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Discussion of tide gauge location and the measurement of global sea level rise

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ABSTRACT

Many works still misrepresent the sea level behaviour by applying statistics to different populations of tide gauges having variable length and completeness, experiencing more or less intense subsidence or uplift, and having different phases, amplitudes and periodicities of the multi-decadal and inter-annual oscillations, to support claims of sea levels rising in response to the anthropogenic carbon dioxide emission. A recent paper has suggested some inconsistency in between actual tide gauge measurements and the computed global sea level rise despite neglectingthe vertical tide gauge motion and the minimum length and quality requirements of the tide gauge records. Commenting this paper it is shown once more that appropriate mathematic applied to suitable data sets permit to conclude that:1) all the tide gauges of the world are experiencing oscillations and not accelerations of the relative sea levels over the last two decades;2) the average relative rate of rise of the sea level in the tide gauges of enough quality and length is less than 0.25 mm/year; 3) this relative rate of rise is mostly the result of subsidence more than uplift at the tide gauge; 4) the global mean sea level rated 3.2 mm/year by climate model-like corrections of flat and noisy satellite altimeter signals has same lack of value than all the other never validated climate model prediction.

THE OSCILLATING WORLDWIDE AVERAGE TIDE GAUGE SIGNAL

The author of[11] attempt to find similarities in between an experimental result, the relative sea level rate of rise measured by the tide gauges included in Permanent Service for Mean Sea Level (PSMSL) data base[12], and a result that is only a computation following the same logic of climate models, the nominally satellite altimeter inferred absolute global mean sea level. The conclusion of their statistical analysis is that the location of the tide gauges is not "*random*" with the "*randomness*" actually the similarity in between the measurements or the result of climate models for two different quantities evaluated over different time windows.

The authors of[11] as many others should realize first that the world tide gauges measure the local relative sea level that is oscillating with many periodicities. Because of the oscillatory behaviour, with important periodicities up to a quasi-60 years, more than 60 years of data recorded without major gaps and in absence of perturbing events are needed to infer the local rate of rise of the relative sea level and the time rate of change of this parameter representing the sea level acceleration[1,2].

A tide gauge then does not measure the absolute sea level but only the value relative to the tide gauge position. Because of the general subsidence or uplift for an area, and the additional subsidence at the tide gauge, the vertical velocity of the tide gauge may be in module even larger than the module of the relative rate of rise of sea levels[3,4]. GPS -based computations of the absolute vertical velocity GPS domes close to the tide gauge still suffer of inaccuracies of ±1-2 mm/year much larger than the module of the worldwide average relative rate of rise[3,4]. Therefore, acceleration criteria applied to the relative sea level records are superior vs. the computations of absolute sea levels to infer the effects of the carbon dioxide emission.

Traditonally the relative rates of rise are computed through the linear fitting:

$$\mathbf{y}^{+}(\mathbf{x}) = \left(\mathbf{A}^{+} + \mathbf{SLR}^{+} \cdot \mathbf{x}\right) \qquad (1)$$

applied to a distribution of measured points $\{x_i, y_i\}$ i=1, …, n where y_i is the monthly average relative mean sea level at the time x_i. SLR^+ is the relative rate of rise, A^+ the intercept and y^+ the fitted value at the time x. The residual:

$$\boldsymbol{\varepsilon}_j = \left(\mathbf{A}^{+} + \mathbf{SLR}^{+} \cdot \mathbf{x}_j\right) - \mathbf{y}_j \qquad (2)$$

is the error that includes mostly periodical oscillations, noise, fitting inaccuracies or eventually the influence of global warming (if detectable) that would in case produce a departure from the linear trend.

The relative rate $SLR_{j,k}$ is computed over the time window $(x_k - x_j)$ by linearly fitting the data $\{x_i, y_i\}$ i=j, …, k through the formula:

$$\mathbf{SLR}_{j,k} = \frac{\sum_{i=j}^{k} (\mathbf{x}_i - \overline{\mathbf{x}}) \cdot (\mathbf{y}_i - \overline{\mathbf{y}})}{\sum_{i=j}^{k} (\mathbf{x}_i - \overline{\mathbf{x}})^2} \qquad (3)$$

where $\overline{x}$ and $\overline{y}$ are the sample means. Usually j=1 is the oldest record, and k=n is the latest record, and $SLR_{1,n}$ is the latest estimation of the relative rate of rise. Equation (2) with j variable and k=n permit to compute the present velocities simulating the effect of tide gauge recording started at different times x_j.

PSMSL[5] proposes in their latest "*Table of Relative Mean Sea Level Secular Trends derived from PSMSLRLR Data*" update 14-Feb-2014 the relative rates of rise computed for 2133 tide gauges of variable record length (maximum 183, minimum 21, average 56.5 years) with the more recent, shortest tide gauges collected mostly in areas of subsidence and geographical coverage still non uniform.

The use in different times of different populations of tide gauges of different length, different rates of subsidence or uplift, and different parameters of the oscillations is what permits the false claim the sea level have been accelerating over the last decades when actually all the long term tide gauges of the world have been on average acceleration free.

The average rate of rise of the 2133 tide gauges is 1.04±0.45 mm/year. However, this number has very little significance. By using the relative rates of rises computed by linear fitting of all the tide gauge data in the 170 tide gauges of PSMSL having length more than 60 years at the present time[5], the average relative sea level velocity of the worldwide tide gauges of enough length to infer a trend is better assessed at 0.25±0.19 mm/year[3,4]. The additional information to consider is then that these 170 tide gauges are on average acceleration free and on average subjected to subsidence more than uplift.

By using the GPS velocities of nearby GPS domes computed by JPL[6] or SONEL[7] applying equation (1) to the GPS position time series, unfortunately requesting many realignments, the worldwide average tide gauge is more likely subject to subsidence rather than uplift, so the worldwide average absolute rate of rise is very likely even smaller[3,4].

The rates of rise of the long term tide gauges may increase or decrease from one update to other suggesting local positive or negative accelerations. However, this is simply the result of the oscillations and on average the changes are negligible[3,4]. However, rather than computing inaccurate absolute sea level rates of rise it makes more sense to compute the more reliable relative sea level accelerations. If the relative rates of rise do not increase, why there should be a positive global mean sea level rate of rise? Mass addition by melting of ice and thermal expansion by warming of waters at the rates computed by the climate models should translate in significant accelerations of the rate of rise of sea levels. If this does not occur, it means that the computed effects of ice melting and thermal expansion are overrated.

Equatin (2) with j=1 and k variable permit to compute the velocities at any time x_k to estimate the acceleration:

$$SLA_k = \frac{SLR_{1,k} - SLR_{1,k-1}}{x_k - x_{k-1}} \quad (4)$$

If we want to study the changes in the rate of rise of sea levels over the satellite altimeter era, we do not have to consider all the 170 tide gauges of PSMSL having length more than 60 years at the present time[5], but only those that were already satisfying this requirement 20 years ago. The tide gauges of PSMSL having length more than 80 years at the present time are 100, and the average rate of rise for them is 0.24±0.15 mm/year. For these 100 tide gauges, the rate of rise has been moving up and down over the last 20 years without any sign of globally positive or negative accelerations.

The relative sea level acceleration oscillates and it may be positive or negative simply as a result of the sea level oscillations rather than global warming or cooling. To better clarify, we may consider a fitting with a line and sines having the expression:

$$y^*(x) = \left(A^* + SLR^* \cdot x\right) + \sum_{i=1}^{n}\left[A_i \cdot \sin\left(\pi \cdot \frac{x - x_{c,i}}{w_i}\right)\right] \quad (5)$$

where y^* is the fitted relative sea level and the time x, SLR^* is the relative rate of rise and A^* is the intercept, while A_i, $x_{c,i}$, w_i are the amplitudes, phases and periods of the oscillations. The residual

$$\varepsilon_j^* = \left(A^* + SLR^* \cdot x_j\right) + \sum_{i=1}^{n}\left[A_i \cdot \sin\left(\pi \cdot \frac{x_j - x_{c,i}}{w_i}\right)\right] - y_j \quad (6)$$

is now the error that includes noise, fitting inaccuracies, periodic oscillations not exactly sinusoidal, periodic oscillations that are not included or eventually the influence of global warming (if detectable) that would produce a departure from the linear trend.

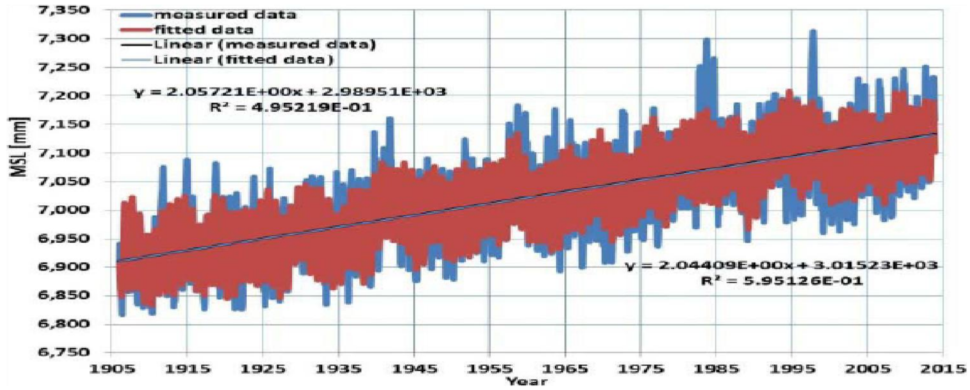
The study of the residuals of equation (6) is very interesting demonstrating that what is represented as sea level acceleration (or deceleration) has been so far actually only oscillation. Similar conclusion is obtained by comparing the time series $SLR_{1,k}(x_k)$ or $SLA_k(x_k)$ computed from the measured data $\{x_i, y_i\}$ i=1, …, k or the fitted data $\{x_i, y^*_i\}$ i=1, …, k where $y^*_i = y^*(x_i)$ from equation (5) that show very close behaviour of measured and fitted distributions. The case of San Diego is shown as an example in Figure1 but about same results is obtained by considering all the others 100long term tide gauges.

$SLR_{1,n}$ from the measured data, i.e. the latest SLR^+, is2.057 mm/year. The $SLR_{1,n}$ from thefitted data is 2.044 mm/year. The value of SLR*, equation (5), is 1.956 mm/year. Over the time span of the satellite altimeter computation, the relative rate of rise of sea level has been increasing in San Diego from 1993 to 1999 and it is decreasing since 1999. This is not the result of global warming or global cooling but only of the phases, amplitudes and periods of the oscillations and the record length.

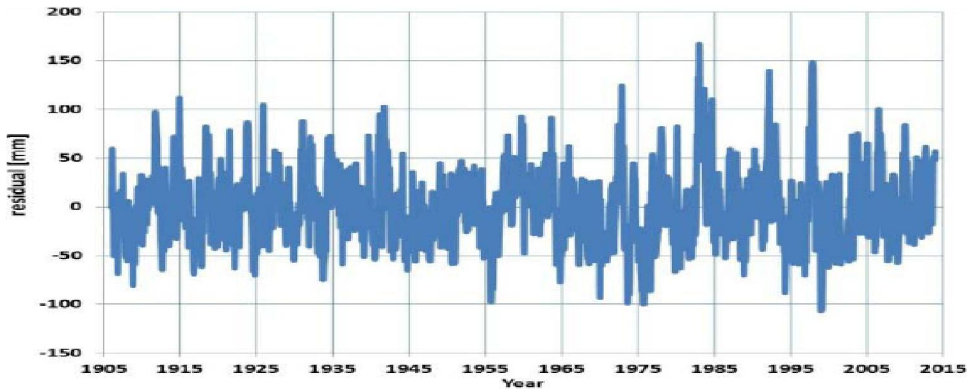
Short records return completely unrealistic rates of rise because of the oscillations. Depending on the local phases, amplitudes and periods of the oscillations the apparent short term rates of rise may be much larger or much smaller than the legitimate. San Diego appears to be a "*cold spot of negative accelerations*" with a rate of rise over the time window 1993 to present much smaller than the legitimate. Being oscillations up somewhere usually associate with oscillations down somewhere else, there are obviously also "*hot spots of positive accelerations*" equally misinterpreted. Unfortunately the most part of the politically correct analyses of sea levels only discuss hot rather than cold spots of accelerations misinterpreting natural oscillations.

The figure also presents the absolute velocity of the GPS domes PLO3 and PLO5 nearby the tide gauge (from[6,7]). The determination of the vertical velocity of the GPS dome is quite difficult and necessitates many breakpoints and realignment of the signal. Different analyses still return significantly different results. The relative position of the tide gauge vs. the nearby GPS dome is unassessed so the vertical velocity of the tide gauge is not known with accuracy. However, the relative sea level rate of rise is very likely close to the rate of subsidence and the absolute rate of rise of sea levels is with 95% certainty zero.

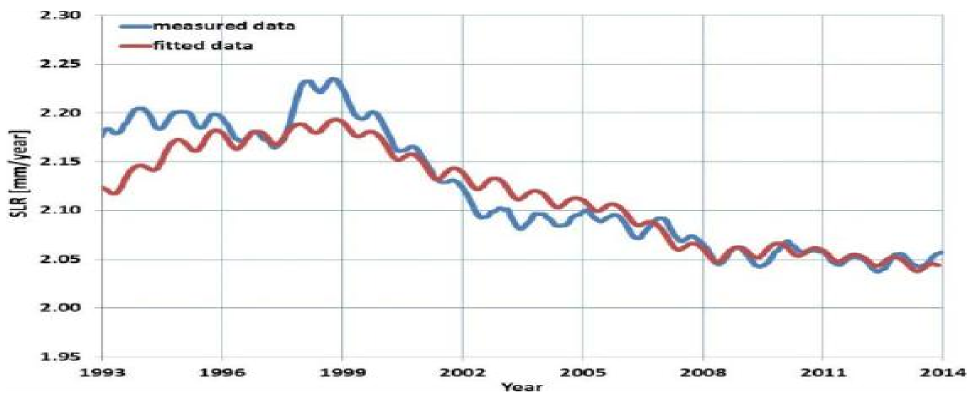
Satellite altimeter based computations of the Global Mean Sea Level (GMSL) have nothing to do with experiments and have same reliability and accuracy of the many other climate models failing any possible validation since ever[3,4]. The GMSL absolute rate of rise of 3.2 mm/year is incompatible with the +0.25 mm/year relative rate of rise of the average worldwide tide gauge that is free of acceleration over the same time window 1993 to present of the GMSL computation.


measured data
fitted data
Linear (measured data)
Linear (fitted data)
y = 2.05721E+00x + 2.98951E+03
R² = 4.95219E-01
y = 2.04409E+00x + 3.01523E+03
R² = 5.95126E-01
MSL [mm]
Year

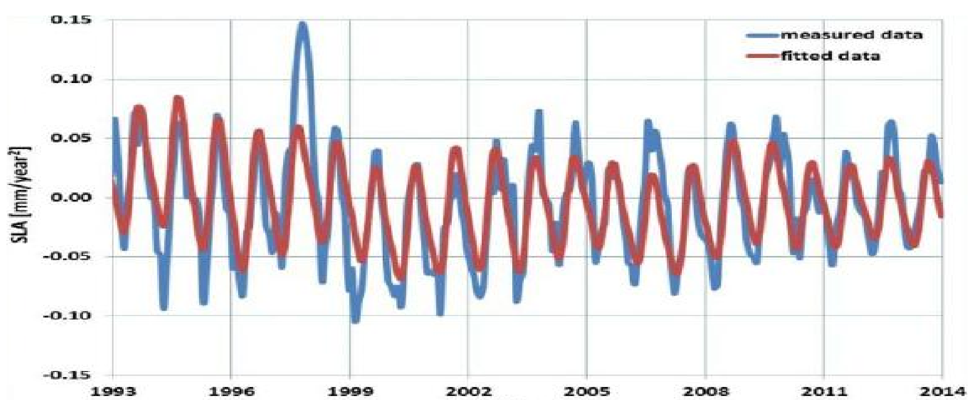
a


residual [mm]
Year

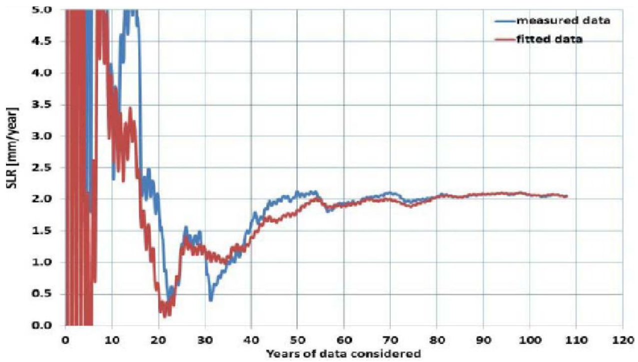
b


measured data
fitted data
SLR [mm/year]
Year

c

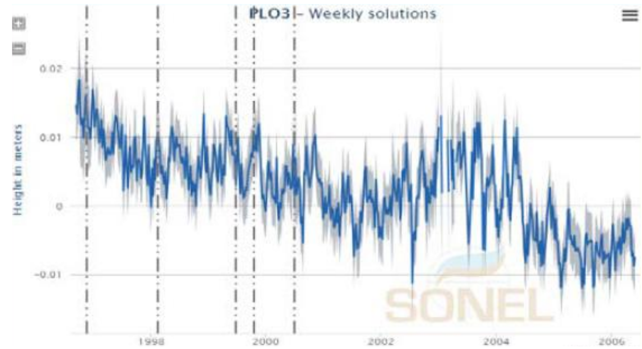

measured data
fitted data
SLA [mm/year²]
Year

d



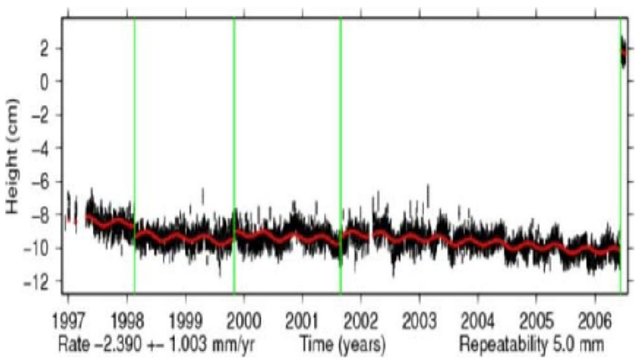
e

↓*PLO3*



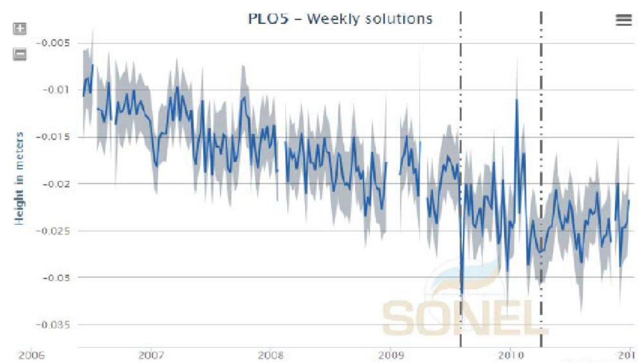
f

↑*SONELvelocity -1.65±0.41 mm/year*



g

↑*JPL velocity -2.390±1.003 mm/year*



h

↑*SONELvelocity -3.23±0.17 mm/year*

Figure 1 : a : Measured relative sea levels in San Diego and values computed with a line and sines fitting; b : residual of this fitting; c, d : SLR and SLA computed at different times from the measured and fitted MSL; e : present SLRcomputed by using different record lengths; f, g, h : absolute velocity of the GPS domesPLO3 and PLO5 nearby the tide gauge. The relative rate of rise of sea level has been increasing in San Diego from 1993 to 1999 and it is decreasing since 1999. This is not the result of global warming or global cooling but only of the phases, amplitudes and periods of the oscillations.Short records return completely unrealistic rates of rise because of the oscillations. The determination of the vertical velocity of the GPS dome is quite difficult and necessitates many breakpoints and realignment of the signal. Different analyses still return significantly different results. The relative position of the tide gauge vs. the nearby GPS dome is unassessed so the vertical velocity of the tide gauge is not known with accuracy. However, the relative sea level rate of rise in this case is very likely close to the rate of subsidence and the absolute rate of rise of sea levels is therefore very likely zero.

Additionally, the GPS monitoring suggests that the worldwide average tide gauge is more likely subject to subsidence than uplift. If there is no acceleration in the worldwide tide gauges of the world of enough length and quality since 1993, it is impossible that the GMSL is not only +3.2 mm/year but also a number different from zero.

The only graph of the raw satellite trends in the literature is the one proposed in[8]. This graph does not show any sea level rise. The fact that the satellite altimeter signal does not show any slope is implicitly admitted in[9], where the authors agreed that the original satellite data didn't show a sea level rise trend, but they objected that their adjusted data – i.e. the satellite data after correction to match the climate modelling evidence - was the only result to consider. If the raw measured data were not reliable and there was the need of a series of adjustments to make the trend "*more realistic*", then the new result is a computation and not a measurement. The reply[10] correctly suggests that the unadjusted satellite altimeter trends of roughly zero slope is the actual instrumental result. The GMSL is growing proportional to the mass addition from melting of ices and the thermal expansion from increased ocean temperatures that have never been measured but only presumed on the basis of flawed theories.

CONCLUSIONS

The authors of[11] claim: "Using individual tide gauges obtained from the Permanent Service for Mean Sea Level during 1807-2010, we show that tide gauge locations in 2000 were independent of SLR as measured by satellite altimetry. Therefore these tide gauges constitute a quasi-random sample, and inferences about global SLR obtained from them are unbiased."

The authorsof[11] then say: "Using recently developed methods for non-stationary time series, we find that sea levels rose in 7 % of tide gauge locations and fell in 4 %. The global mean increase is 0.39-1.03 mm/year. However, the mean increase for locations where sea levels are rising is 3.55-4.42 mm/year."

By considering only tide gauges of length above 60 years and obviously same population of tide gauges in every year the average value of relative sea level rise would have been much smaller, while the locations where the sea levels are rising 3.55-4.42 mm/year would have been not that many.

The conclusion of the authors of[11] is that: "These findings are much lower than estimates of global sea level (2.2 mm/year) reported in the literature and adopted by IPCC (2014), and which make widespread use of imputed data for locations which do not have tide gauges"That is correct. However, it could have been a much stronger"the IPCC estimate of global mean sea level suffer from changing the demography of the population adding more tide gauges where subsidence or the oscillatory behaviour for the short time window suggest unrealistically high rates of rise, basically cherry-picking the information".

Finally the authors of[11] conclude: "We show that although tide gauge locations in 2000 are uncorrelated with SLR, the global diffusion of tide gauges during the 20th century was negatively correlated with SLR. This phenomenon induces positive imputation bias in estimates of global mean sea levels because tide gauges installed in the 19th century happened to be in locations where sea levels happened to be rising." Going straight to the point, the author should have better stated, possibly further refining their technique including minimum length requirement, that "there is no sign in what is measured by the tide gauges that the relative sea level accelerated because of global warming" and"the climate model computations of absolute global mean sea levels are wrong as all the other climate model computations are".

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