PL34C-1856 - Tuning Tidal Perturbations for Augmented State Ensemble Kalman Filter (ASEnKF) Improvements

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Objective – to make the RMS error of the tides in global HYCOM as low as possible.

How well do we know the tides?

- In Stammer et al. (2014), 7 state-of-the-art altimetry-constrained barotropic tide models were compared to observations
  - Deep water errors ~0.5 cm M_2 and 1 cm for 8 major tides
  - Continental Shelf errors ~3.5 cm M_2 and 5 cm for 8 major tides
  - Coastal errors ~ 5 cm M_2 and 7 cm for 8 major tides
  - Arctic errors ~ 5 cm M_2 and 7 cm for 8 major tides
  - Differences between models smaller than differences relative to gauges

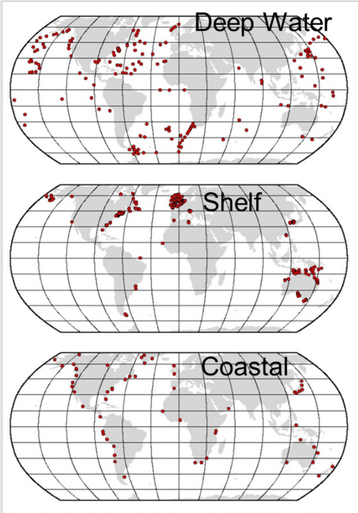

Figure 2. Station locations for the "ground truth" tidal data used in section 4. (top) Deep-water stations. (middle) Shelf stations. (bottom) Coastal stations.

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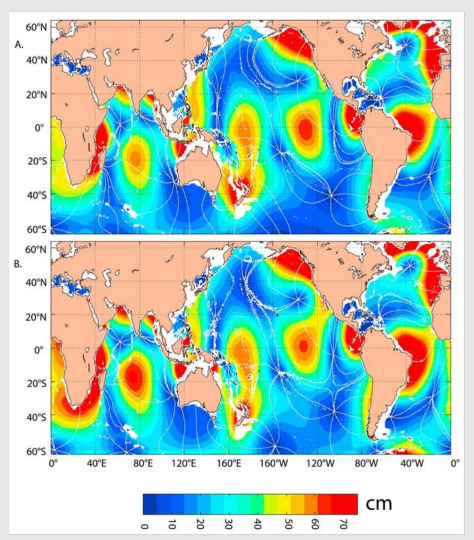
Modeling tides in global HYCOM

First HYCOM with tides run



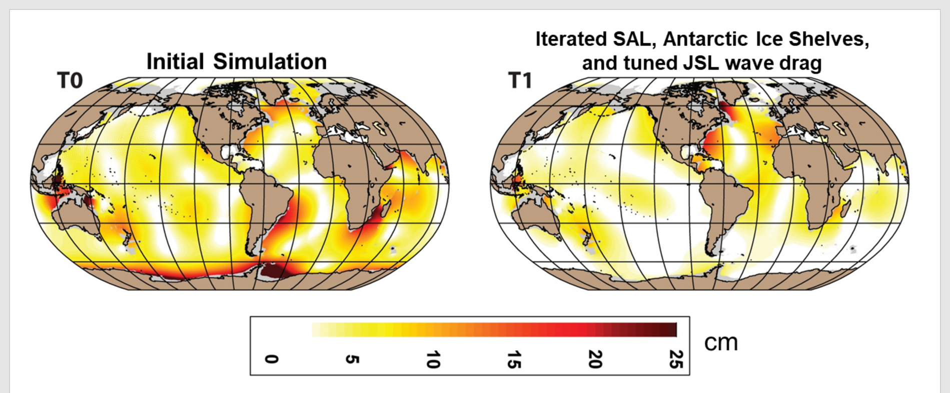
From Shriver et al. (2012)

- The circulation model is modified to include
  - Gravitational Potential of the Sun and Moon
    - 8 leading constituents
    - M_2, S_2, N_2, K_2 semidiurnal tides
    - K_1, O_1, P_1, Q_1 diurnal tides
  - Self Attraction and Loading (SAL) due to the deformation of the ocean and solid earth
    - Scalar approximation in initial simulation
  - Topographic wave drag to parameterize effects of internal wave generation and breaking
    - Coarse resolution Garner (2005) wave drag in initial simulation

Initial simulation M_2 RMS Error 7.0 cm

- The initial tidal simulation (T0) identified several issues
  - SAL poorly modeled
  - Wave drag needed tuning, replaced Garner (2005) drag with Jayne and St. Laurent (2001) wave drag
  - Tidal resonances with Antarctic ice shelves need to be included
- New simulation (T1) addressing these issues leading to a reduced rms error of 4.4 cm
- *Good, but not at acceptable forecast levels*

Maps of the M2 RMS error (cm) between HYCOM simulations and TPXO8



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A new approach to correcting the tides in global HYCOM

- Best Barotropic Tide Models assimilate data to get an accurate state
  - Techniques used in barotropic tide models can't be used in the global ocean model
  - We need a continuous, concurrent forecast of the tide not a one time state estimate
- We borrow from the traditional data assimilation to make a correction to the model forcing
  - Augmented State Ensemble Kalman Filter (ASEnKF)

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Kalman Filter State Estimation

- Ocean model dynamics—state variable **X**

$$\frac{\partial \mathbf{X}}{\partial t} = F(\mathbf{X}) + f$$

- Observations—**Y** [Observation error ε (covariance C_ε)]

$$\mathbf{Y} = H\,\mathbf{X} + \varepsilon$$

- Analysis—$\mathbf{X}^a$

$$\mathbf{X}^a = \mathbf{X} + \mathbf{B}\,HT\,(H\mathbf{B}H^T + C_\varepsilon)^{-1}(\mathbf{Y} - H\,\mathbf{X})$$

- Use n-member ensemble of model runs to create background error covariance **B**

$$\mathbf{B} = \frac{1}{N-1}\sum_{n=1}^{N}(\mathbf{X}^n - \overline{\mathbf{X}})(\mathbf{X}^n - \overline{\mathbf{X}})^T$$

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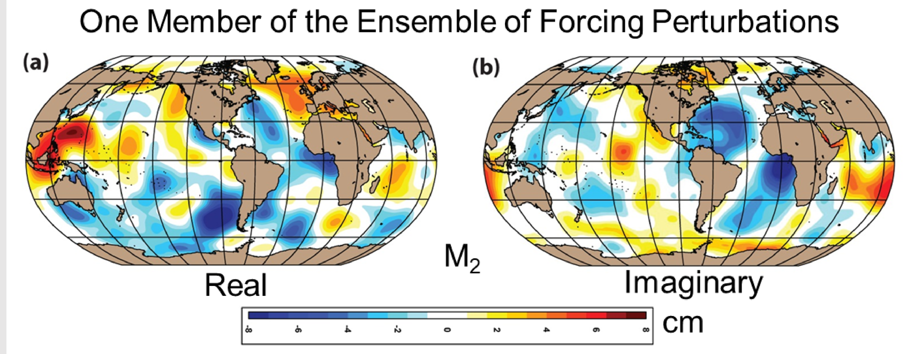
Augmented State Ensemble Kalman Filter (ASEnKF)

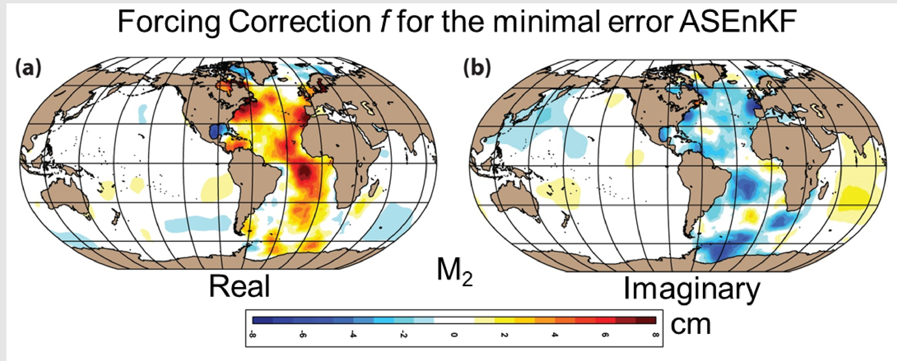
- Prediction of tide inside the global circulation model
  - More than an optimal estimate of the barotropic tide
- Augment dynamical model
  - $\frac{\partial}{\partial t}\begin{pmatrix}\mathbf{X}\\ f\end{pmatrix} = \begin{pmatrix}F(\mathbf{X}) + f\\ -\rho f\end{pmatrix} + \begin{pmatrix}0\\ u\end{pmatrix}$
- New state variable
  - $Z = \begin{pmatrix}\mathbf{X}\\ f\end{pmatrix}$
- For ensemble, generate a set of random forcing perturbations to drive 3d ocean model—100 members to the ensemble

One Member of the Ensemble of Forcing Perturbations



- Solving the Kalman filter on the 3d dynamics is prohibitive, we simplify to
  - $\frac{\partial \mathbf{X}}{\partial t} = F(\mathbf{X}, \langle T_{pot}\rangle + \langle SAL\rangle + \langle f\rangle)$
- where ⟨ ⟩ represents terms defined in frequency space for each constituent and expressed in time for the dynamics
- For the state variable we use SSH_{tidal}

Forcing Correction *f* for the minimal error ASEnKF



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M_2 Error relative to TPXO8

Several Experiments performed where the observation error is changed using the same ensemble

T2 1 cm constant observation error

T3 Spatially varying observation error which varies similar to the error in Stammer et al. (2014)

T4 5 mm constant observation error

T5 Blended Atlantic-only and **T3** solution for rest of ocean

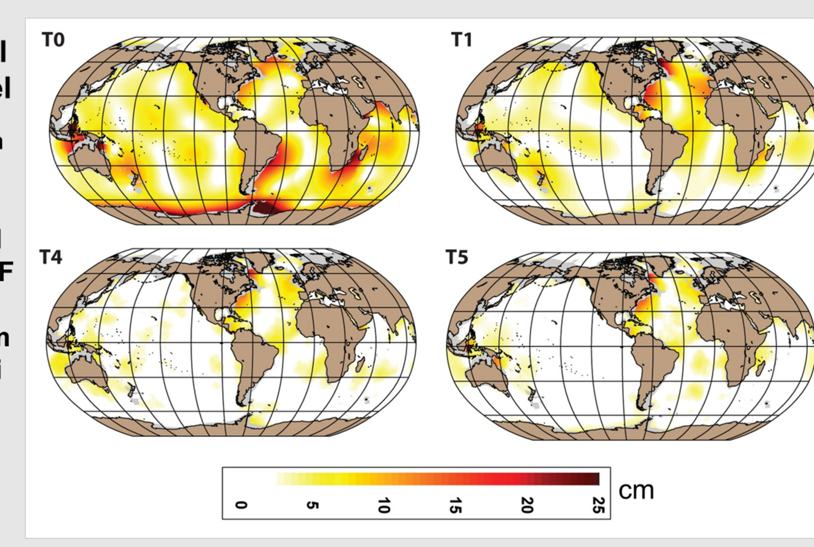
Simulation	Global RMS	Median Global RMS	Atlantic RMS	Median Atlantic RMS	Global excluding Atlantic RMS	Median Global excluding Atlantic RMS
Initial T0	7.0	5.3	6.8	5.6	7.0	4.8
Intermediate T1	4.4	3.2	7.3	7.1	3.5	3.5
1 cm constant observation error ASEnKF T2	2.8	1.7	5.2	5.2	2.0	1.8
Spatially varying observation error ASEnKF T3	3.2	1.6	6.3	6.2	2.0	1.5
0.5 mm constant observation error ASEnKF T4	2.8	1.9	4.6	4.6	2.3	1.9
Blended ASEnKF T5	2.6	1.7	4.4	3.8	2.1	1.5

Initial Model

7.0 cm rmse

Global ASEnKF With uniform apriori error

2.8 cm rmse



Iterated SAL Antarctic Shelves JSL drag

4.4 cm rmse

Atlantic Patch Correction

2.6 cm rmse

White areas are regions with RMS error less than 2 cm

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Performance of ASEnKF

- M_2 Tides with the ASEnKF forcing correction have smaller errors than the initial and intermediate simulations
  - None of the ASEnKF models could reduce the RMS errors to the level of apriori obs error
  - None of the models perform well in the Atlantic or Indonesian Seas
    - Two possible explanations
      - Ensembles generated with large scale perturbations
      - If the ensemble doesn't contain the error structures then the EnKF can't make correction
- Way forward – based upon the "back effect" of large coastal tides upon open-ocean tides (Arbic et al. 2007, 2009; Arbic and Garrett, 2010)
  - Two way nesting with high resolution coastal domains
  - New perturbations with smaller scales *(focus of this effort)*

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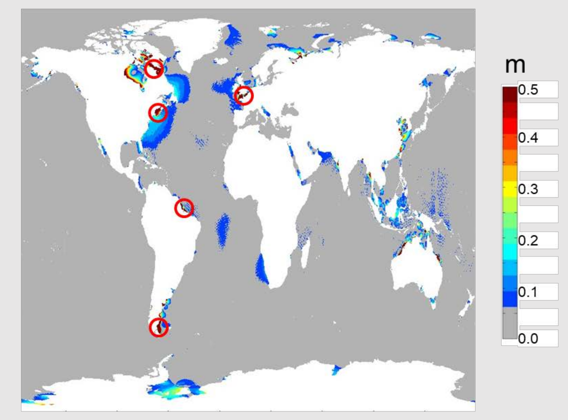
Where to Test New Perturbations?

HYCOM M_2 Error Map relative to TPXO8



Test forcing perturbations in regions of highest M_2 error, first focusing on the Atlantic.

If the perturbations have an impact, then they have can help reduce the error in these areas. The ASEnKF machinery will ultimately scale these perturbations to maximize impact.

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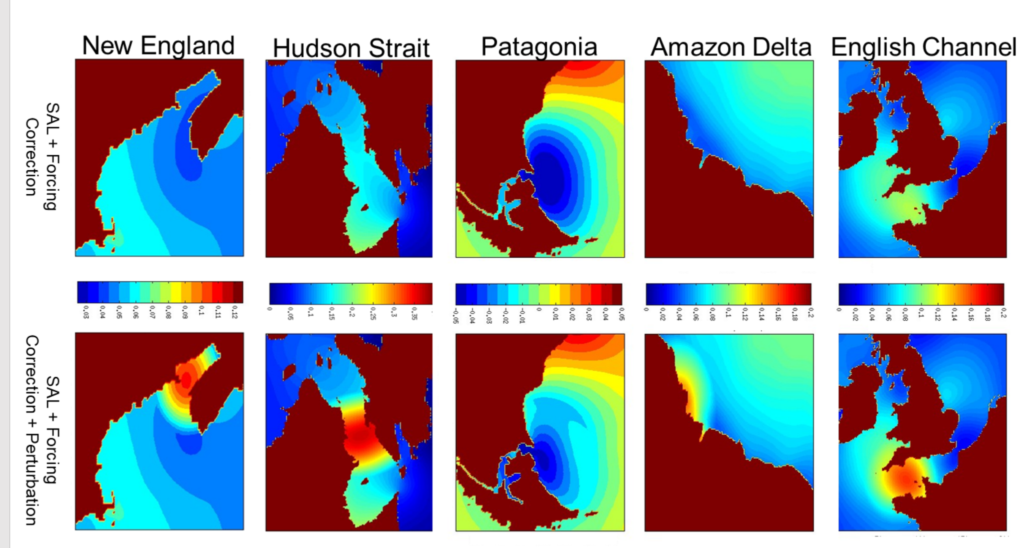
Forcing Perturbations Which Were Tested



In HYCOM, the ASEnKF forcing perturbations are included in the SAL.

Displayed are only the real part of the SAL + forcing perturbation.

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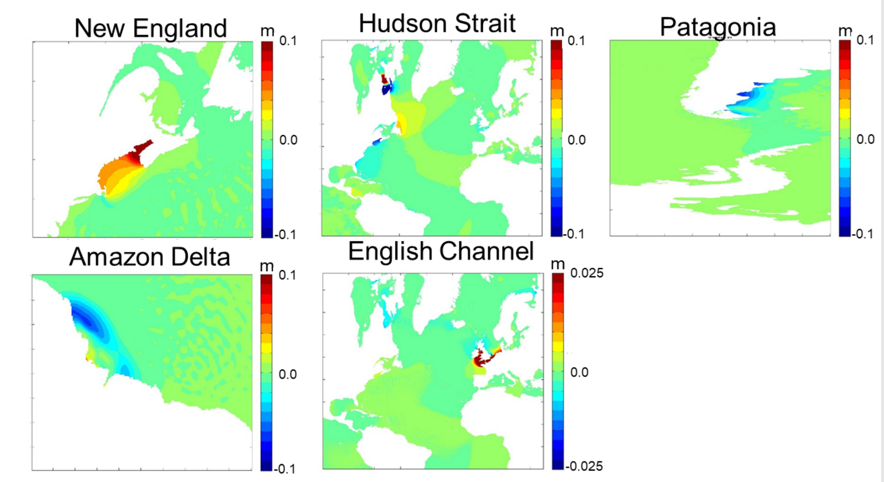
Impacts of Tested Perturbations



- Model is run for 2 months with forcing perturbations. A tidal harmonic analysis is performed on the second month. Displayed is the M_2 amplitude difference between the "normal" and "perturbed" cases.
- The targeted perturbations have both local and remote impacts in areas of large error. An impact (regardless of sign) suggests that the inclusion of these perturbations in our ASEnKF ensemble set could help reduce the large errors in these areas.

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Conclusions and Future Work

- Targeted forcing perturbations in the regions of large HYCOM M_2 error relative to TPXO have both local and remote impacts. This suggests that the inclusion of these perturbations in our ASEnKF ensemble set could help reduce the large errors in these areas.
- Work is underway to use the TPXO adjoint model to better target these perturbations by identifying upstream regions connected with areas of large error.
- Once a better list of target areas for perturbations has been identified, a new ensemble can be created to use with the ASEnKF for an improved correction.

Acknowledgements

This work was supported by the projects "Improving Global Surface and Internal Tides through Two-Way Coupling with High Resolution Coastal Models " and "Navy Earth System Prediction Capability", sponsored by the Office of Naval Research (ONR).

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