# Response to RC1: Tal Ezer

> *General Comments:*
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> *The (very short) paper looks at linear relations between global sea level rise (SLR) rates and time-mean temperatures in both observations and climate model projections- the results suggest that models may underestimate future sea level rise, which is a very important finding. The study is clearly written, and the results are interesting, though since I am not a global climate modeler, I am not sure if this result about the SLR-SST relation in models is new or already known to climate modelers. There are several caveats in the study with its very condensed presentation (only one figure and 1 table), that are needed to be explained (with potentially expanded calculations).*

It was our intent to write a brief discussion letter where we introduce the Transient Sea Level Sensitivity metric. We hope this metric will be adopted by the community as a simple way to compare the first order transient response between different models. In the paper we plot the results of published work in a thought-provoking way. It is therefore our opinion that this is much better suited as a discussion letter, rather than a longer more traditional article.

We are not the first to note that there must be some relationship between sea level rate and temperature. Awareness of this is evident already in the first IPCC assessment report, and the idea was explicitly exploited by Rahmstorf (2007) to construct a semi-empirical model projection. So, we do not consider this to be the main contribution of the paper, although clearly many modelers are not aware of these developments. In our opinion the main contributions of our paper are more prominent and here emphasized explicitly in order of importance:

1) The introduction of the Transient Sea Level Sensitivity (TSLS) metric.
2) The finding that a straight line is a good approximation to the transient response in the models assessed in AR5 and SROCC. I.e. that TSLS is a useful metric that captures most of the transient response according to present physical understanding.
3) The highlighted apparent discrepancy between the TSLS of models used for sea level projections and historical data.

Note especially, that we do not consider the observational extrapolation to be a projection. We explicitly say: "*This does not automatically demonstrate a bias in model projections, but as a minimum call for a detailed explanation*". This is intended as a very clear and explicit caveat, and a call for further work. So, we agree with the referee that more analysis is needed to understand the discrepancy, but also that this is beyond the scope of this discussion letter. However, we gather from the full set of reviews that we need to be more explicit about the limitations of the TSLS metric and will make this point more prominent.

**Revision plan:**

- Elaborate substantially on the limitations of the metric.
- Discuss the physical mechanisms behind the relationship and thereby stress that sensitivity may be different in future from past, and that this could potentially explain "the discrepancy".
- Expand the discussion to better clarify that extrapolation is only used for a comparison, and not a projection.

*Major Comments: There are several assumptions that are not completely correct, so their impact should be addressed more extensively.*

*1. SLR rates are far from being linear, they are in general accelerating, but there are also significant multi-decadal variations in SLR rates (e.g., see Frederikse et al., Nature, 2020, doi:10.1038/s41586-020-2591-3). Therefore, the assumption that the SLR-SST linear relation in the past should be the same as in the future may not hold. Moreover, the period chosen for time-averaged SST and SLR may affect the results some experiments to see how sensitive the results are to different chosen periods may be useful.*

We do not assume "*that the SLR-SST linear relation in the past should be the same as in the future*". We simply compare past with future sensitivity and note that there is a discrepancy. But we also stress that "*This does not automatically demonstrate a bias in model projections, but as a minimum call for a detailed explanation*" and "*Future TSLS may well be different from the past…*". We do this for exactly that reason – we will emphasize this even further.

We do not assume a steady acceleration over time. There is multi decadal variability temperature, and that should be reflected in the sea level rate. We get the reviewers point though: that the simple straight line cannot capture all variability. We acknowledge that the TSLS metric is a simplification of a complex system. It can only characterize the first order response. But this is no different from established metrics such as the Transient Climate Response which have proven their usefulness. We will emphasize that this is exactly how we see the value of studying TSLS.

**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..Discuss time periods more clearly. Both in figure caption, and when introducing TSLS.

*2. The SLR-SST relation assumes that SLR is related to SST through thermal expansion, but what about the contribution from water masses? In recent years and in the future contribution to SLR from ice melt will increase relative to thermal expansion (Frederikse et al. 2020, and many others). This by itself may explain the main results here. To see if this is the case, you may add to the calculation results from the same models over the same period as the observations to see if the results are due to model biases or the neglection of water mass contribution.*

We agree that changes in the state of the climate system between the 20th and the 21st century, could potentially explain the discrepancy between the sensitivity in past and in the future. But without further analysis this is speculation. We write: "*This does not automatically demonstrate a bias in model projections, but as a minimum call for a detailed explanation*".

We also agree that it would be great if we could plot the results of the AR5&SROCC models for the historical period to compare to the historical data. Unfortunately, that is simply not possible because such historical runs were never made with the same aggregate model that was used for projections. This lack of a validation is precisely the reason why we feel that it is necessary to compare past and future sensitivity even if this may be an imperfect comparison.

The SLR-SST relation does not hinge on an assumption "*that SLR is related to SST through thermal expansion*". We do not assume this, and we do not neglect the ice mass contribution. Every point in figure 1 include both expansion and water mass contributions.

We do not assume that the relative proportions of the different sea level contributors remain the same. Further, changing proportions is insufficient explanation of the discrepancy. We illustrate this in Note R1 at the end of this document.

**Revision plan**

- Point out that AR5 & SROCC have no hind casts in their presentation of the SLR discussions and it has therefore not been demonstrated that these models can reproduce past sea level rise.

> *3. Linear regression in Fig. 1 is obtained from only ~5 points, can accuracy be improved by regression over several models, not just the mean of each scenario? Are there for example, models (recent high-resolution) that do follow the observed line? These suggestions may be outside the scope of the study but would greatly help to explain the results and its implications.*

The problem is that sea level rise is not an output from current generation Earth System Models ESM. E.g. The contribution from Greenland is calculated by driving an ice sheet model and a regional climate model with projected weather from an ESM. The total sea level rise is the sum of the contribution from many processes – each with their own model. It is therefore challenging to talk about a recent high-resolution model, as it is a combination of many different models. This is what the IPCC provides, and they also attempt to account for modelling uncertainties as well as possible. The likely range of the IPCC projections are presumably intended to be a fair representation of the modelling uncertainty, and should therefore span recent high resolution models.

A way to understand the discrepancy we observe would be to study how the IPCC models reproduce the historical rates of sea level rise. If hindcasts can reproduce the PI, TG, and SAT rates, then there is no issue. If not, then the historical sea level budget of the models can be dissected to understand if there are issues. Unfortunately, this is not done in the IPCC reports, as they only run the models used for projections for the 21st century and do not show hind casts.

**Revision plan:**

- Point out that AR5 & SROCC have no hind casts in their presentation of the SLR discussions and it has therefore not been demonstrated that these models can reproduce past sea level rise.
- Call for hindcast validations for future sea level projections.

> *Minor Comments:*
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> *4. Lines 9-10: "To understand this discrepancy"- I am not sure this is a real discrepancy or just different estimations of future changes.*

This is a question of wording. The difference is a discrepancy, even if there is an as of yet unknown explanation for it.

**Revision plan:**

- Stress that sensitivity may be different in future from past, and that this could potentially explain "the discrepancy".

- Emphasize more strongly the limitations of the comparison to the observational estimate. Especially in abstract.

> *5. Line 38: ". . . century averaged temperature"- can you define exactly over what period the averaged was calculated (in Fig. 1 it says CO2 since 1850). As mentioned before, it will be useful to know how sensitive the results are to the chosen period, given the non-linear nature of SST and SLR.*

In the current version of the manuscript the time periods are mentioned in the methods section. In the plot the different points were calculated over different time intervals:

- SAT: 1993-2017
- TG: 1900-1990
- PI: 1850-1900
- AR5/SROCC/Experts: 2000-2100

At the moment this is very briefly mentioned in the methods section. Thus, the observational fit is based on data from 1850-2017, and projections are based on data from 2000-2100.

**Revision plan:**

- State time-intervals in figure caption.
- Discuss "century time scale" choice more in main text.

> *6. In Fig. 1, what are the superscript numbers above labels (numbered references left from a previous submission?)*

That is correct. This will be fixed.

**Revision plan:**

- Remove superscripts from figure.
- Expand caption – Explain what each point is, especially their time span.

> *7. In Table 1, only 1 out of 4 sensitivity numbers is statistically significant. . . can this be improved by larger set of data from different models, as suggested above?*

As mentioned above then there is no ensemble of models that we can draw from. Also, the aim of the IPCC assessments is to capture the full uncertainty. So presumably the AR5 and SROCC would span the distributions based on different models.

In our view the significance test is just a tool to help us avoid over-interpreting small differences between rows in the table. It is better that these tests are conservative, and we have therefore no goal of improving the significance. Indeed, it would be nice if the entire table was insignificant because that would mean that all the estimates were more consistent with the observational estimates.

There are four TSLS rows in table 1, and we test if they are significantly different from the first row (the observational estimate). So, there are only three tests for TSLS, not four. These shows:

- That expert estimates are not incompatible with historical data.

- That the AR5 TSLS is significantly smaller than the historical TSLS.
- That the SROCC TSLS (as estimated over the entire range) is in better agreement with historical data.

**Revision plan:**

- Explain statistical tests in methods section.

> *Is there physical meaning to the "balance temperature"?*

Yes. It can be framed as the amount of cooling needed to stop sea level rise (in the short term).

## Note R1: Changing proportions, yet constant sensitivity

The sea level budget is changing, and we expect ice sheet melt to increasingly dominate the budget. This might lead one to argue that the sensitivity must be changing as we don't expect the individual contributors to be equally sensitive to warming. In this section we present a case for why that is a flawed argument. We show that even in a completely linear model the relative proportions of the individual sea level contributors can change.

Let's assume for the moment, that the rate of sea level rise is just the sum of the contribution from ice melt ($\dot{M}$) and the contribution from thermal expansion ($\dot{E}$). We write:

$$\dot{S} = \dot{M} + \dot{E}$$

Let's also assume that these two contributions respond linearly to warming.

$$\dot{M} = a_M T + b_M$$

$$\dot{E} = a_E T + b_E$$

We insert and get a linear model for the sea level rate:

$$\dot{S} = (a_M + a_E)T + b_M + b_E$$

The proportion of sea level rise due to ice melt becomes

$$\frac{\dot{M}}{\dot{S}} = \frac{a_M T + b_M}{(a_M + a_E)T + b_M + b_E}.$$

This is not generally constant in T. This demonstrates that a changing proportion of ice melt does not necessarily imply a changing sensitivity to warming.