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Assessment of 20th century sea level rise in New Zealand including measurement inaccuracy

Albert Parker
Rmit University, Bundoora Vic, (AUSTRALIA)
E-mail: albert.parker@rmit.edu.au

ABSTRACT

The relative rate of rise of sea level is traditionally computed by linear fitting of the data collected over a time span long enough without gaps and measurement issues. This procedure returns on average small rates of rise and zero time rates of change of these velocities. This is the best available measure of the effects of global warming on sea levels. The use of GPS to infer the vertical velocity of the tide gauge introduce significant inaccuracies, and even larger inaccuracies are provided by computations linked to satellite altimetry or proxy data. There is no reason to search for alternative methods simply because the climate models predicted different trends.

NEW ZEALAND 20TH CENTURY SEA LEVEL RISE

The results of the analyses presented in the paper[1] are flawed by a misinterpretation of the limitations of the different techniques used to compute the velocity ofsea level rise relative to the tide gauge and the absolute vertical velocity of the tide gauge.

The authors also wrongly diminishthe value of the vertical land motions from GPS in favour of the "*advanced*" altimeter-gauge and geological vertical rates that are claimed to be better only because their flaws are less knownas their use is very limited.

Their conclusion TABLE 1 presents the rates of "*Relative Sea Level Change at Tide Gauges and Salt-Marsh Sites Derived From (i) Geological, GPS, and Advanced Altimeter-Gauge (ALT-TGADV) Vertical Land Motion Estimates at Tide Gauges Sites and From (ii) Geological and GPS Vertical Land Motion Estimates at Salt-Marsh Sites*" from the latest and other prior studies by the same authors[2-5].The table, thatactually presents "*absolute*" and not "*relative*" rates of rise, proposes inaccurate estimations of the relative rate of rise of sea levels at the tide gauges plus inaccurate estimations of the absolute velocity of the tide gauge.

The computation of the relative rate of rise of sea levels is generally not supported by tide gauges of sufficient quality and record length to infer a reliable relative rate of rise trend. The area has important quasi-20 and quasi-60 year's multi-decadal oscillations[6,7]. Without 60-70 years of data with only few missing points recorded by the same tide gauge,and in the absence of significant biases and errors, the computation of the relative rate of rise is pointless[6,7], but the authors neglect this fact.

None of the proposed locations has a tide gauge spanning the years claimed and only four tide gauges have acceptable length and completeness, AUCKLAND II, WELLINGTON HARBOUR, LYTTELTON II and DUNEDIN II. The first three are those mentioned in the surveys of PSMSL[9] and National Oceanic and Atmospheric Administration (NOAA)[10].

- Dunedin II has time span of data 112 years but completeness % 72[8];
- Auckland II, has a time span of data of 98 years and completeness % 96[8];
- Wellington Harbour has a time span of data of 68 years and completeness of 94%[8];
- Lyttelton II has a time span of data of 77 years and completeness of 89% [8].

Tide gauges of short, incomplete records do not permit one to infer any reliable trend, and the same applies to records obtained by infilling, extension or reconstruction or puzzles of non-homogeneous information from multiple sources.

- WHANGAREI HARBOURhas time span of data 1964 – 2012 and completeness only 51%. Only a few months are recorded about 1965, and the measurements then restarted only about 1985. 27 years of recordingdoes not permit one to infer a reliable trend.
- BLUFF (SOUTHLAND HARBOUR) has a time span of data 1917 – 2012 but completeness only 27%. With about 3 missed months for every 1 month recorded, there is no opportunity to compute a realistic trend.

More likely relative rates of rise in these tide gauges are:

- Auckland II, + 1.26 ± 0.13 mm/year;
- Wellington Harbour, +2.43 ± 0.18 mm/year;
- Lyttelton II, +2.35 ± 0.19 mm/year;
- Dunedin II, +1.23 ± 0.20 mm/year.

However, the standard error above is a statistical error and does not account for the effects the record length and the completeness of the record have on the result of the computation, and does not account for the errors and biases that every measurement may have, including those from tide gauges.

To understand the effect of the time span of data and completeness on the relative rate of rise computed by linear fitting, the analysis of the nearby composite Sydney tide gauge, obtained coupling the two tide gauges of sydney, fort denison and sydney, fort denison ii of successful overlapping of 80 years without any appreciable difference, may certainly help. This is the longest tide gauge of the Southern Hemisphere spanning the time window 1886 to 2012 with 100% completeness. Figure 1 presents the measured monthly mean sea levels, plus their fitting with a line and sinus. The periodicities of the oscillations have remarkable quasi-20 and quasi-60 years multi-decadal periodicities detected. For sake of simplicity, the equivalent record length is defined for the tide gauges of New Zealand by multiplying the time span of data by the completeness %. This is equivalent to assume that all the gaps are located at the beginning of the record. The influence of the actual gaps may be different. TABLE 1 presents the different rates of rise computed by using same equivalent record length of Dunedin II, Auckland II, Wellington Harbour, Lyttelton II, Whangarei Harbour and Bluff (Southland Harbour) in the analysis of the composite tide gauge of Sydney. The rates of rise are computed by using both the measured data and their

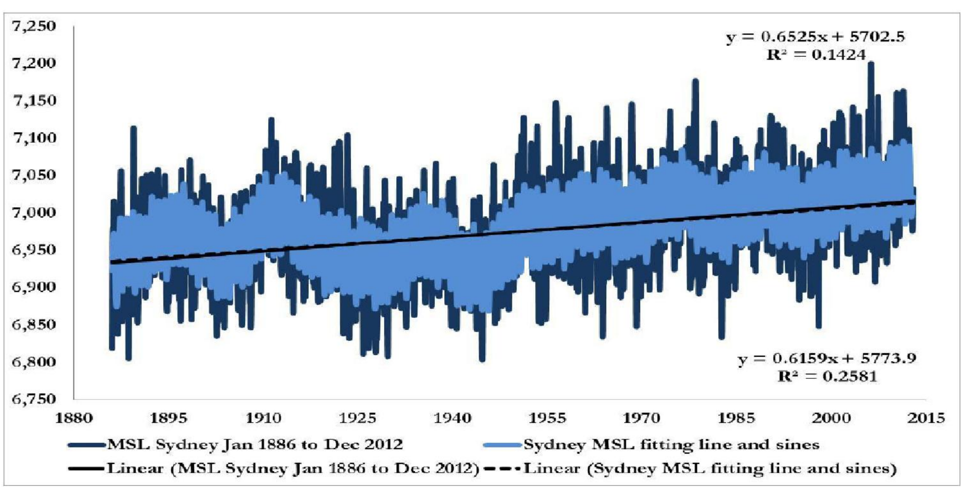

Figure 1 : Monthly average mean sea level measured in Sydney, Fort Denison and their approximation with a line and sines.

TABLE 1 : Different rates of rise computed by using same equivalent record length of Dunedin II, Auckland II, Wellington Harbour, Lyttelton II, WHANGAREI HARBOUR and BLUFF (SOUTHLAND HARBOUR) in the analysis of the composite tide gauge of Sydney

tide gauge	time span, years	Comple-teness %	Equi-valent record length, years	SLR Sydney measured variable record length, mm/year	delta, mm/year	SLR SydneyLine and sines fittingvariable record length, mm/year	delta, mm/year
Sydney composite	127	100	127	0.65	0.00	0.62	0.00
Dunedin II	112	72	81	1.08	0.43	1.07	0.46
Auckland II	98	96	94	1.03	0.38	1.08	0.46
Wellington Harbour	68	94	64	0.72	0.07	0.73	0.12
Lyttelton II	77	89	69	0.97	0.32	0.97	0.36
WHANGAREI HARBOUR	49	51	25	1.11	0.45	1.17	0.55
BLUFF SOUTHLAND HARBOUR	96	27	26	1.30	0.65	1.14	0.52

fitting with a line and sines.

TABLE 1 indicates that with equivalent record length of 25 to 94 years, average 60 years, the apparent rates of rise may differ of 0.07 to 0.65 mm/year, average 0.38 mm/year, or even 0.12 to 0.55 mm/year, average 0.41 mm/year, simply because there are multi-decadal, decadal and inter-annual oscillations.

The computation of the GPS absolute velocity of the tide gauges actually uses for the tide gauge velocities the velocities of the nearby GPSdomes, with computations done from only one provider of the many that usually return significantly different estimations for the same GPS domes.

The error in assessing the vertical velocity of the GPS dome is admittedly still much larger of ± 1 mm/year[11]: "*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 an accuracy better than 1 mm/yr is still a very challenging problem in Geodesy today*".

Computations by different groups for the same GPS domes differ considerably one from the other as for example Tofino (UCLU), BC, Canada that is + 4.10 ± 0.14 mm/year in[12] and +2.54 ± 0.30 mm/year in[13]. The difference in between +4.10 and +2.54 is much larger than the standard error.

The authorsclaim impossible accuracies and ignore the fact that the relative motion of the tide gauge vs. the GPS dome is unassessed. The error in the absolute velocity at the tide gauge is significantly larger than what is claimed.

The vertical land motion of the GPS domes nearby the four tide gauges above indicates very likely significant subsidence at the tide gauge[13]:

- nearby Dunedin II:OUS2 -1.479 ± 0.722 mm/year; DUNT -0.517 ± 0.636 mm/year& DUND -1.575 ± 0.621 mm/year;
- nearby Auckland II: AUCK -0.243 ± 0.376 mm/year;
- nearby Wellington Harbour:WGTN -2.937 ± 0.390 mm/year&WGTT -3.642 ± 0.415 mm/year;
- nearbyLyttelton II: LYTT -0.499 ± 0.468 mm/year.

The error in assessing the absolute velocity of the tide gauge then includes the error of a survey of the relative position tide gauge to GPS dome that is not zero if the survey is omitted, and it is much larger than the error in assessing the vertical velocity of a nearby GPS dome.

Considering the error in estimating a function C sum or difference of two measurements A and B is the sum of the two errors, as it is not clear in[1], the most likely absolute rates of rise are therefore the following (the values are compared to those of the GPS and ALT-TG ADV values of TABLE 1):

- Dunedin II, + 0.04 ± (0.86+δ)mm/year vs. 0.61 ± 0.19 & 0.59 ± 0.16 (GPS) and 1.46 ± 0.36 & 1.51 ± 0.36 mm/year (ALT-TG ADV) of TABLE 1 for Dunedin;
- Auckland II, +1.02 ± (0.51+δ) mm/year vs. 1.44 ± 0.25 & 1.25 ± 0.23 mm/year (GPS) and 1.54 ± 0.34 & 1.44 ± 0.40 mm/year (ALT-

TG ADV) of TABLE 1 for Auckland;

- Wellington Harbour, -0.86 ± (0.58+δ) mm/year vs."0.24 ± 0.18 & "0.12 ± 0.17 mm/year (GPS) and 1.28 ± 0.33 & 1.38 ± 0.34 mm/year (ALT-TGADV) of TABLE 1 for Wellington;
- Lyttelton II, +1.85 ± (0.66+δ) mm/year vs. +1.72 ± 0.34 & +1.62 ± 0.32 mm/year (GPS) and 1.56 ± 0.34 & 1.41 ± 0.34mm/year (ALT-TG ADV) of TABLE 1 for Lyttelton.

In the expression above, δ accounts for the errors in assessing relative and tide gauge velocities additional to the statistical error of the fittings, and it is expected to be much larger than the module of the trends.

The rates of rises of TABLE 1 of[1] are therefore generally overrated, while the errors are strongly underestimated. Even with δ=0,the errors above are two to five times the values proposed in TABLE 1.

In case of the ALT-TG ADV computations, returning about same high rates in all the locations, the differences in the absolute rates of rise are even larger than the GPS.

Even if the authors propose the satellite altimeter estimation as better quality resultfor the absolute velocity of the tide gauges than the GPS result, as a matter of fact, while the GPS is a global solution providing critical capabilities to military, civil and commercial users around the world, the satellite altimetry is a questionable technique used by a restricted circle of "*climate scientists*" with no independent validation claiming impossible accuracies[14-16].

Despite the claimed ability to measure the instantaneous position of the continuously moving surface of the ocean waters to derive a time rate of change of the volume at about 3.2 ± 0.4 mm/year since the 1990s, this number actually originates frommany subjective corrections and it is more a computation than a measurement [14-16].

The actual measurement had zero slope of the trend line[14-16]before corrections, and consistently with the actual measurements the latest trend table of PSMSL[9] returns an average relative rate of rise of sea levels of +0.40 ± 0.19 mm/year when only the 170 tide gauges having more than 60 years of data are considered. Being most of these tide gauges located in areas of known subsidence rather than isostasy, on average the relative rate of rise is small, and the absolute rate of rise is therefore even smaller.

Finally, the authors suggest the proxy geological estimation of the tide gauge velocity may also have better quality result than the GPS,statement that is even harder to believe than the already hard-to-believe satellite altimeter claim, being proxy measurements very well-known to be much less reliable of the instrumental measurements. The proposed salt-marsh proxy estimation of the rates of rise may not be better quality than the instrumental records.

CONCLUSION

If the tide gauges time series suggest relative rates of rise nearly constant and small, and theGPS time series suggest the presence more often of subsidence rather than isostasysuggesting an even smaller rise, there is no reason to search for alternative methods simply because the climate models predicted different trends.

The error estimating the relative rate of rise is small and close to the statistical standard error of the linear fitting estimation only providing enough data are available without gaps and without any measurement issues. The error in estimating the vertical velocity of the tide gauge is definitively an order of magnitude larger than the statistical standard error of the linear fitting estimation. The error in estimating the absolute rate of rise is much larger than the module of the rate of rise or fall.

The satellite altimetry and the proxy are not competitive with the above technique to assess the absolute rate of rise.

The best option to assess the effects of global warming on the rate of rise of sea level is to analyse the relative sea level record of individual tide gauges of good quality and length. If they are on average acceleration free, then the effects of global warming are negligible and smaller than the measurement error.

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