

“What the South Pacific Sea Level and Climate Monitoring Project is Telling Us”

Pacific Climate Change Discussions at AusAID, Friday 10 November 2006

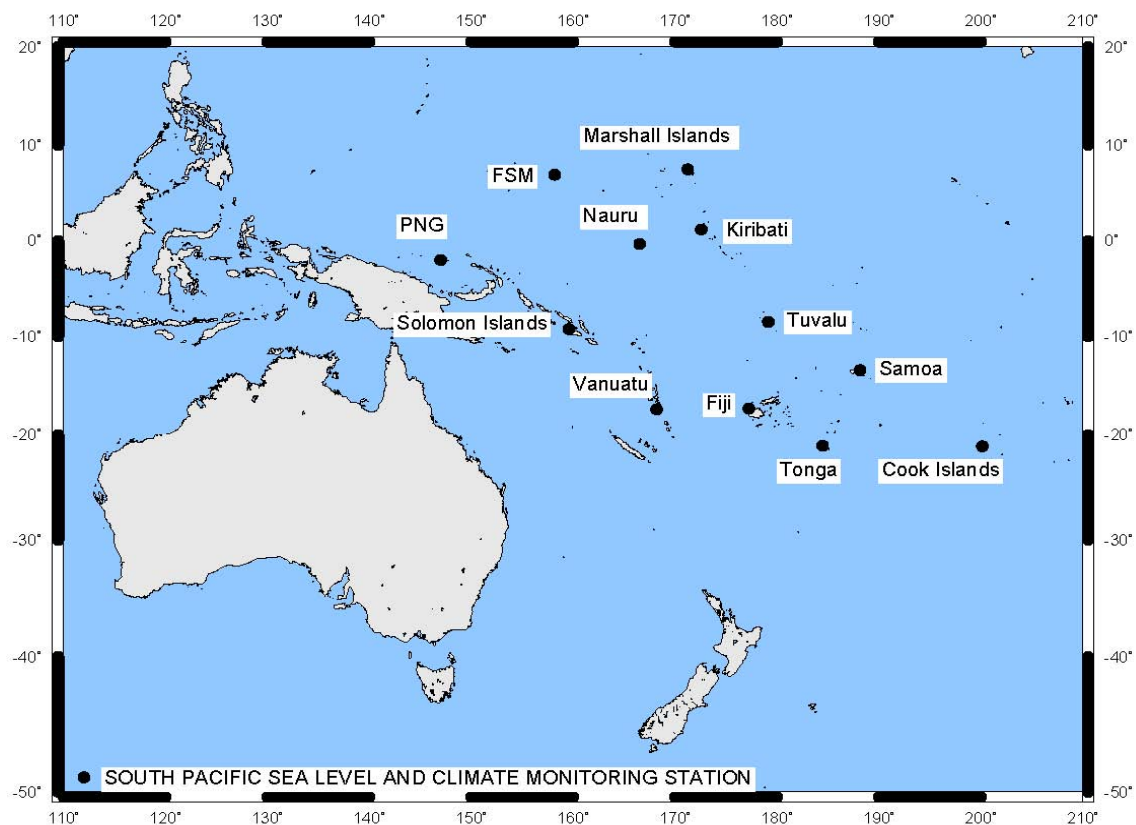
Briefing by Philip Hall, SPSLCMP Project Manager

1. Project Overview

The South Pacific Sea Level and Climate Monitoring Project (SPSLCMP) was developed in 1991 as an Australian response to concerns raised by the member countries of the South Pacific Forum over the potential impacts of global warming on climate and sea levels in the Pacific. Its primary goal is *“to generate an accurate record of variance in long-term sea level for the South Pacific and to establish methods to make [these] data readily available and usable by Pacific Island Countries”*.

A sea level and climate monitoring network of 12 SEAFRAME stations has since been installed involving participating Forum countries (Cook Islands, FSM, Fiji, Kiribati, Marshall Islands, Nauru, PNG, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu), providing a wide coverage across the Southwest Pacific basin. All of the stations, with the exception of Pohnpei (FSM), which was established in December 2001, have been operational since October 1994.

The Project has been running for over 14 years and is now in its fourth phase, which commenced on 1 January 2006 and is due to end on 31 December 2010.



SEAFRAME stations not only measure sea level by two independent means, but also observe a number of “ancillary” variables – air and water temperatures, wind speed, wind direction and atmospheric pressure. There is an associated program of leveling to first order to determine shifts in the vertical 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. **SPSLCMP Monthly Data Report for September 2006**

The Monthly Data Report, one of a range of information products produced by the Project, is the primary form of SPSLCMP data dissemination. Its content provides users with up-to-date access to the Project’s data and is a primary source of information for other organisations climate products, such as the monthly “Island Climate Update” (ICU) newsletter produced by NIWA.

This Briefing Paper is based on the information provided in the Monthly Data Report for September 2006 and the 2005 Annual Country Report for the Cook Islands; both are available via the Project’s website, <http://www.bom.gov.au/pacificsealevel/>.

The overview provided in the summary below and following sections is intended to provide a synopsis of the Monthly Data Report for September 2006 and the trends observed over the life of the SPSLCMP to date.

- Sea levels recorded by the project’s SEAFRAME stations during September 2006 showed no evidence of any extreme event such as a storm surge or tsunami.
- Monthly mean sea levels were lower than normal at 8 of the 12 stations, but only by about 5cm. During the last El Niño event in 1997/1998 sea levels fell to as much as 30cm below normal.
- Climate conditions typical of a developing El Niño continue to be observed across the equatorial Pacific and include warmer than normal sea surface temperatures and weaker than normal trade winds.
- The majority of international climate models predict further warming in the Pacific, which suggests the developing El Niño pattern may strengthen. The November issue of the ICU reported that most models show an El Niño state through to at least January, consistent with last month’s predictions. About half of the model predictions retain the El Niño into the southern hemisphere to autumn 2007, but several predict an easing to neutral by April 2007.

Tropical Cyclones

The November issue of the ICU reported that 'Xavier', the first tropical cyclone of the season occurred on 22 October east of the Solomon Islands, and then tracked southeast to dissipate over the seas between Vanuatu and Fiji after 25 October. Estimated maximum sustained wind speeds reached 213 km/h, which is Category 4 on the Saffir-Simpson scale. This was the earliest start to the season since 1997. An early start to the tropical cyclone season was signaled this year, due to the El Niño conditions.

The chances of tropical cyclone activity for the November through May period remains higher than normal for several South Pacific islands near and east of the Date Line, while islands west of the Date Line are still likely to experience normal rates of occurrence. The monthly ICU is one source that provides updates on information relating to further occurrences of tropical cyclones in the region.

Air Temperature Anomalies

During September air temperatures were near average at most stations. The largest anomaly was observed at Tonga where air temperatures were around 0.5°C warmer than average. Over the duration of the record the air temperature anomalies generally (although not always) follow the water temperature anomalies, which is an indication of the large influence the ocean has upon the climate of the Pacific Islands.

Barometric Pressure Anomalies

During September near normal barometric pressure was observed at most SEAFRAME stations, whereas substantially higher than normal barometric pressures were observed at SEAFRAME stations during the 1997-1998 El Niño. The October issue of the ICU reported that new September minimum barometric pressures were recorded at FSM and Fiji.

Water Temperature Anomalies

During September water temperatures were mostly near to or slightly above average. An anomaly of +1.2°C at Kiribati is consistent with warmer than average sea surface temperatures across the equatorial Pacific, and an anomaly of -0.7°C at Vanuatu is consistent with a patch of cooler than average sea surface temperatures. The October issue of the ICU reported that a new September maximum water temperature was recorded at PNG.

Sea Level Anomalies

During September sea levels around 5cm below normal were being observed at Marshall Islands, FSM, PNG, Solomon Islands, Tuvalu, Samoa, Vanuatu and Tonga. Further development of negative sea level anomalies across the region is expected if El Niño patterns in the equatorial Pacific climate continue to strengthen.

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 SPSLCMP. 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). As the data sets increase in length, the trend estimates will begin to

reflect longer-term change rather than short-term fluctuations, although this transition continues for many decades.

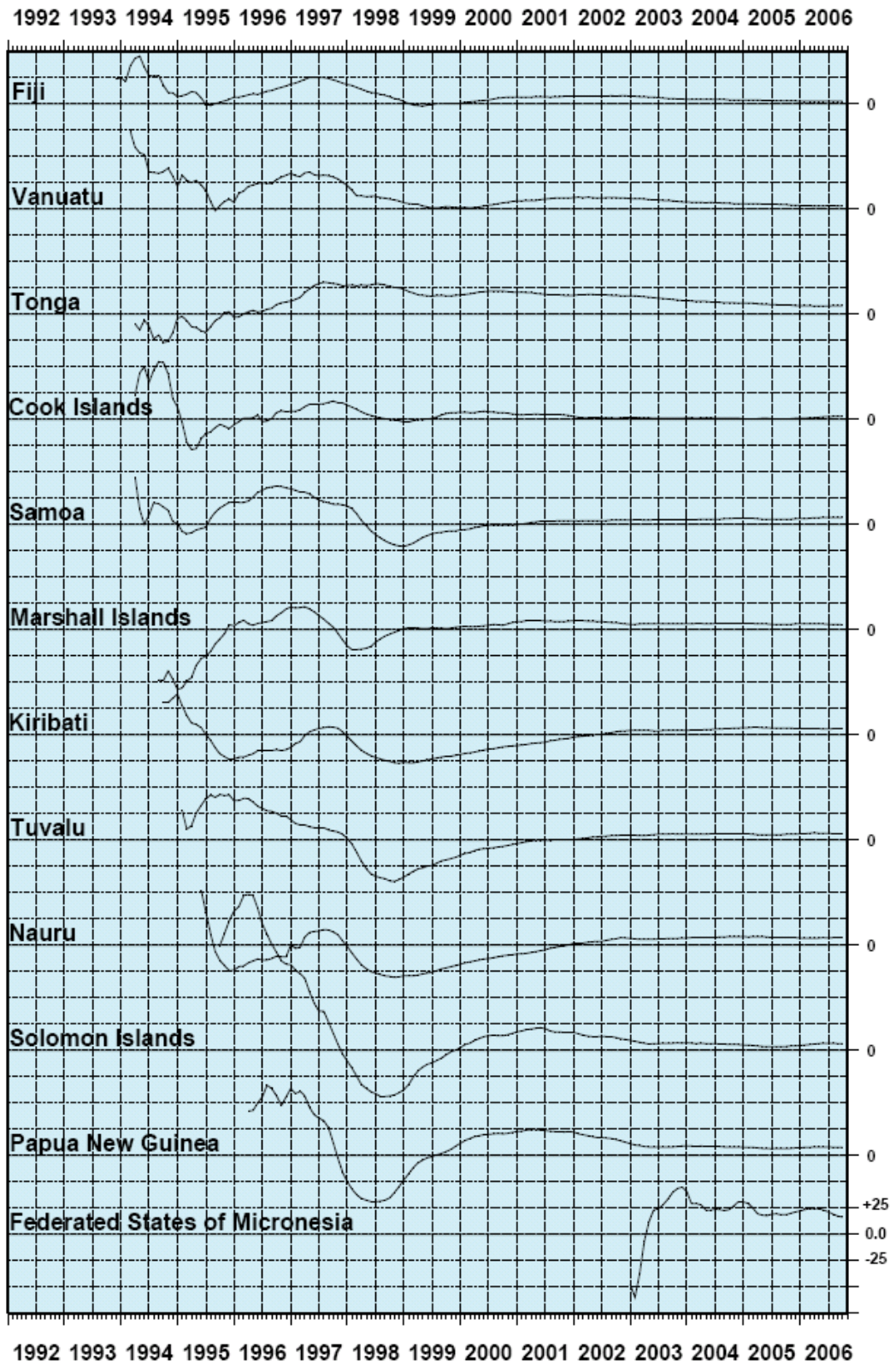
The effects of the vertical movement of the tide gauge platform (para 4) and the inverse barometer effect (para 5) are removed from the observed rate of relative sea level change to provide the combined net rate of relative sea level trend. The short-term sea level trends to September 2006 for the 12 SEAFRAME stations are provided in the following Table.

Recent short-term sea level trends in the Project area based upon SEAFRAME data through September 2006				
Location	Lat / Long	Installation Date	Trend (mm/yr)	Change from previous month (mm)
Fiji	17 36'19"S / 177 26'17"E	Oct 1992	+2.7	0.0
Kiribati	01 21'45"N / 172 55'48"E	Dec 1992	+6.0	+0.1
Vanuatu	17 45'41"S / 168 17'35"E	Jan 1993	+3.0	-0.1
Tonga	21 08'25"S / 175 10'45"W	Jan 1993	+8.1	-0.1
Cook Islands	21 11'58"S / 159 47'10"W	Feb 1993	+3.1	+0.2
Samoa	13 49'09"S / 171 45'21"W	Feb 1993	+6.7	-0.1
Tuvalu	08 30'10"S / 179 12'33"E	Mar 1993	+5.8	-0.1
Marshall Islands	07 06'27"N / 171 22'15"E	May 1993	+4.8	-0.1
Nauru	00 31'55"S / 166 54'33"E	Jul 1993	+7.5	+0.1
Solomon Islands	09 25'18"S / 159 57'19"E	Jul 1994	+6.3	-0.2
PNG Manus	02 02'10"S / 147 22'31"E	Sep 1994	+7.7	-0.2
FSM	06 58'42"N / 158 11'50"E	Dec 2001	+16.6	-0.9

These net rates are spatially coherent (with the exception of FSM and Tonga) and consistent with regional sea level trends observed from satellite altimeters over a similar timeframe. The net 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, which could possibly be due to vertical motion of the whole island, but the CGPS record there is still too short (since February 2002) for this motion to be reliably quantified.

Figure 13 provides the "time history" of the short-term sea level trend (in mm per year), at individual SEAFRAME stations, from one year after installation to the present (September 2006). Details on how these values are calculated are available from the National Tidal Centre (NTC), Australian Bureau of Meteorology. It is important to stress that as the sea level record becomes longer, the short-term trend estimate becomes more stable and reliable. It is also to be noted that the observed trends in sea level include natural variability, for example, events such as El Niño and effects due to other atmospheric, oceanographic and geological processes. Longer-term data sets for all stations are required in order to separate the effects of the different signals. *Caution should be exercised in interpreting these data* – they will almost certainly change over the coming years as the data set increases in length. The trend value is highly variable for the abovementioned reasons.

Figure 13
SEA LEVEL TRENDS THROUGH SEPTEMBER 2006 (mm/year)



4. **Precise Levelling Summary**

Precise datum control is an essential component of the SPSLCMP. Precise leveling of the height of the SEAFRAME relative to an array of land-based benchmarks are undertaken periodically, preferably every eighteen months. The precision to which the survey must be performed is dependant on the distance (km) between the SEAFRAME sensor benchmark and the primary tide gauge benchmark (TGBM) and forms part of Project design specifications.

The precise leveling program essentially monitors the vertical stability of the SEAFRAMES. For example, substantial subsidence of the tide gauge at Samoa is occurring at a rate of -1.1 mm/year. Subsidence is also occurring at Marshall Islands and Solomon Islands. The tide gauges at Cook Islands, Fiji, and Vanuatu are rising at 0.3 mm/year with respect to the tide gauge benchmark.

5. **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.

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 provided in the Monthly Data Reports and Annual Country Reports. The estimates are mostly positive, which means relative sea level trends are overestimated without taking the barometric pressure effect into consideration.

6. **Regional Climate and Oceanography**

This section provides an overview of aspects of the climate and sea level of the SPSLCMP region as a whole.

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.

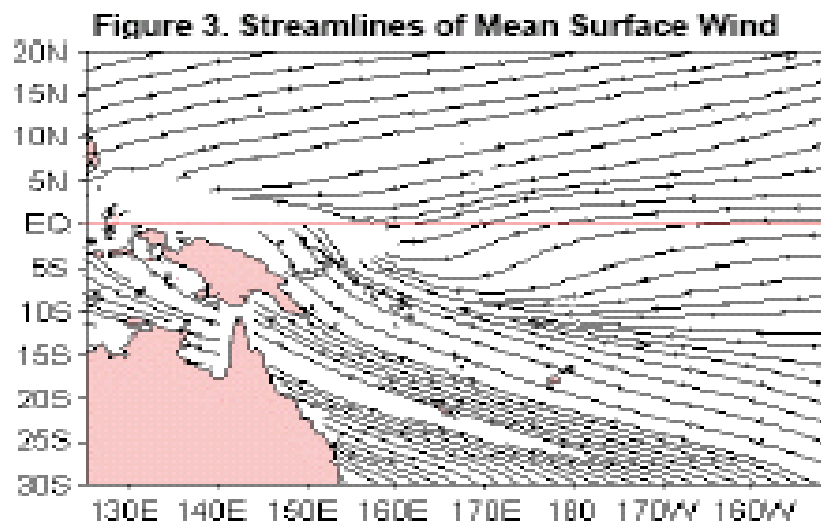
Compared to higher latitudes, air temperatures in the tropics vary little throughout the year. Of the SEAFRAME sites, those furthest from the equator naturally experience the most extreme changes – the Cook Islands (at 21°S) recorded the lowest temperature, 13.1°C, in August 1998. The Cook Islands regularly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

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.

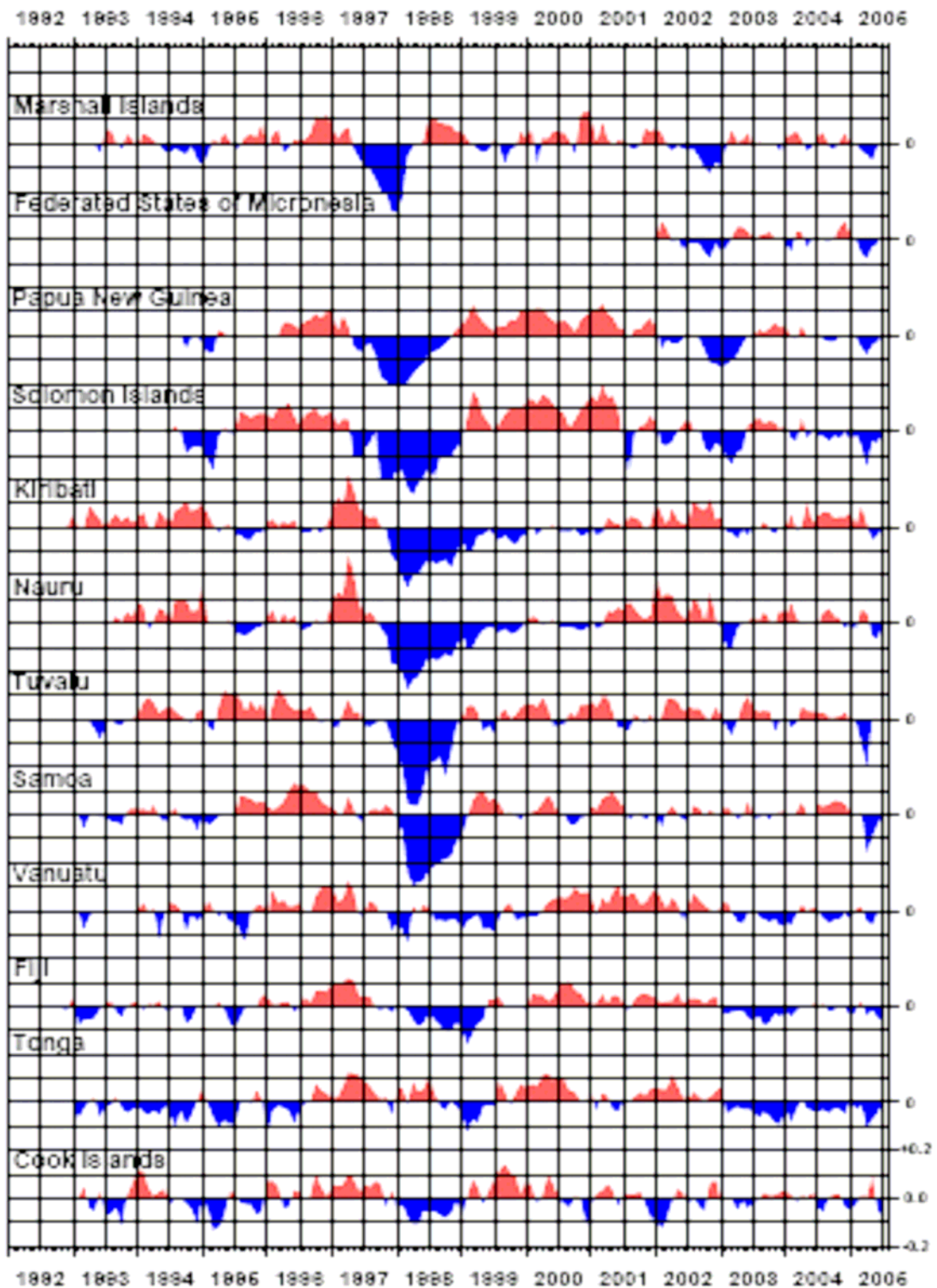
Most Pacific Islanders are very aware that the sea level is controlled by many factors, some periodic (like the tides), some brief but violent (like cyclones), and some prolonged (like El Niño), because of the direct effect the changes have upon their lives. The effects vary widely across the region. 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.

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.



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).

Figure 1. Sea level anomalies* at SEAFRAME sites



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

7. Historical Sea Level Trends and their Confidence Intervals

With the great diversity in climatic environments, vertical land movement and ocean variability, the relative sea level trends measured at different stations over different time periods also vary. This 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 SPSLCMP. 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/year⁰

Data from University of Hawaii as at June 2002

Figure 1 illustrates that sea level can undergo significant short-term fluctuation, yet it can also undergo significant fluctuation on decadal timescales. This sea level variability can affect any estimate of the underlying long-term trend. 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.

8. But What Can the SPSLCMP Tell Us?

The SPSLCMP is first and foremost a data gathering network that enables us to “monitor” what the climate in the region is doing today, and to enable meteorologists and climatologists to predict with a moderate-to-high degree of confidence what it will be like over the next three to six months. The data is also used by international scientific agencies and organisations in their long range modeling of climate change and the potential impacts, both regionally and internationally.

The SEAFRAME network, however, also plays a critical role in contributing to a regional and international early warning capability for climate change. For example, there is a lag from when the melting of the Greenland and Antarctic ice expanses starts to have a significant impact on global sea levels, and the SEAFRAME network will enable us to detect the early stages and monitor the ongoing trends of those impacts on sea level change in the South Pacific region. We may be detecting those early stages now, but they may not yet be discernable from the prevailing short-term trends.

Similarly, the SEAFRAME network will enable us to detect and monitor the subtle changes in trends for air and water temperature, and barometric pressure that are more directly driven by the increasing effects of green house gas emissions on the earth’s atmosphere rather than the ocean.

Historical sea level trends, and even to an extent the current SEAFRAME sea level trends, would suggest that we could expect sea level rises of less than 0.5m over the next 50 years, which is considerably at variance to current scientific commentary. It is possible, therefore, that the effects of recent accelerations in climate change have not yet started to have a significant contribution to or impact on current sea levels; but based on international scientific opinion, it is more a case of when, rather than if.

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