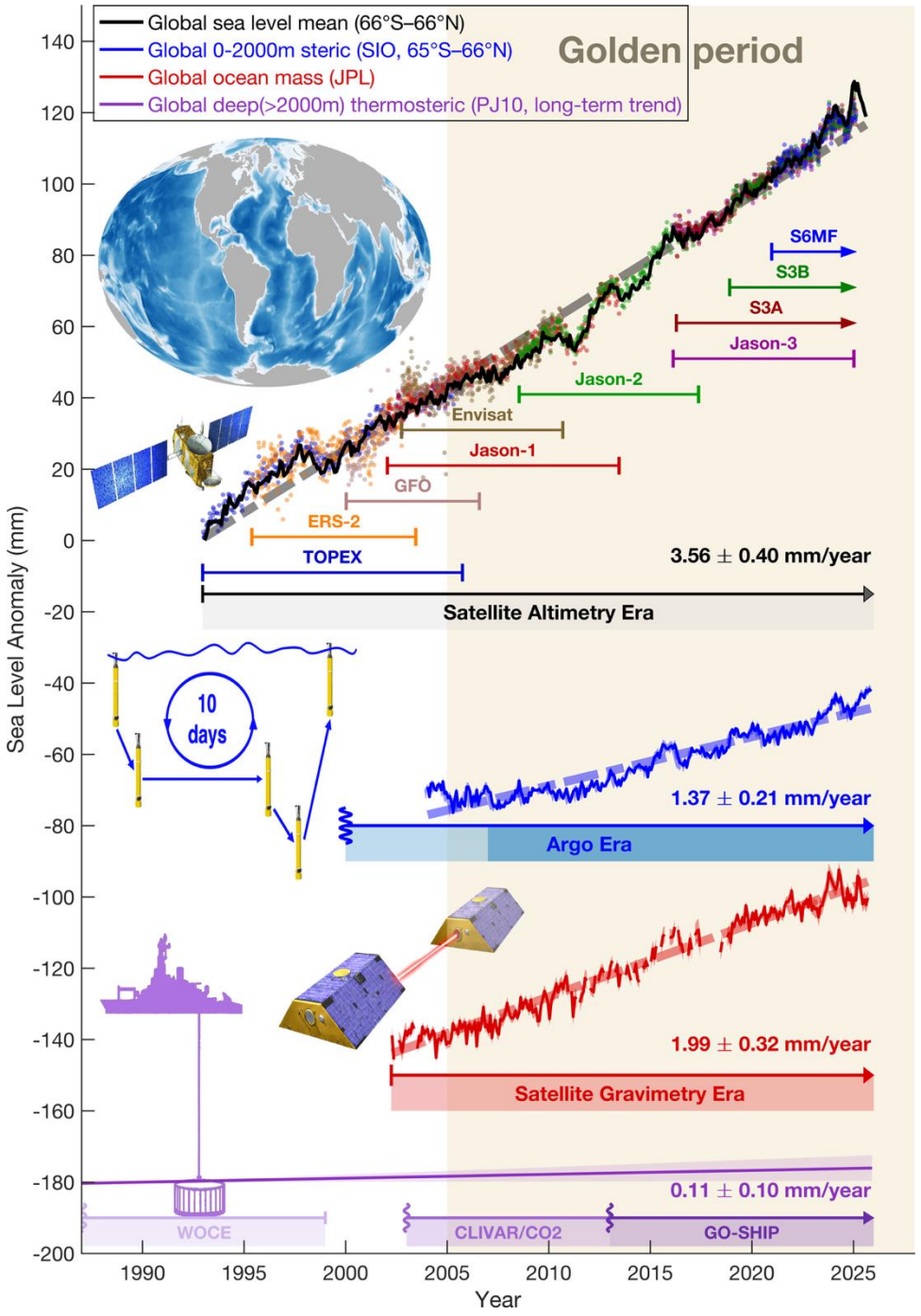
Detecting Long-Term Deep-Ocean Steric Changes through Sea Level Budget Analysis Remains Challenging

Yang Zhang[1], Xinfeng Liang[1*], Don Chambers[2]

1. University of Delaware
2. University of South Florida

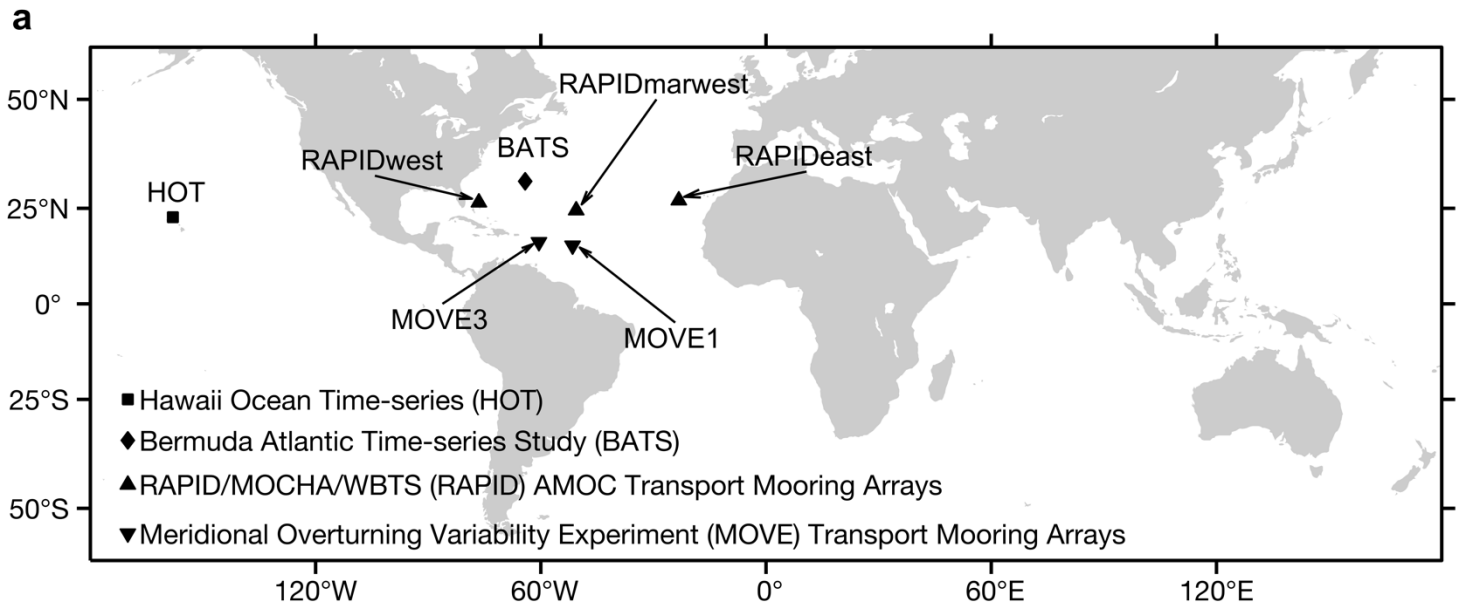
Motivation

- The deep ocean (>2000m) accounts for 50% of ocean volume, yet observations are sparse.
- A promising method to estimate deep-ocean steric changes involves subtracting upper-ocean steric (Argo) and mass (GRACE/FO) from total sea level (Altimetry).
- Here, we want to evaluate the detectability of regional deep-ocean signals over a 20-year period (2005–2022) using long-term *in situ* benchmarks.



Data & Methods

- Combined use of Satellite Altimetry, GRACE/GRACE-FO (mass), and an ensemble of five Argo products (upper 2000m)
- Validated against 7 long-term deep-ocean sites, including BATS, HOT, RAPID, and MOVE mooring arrays.

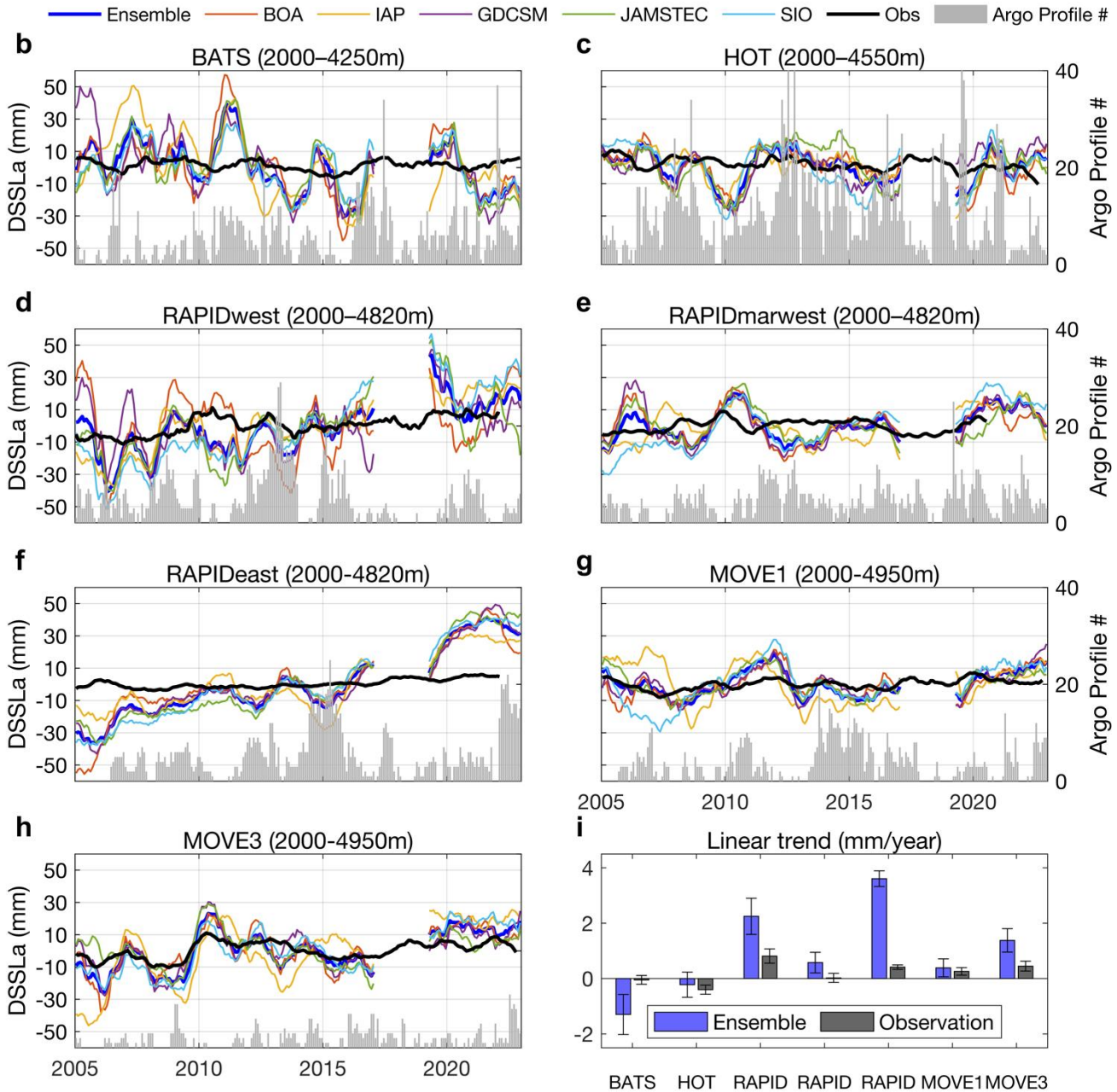


Zhang et al., In Review

Validation Against Direct Observations

Variability:

- Directly measured deep steric variability is 2 to 7 times smaller than residual estimates based on sea level budget analyses.
- Correlations are generally low to moderate across most sites.

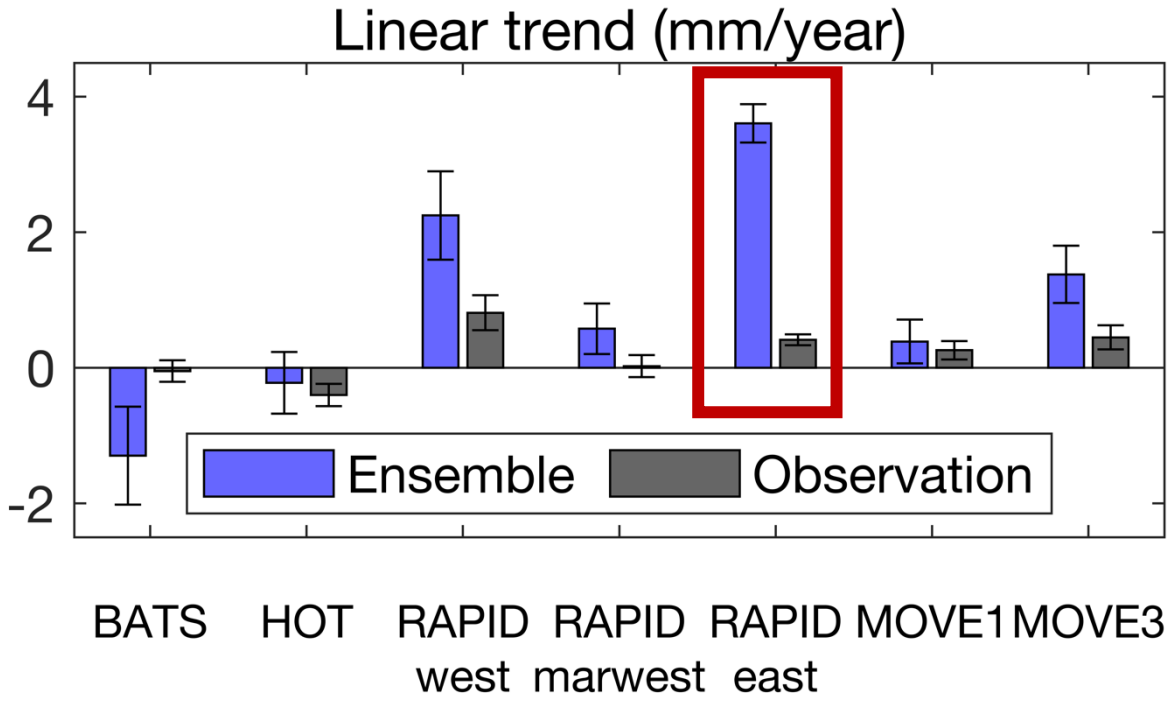


Zhang et al., In Review

Validation Against Direct Observations

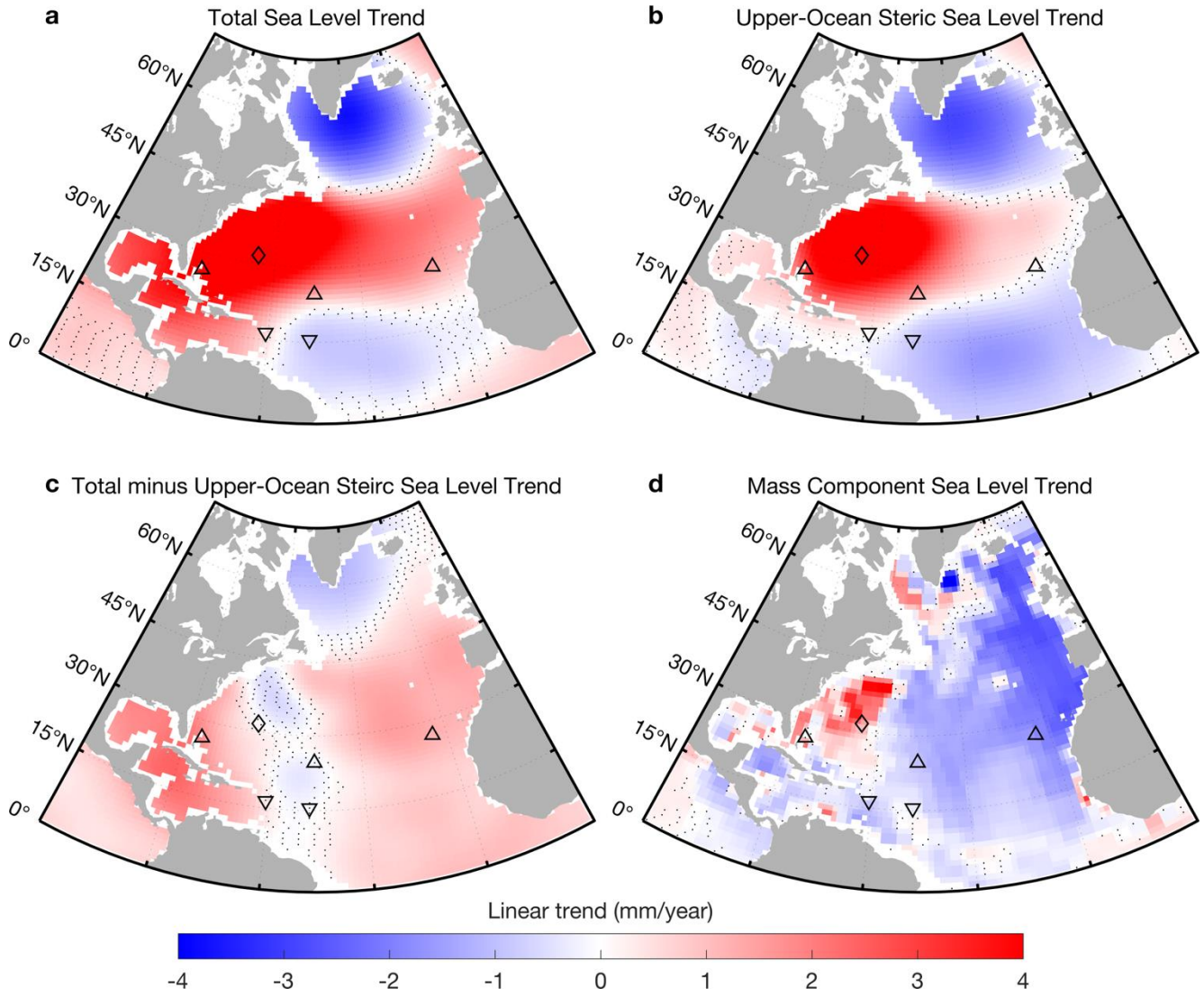
Trend:

- While the residual method often captures the *sign*, it consistently inflates the magnitude.
- At the **RAPIDeast** site, the residual trend (3.61 mm/yr) is nearly 9 times larger than the observed trend (0.41 mm/yr).
- This massive mismatch suggests a significant bias in one of the sea-level components.



The Northeast Atlantic Discrepancy

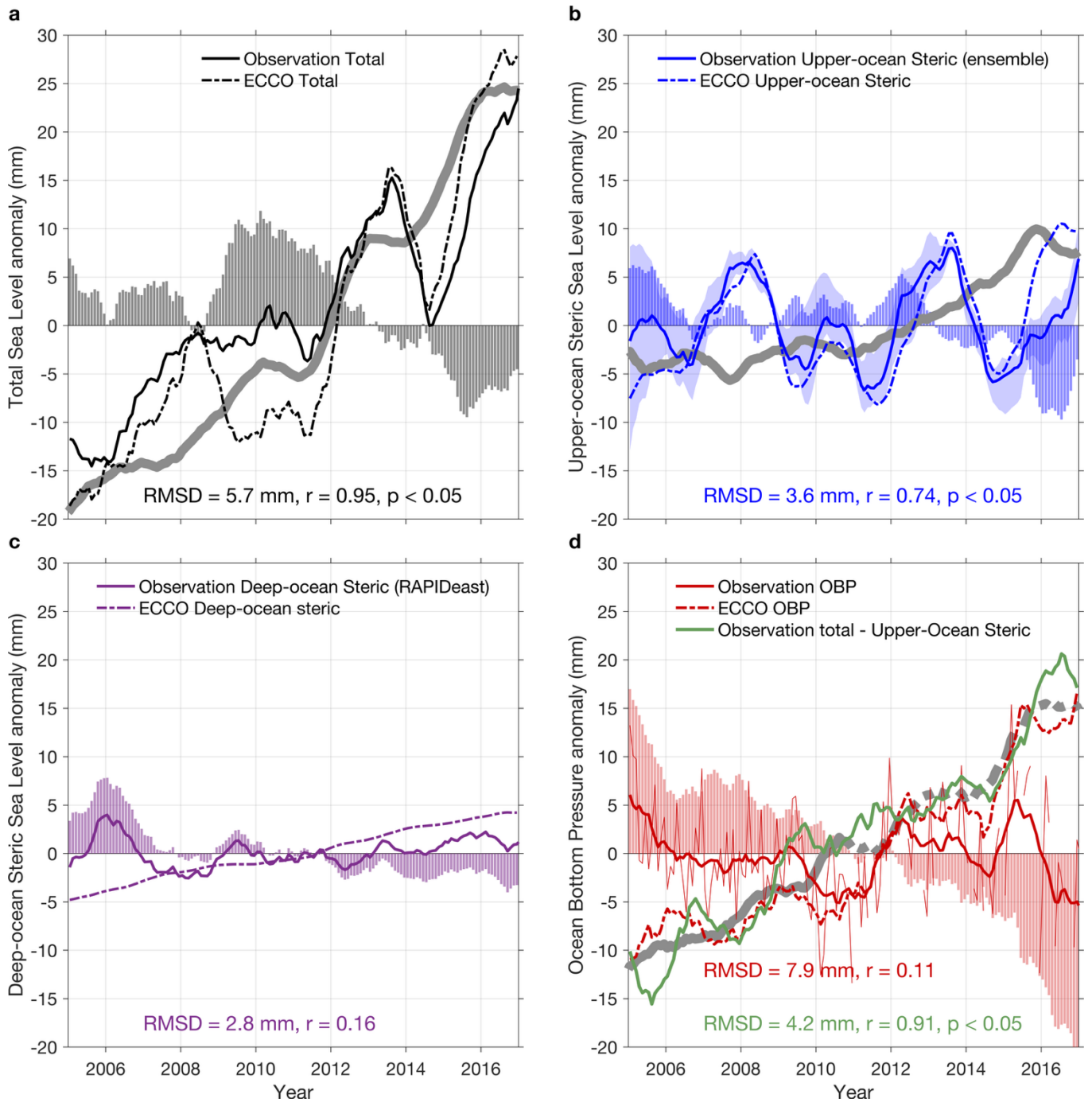
- Both the total sea level trend and the upper-ocean steric sea level trend are reasonable.
- Their difference shows a mostly positive trend across most of the North Atlantic.
- But the mass component (GRACE/FO) displays a different magnitude and pattern.



Zhang et al., In Review

Evidence for GRACE/FO Issue

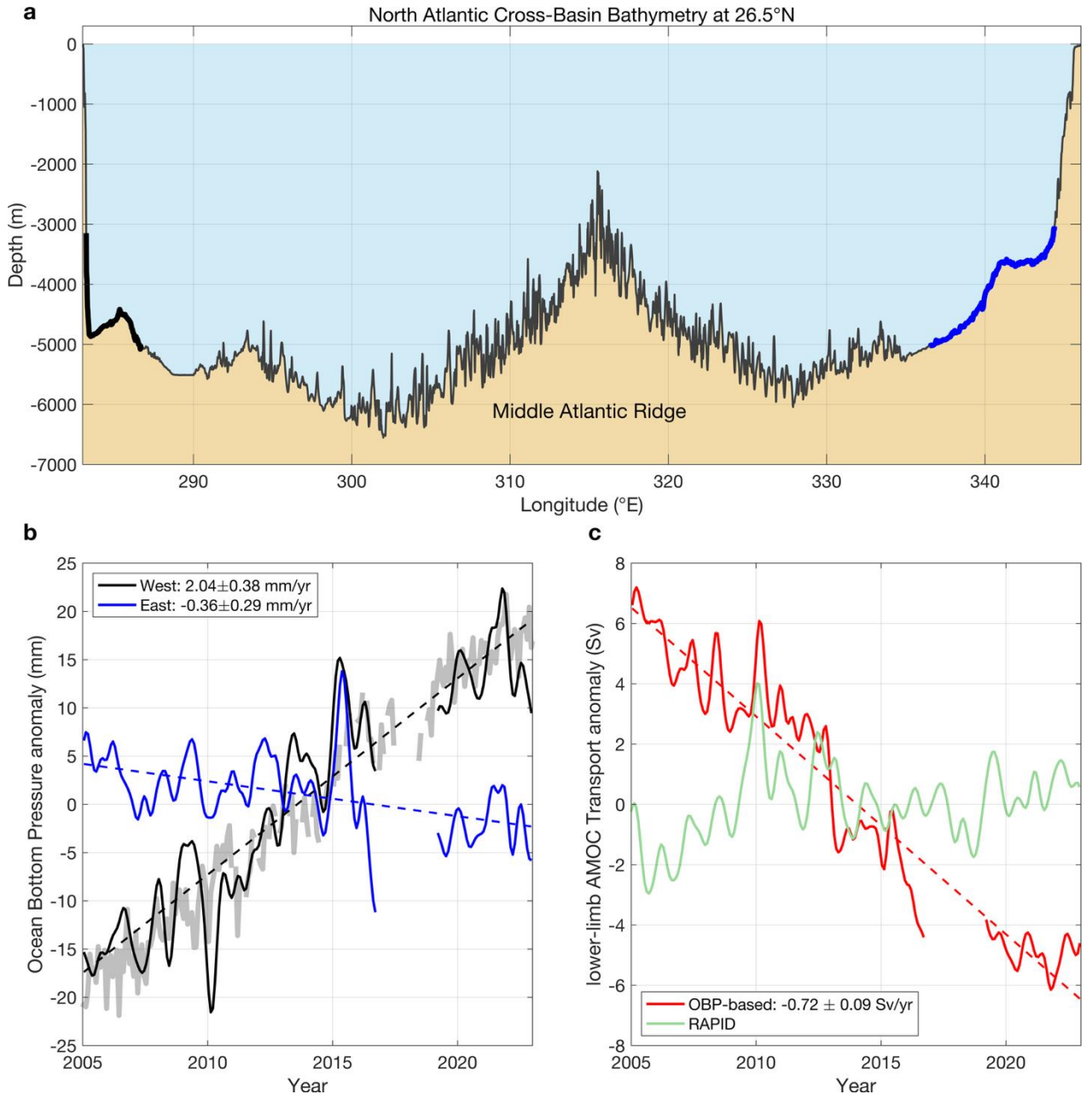
- ECCO does *not* show this Northeast Atlantic mass decrease.
- Observed total sea level and upper-ocean steric data agree well with ECCO; the mismatch resides almost entirely in the GRACE/FO mass/OBP term.
- This analysis indicates the misclosure is due to mass-term contamination rather than Argo "salty drift".



Zhang et al., In Review

Evidence for GRACE/FO Issue

- Assuming the GRACE/FO signals are real, we can calculate the transport in the deep ocean following **Landerer et al. (2015).**
- Interpreting the GRACE/FO signal as ocean mass would imply a massive, unobserved trend of the lower-limb AMOC transport.
- Multiple lines of evidence suggest the signal is a "solid earth" gravity change (potentially from the mantle or core) rather than water mass movement.



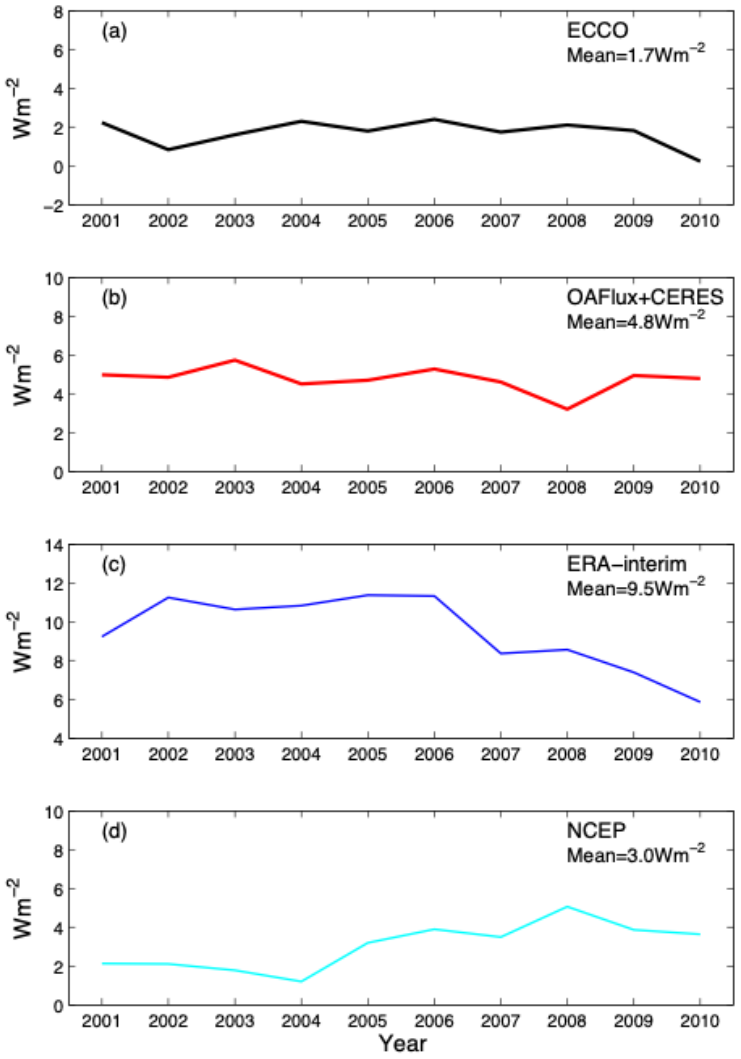
Zhang et al., In Review

Conclusions

- Detecting long-term deep-ocean steric changes through sea level budget analysis remains challenging, even with longer records.
- Users of GRACE/FO data in the North Atlantic should be wary of unmodeled solid-earth gravitational signals and the issue with ocean mass /ocean bottom pressure data.
- Future work is needed to isolate and model these deep-earth processes to improve estimates of ocean mass and ocean bottom pressure, as well as the accuracy of oceanographic budget analyses.

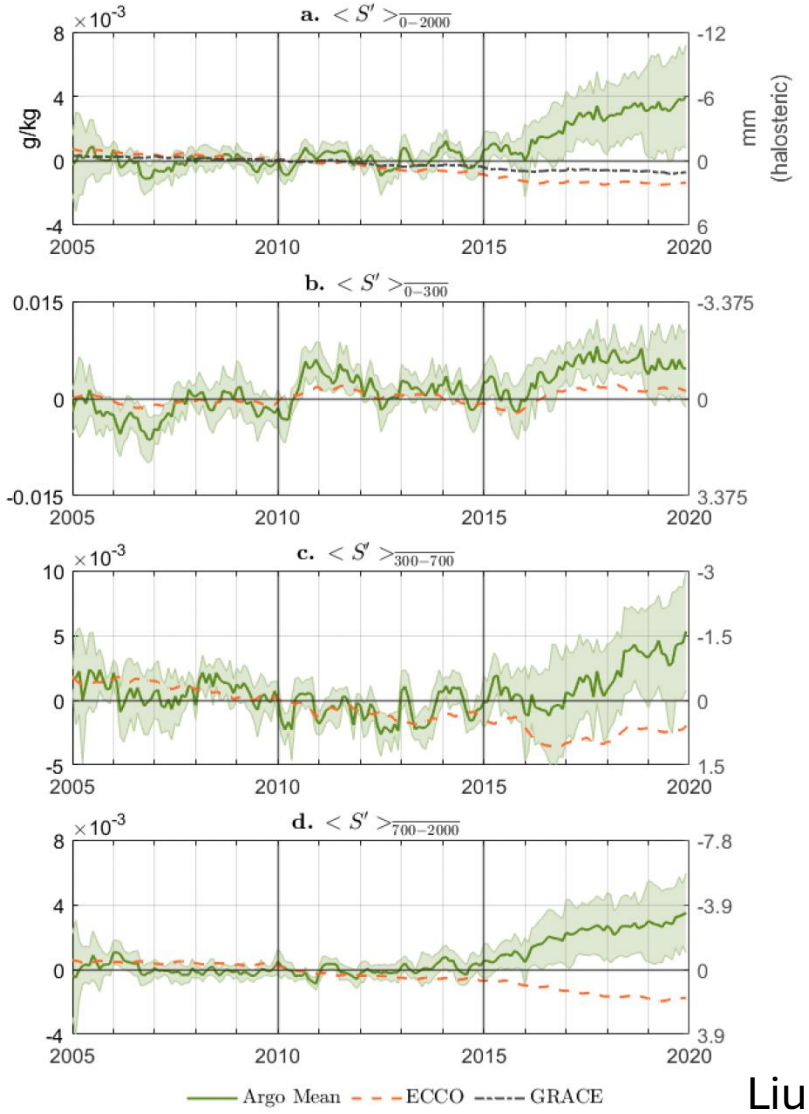
Two Other Examples:

Annual Means of the Globally Averaged Qnet



Liang & Yu, 2016

Global “Salinification” in Gridded Argo Products

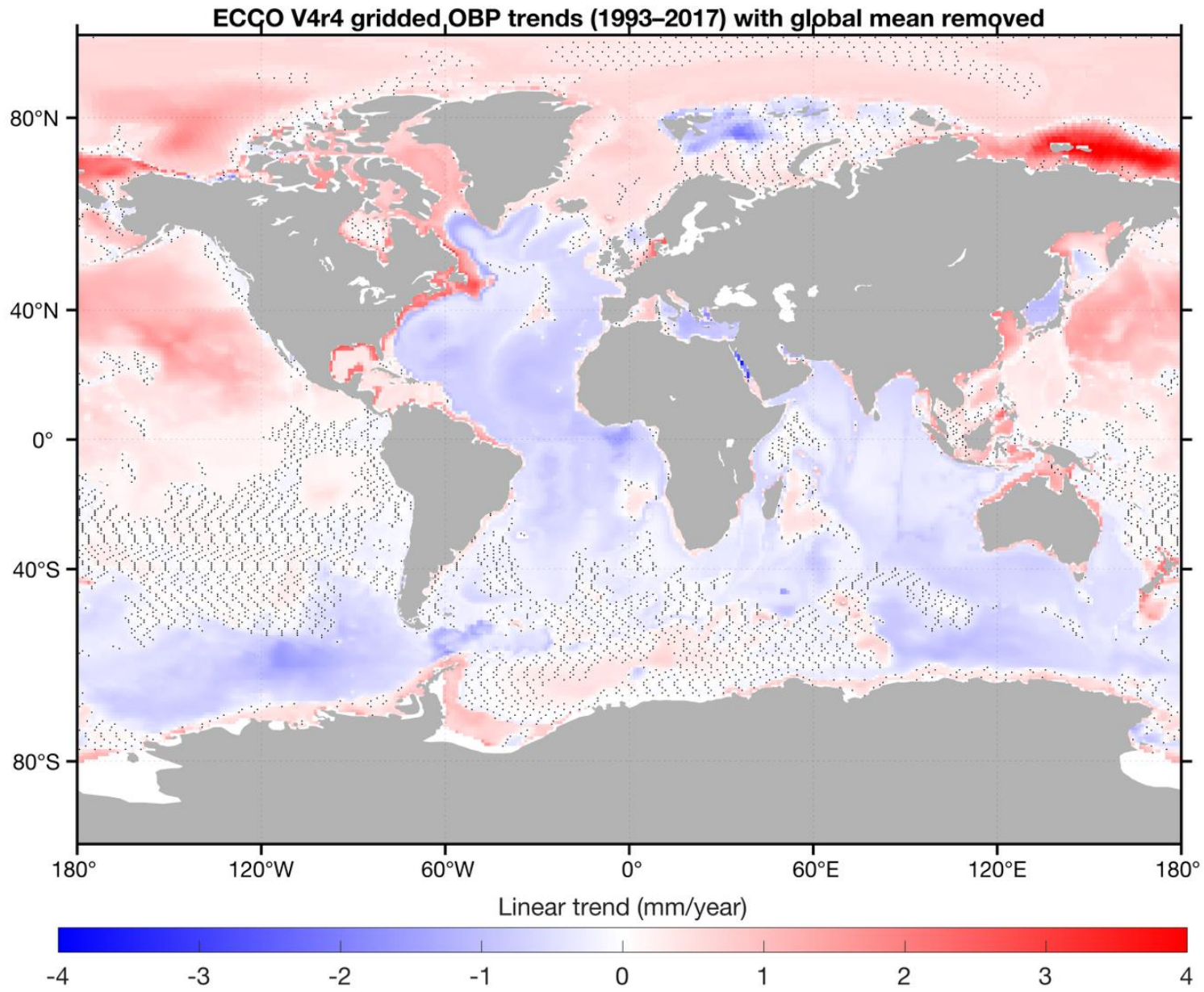


Liu et al., 2024

What does this mean for ECCO?

- The disagreements/misfits between ECCO estimates and various observational data that ECCO assimilated are useful.
- They are not necessarily a bad thing. Sometimes they are, and efforts are needed to reduce them.
- Sometimes they are not and they in fact provide valuable information about potential issues of the observational datasets.
- More efforts can be put into examining those disagreements/misfits.

Thanks!


ECCO V4r4 gridded OBP trends (1993–2017) with global mean removed
80°N
40°N
0°
40°S
80°S
180°
120°W
60°W
0°
60°E
120°E
180°
Linear trend (mm/year)
-4
-3
-2
-1
0
1
2
3
4