

Response to RC4: Anonymous Referee #4

The paper The transient sensitivity of sea level rise by Grinsted and Christensen discusses the relationship between global mean surface temperature and global mean sea level rise on a time scale of the order of a century. The authors acknowledge earlier work on the topic and frame the relation between temperature and sea level rise as an independent proxy for the evaluation of recent assessments of sea level rise projections that are biased low compared to observations. The article claims a linear sea level sensitivity of 0.4 m/century/K based on observations and either lower sensitivity in AR5 or higher balance temperature in SROCC and Bamber et al., 2019., respectively.

General comments

The paper is very short and concentrates on the discussion of the discrepancy between the parameters of linear regressions between averaged global mean surface temperature and global mean sea level rise, based on observations (past) and climate projections (future). In the face of high and rising stakes on the response to sea level rise additional proxies for the evaluation of projections of sea level rise are needed. The paper contributes to this end in bringing back the sea level sensitivity into the discussion. I think it is worth to be published and discussed in the community. The paper misses the opportunity to go deeper into the matter and offer thoughts or strategies how to address the discrepancies in transient sea level sensitivity between observations and climate projections.

Thank you. We agree there are limitations to the metric, but also that it serves as a useful reality check on sea level models – the comments here indicate that we may expand on the underlying ideas. In particular, we gather from the full set of reviews that we need to discuss limitations more.

Revision plan:

- Add more to the motivation part of the manuscript
- Elaborate substantially on the limitations of the metric.
- Add an outlook for how TSLS discrepancies can be addressed.
 - Brainstorm to consider when revising:
 - Ensure that projection models also have hindcasts of the historical past.
 - Look into the transient sensitivity of individual contributors.
 - Understand how TSLS changes over time
 - Model studies to understand the limitations of TSLS.

Specific comments

I wonder whether we could learn something more about the impact of model development if the current analysis would include older projections like AR3 and AR4. Those were already below GMSL rise according to Rahmstorf 2007, Horton et al. 2008.

It is a great idea to look into the TSLS of sea level models used in past IPCC reports (including FAR and SAR to complete the picture). However, this is a distraction and beyond the scope in this manuscript.

One weak point of the analysis, as I see it, is the different ranges of GMST used for the regressions of the observations and model projections. Would it be possible and useful to include model estimates from paleo runs that had GMST anomalies in the same range as those projected for the 21st century?

We agree that this is an important limitation, and based on the full set of reviews we also realize that we need to more explicitly discuss this limitation. Unfortunately, there is very little we can do about it as AR5 and SROCC has not published hindcasts with the same models used for hindcasts.

Revision plan:

- Stress that sensitivity may be different in future from past, and that this can possibly explain “the discrepancy” and assess the involved physical mechanisms more clearly.
- Expand the discussion and emphasize more strongly the limitations of the comparison to the observational estimate.

The regression lines in Fig. 1 should pass through the mean time-averaged GMST anomaly and the mean sea level rate. Is there any information contained in the scatter of the mean GMST and mean GMSL rate of the individual regressions?

For the observational trend, and the AR5 trend then the scatter around the trend line is so small compared to the uncertainty of the individual points that I would be careful to read anything into this. However, SROCC responds more non-linearly and there is deviation a straight line fit. The sensitivity is clearly increasing with warming. The TSLS we report is an average over the range of scenarios plotted.

If you were asking for more details about the statistical procedures, then please take a look at our replies to reviewer 2.

It would be interesting to discuss some of the physical processes, thresholds, time scales and limitations, that would render the relationship between averaged GMST and GMSL rate non-linear. It would help to establish the transient sea level sensitivity as a metric next to equilibrium sea level rise on longer time scales.

We agree.

Revision plan:

- Stress that sensitivity may be different in future from past, and that this can possibly explain “the discrepancy” and assess the involved physical mechanisms more clearly.
- Emphasize more strongly the limitations of the comparison to the observational estimate. Discuss time scales.

Are current climate models or model ensembles good enough so that their uncertainty in GMST was smaller than the uncertainty in balance temperature in Table 1? Is the spread in balance temperature inherent in climate models or does it come from the combination of climate models (GMST, steric) with process models (ice sheets dynamics)?

The answer here will be a little speculative, and so we have not added it to the manuscript. I believe the uncertainty in balance temperature is a consequence of the long equilibration time scales for several of the contributors. It requires a long spin-up of both the ocean and the ice sheets to ensure that it has the full memory of the long term forcing. This will be reflected in the model balance temperature. It will also put strong demands on the long term forcing. We will consider to add a short paragraph on this in the discussion, if it helps to reassure other parts of our discussion.

Revision plan:

- Consider adding a short speculative paragraph on uncertainties in balance temperature.

From Table 1 one could deduce sea level rise of 0.28, 0.05, 0.17 and 0.17 m/century at balance temperature. The 0.28 m/century sea level rise in the observations at balance temperature is already above the 0.1-0.2 m/century sea level rise for the 20th century. Since sea level rise is accelerating we are probably above balance temperature since at least the satellite era. This seems to point to a contradiction in the data and the assumption of a linear process. How can the balance temperature be interpreted or how well can we know it?

There appears to be some confusion with the meaning of the terms “balance temperature” and the “baseline temperature”. The quoted numbers (0.28 etc.) are the sea level rate at $T=0$, calculated as $\dot{S} = TSLS \cdot (0 - T_{balance})$. So, the 0.28m/century is the sea level rate when temperature is equal to the baseline temperature reference (rather than “at balance temperature”).

This may seem like a minor point but: we would disagree that we assume a linear process. Rather we argue that a linearization is a reasonable approximation to the response. There are limits to how far that linearization would work, but that does not mean that TSLS is not useful. It just means that the state of the system can change so much that the sensitivity to warming changes.

Technical corrections

*l6: assessments from the Intergovernmental Panel on Climate Change implies
l20: and melts.. A perturbation
l20: perturbation in greenhouse gas concentrations change
l47: table 1 and figure 1
l52: table 1
l63: figure 1
l69: figure 1*

We have checked the lines mentioned, but we cannot understand what technical corrections the referee has in mind. These specific lines look good to us.