ABSTRACT

It is shown that the local tide gauges of the Black Sea similarly to the other worldwide tide gauges of any other area do not support alarmist messages. The Black Sea relative sea level rise is about same of land subsidence without any acceleration.

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KEYWORDS

Sea level; Measurements; Computations; Tide gauges; GPS; Satellite altimeter.

THE BLACK SEA RELATIVE SEA LEVEL RISE

The authors of[1] motivate their work claiming the vulnerability of beaches to climate change induced sea level rise uncritically assuming sea levels are rising faster because of the anthropogenic carbon dioxide emission worldwide. The authors then assess the erosion risk of the Black Sea beaches with estimations of the sea level rise-induced retreat of 11 scenarios of sea level rise up to a 2 metres sea level rise. The authors of[1] neglect the fact that the worldwide average tide gauge shows oscillations about a trend of relative sea level rate of rise of +0.24 mm/year with no sign of carbon dioxide induced acceleration[2-8] and the fact that the area is subject to generalised subsidence particularly relevant in some areas (for example Georgia wetlands) where anthropogenic factors completely unrelated to the carbon dioxide emission may also play a significant role[12-16]. The Black Sea beaches may suffer from subsidence as it is claimed in past works[11-13].

The global view

The acceleration free long term tide gauge results show that the relative sea levels are only oscillating worldwide and this relative rate of rise is mostly due to subsidence. The small average rate of rise of the acceleration free worldwide average tide gauge of enough quality and length to infer a realistic trend is shown in[2-8]. Results of the analysis of[6-8] are summarised below. The Permanent Service for Mean Sea Level (PSMSL) data base includes many world-wide tide gauge records of erratic quality and length located in areas of more or less intense subsidence or uplift, tidal range, and characteristics of the sea level oscillations. These tide gauges have consequently variable relative sea level velocity and acceleration. 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[2-4].
The tide gauge does not measure the absolute sea level but only the value relative to the tide gauge position. Because of subsidence or uplift, 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\(^5\)\(^6\), but GPS-based computations of the absolute vertical velocity GPS domes close to the tide gauge suffer of inaccuracies of ±1-2 mm/year that are much larger than the module of the worldwide average relative rate of rise\(^5\)\(^6\). The tide gauges are far from the inland GPS domes, and their relative position is unassessed. This translates in huge inaccuracies, i.e. errors much larger than the trend modules. Furthermore, tide gauges installations as other coastal installation may suffer of subsidence even in subsidence free areas for compaction and erosion and other very well-known phenomena.

PSMSL\(^9\) proposes in their most recent “Table of Relative Mean Sea Level Secular Trends derived from PSMSL RLR Data” update 14-Feb-2014 the relative rates of rise computed for 571 tide gauges of uneven record length (maximum 183, minimum 21, average 56.5 years) and erratic completeness with the more recent, shortest tide gauges collected mostly in areas of subsidence and geographical coverage still strongly non uniform. The average rate of rise of the 571 tide gauges is 1.04±0.45 mm/year. However, this number is meaningless.

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. 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 is 0.25±0.19 mm/year\(^5\)\(^8\). These 170 tide gauges are on average acceleration free.

By using the GPS velocities of nearby GPS domes computed by JPL\(^10\) or SONEL\(^11\), the worldwide average tide gauge is more likely subject to subsidence rather than uplift. The JPL and SONEL result is relatively non accurate as it is affected by errors of ±1-2 mm/year that are much larger than the average relative sea level trend module. The JPL and SONEL result then only refers to inland GPS domes and not the coastal tide gauges that may suffer of more subsidence because of compaction or other localised phenomena, as indicated for example by the levelling of the Hong Kong tide gauges built on reclaimed land vs. the Hong Kong datum, that in the description by JPL and SONEL is also subject to vertical velocity. The worldwide average absolute rate of rise of sea levels is therefore very likely even smaller than the +0.25 mm/year\(^5\)\(^8\).

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\(^2\)\(^4\),\(^5\)\(^8\). If we want to study the changes in the rate of rise of sea levels over the satellite altimeter era, we do have to consider only the tide gauges that were already satisfying the minimum 60 years length 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\(^8\) and a rate of rise that has been moving up and down over the last 20 years without any sign of globally positive or negative accelerations\(^5\)\(^6\)\(^8\).

If the relative rates of rise from the worldwide tide gauges do not accelerate, there is no reason to compute absolute velocities by using very poor estimations of the vertical land velocity at the tide gauge to conclude that the mass addition and the thermal expansion effects have been negligible over the time window. If the ice caps could have been melting at an increased rate and the ocean waters could have been expanding warming at a faster rate because of the increasing heat uptake, then the relative rates of rise would have been all or at least mostly accelerating and this is not the case.

The local view

For the specific of the Black Sea, the area is
very well known to be subject to unequal subsid-ence, with rates that in some areas (for example Poti and Batumi in Georgia) are huge and other areas as for example Burgas and Varna in Bulgaria that are relatively stable\cite{12-16}. One thing to consider is the tectonic-isostatic factor\cite{12-16}, another is the stability of the point where the tide gauge is located with compaction playing a major role. Other phenomena are also important. For example Georgia low lands are well known to be prone to subsidence, which is exacerbated by human activity, such as drainage of peatland and river impoundment and obviously oil drilling. The subsidence rate of the region varies from 2 to 6 mm/year\cite{15}. Poti and Batumi are very well known subsiding cities facing inundations by the sea already without any global-warming induced sea level rise.

The tide gauges included in the complete PSMSL database are more than the 571 tide gauges of the survey\cite{9}. The Black Sea tide gauges in this extended data bases include BOURGAS, VARNA, CONSTANTZA, SEVASTOPOL, TUAPSE, POTI, BATUMI (that is quality control flagged), TRABZON II, IĞNEADA and AMASRA. BOURGAS, VARNA and CONSTANTZA are not updated since the mid-1990, have record lengths of 50-58 years, less than the minimum to infer a reliable trend, and relative rates of rise of 1.19-1.51 mm/year\cite{9}. SEVASTOPOL is also not updated since the mid-1990, but has a record length of 82 years and a relative rate of rise of 1.32 mm/year\cite{9}. TUAPSE has been recently updated (2011), record length 93 years and relative rate of rise of 2.42 mm/year\cite{9}. POTI is similarly recently updated (2009), record length 117 years, and relative rate of rise of 6.56 mm/year\cite{9}. BATUMI, TRABZON II, IĞNEADA and AMASRA are not included in the survey\cite{9}, but while BATUMI has a long record (but is quality control flagged), TRABZON II, IĞNEADA and AMASRA are definitively too short. Over the time window 2001-2009, AMASRA has a relative rate of rise of -0.62 mm/year (i.e. a small sea level fall) and over the time window 2002-2009 IĞNEADA has a relative rate of rise of -6.33 mm/year (a huge sea level fall) and TRABZON II a similar relative rate of rise of -6.60 mm/year (again a huge sea level fall). While these records are certainly too short, it has to be mentioned that often somebody else finds legitimate the use of short records when they show huge positive relative sea level rates of rises. Over the time window 1882-2009, the quality control flagged BATUMI has a rate of rise of 1.92 mm/year computed by using there consecutive sets of data showing significant non-homogeneities as they could be homogeneous and neglecting the gaps.

POTI and TUAPSE are two of the 100 tide gauges of PSMSL having length more than 80 years at the present time of average rate of rise 0.24±0.15 mm/year\cite{8}. 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\cite{8}. Some of these long term tide gauges may have mostly negative accelerations during the last 20 years (San Diego and Seattle for example), some others have mostly positive accelerations (Poti and Tuapse in this case). On average, the acceleration is very close to zero, and always, the local mostly positive or mostly negative accelerations are the result of the amplitudes, phases and periods of the natural oscillations. This is exemplified below for POTI and TUAPSE.

The mathematics of sea level is everything but difficult to understand and we have proposed many times the tools needed to assess accelerating or non accelerating trends, as\cite{2-7} and many others. The formulation below is reproduced from\cite{7}. From 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 \( x_i \), the relative rates of rise are traditionally computed through the linear fitting:

\[
y^*(x) = (A^* + \text{SLR}^* \cdot x)
\]

Where \( \text{SLR}^* \) is the relative rate of rise, \( A^* \) the intercept and \( y^* \) the fitted value at the time \( x \). The residual:

\[
\varepsilon_i = (A^* + \text{SLR}^* \cdot x_i) - y_i
\]

is the error that includes mostly periodical oscillations, noise, fitting inaccuracies and the influence of global warming (if detectable) that would in case produce a departure from the linear trend. Generalising the concept, a relative rate \( \text{SLR}_{j,k} \) is
computed over the time window \((x_k-x_j)\) by linearly fitting the data \(\{x_i, y_i\} i=j, \ldots, k\) through the formula:

\[
SLR_{jk} = \frac{\sum_{i=j}^{k} (x_i - \bar{x}) \cdot (y_i - \bar{y})}{\sum_{i=j}^{k} (x_i - \bar{x})^2}
\]

(3)

where \(\bar{x}\) and \(\bar{y}\) are the sample means. Traditionally \(j=1\) 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. However, equation (3) may permit the recognition of the relative rate of rise patterns by considering a variable \(x_j\) or \(x_k\) with fixed the other extreme of the interval. Equation (3) with \(j=1\) and \(k\) variable permit to compute the velocities at any time \(x_k\) to estimate the acceleration:

\[
SLA_k = \frac{SLR_{1,k} - SLR_{1,k-1}}{x_k - x_{k-1}}
\]

(4)

Equation (3) with \(j\) variable and \(k=n\) permit to compute the present velocities simulating the effect of tide gauge recording started at different times \(x_j\). The relative sea level acceleration oscillates and it may be positive or negative simply as a result of the sea level oscillations. This is clear when we introduce a slightly more complex mathematics. A fitting with a line and sines having the expression:

\[
y(x) = (A^* + SLR^* \cdot x) + \sum_{i=1}^{s} A_i \cdot \sin \left( \pi \cdot \frac{x-x_i}{w_i} \right)
\]

(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 \(A_i, x_i, w_i\) are the amplitudes, phases and periods of the oscillations permits to study the effect of the natural oscillations. The residual is the error that includes noise, fitting inaccuracies, periodic oscillations not exactly sinusoidal, periodic oscillations that are not included or the influence of global warming (if detectable) that would produce a departure from the linear trend.

\[
e_i^* = (A^* + SLR^* \cdot x_i) + \sum_{i=1}^{s} A_i \cdot \sin \left( \pi \cdot \frac{x_i-x_{i+1}}{w_i} \right) - y_i
\]

(6)

Figures 1 and 2 present the measured relative sea levels in Poti and Tuapse and the values computed with a line and sines fitting, the residuals of the fittings, the SLR and SLA computed at different times from the measured and fitted MSL.

The relative rate of rise of sea level has been increasing in Poti from 1993 to 2006 and it is decreasing since 2006, and it is increasing in Tuapse from 1993 to 2006 and it is about constant since 2006. This is the result of the phases, amplitudes and periods of the oscillations for this area being the line and sines fitting behaving perfectly identical to the measured distribution.

The very high relative sea level rate of rise of Poti is very likely due to the high rate of subsidence that may be close to 6 mm/year in Poti\(^{[15]}\). Tuapse is also affected by subsidence apparently at a slower rate, that may be possibly 2 mm/year. The absolute rates of rise of sea levels are therefore very likely zero, i.e. it is the tide gauge that is moving down rather than the sea level to go up. In any case, being the tide gauge records oscillating and not accelerating, the signs of carbon dioxide driven sea level rises are missed also here.

The accuracy of computing the absolute vertical velocity of the tide gauge where a long tide gauge record is available by assuming the sea level does not change is much better than using GPS monitoring of nearby GPS domes at the best 10-15 km away that are subject to inaccuracies of \(\pm 1-2\) mm/year\(^{[5, 6]}\) and neglecting the relative motion tide gauge vs. GPS dome.

The non-GPS based estimations of the vertical land motion\(^{[12-15]}\) suggest non uniform subsidence having in some area (as the coastline of Georgia) very high rates. SONEL\(^{[10]}\) or JPL\(^{[11]}\) are however not that helpful to determine the vertical velocity nearby the tide gauges, with only the GPS dome of TRAB close to TRABZON having a computed vertical velocity of \(+0.22\pm0.23\) mm/year, i.e. minimal uplift that is more likely a stable GPS dome vertical position in\(^{[10]}\). According to\(^{[16]}\), the vertical velocity of TRABZON is a significant subsidence of \(-3.27\pm0.48\) mm/year.

Figure 3 presents the map of relative sea level rise trend 1984 to 2013 (minimum time window), 1964 to 2013 (latest 60 years’ time window) and 1900 to 1959 (oldest 60 years’ time window) from\(^{[9]}\). The sea level of the area is characterised by a remarkable stability with relative rates of rise about the same in the first and the second half of the past century without any sign of acceleration.
Figure 1: a: measured relative sea levels in Poti and the values computed with a line and sines fitting; b: residuals of the fittings; c: SLR computed at different times from the measured and fitted MSL; d: SLA computed at different times from the measured and fitted MSL. The relative rate of rise of sea level has been increasing in Poti from 1993 to 2006 and it is decreasing since 2006. This is the result of the phases, amplitudes and periods of the oscillations. The very high relative sea level rate of rise of Poti is very likely due to the high rate of subsidence that may be close to 6 mm/year in Poti.
Figure 2: a: measured relative sea levels in Tuapse and the values computed with a line and sines fitting; b: residuals of the fittings; c: SLR computed at different times from the measured and fitted MSL; d: SLA computed at different times from the measured and fitted MSL. The relative rate of rise of sea level has been increasing in Tuapse from 1993 to 2006 and it is about constant since 2006. This is the result of the phases, amplitudes and periods of the oscillations. Tuapse is also affected by subsidence.
Figure 3: Map of relative sea level rise trend a) 1984 to 2013 (minimum time window), b) 1964 to 2013 (latest 60 years’ time window) and c) 1900 to 1959 (oldest 60 years’ time window) from [9]. Images are reproduced from [9]. The sea level of the area is characterised by a remarkable stability with relative rates of rise about the same in the first and the second half of the past century without any sign of acceleration.
CONCLUSIONS

The paper has presented the best practice assessment of the latest relative sea level rise and acceleration for the Black Sea based on real measurements. The absolute rates of rise of sea levels are very likely zero here in the Black Sea as elsewhere, while the relative sea level accelerations surely very close to zero globally.

REFERENCES


[10] www.sonel.org/spip.php?page=gps&idStation=XXX (XXX is the three digits station number)

[11] sideshow.jpl.nasa.gov/post/links/XXXX.html (XXXX is the four digit station name)


