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Rise and fall of sea level in Nauru area over a nodal cycle

Muhammad Ali S. Hussein[1], Awnesh Singh[2] and Than Aung[1]

[1]*Borneo Marine Research Institute, Universiti Malaysia Sabah, 88999 Kota Kinabalu, Sabah, Malaysia.*
[2]*L'Institut de Recherche pour le Développement, Laboratoire d'Etudes en Géophysique et Océanographie Spatiales, 14 Avenue Edouard Belin, Toulouse, France.*

Abstract

The sea level rise issue is one of the major topics that have gained global attention. In particular, its impacts on many Pacific island countries have been more prevalent over the last two decades. The tiny island of Nauru, once a wealthy nation, is no exception to the effect of climate change. With its highest point ~61 m above sea level, and the threat of sea level rise evident, Nauru is under pressure to save itself from sea level rise problem. Sea level data from the AusAID funded South Pacific Sea Level and Climate Monitoring Project will be focussed on 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 for 20 years initially. Based upon 17 years of sea level data from the project, the sea level rise rate in Nauru as at July 2010 was 4.4 mm yr^{-1}. This is at least 2-3 times higher than the global average of 1-2 mm per yr^{-1}. Sea level in the Nauru area has risen approximately 7.5 cm since the inception of the project 17 years ago (July 1993). Although there is no significant impact on the sea level trends, it is to be noted that the land is quite stable and the rate of land rising is 0.01 mm yr^{-1}. Although the data length is for the last 17 years, the sea level trend values do not fluctuate significantly since 2002. It simply indicates that the rate of sea level rise in the Nauru region is not accelerating as anticipated by the community.
Keywords: *Sea level rise, Nauru, climate change, nodal cycle, AusAID*

1. Introduction

It is not only some small island states that 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). Over the 20th century, sea levels rose between 10 and 20 cm. 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. What we do know is that even a small amount of sea level rise will have profound negative effects on our daily lives.

The inhabitants of every Pacific island atolls and small islands are convinced that what they are observing regarding the changes in their islands today is in many cases very different from what they knew one or more decades ago. These include extensive coastal erosion, persistent alteration of regional weather patterns and decreased productivity in fisheries and agriculture. Higher sea levels are making some soils too saline for cultivation of tropical crops such as taro, pulaka and yams. Coastal roads, bridges, foreshores and plantations are suffering increased erosion, even on islands that have not experienced inappropriate coastal development. It is obvious that we cannot prevent sea level rise and we will never be able to. All we can do is to mitigate and adapt to avert the most extreme scenario. As usual, the least developed nations are at most risk, and Nauru, once a very wealthy island nation, is one of several in the Pacific Ocean.

1.1 A Brief Background History of the Study Area

Nauru is a small island nation in the South Pacific Ocean, south of the Marshall Islands located at 0.32°S latitude and 166.55°E longitude. The total land area is only 21 km^2 and it has a 30 km long coast line around the potato-shaped island with an exclusive economic zone (EEZ) of 320 000 km^2 as shown in Figure 1. The lowest topographic point (from the beach) to the highest point is ~61 m above sea level. The 2002 census shows a population of 10 065. The climate is equatorial marine in nature. There are no cyclones in the area since it is almost at the equator. Although rainfall is cyclic and periodic droughts are a serious problem during the last two decades. There are limited natural fresh water resources – roof storage tanks collect rainwater, but islanders are mostly dependent on a single aging desalination plant. Producing portable water in a cost effective manner is a priority to Nauru and therefore solar desalination is an opportunity to be investigated (SPREP, 2010).

The people of the tiny, potato-shaped Republic of Nauru were once the second richest nation on Earth some 20 years ago. Nauru's wealth was bird droppings: phosphate used in fertiliser production. During that rosy time Nauru could afford everything and even fresh water was imported from Australia. Things have gradually changed due to several years of mismanagement. In reality, not only sea level around Nauru, but also its economy was also rising and falling over the last 20 years or so.

1.2 Historical Sea Level Changes

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 yr^{-1} (or 1 m per century), and with peak rates of the order of 40 mm yr^{-1} (or 4 m per century), until about 6000 years ago (Church *et al.*, 2001). Figure 2 shows the historical sea

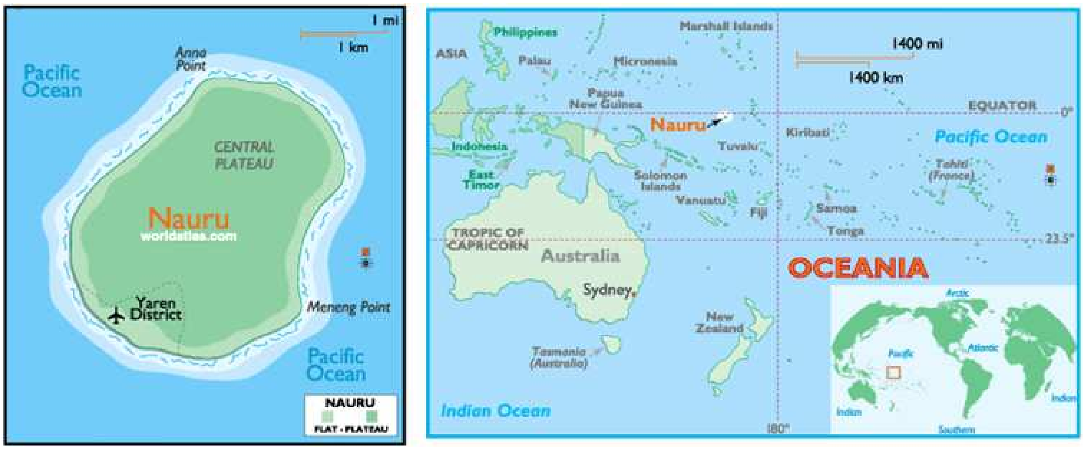

Figure 1. Map showing the island topography and location of Nauru in the Pacific Ocean.

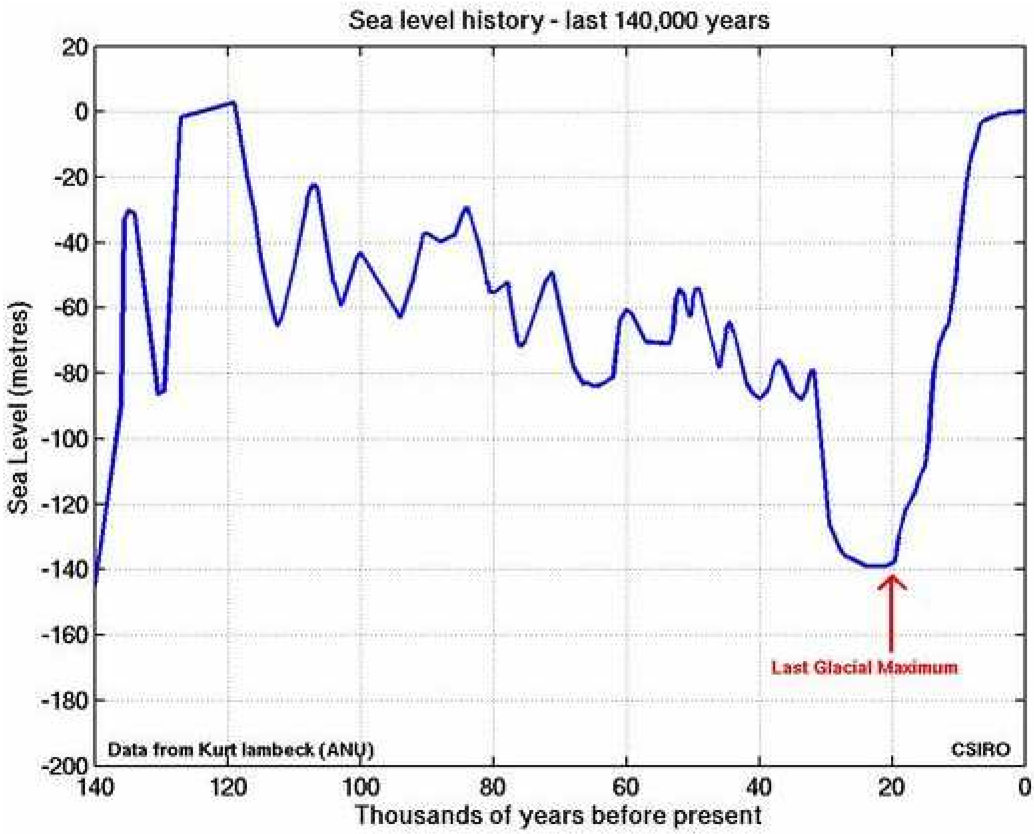

Figure 2. Sea level changes over the last 140 thousand years (CSIRO, 2010).

level changes to indicate that rise and fall of sea level is not a new phenomenon.

It is to be noted that sea level changes on a range of temporal and spatial scales. For example, sea level in Nauru is rising but the sea level in New Zealand may be falling due to melting of land ice and the rebound effect. In fact, the total volume of the ocean can change as a result of changes in ocean mass (addition of water to the ocean from land or evaporation) and expansion or contraction of ocean water as it warms or cools (due to thermal expansion), respectively.

1.3 What Can We Expect Now?

According to the latest IPCC (2007) Summary for Policymakers, the following can be noted:

- The estimated rate of sea level rise based upon the thermal expansion of water, melting of glaciers and ice caps, Greenland ice sheets and Antarctic ice sheets is 1.1 ± 0.5 mm yr^{-1} between 1961 and 2003 and 2.8 ± 0.7 mm yr^{-1} between 1993 and 2003. It is indicated that the rate is faster during the last 10 years.
- The observed rate of sea level rise is 1.8 ± 0.5 mm yr^{-1} between 1961 and 2003 and 3.1 ± 0.7 mm yr^{-1} between 1993 and 2003.
- Whether the faster rate for 1993-2003 reflects decadal variability or an increase in the longer term trend is unclear. There is high confidence that the rate of observed sea level rise increased from the 19^{th} to the 20^{th} century.
- The total sea level rise in the 20^{th} century is estimated to be 17 ± 5 cm.

This new report mentions that global warming is "very likely" man-made. This is the most powerful language used by the world's leading climate scientists.

2. Methods

2.1 The Australian Project [South Pacific Sea Level and Climate Monitoring Project]

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 region, the South Pacific Sea Level and Climate Monitoring Project was set up in early 1990s. It has been fully funded by *AusAID* for the forum region. As part of the project, a SEAFRAME (SEAlevel Fine Resolution Acoustic Measuring Equipment) gauge was installed in Nauru in July 1993. The gauge has been returning high resolution and reliable scientific quality data since then.

SEAFRAME gauges not only measures sea level by two independent means, but also a number of ancillary variables, such as, air and water temperatures, wind speed, wind direction, wind gust and atmospheric pressure. There is an associated programme of levelling 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 and to determine the vertical movement of the land with respect to the International Terrestrial Frame (ITF).

2.2 Rise and Fall of Sea Level

Before this discussion, it is appropriate to be familiar with what sea level means. The mean sea level can be defined as the arithmetic mean of hourly water heights observed over the 18.61 years period (one nodal cycle). Shorter series are specified in the name as monthly mean sea level and yearly mean sea level (Rockville, 1989). A noteworthy point here is that sea level is the result from the complicated combination of many influences, such as: (i) daily tides; (ii) meteorological effects (atmospheric pressure and winds, evaporation, precipitation); (iii) thermal effect (volume expansion of water due to global warming, melting land ice); (iv) seismic activity (underwater earthquake, tsunami); (v) oceanographic effects (El Niño, Rossby waves, Kelvin waves, density changes, etc.); and (vi) vertical land movement.

This brief definition alone can highlight the complexity of sea level changes since there are many physical phenomena involved and most of them cannot be predicted. As a simple and clear example, using the data from the Australian Project, the barometric pressure and sea level anomalies plot are shown in Figure 3. Basically, we are aware of the inverted barometer effect and 1 hPa change in pressure can vary the sea level by approximately 1 cm (e.g. Singh and Aung, 2005).

If one focuses in 1997-98 period of the plots, it would be remembered that a very severe El Niño took place during that time. As a consequence of the El Niño, barometric pressure in the Nauru area was significantly high for many months. Despite the slight time lag, the inverted barometer effect played a major role and the fall of sea level was clearly evident in the lower panel of Figure 3. The significant fall of sea level for many months resulted in negative sea level anomalies in the Nauru area, which can be seen in Figure 4. In fact, the sea level fall during that time was more than the inverted barometer effect and it will make the concept of sea level changes more complex. If we carefully analyse the barometric pressure anomaly, the highest increase is ~3 hPa, but the sea level fall during that time is over 20 cm, which is evident in the lower panel of Figure 3. This incidence alone can portray that the sea level issue is much more complex than one can imagine.

3. Results and Discussion

3.1 Sea Level Trends in Nauru Over a Nodal Cycle

Most Pacific islanders are fully aware that sea level is controlled by many factors; some periodic like tides, some brief but violent like cyclones, and some prolonged like El Niño – because of the direct effect of changes it has upon their lives. The effects vary widely across the region. Along the Melanesian archipelago, from Manus Island (in PNG) to Vanuatu, tides are predominantly diurnal, or once daily, while elsewhere the tide tends to have two highs and two lows each day (semidiurnal) including Nauru.

Figure 4 depicts the evolution of the short-term sea level trends at Nauru SEAFRAME station, from one year after installation to July 2010. During that period, there were four El Niño events that took place, including a very severe one in 1997-98, which generated a significant sea level drop in the Nauru area. The usual positive (rising) sea level trends were changed to negative values (falling) for several months due to the effect of the El Niño. The

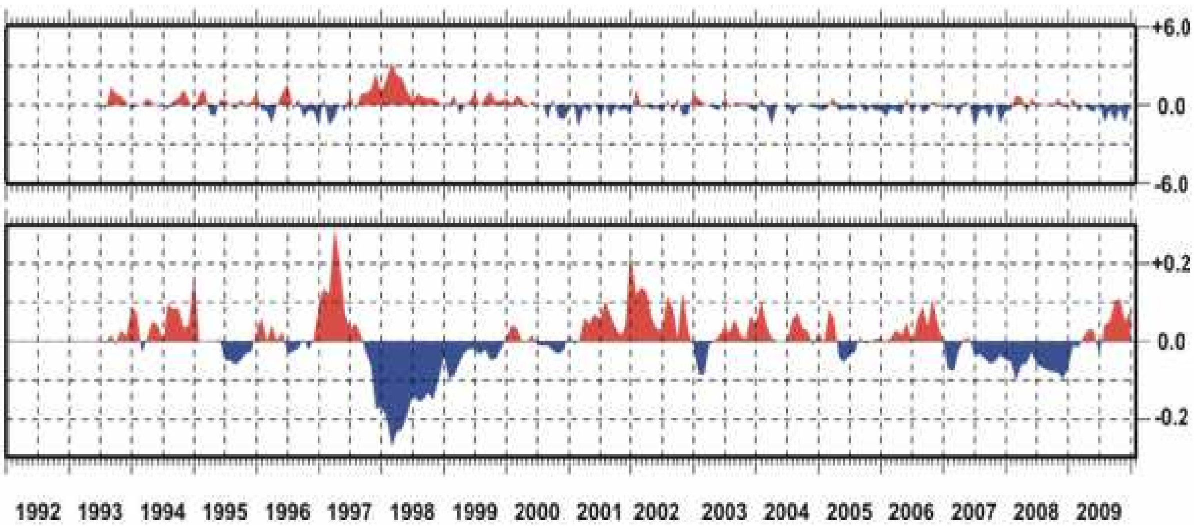

Figure 3. Barometric pressure (hPa) [Top] and sea level anomalies (m) in Nauru (NTC, 2010) [bottom].

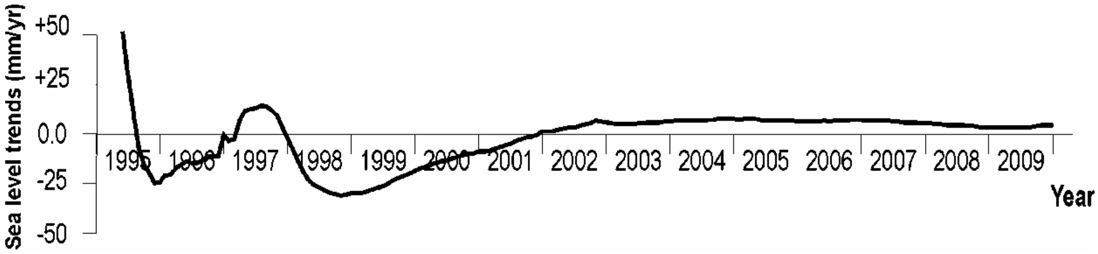

Figure 4. Sea level trends for Nauru during the last 17 years.

process of data analysis and trend calculation is as follows: To begin the analysis, the first year of observed hourly values of sea level for a location [say Nauru in this case and the data from July 93-June 94] was analysed for a trend value. The full harmonic model of 112 tidal constituents was applied so as to identify the tidal component and at the same time a trend analysis is conducted. The value of this trend is plotted as the first point in Figure 4. The next stage begins by adding just one month of additional hourly data, repeating the analysis and plotting the trend result in Figure 4. The processed is repeated adding one month at a time to the data set presented for analysis until the entire available data set is exhausted. Each estimate given and plotted then is the sea level trend evaluated over the entire preceding time series, regardless of the start date for a particular station.

It is to be noted that the early part of the trend line was not stabilised due to a very short length of data. But we can see that the estimate is becoming progressively smaller in magnitude and that the line is becoming smoother and stable. The length of the data so far is slightly over 17 years (not exactly one nodal cycle yet); some significant fluctuations in the trends do not show any more. During the last 17 years or so, there were at least five El Niño periods; one was prolonged, one was very severe and the others were weak ones. It is also to be noted that the gauges located close to the equatorial wave guides, and in particular those near to the western boundary of the Pacific, will undergo substantial fluctuations during ENSO episodes. Based upon these 17 years long sea level data (NTC, 2010), the rate of sea level rise in Nauru area is 4.4 mm yr^{-1} (as of July 2010). The value is very much stable and the variation from the previous months is minimal and as small as ± 0.1-0.2 mm yr^{-1}. This local value is still approximately 2-3 times larger than the IPCC global average of 1-2 mm yr^{-1}. During these 17 years, sea level in Nauru rose approximately 75 mm. When we look at the surveying data for the vertical land movement, the SEAFRAME station area is rising 0.12 mm for the last 11 years period through conventional surveying. Accordingly, the rate of rising land is ~+0.01 mm per year and there is no significant impact on the sea level rise trends although it is reducing the sea level rise rate slightly. In this paper, a special focus is made on physical aspects of sea level rise and we are not in a position to touch island geology or sediment budget. In summary Table 1 highlights the critical values for sea level issue in the Nauru area.

3.2 Length of Data

From a statistical point of view, every scientist has the same view that the longer the data length, the better will be the trend calculation. Some have even argued that the data from the Australian Project is not long enough to do anything for scientific purpose. When we discuss the data length for trend calculation with reasonable certainties, it is appropriate to introduce a term called *nodal cycle*. It is a period of approximately 18.61 Julian years required for the regression of the Moon's nodes to complete a circuit of 360º of longitude. It is accompanied by a corresponding cycle of changing inclination of the Moon's orbit relative to the plane of the Earth's equator, with resulting inequalities in the rise and fall of the tide and speed of the tidal currents (Rockville, 1989). According to Rockville (1989), the specific 19-year period is adopted as the official time segment over which tide observations are taken and reduced to obtain mean values for tidal datum. It is necessary for standardisation because of periodic and apparent secular trends in sea level, that is, non-periodic tendency of sea level to rise, fall or remain stationary with time. Technically, it is the slope of a least-squares line of regression through a relatively long series of sea level values. For this reason, the Australian project was initially set to run four 5-year phases, in total of 20 years for the whole project. The project has now been planned to continue long over the initial 20-year period.

3.3 Sea Level Trends from Satellite Altimeter Data

In order to enhance the land-based sea level data and the trends calculation, we will briefly look at the satellite data as well to achieve a more realistic point of view on sea level changes. According to (CSIRO, 2010), high quality measurements of global sea level have been made since late 1992 by satellite altimeters, in particular,

Table 1. Significant parameters for the sea level situation in the Nauru area.

Parameters	Values	Comments
length of data	17 years	not long enough yet (almost one nodal cycle)
sea level trend	+4.4 mm yr^{-1}	very small change from previous months
sea level rise	~7.5 cm	for the last 17 years
vertical land movement	~+0.01 mm yr^{-1}	not significant (slight reduction in sea level)
number of El Niño	5	including one severe and one prolonged

TOPEX/Poseidon (launched in August, 1992), Jason-1 (launched in December, 2001) and Jason-2 (launched in June, 2008). These data have shown a more or less steady increase in Global Mean Sea Level (GMSL) of around 3.3 ± 0.4 mm yr^{-1} over that period. This is more than 50% larger than the average value over the 20^{th} century and more than the IPCC estimate of 1-2 mm yr^{-1}.

Figure 5 shows the GMSL measured from TOPEX/Poseidon, Jason-1 and Jason-2 satellites. It is believed that global warming from increasing greenhouse gas concentrations is a significant driver of both increases in ocean mass and ocean thermal expansion as components of recent and future sea level rise.

3.4 Is the Rate of Sea Level Rise Increasing in the Nauru Area?

As mentioned in earlier sections, sea level has been rising and falling for a long time in history, long before the global warming issue was introduced. Accordingly, the sea level rise issue is not really a new problem to our daily lives. But the real danger may be if the rate of sea level rise increases with time (i.e. accelerating) as claimed by many people. The main question for us is to find out if sea level rise rate is gradually increasing in the recent past. If being the case, the real danger is getting closer and the Pacific islanders might need to find a new land to live for their future and people from Nauru are no exception.

If we look at the sea level trends with time shown in Figure 4 for the Nauru area, it is quite obvious that trends for Nauru are more or less horizontal since early 2002 (once the length of data is stabilised for trends calculation and out of the severe effects of the 1997-98 El Niño related sea level drop). It clearly indicates that the sea level rise rate is not gradually increasing in the recent past or at least during the Australian Project period although monthly fluctuation of ± 0.1-0.2 mm y^{-1} takes place. It is also to be acknowledged, nevertheless, that visually at least and at this stage, there is no clear evidence for acceleration in sea level trends over the course of the last century based upon the long-term data elsewhere. More precisely, Mitchell *et al*. (2000) stated that the acceleration assessment from worldwide industrialisation over the last two centuries seems to be very slow to appear. Accelerations of the trends identified in their exercise are at best extremely small, at least on this evidence from just five available long data sets.

Indeed, it is good news for the future generation of Nauru and they now can concentrate more on the recovery of their failed economy. However, to see the reality and to accept the scientific fact, local people need necessary education and a Pacific wide capacity building programme is essential. Otherwise, hearsay stories will continually disturb their lives.

3.5 Thermal Effect Due to Global Warming

Thermal expansion is one of the main contributors to long-term sea level change, as well as being part of regional and short-term changes. Water expands as it warms and shrinks as it cools. From 1993 to 2003, the thermosteric contribution was estimated to be about 0.79 mm yr^{-1}, about a quarter of the total GMSL trend of 3.3 mm yr^{-1} over the same period (Domingues *et al.*, 2008). From 1955-95, earlier estimates of ocean thermal

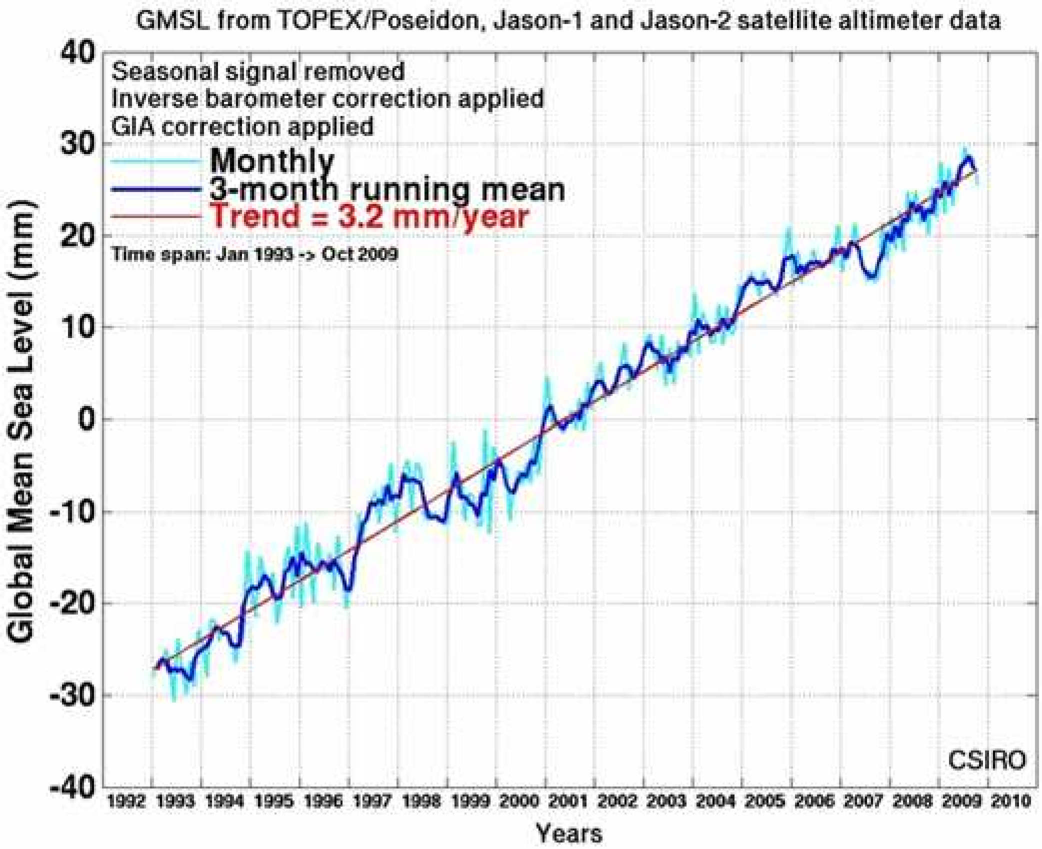

Figure 5. Global mean sea level measured from TOPEX/Poseidon, Jason-1 and Jason-2 satellites during a nodal cycle (CSIRO, 2010).

expansion is estimated to have contributed about 0.4 mm yr^{-1} to sea level rise, less than 25% of the observed rise over the same period.

Kaser *et al.* (2006) estimate the melting of glaciers and ice caps (excluding the glaciers surrounding Greenland and Antarctica) contributed to sea level rise by about 0.4 mm yr^{-1} from 1961-90 increasing to about 1.0 mm yr^{-1} from 2001-04. Meier *et al.* (2007) also state that mass loss from glaciers is dominating the eustatic component of sea level rise in the 21st century, providing 1.1 mm yr^{-1} of the total eustatic contribution of 1.8 mm yr^{-1} in 2006. These estimates are somehow in agreement with other studies of Gregory and Huybrechts (2006).

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 yr^{-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 the Nauru area, the present sea level rise rate is 4.4 mm yr^{-1} (in mid 2010) and it is not gradually increasing for the last decade. The rate is definitely higher than the IPCC global average rate (1-2 mm yr^{-1}) and the GMSL trends calculated from satellite data (3.2 mm yr^{-1}). During the last 17 years or so, the total sea level rise in the Nauru area is ~7.5 cm. When making plans and policy for the economic rapid recovery and development of Nauru, the threat of sea level rise problem should be taken into account appropriately. While there is always likelihood to be a debate over the scientific accuracy of sea level trends and the length of data used, the Pacific islanders cannot wait indefinitely to see the more accurate sea level rise results. Still, it is possible to address some of the uncertainties related to sea level monitoring and a better understanding of island change to make a better plan and policy for their own islands.

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Correspondence to : Awnesh Singh
Tel. : +33 (0) 561332719
E-mail : awneshsingh@gmail.com