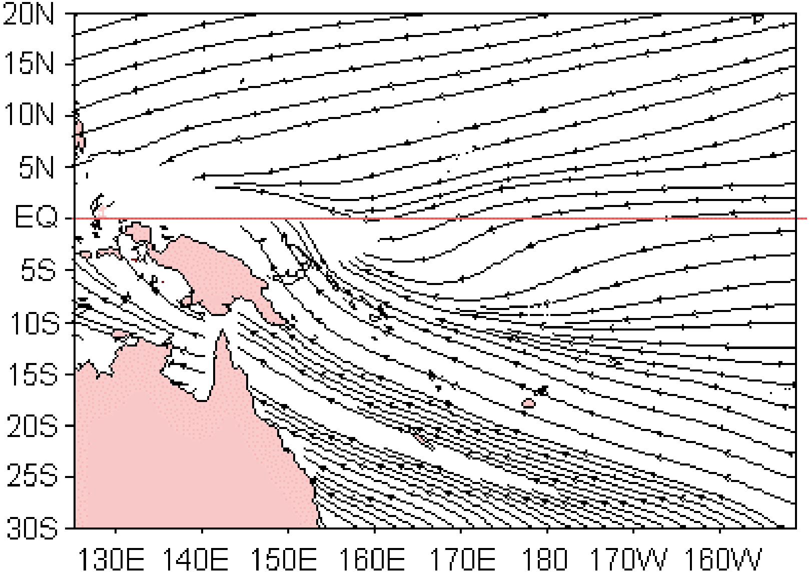


Note the warm temperatures in the SPCZ and just north of the equator.

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) 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 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. Historical Sea Level Trends and their Confidence Intervals

With the great diversity in climatic environments, vertical land movement and ocean variability, one might expect that the relative sea level trends measured at different stations over different time periods may also vary. This is indeed the case and is demonstrated by Table 2, which contains the relative sea level trends from all the 'historical' regional stations. The term 'historical' in this case refers to tide gauges that were installed prior to the South Pacific Sea Level and Climate Monitoring Project. In general, these historical gauges were designed to monitor the sea level variability caused by El Niño and shorter-term oceanic fluctuations rather than long-term sea level change, for which a high level of precision and datum control is required.

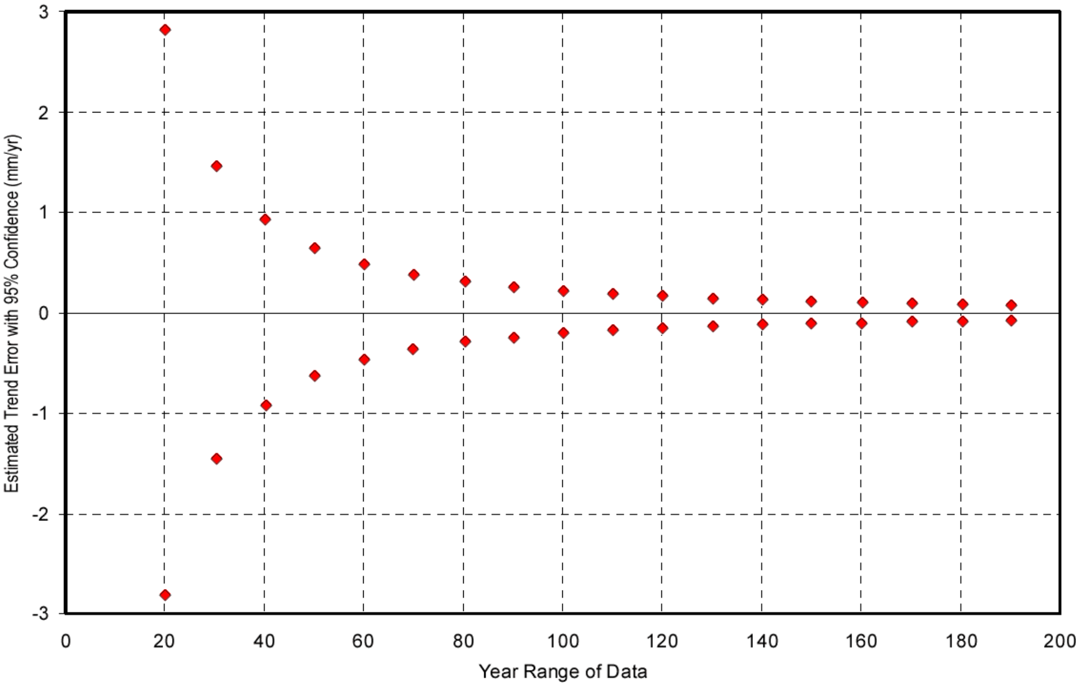
Table 2. Historical Sea Level Data and their Relative Sea Level Trends

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
Funafuti	Tuvalu	21.6	+0.92	5.1

Mean trend: 0.67 mm/year (all data) Mean trend of data > 25 years: 0.8 mm/year
Data from University of Hawaii as at June 2002

Figure 1 illustrates that sea level can undergo significant short-term fluctuation, the occurrence of which can affect any estimate of the underlying long-term trend. The expected width of the 95% confidence interval (±1.96 times the standard error) of a linear trend 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 Figure 4. 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 4. 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].



2.3. Short-Term Sea Level Trends from SEAFRAME stations

The importance of precise measurements and vertical datum control for long-term sea level monitoring is integral to the South Pacific Sea Level and Climate Monitoring Project. Nevertheless the data collection program to date has been operating for a relatively short term, and so the trends are still prone to the effects of shorter-term ocean variability (such as El Niño and decadal oscillations). The nature of this effect is shown in Figure 5, which 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.

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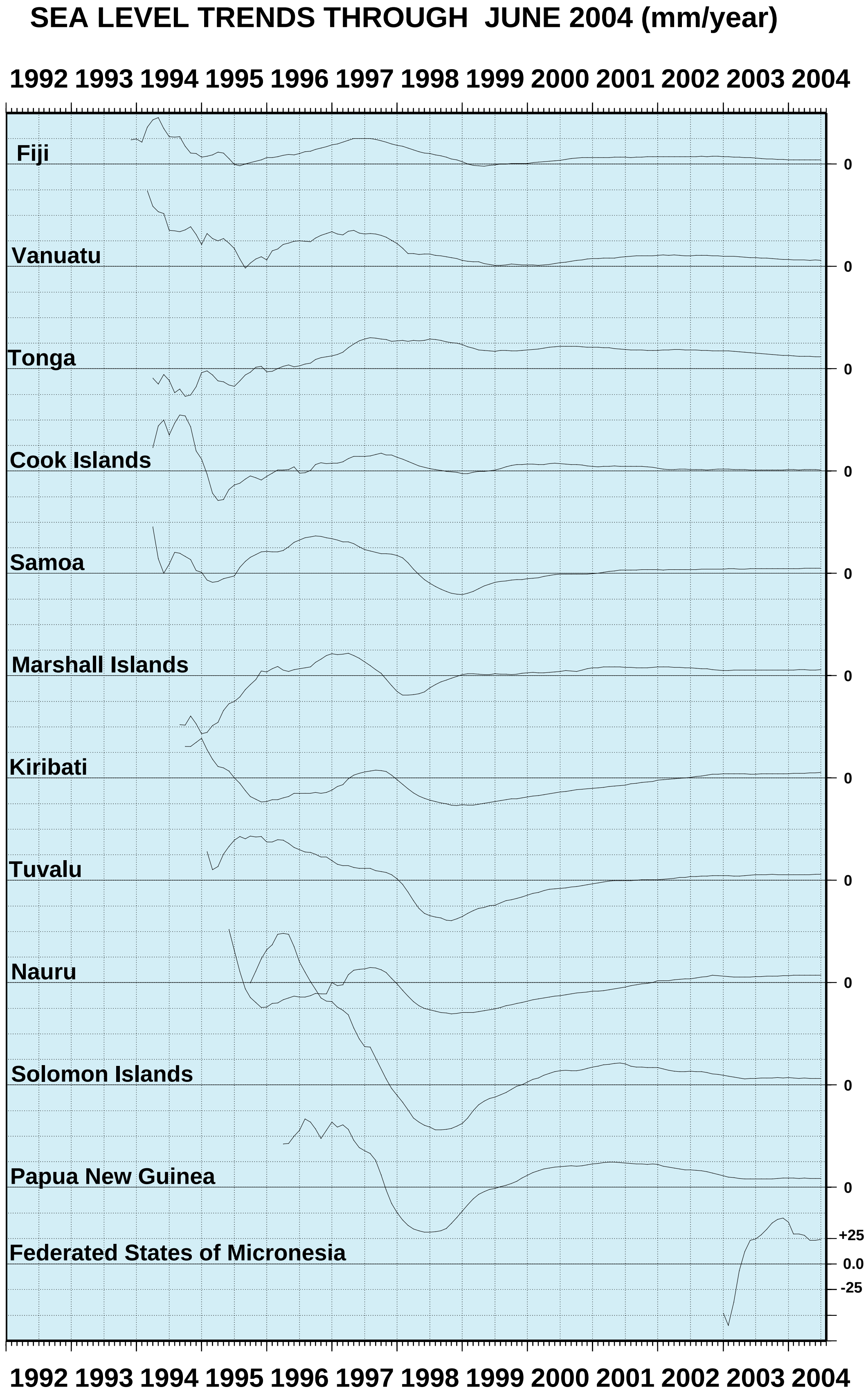
[1] Zervas, C. (2001) Sea Level Variations of the United States 1854-1999. NOAA, USA.

Figure 5. Short Term Sea Level Trends (mm/year)



2.3.1 Geodetic Levelling Summary

Precise datum control is an essential component of the Pacific Project. Surveys are carried out every eighteen months. Table 3 shows the distances K_m (km) between the SEAFRAME Sensor benchmark and the Tide Gauge Benchmark (TGBM) and also gives the "maximum allowable vertical movement *misclosure*" between the two. The misclosure, an indicator of the precision to which the survey must be performed, forms part of Project design specifications. Additional coastal benchmarks are also used to ensure the vertical stability of the TGBM. These latter, which are known as the "coastal array", are not presented here.

Table 3 also shows the rate of vertical movement of the gauge relative to the TGBM (determined by fitting a straight line to the survey results) that is contributing to the observed sea level trend. For example, a substantial subsidence of the tide gauge at Samoa is occurring at a rate of -1.2 mm/year. Subsidence is also occurring at Marshall Islands and Solomon Islands. The Cook Islands tide gauge is rising at 0.9 mm/year with respect to the tide gauge benchmark. The rates of vertical tide gauge movement listed in Table 3 should be added as a correction to the sea level trend estimates and is accounted for in section ***2.3.3. Combined net rate of relative sea level trends***. Additional levelling details for individual countries are provided in section ***3.6. Geodetic Levelling Results***.

Location	K_m (km)	$\pm 2\sqrt{K_m}$ (mm)	Number of Surveys	Vertical movement (mm/year)
Cook Is	0.491	1.4	7	+0.9
FSM	0.115	0.7	2	N/A
Fiji	0.522	1.4	7	+0.2
Kiribati	0.835	1.8	8	+0.1
Marshall Is	0.327	1.1	8	-0.5
Nauru	0.120	0.7	8	+0.0
PNG	0.474	1.4	6	-0.2
Samoa	0.519	1.4	7	-1.2
Solomon Is	0.394	1.3	4	-0.4
Tonga	0.456	1.4	7	-0.0
Tuvalu	0.592	1.5	7	-0.0
Vanuatu	1.557	2.5	6	+0.3

Table 3. Distance (km) between SEAFRAME and TGBM, misclosure, and the rate of movement of the SEAFRAME relative to the TGBM.

During Phase 3 of the Project, Continuous GPS stations are being installed on islands in association with the SEAFRAME gauges. Their purpose is to close the final link in establishing vertical datum control – that is, to determine whether the island as a whole (or in some cases the coastal array) is moving vertically. To date, the length of the CGPS data time series is inadequate to make definitive conclusions.

2.3.2. Inverted barometric pressure effect

Another parameter that influences the estimates of relative sea level rise is atmospheric pressure. 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). Therefore, if there are trends in the barometric pressure recorded at the tide gauge sites, there will be a contribution to the observed relative sea level trends. The contribution will be a 10 mm/year increase (decrease) in relative sea levels for a 1 hPa/year decrease (increase) in barometric pressure.

Table 4 contains the estimates of the contribution to relative sea level trends by the inverted barometric pressure effect in mm/year at all SEAFRAME sites over the period of the project.

Location	Length of data (months)	Barometric Pressure Contribution to Sea Level Trend (mm/yr)
Cook Is	135	+0.07
FSM	30	-0.34*
Fiji	140	+1.25
Kiribati	133	+0.58
Marshall Is	128	+0.31
Nauru	130	+0.55
PNG	102	+1.56
Samoa	135	+0.27
Solomon Is	115	-0.12
Tonga	136	+0.81
Tuvalu	133	+0.47
Vanuatu	126	+1.63

Table 4. Recent short-term barometric pressure trends expressed as equivalent sea level rise in mm/year based upon SEAFRAME data to June 2004. *The trend at FSM is from a comparatively short series and therefore varies considerably.

Table 4 shows that the contribution of pressure to the observed rates of sea level rise are substantial when compared to the global average rates of between one and two millimetres per year. In this region for the past decade the contribution is mostly positive, that is, the relative sea level trends are overestimated without this effect being taken into consideration.

2.3.3. Combined net rate of relative sea level trends

The effects of the vertical movement of the platform and the inverse barometer effect are removed from the estimated relative rates of sea level change and presented in Table 5. There is a high degree of spatial coherency in these rates with the smallest rates of +2.1 mm/year being in the southeast grading up to +7.5 mm/year in the northwest. There is an anomalous value of +10.8 mm/year at Tonga. This may be due to a vertical motion of the whole island, but since the CGPS station has only recently been installed (in February 2002) the estimates are still too noisy to be reliable.

Location	Length of data (months)	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	135	+1.3	+0.07	-0.9	+2.1
FSM	30	+24.3*	-0.34*	N/A	+24.6*
Fiji	140	+4.1	+1.25	-0.2	+3.1
Kiribati	133	+5.5	+0.58	-0.1	+5.0
Marshall Is	128	+5.8	+0.31	+0.5	+5.0
Nauru	130	+7.5	+0.55	+0.0	+7.0
PNG	102	+8.7	+1.56	+0.2	+6.9
Samoa	135	+5.1	+0.27	+1.2	+3.6
Solomon Is	115	+6.3	-0.12	+0.4	+6.0
Tonga	136	+11.6**	+0.81	+0.0	+10.8**
Tuvalu	133	+5.9	+0.47	+0.0	+5.4
Vanuatu	126	+6.1	+1.63	-0.3	+4.8

Table 5. The net relative sea level trend estimates after the inverted barometric pressure effect and vertical movements in the observing platform are taken into account.

*FSM is a comparatively short series and therefore varies considerably.

**The relative sea level trend at Tonga appears to be affected by vertical movement of the island as a whole.

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.

3. Project findings to date - Kiribati

3.1. Extreme Events

3.1.1. Tropical Cyclones

Kiribati, being within 3° of the equator, is not subject to cyclones.

3.1.2. Tsunamis

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." During the period since the SEAFRAME installation, there have been no detectable tsunami-generated waves.

Despite recent history, Tarawa is not immune from potential problems should there be a large tsunami-generating undersea earthquake in the vicinity. Figures 6 and 7 show how, many hours after the initial earthquake, tsunamis can generate large disturbances in coastal locations.

Figure 6. Travel Times for Tsunami Wave from Peru Earthquake

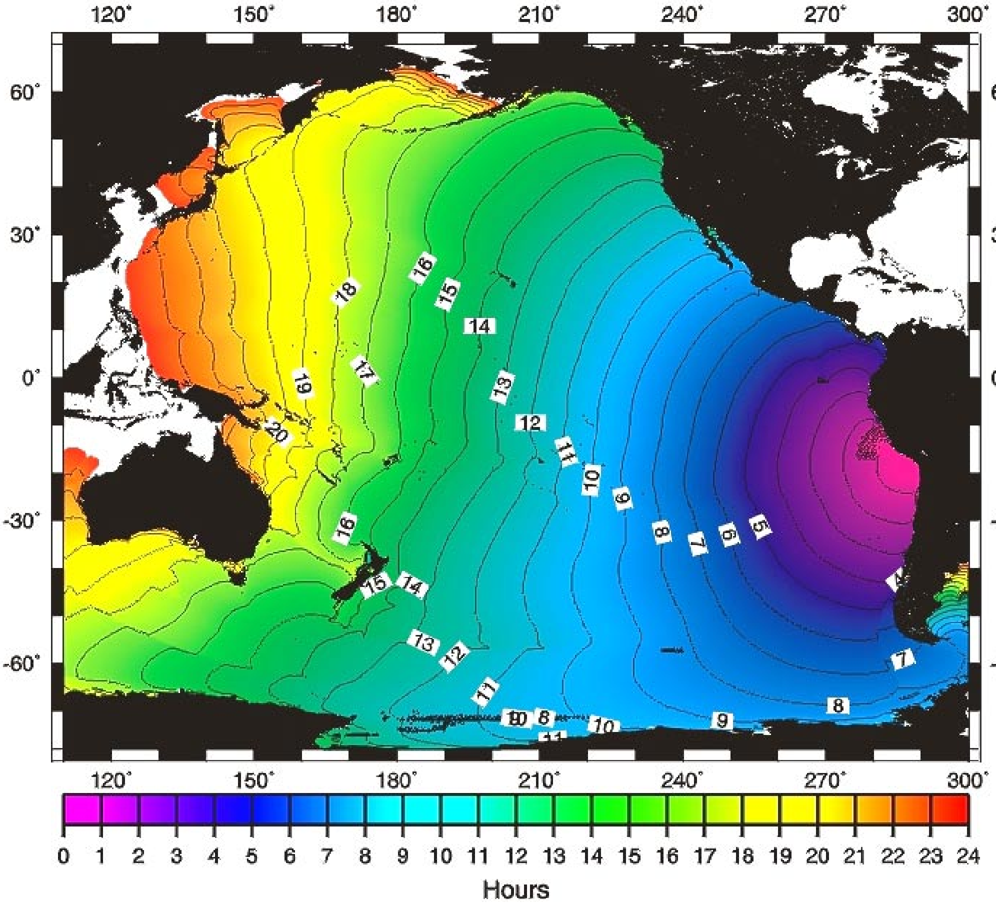
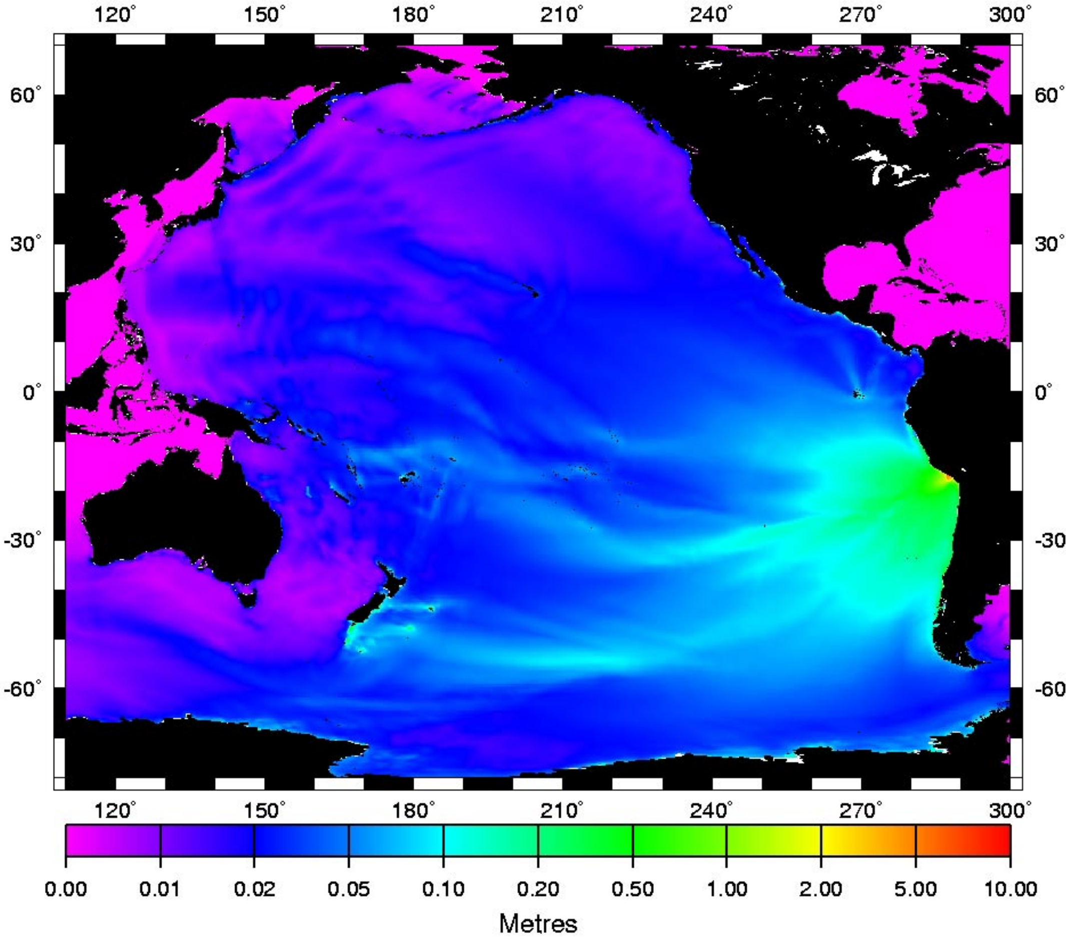


Figure 7. Tsunami Wave due to Peru Earthquake (simulated magnitude)



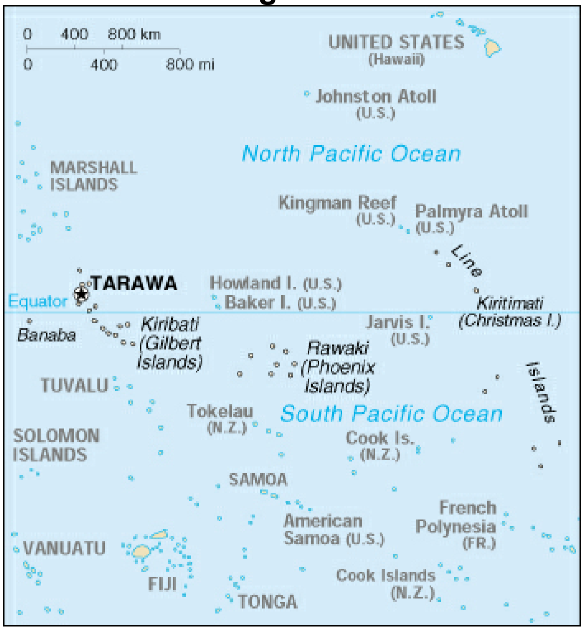
3.2. Short-term sea level trend

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 Figure 5. Short Term Sea Level Trends) which show how the trend develops as more data becomes available. We caution against drawing conclusions prematurely.

As at June 2004, based on the short-term sea level trend analyses performed by the National Tidal Centre of the eleven years of Tarawa data, a rate of **+5.5 mm per year** has been observed. Accounting for the inverted barometric pressure effect and vertical movements in the observing platform, the sea level trend is **+5.0 mm per year**. By comparison, the Intergovernmental Panel on Climate Change (IPCC) in its Third Assessment Report (IPCC TAR, 2001) 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 5 shows how the trend estimate has varied over time, and because the data set is still relatively short, 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 25 cm below average, the trend actually went negative, and remained so for the next three years. Over most of the past four years, the sea level appears to have been falling. Only in 2002 has the trend returned to positive values. It is still far too early to deduce a long-term trend (or even whether it will be positive or negative) from this data.

Figure 8

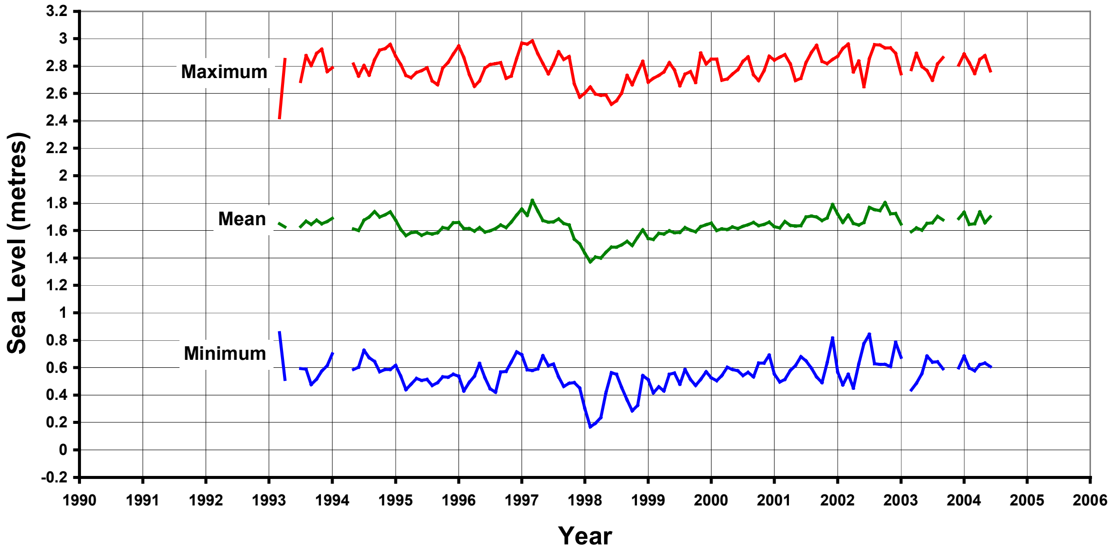


The sea level data recorded since installation is summarised Figure 9. The middle curve (green) represents the monthly mean sea level. The upper and lower curves show the highest and lowest values recorded each month. We see that largely, the monthly mean values are quite stable throughout the year, with the exception of 1997 and 1998, where the level fluctuates during the El Niño.

Seasonal cycles are weak. There is normally about a two metre difference between the highest and lowest recorded levels in a given month, a relatively limited range in comparison to many sites. The red curve (highest value for the month) in Figure 9 is the most variable of the three. This relates to the oceanography of the Kiribati region, which is subject to the occasional passage of large-scale equatorial waves. The waves, which are generated by westerly winds on the equator, create large-scale disturbances of the sea surface. These then travel eastwards, temporarily raising the sea surface by several tens of centimetres as they pass. The passage of these waves is most active in the early stages of an El Niño event.

Figure 9

Monthly sea level at Betio SEAFRAME gauge



The mean sea level over the period was 1.634 metres, with a maximum of 2.98 metres in March 1997, and a minimum of 0.17 metres in February 1998.

3.3. Historical Sea Level Trend Assessment

Longer sea level records are available at Kiribati, from gauges operated by the University of Hawaii (UH) at Tarawa, Kanton, Kiritimati, and Fanning. Records of hourly tide gauge data were kept for about 24, 45, 40, and 17 years respectively. The UH data is summarised in Figures 10 - 13. The respective overall relative trends were **–2.24, +0.26, -0.68 and +2.17 mm/year**. These gauges were 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 these longer data sets, the trend can not be established without sizeable uncertainties.

Figure 10

Monthly sea level at Tarawa
University of Hawaii data

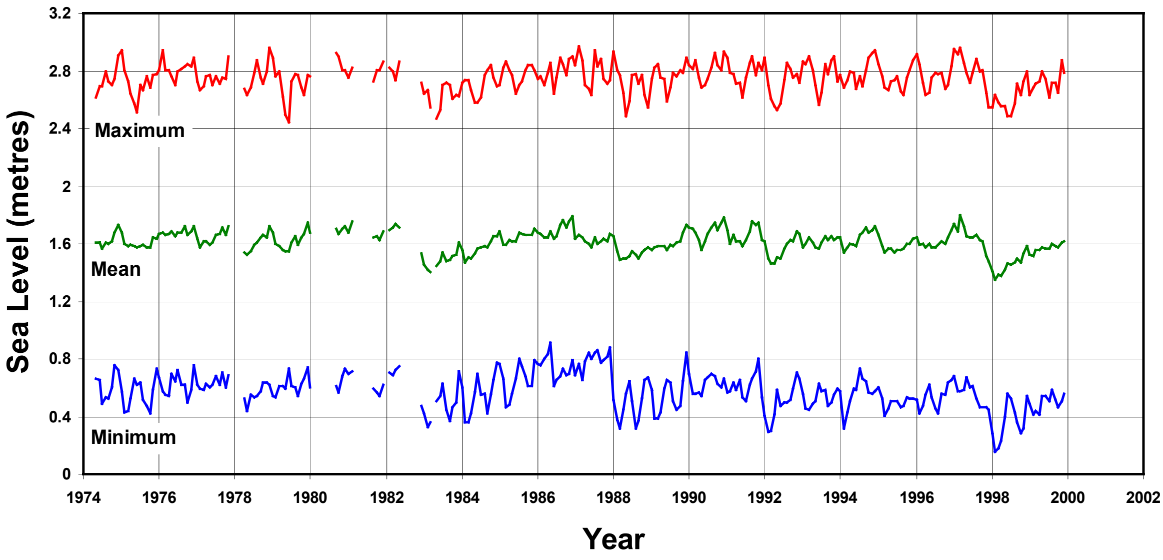


Figure 11

Monthly sea level at Kanton University of Hawaii data

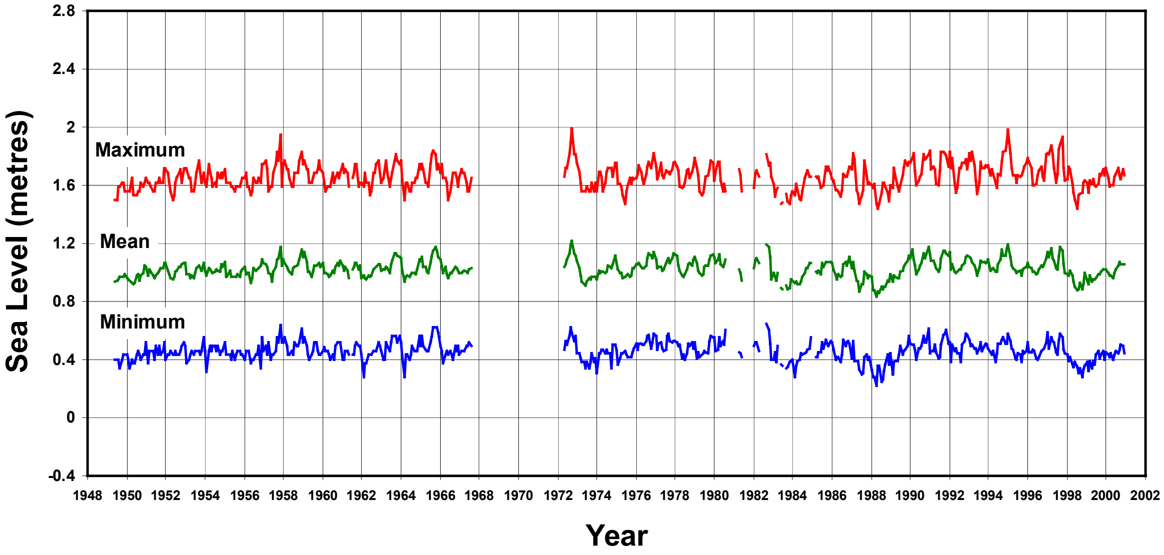


Figure 12

Monthly sea level at Kiritimati Island University of Hawaii data

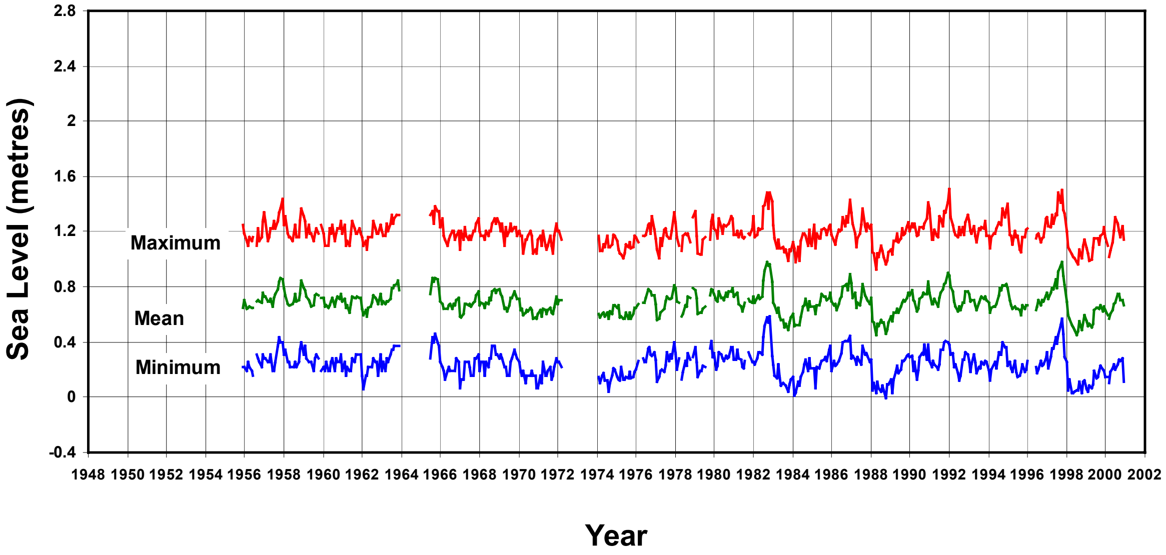
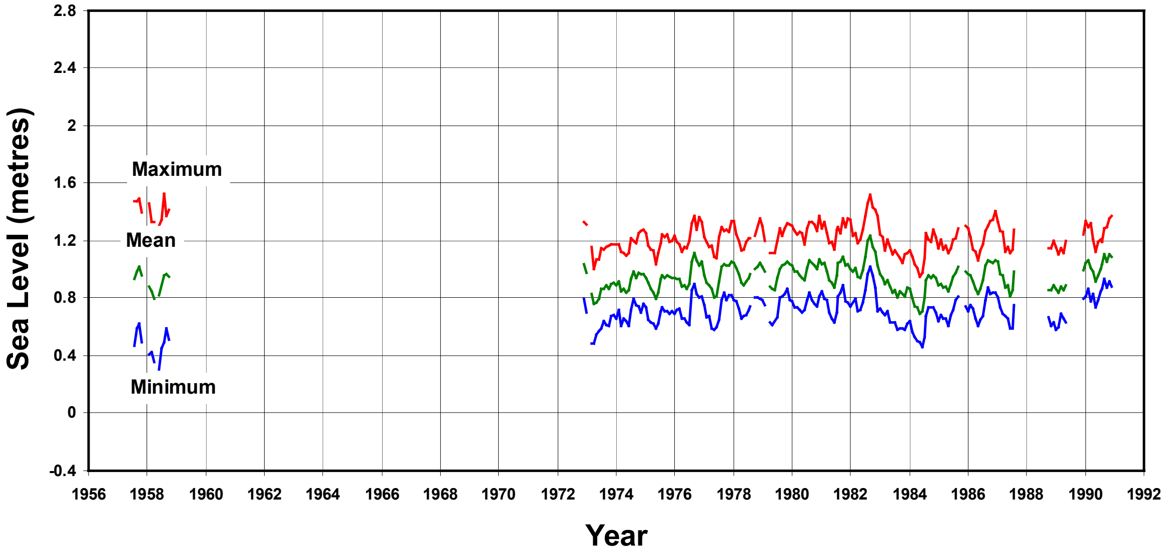


Figure 13

Monthly sea level at Fanning
University of Hawaii data

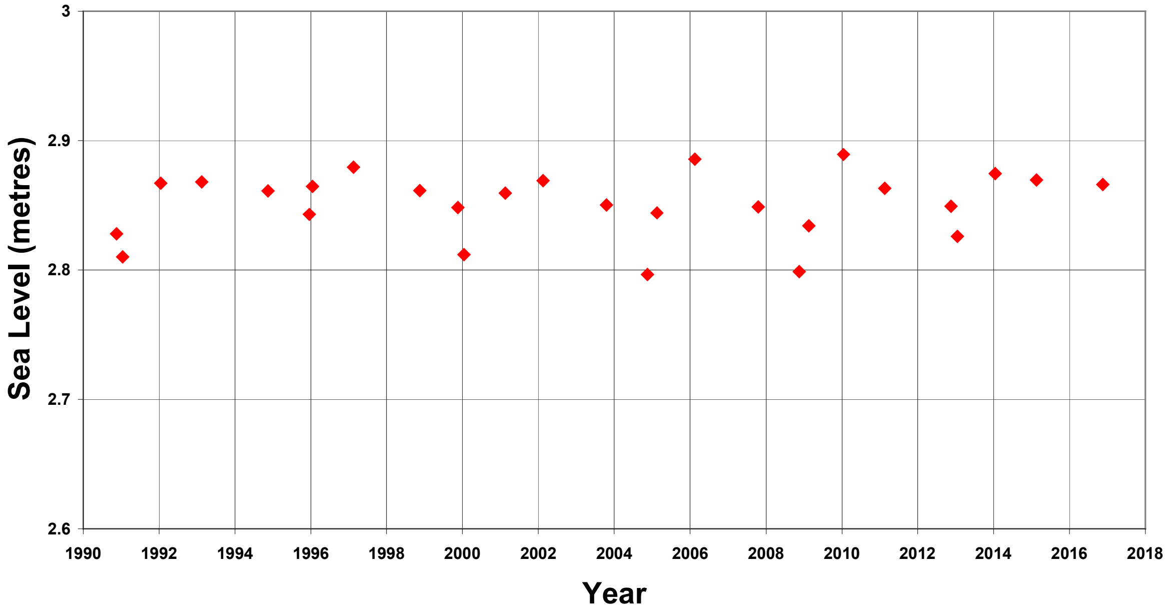


3.4. Predicted highest astronomical tide

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. It is primarily due to the ellipticity of the orbit of the Earth around the Sun, and that of 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. Figure 14 shows that the highest predicted level (2.9 m) over the period 1990 to 2016 will be reached at 17:33 Local Time on the 31 October 2010.

Figure 14

Predicted highest tide each year for Betio



The location of the gauge within the atoll lagoon leads to unique characteristics showing up in the data, such as the effect of solar heating of the lagoon waters. It also shelters the gauge from ocean wave swell, particularly from the east. Swell is caused by surface winds. It is an important source of error in many tide gauges, especially the older conventional gauges with stilling wells.

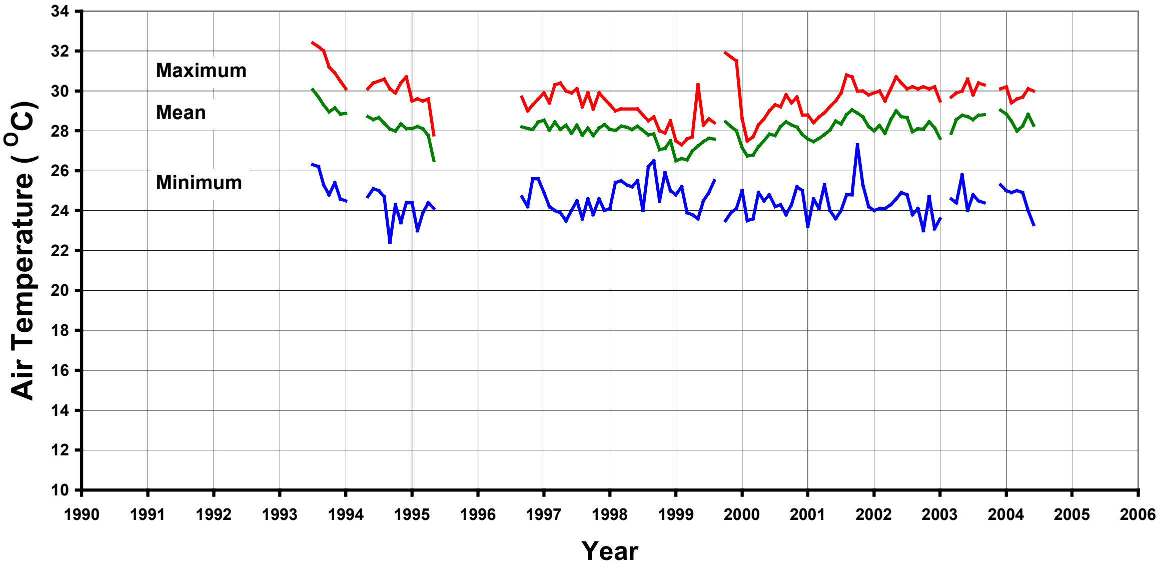
3.5. Monthly means of air temperature, water temperature and atmospheric pressure

The data summarised in Figures 15 - 17 follow the same format as the monthly 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.

The mean air temperatures at Tarawa have undergone annual fluctuations since the 1997/1998 El Niño, with highest temperatures appearing in September and October. The range is not large, generally having only 4°-6°C separating the highest and lowest temperatures recorded each year. The mean air temperature was 28.1 °C. The highest recorded air temperature was 32.9°C in September 1999, and the minimum was 22.4°C in September 1994. Data was interrupted for over a year, beginning in 1995, due to a combination of power failures at Tarawa and a technical fault with the air thermometer.

Figure 15

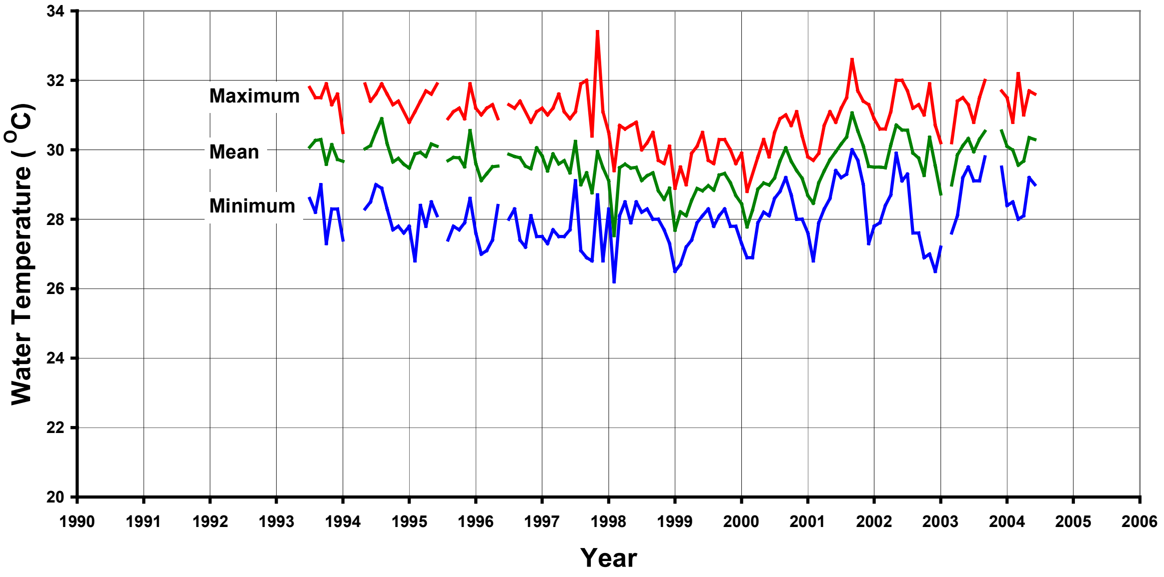
Monthly Air Temperature at Betio SEAFRAME Gauge



The annual change in water temperature at Tarawa has about half the range seen in air temperature. The mean water temperature was 29.6°C. The highest recorded water temperature was 33.4°C in November 1997, and the minimum was 26.2°C in February 1998. Very large water (but not air) temperature fluctuations marked the start of the 1997/1998 El Niño. As with the sea level changes at the time, the water temperatures varied with the passage of large scale, eastward-travelling equatorial waves.

Figure 16

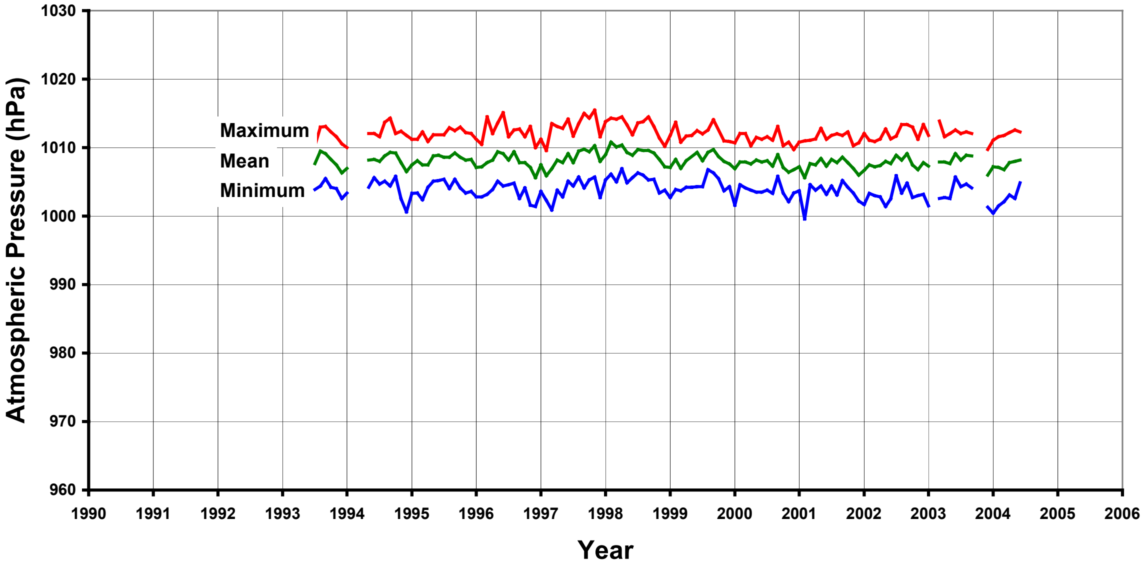
Monthly water temperature at Betio SEAFRAME gauge



The monthly atmospheric pressure at Tarawa shows a decline in the years after the El Niño of 1998. The highest pressure recorded was 1015 hPa in November 1997, while the lowest was 999.6 hPa in February 2001.

Figure 17

Monthly atmospheric pressure at Betio SEAFRAME gauge



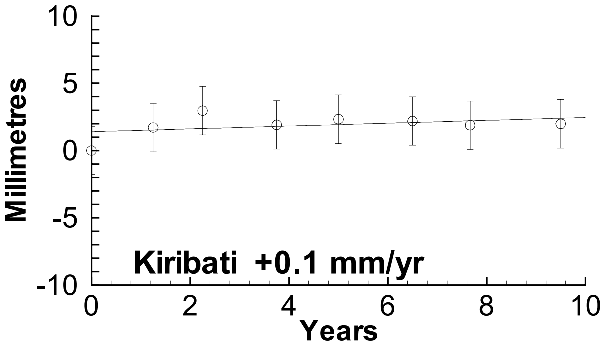
3.6. Geodetic Levelling Results for Kiribati

While the SEAFRAME gauge exhibits a high degree of datum stability, it is essential that the datum stability be checked periodically by precise levelling to an array of deep-seated benchmarks located close to the tide gauge. For example, the SEAFRAME is normally supported by a wharf. Wharf pilings are often subject to gradual vertical adjustment, which in turn can raise or lower the SEAFRAME.

Precise levelling is carried out on a regular 18-monthly cycle between the SEAFRAME Sensor Benchmark and an array of at least six deep benchmarks. The nearest stable benchmark is designated the “Tide Gauge Benchmark (TGBM)”, and the others are considered the “coastal_array”.

Figure 18 summarises the most important survey information being the movement of the SEAFRAME Sensor benchmark relative to the TGBM. The graph does not include the results for the other benchmarks on the coastal array. In this graph, the first survey was performed in “year zero”. Each subsequent survey is plotted relative to the first. Thus, the second survey at Kiribati found that the SEAFRAME Sensor benchmark had *risen* relative to the TGBM by 2 mm, and it has continued to rise at an average rate of 0.1 mm/year. This movement is accounted for in section ***2.3.3. Combined net rate of relative sea level trends***.

Figure 18. Movement of SEAFRAME Sensor relative to the Tide Gauge Bench Mark



Levelling of SEAFRAME Sensor benchmark. Seated next to SEAFRAME: Andrick Lal, SOPAC. Standing: John Ovenden, NTC. Photo credit: Steve Turner, NTC.

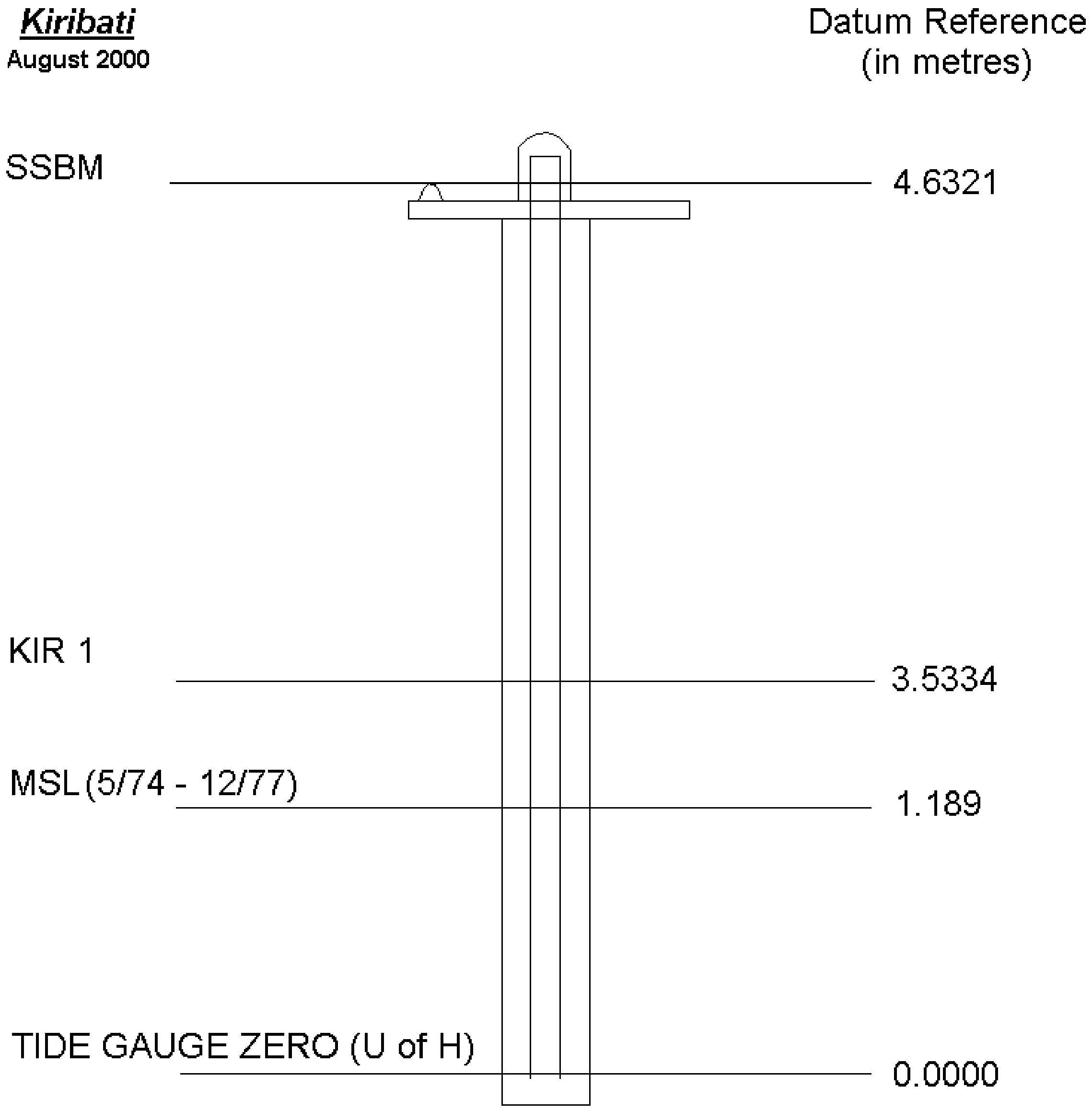
Appendix

A.1. Definition of Datum and other Geodetic Levels at Tarawa

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 NTC sea levels relate to the depths on the marine chart?” and “how do the UH sea levels relate to NTC’s?”.

Regular surveys to a set of coastal benchmarks are essential. If a SEAFRAME gauge or the wharf to which it is 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.

Figure 19



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 NTC data are normally reported relative to “Chart Datum” (CD), thus enabling users to relate the NTC data directly to depth soundings shown on marine charts – if the NTC sea level is +1.5 metres, an additional 1.5 metres of water may be added to the chart depths. Unfortunately, at Tarawa the original benchmark used for the marine surveys is unrecoverable, so it is not possible to place CD on Figure 19. In the absence of a known CD, NTC has chosen to refer sea level to the older UH datum, or “Tide Staff Zero”. With this choice, the Mean Sea Level of either data set is close (though not necessarily identical).

Mean Sea Level (MSL) in Figure 19 is the average recorded level at the gauge over the three and a half year period 1974/1977 (as indicated). The 1974/1977 MSL at Tarawa was 1.189 metres above the UH Tide Staff Zero (and the SEAFRAME zero level).