Explanation of thermal expansion differences between climate models

Summary

More than 90% of the positive Earth's energy imbalance - mainly anthropogenic as origin (Church et al. 2013) - is stored in the ocean as heat. Ocean warming results in thermal expansion and finally converts into sea level rise. During the last century, around half of the rate of sea level rise - globally averaged - was due to thermal expansion, called thermosteric sea level. For the coming century, Earth's energy imbalance is expected to be constant or to increase, depending of human activity scenarios. Consequently, sea level rise is expected to be constant or to increase, and projection accuracy of sea level is dependent on the ability of climate models to predict ocean thermal expansion.

In a recent study, two researchers from the Laboratoire d'Etudes en Géophysique et Océanograohie Spatiales (LEGOS), which are members of the international team of the International Space Science Institute (ISSI) on "Contemporary global and regional sea level rise" (http://www.issibern.ch/teams/climatemodels/), compare the thermal expansion obtained by climate models (from the Coupled Model Intercomparison Project phase 5), driven by atmospheric re-analyses, with observations over the period 1961 – 2005. The ensemble mean of sea level rise due to ocean warming from climate models is close to the observations - within observation uncertainty - in terms of absolute sea level rise as well as of rate of sea level rise (see Figure 1). However, the model ensemble exhibits a large spread. The authors then aim to explain this climate model spread over the twentieth and twenty-first centuries.

By deriving the Earth energy budget - under the condition of continuously increasing radiative forcing F - the authors show that the thermosteric part of sea level rise depends linearly on the time-integrated radiative forcing, which represents the total energy accumulated into the Earth system due to the current positive Earth's energy imbalance. The linear relationship between thermosteric sea level rise and time-integrated F is confirmed by climate models under transient climate change like during the 20th century or the 21st century (under rcp4.5 and 8.5 scenarios). The constant of proportionality μ between time-integrated F and thermosteric sea level rise expresses the transient thermosteric sea level response of the climate system. It depends on the fraction of excess of heat stored in the ocean β, the expansion efficiency of heat ε, the climate feedback parameter α, and the ocean heat uptake efficiency κ. The model spread in μ explains most (>70%) of the model spread of the thermosteric sea level rise over the twentieth and twenty-first centuries, while the model spread in F explains the rest (see Figure 2 & 3). Furthermore, the spread in μ comes from the spread in the climate feedback parameter and in the ocean heat uptake efficiency, which both vary widely across models. Over the 21st century simulations, F explains less variance in the spread of thermosteric sea level than over the twentieth century because the anthropogenic aerosol forcing, which is responsible for most of the spread in F over the 20th century, becomes relatively small.

Remarks

The thermal expansion of ocean from climate models comes from the three-dimensional CMIP5 temperature and salinity fields annually averaged and converted into global mean thermosteric sea level using the UNESCO 1980 International Equation of State (IES80) and removing marginal seas and lakes ; finally, the resulting sea level is detrended by removing the corresponding long-term drift of individual climate models.

The thermal expansion of ocean from climate models (average of all models) shows a rate of around 0.45 mm yr^{-1} for the 0 – 700 m layer and 0.6 mm yr^{-1} for the whole column, similar to observations, over the 1961 - 2005 period.

Only few models reproduce the observed thermal expansion of global mean sea level within observation error bars (regarding 1900 – 2005 or 1961 – 2005 time period, for the 0 – 700 m depth layer or the whole column) ; Models generally overestimate thermosteric sea level rise compared to observations because their value of μ is too large.

The value of β, which represents the fraction of excess heat stored into the ocean, happens to higher than 1 within some climate models, suggesting energy conservation problems in these climate models.

The climate model spread of α, which represents essentially the cloud feedback, is due to an incomplete knowledge of the cloud feedback as well as different ways to model the associated processes.

The climate model spread of μ, which represents the link between thermosteric sea level rise and time-integrated radiative forcing, is essentially due to climate modeling of the heat transport processes within the ocean, i.e. the ocean circulation.

Interesting enough, the present results suggest that observations of thermosteric sea level changes can give a constraint on μ estimated from climate models, and thus can help in reducing the spread in μ across models as well as further improve climate projections.

The linear relationship between time-integrated F and thermal expansion of sea level is found to hold only during years which are not affected by intense explosive volcanic eruptions.

In a warmer climate, like at the end of the 21^{st} century under rcp8.5 scenario, the transient thermosteric sea level response of the climate system tends to decrease as the forcing increases. It suggests that projections of future sea level beyond 2100 - based on a linear equation – probably overestimate thermosteric sea level rise when the radiative forcing increases with time.

Main references

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Figures

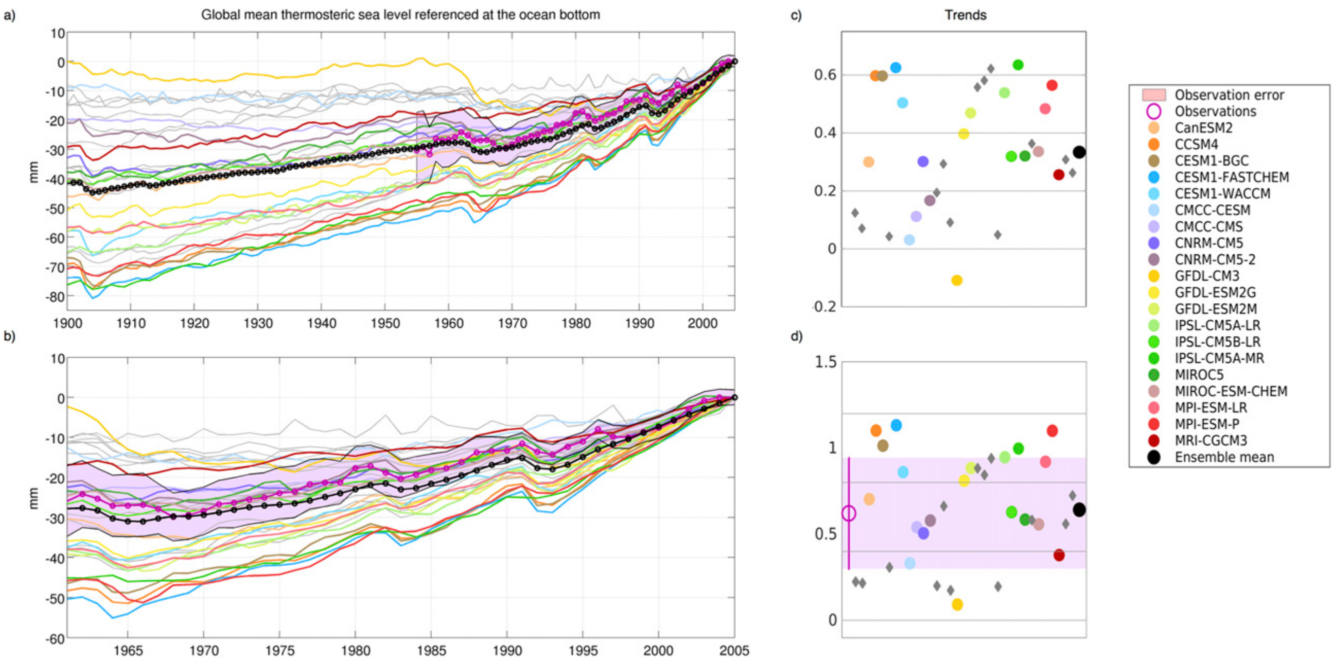

Figure 1. Thermosteric sea level (mm) and trends (mm yr^{-1}) referenced in 2005 over (a, c) 1900–2005 and (b, d) 1961–2005.

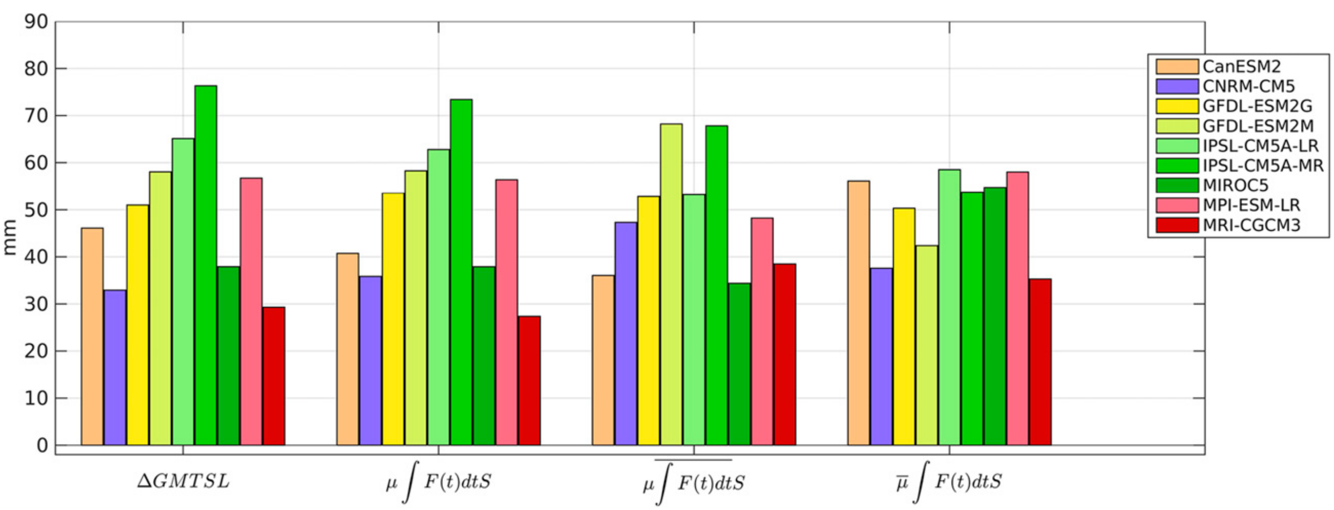

Figure 2. Thermosteric sea level rise (global mean from climate models) in 2005 relative to 1900 (mm) computed from the 3D temperature and salinity fields (first group), from the climate coefficient relationship (second group), from the climate coefficient relationship using the model ensemble mean values F (third group), and for μ (fourth group).

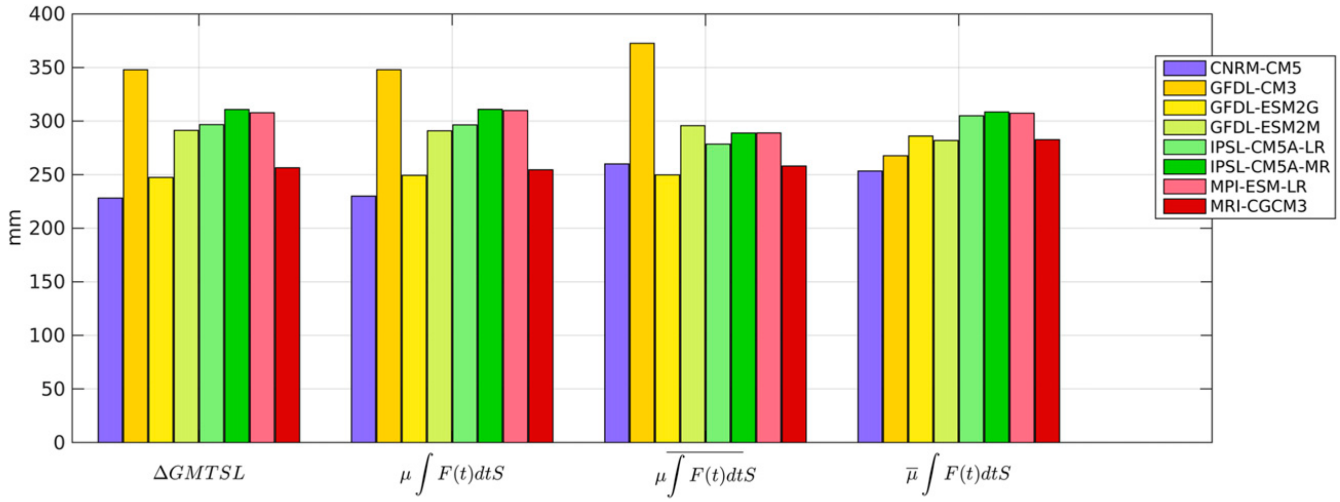

Figure 3. Thermosteric sea level rise (global mean from climate models) in 2099 relative to 2006 (mm) under the RCP8.5 IPCC scenario computed from the 3D temperature and salinity fields (first group), from the climate coefficient relationship (second group), from the climate coefficient relationship using the model ensemble mean values F (third group), and for μ (fourth group).