Pattern Recognition in Physics

Pattern Recogn. Phys., 2(2), 65–74, 2014.

http://www.pattern-recognition-in-physics.com

Problems and reliability of the satellite altimeter based Global Mean Sea Level computation

A. Parker[1]

Abstract
The recognition of the present pattern of sea levels has been made more and more difficult from the definition of procedures and methods that generate estimations of a global mean sea level (GMSL). This GMSL is weekly related to what is actually measured by tide gauges and satellite altimeters. This GMSL is strongly dependent to 'calibrations' of subjective nature and it seems rather to be a product of computation than a true measurement. This problem is highlighted with a couple of case studies, and it is concluded that the effects of global warming on the rates of rise of sea levels have, so far, been very small or negligible.

Keywords: Earth Sciences — Climate Change
Received: 04/Apr/2014 - **Revised:** 13/Jun/2014 - **Accepted:** 15/Jun/2014 - **Published:** 23/Jul/2014

[1] *School of Aerospace Mechanical and Manufacturing Engineering, RMIT University, Bundoora, VIC, Australia.*
Correspondence to: A. Parker (albertparker@y7mail.com)

1. Introduction

The sea levels relative to a datum have historically been measured by tide gauges providing consistent, reliable and accurate representation in the best of the cases since the 1800s. Over the last 2 decades, the long term tide gauges have continued to supply data consistent with a pattern of sea levels on average weakly rising (less than half a millimeter per year) with no significant component of acceleration.

Satellite altimetry is an alternative method of measuring changes in sea level, and GPS is a complimentary method of assessing the vertical land motion at tide gauge stations.

This paper discusses these novel techniques and it will be demonstrated that both techniques are presently still far from providing any improved information on the possible effect of ice melting and thermal expansion on sea levels.

2. One More correction to the GMSL computation

The tide gauges, indicate that relative sea levels are oscillating with regular periodicities up to quasi 60 years (many good examples, (e.g. records from Sydney to Fremantle, and from San Francisco to Seattle, as available in [4] & [5]). We have experienced a decade of lack of warming measured in the world oceans 0-2000 m 60 N to 60 S [6]. The sea ice extent of Arctica and Antarctica is globally increasing over the same time window [7].

In view of these facts, it seems quite surprising that Cazenave et al., in a recent paper [1] claim (quotation):

"Here we present an analysis based on sea-level data from the altimetry record of the past ∼20 years that separates inter annual natural variability in sea level from the longer-term change probably related to anthropogenic global warming. The most prominent signature in the global mean sea level inter annual variability is caused by El Niño-Southern Oscillation, through its impact on the global water cycle. We find that when correcting for inter annual variability, the past decade's slowdown of the global mean sea level disappears, leading to a similar rate of sea-level rise during the first and second decade of the altimetry era. Our results confirm the need for quantifying and further removing from the climate records the short-term natural climate variability if one wants to extract the global warming signal."

Figure 1 presents the temporal evolution of the GMSL rate from 5 different groups and their corrected GMSL rates. The rate of rise of the GMSL computed by the 5 groups with everything but clear procedure based on a satellite result that before correction was only noise, having no understandable relationship with what is measured by good quality tide gauges along the coasts, seems to be slowing down (Fig. 1a).

The authors [1] de-trend the records in order to estimate

a
b
c

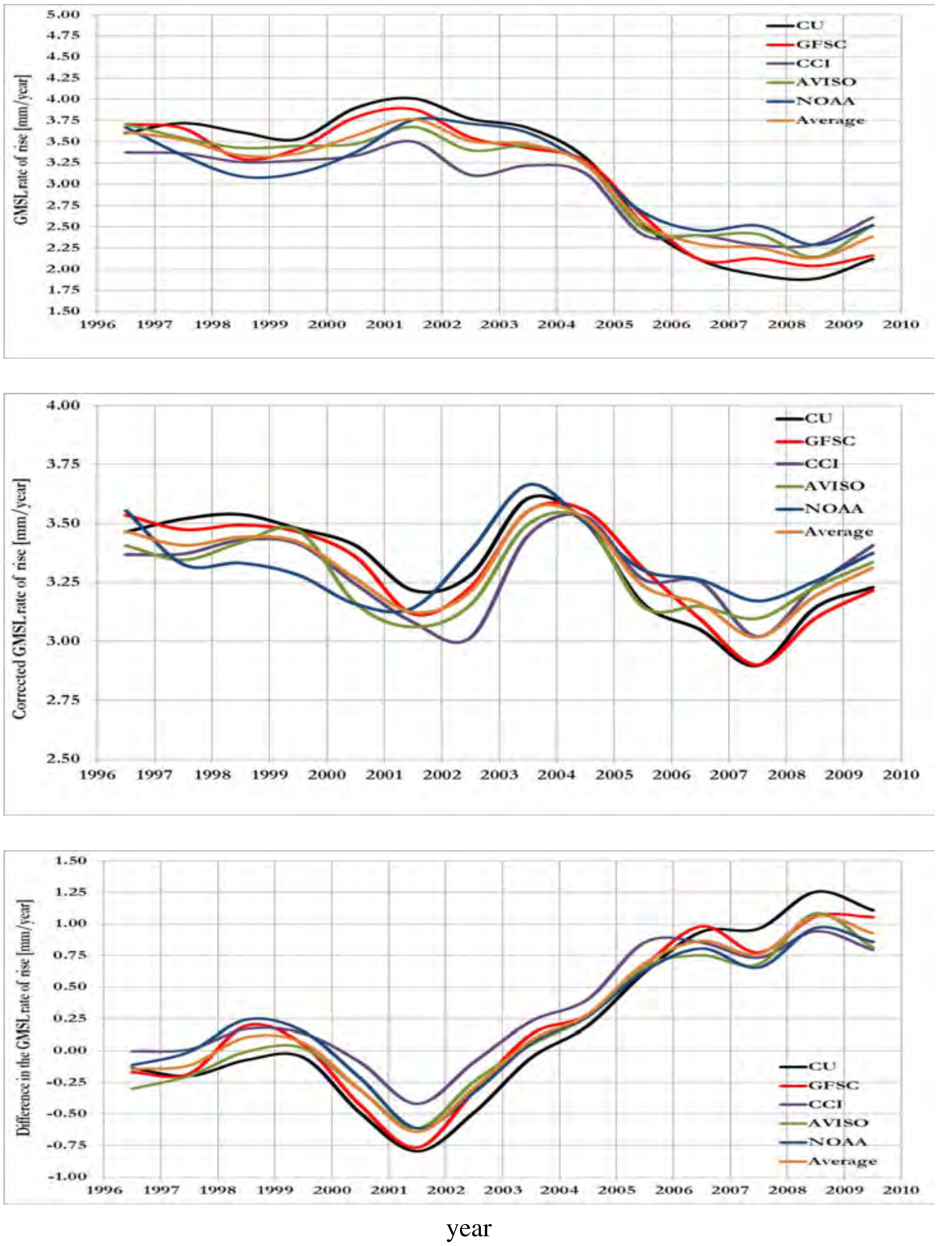


Figure 1. **a**: temporal evolution of the GMSL rate computed over five-year-long moving windows shifted by one year (start date: 1994). **b**: temporal evolution of the corrected GMSL rate (nominal case) computed over five-year-long moving windows shifted by one year (start date: 1994). GMSL data from each of the five processing groups are shown. Data used for picture is from [1]. Caption of picture is from [1]. The average result is introduced here. **c**: differences in between the original and corrected GMLS rates of rise.

the two components that make up the sea level changes, viz. the water mass component from ice melting or rainfall shifting, and the thermo-steric component, from thermal expansion of the oceans. This implies that the mass and thermo-steric components are nothing measured and only modeling results as customary.

The sum of the mass and steric components is subtracted from the average of the 5 groups' GMSL results. This apparently gives the correction then applied to each of the 5 groups' GMSL. The new GMSL, Fig. 1b), is at this stage almost constant. Conclusion is therefore that the rate of rise of the GMSL is about constant over the short time window of the satellite-based reconstruction and global warming is not slowing down.

In the paper by Cazenave et al. [1] the methods applied are far from clear either in the main text or in the figure captions (e.g. Fig. 1b).

According to [12], the GMSL 'measurements' are *"continuously calibrated against a network of tide gauges"* but the GMSL *"cannot be used to predict relative sea level changes along the coasts". "We do calibrate the altimeter sea level measurements against a network tide gauges to discover and monitor drift in the satellite (and sometimes tide gauge) measurements"* [12]. So basically the GMSL 'measurement' is already a correction of the correction, and [1] only introduces a further correction for the obvious reason to show that the GMSL is not decreasing.

3. Hurdles in determining the vertical position of a continuously oscillating surface by satellite

Not surprisingly, the raw satellite altimeter result when first published was mostly noise. Mörner published a graph of the raw satellite trends from the TOPEX/Poseidon satellite 1992 to 2000 [2]. The graph does not show any sea level rise.

The result was about constant 1993 to 1996, then 1997 to 1999 there were considerable changes up and down probably related to the unusual 1997-98 El Niño, and beginning of 2000 this signal was about same values of end 1992. Then, after a 'calibration', the rate of rise was about 3 mm/year.

The satellite altimetry is in principle certainly a new and important tool. However, the GMSL is not a measured value, but a value arrived at after much 'calibration' of subjective nature [2, 9 and 10].

Comparison of raw satellite measurements and GMSL computations is presented in Figure 3 (pictures reproduced from [9]).

The satellite altimetry may only be a very noisy flat signal, because the determination of the 'absolute' vertical position of 'fixed' objects on land is already very difficult and inaccurate, and the sea surface is continuously oscillating posing particularly challenging computational hurdles.

If we do consider the velocity of the GPS domes nearby some of the most important tide gauges of the world, as for example San Diego, San Francisco and Seattle on the west coast of the United States, Tofino and Victoria on the west coast of Canada, Honolulu in the Hawaii islands, or Sydney in Australia, the land velocities computed by different groups, for example [5] and [11], differ considerably:

- The vertical land velocity of Point Loma 3 (PLO3) near the SAN DIEGO (QUARANTINE STATION) tide gauge is -1.65 ± 0.41 mm/year [5] vs. is -2.39 ± 1.00 mm/year [11]. This GPS dome is decommissioned and the time span of data 1996 to 2006 is the same. In [5], the vertical land velocity of PLO5 nearby PLO3 is -3.23 ± 0.17 mm/year over the time window 2006 to 2011.

- The vertical land velocity of Point Blunt (PBL1) near the SAN FRANCISCO tide gauge is -1.12 ± 0.25 mm/year [5] vs. -0.69 ± 0.43 mm/year [11]. This GPS dome is decommissioned and the time span of data 1996 to 2004 is the same.

- The vertical land velocity of Seattle (SEAT) near the SEATTLE tide gauge is -1.34 ± 0.23 mm/year [5] vs. -1.35 ± 0.12 mm/year [11]. This GPS dome is active, and the time span of data is 1998 to 2010 in [5] and 1998 to 2013 in [11]. The rate of subsidy in this case is about the same, but this is the exception.

- The vertical land velocity of Sydney (SYDN) near the FORT DENISON 1 & 2 tide gauges is -0.89 ± 0.65 mm/year [5] vs. -0.54 ± 0.37 mm/year [11]. This GPS [11] dome is active, and the time span of data is 2005 to 2011 in [5] and 2005 to 2013 in [11]. The difference in the time span does not seem to be the reason for the difference in the rates of subsidy.

- The vertical land velocity of Honolulu (HNLC) near the HONOLULU tide gauge is -0.36 ± 0.16 mm/year [5] vs. -0.44 ± 0.13 mm/year [11]. This GPS dome is active, and the time span of data is 1998 to 2010 in [5] and 1998 to 2014 in [11]. The difference in the time span does not seem to be the reason for the difference in the rates of subsidy.

- The vertical land velocity of Tofino (UCLU) near the TOFINO tide gauge is + 4.10 ± 0.14 mm/year [5] vs. +2.54 ± 0.30 mm/year [11]. This GPS dome is active, and the time span of data is 1995 to 2010 in [5] and 1995 to 2013 in [11]. The difference in the time span does not seem to be the reason for the significant difference in the rates of isostasy.

- The vertical land velocity of Albert Head (ALBH) near the VICTORIA tide gauge is -0.34 ± 0.31 mm/year (subsidy) in [5]. According to [11], this velocity is +0.44 ± 0.19 mm/year (isostasy). This GPS dome is active. The time span of data is 1995 to 2010 in [5] and 1995 to 2013 in [11]. The different time span does not seem to be the reason for the significant difference from subsidy to isostasy.

Other examples of different velocities for the same GPS domes mentioned above may be found in [17] or [18], with generally significant differences becoming dramatic in some cases, as for example Seattle SEAT that in [18] has a vertical velocity of +0.20 ± 0.50 mm/year vs. the -1.34 ± 0.23 mm/year of [5] and the -1.35 ± 0.12 mm/year of [11] or the -0.9 ± 0.7 of [17].

Surprisingly, while the velocities of fixed GPS domes differ considerably from one computation to the other, the time rate of change of the global volume of the world oceans is very close in the different reconstructions by the different groups; see Figure 1 and the GMSL rates below (values from [12]):

- CU: 3.2 ± 0.4 mm/yr

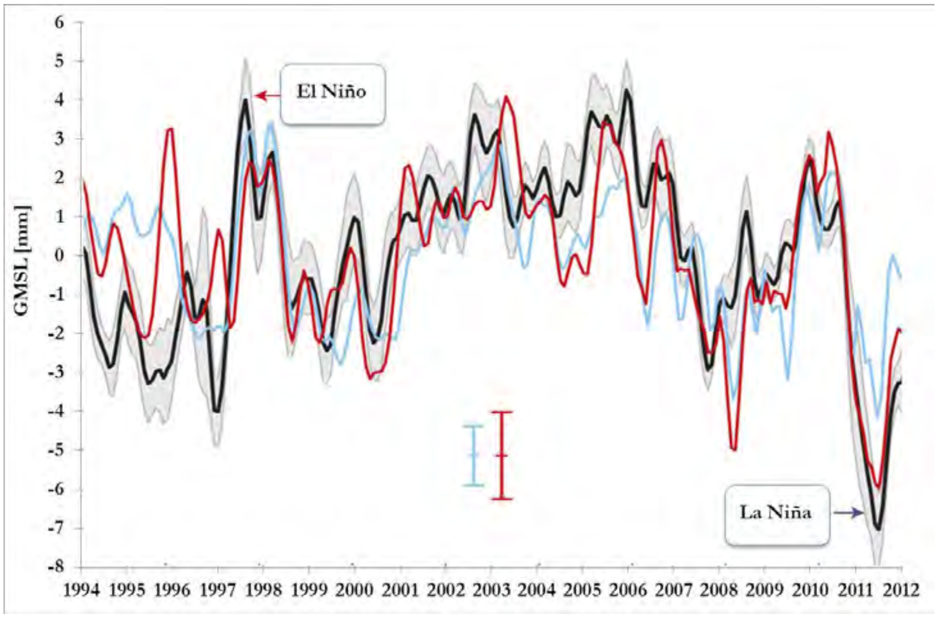


Figure 2. Black curve: mean de trended GMSL time series (average of the five satellite altimetry data sets) from January 1994–December 2011 and associated uncertainty (in grey; based on the dispersion of each time series around the mean). Light blue curve: inter annual mass component based on the ISBA/TRIP hydrological model for land water storage plus atmospheric water vapor component over January 1994 – December 2011. The red curve is the sum of the inter-annual mass and thermo steric components. This is the signal removed from the original GMSL time series (nominal case). Vertical bars represent the uncertainty of the monthly mass estimate (of 1.5 mm; light blue bar) and monthly total contribution (mass plus thermo steric components; of 2.2 mm; red bar). Data of picture and caption are from [1].

- AVISO: 3.3 ± 0.6 mm/yr
- CSIRO: 3.2 ± 0.4 mm/yr
- NASA GSFC: 3.2 ± 0.4 mm/yr
- NOAA: 3.2 ± 0.4 mm/yr (w/ GIA)

Whilst Wöppelmann [19] states *"the use of GPS to monitor vertical land motions at tide gauges has proven to be not as straightforward as some supposed 15 years ago. Determining rates of vertical land motion with accuracy better than 1 mm/yr is still a very challenging problem in Geodesy today*", the time rate of change of the global volume of the ocean waters is claimed to be known within an accuracy of ± 0.4 mm/year.

4. A more reliable and consolidated measure of the relative rates of rise by tide gauges

It becomes clear that something is not going well in the GMSL computation when we compare the global and regional MSL time series from satellite altimetry [12] and the actual measurements of tide gauges.

The rate of rise of the relative sea level locally measured by the tide gauges with an accurate and consolidated procedure is the result that should be considered for the monitoring of the effects of climate change.

Attempts to correct the local rates of rise accounting for the vertical land motion to compute an absolute local rate of rise of sea level is pointless, because the vertical land velocity is not known with same accuracy as the relative rate of rise of sea levels, and a shift of a constant land velocity does not change the non-accelerating behaviour of a tide gauge.

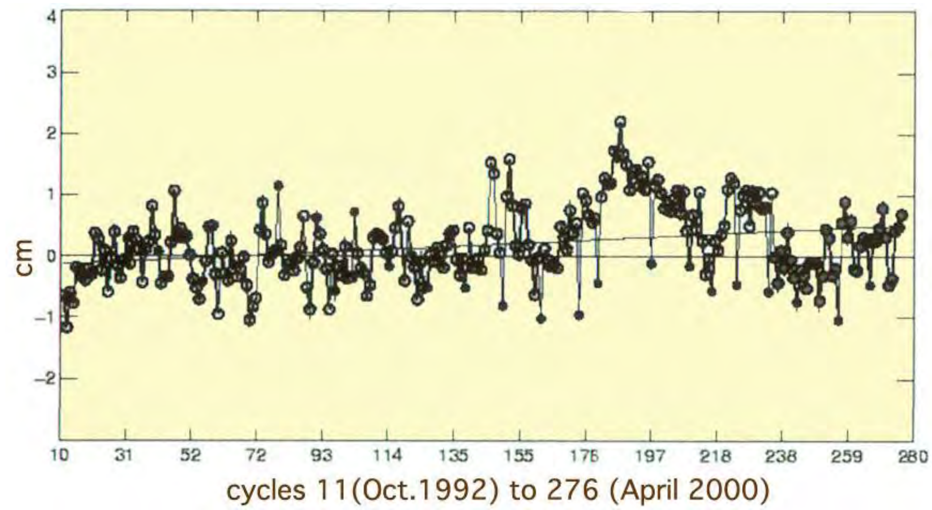
The long-term global tide gauge network [4] does not exhibit any positive acceleration; only oscillations about a constant rate of rising trend [13-16].

A table of long-term trends derived from annual mean values of sea level in the PSMSL Revised Local Reference (RLR) data set [4] records the rate of change of sea level at each station. The latest (update 14-Feb-2014) "Table of Relative Mean Sea Level Secular Trends" derived from PSMSL RLR data includes the relative sea level rates of rise for 560 individual locations along the coast mostly in the northern hemisphere and mostly in areas of subsidy.

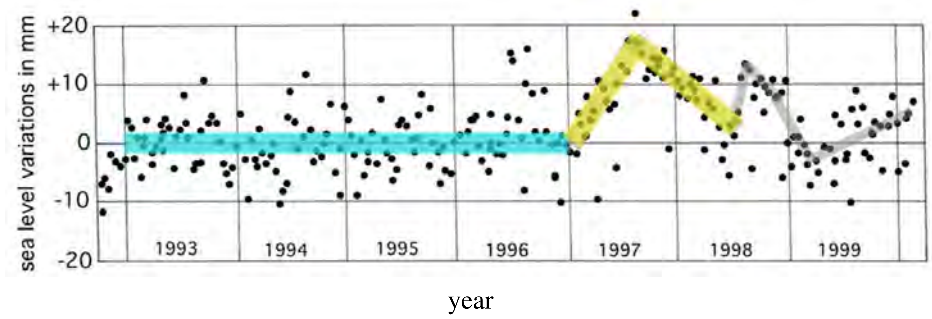
The number of years of data used to compute the trend, the range of years used and the relative sea level trend vary considerably from one location to the other where subsidy or isostasy, quality and length of the record and other factors affect the computed trend.

Records of length less than 60-70 years should not be

a



b



c

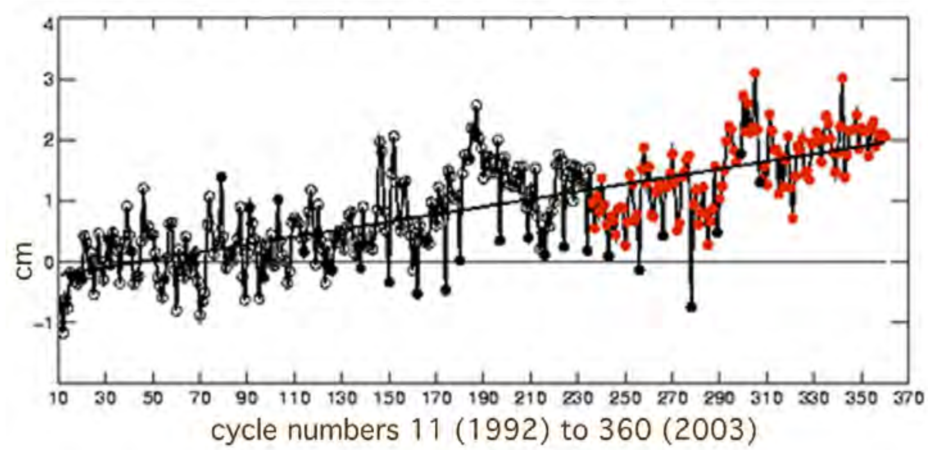


Figure 3. Comparison of raw satellite measurements and GMSL computations (pictures reproduced from [9]). **a**: Annual mean sea level changes from TOPEX/POSEIDON satellite observations in year 2000 after technical "corrections" were applied (from [25]). The trend computed by ignoring the ENSO event in cycles 175-200 is 1 mm/year. **b**: Same sea level changes but taking into account the ENSO peak. There is stability over the first 5 years and possibly over the whole period with zero trend line (from [2]). **c**: Sea level changes after the 2003 "calibration". The satellite altimetry record is shown for TOPEX/POSEIDON (black) and Jason (red). This graph was proposed by AVISO in 2003. The data now have a trend of 2.3 mm/year obtained by tilting the original record. As in every measurement not confirming the global warming theory, the measured values are corrected to validate the theory. But this is not any more a measurement.

used to infer any trend (they are too short and would suggest a longer term trend inclusive of the strong multi-decadal oscillations up to quasi-60 years). For the establishment of meaningful long-term trends, only the 170 stations with more

PSMSL	GNS S	GPS land v mm/y	RSL start year	RSL % completeness	RSL v mm/y	RSL v since 1993 mm/y
Sydney, NSW	SYDN	-0.89	1886	100	0.92	3.16
Honolulu, HI	HNLC	-0.36	1905	100	1.44	0.12
San Diego, CA	PLO3	-1.65	1905	98	2.06	0.64
	PLO5	-3.23				
San Francisco, CA	PBL1	-1.12	1854	100	1.61	0.96
Seattle, WA	SEAT	-1.34	1906	100	1.99	-0.49
Tofino, BC	UCLU	4.1	1909	76	-1.68	-4.17
Vancouver, BC	BCVC	**-0.3***	1910	82	0.33	-0.55
Victoria, BC	ALBH	-0.34	1909	99	0.64	-0.5
Prince Rupert, BC	BCPR	**-1.7***	1909	82	1.09	1.44

Table 1. GPS land velocity (from [5]) and relative sea level velocity long term and since 1993 (data from [4]) of Pacific tide gauges. GPS land velocities indicated with (*) are values from [17].

than 60 years of data are considered, and for these stations, the average relative sea level trend is +0.403 mm/year [3,13-16].

Subsequent updates of compilations of tide gauges of sufficient quality and length not only verify that the average relative sea level trend is low and very close to zero, but also indicate that the time rate of change of this velocity is zero, implying an absence of the so-called "sea level acceleration".

This result is only an average of observations of the relative mean sea levels in selected locations. However, the above +0.403 mm/year measured in areas generally representing subsidy suggest that the GMSL should have a rate of rise not that far from zero and be about constant. The claimed +3.2 mm/year by computations is a value very difficult to conciliate with the +0.403 mm/year by measurements.

Table 1 summarizes the results for all the tide gauges of the Pacific more than 100 years long and presently recording.

The apparent relative rate of rise computed by using the short 20 year time window is above (Sydney, NSW; Prince Rupert, BC) or below (Honolulu, HI; San Diego, CA; San Francisco, CA; Seattle, WA; Tofino, BC; Vancouver, BC; Victoria, BC) the long term trend. This is the result of the natural oscillations of different phases.

The vertical land motion data of Table 1 is obtained from [5] with the exception of Vancouver, BC and Prince Rupert, BC. For these two locations, the vertical land motion is obtained from [17]. Worth of mention, for Seattle, WA, and Victoria, BC the vertical land velocities of [17] are much larger than those proposed in [5], -0.9 ± 0.7, and +0.6 ± 0.7 mm/year vs. -1.34 ± 0.23 and -0.34 ± 0.31 mm/year respectively, while for Tofino, BC are much smaller +2.6 ± 0.8 vs. +4.10 ± 0.14 mm/year.

The average relative rate of rise of this reduced compilation is +0.93 mm/year. As previously stated, the vertical land motion is not known with sufficient accuracy, but there are certainly more stations with subsidy than uplift.

The vertical positions of the GPS domes a few km away from the tide gauge are not the vertical position of the datum of the tide gauges.

The average absolute rate of rise has less value than the average relative rate of rise, however. According to Table 1 this reduces the mean rate to 0.4 mm/year.

It is well known that the sea levels (similar to the temperatures) oscillate with multi-decadal periodicities detected up to quasi-60 years [3].

5. Addressing sea level rise in global key sites

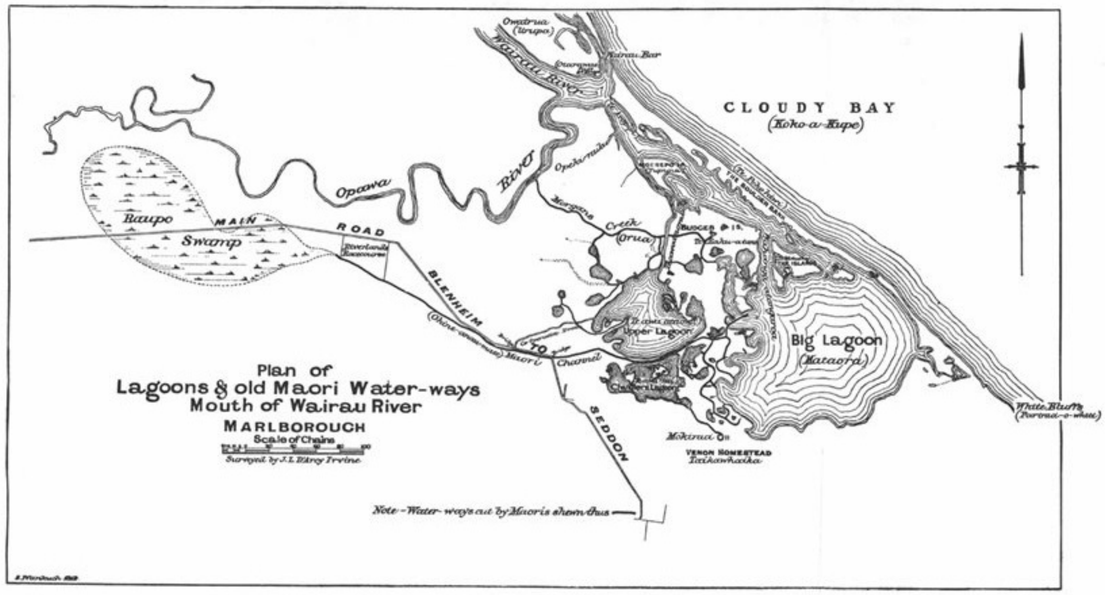
A further support to the stable pattern of sea levels suggested by tide gauges is to address 'global key sites' [2, 10], sites having special importance like the Maldives, Bangladesh, Tuvalu, Kiribati and Vanuatu, or sites where the sea level rise can be easily tested like in Venice, the North Sea and French Guyana. At all these sites sea level seems to have remained stationary over the last 40-50 years [2, 10].

Other 'global key sites' to mention is the sea level benchmark etched onto a cliff on the Isle of the Dead, Tasmania, Australia in 1841 by J. C. Ross [20] or the Cloudy Bay lagoons in New Zealand [23].

The Ross benchmark currently stands more than 30 cm above present-day mean sea level as measured by an acoustic tide gauge a km away at Port Arthur. Ross in his account of his visit to Tasmania in 1841 stated clearly that the mark was struck at "zero point or the mean level of the sea" as he estimated it to be in 1841 [21]. In 1888, the then Government meteorologist J. Shortt found the mark to be 34 cm above mean sea level [22]. Since Tasmania is geologically stable, the land uplift could not be used to explain why the benchmark is above the present mean level of the sea.

Not surprisingly, the only work published on the Ross benchmark is a paper correcting the benchmark location and wrongly claiming that the benchmark was originally set 44.5 cm above the mean level of the sea in 1841, to conclude that since it now sits at 31.5 cm above, the sea level has risen 13 cm. According to Shortt [22], the 13 cm are at the most 2.5 cm.

a



b

Figure 4. Cloudy Bay lagoons in New Zealand a) in a map of 1912 and b) in Google Earth 5/8/2013. The channels and waterways are perfectly conserved. The survey for the years 1902 and 1903 had no support of aerial images.

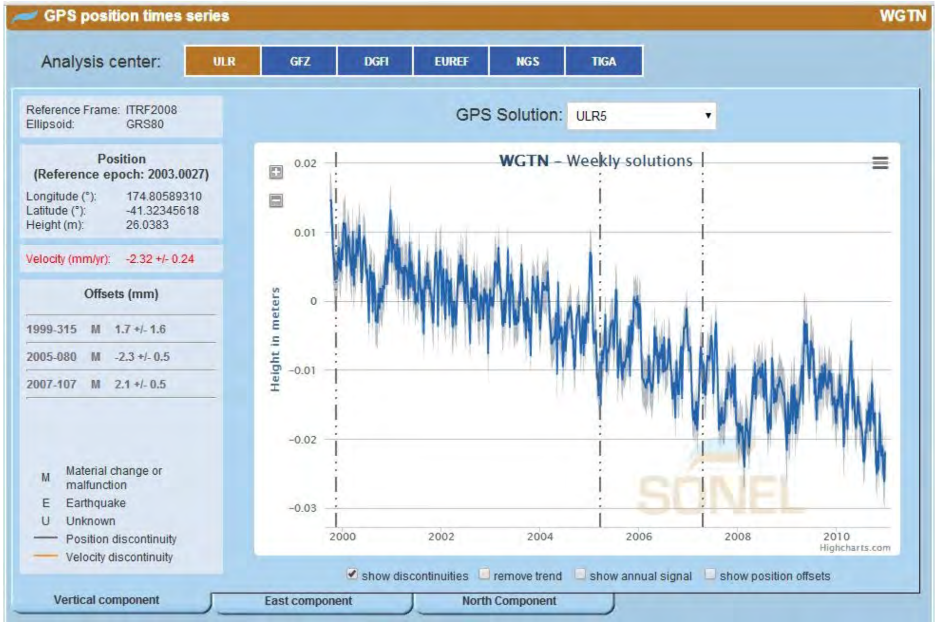
In Cloudy Bay, a 1912 map of canals dug with wooden spades by ancient Maori closely resemble the present satellite image from Google Earth revealing a lack of sea level invasion on the narrow shoal comprised of rock and pebbles linking the lagoons to the sea.

"THE report of Department of Lands and Survey, New Zealand, for year 1902-1903, Appendix VIII., contains a short account by C. W. Adams, Esq., Chief Surveyor, of a series of Canals and Waterways traversing the lagoons and mud flats in the vicinity of the mouth of Wairau river. The report has an excellent map attached, the result of a survey made by Mr. D'Arcy Irvine, Assistant Surveyor, and which is here reproduced, with the addition of many of the old Native names" [24]. Figure 4a presents the old map from [24]. Figure 4b gives the present satellite image.

Cloudy Bay is on the South Island facing Wellington on the North Island.

As shown in Figure 5, the tide gauges of WELLINGTON HARBOUR and WELLINGTON II (data from [4]) show a relative rate of rise of sea levels of +2.07 to +2.49 mm/year,

a



b

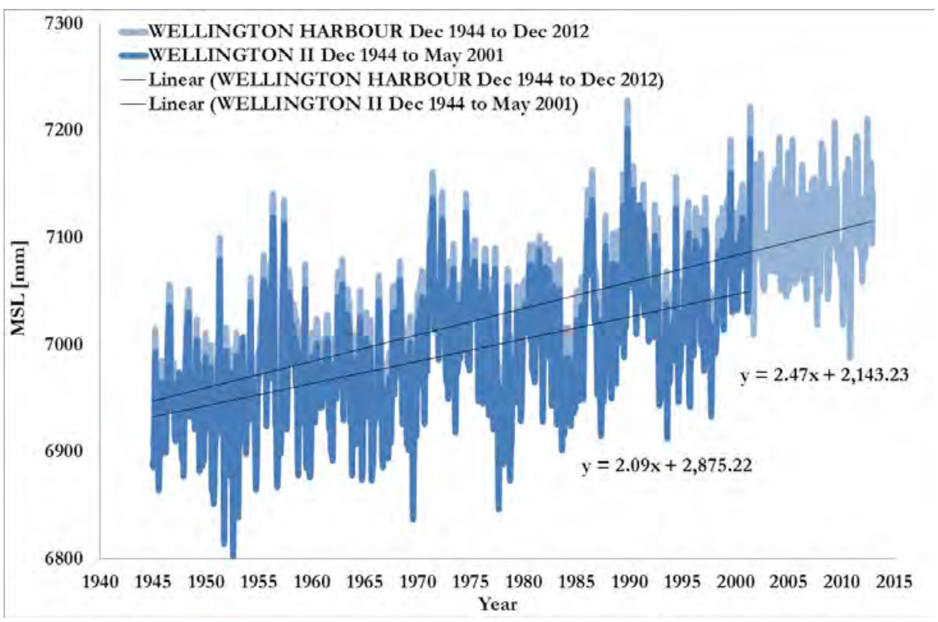


Figure 5. The land velocity (of subsidy) nearby the tide gauge of Wellington, New Zealand in a) is very close to the relative rate of rise of sea level obtained by linearly fitting the monthly averaged mean sea levels measured by the tide gauges in b).Figure a) is from [5], data analyzed in Figure b) are from [4].

however in a location subject to subsidy, with the Wellington Airport GPS dome WGTN showing a vertical velocity of -2.32 ± 0.24 mm/year over the time window 2000 to 2011 [5]. The channels and waterways so perfectly well conserved at Cloudy Bay indicate little or no rise in relative sea level over the last century.

6. Discussion

The GMSL is the result of a numerical procedure adopted to correct a nearly flat, noisy satellite altimetry signal. There is the p0sibility that the 'correction' is defined to match a few carefully selected short-term tide gauge signals (because of the local land motion and the phases of the oscillations make the GMSL rate of rise very high). But there is also the possibility that the GMSL is 'correction' product simply to comply with climate models.

With reference to the paper by Cazenave et al. [1], Eschenbach [8] provides an analysis of the model correction to the model correction of the satellite altimeter result that should represent the measured global mean sea level concluding as follows (in direct citation of [8]):

1. *"Even if the models are accurate and the corrections are real, the size doesn't rise above the noise.*
2. *Despite a claim that they used DE trended data for their calculations for their corrections, their graphic display of that data shows that all three datasets (GMSL, mass component, and mass + steric components) contain trends.*
3. *We have no assurance that 'correction', which is nothing more than the difference between observations and models, is anything more than model error.*
4. *The net effect of their procedure is to transform observational results into modelled results. Remember that when you apply their 'correction' to the average mean sea level, you get the red line showing the modelled results. So applying that same correction to the five individual datasets that make up the average mean sea level is ... well ... the word that comes to mind is meaningless. They've used a very roundabout way to get there, but at the end they are merely asserting is that the models are right and the data is wrong".*

This analysis indicates, at least to the present author, that the work of Cazenave et al. [1] provides an additional argument for disqualifying the GMSL result as a reliable measure of the effects of mass shift and thermo-steric expansion on sea levels.

7. Conclusion

What has been measured this century is a constant temperature of the oceans at a depth of 0-2000 m ranging from 60N to 60S [6], plus a globally increasing sea ice extent, with the expansion in Antarctica more than compensating the shrinking in the Arctic [7].

In addition, all the long-term tide gauges of the world of good quality and sufficient length have demonstrated the absence of traces of any acceleration [3, 13-16].

The latest average relative rate of rise of sea levels from a compilation of 170 worldwide tide gauges of record length exceeding 60 years is +0.43 mm/year (without any component of acceleration).

The satellite altimetry does not provide accurate computations of the vertical velocity of "fixed" GPS domes on land. Therefore, it is hard to believe that the satellite may provide an accurate picture of the continuously oscillating sea surface.

Rather than oscillating about a 3 mm/year slope, the GMSL should is likely be close to a flat zero mm/year slope noisy distribution.

There is no scientific reason to focus on the corrected rate of rise of the reconstructed GMSL following a model correction after a model correction.

If there is any effect of global warming, this should be detected by an increase in the relative rates of rise measured locally by the tide gauges with a consolidated and accurate procedure.

Because this is not the case, I must conclude that there is no effect of global warming on the rates of rise of sea levels.

Acknowledgments

The author wishes to acknowledge the rapid, scrupulous peer-review process and professional processing of the paper by the members of the editorial board.

References

[1] Cazenave, A., Dieng, H.-B., Meyssignac, B., Von Schuckmann, K., Decharme, B., Berthier, E.: The rate of sea-level rise. Nature Climate Change 4(5), 358-361 doi:10.1038/nclimate2159, 2014.

[2] Mörner, N.-A.: Estimating future sea level changes from past records. Global and Planetary Change 40(1-2), 49-54, doi:10.1016/S0921-8181(03)00097-3,2004.

[3] Parker, A.: Natural oscillations and trends in long-term tide gauge records from the pacific. Pattern Recogn. Phys. 1, 1-13, doi:10.5194/prp-1-1-2013, 2013.

[4] http://www.psmsl.org [visited 17/07/2014]

[5] http://www.sonel.org [visited 17/07/2014]

[6] http://www.argo.net [visited 17/07/2014]

[7] http://nsidc.org/ [visited 17/07/2014]

[8] http://wattsupwiththat.com/2014/03/28/sea-water-level-fresh-water-tilted/ [visited 17/07/2014]

[9] Mörner, N.-A.: The great sea-level humbug. There is no alarming sea level rise. 21st Century Science & Technology, winter 2010/11, 12-22, 2011. www.21stcenturysciencetech.com/Articles_2011/Winter-2010/Morner.pdf [visited 17/07/2014]

[10] Mörner, N.-A.: Sea level changes: past records and future expectations. Energy & Environment 24(3-4), 509-536, doi:10.1260/0958-305X.24.3-4.509, 2013.

[11] http://sideshow.jpl.nasa.gov/post/series.html [visited 17/07/2014]

[12] http://sealevel.colorado.edu/ [visited 17/07/2014]

[13] Parker, A., Saad Saleem, M., Lawson, M.: Sea-level trend analysis for coastal management. Ocean and Coastal Management 73, 63-81, doi:10.1016/j.ocecoaman.2012.12.005, 2013.

[14] Parker, A.: Sea level trends at locations of the United States with more than 100 years of recording. Natural Hazards 65(1), 1011-1021, doi:10.1007/s11069-012-0400-5, 2013.

[15] Parker, A.: Oscillations of sea level rise along the Atlantic coast of North America north of Cape Hatteras. Natural Hazards 65(1), 991-997, doi:10.1007/s11069-012-0354-7, 2013.

[16] Parker, A.: A realistic lower bound to the 2050 sea-level rise. International Journal of Sea and Climate Systems 4(3), 197-211, doi:10.1260/1759-3131.4.3.197, 2013.

[17] Mazzotti, S., Jones, C., and Thomson, R.: Relative and absolute sea level rise in western Canada and north western United States from a combined tide gauge-GPS analysis. Journal of Geophysical Research: Oceans 113, C11, doi:10.1029/2008JC004835, 2008.

[18] http://www.nap.edu/download.php?record_id=13389 [visited 17/07/2014]

[19] http://www.sonel.org/stations/cgps/surv_update.html [visited 17/07/2014]

[20] http://www.john-daly.com/deadisle/ [visited 17/07/2014]

[21] Ross, J.C.: A Voyage of Discovery and Research in the Southern and Antarctic Regions, During the Years 1839-43. John Murray, London, 1847.

[22] Shortt, J.: Notes on the Possible Oscillation of Levels of Land and Sea in Tasmania During Recent Years. Royal Society of Tasmania papers, State Library of Tasmania, Hobart, 1889.

[23] http://wattsupwiththat.com/2012/04/26/sea-level-surprise-in-new-zealand/ [visited 17/07/2014]

[24] Skinner, W. H.: Ancient Maori canals. Marlborough, N.Z. Journal of the Polynesian Society 21(3), 105-108, 1912.

[25] Menard, G.: Satellite-based altimetry reveals physical ocean. MEDIAS Newsletter 12, 9-17, 2000.