Earth System Dynamics Discussions

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Comment on esd-2022-2

Anonymous Referee #1

Referee comment on "Process-based estimate of global-mean sea-level changes in the Common Era" by Nidheesh Gangadharan et al., Earth Syst. Dynam. Discuss., https://doi.org/10.5194/esd-2022-2-RC1, 2022

General Comments

This paper quantifies the contribution to Common Era global mean sea level (GMSL) from changes in ocean volume caused by temperature (salinity is not evaluated with justification provided) and from changes in ocean mass (Antarctica, Greenland, and glaciers are separated; land-water storage is not evaluated with justification provided). Each of these contributions is estimated, with uncertainty, through modeling. The sum of the components (GMSL) is reconciled with two, closely-related (and previously published) estimates of GMSL generated through application of a spatio-temporal model to proxy reconstructions. The similarity between modeled and reconstructed GMSL is compelling, except for a notable underestimate for GMSL change since ~1800 CE.

As the authors note, previous efforts to connect Common Era GMSL changes with other parts of the climate system (e.g., ice mass) largely focused on correlations (or lack of) with other proxy data. The application of process-based models in this paper therefore represents a welcome scientific advance and a substantive contribution toward our understanding of how and why GMSL changed during the Common Era. I recommend that it be published in Earth System Dynamics and hope that the open review forum will attract input from others to strengthen the paper further.

I am familiar with the proxy sea-level reconstructions that modeled GMSL is compared to and therefore my review focuses on that aspect of the paper. I am wholly unfamiliar with process-based models and cannot provide an expert evaluation of choices made within and among the models used.

Specific Comments

1. Section 2.4 provides a short summary of the proxy-based GMSL reconstructions. I think that this section would benefit from a modest expansion to include some missing (but potentially important) information and some material that appears elsewhere in the paper already.

The Kopp (2016), Kemp (2018), and Walker (2021) GMSL reconstructions are largely iterations of a spatio-temporal statistical model applied to a growing database of Common Era proxy reconstructions. The authors might emphasize a little more that the GMSL reconstructions are less different models and more an evolution in the underlying data. Notably the GSML reconstruction became smoother over these sequential publications. The authors may also want to highlight that the geographic distribution of proxy records is very uneven, but that Kopp (2016) performed sensitivity tests to explore this influence. It is also important to recognize that GMSL is not a quantity that was reconstructed from a proxy, but is rather one component of the relative sea-level signal that is estimated during the record decomposition performed by the spatio-temporal model.

Text on lines 363-365 and 374-375 could be moved into section 2.4.

In this section it might also be appropriate to highlight when notable differences exist between the two GMSL reconstructions (e.g., before ~600 CE).

2. Sea-level fingerprints. Changing the mass of water stored on land as ice results a in fingerprint of sea level change. Although its beyond the paper's focus on GMSL, I think it would be interesting and helpful to show the fingerprints (from individual sources and their sum) that occur as a consequence of the modeled changes in mass from Greenland, Antarctica, and the 18 regions of glaciers. The fingerprints could be compared to the distribution of proxy records, or to estimates of regional sea level trends. It is possible that fingerprinting could help inform model choice if proxy records support/refute particular melt histories. As minimum could the regional contributions from glaciers be provided as a supplemental output for others to convert into sea-level fingerprints.

3. Glaciers appear to be the single most important driver of Common Era GMSL change, but also the most problematic to model and quantify. Please could the authors show the contributions from the 18 different regions of glaciers. In Figure 3D the glacier contribution is shown against global temperature, which the paper does acknowledge (line 460) is an imperfect comparison since glaciers respond to regional climate. Could the glacier contribution from the 18 regions be compared to regional climate from Neukom et al (2019)?

The modeled glacier contribution is large (even described as "remarkable" on line 456), which presumably indicates that some proportion of the 18 regions were behaving in a temporally-coherent fashion (growing/melting at the same time as one another), or possibly that a subset of regions dominate the glacier signal. Simultaneous contributions across multiple regions in the pre-anthropogenic Common Era might be surprising since a

principal conclusion of Neukom et al. (2019) is that temperature trends were not spatially-coherent during this time. I was therefore surprised to see such a large and sustained glacier contribution, because the Neukom et al (2019) analysis led me to think that as one region warmed, another cooled and therefore that the change in glacier mass (and its contribution to GMSL) would be moderated. This is even more surprising because Neukom et al. (2019) conclude that 20th century warming is the only temperature signal which is globally coherent and therefore would effect all the glacier regions simultaneously, yet the contribution to GMSL from glaciers is smaller and slower that it was during times of incoherent temperature variability. I think some regional analysis of glaciers by region would be a useful addition to this paper.

The authors note that modeled GMSL is considerably less than observed and reconstructed 20th century rise. The difference is attributed to underestimating the barystatic contribution, especially from glaciers. In particular, the distribution and size of glaciers at the start of the Common Era was set (by necessity) to be the same as that observed in ~2000 CE, despite anthropogenic warming having already impacted them significantly by ~2000 CE (including some glaciers being lost – line 425 – and therefore missing from the modeled contribution throughout the Common Era presumably). The authors discuss how this effects modeled GMSL since ~1800 CE, but offer less insight into how the problem could bias GMSL estimates before 1800 CE (other than suggesting that the very large contribution from glaciers before ~400 CE could be a spin-up effect from using ~2000 CE as the initial state). I would be interested to read an expanded discussion about how modeled GMSL appears to be an underestimate for the past 200 years, but agrees well with reconstructed GMSL at least for ~800-1800 CE despite the difficulties with glaciers. For example, the difference between GMSL as modeled and reconstructed by Walker is large before ~600 CE. Could (and how) might glaciers solve/cause this discrepancy? If some glaciers are missing, does this mean that the modeled contribution from glaciers is a minimum, and would somehow adding them back in to the GMSL calculation fix the discrepancy since ~1800 CE at the expense of creating a new discrepancy before ~1800 CE?

Technical Corrections

Line 49: The Walker et al. paper is cited as a 2020 publication, but it is listed (correctly) as a 2021 publication in the reference list.

Line 217: Title needs a capital letter.

The 20th century is variously referred to as "20thC" (section 4.1), "twentieth century" (e.g., line 30), or "20th century" (e.g., line 204). These could me made consistent throughout the manuscript.

Line 196: "R" should be changed to "r" for consistency with other titles.

I found Figure 1 to be a little confusing. Readers might find it easier if a third panel was added to show the "below 700m" component rather than including it in panel B which is described initially in the caption as the "top 700m". Or alternatively place the below 700 m, above 700m and total in a single panel.

The use of two y-axes in figure 5a to show the same quantity (sea level, cm) at different scales made the figure difficult to use.