Forecasting Tides in Global HYCOM

James G. Richman
Oceanography Division
Naval Research Laboratory
Stennis Space Center, MS

In collaboration with
Brian Arbic, Univ. Michigan
Joe Metzger, Jay Shriver & Alan Wallcraft, NRL
Patrick Timko, Univ. Bangor, Wales

Forecasting Tides in Global HYCOM

- Today I will briefly describe the NRL effort to include tidal forcing in the global ocean forecast system
  - We have a long simulation with forcing by the tidal geopotential and realistic wind stress and buoyancy forcing with an equatorial resolution of 9 km
  - The model drag is tuned to give good agreement with the pelagic tide gauges Maarten Buijsman will talk more on tuning of the bottom drag and dissipation
  - The global model will be used to provide 3-d (including internal tides) boundary conditions for regional model

- The model is validated against 102 pelagic tide gauges and data-assimilative tide models
  - Presently have a good forward model, but not a forecast quality model
  - Phase errors in barotropic tide affect the baroclinic tide

- The barotropic and internal tidal kinetic energy in the model compares well with historical current meters and data-assimilative tide models
  - Recent work by Patrick Timko in Atlantic Ocean comparison paper published in JGR-Oceans and submitted global paper
  - Barotropic tidal velocities are difficult to estimate from deep ocean current meter moorings

- Tidal resonances and bathymetry play an important role in global tide modeling

- The current 3DVAR mesoscale data assimilation scheme (NCODA) works in the tides in the model

- Model internal waves can play an important role in the boundary conditions for regional models and global HYCOM can be reproduced in regional twin experiments

Modeling tides in the global model

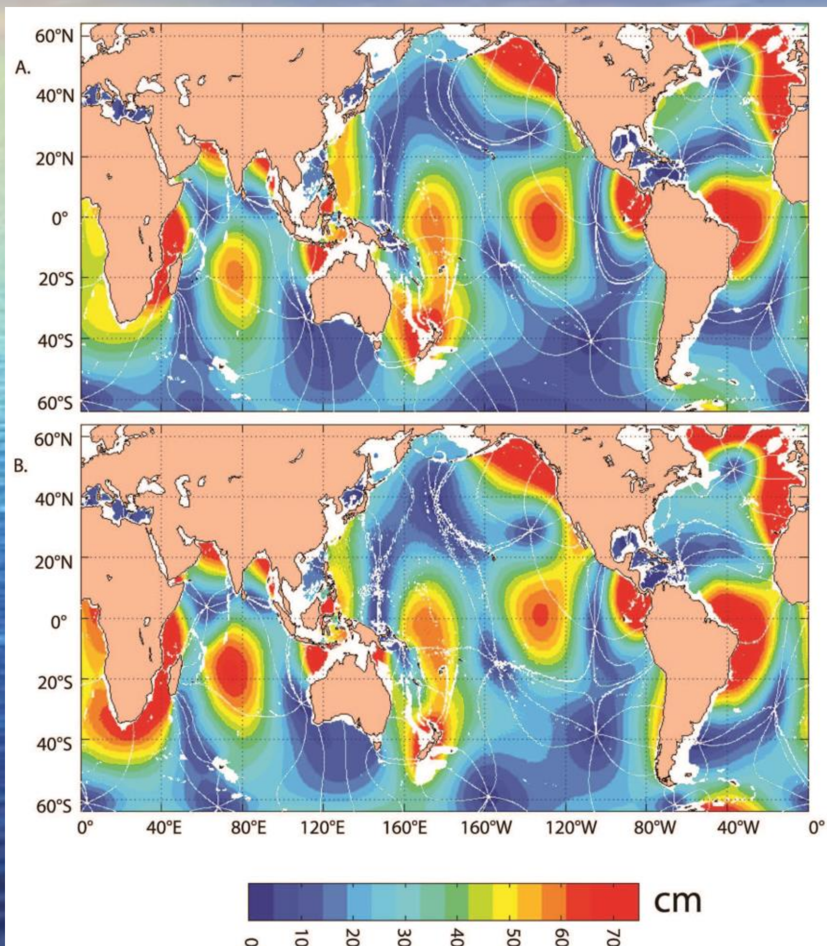
- In the global model, the body forces due to the tidal potential, self attraction and loading (using a scalar approximation) have been added
- Tidal Forcing with 8 constituents:
  - Semidiurnal M_2, S_2, N_2 and K_2
  - Diurnal O_1, P_1, Q_1 and K_1
- Topographic wave drag is applied to the tidal motions
  - The form of the drag is generalized from the linear topographic wave drag as proposed by Jayne and St. Laurent (2001), but tuned to minimize the difference with the 102 pelagic tide gauges using a barotropic version of the model
    - Maarten Buijsman will talk about refinements in the wave drag

Model Tides compared to TPXO7.2

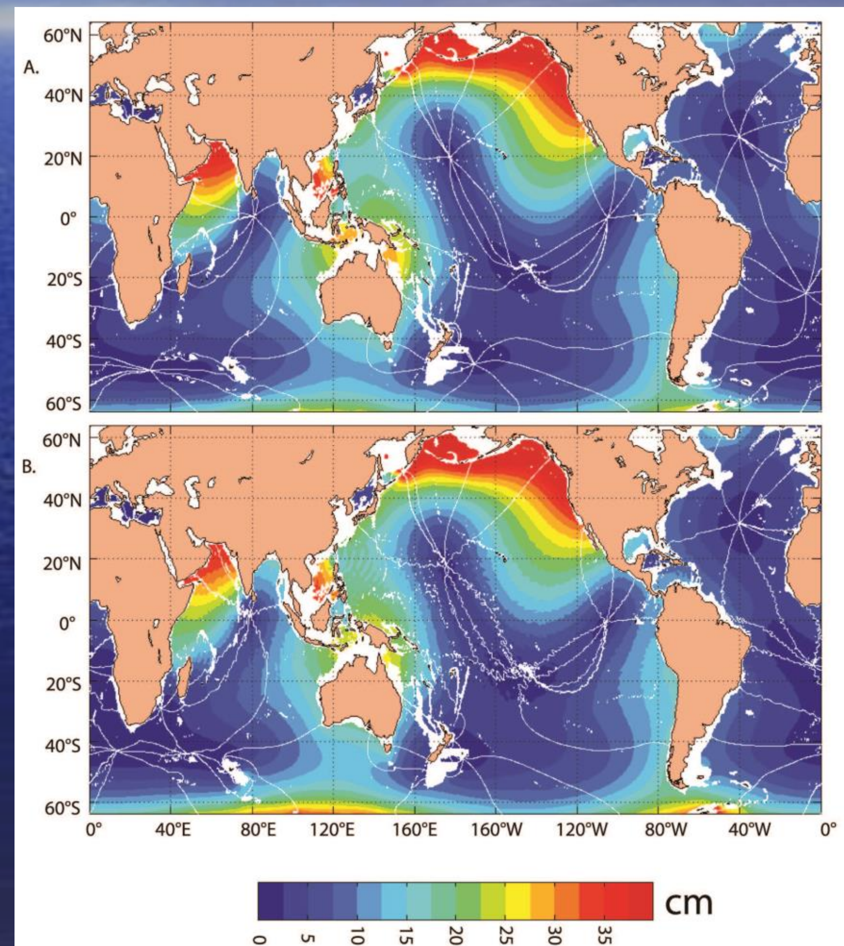
M_2 | K_1

TPXO 7.2

HYCOM



RMS Error 7.5 cm (5.6 amp, 5.0 phase)



RMS Error 2.3 cm (1.6 amp, 1.6 phase)

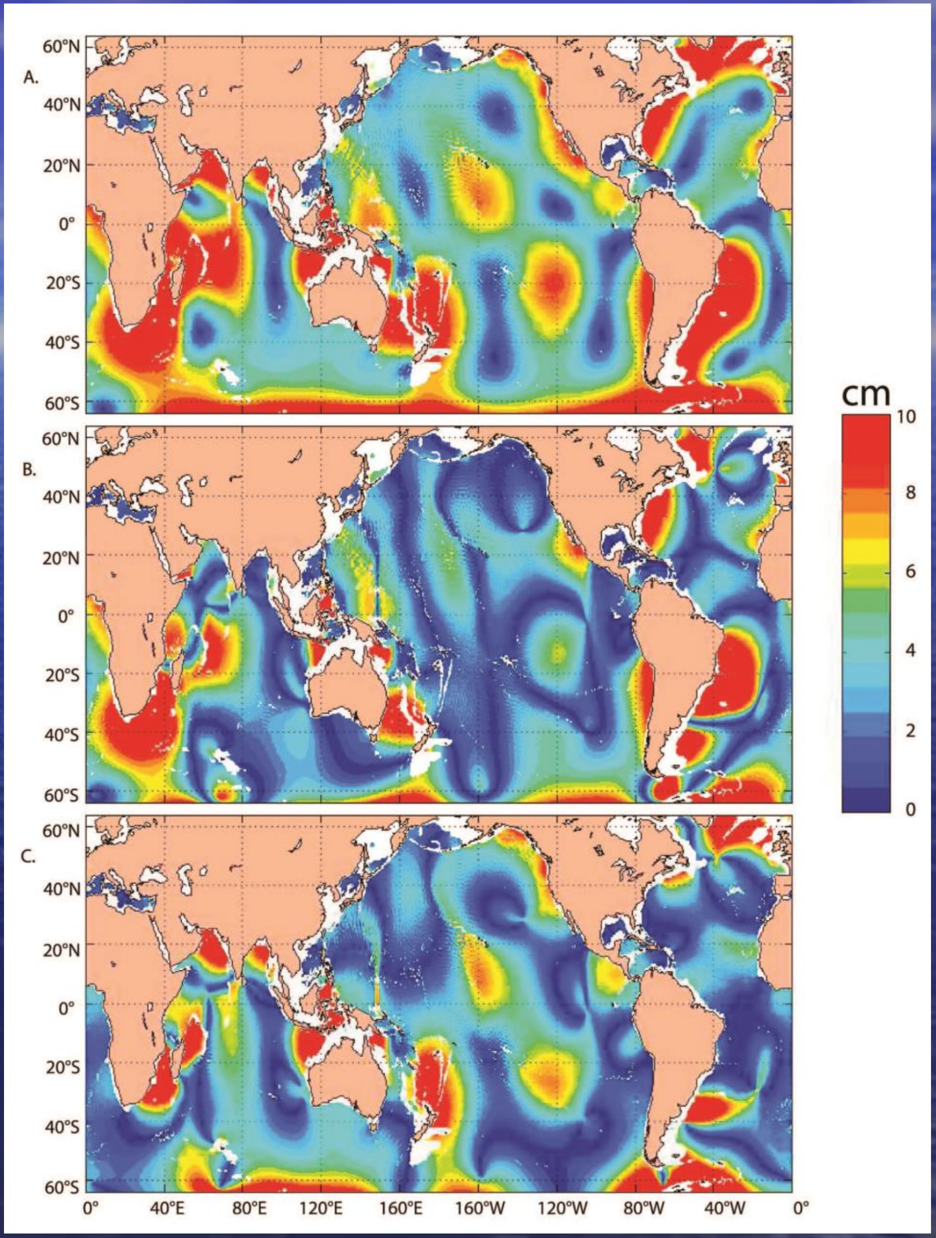
M2 Tidal Error relative to TPXO separated into amplitude and amplitude weighted phase errors

Mean Square Error (MSE)

$$MSE = \frac{1}{2} \| AHYCO_M e^{i\varphi_{HYCOM}} \text{-} A_{TPXO} e^{i\varphi_{TPXO}} \|^2$$

Which can be re-written in a form involving amplitude differences only and amplitude weight phase errors

$$MSE = \left[\frac{1}{2}(A_{HYCOM} - A_{TPXO})^2\right] + \left[A_{HYCOM} A_{TPXO} \left(1 - \cos(\varphi_{HYCOM} - \varphi_{TPXO})\right)\right]$$

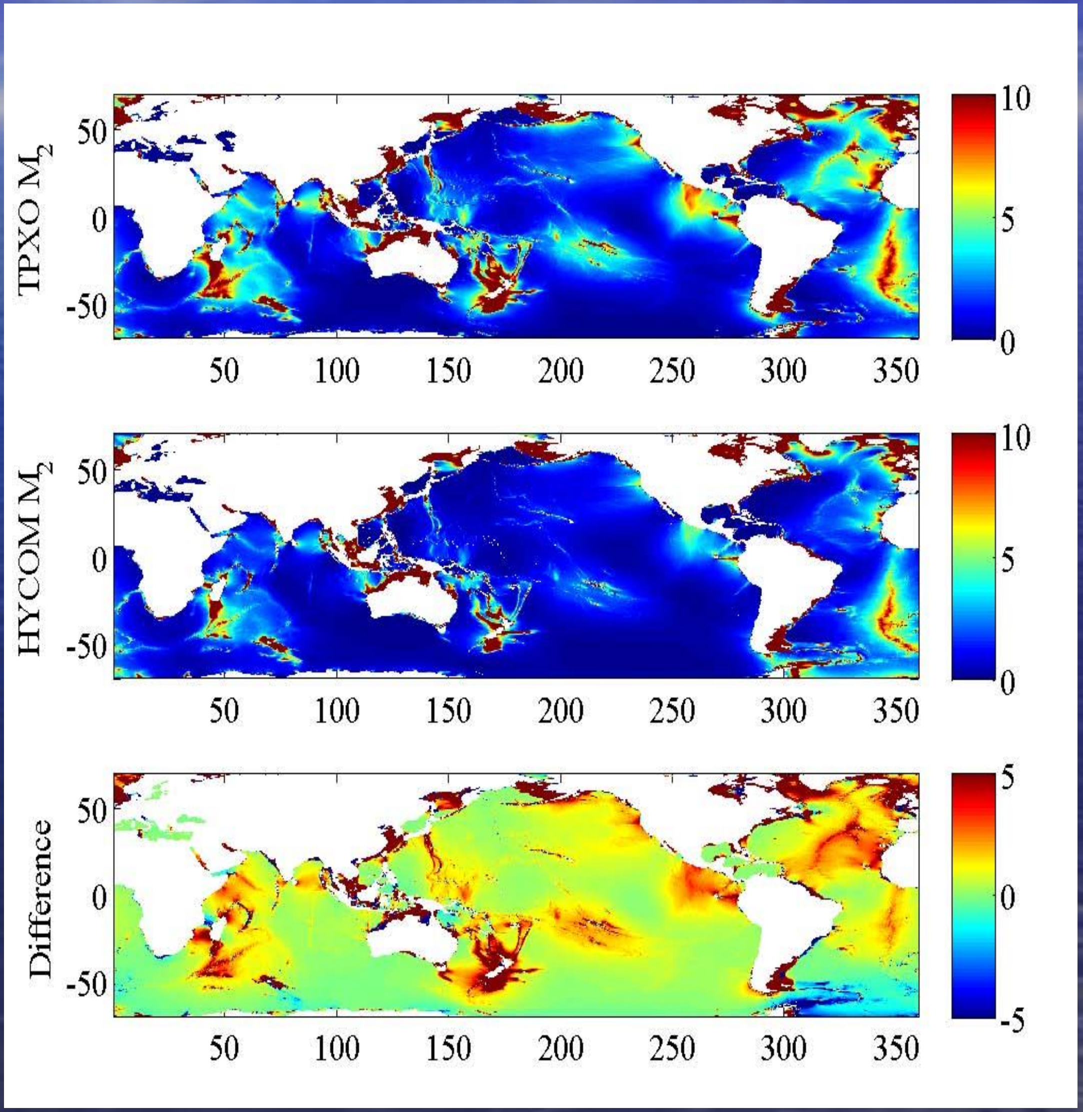


Kinetic Energy of the M_2 Tide in HYCOM and TPXO 7.2

The kinetic energy in the global model and TPXO have similar amplitudes and spatial distribution

The errors are large in the same regions where the elevation errors are large, Atlantic, Southern Ocean and Southeast Indian Ocean

No independent verification of the tidal velocities

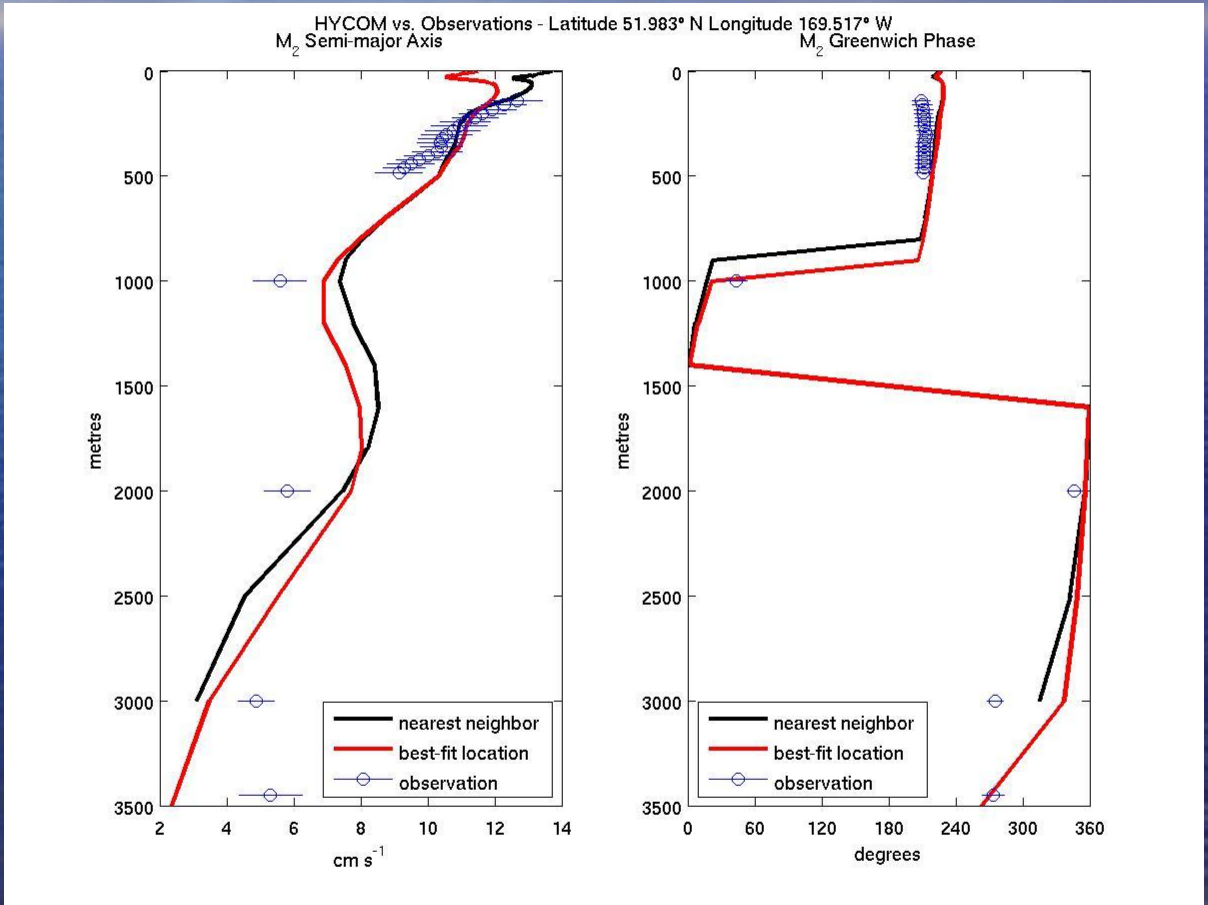


Comparison to historical current meter data (from Timko et al. JGR Oceans submitted

The tidal velocities can be converted from velocity components to tidal ellipses at each instrument depth on the mooring

The example from the North Pacific is one of the best comparisons

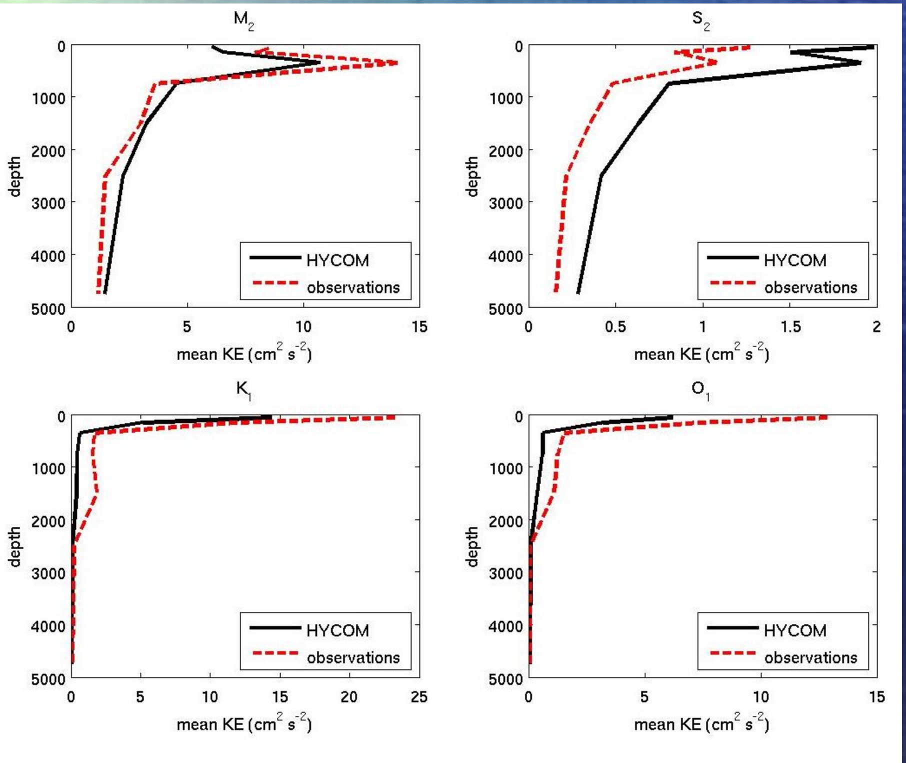
5000 individual current meter records available

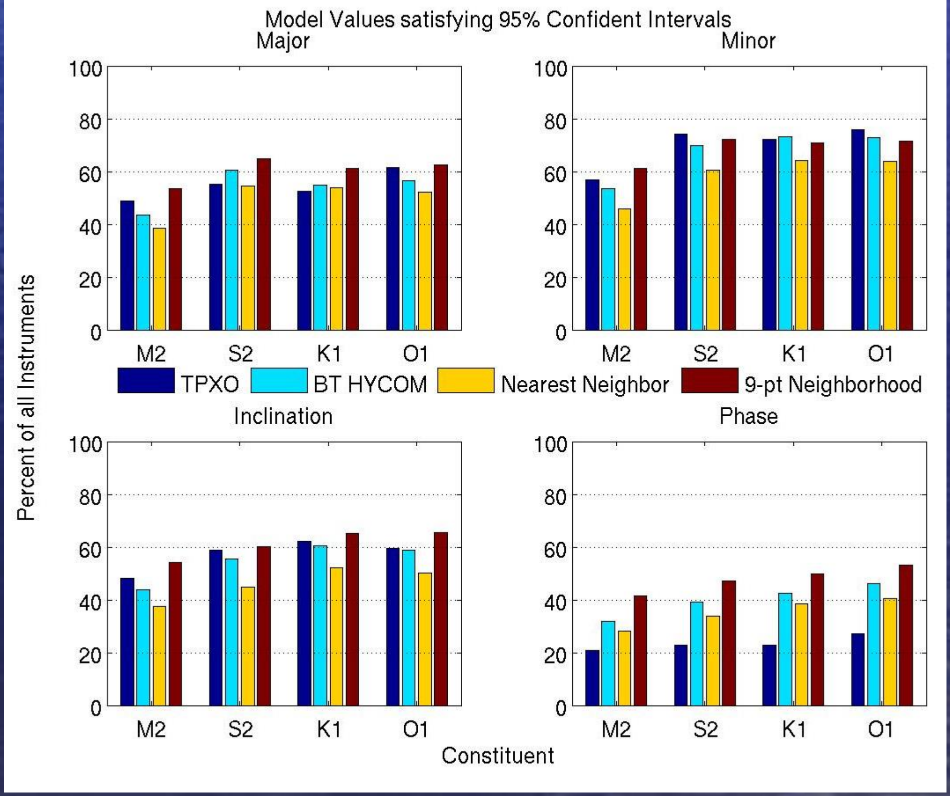


Comparison to historical current meters

Profiles of the Average Kinetic Energy for all 5000 current meters

Statistic for the ellipse parameters for all 5000 current meters



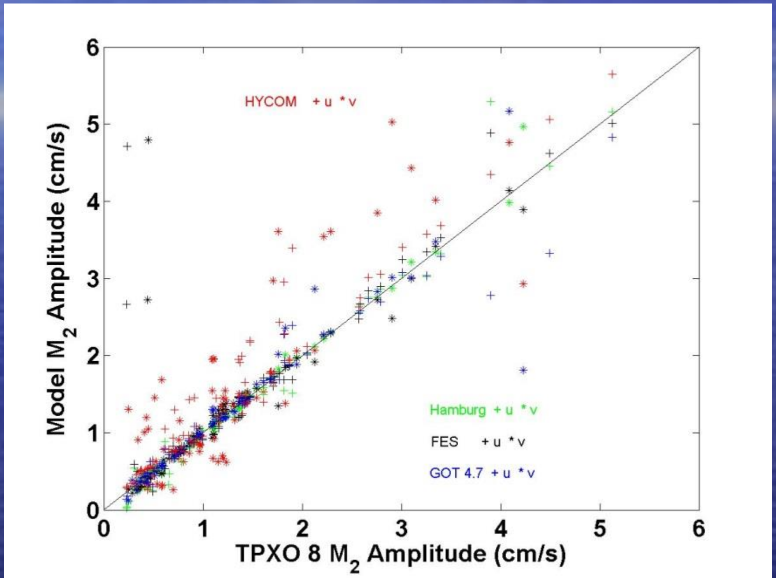


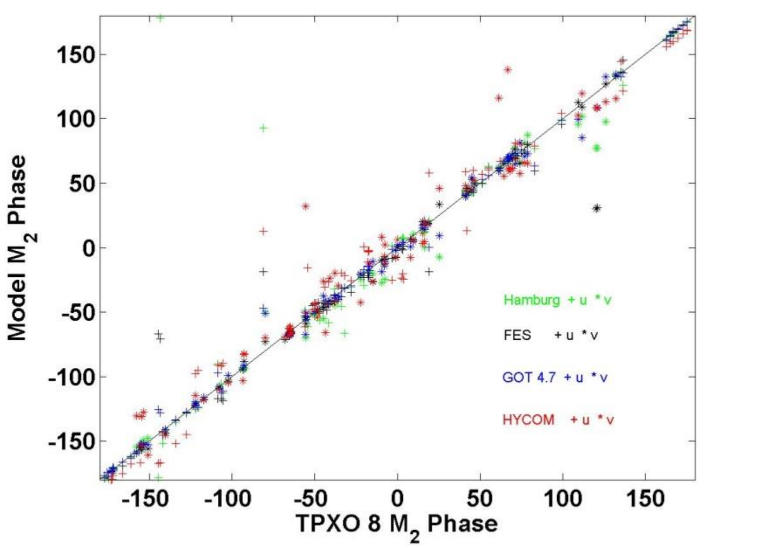
Comparison of Barotropic HYCOM Tides with Data Assimilative Tide Models

Results from 71 current meter moorings

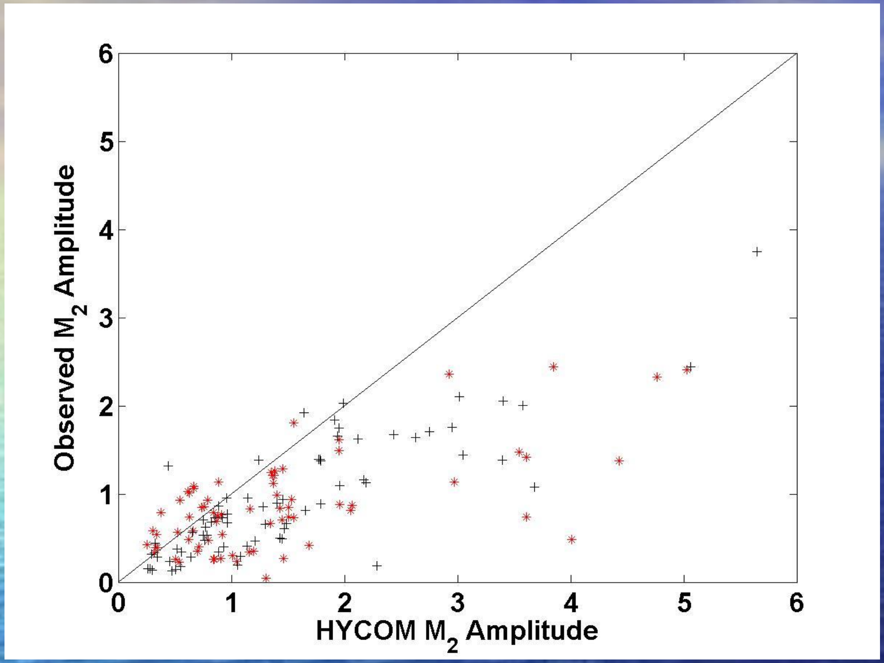
The tides in the global model compare well in amplitude and phase with the data-assimilative tidal models in amplitude and phase. Although HYCOM appears to overestimate the amplitude with larger scatter than FES or GOT4.7

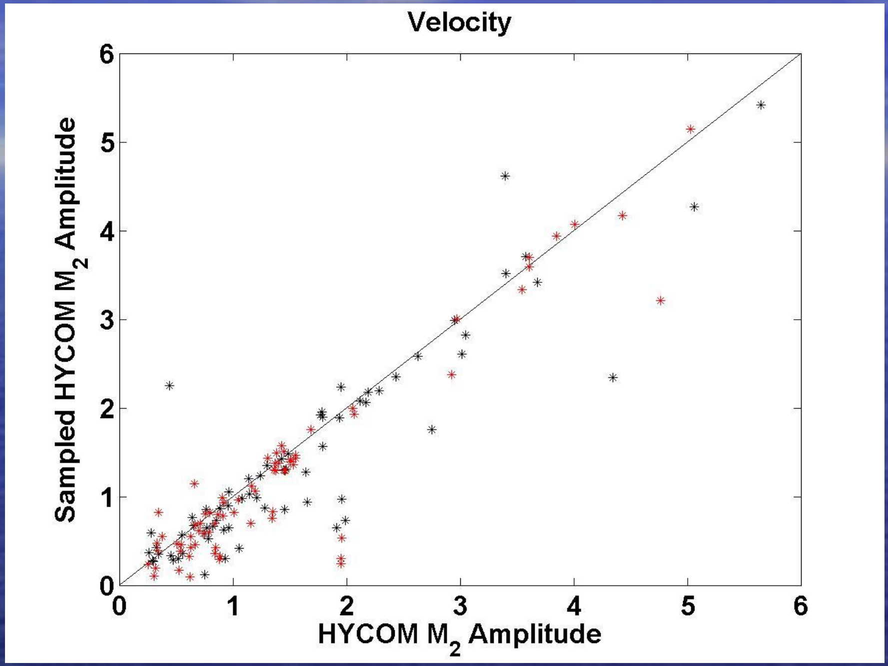
The difference between the data-assimilative models is much smaller than the difference between the global model and any of the data-assimilative tide models with the possible exception of the Hamburg tidal model





The Barotropic velocity is difficult to estimate





The tides in the global model overestimate the barotropic tidal velocities from vertical regressions at historical current meter moorings. The barotropic velocities estimated by regression in the model with the same sampling in the vertical. Phases are poorly recovered

Possible Causes for Model Error

- The largest error between the global model and TPXO occurs in the Southern Ocean
- Large differences in the model bathymetry and geometry exist in the Southern Ocean
- TPXO extends the ocean to beneath the floating ice shelves and reduces the ocean depth by the thickness of the shelves

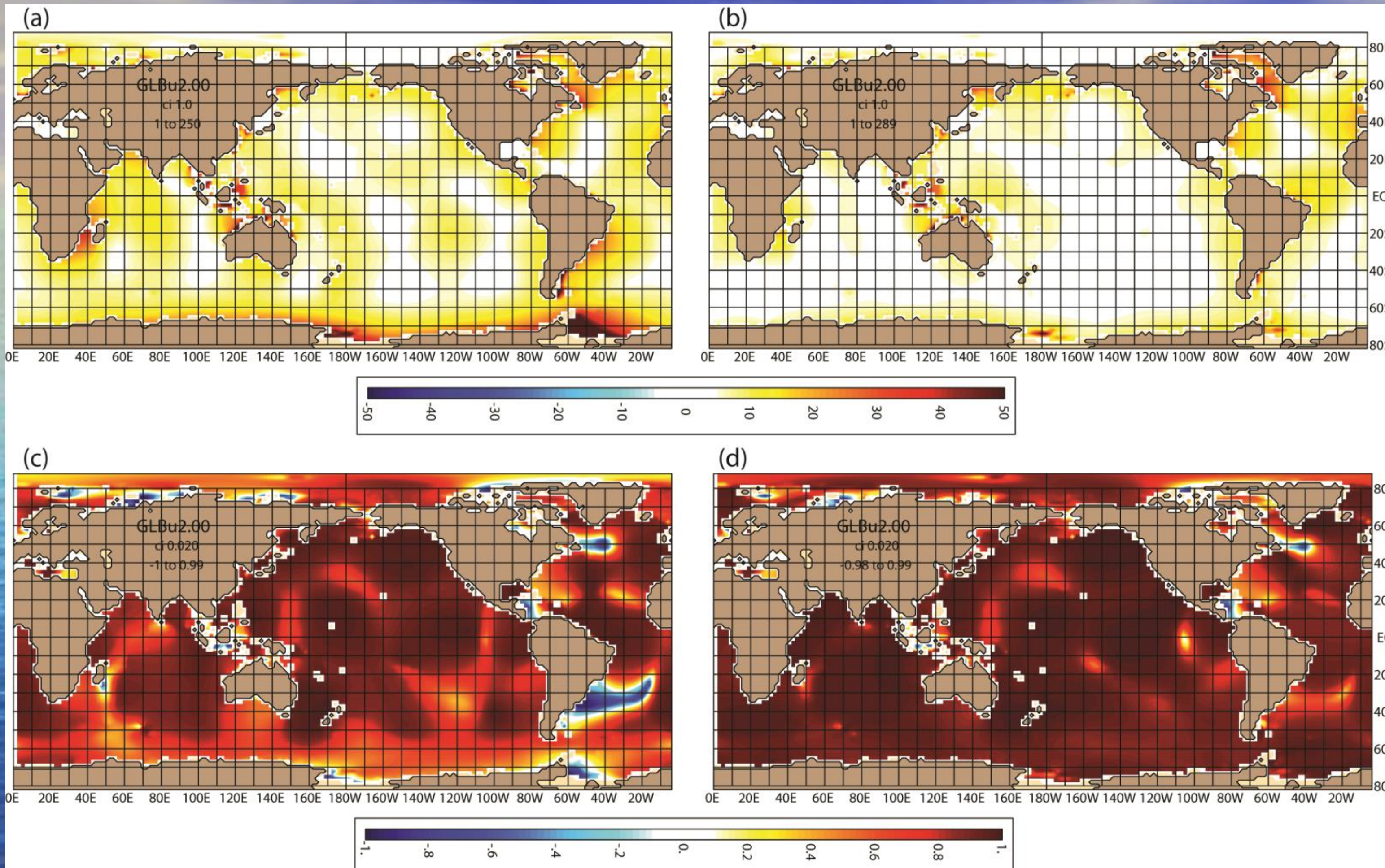
Improvements underway for the tides in HYCOM

Current Model

New Southern Ocean BC

RMS Error

Skill Score



A large difference between the data-assimilative TPXO model and HYCOM is the treatment of the floating ice shelves around Antarctica

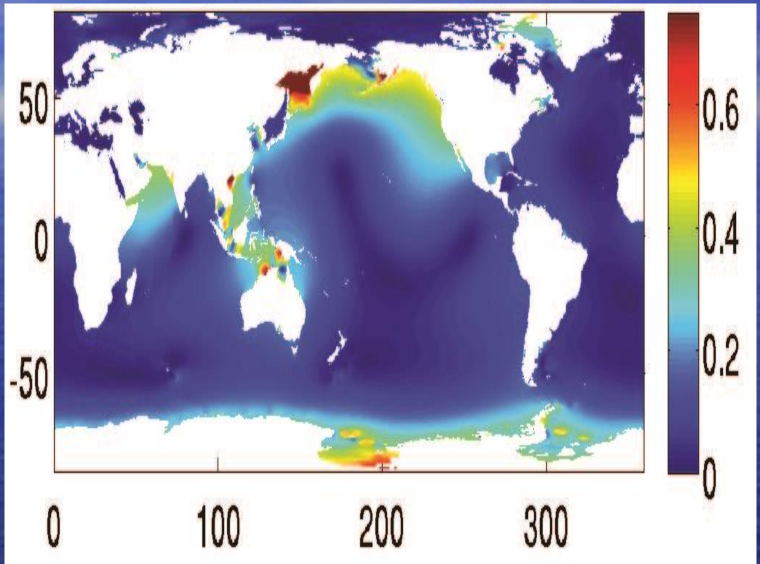
Using the TPXO tides as a boundary condition at the floating ice shelves reduces the rms difference (a and b) and improves the skill (c and d) over much of the globe, not just the Southern Ocean.

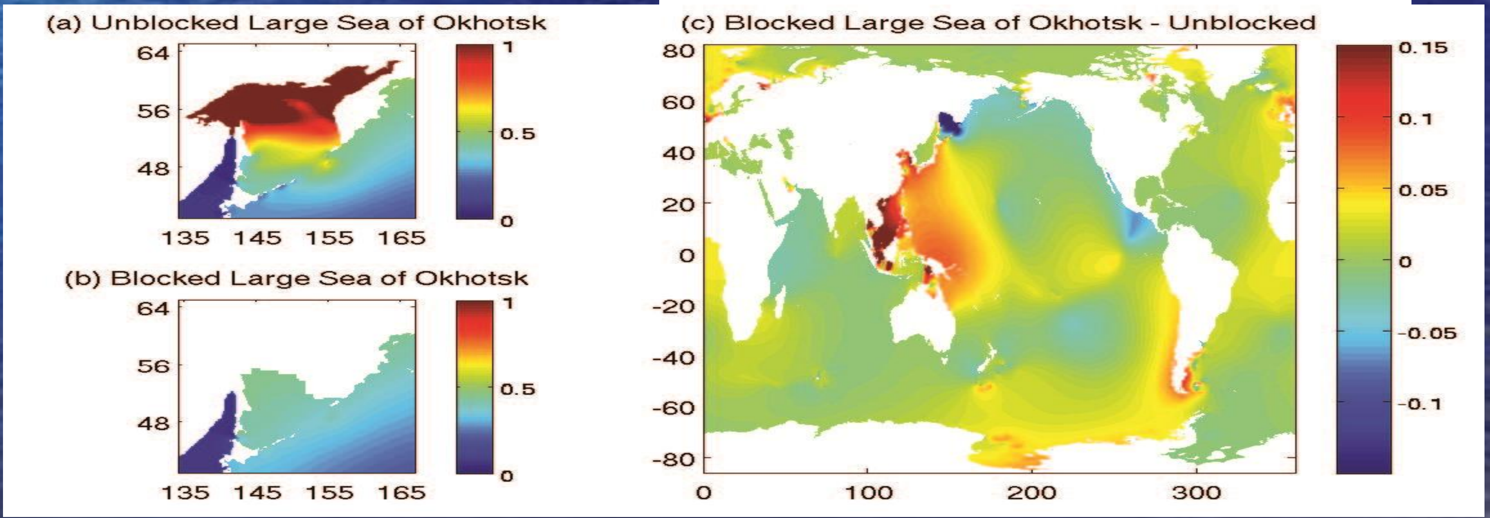
Resonances affect the tidal amplitudes

In Skiba, Zeng, Arbic, Muller and Godwin (JPO, in press) the coastal ocean tides significantly impact the deep ocean tides.

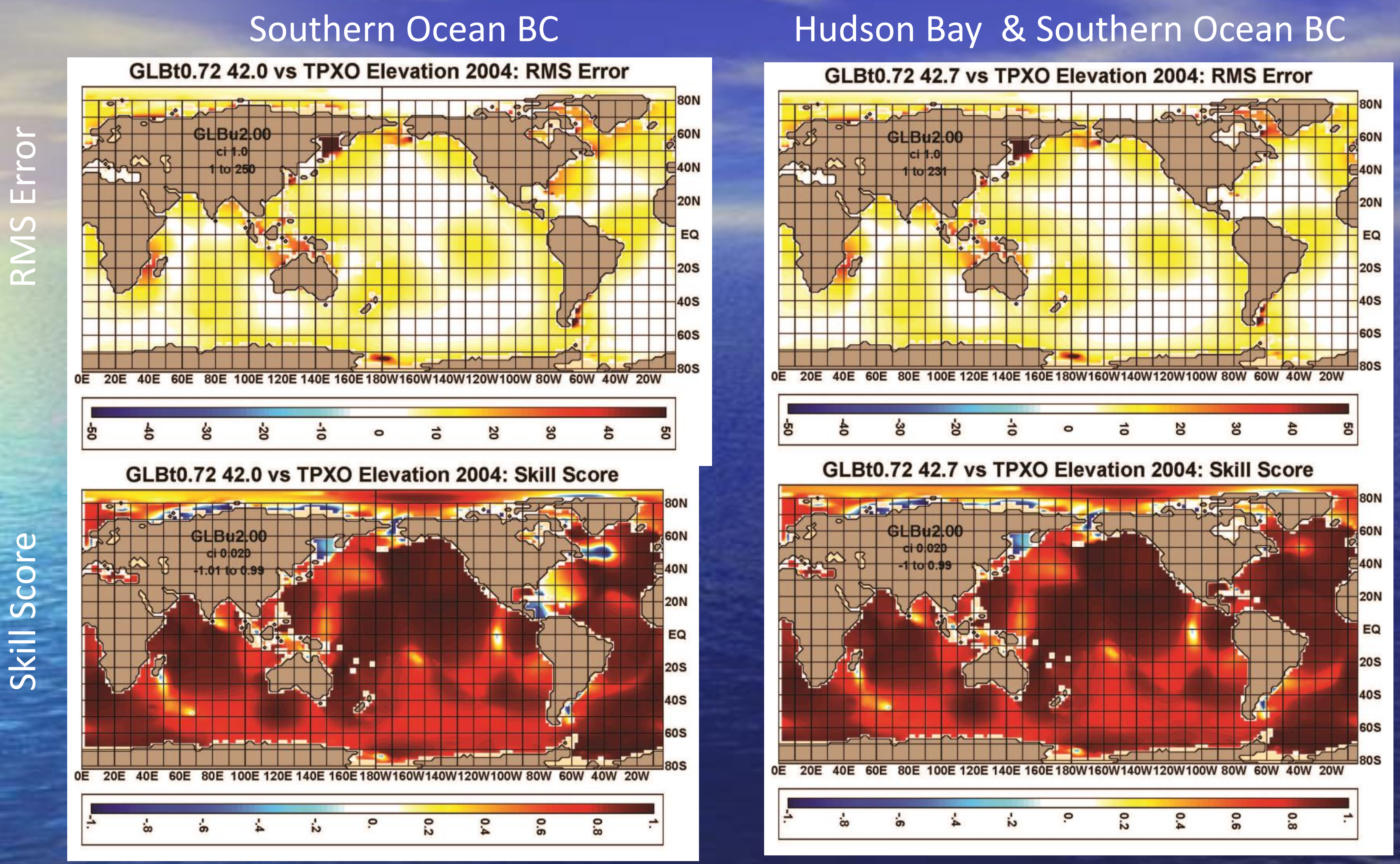
Blocking the Sea of Okhotsk creates differences in the tidal amplitudes over much of the global ocean, which approach 50% of the unperturbed amplitude

K_1 Diurnal Tidal Amplitude (m)





Effect of Tidal Resonance



If the Hudson Strait is blocked in the model and replaced with the TPXO M_2 transport, then we see substantial improvement in the North Atlantic, reducing the RMS error and increasing the skill. Unfortunately, we can't use this approach in the baroclinic global model with sea ice.

Tidal resonances represent a challenge for all forward (non-assimilative) tide models.

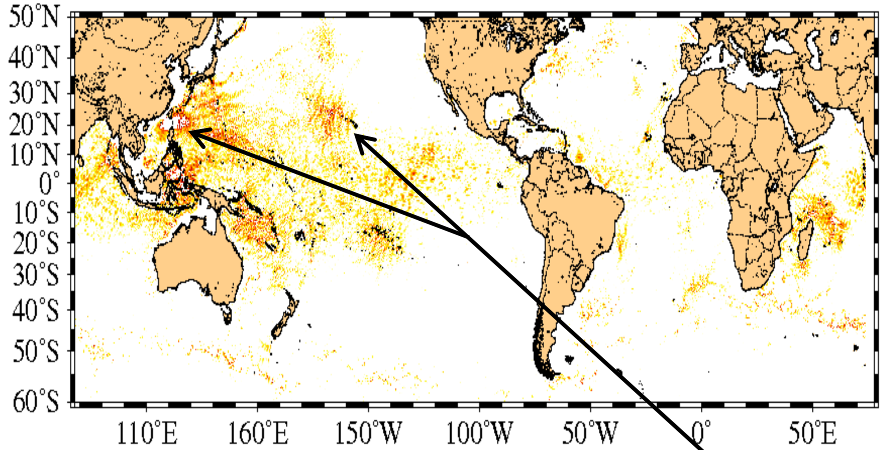
Data Assimilation in the Presence of Tides

- The present forecast system uses 3DVAR to assimilate data into the model
  - The dominant length scale of the assimilation is based upon mesoscale varibility
  - The spatial scale of the low vertical mode internal tides is similar to the scale of mesoscale eddies
- Preliminary experiments show that the 3DVAR scheme doesn’t degrade the tidal solution but does add additional internal wave variability

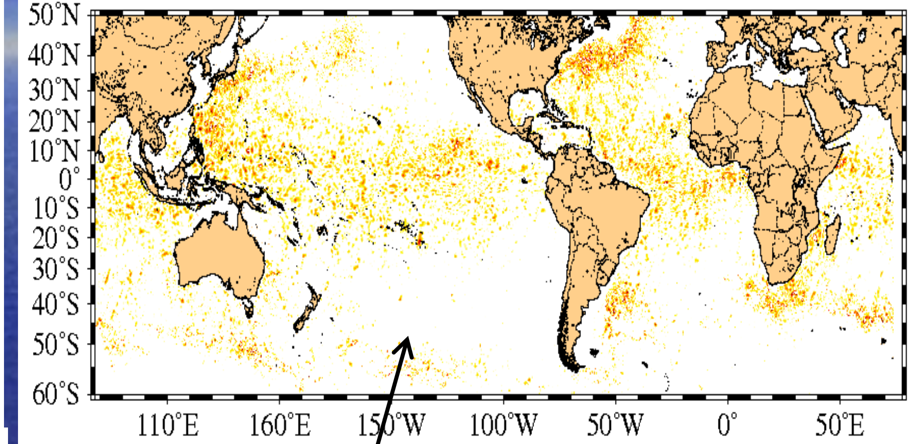
HYCOM/NCODA with tidal forcing on 1/12° domain

August 2008 animation of the daily variance of hourly steric SSH

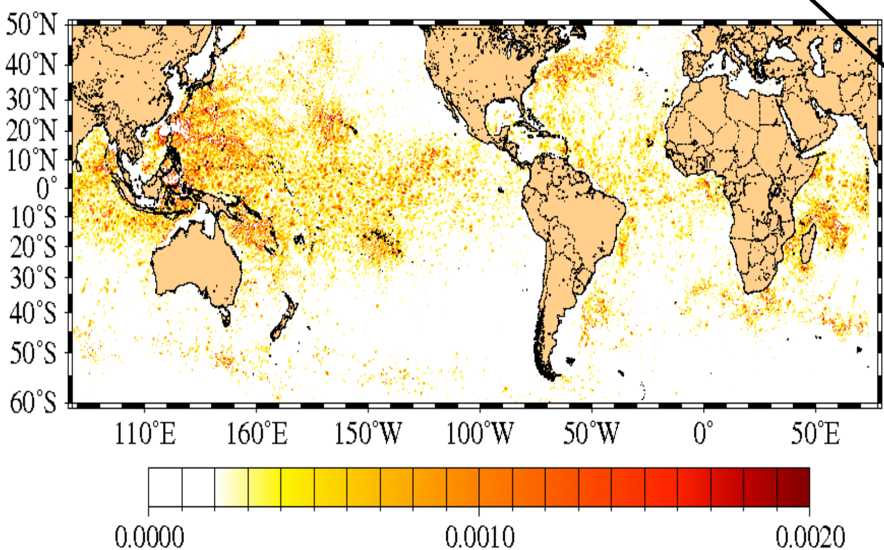
Tides – no data assimilation



Data assimilation - no tides



Data assimilation with tides

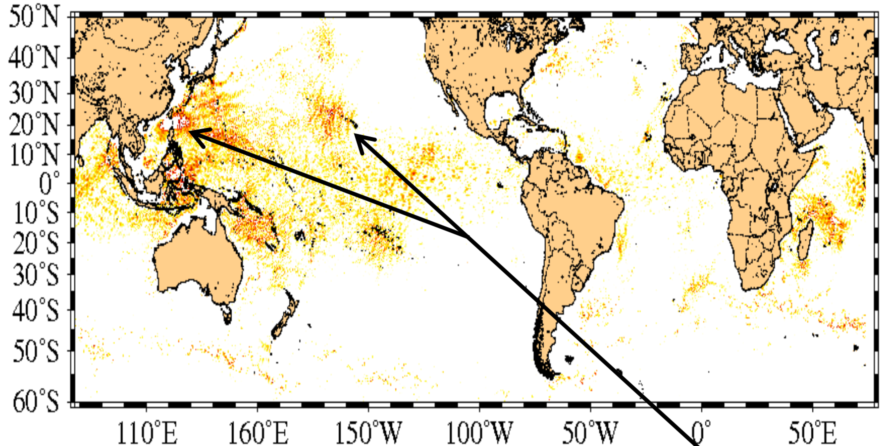


- Transient waves from the insertion of NCODA analysis increments
- Strong generation of internal tides at 'hot spots' that can propagate 1000s of km away from generation regions – need a global model with tides

HYCOM/NCODA with tidal forcing on 1/12° domain

August 2008 animation of the daily variance of hourly steric SSH

Tides – no data assimilation



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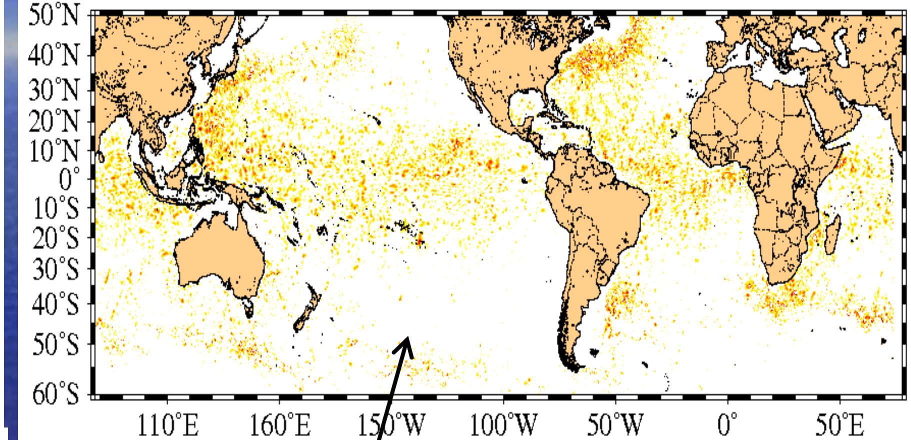
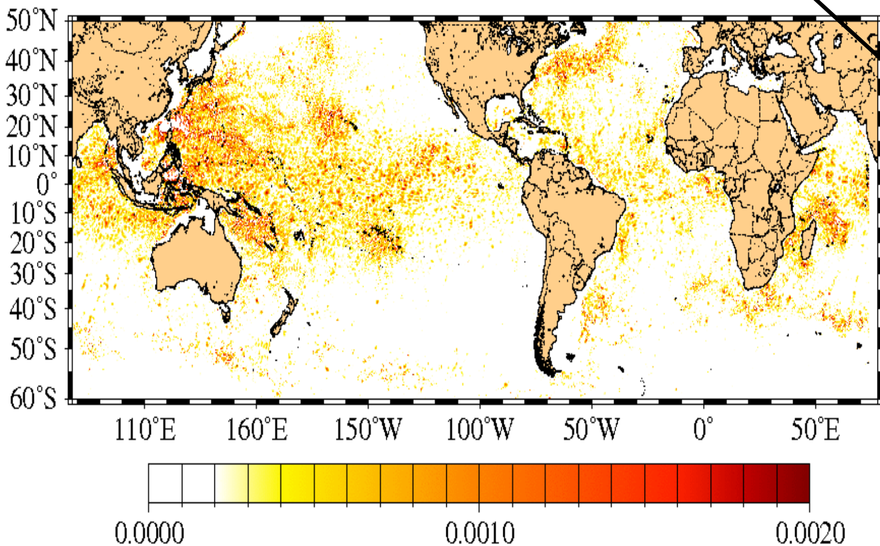


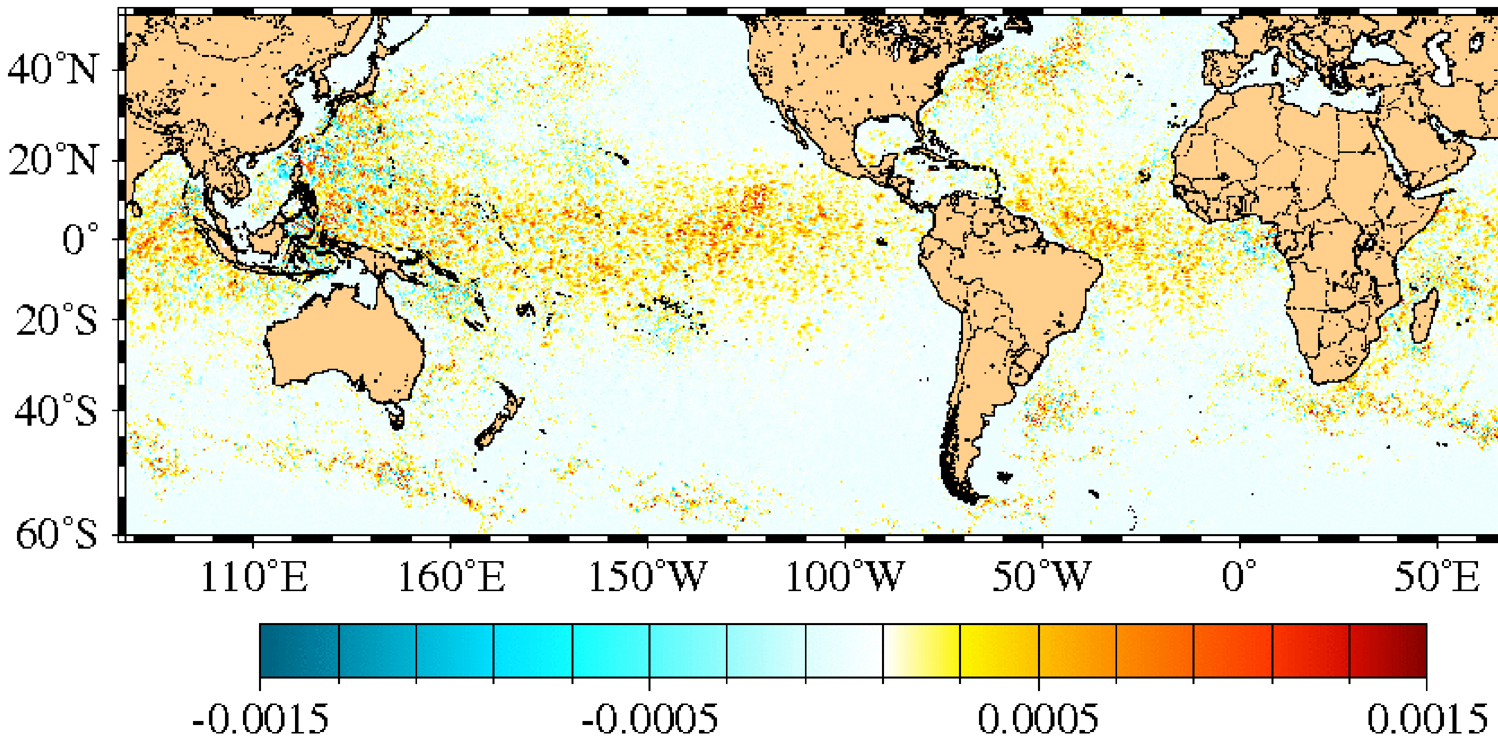
Data assimilation with tides



- Insertion of T-S anomalies with large vertical scale will generate internal tides
- A first mode internal semi-diurnal tide has a wavelength of 160 km – similar to the scale of mesoscale eddies

HYCOM/NCODA with tidal forcing on 1/12° domain

August 2008 animation of differences between the variances of steric SSH of(tides only + DA without tides) minus DA with tides

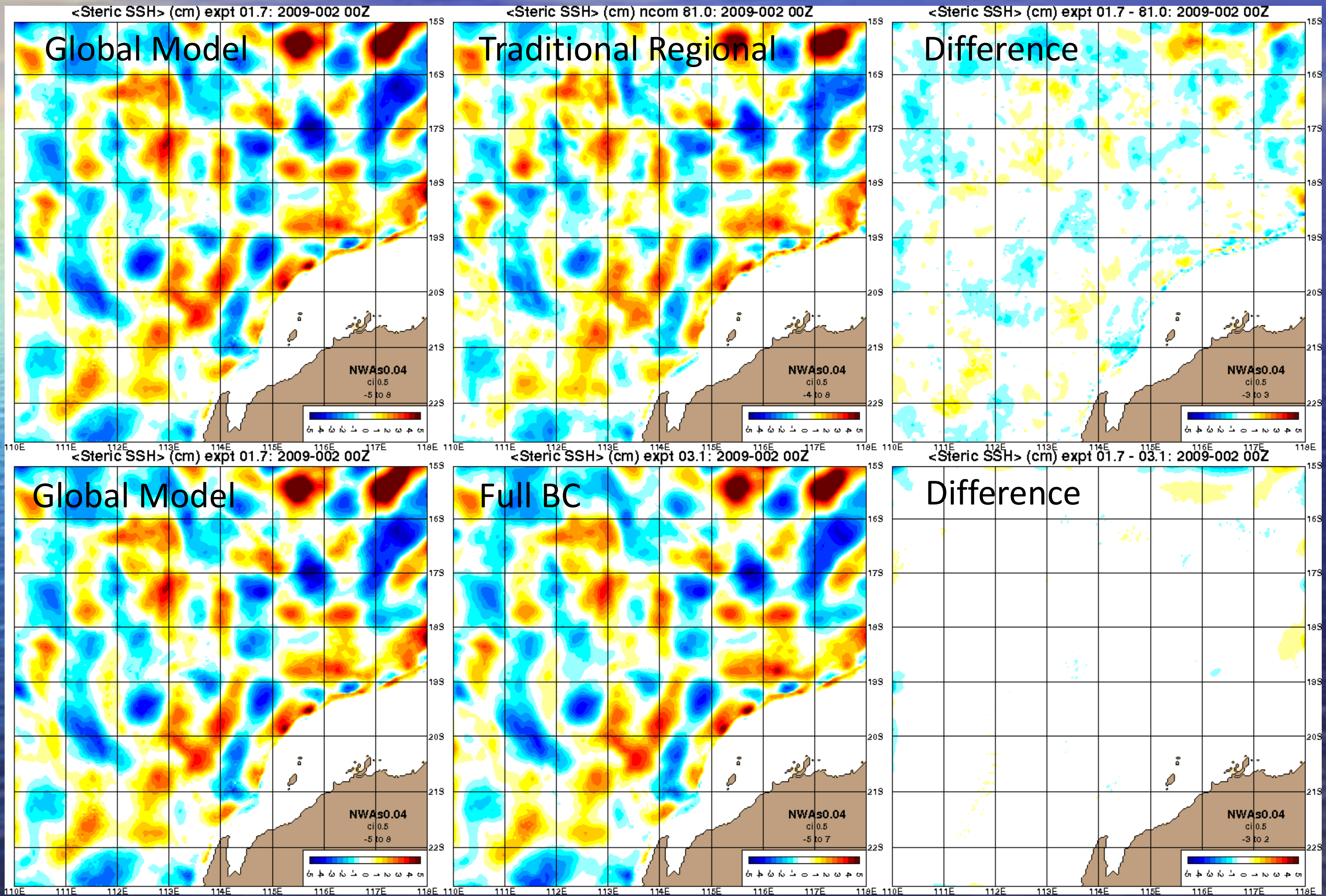


- Data assimilation does not appear to be adversely affecting the tidal solution
- Tides do not adversely affect the large scale circulation

Global Model will be used to provide boundary conditions for Regional Model

- The current generation of regional model uses the non-tidal model and the tidal transport from data-assimilative tidal models for boundary conditions
- Internal waves can impact the regional and shelf circulation
- If the global model with tides is accurate enough it can provide complete boundary conditions for regional models

Impact of internal waves on regional ocean models



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  - Phase errors in barotropic tide affect the baroclinic tide
- The barotropic and internal tidal kinetic energy in the model compares well with historical current meters and data-assimilative tide models
  - The model tidal amplitudes compare well with the data-assimilative models
  - Barotropic tidal velocities are difficult to estimate from deep ocean current meter moorings
- Tidal resonances and bathymetry play an important role in global tide modeling
  - Forcing the southern boundary with TPXO tides improves the global solution
- The current 3DVAR mesoscale data assimilation scheme (NCODA) works in the tides in the model
- Model internal waves can play an important role in the boundary conditions for regional models and global HYCOM can be reproduced in regional twin experiments