Relative importance of mass and volume changes to global sea level rise

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Abstract

We examine the relationship between 50 year long records of global sea level (GSL) calculated from 1023 tide gauge stations and global ocean heat content (GOHC), glacier and ice sheet melting. We provide clear evidence of the substantial and increasing role in GSL from the eustatic component (47%) compared with the contribution from increasing heat content (25%), suggesting that the primary role is being played by the melting glaciers and ice sheets. There remains about ¼ of GSL rise unaccounted for by the best estimates of both eustatic and thermosteric effects. This fraction also exhibits large variability that is not readily associated with known causes of sea level variability. The most likely explanation of this unknown fraction is underestimated melting, climate- driven changes in terrestrial storage components and decadal time scale variability in global water cycle. This argues for a concerted effort to quantify changes in these reservoirs.

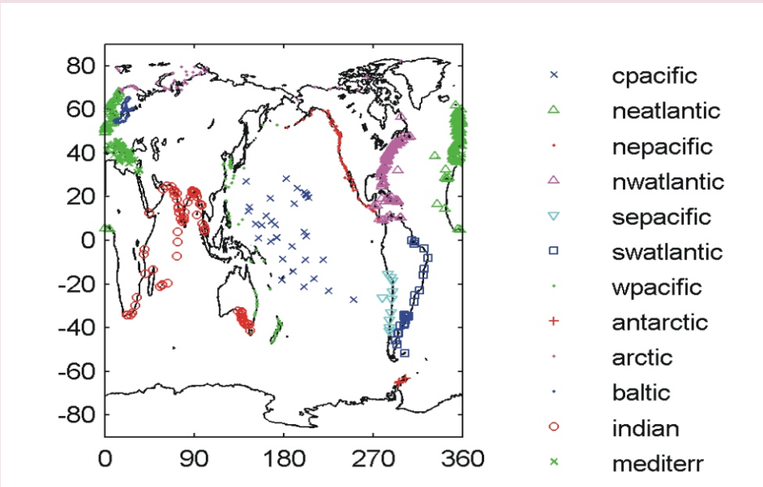


Figure 1. Location of the tide gauges included in this study (13 regions: cpacific- Central Pacific, neatlantic- Northeast Atlantic, nepacific- Northeast Pacific, nwatlantic- Northwest Atlantic, sepacifc- Southeast Pacific, swatlantic- Southwest Atlantic, wpacific- Western Pacific, Antarctic- Antarctica, arctic- Arctic, baltic- Baltic, indian- Indian, mediterr- Mediterranean, seatlantic- Southeast Atlantic).

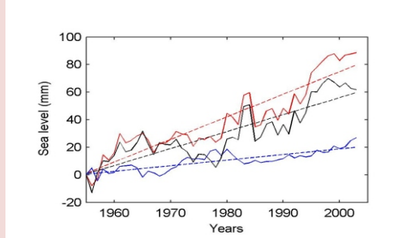
Data

- thermosteric sea level (TSL) rise 1955-2002 [*Antonov et al.*, 2005], associated with changes in GOHC;
- eustatic sea level (ISL) rise, related to the melting of continental glaciers and ice sheets in Greenland and Antarctica [*Dyurgerov and Meier,* 2005; *Krabill et al.*, 2004; *Thomas et al.,* 2004];
- global sea level (GSL), calculated from 1023 tide gauges [*Jevrejeva et al.*, 2006]

Objectives

- Here we challenge the hypothesis that GOHC is the principal driving force for sea level rise since the 1950s by showing how the relationship between GSL calculated from 1023 tide gauge records [*Jevrejeva et al.*, 2006] and GOHC [*Levitus et al.*, 2005] is very variable over time.
- In contrast with previous studies, where only slopes of trends in individual sea level time series were compared with slopes of trends in regional ocean heat content, in this paper for the first time we investigate temporal correlations between global sea level and GOHC.
- We then estimate the contributions to GSL rise from two separate components: thermosteric sea level (TSL) rise [*Antonov et al.*, 2005], associated with changes in GOHC; and eustatic sea level (ISL) rise, related to the melting of continental glaciers and ice sheets in Greenland and Antarctica [*Dyurgerov and Meier,* 2005; *Krabill et al.*, 2004; *Thomas et al.,* 2004].

Is the thermal expansion of the ocean a dominant contributor to sea level rise?



For the period 1955-2003 **only** 25% of the 1.6 mm·yr^{-1} linear trend in global sea level GSL can be explained by the contribution from thermosteric sea level (TSL) in the upper 1500 m global ocean layer (linear trend of 0.41 mm·yr^{-1}).

Figure 2 shows time series of sea level with linear trends: GSL calculated from tide gauges (red), 1.6 mm·yr^{-1}; thermosteric sea level (TSL) (blue), 0.41 mm·yr^{-1} and the residuals, assumed to be estimated non-thermal component (black), 1.2 mm·yr^{-1}.

Figure 3a reveals, with the use of a running correlation coefficient (10 -year window), that the relationship changes with time, with a minimum (-0.6) in 1982 and maximum (0.8) for the last 10 years (1993-2003). A rapid increase in heat content in 1976 followed by a fall in the 1980s is not present in GSL.
Figure 3b demonstrates that the relationship between the GOHC and the GSL changes dramatically from positive to negative for any moving correlation window between 3-25 years, suggesting that the relationship changes over past 50 years for different time scale.

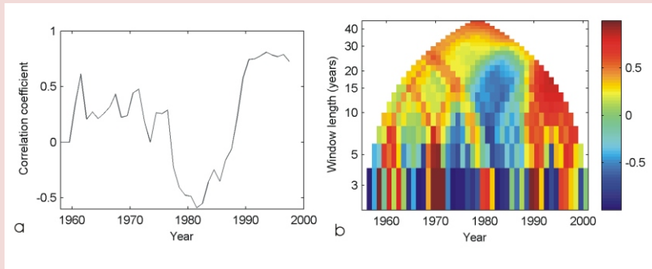


Figure 3. Running correlation coefficient (10- year window) between the GSL and GOHC during 1955-2003 (a); running correlation coefficients with varying window length between the GSL and GOHC during 1955-2003 (b).

Non-thermal contribution to GSL rise

Figure 4 shows that the contribution from melting (calculated using direct measurements of glacier volume changes [*Dyurgerov and Meier,* 2005] and ice sheet melting in Greenland [*Krabill et al.*, 2004] and Antarctica [*Thomas et al.,* 2004], named here as ISL, black line) progressively increased over the last 49 years. The linear trend in ISL is 0.75 mm·yr^{-1}, which amounts to 47% of GSL rise during the 1955-2003 period.

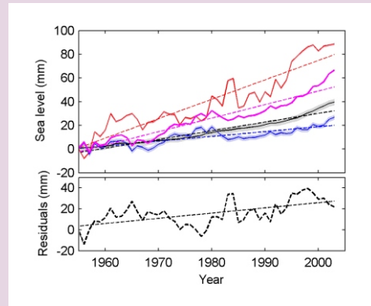


Figure 4. Top: Time series of sea level with linear trends: GSL calculated from tide gauges (red), 1.6 mm·yr^{-1}; thermosteric sea level (TSL) (blue), 0.41 mm/yr; ISL as a contribution to sea level rise calculated form continental glacier volume changes and ice sheets melting in Greenland and Antarctica (grey), 0.75 mm·yr^{-1}; reconstructed GSL (TSL+ISL) in purple, 1.1 mm·yr^{-1}. Shadows paralleling the GSL, TSL and ISL are errors. Bottom: Unexplained residuals (GSL-reconstructed GSL), with linear trend of 0.44 mm·yr^{-1}.

Unexplained residuals, where residuals = GSL-TSL-ISL, are characterized by a trend of 0.44 mm·yr^{-1} and a temporal pattern of decadal variability (Figure 5, bottom), suggesting that the unexplained residuals are not systematic errors, but more likely to be climate change related.

Conclusion

- The sea level contributions calculated from continental glacier volume changes and ice sheet melting in Greenland and Antarctica make up the leading component (47% contribution to sea level trend) compared with 25% contribution from thermal expansion.
- We find a large unexplained sea level rise (about ¼ of GSL) with substantial variability that is likely caused by combination of underestimating the contribution from melting ice masses, the linear trend component, and decadal variability associated with the hydrological cycle and climate driven changes in continental water storage contribution.

Jevrejeva et al., 2008, JGR, 2007JD009208, Relative importance of mass and volume changes to global sea level rise