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Ocean Science Discussions

Interactive comment on "El Niño, La Niña, and the global sea level budget" *by* Christopher G. Piecuch and Katherine J. Quinn

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Reviewer's Comment (RC): The paper discusses the steric and barystatic contributions to the global mean sea level record from satellite altimetry during ENSO events. While previous studies have mainly focused on barystatic contributions, this study focuses primarily on the steric contribution to La Nina and El Nino events in sea level. The paper is well written and structured and presents some interesting ideas. Similar to reviewer #1, I mainly have a few general questions for the authors.

Authors' Response (AR): We appreciate the reviewer's positive evaluation of our paper. The manuscript will be revised accordingly, as described in the responses given below.

RC: Correlation/regression analysis: Given the complex nature of the response to ENSO particularly in barystatic sea level, I wonder if a correlation analysis directly

provides conclusive results. As for example Llovel et al., 2010, Fasullo et al., 2012 allude to, the response of the barystatic sea level to ENSO events is related to the complex response of the water cycle, which includes where evaporation/precipitation is generated, what the specific wind patterns are like, what is the setup of the hydrologic basin etc. Hence, the response in the mass part of sea level may be tied to regional variability in the extent of ENSO events as well as their strength. This makes it difficult to only use correlation and regression to quantify the response. However, for the steric part the response may be a bit more straightforward as it is mainly a warming/cooling signal of the upper ocean as this study partly also suggest. In general – as reviewer #1 also mentions – a correlation analysis can easily be misleading if one of the components is not well determined (be it by length of record or definition of indices etc.). Nevertheless, it is very interesting to see the impacts on the different layers in various ocean basins (e.g. Fig. 3, line 142ff) and think it would be great to see more details on this aspect of the study. In particular, it may be interesting to see how spatial patterns of the warming/cooling signals compare – in particular, between the different ARGO products and also compared to altimetry minus GRACE (e.g. total warming vs. layer structure).

AR: There are many warranted concerns being voiced here. Some are already addressed in the manuscript. We acknowledge that, due to the short duration of the data records, some of the relationships seen here may be specific to the time period studied, and not representative of 'the' GMSL response during ENSO (cf. lines 189-191).

We admit that more details on the spatial patterns of steric changes would be of interest to the reader. While the difference between altimetry and GRACE is a vertically integrated measure, and does not give insight onto vertical structure, some analyses along the lines suggested by the reviewer are possible. For example, comparing steric changes globally and regionally from the two Argo centers (Scripps and IPRC) would be straightforward to perform and interpret (i.e., in terms of differing data processing strategies between the two centers), and will be included in the revised manuscript

(see immediately below).

RC: Data products: Two ARGO products are being used for this study. Given the spread between data products and the focus of this paper being the steric contribution, it would be interesting to see a more detailed comparison between the two products used (or even add a third). So far, the differences in the products have mainly been evaluated to determine the error bar for the estimates but it may be worthwhile to look into the spatial distribution and spread for specific ENSO events in more detail.

AR: Given our focus on steric contributions, assessment of uncertainties in various steric products is important. A comprehensive assessment is beyond our scope, better left to a more technical dedicated manuscript, but we will give a few preliminary 'case examples' comparing Scripps and IPRC during particular events. As shown in the figures below, the two products differ noticeably in terms of anomalous regional temperature and global steric changes during the recent El Niño (e.g., last six months of 2015, July-December).

We will include similar figures in the revised paper, point out the discrepancies, and encourage a more thorough future assessment.

RC: Additional data: To add statistical significance to the steric analysis, I am wondering if the inclusion of ECCO output might be useful. The longer time series could support the correlation and regression analysis as well as basic comparisons of depths of the warming/cooling signals in the different ocean basins.

AR: We agree that considering an ECCO solution would allow analysis of a longer period (1992-present). It would also facilitate a more detailed mechanistic understanding of the processes contributing to the global and regional steric changes. Yet, such consideration would make for a much longer paper with a considerably different scope. We think that there is value in providing a concise "first analysis" of the GMSL budget related to ENSO events based purely on observations.

In the discussion of the revision, we will point more explicitly to an analysis along the lines suggested by the reviewer as a logical "next step" in the investigation of GMSL changes linked to ENSO variability.

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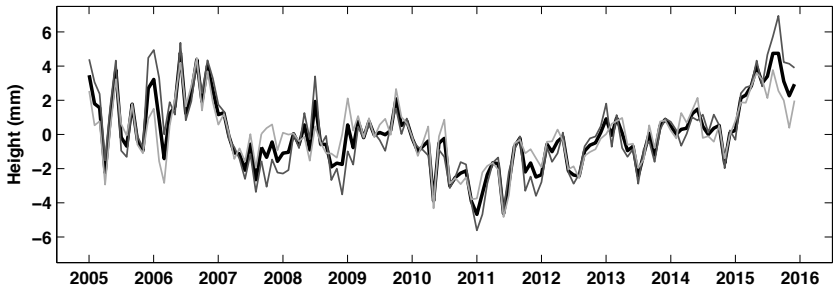

Fig. 1. Time series of nonseasonal anomalous thermosteric sea level from: average of SIO and IPRC products (black); SIO product (dark gray); and IPRC data (light gray).

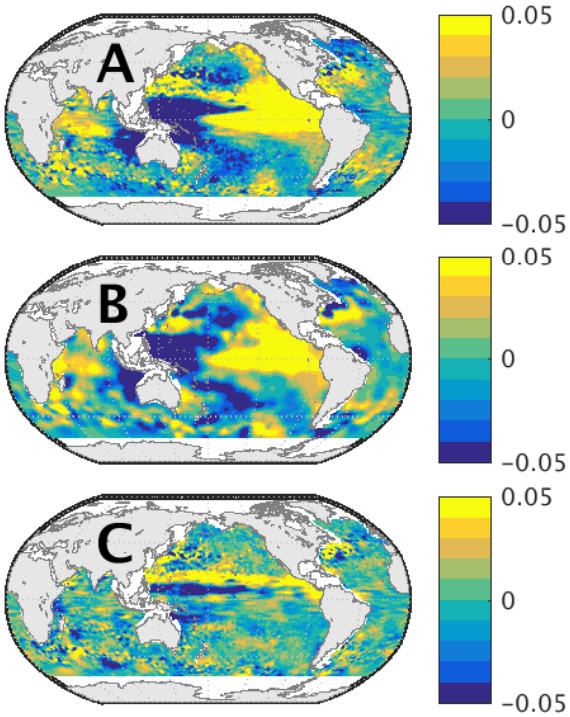

Fig. 2. (A) Nonseasonal anomalous steric sea level averaged over July-December 2015 based on SIO gridded data. (B) As in (A) but computed using gridded data from IPRC. (C) The difference (A)-(B).