CLIMATE CHANGE AND LOW-LYING PACIFIC ISLANDS

A plain person's guide to global warming, sea-level rise, and the threat to Pacific Islands

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ABSTRACT

It is now widely acknowledged within the scientific community that the global rate of sea-level rise is quickening – and is likely to continue to do so – as a result of anthropogenic climate change. It is expected, therefore, that any resulting increase in the frequency or intensity of extreme sea-level events will cause serious problems for the inhabitants of low-lying coastal communities and islands during the 21st century.

Many Pacific Islands are already suffering more frequent and severe instances of sea inundation due to larger monthly and annual peak tides events. Increases in the height of peak tide events, especially king tides, are being driven by sea levels which have been rising for many decades, but they have intensified in recent years under the effects of human-induced climate change. Unfortunately, this trend will continue to worsen for some years and several Pacific Islands face immediate danger, whatever climate policy is adopted.

This paper attempts to provide simple and credible explanations in response to the three underlying questions which sceptics and everyday people are preoccupied: (1) *Is global warming contributing to the rate of sea-level rise?,* (2) *Why do the rates of sea-level rise vary from place to place?* and (3) *What is the threat to low-lying islands?* A simple analogy – the "Waterbed Effect" – is used to develop and describe the complex interactions that link climate change and sea-level rise, and to help understand and interpret current sea-level data to determine whether the effects of global warming are contributing to the rate of sea-level rise.

This paper also suggests that scientists and those charged with the responsibility for developing and implementing practical strategies to deal with climate change need to look closer at the current short and medium term trends and the extremes. While the underlying sea-level trend can look slow and low-lying coastal communities and island countries are concerned about gradual sea encroachment, it is the vulnerability now and tomorrow of these communities and countries to increasingly frequent and severe sea inundation that is a far more real and urgent problem.

INTRODUCTION

It will perhaps be useful to explain why I have used the sub-title "A plain person's guide….", and why I have decided to write this paper at all.

Since publication of my paper *What the South Pacific Sea Level and Climate Monitoring Project is Telling Us* [1] in November 2006 I have received a number of enquiries from a wide range of people around the world seeking my views on sea-level rise analysis and climate change forecasts. (See Appendix 1 for some details.) Diverse as their professions, interests and origins are, each is seeking to gain a better understanding of the link between global warming and sea-level rise, and the likely impact on low-lying coastal communities and small islands.

Each person has made a serious attempt at researching and understanding the mountains of scientific literature and media commentary now readily available. But rather than finding satisfactory answers to their questions, they have become more confused and, therefore, irritated and uncertain as to what to believe and who to trust.

A primary reason for public frustration and disenchantment is the inability of the scientific community to translate their knowledge and expertise into a language that sceptics and everyday people can readily understand. Another reason is that, while historical and projected sea levels for islands in the tropical Pacific and Indian oceans is a subject of considerable public interest, it is also a subject of some controversy. Unfortunately, at a time when some island countries are already experiencing increasing instances of severe sea inundation, the real contribution of global warming to climate change and the rate of sea-level rise continues to be debated within the scientific community. This debate is being seized upon by sceptics (some with vested interests) and by some of the media, to question the accuracy and integrity of the science.

The three main underlying questions that resonate through these enquiries are: (1) *Is global warming contributing to the rate of sea-level rise?,* (2) *Why do the rates of sea-level rise vary from place to place?,* and (3) *what is the threat to low-lying islands?* In this paper I will endeavour to provide in response to all three questions an explanation that is considerably easier to understand than those offered in current scientific commentary.

Before I do, it is important that I point out that I have no formal qualifications in the areas of meteorology, climatology, oceanography or the geosciences. My expertise is in applied science. I have a postgraduate degree in engineering and considerable practical experience in the design, installation and maintenance of complex meteorological facilities and monitoring systems, and their operation in gathering and reporting scientific data. This experience includes recent responsibility for the management and operation of one of the most highly regarded sea level and climate monitoring networks in the world.

IS GLOBAL WARMING CONTRIBUTING TO THE RATE OF SEA-LEVEL RISE?

The primary basis for uncertainty among the general population about the real contribution of global warming to climate change and the rate of sea-level rise is the ongoing debate on the subject within certain sections of the scientific community, and the seizing by sceptics and the

[1] Hall P. *What the South Pacific Sea Level and Climate Monitoring Project is Telling Us,* Pacific Climate Change Seminar held at AusAID, Canberra, Australia, November 2006; published on the SPSLCMP website at http://www.bom.gov.au/pacificsealevel/presentations.shtml.

media on that debate to question the accuracy and integrity of the science. While I personally believe that there is an undeniable link between global warming, climate change and sea-level rise, it is a debate that I am neither qualified or willing to enter into at a professional level. Rather, I believe it is much more productive to engage in meaningful discussion on practical strategies for addressing our vulnerability to climate change and what adaptation measures can – and should – be taken to mitigate that vulnerability.

It is timely and appropriate, therefore, that I revisit my November 2006 paper and update my comments based on the most recent data now available to me, that being the June 2006 Pacific Country Report for Tuvalu[2] and the November 2007 Monthly Data Report[3] produced by the National Tidal Centre, Australian Bureau of Meteorology, under the auspices of the South Pacific Sea Level and Climate Monitoring Project (SPSLCMP). In doing so, keep in mind that 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*. Remember also that data gathered by the SPSLCMP contributes to the research quality datasets[4] used by international scientific organisations and agencies in their long range modeling of climate change and the potential impacts, both regionally and internationally.

As I mentioned in my November 2006 paper, the SPSLCMP SEAFRAME network also plays a critical role in contributing to a regional and international early warning capability for climate change. I suggested that 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. As an example I referred to the delay – or lag – from the point where the melting of the Greenland and polar ice expanses actually starts to have a significant impact on global sea levels, to the point where 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. I indicated then that we may be detecting those early stages already, but those stages may not yet be discernible from the prevailing short-term trends. The capability to make these detections is particularly relevant in the context of the waterbed analogy presented later in this paper, which is a simple descriptive example of what I was trying to convey.

In closing I made the comments that historical trends, and even to an extent the then current SEAFRAME trends, suggest that we could expect sea-level rises of an order that were considerably at variance to current scientific commentary, and that it was possible that the effects of recent accelerations in climate change had not yet started to have a significant contribution to or impact on current sea levels. As my comments are reflected in the questions of those seeking a better understanding of the subject, let us inspect the current data available from the SPSLCMP and see if we can make a sensible interpretation of it; an interpretation that sceptics and the everyday person may be able to understand.

In Table 1 below I have collated the recent sea-level trends from the SPSLCMP based on SEAFRAME data through to November 2007 (extracted from the Monthly Data Report for

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2 Available on the SPSLCMP website at http://www.bom.gov.au/pacificsealevel/picreports.shtml

3 Available on the SPSLCMP website at http://www.bom.gov.au/oceanography/projects/spslcmp/reports.shtml

4 The research quality datasets available from the Joint Archive for Sea Level (JASL) may be accessed online at http://uhslc.soest.hawaii.edu/uhslc/jasl.html. Data is also available via the University of Hawaii Sea Level Center (UHSLC) website at http://ilikai.soest.hawaii.edu/uhslc/data.html.

November 2007) with the historical sea-level trends for Pacific Forum Stations on the Joint Archive for Sea Level (JASL) Data Holdings as at March 2006 (extracted from the June 2006 Pacific Island Country Report for Tuvalu). I have matched SEAFRAME stations with Historic stations, removing the trend data for the Pohnpei (FSM) SEAFRAME station and the two Tarawa (Kiribati) historical stations on the basis that their record length is less than the "youngest" SEAFRAME station, PNG Manus (13.17 years) – excluding Pohnpei in the Federated States of Micronesia (FSM).[5].

LOCATION	SEAFRAME Installation Date	SEAFRAME Years of Data	SPSLCMP Trend Nov 2007 (mm/yr)	Historical Record (Start / End)	Years of Historical Data	Historical Trend (mm/yr)	Difference SEAFRAME v Historical (mm/yr)
Belau (Malakal - A)				01Jan26 to 31Dec39	14.0	-6.27	
Belau (Malakal - B)				01Jan69 to 31Dec03	35.0	0.84	
Cook Islands (Rarotonga - A)	Feb-93	14.75	4.7	01Jan77 to 31Dec97	21.0	4.34	0.4
Cook Islands (Penrhyn)				01Jan77 to 31Dec03	27.0	1.69	
Fiji (Lautoka)	Oct-92	15.08	3.4				
Fiji (Suva -A)				01Jan72 to 31Dec97	26.0	4.67	
Kiribati (Christmas - A)				01Jan55 to 31Dec72	18.0	-3.78	
Kiribati (Christmas - B)				01Jan74 to 31Dec03	30.0	0.80	
Kiribati (Kanton - A)				01Jan49 to 31Dec67	19.0	3.15	
Kiribati (Kanton - B)				01Jan72 to 31Dec01	30.0	-0.43	
Kiribati (Fanning - B)				01Jan72 to 31Dec87	16.0	1.84	
Kiribati (Tarawa - A)				01Jan74 to 31Dec83	10.0		
Kiribati (Tarawa - C)	Dec-92	14.92	5.2	01Jan88 to 31Dec97	10.0		
Marshall Islands (Majuro - A)	May-93	14.50	4.3	01Jan68 to 31Dec99	32.0	2.31	2.0
Marshall Islands (Enewetck - A)				01Jan51 to 31Dec71	21.0	1.29	
Marshall Islands (Kwajalen)				01Jan46 to 31Dec04	59.0	1.20	
Nauru - A	Jul-93	14.33	6.2	01Jan74 to 31Dec95	22.0	-0.42	6.6
PNG (Manus)	Sep-94	13.17	6.8				
PNG (Rabaul)				01Jan66 to 31Dec97	32.0	-2.21	
Samoa	Feb-93	14.75	6.3				
Solomon Islands	Jul-94	13.33	5.8	01Jan74 to 31Dec95	22.0	-5.65	11.5
Tonga	Jan-93	14.83	8.7				
Tuvalu (Funafuti - A)	Mar-93	14.67	5.9	01Jan77 to 31Dec99	23.0	0.92	5.0
Vanuatu	Jan-93	14.83	3.7				
FSM (Pohnpei - B)	Dec-01	5.92		01Jan74 to 31Dec04	31.0	1.78	
FSM (Kapingamarang)				01Jan78 to 31Dec03	26.0	1.46	
FSM (Truk)				01Jan63 to 31Dec91	29.0	1.79	
FSM (Yap - B)				01Jan69 to 31Dec04	36.0	-0.42	
US Trust (Guam)				01Jan48 to 31Dec04	57.0	0.61	
US Trust (Pago Pago)				01Jan48 to 31Dec04	57.0	1.85	
Average		**13.8**	**5.5**		**28.1**	**0.49**	**5.1**

Table 1: *Comparison of Current (November 2007) and Historic Sea-Level Rise Trends.*

The first important piece of information from Table 1 is that the historical data for the longest records provides supporting evidence that mean sea levels in the Pacific region have been rising in the order of approximately +1mm/yr for over 60 years and in all probability, much

[5] The National Tidal Centre, Australian Bureau of Meteorology, strongly advise that ***caution be exercised in interpreting the short-term trends in the table*** for they will almost certainly change over the coming years as the data set increases in length. The sea level trend at FSM is derived from a comparatively short data record and recommends it be excluded from any analysis.

longer. The other important point from Table 1 is that the average sea-level trend across the 11 SPSLCMP SEAFRAME stations (i.e. excluding FSM) – currently 5.5mm/yr – is more than 11 times the historical trend of 0.49mm/yr across all stations in the region, which is highly conservative in comparison to the 1.14 mm/yr mean trend derived from the datasets that span more than 25 years as quoted by the National Tidal Centre in the June 2006 Pacific Island Country Report for Tuvalu[6].

After taking into account the National Tidal Centres' warning to exercise caution in interpreting the short-term trends derived from the SPSLCMP data – and that the historical data are not filtered to account for any fluctuations in land movement – the difference between historical and current trends is an increase in the order of 5 to 11 times. Even at the conservative end of the scale, an increase of 5 times is significant enough to indicate that the rate of sea-level rise in the Pacific has accelerated in recent years.

That the rate of sea-level rise is accelerating is not a new revelation, and there is growing acknowledgement within the scientific community that compared to historical trends, climate change is already having a significant impact on the current rate of sea-level rise in the South Pacific. Take for example the 2006 paper by eminent Australian scientists Church, White and Hunter[7] in which they are clearly of the view that sea levels have been rising at an increasing rate since 1970:

> *For 1950 to 2001, the average sea-level rise (relative to land) from the six longest tide-gauge records is 1.4 mm/yr. After correcting for glacial isostatic adjustment and atmospheric pressure effects, this rate is 2.0 mm/yr, close to estimates of the global average and regional average rate of rise. The long tide-gauge records in the equatorial Pacific indicate that the variance of monthly averaged sea-level after 1970 is about twice that before 1970. The analysis clearly indicates that sea-level in this region is rising. We expect that* ***the continued and increasing rate*** [my emphasis] *of sea-level rise and any resulting increase in the frequency or intensity of extreme sea-level events will cause serious problems for the inhabitants of some of these islands during the 21st century. Our best estimate of relative sea-level rise at Funafuti, Tuvalu is 2±1 mm/yr over the period 1950 to 2001.*

Interestingly, any increase in the rate of sea-level rise is not yet apparent in the Sea-Level Trend being reported by the SPSLCMP. As can be seen from Table 2 below, which is derived from data published in the SPSLCMP Monthly Data Reports for November 2006 and November 2007, the trend in the 12 months to November 2007 is relatively unchanged. This is reflected in the Sea-Level Trend charts presented in Figure 13 of the November 2007 report (provided below for ease of reference), which show that the trend lines across the region are relatively flat with no obvious signs of divergence, suggesting that the recent accelerations in climate change are yet to have an impact on the long term sea-level trend.

When then should we expect to see an increase in the trend reflected in the charts in Figure 13? I believe it will be quite some time, for I am concerned that the approach used to calculate and report the Sea-Level Trend is not appropriate for the extreme climate change situation we are facing.

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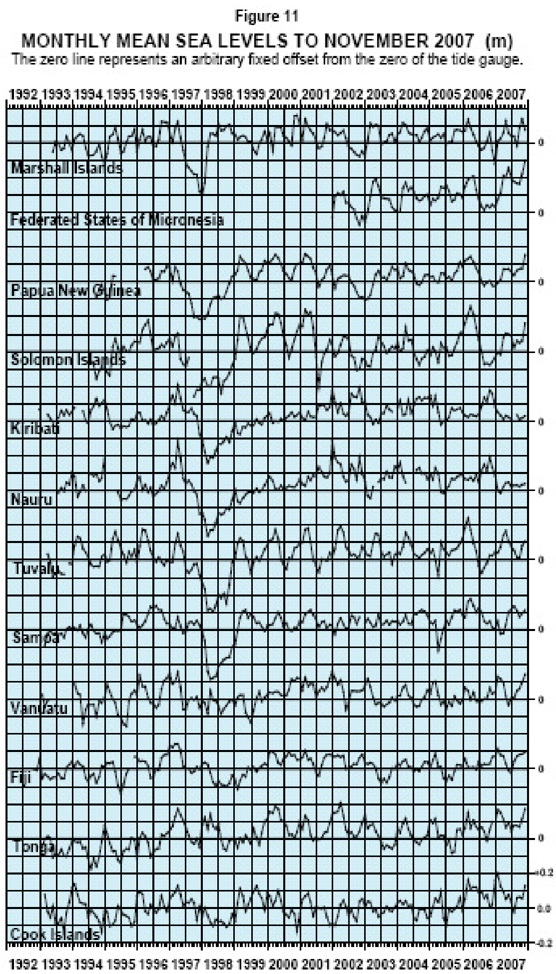
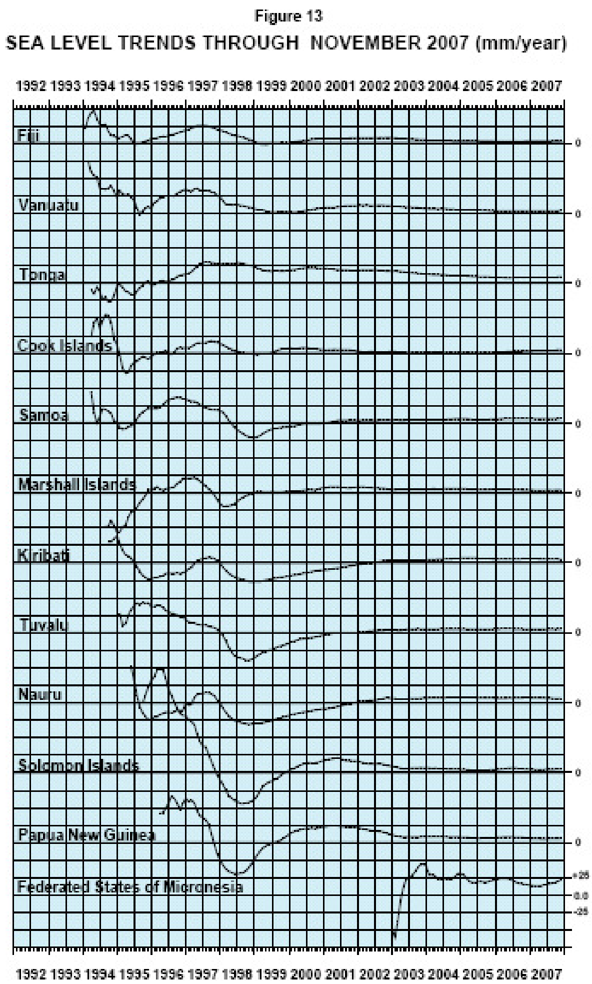
6 The note at bottom of Table 6 on page 15 states "The mean trend for datasets that span more than 25 years (bold font) is 1.14 mm/yr."

7 John A. Church, Neil J. White, John R. Hunter *Sea-level rise at tropical Pacific and Indian Ocean islands,* April 2006; available online at www.sciencedirect.com

LOCATION	Installation Date	Nov 2006 Trend (mm/yr)	Nov 2007 Trend (mm/yr)	Nett Change (mm/yr)
Cook Islands	Feb-93	3.2	4.7	1.5
Fiji	Oct-92	2.7	3.4	0.7
Kiribati	Dec-92	6.5	5.2	-1.3
Marshall Islands	May-93	4.5	4.3	-0.2
Nauru	Jul-93	7.9	6.2	-1.7
PNG Manus	Sep-94	7.1	6.8	-0.3
Samoa	Feb-93	6.5	6.3	-0.2
Solomon Islands	Jul-94	5.6	5.8	0.2
Tonga	Jan-93	8.1	8.7	0.6
Tuvalu	Mar-93	5.7	5.9	0.2
Vanuatu	Jan-93	3.0	3.7	0.7
Average		**5.53**	**5.55**	**0.02**

Table 2: *Comparison of Mean Sea-Level Trends for November 2006 and November 2006, using data reported by the SPSLCMP.*





CALCULATING THE SEA-LEVEL TREND

On the understanding that the Sea-Level Trend is calculated as a running average over the life of the data record, and acknowledging that we are dealing with comparatively small numbers, my concern is that any significant increase in the rate of sea-level rise (i.e. an acceleration in the trend) over a relatively short period will be smoothed out by the length of the historical record. In other words, a long stable history will act to smooth out a relatively short turbulent present. To illustrate this, let us examine the available sea-level trend data for Tuvalu, which is presented in Table 3.

Data collected and analysed by the SPSLCMP since 1993 indicates a trend of 5.9mm/yr, whereas the historical trend from 1950 to 2001 (Church et al) – which has an eight year overlap with the SPSLCMP – is about 2mm/yr. The Monthly Mean Sea Level chart for Tuvalu in Figure 11 does not show any evidence of a cataclysmic event that would explain a sudden rise in sea-level trends from 2mm/yr to 5.9mm/yr since the SPSLCMP records for Tuvalu commenced in 1993, so why is there such a significant difference between the current and historical trends and no sign of acceleration in either?

Tuvalu – Mean Sea-Level Trend			
Period	**Trend (mm/yr)**	**Length of Record (yrs)**	**Source**
1993 – 2007	+5.9	14.7	SPSLCMP Current
1977 – 1999	+0.92	23	SPSLCMP Historical
1950 – 2001	+2 ± 1	51	Church et al

Table 3: *Comparison of Mean Sea-Level Trend data for Tuvalu.*

I believe the answer is in how the mean sea-level trend is calculated, and hence the basis of my comment above that it will be quite some time before we see an increase in trend reflected in the charts in Figure 13. For example, let us assume that we continue the historical record for Tuvalu beyond 2001 (when the current trend was 2mm/yr) by adding on the SPSLCMP data record for the period 2001 to 2007 (which has a trend of 5.9mm/yr). The resultant trend based on the combined record for the period 1950 to 2007 would be only about 2.4mm/yr. If we "backdated" the historical record to 1993 when the SPSLCMP record commenced, and again assuming a current trend of 5.9mm/yr, the trend based on the combined record for the same period (1950 to 2007) would be still only around 3.0mm/yr.

What is more worrying is that, assuming the current trend stays constant at 5.9mm/yr until the year 2100, the trend based on the combined record for the 150 years to 2100 will be in the order of only 4.8mm/yr, as I have illustrated in Figure 1 below. This of course will not be a true reflection of what would be happening at the time. Hence my concern that the approach currently being used to calculate and report the Sea-Level Trend is not appropriate in the current situation for determining what we need to know today about the real trend in sea-level rise and how it will impact us tomorrow. While I touch on this point again in a later section of this paper, it is very much a discussion for another day.

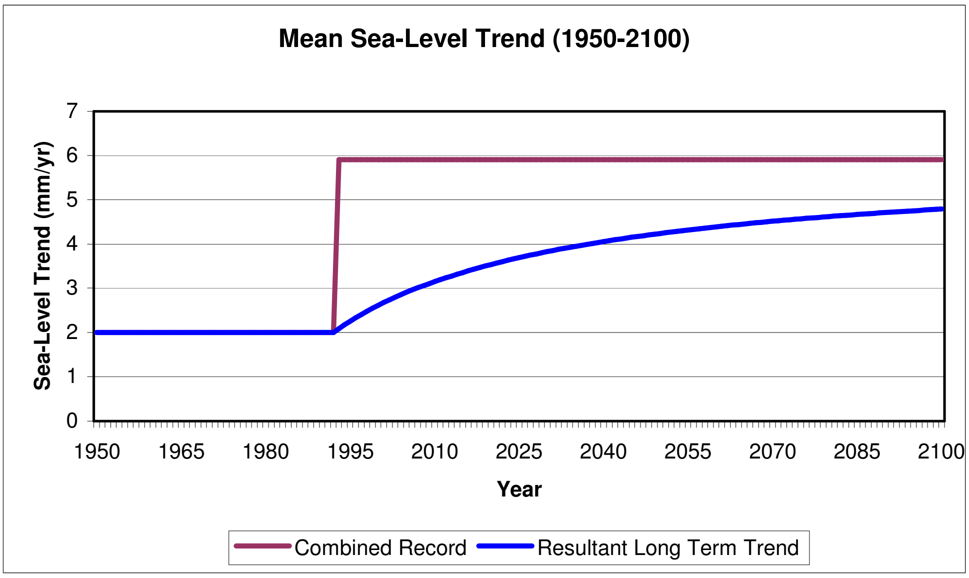


Figure 1: *A hypothetical projection of Mean Sea-Level Trend for Tuvalu based on combined historic and current trends.*

WHY DO THE RATES OF SEA LEVEL RISE DIFFER FROM PLACE TO PLACE? THE "WATERBED EFFECT"

In offering a response to this question it is important to understand that the global climate is inter-connected and that the sea level at any given location on the planet is determined by the complex interaction of many factors. Many people think of the global ocean expanse as being like water in a bath tub. Indeed, to some extent it is, except that the common perception is that the sea is at the same level around the world, somewhat like still water in a bath tub. However, as we all know, the ocean is not still. It is a hugely dynamic system, and as such is always in motion (and often an excited state of motion at that). Similarly, we can all relate to water in a bath tub sloshing around and up and down the sides of the bath at different places when it is disturbed. So yes, the bath tub analogy works – to a point – but it doesn't really *explain* why the rate of sea-level rise varies between islands and around the world.

Rather than water in a bath tub, let us consider that the ocean expanses of the world as being like a large bladder filled with water and contained in a rigid enclosure – such as a waterbed[8]– and your hands are the atmospheric pressure systems. Imagine kneeling beside the long side of a waterbed and placing your hands – spread about 90cm or three feet apart from each other – gently on the surface of the waterbed. Now press down on your left hand, simulating a High Pressure System. As you press down the water displaces from under your left hand and spreads throughout the rest of the waterbed, causing the remaining surface of the waterbed to rise slightly; in other words, the water has moved to locations of relative Low Pressure. (A more graphic illustration is how water rises in the bath as you lower your body into the water; your body mass represents the high pressure system that displaces the water!)

In the context of global climate, if one region gets high pressure then another has to get low pressure and vice-versa; like a waterbed, if the sea surface is forced down in one place it will

[8] I would like to claim the waterbed analogy as my own, but unfortunately I have recently discovered that Alastair McDonald (http://www.abmcdonald.freeserve.co.uk/index.htm) beat me to it by several months. He described the atmosphere as being like a waterbed, whereas in this paper I am applying it to describe the oceans and sea-level rise. I do, however, claim the full description of the waterbed analogy presented in this paper as my own work.

rise up somewhere else. And there are literally hundreds of High-Low Pressure System interactions randomly happening in the atmosphere and impacting on the surface of the earth all the time. To better understand this, imagine now that there are several people kneeling around the waterbed, each doing exactly the same thing as you are, but totally independent of each other; the result is not exactly what one would consider a stable system!

This relationship forms the basis of the typical short and medium term sea level changes caused by the atmospheric pressure influences of seasonal weather patterns and events, such as tropical storms, El Nino cycles, etc. Remember also that "wind' is air moving from a region of High Pressure to a region of Low Pressure, and this is why the coincidence of a Low Pressure System with a high tide or king tide often produces an extreme sea-level event that causes severe inundation and has such a devastating impact on low-lying coastal areas, islands and coral atolls like Tuvalu. Tropical storms, cyclones, hurricanes and typhoons are intense Low Pressure Systems, and the air masses that rush toward them (like water swirls and rushes down the bath drain when the plug is removed) form their destructive winds, which in turn generate the stormy seas and storm surge conditions typically associated with them.

> *In summary, variations in atmospheric pressure and sea level are inextricably linked; a global trend of increasing atmospheric pressure (i.e. pushing down harder on the waterbed) supports a global trend of rising sea levels. As High Pressure Systems become more intense more often, so must Low Pressure Systems, bringing about an increase in the frequency and intensity of severe weather events with their disastrous consequences, including greater sea inundation on low-lying coastal areas and islands.*

Now consider that the waterbed has many irregular, interconnecting compartments and that these compartments represent localised "regions". Imagine that water can flow from one compartment to another through openings of various sizes; noting that the movement of water between compartments represents the ocean currents travelling through the global regions. Consider also that the compartments can be heated or cooled by the air passing over their surface, so that the temperature of the water in one region can be different to the temperature of the water in another (i.e. such as in the Pacific Ocean, which can be several degrees warmer at Majuro in the Marshall Islands at 07°06'27"N than it is at Rarotonga in the Cook Islands at 21°11'58"S). Because water expands as it warms and contracts as it cools, sea-level change is also directly related to changes in sea surface temperature. In the global climate context, the heating and cooling of the sea is localised and occurs through a combination of air and ocean currents, such as the prevailing winds and jet streams in a particular region.

> *In summary, variations in air and sea surface temperatures and sea level are also inextricably linked; a global trend of increasing sea surface temperature (i.e. a permanent warming of the water in the waterbed due to a permanent rise in air temperature) supports a global trend of rising sea level through overall ocean expansion due to the warming of the atmosphere.*

If only it was that simple. Now consider also that the base of the waterbed – unlike a real waterbed – is extremely uneven and irregular (representing the sea bed) and that the surface of the waterbed is moulded around a variety of forms of different shapes and heights rising up from the "ocean floor". Consider that some of these forms protrude well above the surface of the waterbed (representing the continents and volcanic islands), and others protrude only just above the surface (representing small islands and atolls). Let us also assume for this analogy, that the bladder of the waterbed is made of an extremely light weight and flexible material that is barely strong enough to contain the water within the waterbed without restricting its movement in relation to the "land forms". By randomly pushing down on the surface of the waterbed at different places and at varying pressures, and at the same time varying the temperature of the water in its compartments up and down by small amounts, we can simulate the different variations in sea-level change around the islands and continents.

> *In summary, local changes in atmospheric pressure and temperature both directly and indirectly drive local changes in sea level, and when the changes in atmospheric pressure and temperature become more severe and prolonged due to climate change, the resulting changes in sea levels will also become more severe and prolonged. In a global context, these changes in local sea level are averaged over the earth's surface and are reflected in the "global mean sea-level trend".*

Finally, let us now consider the impact of simultaneously adding more water to the waterbed via a number of different points and at different rates. Imagine that several large blocks of ice are suspended in individual bladders at various points at each end of the waterbed (like ice block "pillows"), and that these ice blocks represent Greenland, the polar ice caps and the glaciers. Imagine that these pillows of ice are individually connected by a tube to the waterbed so that as the ice melts, the water released is added to the volume of water in the waterbed. Because ice melts faster in warmer conditions than in cool conditions, so will the rate of melt increase as the air temperature over the ice blocks increases, resulting in a corresponding but slightly delayed increase in the rate at which the released water will flow into the waterbed (i.e. it takes time for the increase in air temperature to have an effect on the ice, and for the ice to melt in response). This part of the analogy represents the resultant increase in released water due to the increased melting of Greenland, the polar ice caps and the glaciers. Just as the surface of the waterbed expands and rises to accommodate the water released by the melting ice, so will the oceans expand and sea levels rise if the rate of water being added to the oceans by melting ice caps and glaciers is greater than the rate of any losses (such as evaporation) that occur due to the global weather and climate cycles.

> *In summary, global air temperatures are directly related to the rate of melt of polar ice caps and glaciers, which in turn is directly related to the amount of water they release. When changes in atmospheric temperature become severe and prolonged due to climate change, the rate of melt of ice caps and glaciers also becomes more severe and prolonged, and more water is released at a faster rate. In a global context, warming of the polar ice caps and glaciers releases additional water that eventually finds its way into the oceans and directly contributes to long term sea-level rise.*

I appreciate that the analogy based on a waterbed, as I have attempted to use here, may not be scientifically correct in every respect, but I believe it is sufficiently realistic to provide everyday people with a tangible illustration that enables them to better understand how and why sea levels vary between different islands and around the world. I also hope that this analogy – as simple as I have tried to make it – helps both sceptics and everyday people better understand how climate change (whether due to global warming or not) contributes to the global trend in rising sea levels; restricted in my analogy only by the elasticity and strength of the material of the waterbed bladder and the limited amount of ice in the pillows.

WHAT IS THE THREAT TO LOW-LYING PACIFIC ISLANDS?

While I have great respect for the scientific community and agree that their achievements to date are much to be admired and appreciated, to understand what is actually happening now at places like Tuvalu and other low-lying islands in the Pacific we need to be paying more attention – not on the long term trend based on the historical record – but on the recent and current short term trends, particularly those of Peak Sea Levels and Monthly Mean Sea Levels. This is because the long term Sea-Level Trend, by definition, averages the increases in amplitude of sea level peaks and troughs out over time to remove the short to medium term variations in sea level. However, it is the short to medium term variations and their trends that tell us what is happening now and what is likely to happen in the immediate future.

To explain this, let us return to the analogy of the waterbed. Remember that, in general, a High Pressure System has a corresponding Low Pressure System, and an increase in the atmospheric pressure in a High (pushing down harder on the surface of the waterbed, causing a greater localised drop in sea level) will have a corresponding increase in the intensity of a Low (surface of the waterbed rises up somewhere else, causing a localised increase in sea level). While the short term variations in sea level may be quite dramatic, the resultant sea-level change due to these interactions over time may be relatively small because they act to negate each other, or "average each other out", over time (i.e. the mean of –8mm/month and +20mm/month is +6mm/month, as is the mean of –2mm/month and +14mm/month). In other words, the most important information needed by those responsible for identifying and implementing appropriate and practical adaptation strategies to deal with their immediate and medium term vulnerability to climate change and sea-level rise, is that which the long term trend analysis actually filters out.

Tuvalu is an excellent example, and to illustrate my point I have included at Figure 2 below the JASL plot of Monthly Mean Sea Levels and Sea-Level Trend for Tuvalu, which is available online via the University of Hawaii Sea Level Center (UHSLC) website[9]; the two circles and the straight line connecting them are my personal annotations.

The plot shows that in about February 1994 Tuvalu experienced a Monthly Mean Sea Level of around 11cm (110mm) above the long term station datum. This peak (circled), was generally exceeded by consistent incremental rises over subsequent years, except for the 1997-98 period when the influence on a strong El Nino prevailed over the region. In about February 2006 – 12 years later – the Monthly Mean Sea Level at Tuvalu peaked at around 22cm (220mm) (also circled). Over this 12 year period, Tuvalu experienced a real increase in Mean Sea Level of about 110mm, which translates to an effective sea-level trend of approximately 9.2mm/yr over the period, as illustrated by the gradient of the straight line joining the peaks. Referring back to Table 2, we can see that this rate is well above the current sea-level trend for Tuvalu of 5.9 mm/yr (depicted by the squiggly red line in Figure 2) and the long term sea-level trend of 5.5mm/yr for the region. It is also significantly greater than the current scientific estimates of the global average and regional average rate of sea-level rise, which are closer to 2mm/yr as quoted earlier from Church, White and Hunter.

[9] The University of Hawaii Sea Level Center (UHSLC) provides three online databases; the research quality data , the GLOSS/CLIVAR "fast delivery" data, and the JCOMM Sea Level Program in the Pacific map data via its website at http://ilikai.soest.hawaii.edu/uhslc/data.html.

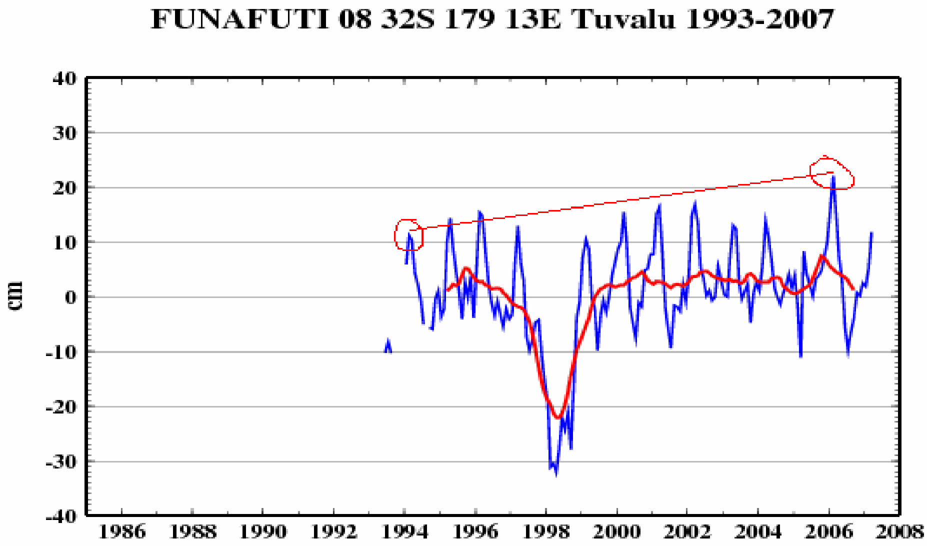


Figure 2: JASL Monthly Mean Sea Levels and Sea Level Trend data for Tuvalu.

The increase in the frequency of "bad" peaks is clearly visible in the Monthly Mean Sea Level chart for Tuvalu in Figure 11, which is generated from the same base data set used to produce Figure 2. Note also in Figure 11 that the charts for a number of other Pacific Islands in the SPSLCMP network, such as the Cook Islands, Tonga and the Solomon Islands indicate similar recent trends of increasing bad peaks. This is an important factor in understanding the fragile predicament of low-lying coastal areas and small island countries, as these peaks indicate the time and conditions when they are most vulnerable to severe sea inundation; and that information is critical for an island such as Tuvalu, where the highest point above mean sea level is only four metres. It is no coincidence that Tuvalu suffered extreme sea inundation during a king tide event in February 2006; the month Tuvalu recorded its highest peak Monthly Mean Sea Level of 22cm (0.22m).

In the broader context, the peaks in Monthly Mean Sea Level and their trend in both frequency and magnitude provide a direct indication – and potentially a measure – of the rate and extent of sea inundation to which low-lying coastal areas and small islands are vulnerable. While gradual sea encroachment (where the sea slowly overtakes the land and does not recede) due to the long term trend in sea-level rise is of major concern to Pacific Island countries and other Small Island Developing States (SIDS), it is their vulnerability <u>today</u> to increasingly frequent and severe sea inundation (where the sea over takes the land and then recedes) – such as those occurences now impacting Tuvalu on an increasingly regular basis – that is a far more real and urgent problem. It is sea inundation – not sea encroachment – that is already having a disastrous impact on their quality of life and the viability of sustainable habitation on their native lands.

CONCLUSION

Over the past two years I have travelled to many Pacific Island countries and have seen how increasing sea inundation is already causing irreversible salinization of the land and fresh water supplies. Unfortunately, as long as the current trends in climate change and sea level continue to be adverse, the situation at Tuvalu and other low-lying islands will only get worse, and these islands will become uninhabitable long before they are consumed by the sea.

For the people of these islands, the range of practical adaptation strategies available to them to deal with the impacts of climate change and increasing inundation is extremely limited. There is no higher ground for them to relocate to, and it is only a matter of several rather than tens of years before they may have no choice but to abandon their native homeland and relocate to other shores. Unfortunately, this is something that even good and well-intentioned people in most developed countries are unable to relate to, and sceptics simply don't care about. That is, until they themselves start to feel the impact of climate change on their own shores and in their daily lives; but by then it may be far too late for many SIDS.

For sceptics, the "bottom line" is even worse than one supposed. The trend in the occurrence and severity of "bad" peaks and inundation is worsening and, as a result, becoming more crippling to those impacted. That this trend is caused by climate change is now beyond doubt. For everyday people, slowly rising sea-level averages must be of less concern than the fact that faster rising peak sea levels are forcing low-lying islands and coastal areas to become quickly and dramatically uninhabitable. What is happening now to these lands is the result of climate change; climate change being accelerated by existing world emissions that have very little likelihood of being reduced in the foreseeable future.

It seems that every day, every month and now every year new records of extremes for weather and climate phenomea are being set; the hottest day, the hottest year, the longest dry spell, the heaviest snow fall, the worst flood, the strongest hurricane, the highest rainfall, the lowest rainfall, unseasonal events, etc. We need to heed these signs that clearly show that climate change is real and upon us, and increasing in its impact.

While it is of course possible that many people may become de-motivated by the growing evidence of climate change and the growing reality that there is very little we can do to avert it, we can – and need to – take significant steps now to help each other mitigate our vulnerability to its impacts, and to adapt to whatever environment may result from it.

> ***There is real data available from when the climate last changed and global temperatures jumped 5C in three years. If we wait until we have data to prove it is happening again, even if we spot it during the first year, it will be too late to prevent it.*** **Alastair McDonald (2007)**

APPENDIX 1: Some enquiries I have received in response to my November 2006 paper.

International Expert on Coastal Zone Management

Philip, could you help me with a specific question regarding the interpretation of the South Pacific Sea Level & Climate Monitoring Project please?

The reason for asking is that I've been contracted by the [organisation] *to run training on coastal V&A* [Vulnerability and Adaptation] *in the Pacific. I'll be referring to your project as a base data set. The question though, is how should the PICs* [Pacific Island Countries] *interpret the data (and how should they go about this)!*

I know this is rather a 'how long is a piece of string' question. But I was hoping for some advice on the process that a PIC would go through to use the data and then make informed projections of SLR [Sea Level Rise], *modified for tectonism & including current known SL variabilities?*

Renown UK-based writer, broadcaster and commentator

Dear Philip Hall, I have been trying to work out what I can usefully say about sea level rise in the Pacific. These two BBC pieces have made me want to address the issue:

http://news.bbc.co.uk/1/hi/sci/tech/7203313.stm

http://news.bbc.co.uk/1/hi/sci/tech/7195752.stm

My inclination is to say something like: [suggested text]

It is often assumed, not least by the IPCC, that man-made climate change and its warming of the planet have caused these sea-level rises. But there is actually a good deal of uncertainty about whether it has yet affected sea levels at all. There is much more agreement that at some point, and probably quite soon, it will.

Thanks a million for any help you are able to give.

International Private Islands Specialist

Dear Mr. Hall, I am one of the largest brokers of private islands in the world, and the issue of sea level rise and threat from global warming to islands has been raised in the media with me.

I have done a great deal of research already. In 2001, the IPCC's Third Assessment Report IPCC predicted that by 2100, global warming will lead to a sea level rise of 9 to 88 cm (0.3-2.9 ft) with regional variation. However, in my research I have discovered that there is a great variety in short sea level rise with Tonga (+8.2 mm/year) and FSM having very high rates, and other countries having lower rates.

Your report concludes "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 "

The majority of the data seems to be based upon data from very recently, what about the other tidal records going back over longer period which show less effect? As the largest body of water on earth I would guess that the Pacific would be the best *indicator of an overall sea-level rise, but the data does not back up the projected general belief and estimates of the IPCC.*

This issue is already starting to raise worries from potential purchasers and investors for private islands. I am not interested in politics, or debunking climate change which is obvious and apparent, but I would just like to get an accurate and scientifically based projection that investors can see as a real indication of future dangers.

European-based Journalist/Editor

Dear Philip, I am journalist and writing for newspapers like Süddeutsche Zeitung (Munich), New Zürich Zeitung (NZZ)(Switzerland), etc.

At the moment I am working on a story about sea level rise and countermeasures in Central Europe, for example in the Netherlands – with giant constructions like maeslant-kering and oesterschelde-barrier. They cost billions. That much money is not affordable in other parts of the world.

What I have seen on your remarkable review of sea level rise within your monitoring project SPSLCMP ("What the SPSLCMP is telling us..."): There are big differences between Islands like Fiji + 2.7 mm/year for example, and Tonga 8.1 mm/year. (For FSM, I understood, the time span is too small.) The estimated rise would also in the South Pacific differ from 27 cm to maybe 81 cm per 100 years.

Why is this gap in between so big? Does it depend on the instrumentarium or the construction of measuring apparatus? Are there probably images from the instruments, you use, and the installation environment? Do you think people living in this area are able to response on the rising level? Is the main problem maybe, before others, than salt water from the sea intrudes in fresh water resources?

I believe, it is more worthy to talk to someone like you, who has been responsible for a project so far. I tried to have a look on the projects that you are working on, and found a lot of paperwork from SIDS [Small Island Developing States] *and UNFCCC* [United Nations Framework Convention on Climate Change], *that is difficult for me to sort out. So, if I may put one question – Why are there so wide-spread results between the different Islands – that might be an argument for scepticists, to say: Oh, no, we see no real resaon to act by now, it is all to uncertain etc.*

AUTHOR PROFILE

Philip Hall is strategic solutions consultant with over 30 years experience across business, science, and technology. Through his company, Faerber Hall (a registered consultancy in Australia and the United States), he works internationally with a wide variety of public and private sector organisations across a diverse range of industries and sectors. His professional association with Pacific Island countries spans over 15 years.

In addition to business and project management consulting he is an international adviser on practical strategies for emergency management and climate change adaptation, drawing on his years of experience gained with the Australian Bureau of Meteorology – where he held several senior management positions in Observations & Engineering and Services Policy – and his long association with the South Pacific region. He was recently engaged by the Australian Government to develop the project implementation strategy and plan for the Australian Tsunami Warning System, and to serve as interim Project Director for Phase IV of the South Pacific Sea Level and Climate Monitoring Project. More recently he has participated on expert panels convened by the UNFCCC and the IPCC to consider the climate-society-environment interactions that are important to understanding climate change and its potential implications in the South Pacific region.

Philip writes and presents on a wide range of topics, including practical strategies for achieving sustainable business performance, integration strategies for renewable energy solutions, cascading effects of climate adaptation strategies, and practical strategies for the development and implementation of emergency management capabilities. He holds a Master of Engineering degree from the Royal Melbourne Institute of Technology, is a Fellow of the Institution of Engineers, Australia, and is a Board Member of the International Association of Emergency Managers (Oceania Region).

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