Improving Global Tide Models Using GRACE Data

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Overview:

Estimates of tidal errors (in GOT4.7) obtained from analysis of GRACE Level 1-B data (R. D. Ray, B. Loomis, S. Luthcke)

→ Suitable for re-processing GRACE range-rate data (or other POD)

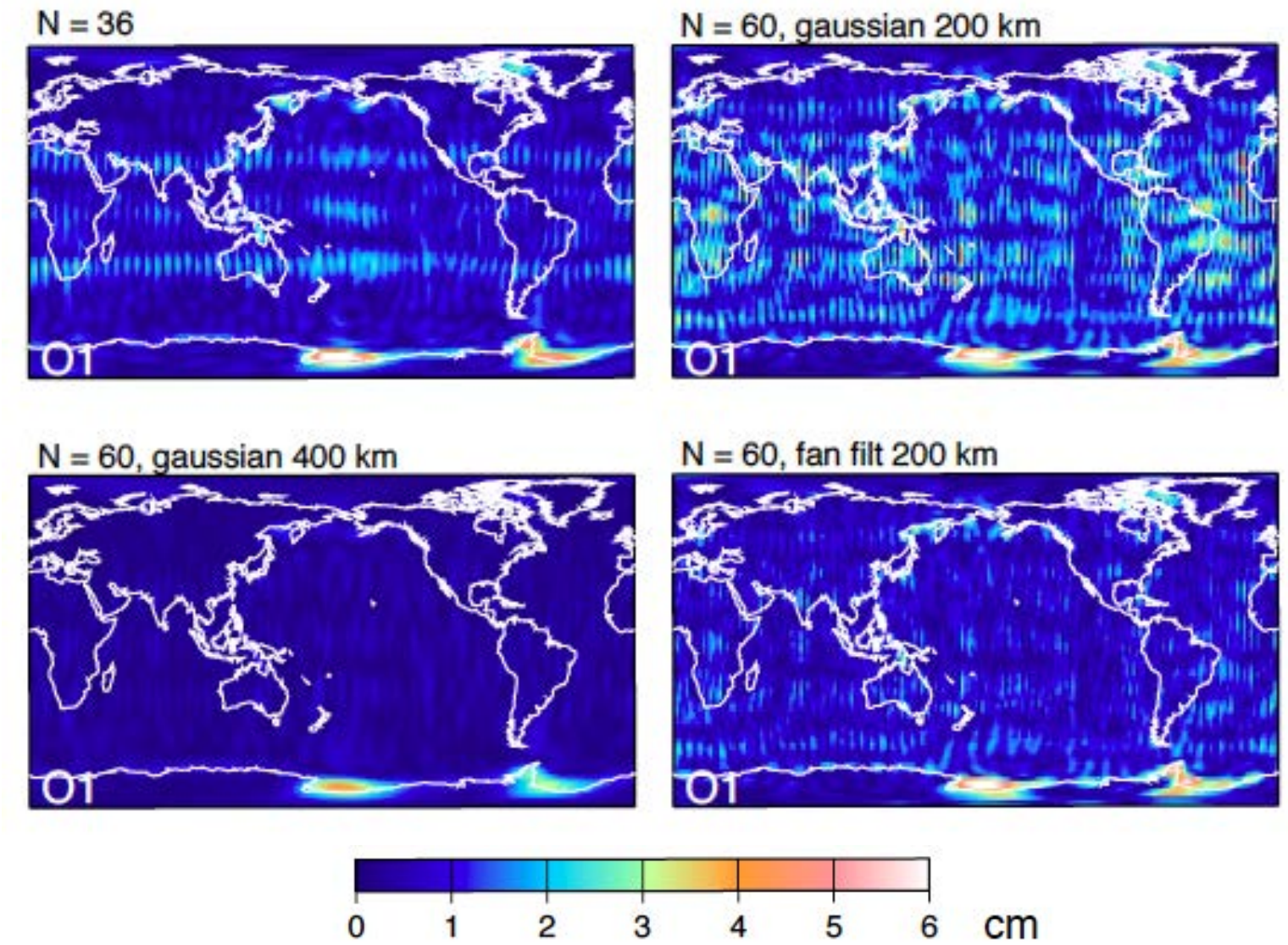
Here we discuss assimilation of the GRACE analysis into a global hydrodynamic tide model (TPXO.#)

→ Improve global tide models for a broader range of applications

Tide Inversion Methodology

1. Analyze GRACE Level-1B data; need at least 7 full years
   (K1 alias period).
2. Tides parameterized in spherical harmonics, up to $N = 90$.
3. Initial experiments suggest constituents can be
   estimated one at a time.
4. Forward modeling of non-tidal variability
   ECMWF operational atmosphere (includes air tides)
   MOG2D barotropic ocean
   GSFC GRACE land (not ocean) mascons: ice + hydrology
5. Simultaneous arc-parameter adjustments
6. Prior tide model:
   short periods - GOT4.7 long periods - TPXO6.2

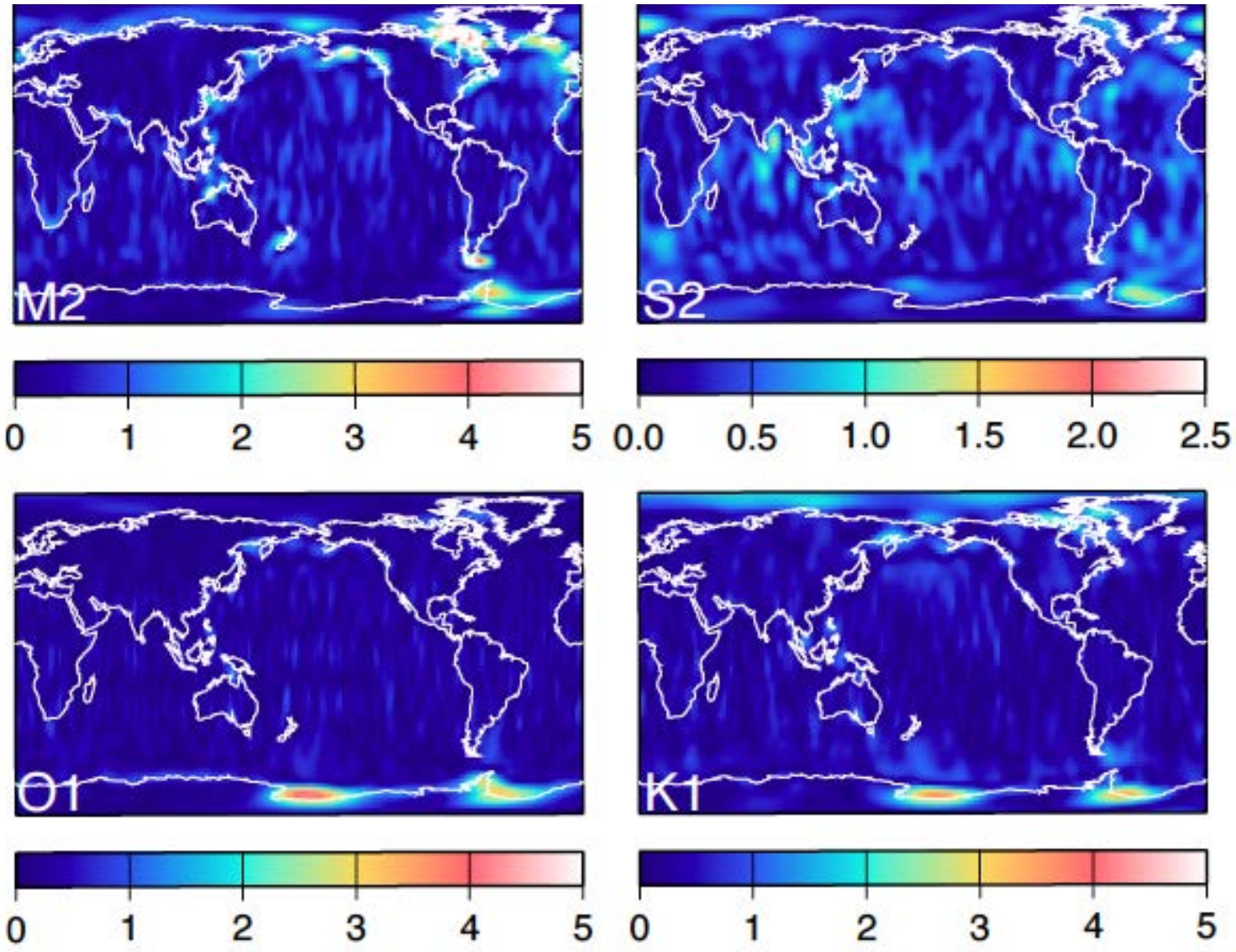
Solutions must be smoothed to be useful: Example of O1



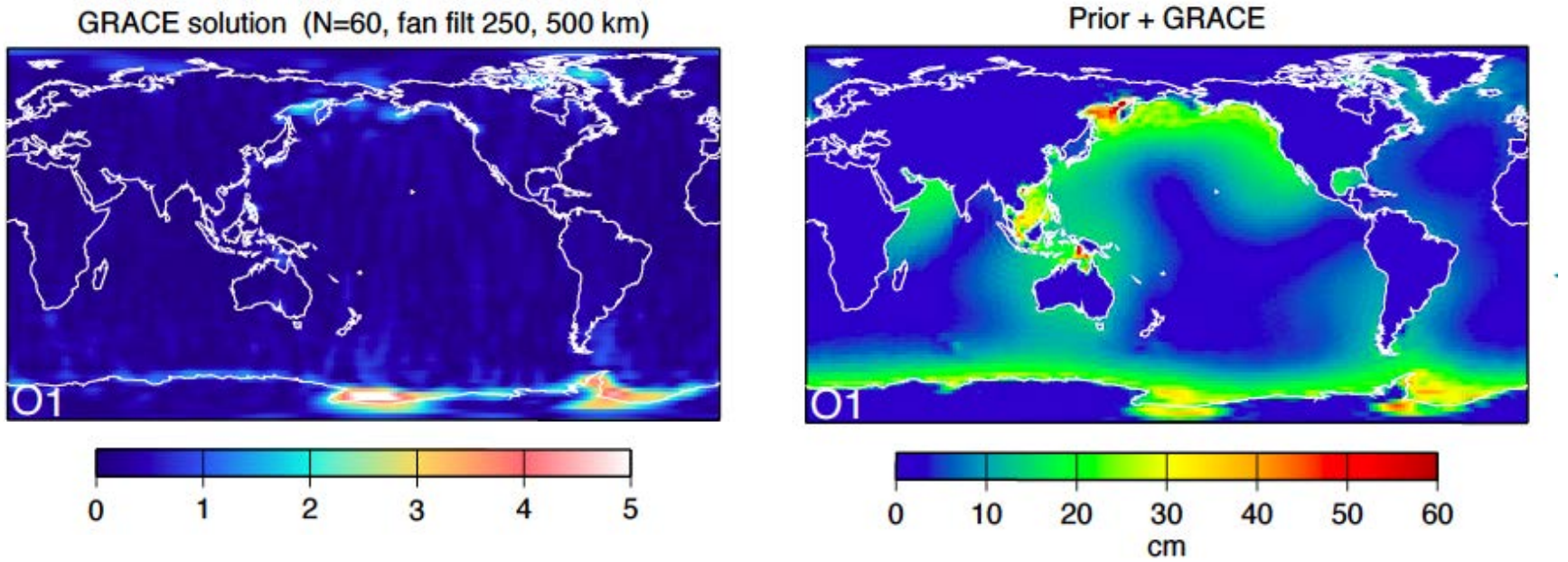
GRACE Tide Solutions

Relative to prior tide model

Gaussian smoothing *r* = 400 km Units: cm

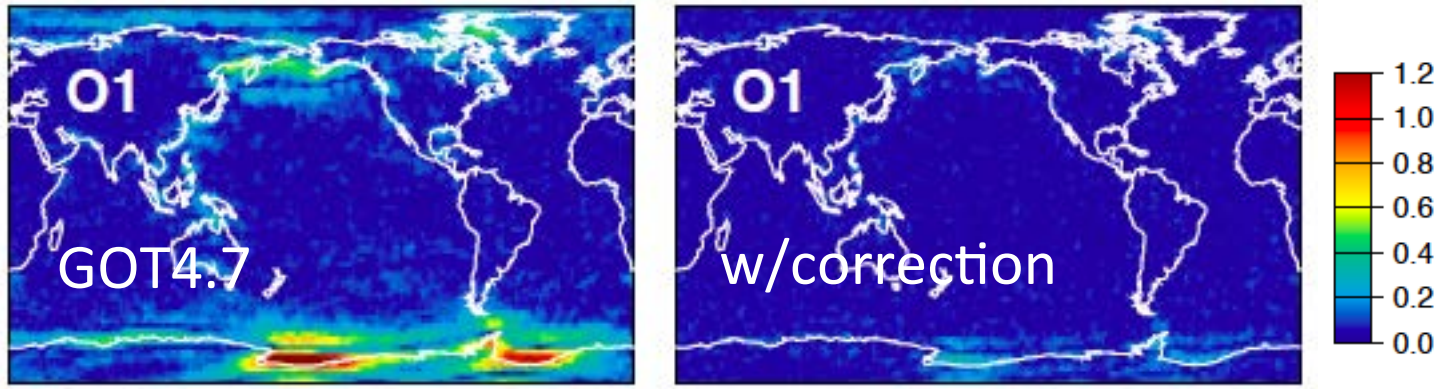


Smoothed GRACE solution + Prior Model



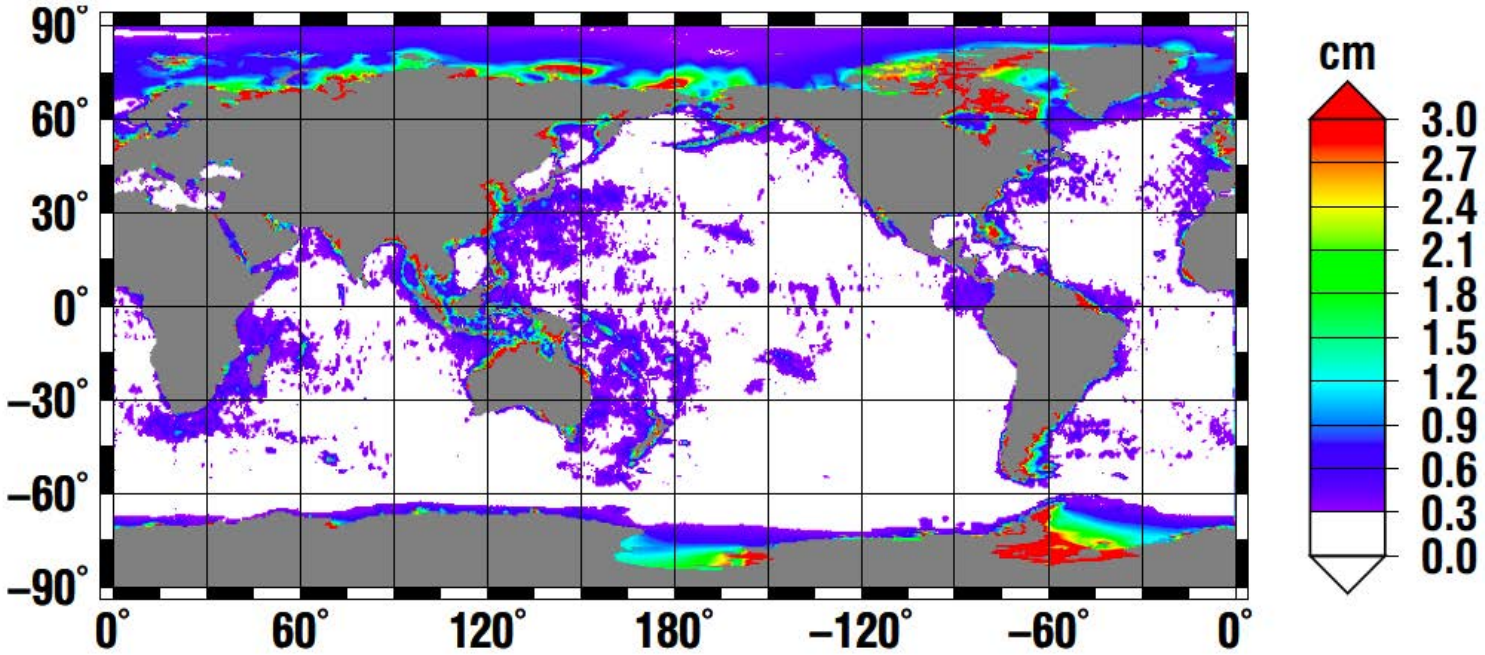
→ improved tide model for GRACE processing

GRACE Accel. Residuals (nm/s^2)



The GRACE tidal solutions could help improve global tide models, especially at high latitudes where errors are still large

Standard deviation of 7 modern global M_2 tide models (Stammer et al., 2014)



We are working toward incorporating constraints from GRACE into a data-assimilating global tide model (TPXO.#)

Variational Data Assimilation

Estimate state (e.g., tidal height + currents) combining :

Dynamical equations $\mathbf{Su} = \mathbf{f} + \delta\mathbf{f}$

Data $\mathbf{d} = \mathbf{Lu} + \delta\mathbf{d}$

Allow for errors in dynamical equations (forcing, boundary conditions, missing physics) and data

Minimize penalty functional

$$\varphi(\mathbf{u}) = (\mathbf{d} - \mathbf{Lu})^{*} \Sigma_{\mathbf{d}}^{-1} (\mathbf{d} - \mathbf{Lu}) + (\mathbf{Su} - \mathbf{f})^{*} \Sigma_{\mathbf{f}}^{-1} (\mathbf{Su} - \mathbf{f})$$

Error covariances encode a priori beliefs about magnitude, spatial/temporal correlation structure of errors in forcing, boundary and initial conditions, data

Representer Approach: Implemented in OSU Tidal Inversion Software (OTIS)

Can show: $\hat{\mathbf{u}} = \mathbf{u}_0 + \sum_k \beta_k \mathbf{r}_k$ ⟵ **representers:**

obtained by solving

Prior model ↗

$$\mathbf{S}^* \lambda_k = L_k \qquad \mathbf{S}\mathbf{r}_k = \Sigma_{\mathbf{f}} \lambda_k$$

Solve adjoint, forward problem for each observation

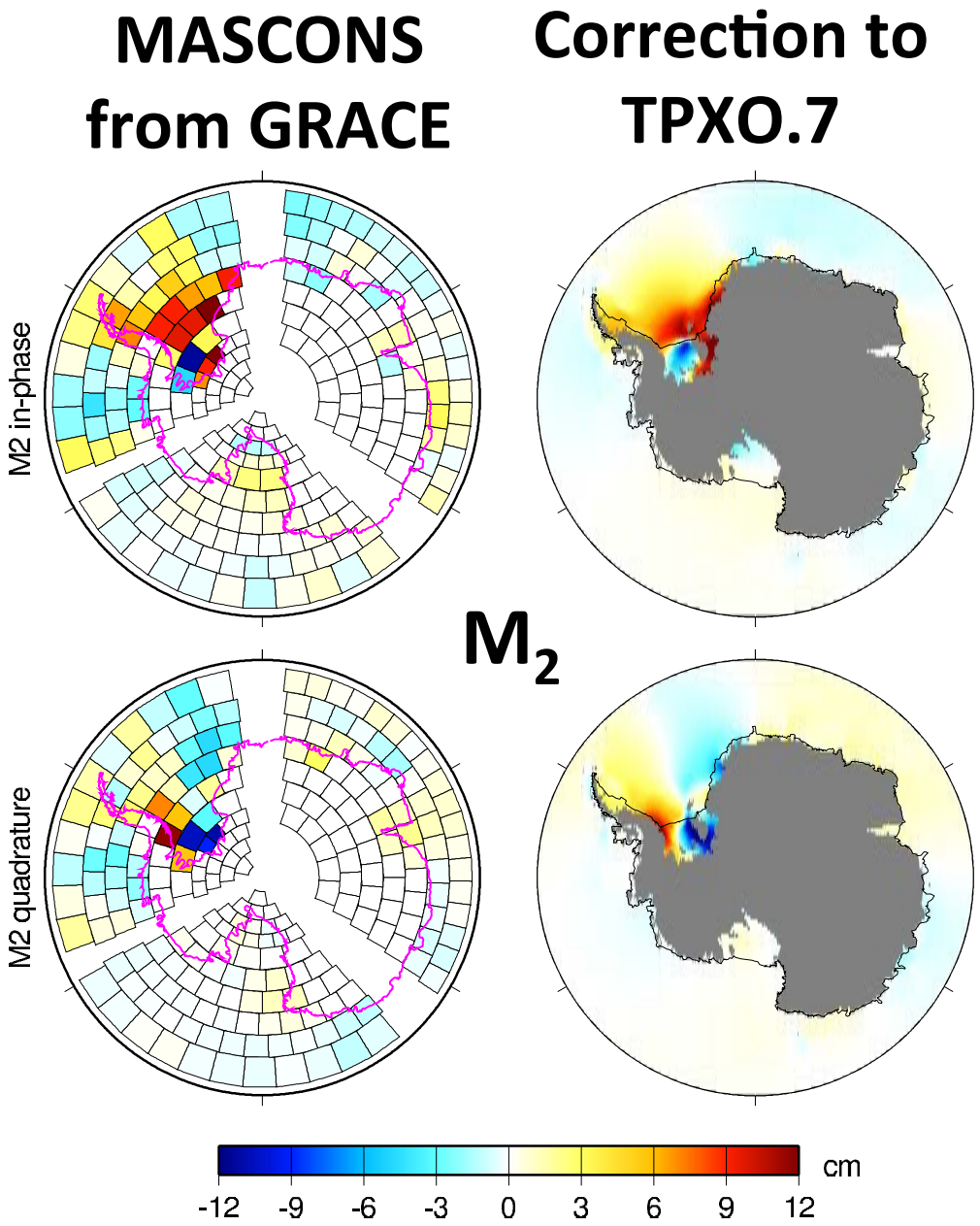
Coefficients b satisfy: $\left[\mathbf{R} + \Sigma_{\mathbf{d}}\right]\mathbf{b} = \mathbf{d} - \mathbf{L}^*\mathbf{u}_0$

Representer matrix ↗

$$R_{jk} = L_j^* \mathbf{r}_k$$

dynamically consistent basis functions

Earlier effort using OTIS: Egbert et al., 2009 assimilation of tidal solutions around Antarctica from 4 years of GRACE data (2003-2007), parameterized as MASCONS



Representers for spherical harmonic coefficients

$$\hat{\mathbf{u}} = \mathbf{u}_0 + \sum_k \beta_k \mathbf{r}_k$$

← **representers:**

obtained by solving

$$\mathbf{S}^* \lambda_k = L_k \qquad \mathbf{S}\mathbf{r}_k = \Sigma_{\mathbf{f}} \lambda_k$$

Prior model

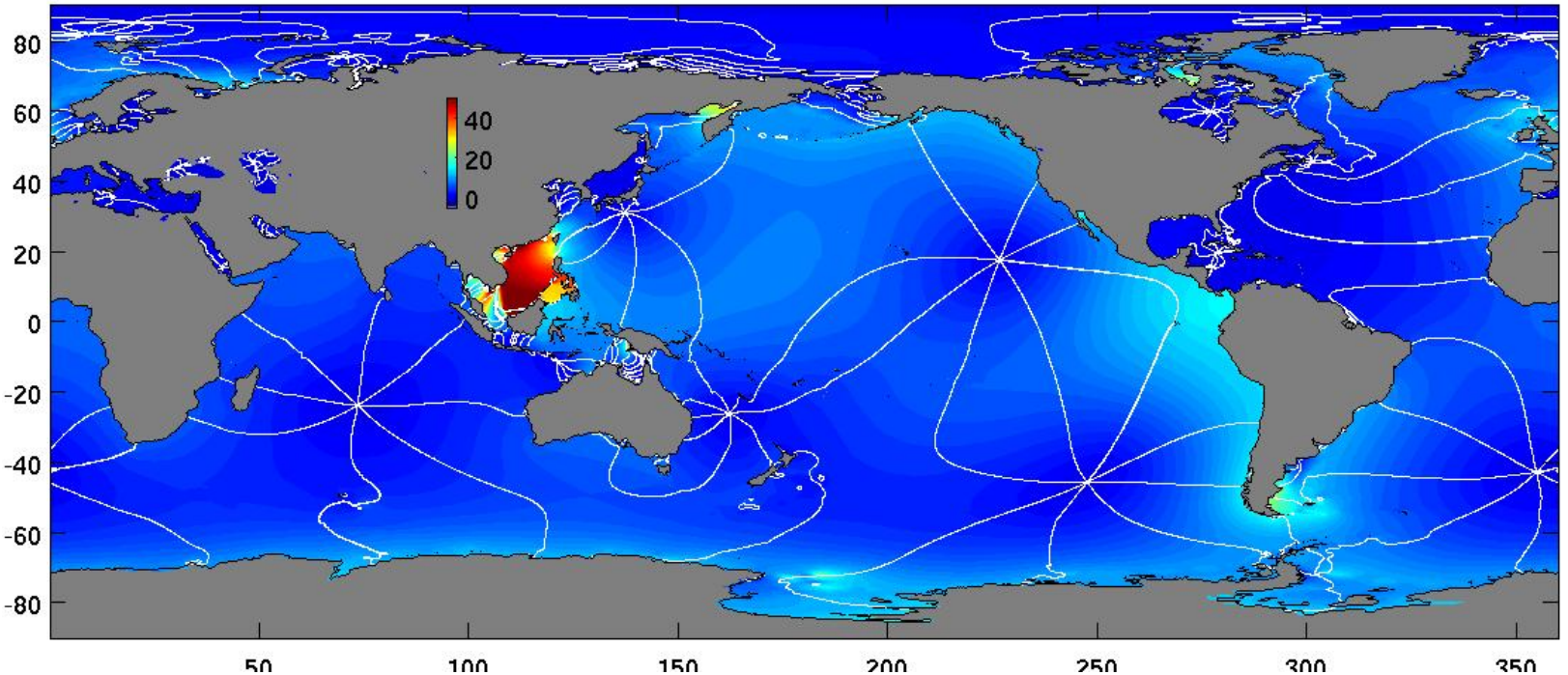
Solve adjoint equations with spherical harmonic forcing (L_k)

Representer matrix

$$R_{jk} = L_j^* \mathbf{r}_k$$

essentially: expand representer in spherical harmonics

Examples of Representers: O_1 : Y_2^{-2}



dynamically consistent basis functions

Note that dynamics of the tides strongly influence representers!

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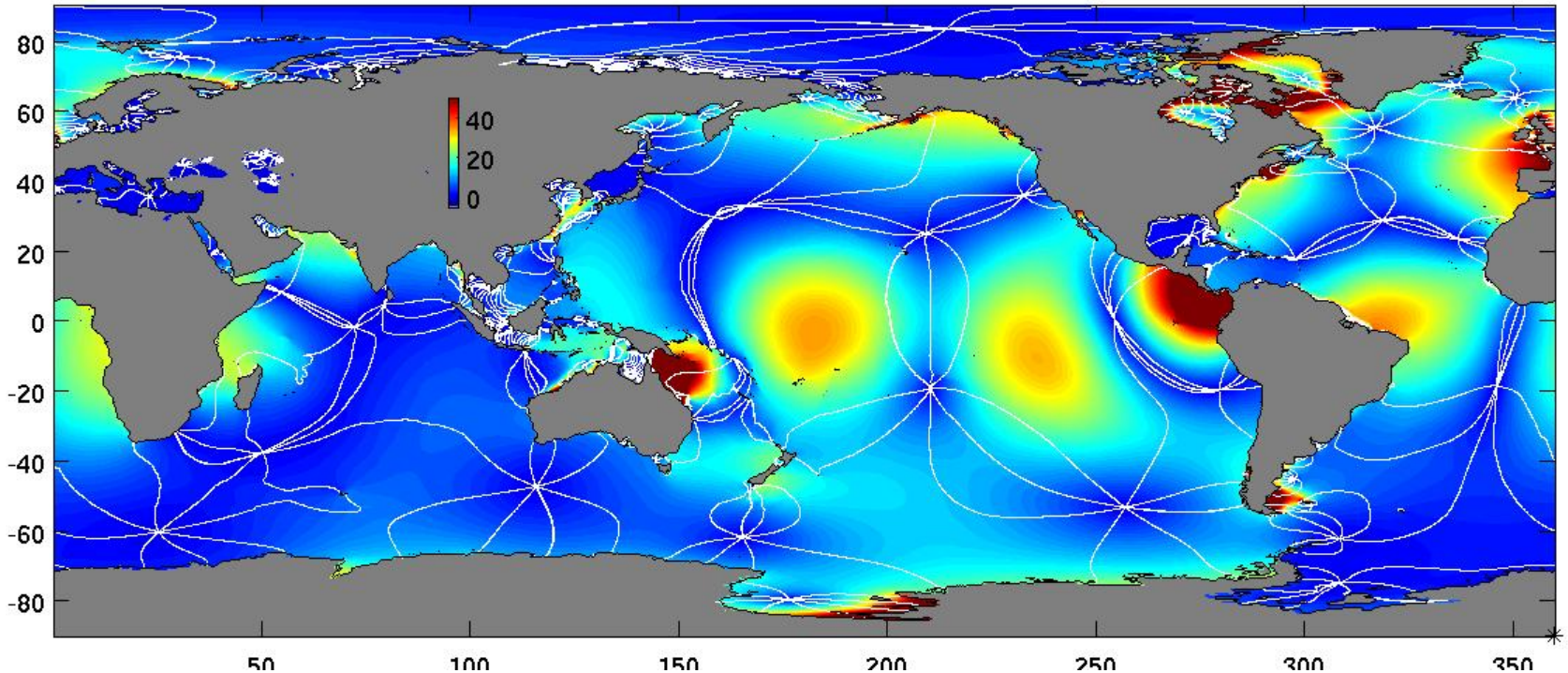

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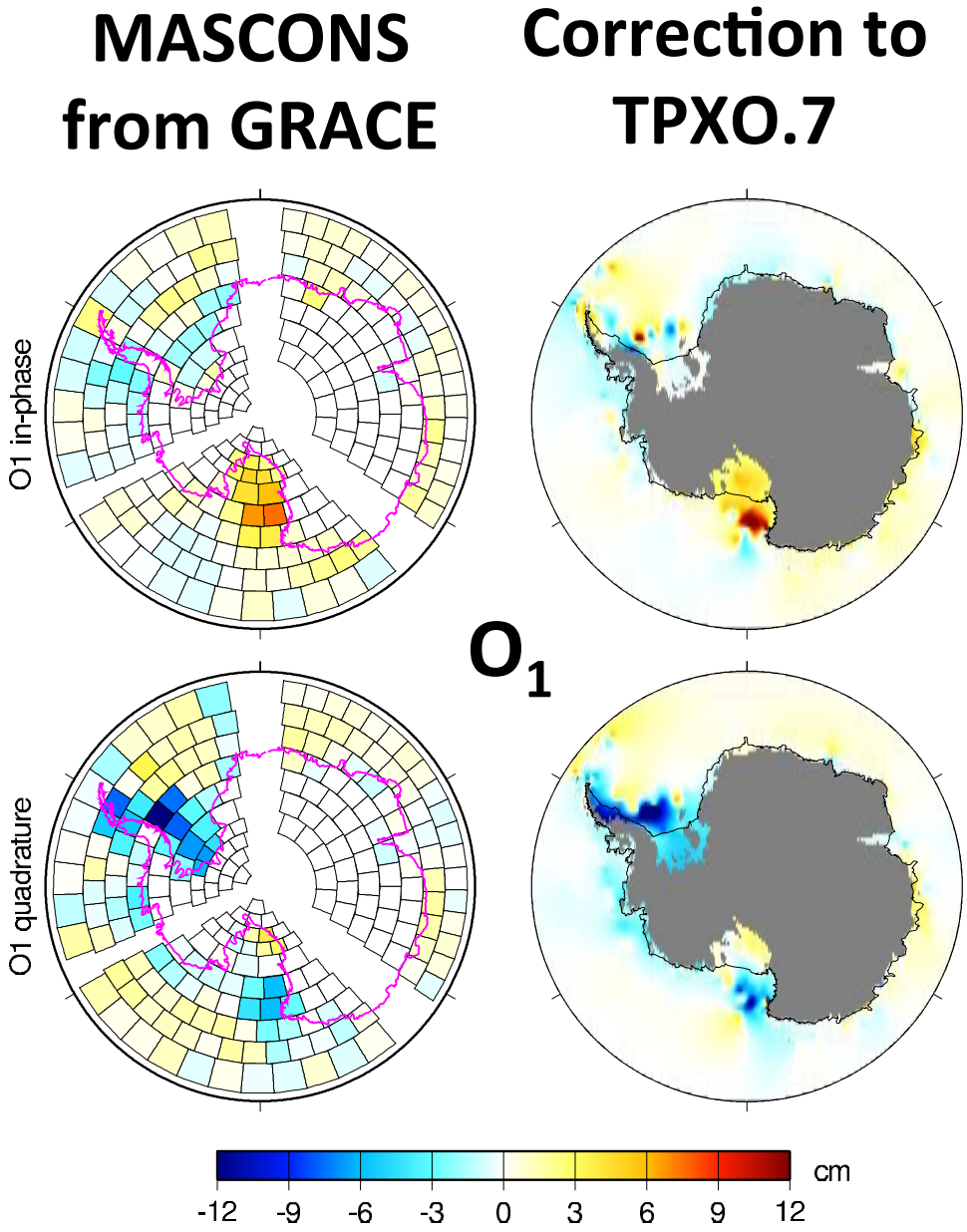
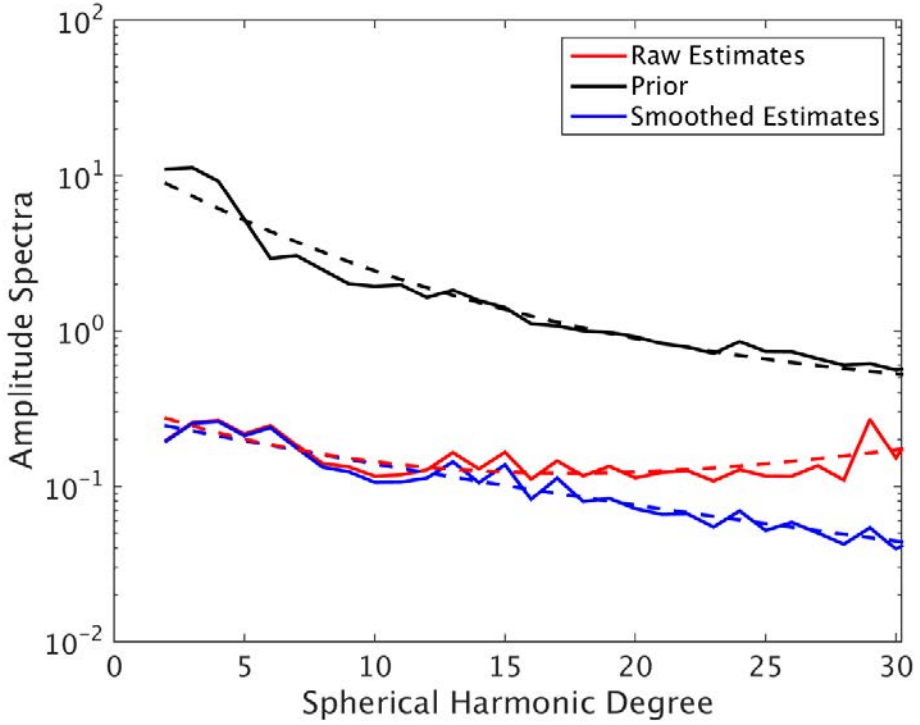


Also need data error covariance (Σ_d)

First cut:
ad hoc, based on spectra of tidal models, GRACE solution

Plan to use full covariance from GRACE analysis



Inverse solutions (still working on this!):

→ **Initially just invert GRACE spherical harmonics to estimate correction to existing global assimilation solution TPXO.8**

→ **Ultimately: simultaneous inversion of multi-satellite altimetry data and GRACE**

→ **Seawater density: another issue that needs attention**

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