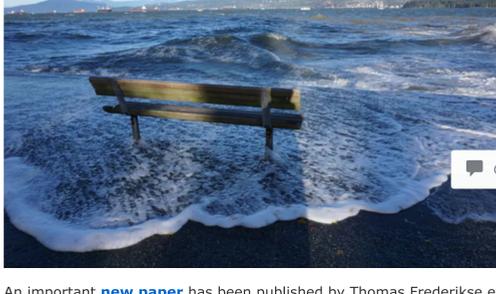


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Sea-level budget along US Atlantic North-West coast



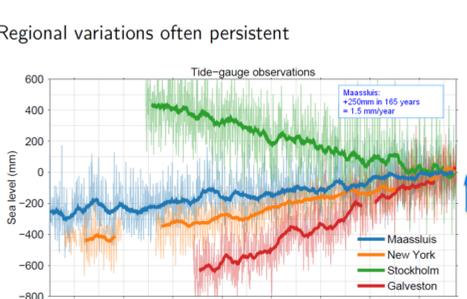
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An important [new paper](#) has been published by Thomas Frederikse et al. (Delft University) on the sea-level changes along the northern part of the US Atlantic West coast (between latitudes 35° and 45°, from Sewells Point to Halifax). The authors try to check if a budget involving changes of salinity and ground level variations would agree with the tide-gauges observations for the last 50 years. I confess that I have a positive bias for sea-level research done by Dutch scientists, as opposed to the scary stories told by people like Stefan Rahmsdorf from the PKI. The Dutch have a centuries long experience with measuring, battling and mitigating a harsh sea that always tries to invade the many regions below sea-level (an area which amounts to about a third of the country). So Dutch research on this topic usually is much more sober and not agenda driven. As a start you may read this [paper by Rovere et al.](#) (2016) as a very good and clear introduction into the subject of sea level change.

1. Sea-level changes at different regions are vastly different

The following figure shows how different the sea-levels measured by tide-gauges can be; remember that these gauges are installed on the ground, and strictly speaking measure the relative sea-level. At Stockholm the ground is rising due to the post-glacial rebound (GIA, Glacial Isostatic Adjustment), whereas in Galveston (Texas, USA) there is a big ground subsidence (ground sinking) mostly due to excessive ground water pumping (see [here](#)), so that local tide gauges report an alarming (relative) sea-level rise..

Regional variations often persistent



Source: PSMSL

T. Frederikse et al.

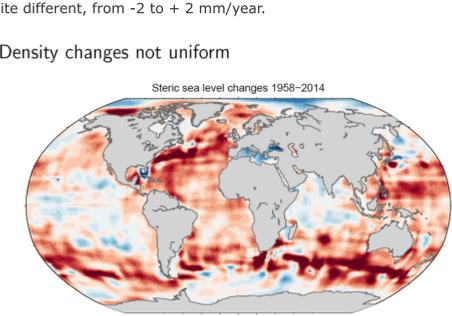
For Dutch people the recordings at the Maassluis (a lock on the outlet of the Maas river to the North Sea) are reassuring: in 165 years the relative sea-level rise is only **1.5 mm/year**, and shows no sign of acceleration. As the globe is leaving a Little Ice Age since 1850, such a rise has essentially a natural cause, and is not (much) caused by human activity or greenhouse gas emissions! What is surprising is that despite the big differences in the amplitude and sign of the changes, the trends are practically linear i.e. persistent!

The figure also tells us that a global sea-level may be an interesting scientific curiosity, but this modeled "virtual" level has no significance at all for local mitigation policies.

2. What are the main contributors to sea-level change?

Steric changes are changes related to density changes; the sea water density can change for instance by warming (often also called **eustatic** changes when given relative to a fixed point as the center of the globe) and/or inflow of less saltier water. Lower density means more volume for a given mass i.e. rising sea level if the geological tub for the oceans remains unchanged (which is not the case!). The following picture shows that the density changes are far from uniform over the globe. As a consequence local steric sea-level changes are quite different, from -2 to +2 mm/year.

Density changes not uniform



Source: MetOffice EN4 v4.1.1

Isostatic changes are related to local vertical ground movements, caused for instance by excessive pumping of ground-water, increased pressure by new buildings or heavy infrastructure, but most importantly by **glacial isostatic adjustment** (GIA): GIA is the rebound of the earth crust (both positive and negative) caused by the disappearing ice mass that accumulated during the last great glacial period (which ended about 10000 years ago). This is a very slow process, with big regional differences. The Baltic coast for instance is rising at Stockholm by more than 4 mm/year, by 12 mm/year around Greenland (see [here](#)); this [paper](#) shows that the New Zealand coast has both uplift and subsidence parts with changes from -1 to +1 mm/year.

The next picture from the paper shows that practically all of the 14 US stations used show negative vertical land movements i.e. subsidence (look at the grey bars: only 4 stations have uplift, mostly negligible except at station #3)

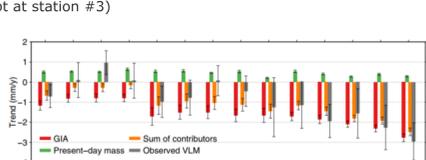


Figure 9. Modeled and observed vertical land motion at each tide gauge, together with the uncertainty estimate on the 1 σ level. The trends of solid earth deformation resulting from present-day mass redistribution are computed over the time span of the individual GPS record. The sum of contributors consists of the effects of solid earth deformation due to GIA and present-day mass redistribution. The stations are numbered according to Table 1.

3. Lessons learnt

The major aim of the Frederiksen paper was to establish a model for local sea-level, i.e. making a budget of the different contributions and comparing the effect of this budget to the observations by the tide-gauges. The results are quite good:

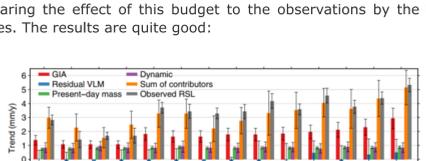


Figure 10. Observed and modeled trends (1965-2014) in sea level for all individual stations, together with the accompanying uncertainty estimates. The residual VLM term is inverted to show its contribution to the sea-level budget.

As this figure shows, the observations of the tide gauges (grey bars) are very (or at least reasonably) close to the results of the budget (orange bars). Especially interesting is the comparison of the contributions of ice melt (glaciers, Arctic and Antarctic) with the GIA: I have highlighted these on the next table:

Table 2. Linear Trends and Accelerations for Individual Contributors, the Sum of Contributors and Observed Relative Sea Level Over 1965–2014 ^a		
	Linear Trend (mm/yr)	Acceleration (mm/yr ²)
Glaciers	0.41 ± 0.02	0.009 ± 0.001
Greenland	0.04 ± 0.01	0.003 ± 0.001
Antarctica	0.12 ± 0.03	0.015 ± 0.002
Dam retention	-0.14 ± 0.02	0.003 ± 0.001
Natural + depletion	0.40 ± 0.06	0.010 ± 0.003
Present-day mass	0.83 ± 0.07	0.040 ± 0.003
Ocean dynamics	0.88 ± 0.25	0.136 ± 0.038
GIA	1.75 ± 0.44	
- Residual VLM	-0.22 ± 0.26	
Nodal cycle	-0.02 ± 0.00	
Sum of contributors	3.22 ± 0.57	0.176 ± 0.038
Observed RSL	3.35 ± 0.38	0.126 ± 0.046

^aThe uncertainties are on the 1 σ level. The bold contributors are summed to obtain the total contribution.

The sum of ice-melt is 0.57 mm/yr, that of the GIA (here subsidence) is 1.75 mm/yr, **about three times higher!** So if we believe that all ice melt is due to the human emissions of greenhouse gases, this anthropogenic "sin" pales in comparison to the natural geological influence.

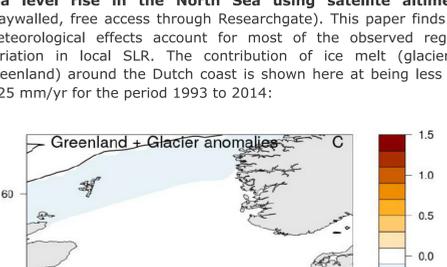
The acceleration (supposed constant) of the ice-melt caused sea-level would cause in 80 years a sea-level rise of 0.5* (0.009+0.003+0.015)*80*2 = 86.4 mm, **less than 10 cm!** This must be compared to the linear geological caused increase of 1.75*80 = 140 mm.

4. Conclusion

The Dutch study does not point to any human caused rise in sea-level that would present a big problem around 2100. Changes in local (relative) sea-level at the West Atlantic US coast are real, but come predominantly from natural factors. This does not mean that no protection work will have to be done in a far future, but it puts the contribution of human GHG emissions into perspective.

PS1: the first two figures are from a slide-show by Frederikse. I lost the link.

PS2: A paper by Paul Sterlini (Koninklijk Nederlands Meteorologisch Instituut) et al. published in GRL July 2017 comes to similar conclusions. The title is "[Understanding the spatial variation of sea level rise in the North Sea using satellite altimetry](#)" (paywalled, free access through Researchgate). This paper finds that meteorological effects account for most of the observed regional variation in local SLR. The contribution of ice melt (glaciers + Greenland) around the Dutch coast is shown here at being less than 0.25 mm/yr for the period 1993 to 2014:



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