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Sea Level Changes in the Pacific Region and Impacts of the 2009 El Niño in Fiji Waters [Assessment from 18 Years Land -Based Data]

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Abstract

The sea level rise issue is one of the major topics that has gained increasing global attention. In particular, its impacts on many Pacific island countries and other low lying countries have been more prevalent over the last two decades. Sea level data from the AusAID funded South Pacific Sea Level and Climate Monitoring Project will be focused in this study despite the fact that the length of data is not sufficiently long. The project was set up in response to concerns raised by Pacific island countries over the potential impacts of an enhanced greenhouse effect on climate and sea levels in the South Pacific initially for 20 years and probably more. Based upon 18 years of sea level data from the project, the range of sea level rise rate in the Pacific region is between 3.1 mm y^{-1} (Kiribati) and 8.4 mm y^{-1} (Tonga) as of June 2011. This is 3-4 times higher than the global average of 1-2 mm y^{-1}. Although the data length is for the last 18 years, the sea level trend values do not fluctuate significantly since 2002. It simply indicates that the rate of sea level rise in the Pacific region is not accelerating as anticipated by the local community. Interestingly, the profound effects of El Niño on sea level changes are quite unpredictable even during the 2009 mild El Niño. In two particular spots in the Pacific and their vicinities (at latitude 12 °S & longitude 180 °E and latitude 14 °S & longitude 157 °E) sea level drop in these areas is ~40 cm during March 2010. Although the present effect of El Niño on sea level changes is isolated and not Pacific wide like in 1997-98 El Niño, it simply indicates the complexity of sea level issue and danger of projecting future sea level trends at a particular area.
Keywords: *Sea level, El Niño, Fiji, Climate change.*

1 Introduction

Among many islands in the Pacific region, it is not only the residents of some low lying small island states who need to worry about sea level rise. More than 70% of the world's population live on coastal plains and 11 of the world's 15 largest cities are on the coast or estuaries (Greenpeace, 2010). According to the sea level records, sea levels rose between 10 and 20 cm over the 20th century. The IPCC (2007) puts predictions of 21st century sea level rise at 9-88 cm. There are many variables influencing sea level rise, including how much the expected increase in precipitation will add to snow packs and, most importantly, our greenhouse gas emissions over the next decades (IPCC, 2007). What we do know is that even a small amount of sea level rise will have profound negative effects.

Variations in sea level and atmosphere are inextricably linked. For example, to understand why the sea level at one island undergoes a much larger annual fluctuation than another island, we need to look at the seasonal shifts of the trade winds. In addition, the climate of the Pacific islands region is entirely ocean-dependent. When the warm waters of the western equatorial Pacific flow eastward during El Niño, the precipitation, in a sense, follows them, leaving the islands in the west in drought.

Although this study is based on short term data of approximately one nodal cycle, and there is no way to make a complete story on sea level issues in the Pacific region, our major aims can be itemised as follows:

Sea level trends values for 12 Pacific Island Countries covering most of the Pacific Region were evaluated,

Trends from land based data were compared with the trends from satellite data and IPCC estimates,

Differences among the global, regional and local sea level trends was judged and which one is more appropriate for making policy and future preparations was decided,

The complexity of sea level due to different components involved and the difficulty to predict the future sea level status were discussed, and

The effect of El Niño on sea level was highlighted using the most recent example.

2 Materials and Methods

In this study, we used 18 years land-based sea level and atmospheric pressure data from an Australian project mainly for sea level trends calculation and to analyze the effects of atmospheric pressure on sea level. In order to obtain a clear view on the sea level situation in the Pacific region, comparison will be made among IPCC estimated global trends, historical sea level changes and sea level trends from satellite data since 1992. The effect of the recent El Niño will be highlighted using a typical example of hugely affected areas in the Pacific. We expect significant sea level changes in some areas as the spatial pattern of the 2009/10 El Niño resembles that of a new type of El Niño (see Figure 1) with maximum sea surface temperature (SST) anomalies concentrated in the central Pacific region.

2.1 South Pacific Sea Level and Climate Change Monitoring Project (The Australian Project)

In response to concerns raised by the Pacific island countries over the potential impacts of an enhanced greenhouse effect on climate and sea levels in the South Pacific region, the South Pacific Sea Level and Climate Monitoring Project was set up in early 1990s. It has been fully funded by Aus*AID* for the forum region and participating countries are shown in Figure 2.

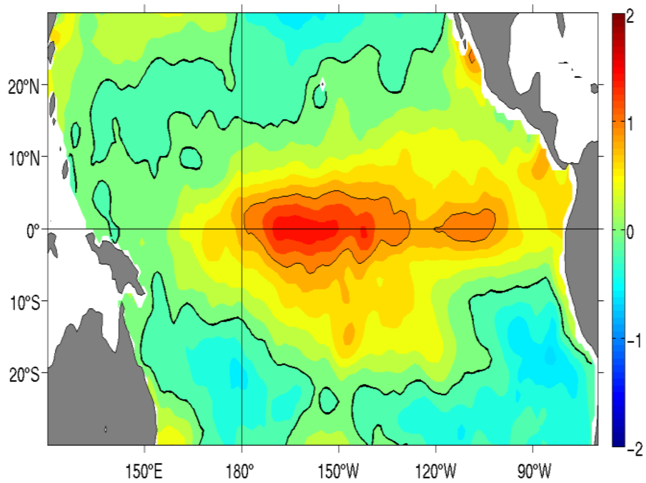


Figure 1. Mean SST anomalies (in °C) during December-January-February of 2009/10.
[Source: http://opendep.aviso.oceanobs.com].

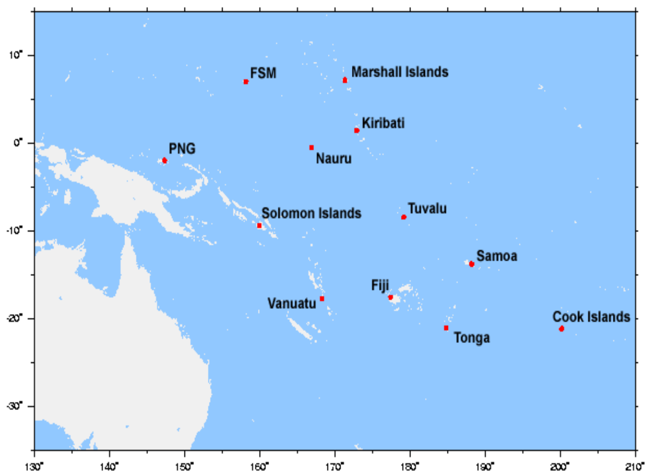


Figure 2. Map of the South Pacific Sea Level and Climate Monitoring Project sites. [Source: www.bom.gov.au].

As part of the project, installation of SEAFRAME (SEAlevel Fine Resolution Acoustic Measuring Equipment) gauges started in late 1992. It took a few years to get all stations set up in the 12 Pacific island countries. These gauges have been returning high resolution, good scientific quality data since then. However, it is to be noted that the station at Federated States of Micronesia (FSM) was deployed only in December 2001 and the length of data is too short to compare with other stations. Consequently, attention is not given in FSM sea level trends in this study.

3 Results and Discussion

3.1 Historical Sea Level Changes

Since an average person lives fewer than 100 years, it is difficult to imagine environmental changes over periods of time as long as thousands or millions years. In fact, the rise and fall of sea level is not a new issue for mankind although it has become one of the most heated topics recently. For example, during the last ice age, sea level fell to more than 120 m below present day sea level as water was stored in ice sheets in North America (Laurentian, Cordilleran), Greenland, Northern Europe (Fennoscandia and the Barents region) and Antarctica. When the ice melted, starting around 20 000 years ago, sea level rose rapidly at average rates of about 10 mm y^{-1} (or 1 m per century), and with peak rates in the order of 40 mm y^{-1} (or 4 m per century) until about 6000 years ago (Church *et al.*, 2001).

3.2 Sea Level Trends From Satellite Altimeter Data

To achieve a more realistic point of view on sea level changes, we look at the satellite data for global rate of sea level rise. According to (CSIRO, 2010), high quality measurements of global sea level have been made since late 1992 by satellite altimeters, in particular, TOPEX/Poseidon (launched in August, 1992), Jason-1 (launched in December, 2001) and Jason-2 (launched in June, 2008). This data set has shown a steady increase in Global Mean Sea Level (GMSL) of 3.3 ± 0.4 mm y^{-1} over that period. This is more than 50% larger than the average value over the 20th century and more than the IPCC estimate of 1-2 mm y^{-1}. It is believed that global warming from increasing greenhouse gas concentrations is a significant driver of ocean thermal expansion as components of recent and future sea level rise (CSIRO, 2010).

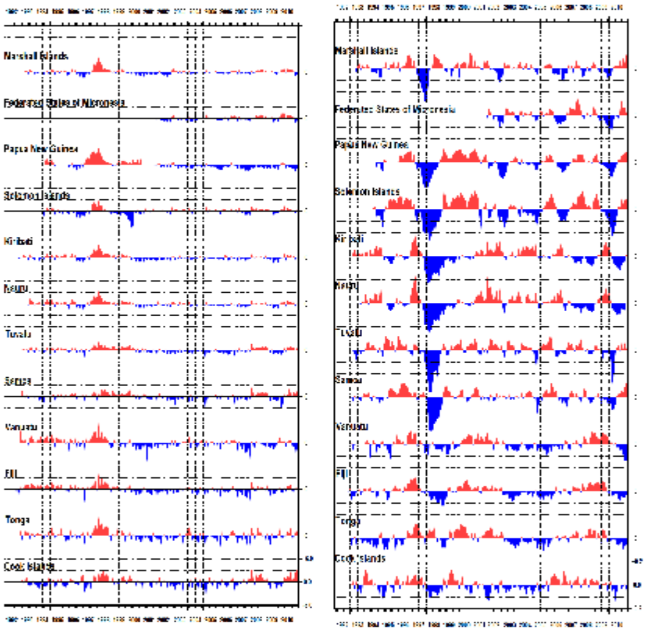
3.3 Barometric Pressure Effect on Sea Level

Although it is not a permanent effect, atmospheric pressure is a significant parameter that can potentially influence relative sea level rise (e.g. Singh and Aung, 2005). The concept is known as the inverted barometer effect: if a 1 hPa fall in barometric pressure is sustained over a day or more, a 1 cm rise is produced in the local sea level (within the area beneath the low pressure system). Trends in barometric pressure over a period of time will cause changes in relative sea level more significantly. It is to be noted that a 1 hPa y^{-1} decrease (increase) in barometric pressure will cause a 10 mm y^{-1} increase (decrease) in relative sea level.

Figure 3 shows the plots of barometric pressure and sea level anomalies for the 12 Pacific island stations. It is evident from Figure 3(a) that as a consequence of the 1997/98 El Niño, barometric pressure in the Pacific area was significantly high for many months. Despite the small time lag, the inverted barometer effect played a major role in the decrease of sea level anomalies. The significant fall of sea level for many months resulted in negative sea level anomalies in the entire project area. In fact, the sea level fall during that time was more in magnitude than the inverted barometer effect and makes the concept of sea level change more complex.

3.4 Present Sea Levels Trends

The short-term sea level trend values at individual stations as of February 2011 are shown in the following Table 1 (NTC, 2011). Sea level trends are updated every month by allowing for a linear trend term in the tidal analysis of all the data available at individual stations. It is necessary to be cautious in interpreting the trends since they will continue to change over the coming years as the data sets increase in length.



(a) (b)

Figure 3. (a) Barometric pressure anomalies (in hPa) and (b) sea level anomalies (in m) through February 2011. [Source: www.bom.gov.au].

Table 1. Recent sea level trends (in mm per year) in the project area (until June 2011). [Source: www.bom.gov.au].

No	Location	Length of Data [year]	Trend [mm y^{-1}]
1	Cook Islands	18.7	4.8
2	Tonga	18.7	8.4
3	Fiji	18.9	4.9
4	Vanuatu	18.7	5.2
5	Samoa	18.7	6.3
6	Tuvalu	18.7	4.0
7	Kiribati	18.8	3.1
8	Nauru	18.2	3.8
9	Solomon	17.2	7.1
10	PNG	16.9	7.7
11	Marshall	17.9	4.7
12	Micronesia	9.7	16.9

The evolution of the monthly trend values at each station from one year after installation to present is shown in Fig 4. It illustrates that as the sea level record becomes longer, the relative sea level trend estimates become more stable and reliable. At present, data from The Federated States of Micronesia is not taken into account in this study. The reason for this is that the trends from short sea level records are affected by the natural sea level variability occurring on interannual and decadal timescales due to atmospheric, oceanographic and geological processes. Longer-term data sets for all stations are required in order for the underlying trend to emerge from these short-term variations.

In the early years, the trend appears to indicate an enormous rate of sea level rise. Later, due to the 1997/1998 El Niño when sea level fell significantly below average, the trend actually went negative, and remained so for the next year. Given the sea level record is still relatively short (although it is almost as long as one nodal period), it is still too early to deduce a concrete long-term trend.

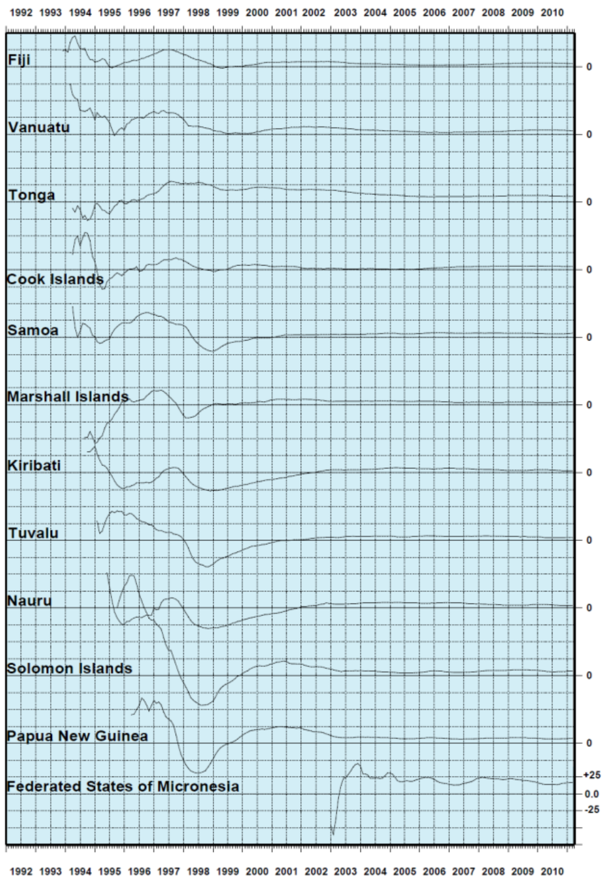


Figure 4. Sea level trends in mm y^{-1} through February 2011. [Source: www.bom.gov.au].

As stated in the Pacific Country Report for Fiji (NTC, 2010b), the sea level trends in Fiji is 4.9 mm y^{-1}. However, taking into account the effects of vertical land movement and inverted barometer pressure, the sea level trends in Fiji are actually 4.8 mm y^{-1}. Vertical land movement in Fiji is + 0.6 mm y^{-1}, which means that land is moving upwards, therefore, relative sea level rise appears to be smaller than it actually is. Value for vertical land movement should be added up to the 4.9 mm y^{-1} to get the actual sea level trends. Inverted barometer pressure effect in Fiji is 0.7 mm y^{-1}, which suggests that due to this effect, sea level is increased (as there is low barometric pressure in that area). To get the actual sea level trends, inverted barometer pressure effect should be taken off (opposite of what was done for vertical land movement). Accordingly, the absolute sea level trends until December 2010 becomes 4.8 mm y^{-1} (4.9 + 0.6 – 0.7). In this present study, the calculated trends which are until June 2011 (Figure 4), and the value from Pacific Country Report is almost the same (4.9 and 4.8 mm y^{-1}). It clearly indicates that sea level trends in that area are not changing significantly, and have not been since 2002. Vertical land movements and pressure effect are not considered in this present study.

3.5 Impact of 2009 El Niño

The most striking oceanic and climatic fluctuations in the equatorial region are not the seasonal, but interannual changes associated with El Niño. These affect virtually every aspect of the system, including sea level, winds, precipitation, and air and water temperature. As seen in Figure 3(b), at most SEAFRAME sites, the lowest sea level anomalies appear during the 1997/98 El Niño. The most dramatic effects were observed at the Marshall Islands, Papua New Guinea (PNG), Nauru, Tuvalu and Kiribati, and along a band extending south-eastward from PNG to Samoa. The band corresponds to a zone known as the South Pacific Convergence Zone (SPCZ).

In March 2010, lower than normal sea levels continued to be observed across the region in connection with 2009/10 El Niño climate conditions. Lower than normal sea levels are typical during El Niño, as can be seen during previous events in 1997/98, 2002/03 and 2006/07. Sea level anomalies are particularly low at PNG, Solomon Islands and Tuvalu as a result of lower than normal trade wind convergence along the SPCZ, and the anomalies are the lowest they have been since the 1997/98 El Niño at many sites. The 2009/10 El Niño event is relatively a mild one and therefore sea level anomalies are not expected to reach the low levels observed during the 1997/98 El Niño (NTC, 2010a).

However it is interesting to note that something unusual took place at two locations in the Pacific region under the coverage of the Australian project. Their vicinities are at 12°S, 180°E and 14°S, 157°E (see Figure 5). The sea level anomaly map is centered on 26 March 2010 and shows that the anomaly in these areas is approximately -40 cm. This effect, attributed to the 2009/10 El Niño, is isolated and not Pacific wide as during the 1997/98 El Niño.

For comparison, Figure 6 shows the sea level anomalies over the last 10 years at 12°S, 180°E. The 2009/10 El Niño is relatively a weak one compared to the last two El Niño, but the effect on sea level in this specific area is much more significant. The Australian project does not have the stations in these locations for further analysis. If we look at the nearest stations of the project (Tuvalu at 8.5°S, 179°E and Solomon Islands at 9.5°S, 160°E), changes of sea level trends before (November 2009) and after (May 2010) the El Niño are -1.5 and -2.1 mm y^{-1}, respectively.

The intriguing part is at Fiji (17.5°S, 177.5°E), the change in sea level trends before and after the El Niño is only -0.2 mm y^{-1}. But in Rotuma (12°S, 177°E; Figure 7), an island located 465 km north of Fiji, a significant sea level drop was observed (see Figure 6). According to a newspaper article published at that time (Vula, 2010), villagers in Rotuma experienced extraordinary low sea level for the preceding few weeks and at the same time, fish and other marine creatures were found beached on the shore. The two bays in Rotuma, *Maka* and *Hap'mafau*, were the two locations identified where dead fish were found floating for almost a kilometre close to the shore in early April 2010.

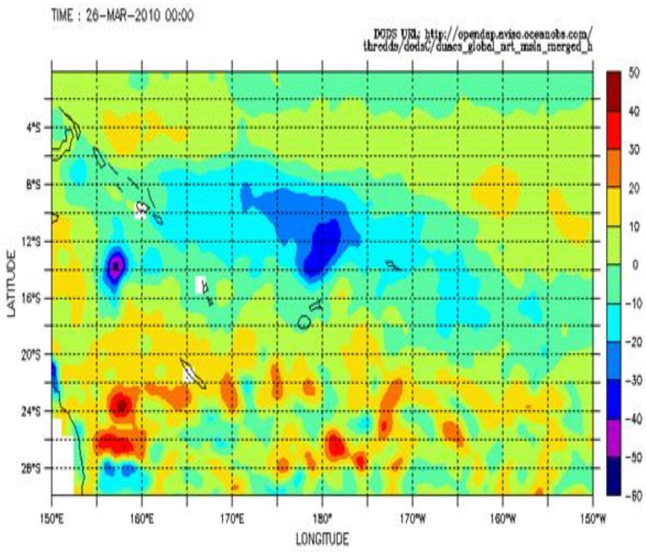


Figure 5. Map of sea level anomalies (in cm) in the general study area. [Source: http://opendep.aviso.oceanobs.com].

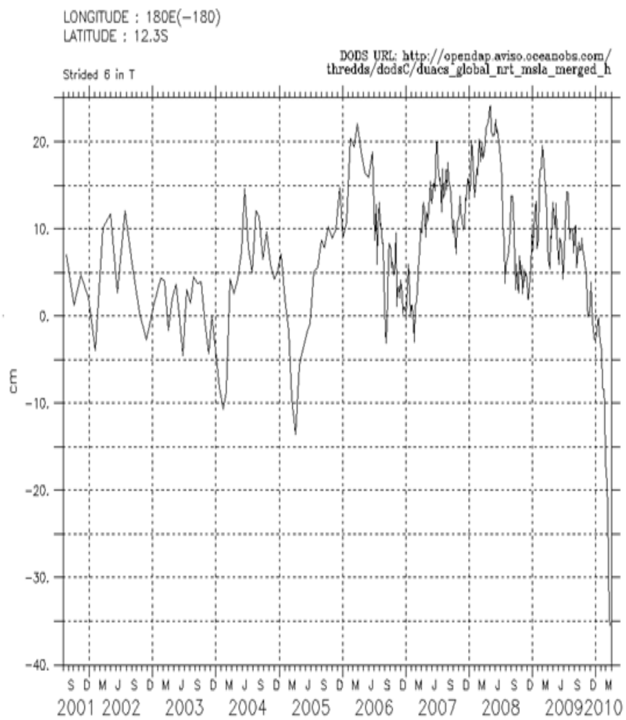


Figure 6. Map of sea level anomalies (in cm) at the 12.3°S, 180°E. [Source: http://opendep.aviso.oceanobs.com].

This incidence simply explains the complexity of sea level changes and why local sea level trends for individual locations or islands are far more important than global average values repeatedly presented by the IPCC reports. 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.

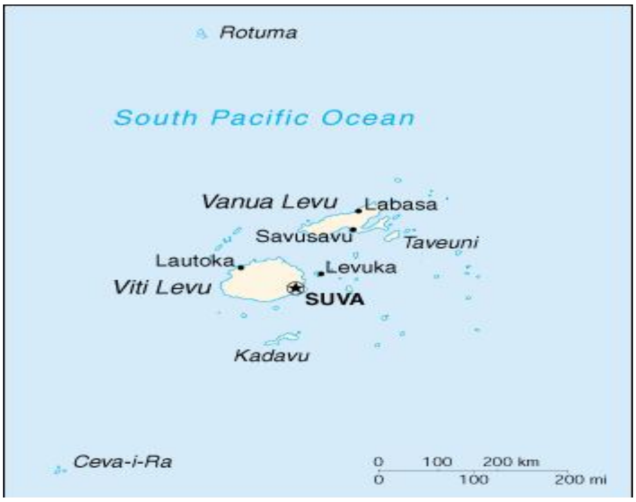


Figure 7. A map of the Fiji islands including Rotuma, which was affected by the negative sea level during the 2009/10 El Niño. [Source: www.google.com].

4 Conclusions

The global mean sea level increased by 19.5 cm between 1870 and 2004, and is continuing to rise at a fairly steady rate of just over 3 mm y^{-1} (Nicholls and Lowe, 2006; Church *et al.*, 2004). This rate of rise is undoubtedly contributing to flooding problems of low-lying island states like Tuvalu and Kiribati in the Pacific and the Maldives in the Indian Ocean.

In general, the present sea level rise rates over the Pacific island countries cannot be regarded as accelerating for the last decade (Mitchell *et al.*, 2000). Based upon ~18 years of sea level data from the Australian project, the range of sea level rise rate in the Pacific region is between 2.9 mm y^{-1} (Kiribati) and 8.4 mm y^{-1} (Tonga) as of February 2011 (not considering The Federated States of Micronesia). These rates are definitely higher than the IPCC global average rate (1-2 mm y^{-1}) and the GMSL trends calculated from satellite data (3.2 mm y^{-1}) in most places. Interestingly, the profound effects of El Niño on sea level changes are quite unpredictable even during the 2009/10 mild El Niño. Sea level drop in the vicinities of 12°S, 180°E and 14°S, 157°E are ~40 cm during March 2010. However the present effect of El Niño on sea level changes is isolated and is not Pacific wide as during the 1997/98 El Niño. It can simply be inferred how difficult it would be to predict sea level rise for the future at a particular location. When making plans and policy for the economy and development of a country, the threat of sea level rise problem should be taken into account appropriately using the local values rather than the global average.

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