# Detecting Deep-Ocean Steric Changes by Conducting Sea Level Budget during the Argo Era

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## Introduction

- Deep oceans (>2,000m) are key heat reservoirs in the Earth System, representing about half of the total ocean volume.
- Only 10% of historical temperature and salinity profiles reach below 2000 m, with just 1.3% of the deep ocean's volume explored twice at this depth.
- Combining data from satellite altimetry, the Gravity Recovery and Climate Experiment (GRACE), and the Argo array makes detecting deep ocean steric height changes possible by conducting sea level budget.
- Earlier research utilizing this approach found that, within a 6-10 year data record, the deep ocean's effect on sea-level changes was undetectable on global and basin scales.
- We extend the analysis to an 18-year period (2005-2022) to see if deep ocean impacts on sea-level changes become detectable on different spatial scales.

## Data and Methods

**Total Sea Level** = **Mass Component** +
Satellite Altimetry (CMEMS) GRACE/GRACE-FO (JPL RL06.1V03)

**Upper Ocean Steric** +
Argo Array (SIO, EN4, IAP, Ishii, JAMSTEC)

**Deep Ocean Steric**
(**Residual**)

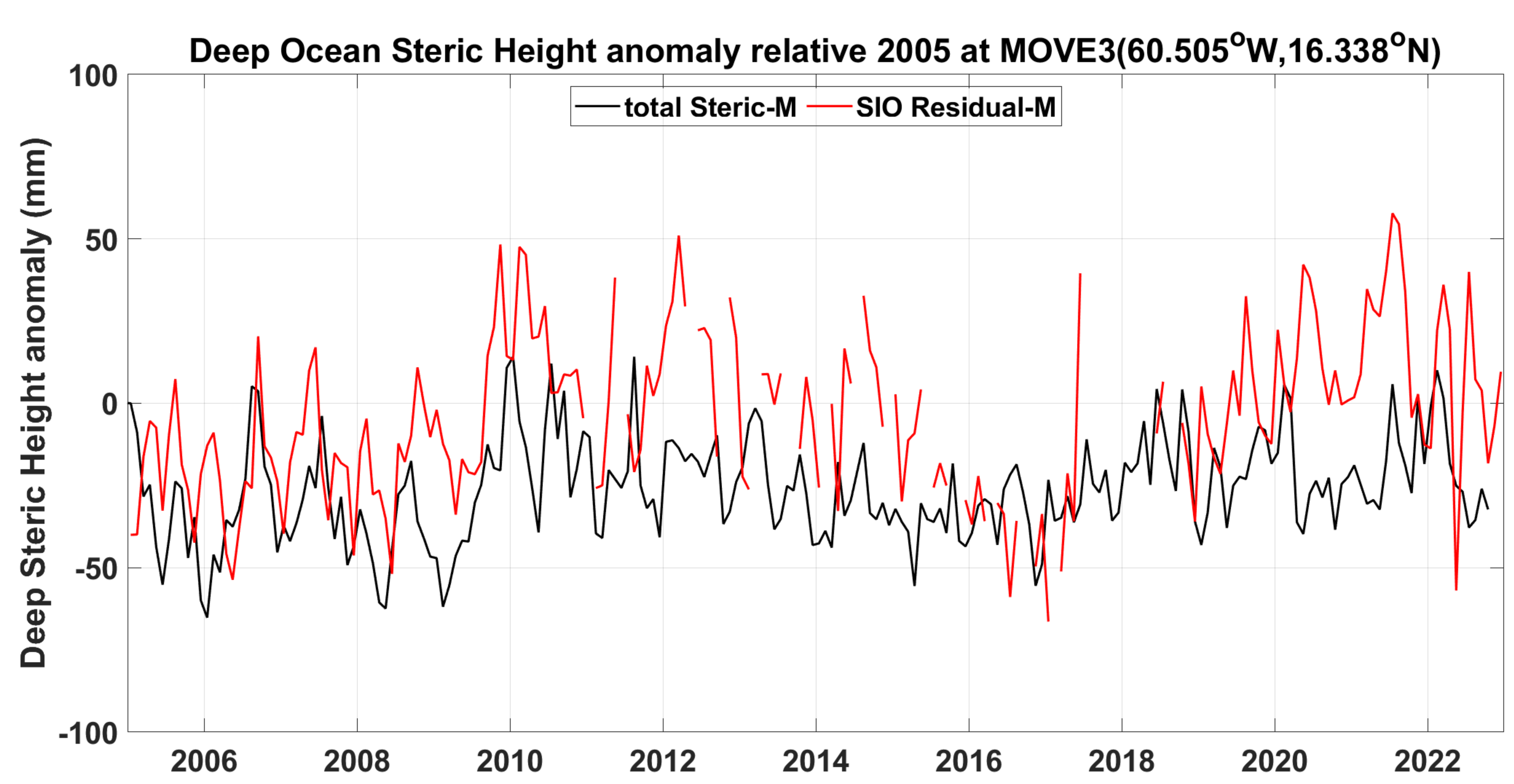


**Figure 1.** Deep Steric height from direct observation (black) and residual method (red) at the MOVE3 location.

## Preliminary Results

### Spatial Map of Residual Steric Linear Trends

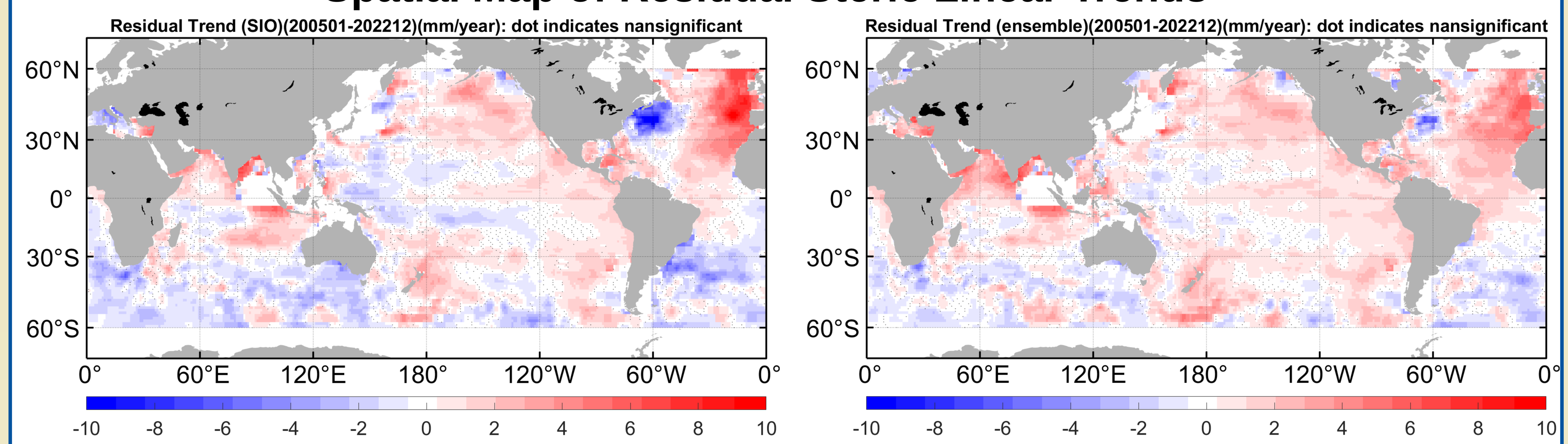


**Figure 2.** Spatial map of residual steric linear trends using SIO-only (left) and ensemble mean (right). Regions with large earthquake signals in the gravity data were masked out.

### Global and Basin Averages

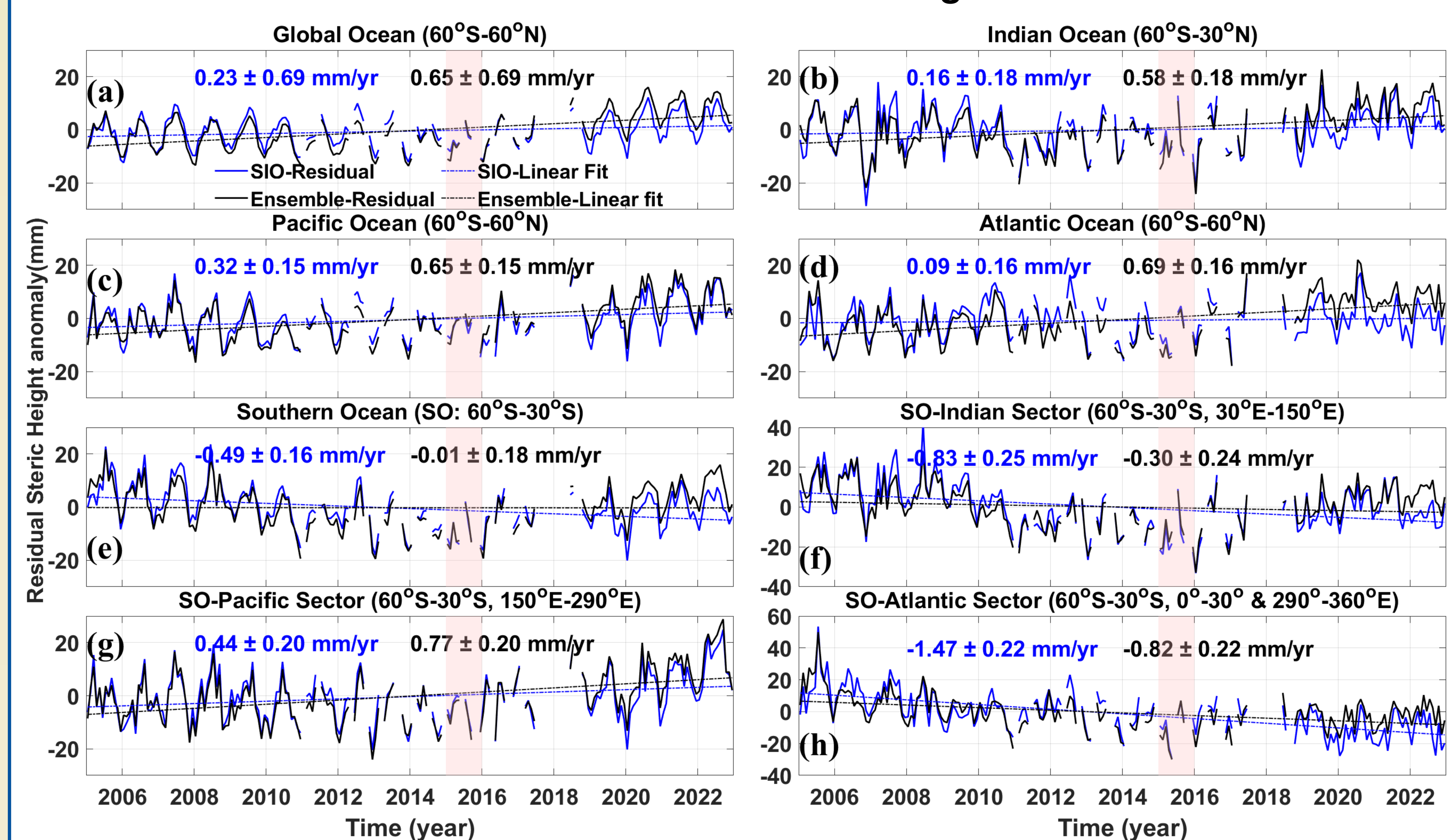


**Figure 3.** Averaged residual steric height and linear trends at global and ocean basin scales for SIO (blue) and ensemble mean (black). Uncertainties of global trends are estimated following Llovel et al.(2014), others are only reported as formal error from the linear fit.

### Sub-basin Averages

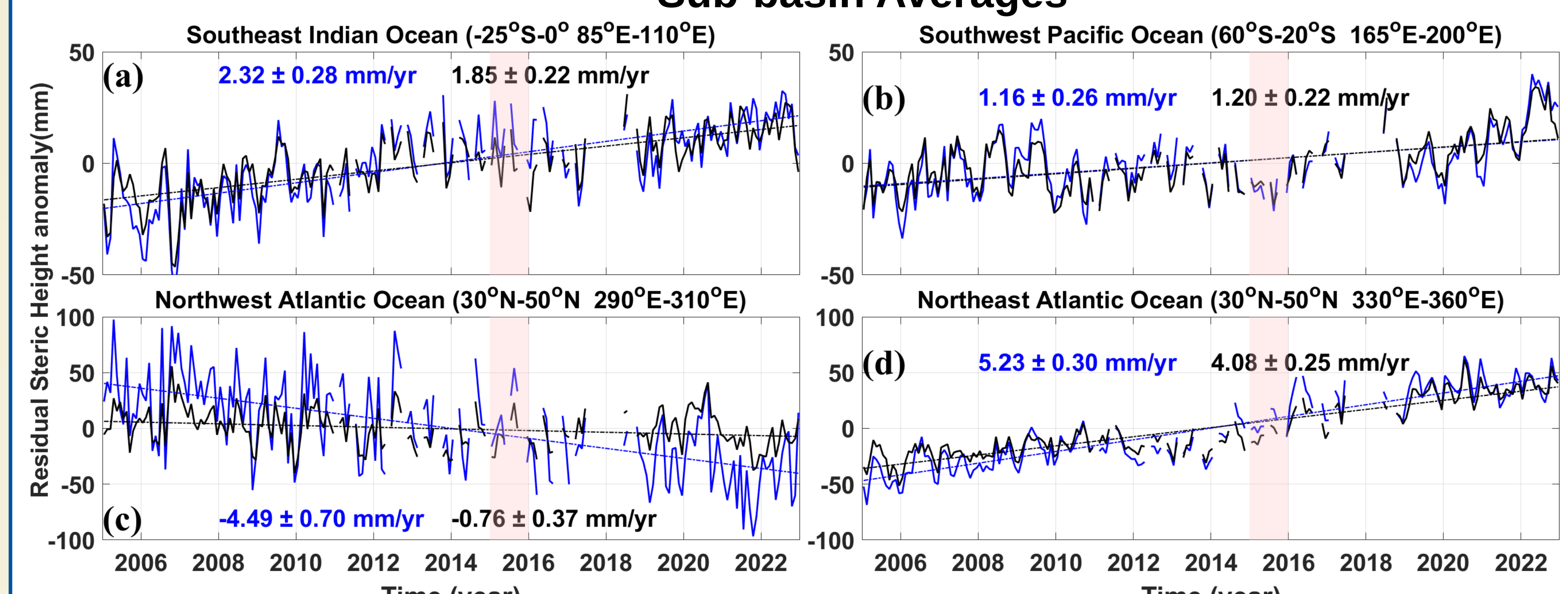


**Figure 4**. Same as Figure 2 but for sub-basin averages.

## Key Findings

- Spatial patterns of residual trends show general consistency across both analyses (**Figure 2)**.
- From 2005 to 2022, both SIO-only (0.23 ± 0.69 mm/year) and ensemble mean (0.65 ± 0.69 mm/year) analyses reveal a positive yet statistically insignificant global residual trend.
- Discrepancies in residual trends across scales in both analyses (**Figures 3, 4**), pre- and post-2015, are linked to Argo floats' salinity drift.
- Observed negative residual trends in the Southern Ocean contradict observational studies showing warming and freshening trends.
- The residual trend exceeding 4 mm/year persistently appears in the northeast Atlantic throughout the entire data record.

## Ongoing Work

- Validating the residual method by comparing with observations in areas where direct measurements are available (e.g., historical hydrographic measurements, AMOC monitoring mooring arrays, deep Argo floats).
- Utilizing the state-of-the-art ocean state estimate ECCO version 4 release 4 (v4r4) to investigate possible cause of large regional residuals like in the North Atlantic.

## Conclusions

- Detecting global and basin-scale deep ocean steric changes through the residual method remains challenging with longer time records but shows potential in smaller regions.
- Information from other measurements, such as the ongoing GO-SHIP full-depth hydrographic measurements and expanded deployment of Deep Argo floats, can be combined to resolve and understand climate signals in the deep ocean.

## References

- Llovel et al., (2014). Deep-ocean contribution to sea level and energy budget not detectable over the past decade. DOI: 10.1038/NCLIMATE2387