

# SOUTH PACIFIC SEA LEVEL: A REASSESSMENT

by Vincent R. Gray



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## **ABSTRACT**

The SEAFRAME sea-level study on 12 Pacific islands is the most comprehensive study of sea level and local climate ever carried out there. The sea level records obtained have all been assessed by the anonymous authors of the official reports as indicating positive trends in sea level over all 12 Pacific Islands involved since the study began in 1993 until the latest report in June 2010. In almost all cases the positive upward trends depend almost exclusively on the depression of the ocean in 1997 and 1998 caused by two tropical cyclones. If these and other similar disturbances are ignored, almost all of the islands have shown negligible change in sea level from 1993 to 2010, particularly after the installation of GPS levelling equipment in 2000.

## **INTRODUCTION**

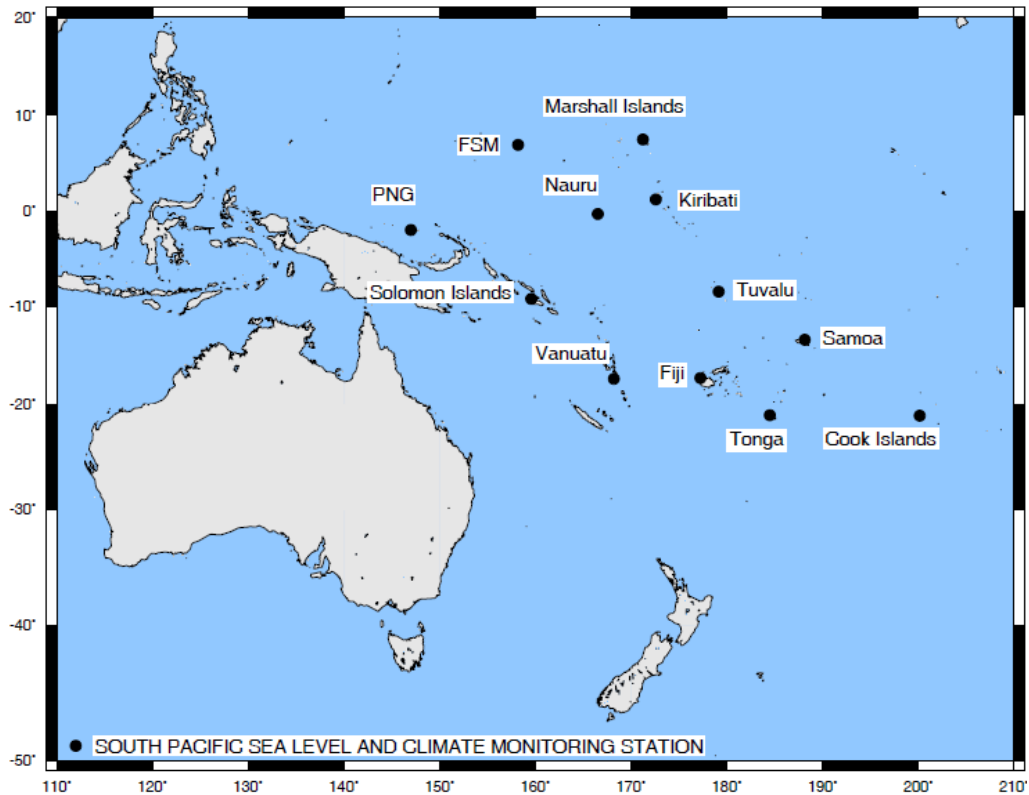
Quotations, diagrams and the Table are taken from the Reports of the Project,<sup>1-17</sup> which describe it as follows:

“The South Pacific Sea Level and Climate Monitoring Project (SPSLCMP) was developed in 1991 as an Australian Government response to concerns raised by member countries of the South Pacific Forum over the potential impacts of human-induced global warming on climate and sea levels in the Pacific region.

“The Project has been running for over 19 years and is now in its fourth phase, which commenced on 1 January 2006 and is due to end on 31 December 2010.

“The first three phases of the project established a network of 12 high resolution SEAFRAME (Sea Level Fine Resolution Acoustic Measuring Equipment) sea level and climate monitoring stations throughout the Pacific. These stations are sited at locations in participating countries (Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu) and provide a wide coverage across the Southwest Pacific basin. All of the stations, with the exception of the one located at Pohnpei (Federated States of Micronesia), which was established in December 2001, have been operational since October 1994.

“A major new initiative in this Phase was the installation of a Continuous Global Positioning System (CGPS) network linked to the SEAFRAME sites and managed by Geoscience Australia. The CGPS network is designed to monitor vertical movement of the gauges and help determine absolute sea level. Ten of the 12 CGPS stations planned were installed from 2000. During this Phase the NTFA became a part of the Australian Bureau of Meteorology and was renamed the National Tidal Centre (NTC), with its offices collocated with the Bureau’s South Australian Regional Office in Adelaide.”



**Figure A.** *South Pacific Sea Level and Climate Monitoring Stations.*

### **SEAFRAME STATIONS**

SEAFRAME stations employ a SUTRON programmable data logger, water level gauges and other sensors. The data logger and associated electronics are normally housed in fiberglass huts. A sketch of a typical station is shown in Fig. B. Water level sensors include:

1. Primary water level using a Bartex 'AQUATRAK' acoustic-in-air sensor, and
2. Secondary water level (or backup) using a Druck pressure transducer mounted close to the seabed.

The primary and backup water level sensors provide water level values, which are averaged over three minutes and are logged every six minutes. The data logger has the memory capacity to store approximately one month of data. The meteorological sensors are logged to the SUTRON data logger on an hourly basis.

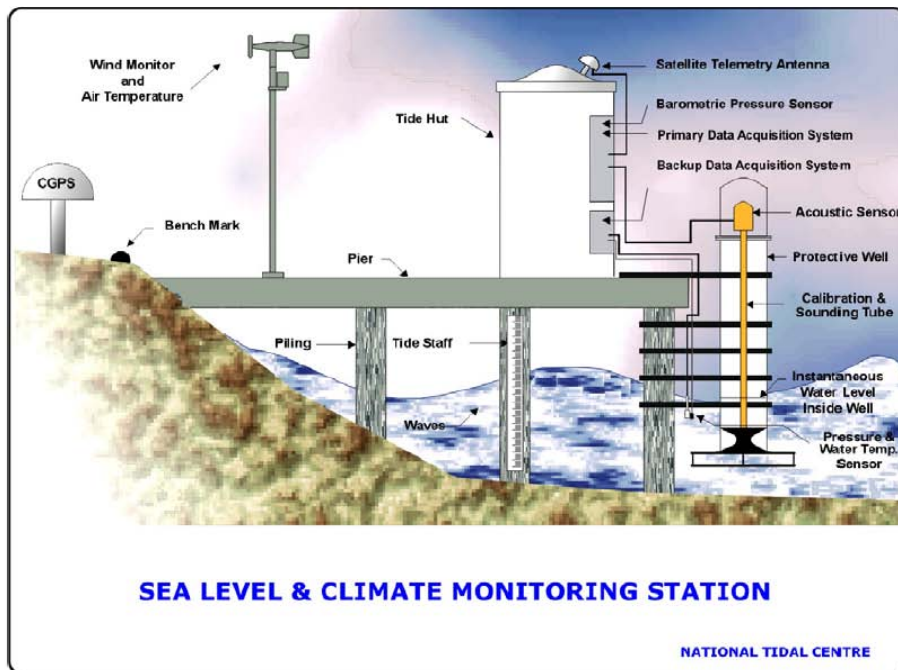


Figure B

“Precise levelling of the height of the SEAFRAME sea level sensor relative to an array of land-based benchmarks is undertaken by Geosciences Australia every eighteen months where possible. 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 after accounting for any adjustments to tide gauge zero) that are contributing to the observed sea level trends are listed in Table 1. Substantial subsidence of the tide gauge at Samoa is occurring at a rate of  $-0.9$  mm/year, and new evidence shows Cook Islands is also subsiding at  $-0.7$  mm/year. Subsidence is also occurring at Marshall Islands, FSM, Solomon Islands and Tonga. The tide gauges at Fiji and Nauru are rising with respect to the tide gauge benchmark. The rates of vertical tide gauge movement are used to correct the observed rates of sea level change relative to the land-based primary tide gauge benchmark.”

Further details are on the SEAFRAME website.<sup>1</sup> Monthly Reports for the entire project<sup>2</sup> and Individual Annual Reports for each island<sup>3-17</sup> are available and give impressive details of the levelling procedure as well as details about many other aspects of the local climate. The most recent summary paper is by Philip Hall.<sup>18</sup> The present paper is based on the information from all of these reports, all of which include the following disclaimer: “The views expressed in this publication are those of the authors and not necessarily those of the Australian Agency for International Development (AusAID).” However, the names of the authors are not given, and the only responsible person named is William Mitchell, the Manager of the National Tidal Centre.

## GENERAL

This project is undoubtedly the most modern and sophisticated attempt to monitor sea level and other climate variables and the reports give impressive details on the equipment and procedures. However, the actual data on sea level measurement are not described fully. The monthly data have been averaged over each entire month in some way, for they are presented in each island report in the form of charts showing the maximum, minimum and mean monthly averages since the beginning of the SEAFRAME installations.

The reports also provide charts of previous sea-level measurements over many of the Pacific islands, but the present paper will assess only the most recent and accurate figures from the SEAFRAME charts.

The consolidated monthly figures<sup>2</sup> are in Figure 1, with the comment:

“**Figure 1** shows the **monthly mean sea levels**, which are simple arithmetic averages of the sea levels, relative to an arbitrary zero. The figure shows that Tuvalu, for example, normally experiences an annual cycle of about 0.2 metres, reaching a peak around February or March. One effect of the El Niño of 1997/1998 was to disrupt the annual sea level cycle at many of the SEAFRAME stations.”

The scale on this graph is the same as the scale on the individual graphs shown later (Figures 4-12) but the year is given between two verticals instead of under a vertical. This means that Figure 1 has an extra half year by comparison. Several records in Figure 1 are different from those given in the individual island reports.<sup>4-17</sup> Fiji, Kiribati, Marshall Islands and Tuvalu have exaggerated peaks and troughs by comparison with the records in the

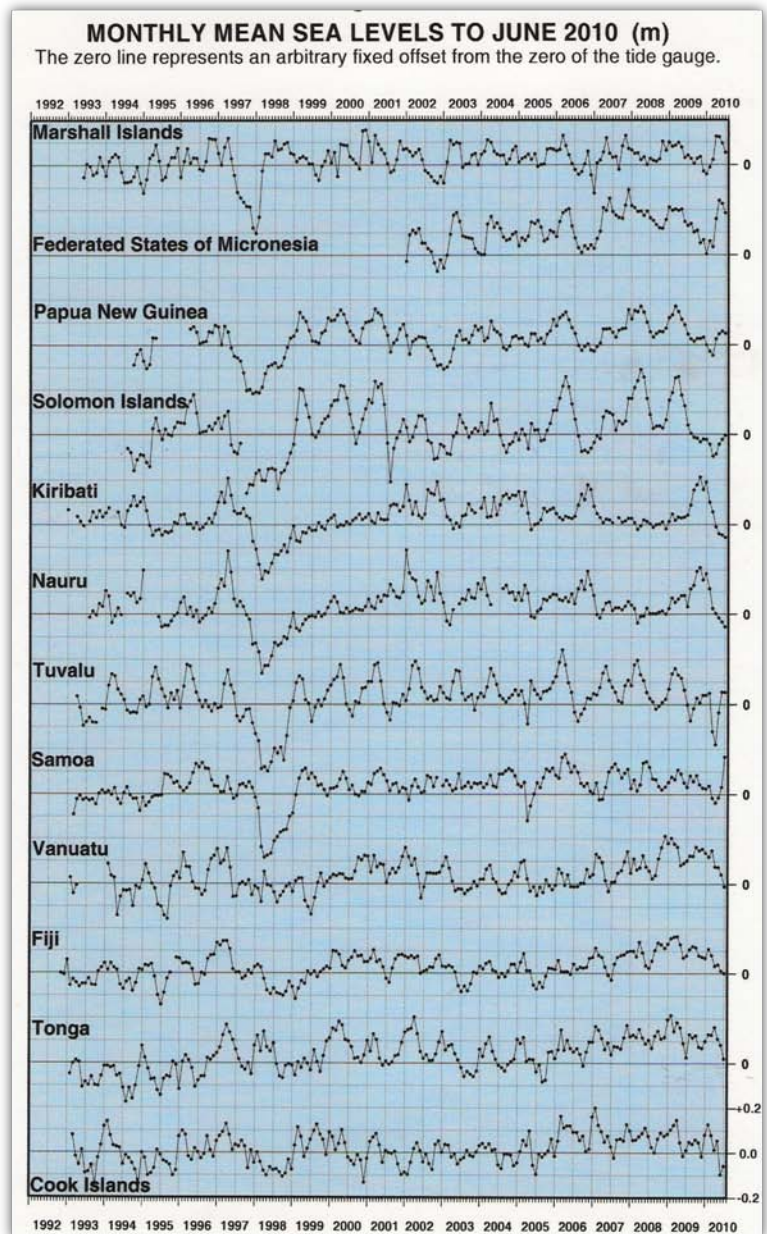


Figure 1

individual island reports. It is unclear which graph was used to derive the “trends” in Table 1. Comments in the present paper will be based on the graphs supplied in the individual island reports. In October-November 1997 Tropical Cyclone Martin and in December 1997 Tropical Cyclone Pam struck all of the islands. The question arises whether these events should be part of an exercise to measure even “short-term” trends. It is obvious that another similar event would immediately cancel most of the positive figures listed in Table 1. If this disruption is removed, 8 of the 12 islands would show no significant short-term trend since the beginning of the study. The others had a slight rise after 2005 which seems to be disappearing. This is attributed, however, to yet another El Niño event as follows:

“Lower-than-normal sea levels are typically observed in the region during El Niño, as can be seen during previous events in 1997/98, 2002/03 and 2006/07. The recent 2009/10 El Niño caused sea levels to fall significantly across the region, but not to the very low levels observed during the strong 1997/98 El Niño.”

<b>Recent short-term sea level trends in the project area based upon SEAFRAME data through June, 2010</b>				
<b>Location</b>	<b>Lat / Long</b>	<b>Installation Date</b>	<b>Trend (mm/yr)</b>	<b>Change from previous month</b>
Cook Is	21°12'17.1"S / 159°47'5.2"W	Feb 1993	+4.9	0.0
Tonga	21°8'12.5"S / 175°10'50.5"W	Jan 1993	+9.2	-0.1
Fiji	17°36'17.7"S / 177°26'17.7"E	Oct 1992	+5.4	0.0
Vanuatu	17°45'19.2"S / 168°18'27.7"E	Jan 1993	+6.4	-0.1
Samoa	13°49'36.4"S / 171°45'40.7"W	Feb 1993	+5.1	0.0
Tuvalu	8°30'8.9"S / 179°11'42.6"E	Mar 1993	+3.7	0.0
Kiribati	1°21'54.2"N / 172°55'58.8"E	Dec 1992	+3.8	-0.2
Nauru	0°31'45.9"S / 166°54'36.2"E	Jul 1993	+4.5	-0.2
Solomon Is.	9°25'44.1"S / 159°57'19.3"E	Jul 1994	+5.7	-0.1
PNG	2°2'31.5"S / 147°22'25.6"E	Sep 1994	+6.3	0.0
FSM	6°58'49.9"N / 158°12'0.8"E	Dec 2001	+14.3	0.0
Marshall Is.	7°6'21.7"N / 171°22'22.1"E	May 1993	+3.8	+0.1

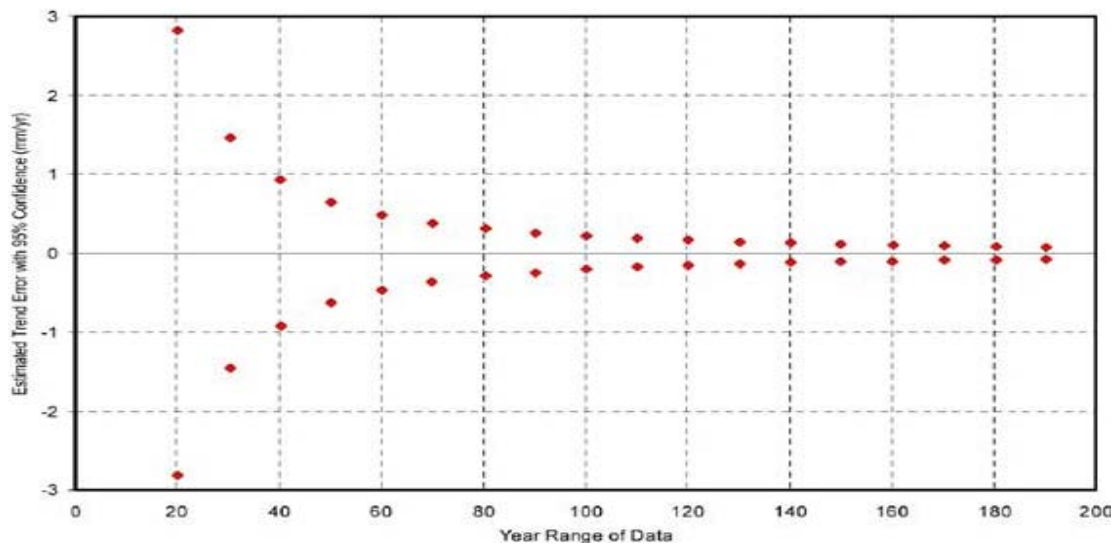
**Table 1**

This raises the question whether every El Niño event should be considered part of a “short-term trend”. Similar questions arise for other irregular, unpredictable events such as seismic activity and tsunamis. Removal of these irregular events is surely the best way to determine whether there is a “trend” associated with changes in the atmosphere.

## ACCURACY

The following statements, and Figure 2, appear in all of the individual island reports:<sup>3-14</sup>

“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 due to seismic events.”



**Figure 2.** 95% Confidence Intervals for linear mean sea level trends ( $\text{mm yr}^{-1}$ ), based on NOAA tide-gauges with at least 25 years' data,<sup>19</sup> plotted as a function of the year range of data.

This graph indicates that for the 20-year run of SEAFRAME the confidence intervals for a linear trend are  $\pm 3\text{mm}$ . This is much less than the 200mm seasonal variability shown in Figure 1. It seems to be derived from an assumption that the monthly average values are constants, whereas they are averages of levels that have varied during each day, thus adding extra confidence levels.

“Long-term trends” cannot be trusted anyway, because of changes in measurement technology. The SEAFRAME series carries out measurements to a much higher standard of accuracy than any previous measurements. Since 2000 there has been GPS levelling equipment. Without this method of levelling many previous measurements are likely not only to prove inaccurate but also to be biased upwards because of the absence of correction for storm damage to equipment and local land subsidence from buildings and removal of ground water and minerals. The “short-term trends” from the current equipment after GPS should be much more reliable, provided of course that they are not contaminated by irregular disturbances of the equipment by unpredictable events such as cyclones, earthquakes and tsunamis. Figure 2 is

unreliable because it assumes that the equipment and measurement systems can remain constant for as long as 200 years.

The individual reports<sup>3-17</sup> will be examined in the alphabetical order in which they appear on the website rather than the order in Figure 1. As there is no knowledge of the possible confidence intervals that ought to be attached to any “trend”, I have made a subjective estimate in all cases.

## **THE COOK ISLANDS**

The site was at Avatiu on the North Coast. The Report<sup>4</sup> states:

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

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

“The sea level trend to date is +5.3 mm/year but the magnitude of the trend continues to vary widely from month to month as the data set grows. Accounting for the precise levelling results and inverted barometric pressure effect, the trend is +4.6 mm/year. Nearby gauges, with longer records but less precision and datum control, show trends of +4.3 and +2.0 mm/year.

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

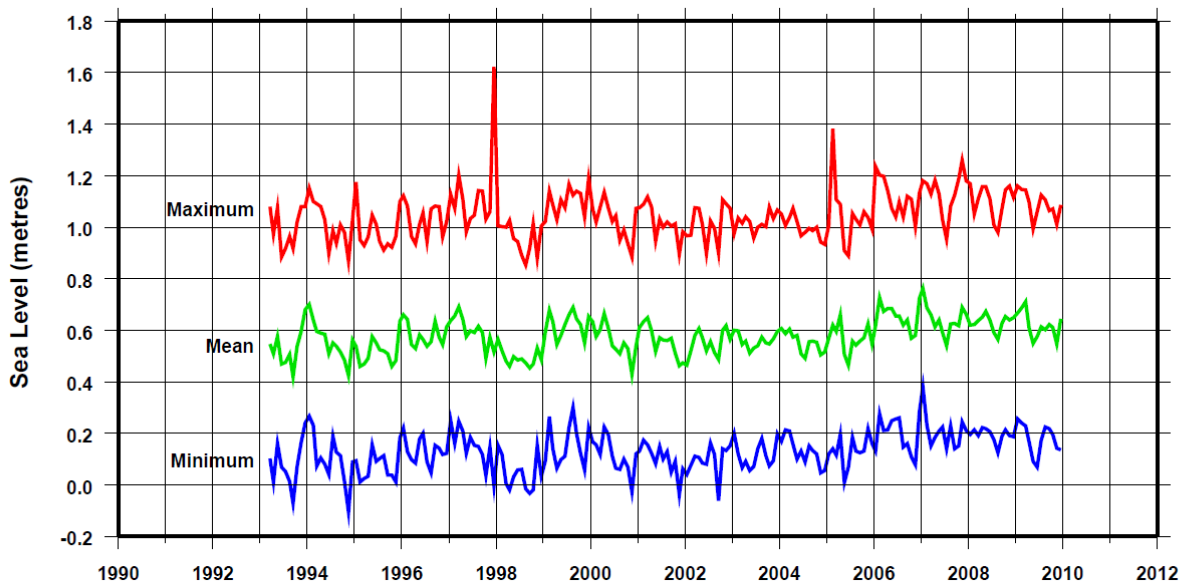
“Variations in monthly mean air and water temperature include more pronounced seasonal cycles and were likewise affected by the 1997/1998 El Niño.

“The SEAFRAME at Rarotonga, Cook Islands has recorded 14 separate tsunami events since its installation. The largest tsunami signal of 63cm followed an earthquake of magnitude Mw8.1 that occurred near Samoa on 29 September 2009.

“Since the SEAFRAME was installed in 1993, one of the worst cyclones of the century for the Pacific region struck the northern Cook Islands. In October/November 1997 Cyclone Martin brought high winds and mountainous seas to Pukapuka, Manihiki, and Ranahanga atolls, and sadly caused a number of deaths along with great destruction. The cyclone barely affected the island of Rarotonga, which is located 1200 km south. However, six weeks later, on 9 December 1997, Cyclone Pam did pass close to Rarotonga. Low pressures and high winds caused a storm surge, which flooded low-lying areas. Maximum winds recorded by the SEAFRAME were over 50 knots (92 km/hr).

“Enhanced tropical cyclone activity occurred during February and March 2005 in the southwest Pacific region that was sustained by higher than normal sea surface temperatures across the equatorial Pacific. Cook Islands encountered a sequence of four tropical cyclones, namely Cyclone Meena (6 February 2005), Cyclone Nancy (16 February 2005), Cyclone Olaf (18 February 2005) and Cyclone Percy (3 March 2005).”





**Figure 3.** Monthly sea level (m) at Avatiu, Cook Islands SEAFRAME gauge.

#### COMMENTS

There was little or no change in sea level between 1994 and 2006, with a small depression caused by the 1997-1998 cyclones. The rise in 2007 has slowly subsided, but is unexplained. It cannot be regarded as indicating an upwards trend unless there is further persistence.

#### FEDERATED STATES OF MICRONESIA

Pohnpei "upon (*pohn*) a stone altar (*pei*)" (formerly known as Ponape) is the name of one of the four states in the Federated States of Micronesia (FSM), and among the Senyavin Islands\_(part of the larger Caroline Islands group). Palikir, the FSM's capital, is located on Pohnpei. Pohnpei International Airport (IATA code PNI) is located near Kolonia, on a small island named Deketik off the northern coast of the main island. The gauge itself is at Kolonia.

The Executive Summary<sup>5</sup> states:

"A SEAFRAME gauge was installed in Pohnpei, FSM, in December 2001. 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.

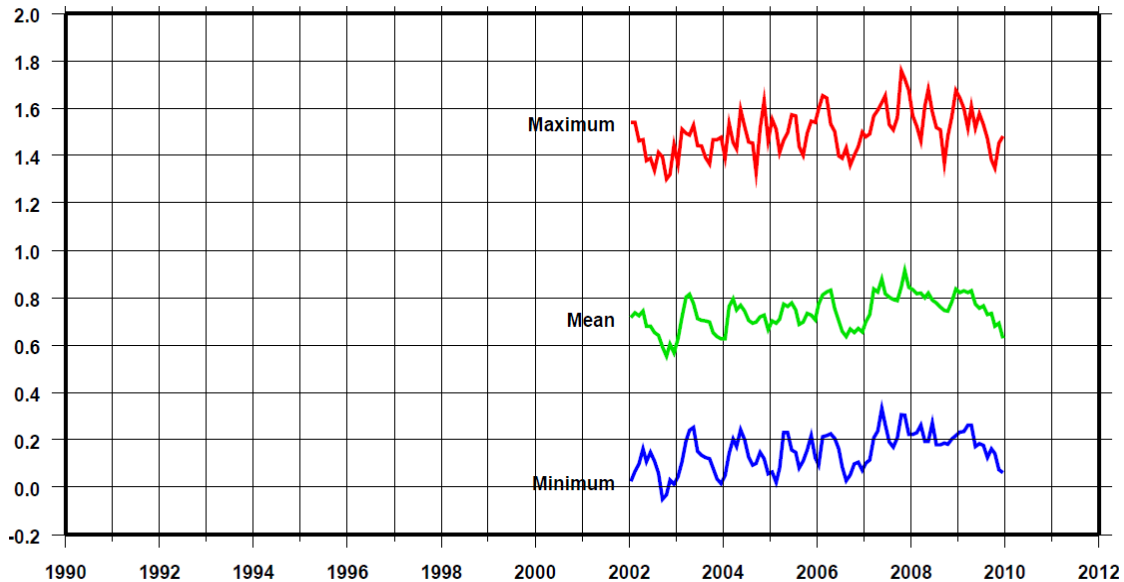
"It is too early to calculate a meaningful sea level trend from the Pohnpei SEAFRAME. Nearby gauges, with longer records but less precision and datum control, show trends of +1.8, -0.4, +1.5, +1.8 and +1.3 mm/year (as compared to a global average of 1-2 mm/year).

"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 were likewise affected by the 1997/1998 El Niño.

“Since installation, no tropical cyclones (or Typhoons as they are called in that region) have affected Pohnpei. A tropical storm that subsequently developed into Typhoon Pongsona did register low barometric pressure and gusty winds on the SEAFRAME in December 2002 and brought heavy rains.

“The SEAFRAME at Pohnpei, FSM has recorded 4 separate tsunami events since its installation. The largest tsunami signal of trough-to-peak height 7 cm was recorded after an earthquake of magnitude Mw8.3 that occurred near Kuril Islands on 15 November 2006.”



**Figure 4.** Monthly sea level (m) at Pohnpei SEAFRAME gauge.

#### COMMENTS

It is possible that the trough in 2003, at the beginning, may be related to typhoon Pongsona in December 2002. There was little change from 2003 to 2007 but after that there was a rise. It is admitted that this information is insufficient to indicate a “trend”.

#### FIJI

Lautoka is the second largest city of Fiji. It is in the west of the island of Viti Levu. The Executive Summary<sup>6</sup> states:

“A SEAFRAME gauge was installed in Lautoka, Fiji, in October 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.

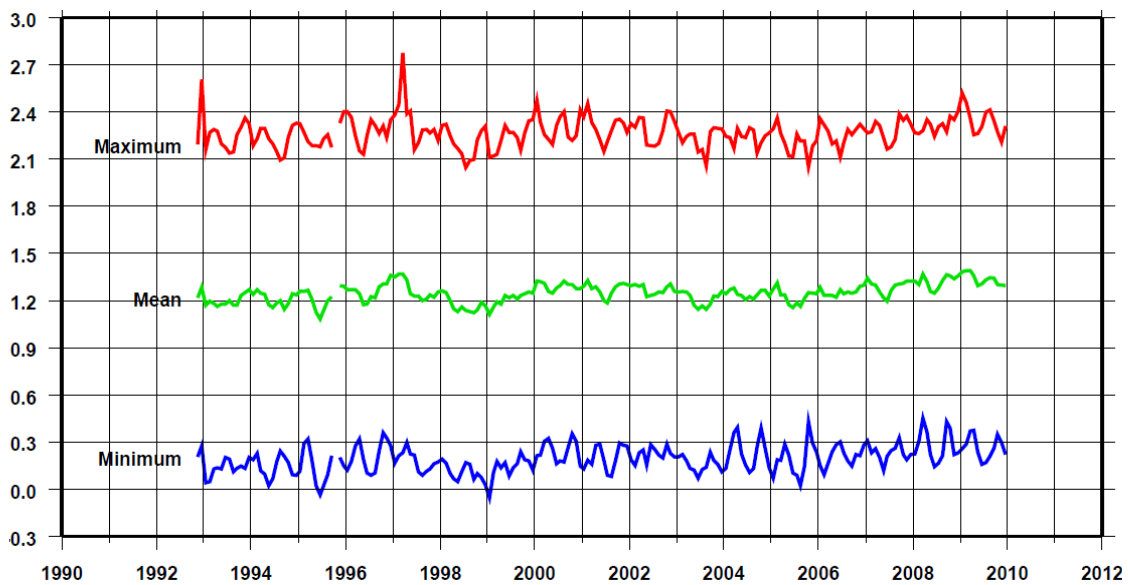
“The sea level trend to date is +5.7 mm/year but the magnitude of the trend continues to vary widely from month to month as the data set grows. Accounting for the precise levelling results and inverted barometric pressure effect, the trend is +5.5 mm/year. A nearby gauge, with longer records but less precision and datum control, shows a trend of +4.7 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 more pronounced seasonal cycles and were likewise affected by the 1997/1998 El Niño.

“In 1993, 1997, 2003 and 2009 tropical cyclones caused widespread devastation in Fiji, including the main islands Viti Levu and Vanua Levu. The 1993, 1997 and 2009 cyclones were recorded as extreme low pressures on the SEAFRAME.

“The SEAFRAME at Lautoka, Fiji has recorded 18 separate tsunami events since its installation. The largest tsunami signal of trough-to-peak height 22 cm was recorded after an earthquake of magnitude Mw7.5 that occurred near Vanuatu on 26 November 1999.”



**Figure 5.** Monthly sea level (m) at Lautoka, Fiji, SEAFRAME gauge.

## COMMENTS

Figure 5 gives the SEAFRAME record. There was a slight peak in 1997 and a small rise from 2000 to 2004, then a rise to 2009. All of these seem to be associated with tropical cyclones so there is no indication of a regular upwards trend.

## KIRIBATI

The Report<sup>7</sup> states:

“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.

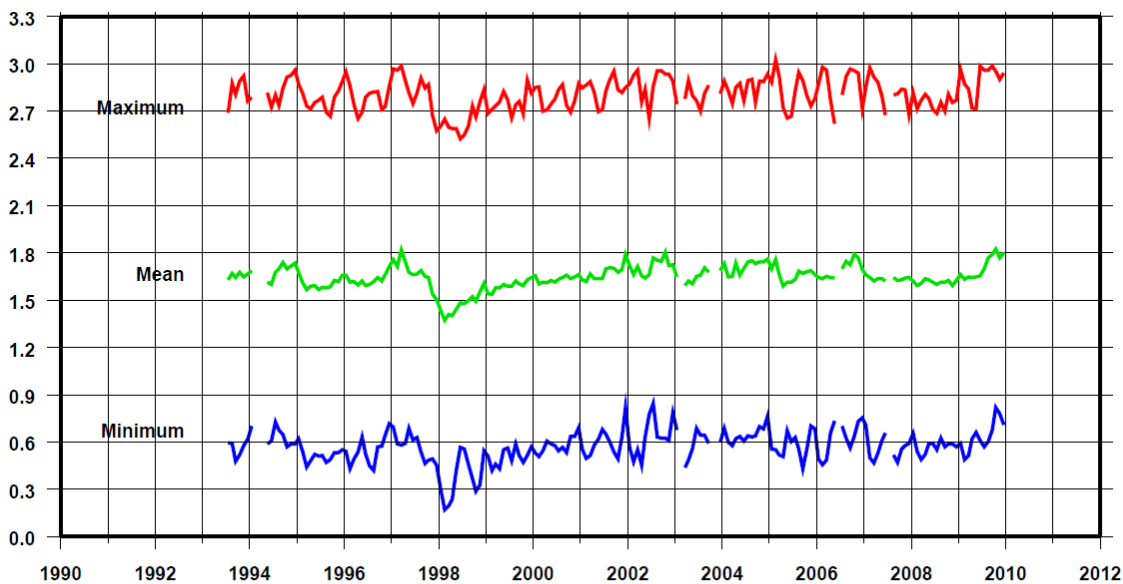
“The sea level trend to date is +4.3 mm/year but the magnitude of the trend continues to vary widely from month to month as the data set grows. Accounting for the precise levelling results and inverted barometric pressure effect, the trend is +3.9 mm/year. Nearby gauges, with longer records but less precision and datum control, show trends of –3.8, 0.8, 3.1 and –0.4 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 SEAFRAME at Kiribati has recorded 12 separate tsunami events since its installation. The largest tsunami signal of trough-to-peak height 9 cm was recorded after an earthquake of magnitude Mw8.2 that occurred near Irian Jaya on 17 February 1996.”



**Figure 6.** Monthly sea level (m) at Betio, Kiribati, SEAFRAME gauge.

## COMMENTS

There was a depression in 1998 which was obviously caused by the El Niño event of that year and seemed to take some time to recover. Otherwise there was little sea level change between 2001 and 2009.

## MARSHALL ISLANDS

Majuro, is the capital and largest city of the Republic of the Marshall Islands, built on the Majuro atoll. The Report<sup>8</sup> states:

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

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

“The sea level trend to date is +3.8 mm/year but the magnitude of the trend continues to vary widely from month to month as the data set grows. Accounting for the precise levelling results and inverted barometric pressure effect, the trend is +3.2 mm/year. Nearby gauges, with longer records but less precision and datum control, show trends of +2.3, +1.3, and +1.7 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 were likewise affected by the 1997/1998 El Niño.

Typhoon Paka passed the Marshall Islands on 10 December 1997 and caused around US\$80 million (1997) in damage.

“The SEAFRAME at Majuro, Marshall Islands has recorded 13 separate tsunami events since its installation. The largest tsunami signal with trough-to-peak height of 11 cm was recorded after an earthquake of magnitude Mw8.3 that occurred near Kuril Islands on 4 October 1997?”

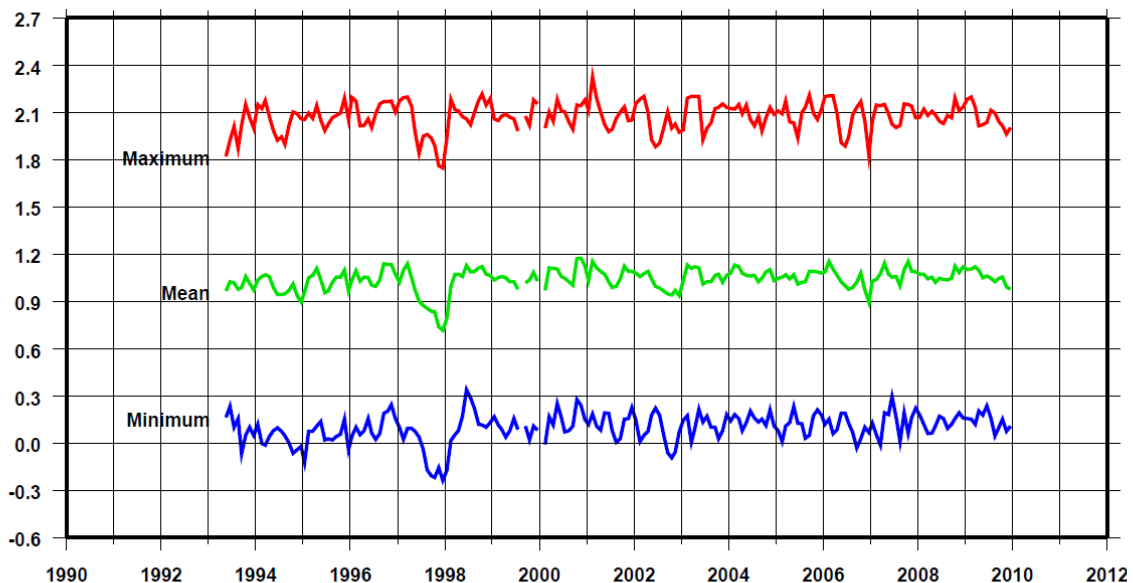


Figure 7. Monthly sea level (m) at Majuro, Marshall Islands, SEAFRAME gauge.

#### COMMENTS

If the depression caused by the El Niño of 1998 is ignored, the sea level at Majuro did not change in the 14 years 1994-2008. The slightly lower figure right at the beginning, 1993-1995, could have been early teething troubles before the GPS equipment was installed.

## NAURU

The Report<sup>9</sup> states:

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

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

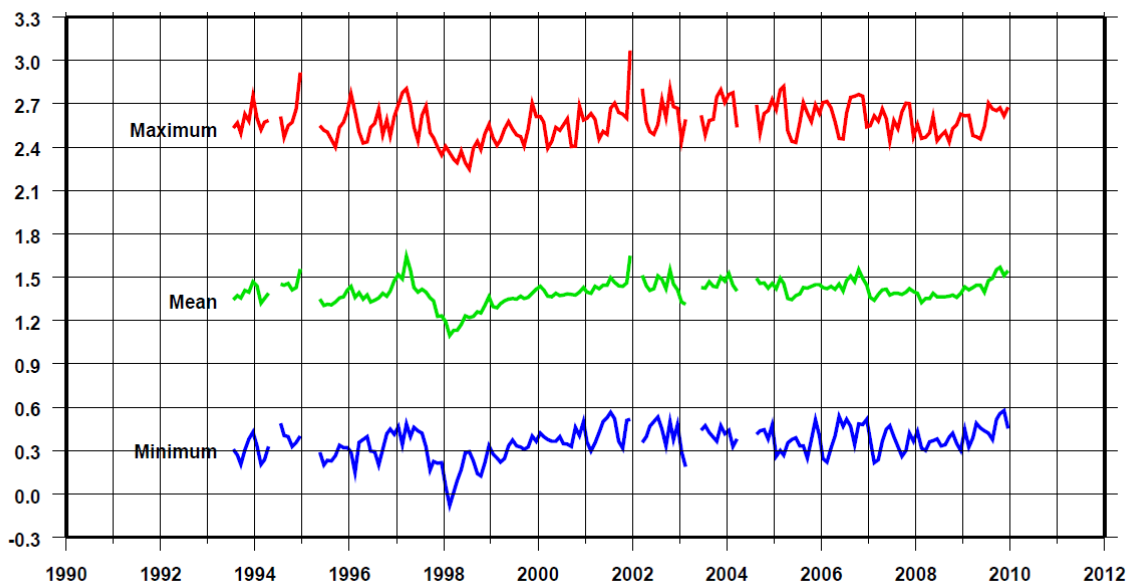
“The sea level trend to date is +5.2 mm/year but the magnitude of the trend continues to vary widely from month to month as the data set grows. Accounting for the precise levelling results and inverted barometric pressure effect, the trend is +4.9 mm/year. A nearby gauge, with longer records but less precision and datum control, shows a trend of –0.4 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 Nauru means that it is not subject to tropical cyclones.

“The SEAFRAME at Nauru has recorded 6 separate tsunami events since its installation. The largest tsunami signal of trough-to-peak height 16 cm was recorded after an earthquake of magnitude Mw8.2 that occurred near Irian Jaya on 17 February 1996.”



**Figure 8.** Monthly sea level (m) at Nauru SEAFRAME gauge.

### COMMENTS

Again, there was a depression in 1998 caused by El Niño of that year and taking several years to recover. A rise in 2010 has now subsided, according to Figure 1. There was no overall trend between 2002 and 2010.

## NIUE, PALAU

These reports<sup>10,11</sup> are ignored as they have no SEAFRAME installation, although Palau has something similar, but only just installed.

## PAPUA NEW GUINEA

The Report<sup>12</sup> states:

“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 +7.4 mm/year but the magnitude of the trend continues to vary widely from month to month as the data set grows. Accounting for the precise levelling results and inverted barometric pressure effect, the net trend is +5.9 mm/year.

“Variations in monthly mean sea level are dominated by seasonal cycles and were affected by 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 were affected by the 1997/1998 El Niño.

“Manus Island is protected from tropical cyclones by virtue of its proximity to the equator.

“The SEAFRAME at Manus, PNG has recorded 5 separate tsunami events since its installation. The tsunami that followed a magnitude Mw7.1 earthquake and underwater landslide on 17 July 1998 caused numerous deaths and widespread devastation near Aitape on the northern mainland.”

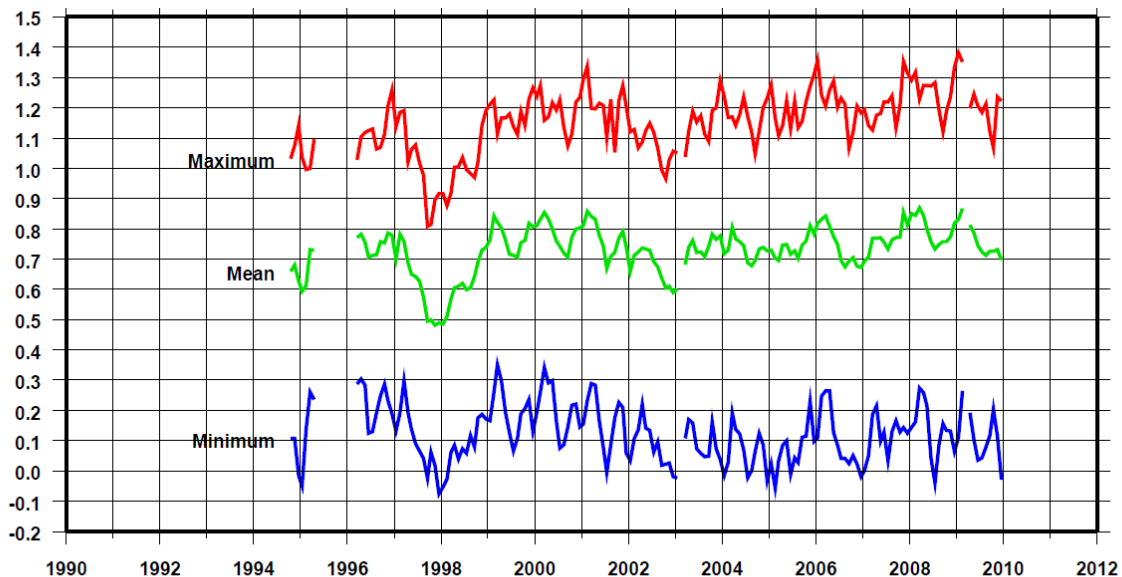


Figure 9. Monthly sea level (m) at Lombrum, Manus Island, SEAFRAME gauge.

## COMMENTS

Again, there was a depression caused by the 1997-1998 Tropical Cyclones, but apart from that, there was no sea-level change from 1995 to 2008, 13 years. A blip on the record in 1993 and a discontinuity in 2003 are probably attributable to equipment problems.

## SAMOA

The Report<sup>13</sup> states:

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

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

“The sea level trend to date is +5.7 mm/year but the magnitude of the trend continues to vary widely from month to month as the data set grows. Accounting for the precise levelling results and inverted barometric pressure effect, the trend is +4.6 mm/year. A nearby gauge, with longer records but less precision and datum control, shows a trend of +2.1 mm/year.

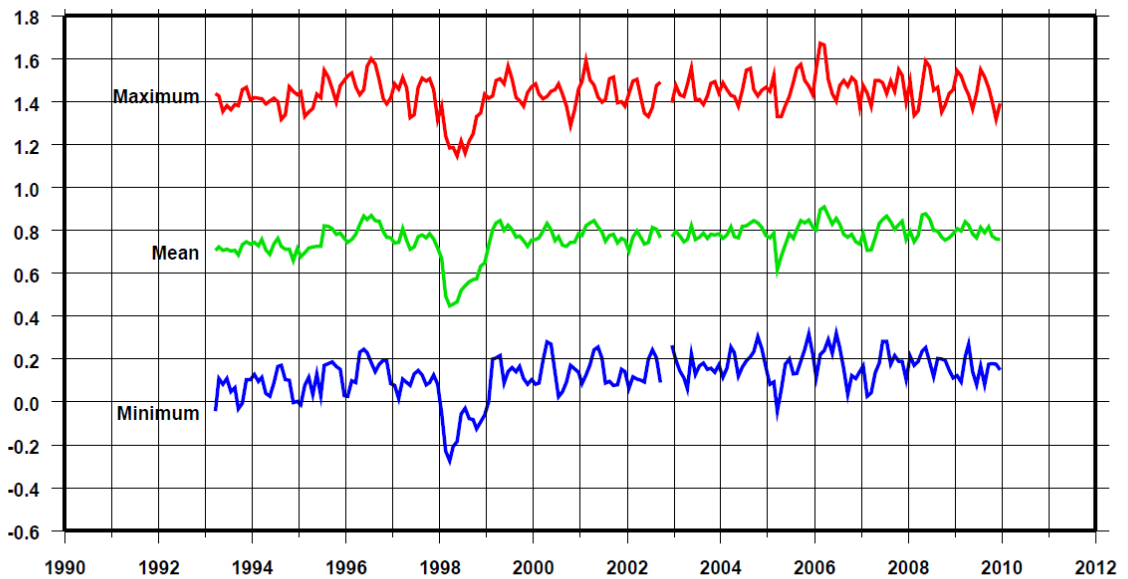
“Variations in monthly mean sea level include a moderate seasonal cycle and were affected by the 1997/1998 El Niño.

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

“A number of Tropical Cyclones have passed near the Samoan Islands since the SEAFRAME was installed. Tropical Cyclone Heta caused widespread damage to Samoa in January 2004.

“The SEAFRAME at Apia, Samoa has recorded 20 separate tsunami events since its installation. The largest tsunami signal of trough-to-peak height 140 cm was recorded after a near-field earthquake of magnitude Mw8.1 that struck 190km south of Apia on 29 September 2009. The tsunami caused loss of life and property, particularly along exposed coastlines of Samoa and American Samoa.”





**Figure 10.** Monthly sea level at Apia, Western Samoa, SEAFRAME gauge.

#### COMMENTS

The 1998 depression owing to the two Tropical cyclones still features. There is no sea-level change from 1996 to 2008, 12 years. The period between 1993 and 1996, which was lower, may have been early teething troubles before the GPS equipment was installed in 2000. The 2009 earthquake does not seem to have affected the sea level.

#### SOLOMON ISLANDS

The Report<sup>14</sup> states:

“A SEAFRAME gauge was installed in Honiara, Solomon Islands, in July 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.

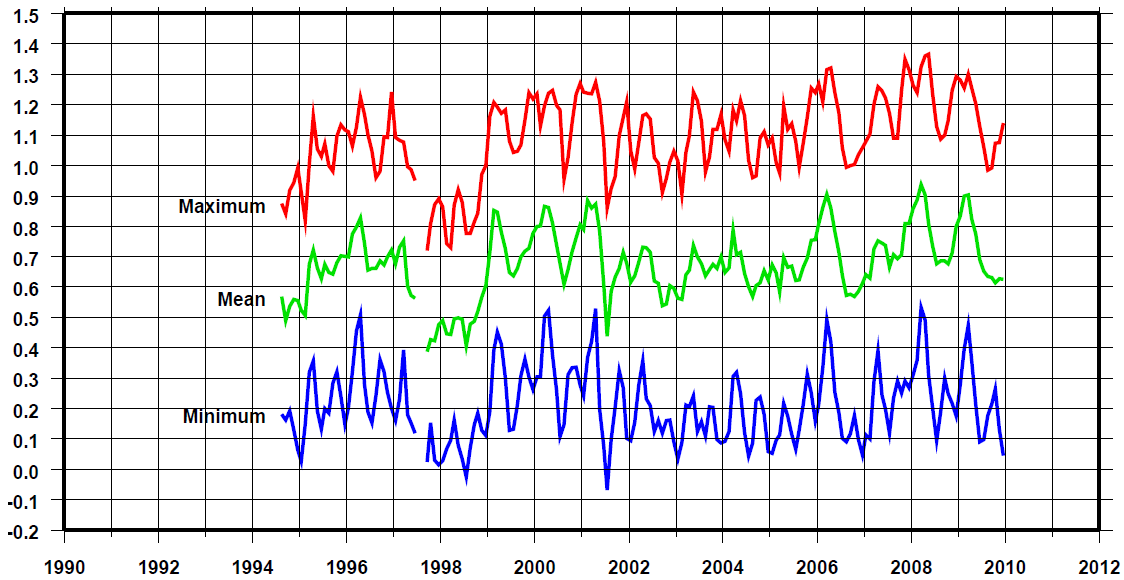
“The sea level trend to date is +7.8 mm/year but the magnitude of the trend continues to vary widely from month to month as the data set grows. Accounting for the precise levelling results and inverted barometric pressure effect, the trend is +7.7 mm/year. A nearby gauge, with longer records but less precision and datum control, shows a trend of -5.7 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 are likewise affected by the 1997/1998 El Niño.

“Since installation, only tropical cyclone Fergus in December 1996 has passed near enough to the Honiara gauge to have caused extreme low barometric pressure. In December 2002 an intense tropical cyclone struck the southern islands of Anuta and Tikopia.

“The SEAFRAME at Honiara, Solomon Islands has recorded 14 separate tsunami events since its installation. The largest tsunami signal of trough-to-peak height 39 cm was recorded after an earthquake of magnitude Mw8.1 some 350 km ESE from Honiara on 1 April.”



**Figure 11.** Monthly sea level (m) at Honiara, Solomon Islands, SEAFRAME gauge.

#### COMMENTS

The seasonal variability is greater than with the other records. The 1997-1998 cyclones appear once more, and this time it seems to have disrupted the measurements, suggesting one reason why they make a slight upwards jump. There is no overall change between 1999 and 2008.

#### TONGA

The Report<sup>15</sup> states:

“A SEAFRAME gauge was installed in Nuku’alofa, Tonga, in January 1993. It records sea level, air and water temperature, atmospheric pressure, wind speed and direction. It is one of an array designed to monitor changes in sea level and climate in the Pacific.

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

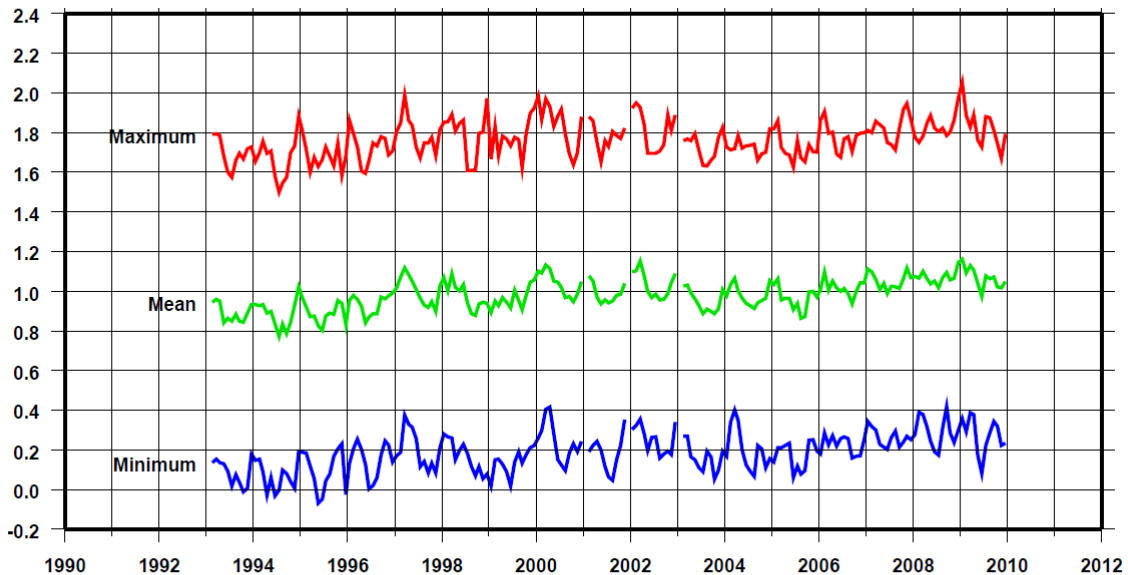
“The sea level trend to date is +9.5 mm/year but the magnitude of the trend continues to vary widely from month to month as the data set grows. Accounting for the precise levelling results and inverted barometric pressure effect, the trend is +8.6 mm/year. A nearby gauge, with longer records but less precision and datum control, shows a trend of +6.3 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.

“In 1997 and 1998 tropical cyclones caused widespread devastation in Tonga, including the main island Tongatapu. Wind gusts recorded by the SEAFRAME at Tonga reached 90 knots and 68 knots respectively.

“The SEAFRAME at Nuku’alofa, Tonga has recorded 20 separate tsunami events since its installation. The largest tsunami signal of trough-to-peak height 40 cm was recorded after an earthquake of magnitude Mw8.0 that occurred near Tonga around 160km NE of Nuku’alofa on 3 May.”



**Figure 12.** Monthly sea level (m) at Nuku’alofa, Tonga, SEAFRAME gauge.

#### COMMENTS

The record has fluctuated, but the period from 1997 to 2007 was almost unchanged. The lower period between 1993 and 1997 may indicate slight instrument adjustment after the cyclones and the slightly higher figures from 2007 now seem have gone (with additional information in Figure 1), possibly influenced by the recent earthquake.

#### TUVALU

The Report<sup>16</sup> states:

“A SEAFRAME gauge was installed in Funafuti, Tuvalu, in March 1993. It records sea level, air and water temperature, atmospheric pressure, wind speed and direction. It is one of an array designed to monitor changes in sea level and climate in the Pacific.

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

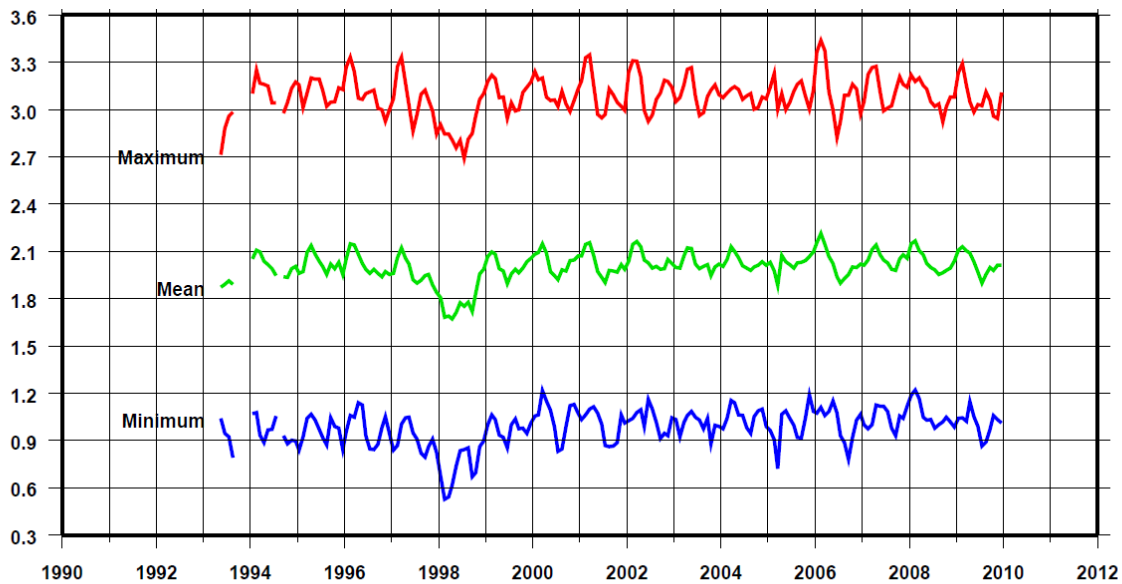
“The sea level trend to date is +5.1 mm/year but the magnitude of the trend continues to vary widely from month to month as the data set grows. Accounting for the precise levelling results and inverted barometric pressure effect, the trend is +4.7 mm/year. A nearby gauge, with a longer record but less precision and datum control, shows a trend of +0.9 mm/year.

“Variations in monthly mean sea level, air and water temperatures are dominated by seasonal cycles and were affected by the 1997/1998 El Niño.

“The seasonal sea level cycle shows a peak early in the year, a time when Funafuti frequently experiences flooding.

“Since installation, at least two cyclones have passed through Tuvalu, but only one, Tropical Cyclone Gavin, was registered as extreme low pressure on the SEAFRAME at Funafuti.

“The SEAFRAME at Funafuti, Tuvalu has recorded 16 separate tsunami events since its installation. The largest tsunami signal of trough-to-peak height 8 cm was recorded after an earthquake of magnitude Mw8.3 that occurred near Kuril Islands on 15 November 2006.”



**Figure 13.** Monthly sea level at Funafuti, Tuvalu, SEAFRAME gauge.

## COMMENTS

If the depression of the 1998 cyclone is ignored, there was no change in sea level at Tuvalu between 1994 and 2009: 14 years. The recent slight fall would probably be related to the recent earthquake.

## VANUATU

The Report<sup>17</sup> states:

“A SEAFRAME gauge was installed in Port Vila, Vanuatu, in January 1993. It records sea level, air and water temperature, atmospheric pressure, wind speed and direction. It is one of an array designed to monitor changes in sea level and climate in the Pacific.

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

“The sea level trend to date is +6.5 mm/year but the magnitude of the trend continues to vary widely from month to month as the data set grows. Accounting for the precise levelling results

and inverted barometric pressure effect, the trend is +5.6 mm/year. An older gauge at Port Vila operated from 1977-1982.

“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.

“A number of destructive Tropical Cyclones (TC) have passed near Vanuatu since the SEAFRAME was installed. In particular TC Prema caused damage to the SEAFRAME in March 1993.

“The SEAFRAME at Port Vila, Vanuatu has recorded 34 separate tsunami events since its installation. The largest tsunami signal of trough-to-peak height 77 cm was recorded after an earthquake of magnitude Mw7.5 that occurred near Vanuatu on 26 November 1999. Vanuatu is prone to tsunamis and two in particular have caused loss of life and damage to property in the period since installation.”

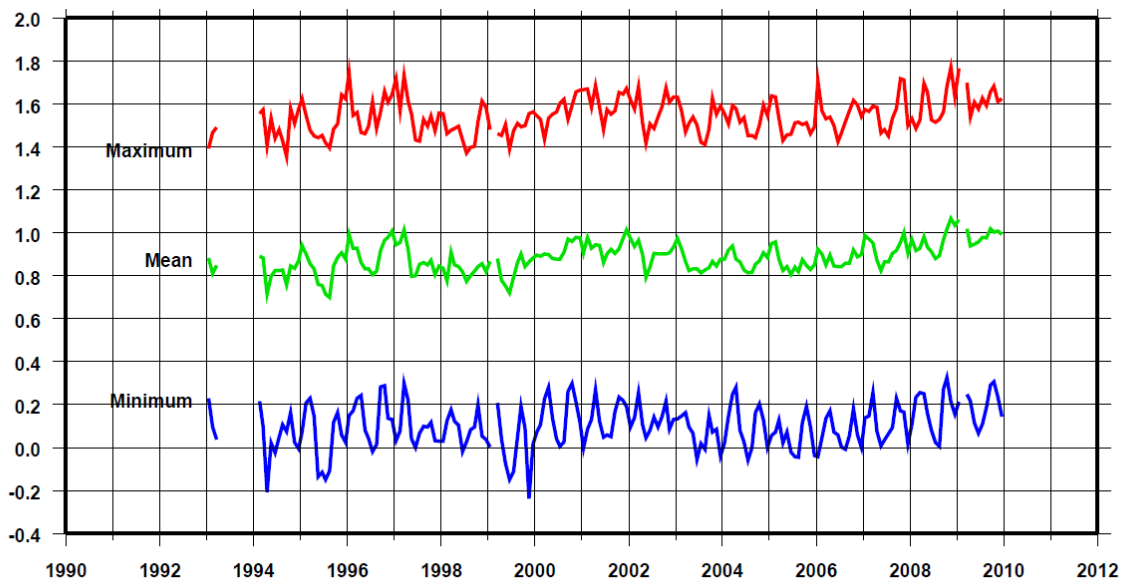


Figure 14. Monthly sea level (m) at Port Vila, Vanuatu, SEAFRAME gauge.

#### COMMENTS

There has been no change in sea level at Vanuatu from 1995 to 2008. The recent slight rise in sea level has now subsided, according to Figure 1.

## CONCLUSION

**Table 2**  
**Summary of This Assessment**

Island State	Claimed Sea-level Trend	Years with Zero Trend
Cook Islands	+4.9 mm yr <sup>-1</sup>	1999-2006
Micronesia		2003-2007
Fiji	+5.4 mm yr <sup>-1</sup>	2000-2007
Kiribati	+3.8 mm yr <sup>-1</sup>	2000-2009
Marshall Islands	+3.8 mm yr <sup>-1</sup>	1999-2010
Nauru	+4.5 mm yr <sup>-1</sup>	2002-2010
Papua New Guinea	+6.3 mm yr <sup>-1</sup>	2000-2010
Samoa	+5.1 mm yr <sup>-1</sup>	2000-2010
Solomon Islands	+5.7 mm yr <sup>-1</sup>	1999-2010
Tonga	+9.2 mm yr <sup>-1</sup>	1999-2007
Tuvalu	+3.7 mm yr <sup>-1</sup>	1993-2010
Vanuatu	+6.4 mm yr <sup>-1</sup>	2000-2008

It is evident that the installation of GPS equipment in 2000 has had an influence on stabilizing the SEAFRAME gauges. Since that date, there has been little evidence that the sea level is changing in the 12 Pacific islands.



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