Inferring Altimetry Data Uncertainty from ECCO Ocean State Estimates

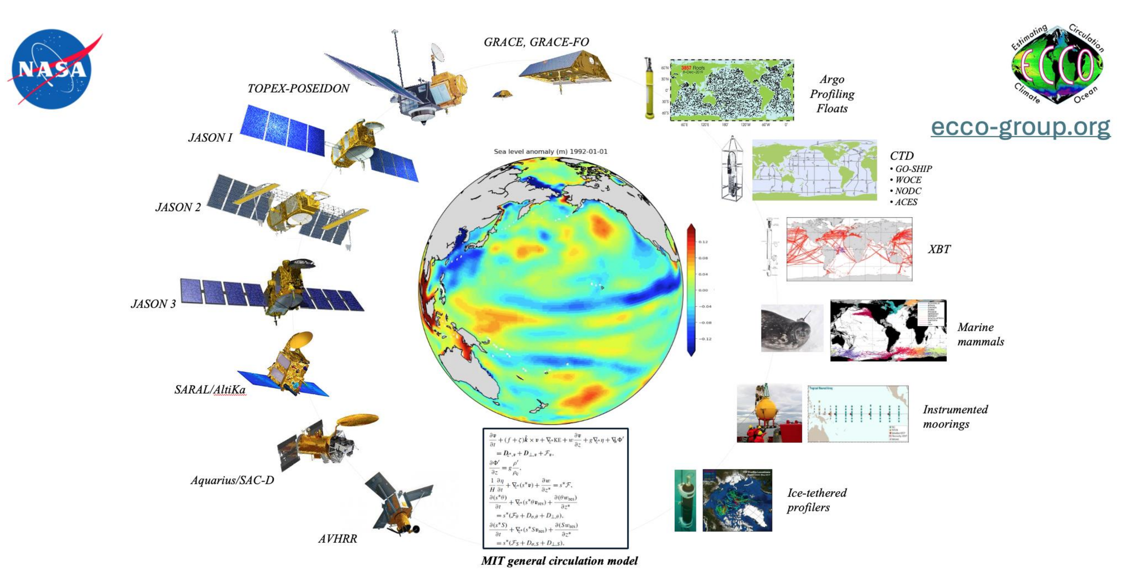
Ou Wang[1*], Ichiro Fukumori[1], Ian Fenty[1,] and Josh Willis[1]

[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, U.S.A.

Introduction & Motivation

- The Challenge: Satellite-altimetric sea level observations are critical for operational oceanography, but their spatial and temporal uncertainty structures are not fully characterized.
- The Goal: Characterize sea-level uncertainty across multiple satellite altimetry missions from the perspective of dynamically consistent ocean state estimation.
- Why it matters: Understanding these error structures improves data assimilation, climate trend analyses, and operational ocean forecasting.

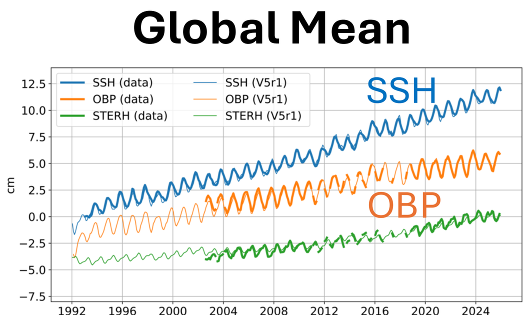
The ECCO State Estimate



•Utilizes the **ECCO Version 5, Release 1** solution from the Estimating the Circulation and Climate of the Ocean (**ECCO**) project. The ECCO framework synthesizes the **MITgcm** with vast observational constraints to produce a dynamically consistent solution that closes budgets for sea level and other properties.
•**Period:** 1992-2025 (Full satellite altimetry era)
•**Spatial Resolution:** Nominal **1/3° horizontal resolution**.
•**Data Constraints:** Explicitly constrained by:
 •Altimetry from **reference** missions: **TOPEX/Poseidon, Jason-1, Jason-2, and Jason-3**
 •Altimetry from **non-reference** missions: **ERS-1, ERS-2, Envisat, SARAL/AltiKa, Geosat Follow-On & CryoSat-2**
 •**RADS** (Scharroo et al., 2013) altimetry data were used with standard corrections.
 •Additional satellites (GRACE/FO, SST, SSS, etc.) and *in situ* (Argo etc.) observations of other ocean variables.
•**Iterative Optimization Process:** Minimizes model-data misfit via the adjoint method in an iterative forward-backward loop.

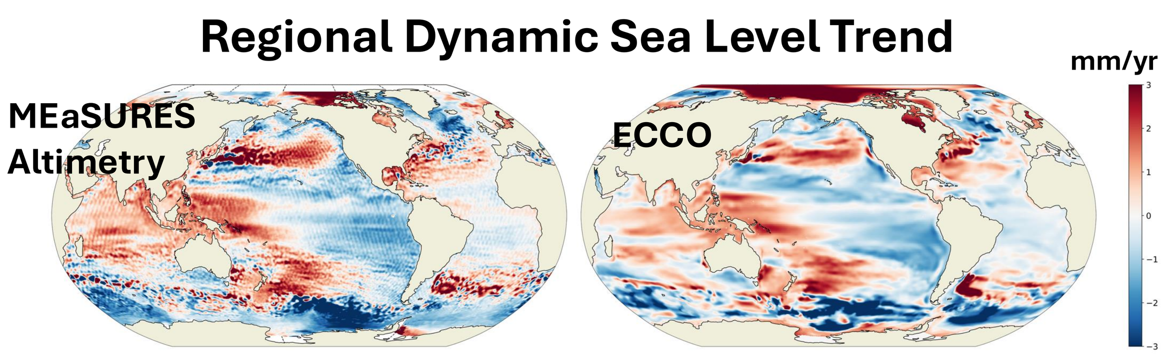
SSH Comparison: Data vs. Model

Global Mean



- ECCO matches observations in both the global mean sea level and regional sea level trends over the satellite altimetry era.

Regional Dynamic Sea Level Trend



Cost Function

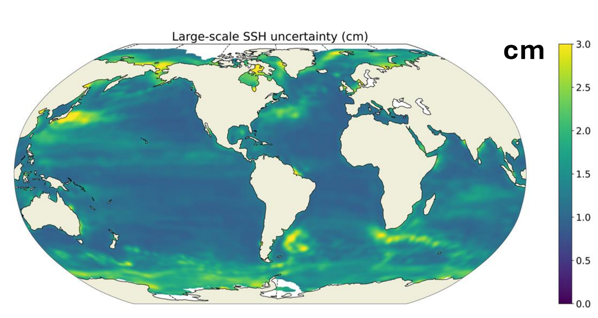
To evaluate the misfit between satellite observations and the ECCO state estimate, we compute a normalized, weighted **cost function *J***:

$$J = \sum_{m,t,s} \left(\frac{\overline{SSHA_{model} - SSHA_{obs}}}{\sigma} \right)^2$$

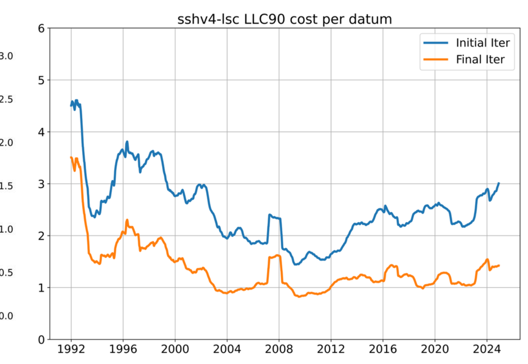
SSHA	Sea surface height anomaly relative to the global mean and time-mean
$\overline{\cdots}$	Denotes that raw model-data difference has been smoothed both spatially (~3°) and temporally (35 days)
σ	The specified target error uncertainty (combining observational and model representation errors).
m	Denotes satellite missions (including both reference and non-reference missions).
t,s	Time and spatial location.

Misfit Reduction & Cost Convergence

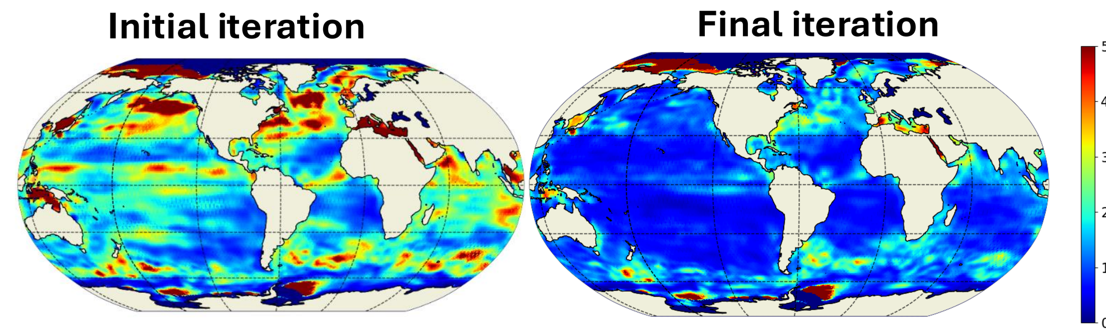
Large-scale SSH uncertainty



Cost per datum vs. time



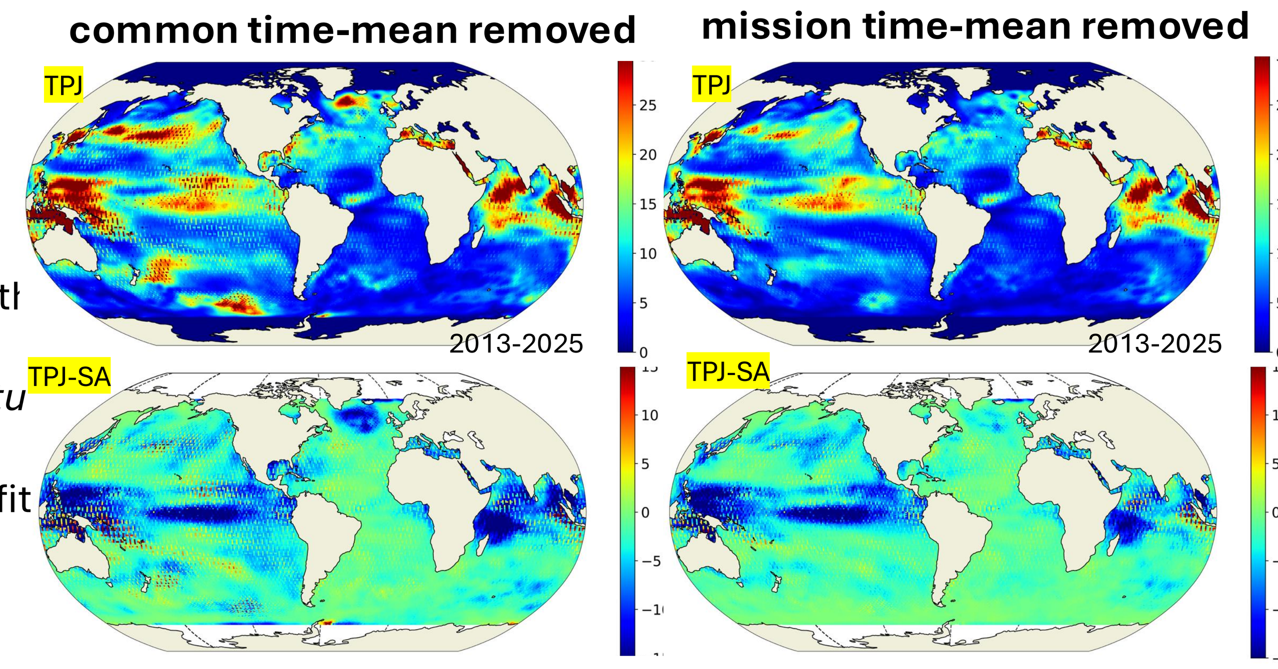
Cost per datum vs. space



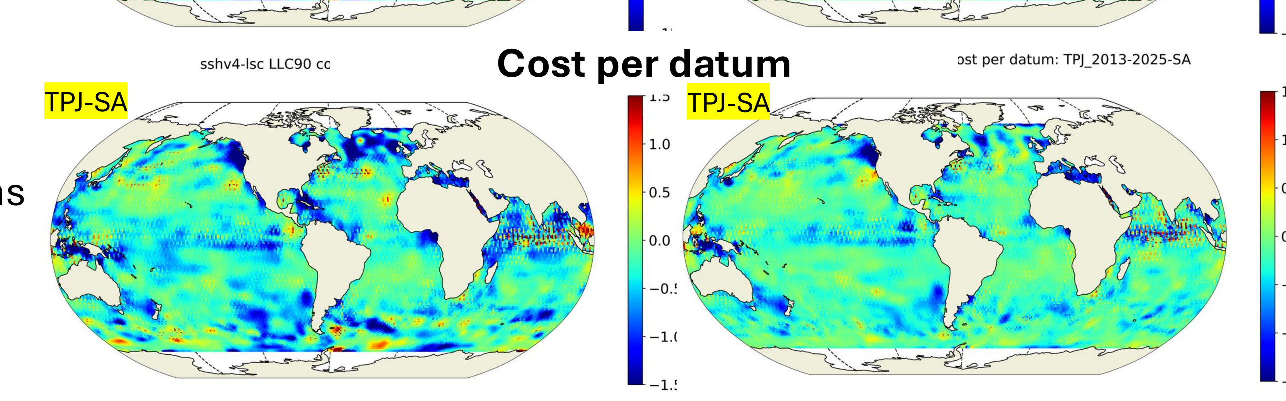
- **Misfit Reduction:** Adjusting the atmospheric forcing control variables successfully drives down the model-data misfit between the initial and final iterations.
- **Cost Convergence:** Both spatial and temporal cost plots show that the final cost converges close to *J≅1* across most regions and times. Persistent misfits *(J>1)* indicate specific areas and time periods where the model and data remain irreconcilable.

The Mean Matters Common vs. Mission-specific

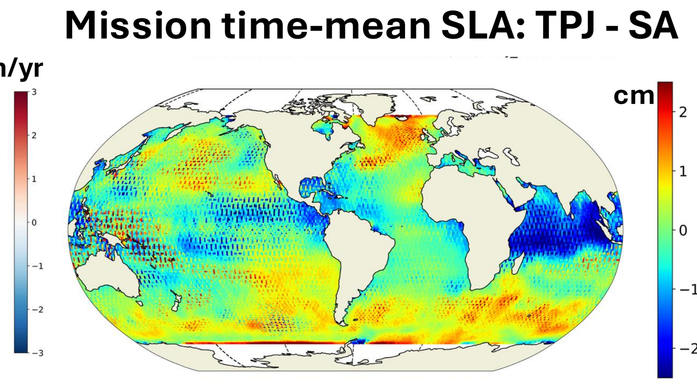
Data variance per datum



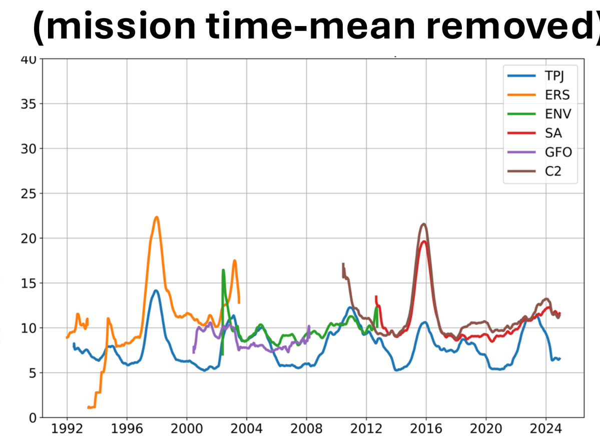
Cost per datum



Mission time-mean SLA: TPJ - SA



Data variance per datum (mission time-mean removed)



- Using mission-specific time-means reduces both data variance and cost compared to using a common mean.
- The regions with the largest differences between the TPJ and SARAL/AltiKa mission-specific means correspond to those where data variance and costs see the largest reductions.
- For TPJ, only data from the SA period (2013-2025) are used.

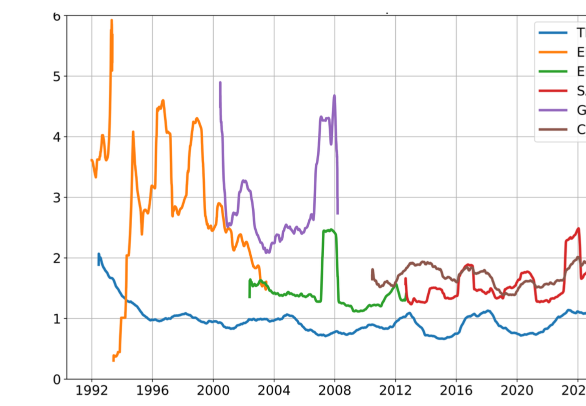
Acknowledgements
This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration (80NM0018D0004). The altimeter data were retrieved from the Radar Altimeter Database System (RADS) provided by Remko Scharroo and Eric Leuliette.

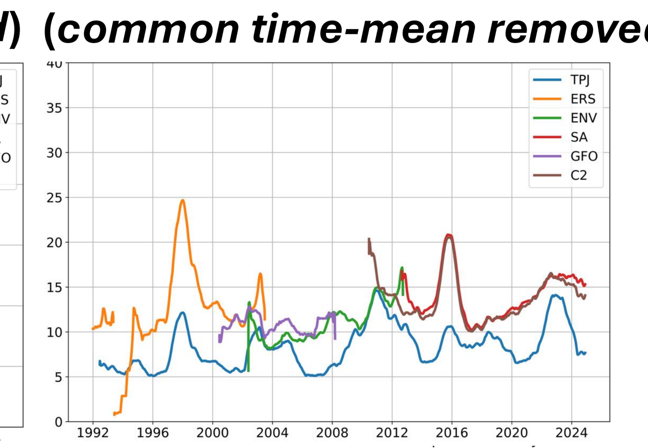
References:
Scharroo, R., E. W. Leuliette, J. L. Lillibridge, D. Byrne, M. C. Naeije, and G. T. Mitchum. (2013). "RADS: Consistent multi-mission products." In *Proceedings of the Symposium on 20 Years of Progress in Radar Altimetry*, Venice, Italy. European Space Agency Special Publication, ESA SP-710.

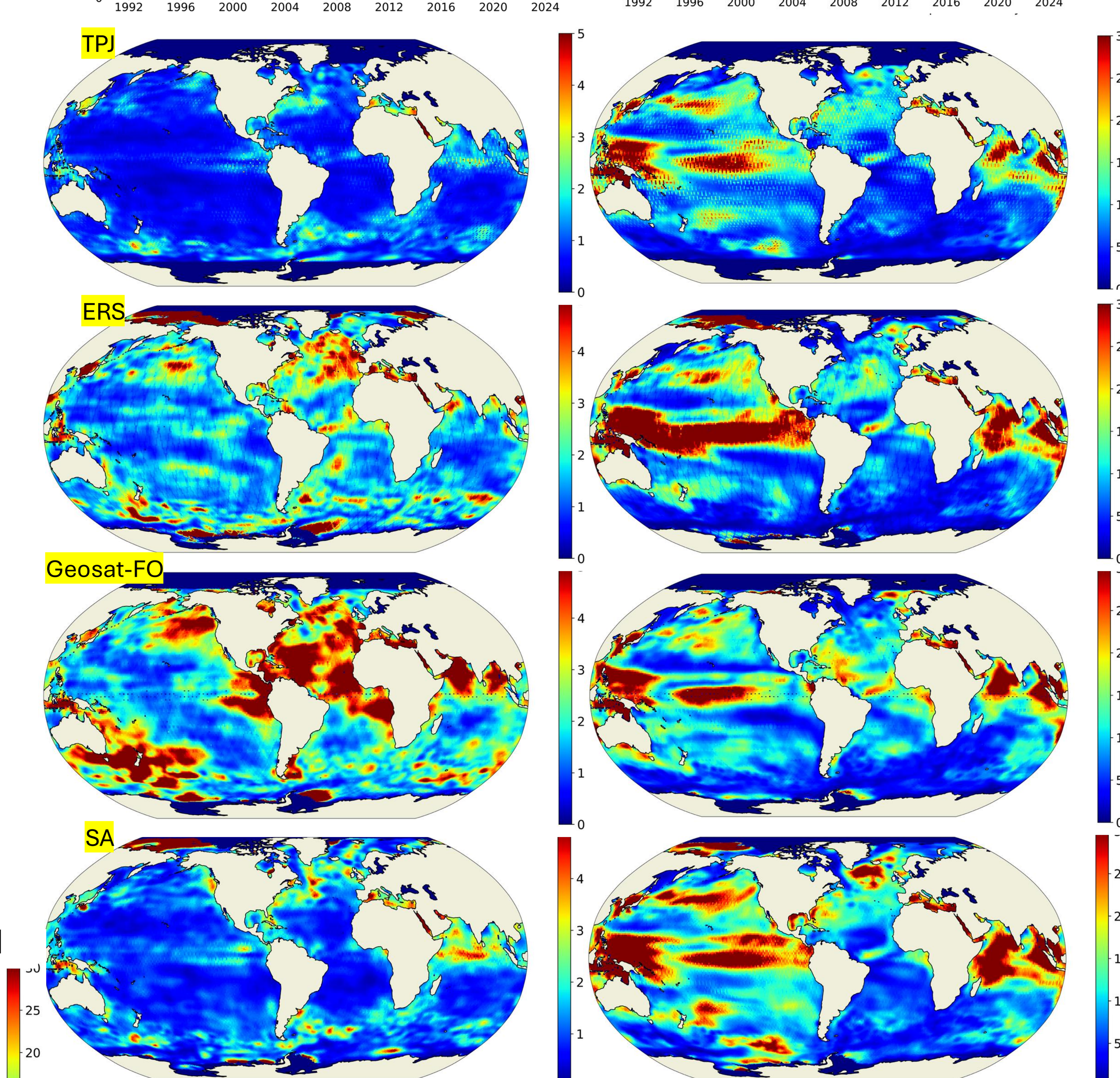
Author Contact Information Ou.Wang@jpl.nasa.gov 1 (818) 393-3204

Mission-Specific Model-Data Mismatch Characteristics

Cost per datum (*common time-mean removed*) / Data variance per datum (*common time-mean removed*)

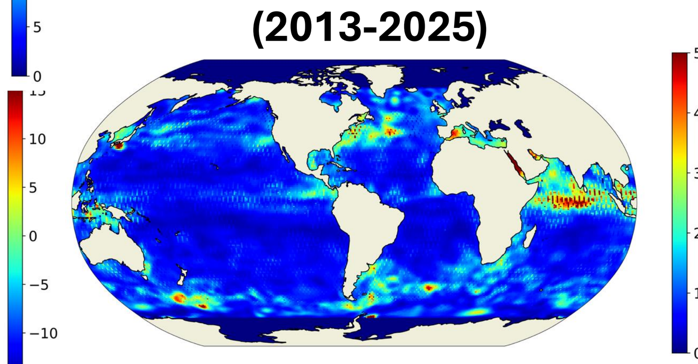






Data variance is computed similarly to cost and therefore normalized.

TPJ cost over SA period (2013-2025)



- Differences in data variances indicate data errors, while similar costs between missions indicate model representation errors.

Dynamics-Based Filtering: Large misfits indicate model rejecting data due to residual data error and/or model representation error.

Temporal Stability (Reference vs. Non-Reference):
- The reference missions exhibit stationary residuals through time with minimal variance.
- Conversely, the non-reference missions display significantly larger, more temporally variable residuals, even though their underlying raw data characteristics are highly similar.

Spatial Distribution of Mismatch
- Non-reference missions exhibit elevated costs in many regions, including high latitudes, the North Atlantic, Northeast Pacific, North Indian Ocean, and shallow waters.
- This highlights increased observational or model representation uncertainty in these regions.

Conclusions & Next Steps

- Non-reference satellite missions exhibit large misfits in many regions and non-stationary characteristics in time, whereas reference missions display low, stable misfits across the global ocean and throughout time.
- Removing mission-specific time-means is preferred over removing a common mean in state estimation.
- By rejecting data in these large-misfit regions and periods, ECCO acts as a dynamics-based filter, identifying potential data errors without relying on traditional cross-calibration.
- Future work will leverage these newly identified spatial and temporal error characteristics to dynamically weight data assimilation constraints, as well as remove mission-specific time means, to improve the accuracy of next-generation ocean state estimates.