Towards TPXO10: the next version of the Oregon State University ocean tide model

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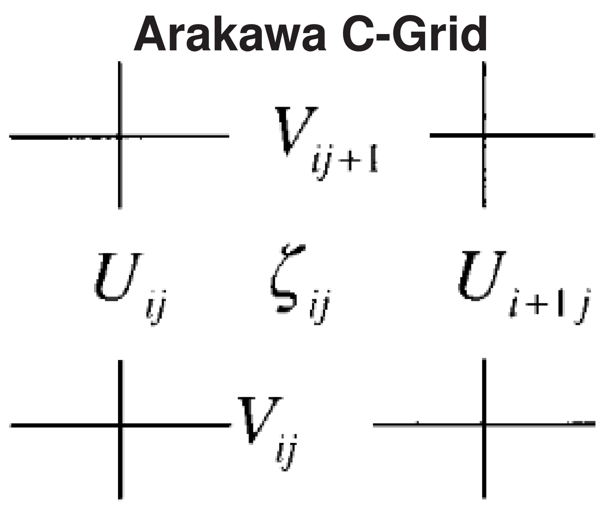
Overview

The hydrodynamic prior model has been comprehensively updated for TPXO10:

- M_2 errors of 12 cm root-mean-square (rms) in the TPXO9 hydrodynamic prior have been reduced to 3 cm rms for TPXO10.
- Prior errors in several minor constituents are comparable to errors of the TPXO9 data-assimilative (inverse) model.
- Treatment of topography has been completely revised.
- The wave-drag parameterizations have been revised and re-calibrated.
- Atmospheric/radiational forcing of S_1 and S_2 tides are included.
- Bottom drag is reduced in the deep ocean.
- A new drifter-derived dataset of tidal currents is used for validation, in addition to tide gauges.
- The forthcoming data-assimilative TPXO10 will use a larger altimeter dataset than previous versions of TPXO.

Bottom Topography

Topography is defined at cell-edges, rather than cell-centers:

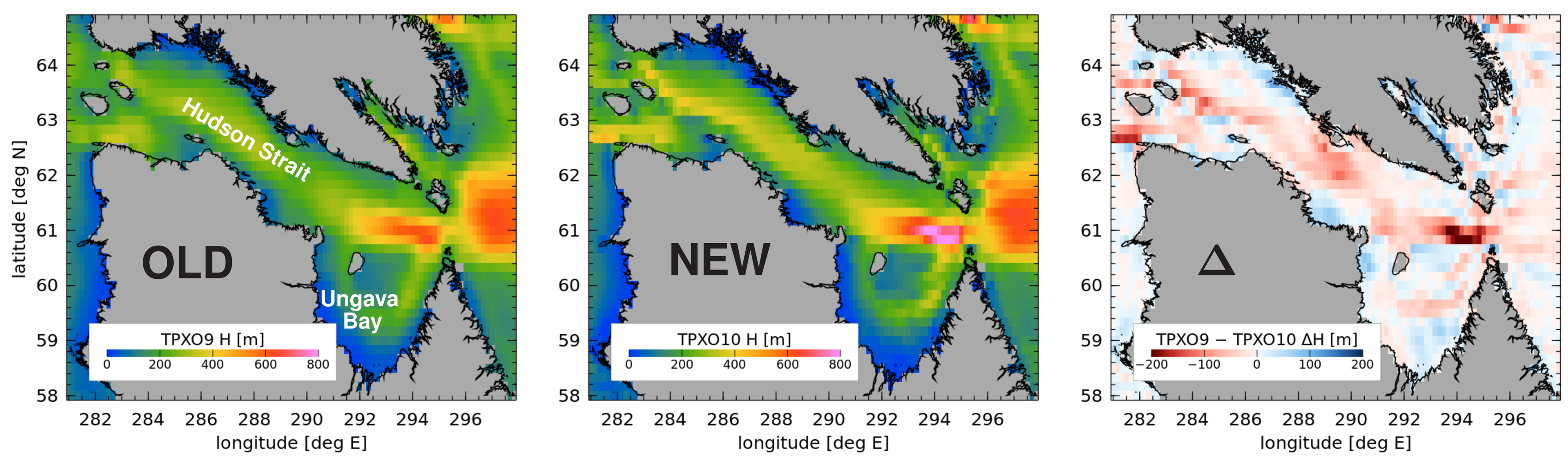


Previously, the topography (H_{ij}, the resting water depth) was specified on ζ_{ij}-nodes and it was averaged to obtain values on U_{ij}- and V_{ij}-nodes. In TPXO10, the depth is specified independently on the U_{ij} and V_{ij} nodes. Note that the solver only uses H_{ij} values on U_{ij}- and V_{ij}-nodes:

$$-i\omega\mathbf{U} + \mathbf{f}\times\mathbf{U} + gH\nabla\zeta = \mathbf{F} \qquad -i\omega\zeta + \nabla\cdot\mathbf{U} = 0$$

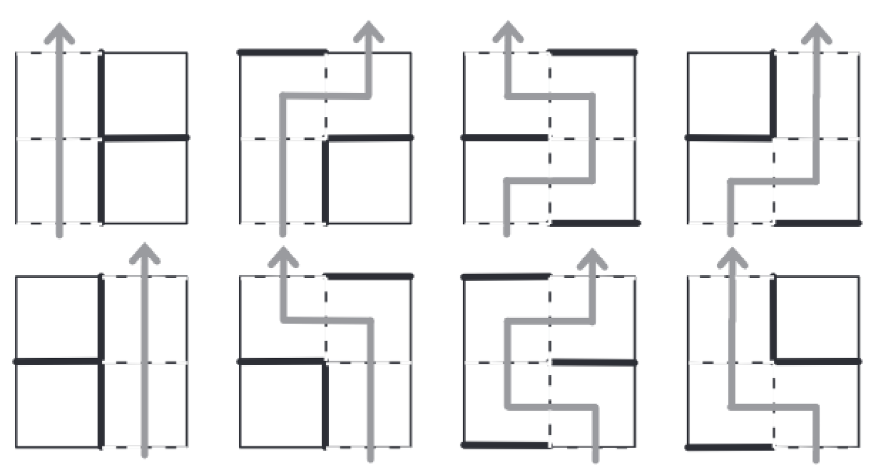
High-resolution water depth is borrowed from the NOAA STOFS model:

The Global Storm Surge & Tide Forecast System (STOFS-2D-Global) is a high-resolution model developed by NOAA and collaborators. STOFS is based on ocean topography (GEBCO) augmented with high-resolution regional bathymetric datasets, and it has undergone extensive "hand-editing." We remapped the STOFS topography from its native high-resolution finite-element mesh to a uniform (1/120)-degree latitude/longitude grid, and then subsampled this to TPXO's global (1/6)-degree resolution.



The $(1/6)^\circ$ grid is created by connectivity-preserving downsampling:

The (1/120)-degree topography is downsampled using the approach of Adcroft (2013). The example below shows the 8 different pathways a water parcel can take between the north and south faces of a cell assuming a factor-of-two coarsening of resolution. Our new approach to topography preserves connectivity of coarse-grid cells by downsampling the data in this manner.



Adcroft, A. 2013: Representation of topography by porous barriers and objective interpolation of topographic data. *Ocean Modelling*, 67:13–27.

Wave Drag and Bottom Friction

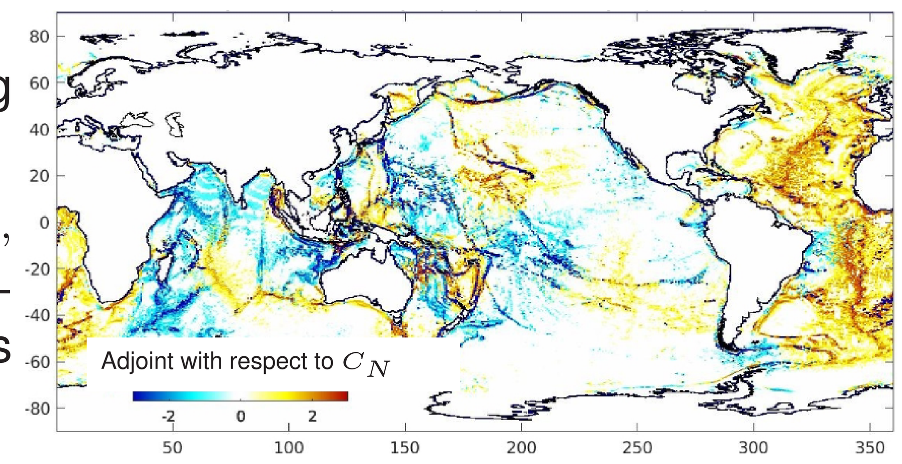
Wave drag parameterization:

Previous versions of TPXO used the Jayne & St. Laurent (2002) parameterization of linear wave drag.

Now, TPXO10 uses the wave drag formulation of Nycander (2005),

$$C_N\left(1-\frac{f^2}{\omega^2}\right)^{\frac{1}{2}} N_b(\nabla H\nabla J + \nabla J\nabla H)\mathbf{U},$$

where H is topography, J is a regularized Green's function, and N_b is buoyancy freq. at the bottom.



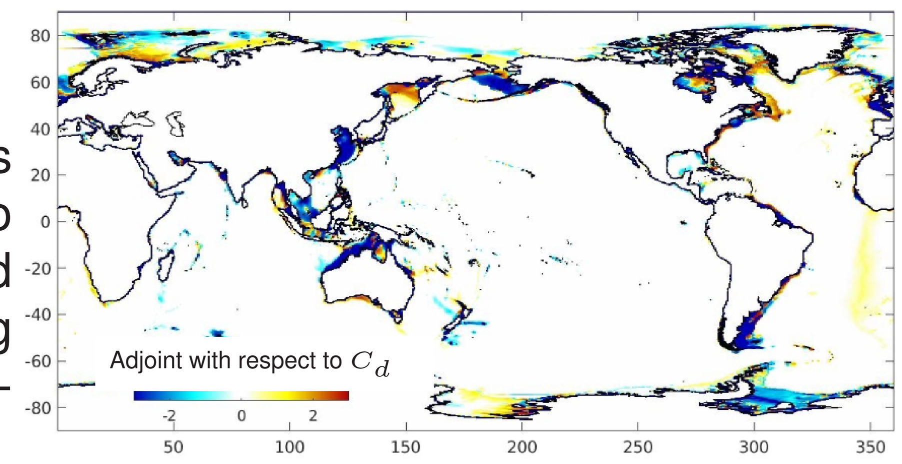
For sub-inertial tides, poleward of the critical latitude, we use a Jayne & St. Laurent-like roughness-based parameterization.

Bottom friction:

Quadratic drag is linearized,

$$C_d|\mathbf{u}|\mathbf{u}/H \approx C_d u_f \mathbf{u}/H.$$

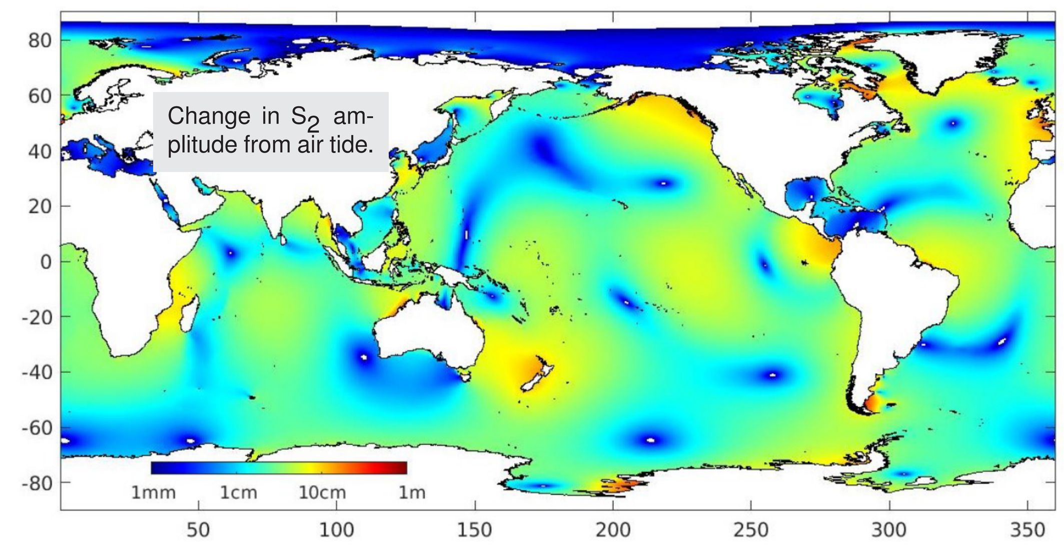
The bottom friction velocity, u_f, varies from 50 cm/s at the coastline to 1 cm/s at 500 m. We experimented with other approaches to computing u_f, but they did not lead to unambiguous improvements.



Jayne, S. & L. St. Laurent, 2001: Parameterizing tidal dissipation over rough topography. *Geophys. Res. Lett.*, 28, 811–814
Nycander, J., 2005: Generation of internal waves in the deep ocean by tides. *J. Geophys. Res.*, 110, C10028

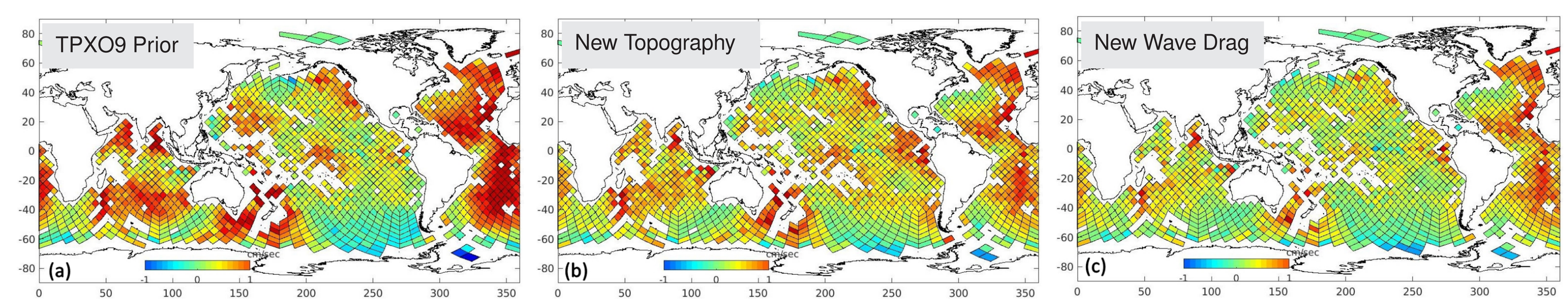
The Radiational Tide

TPXO10 augments the astronomical tide-generating force of S_2 with forcing by atmospheric pressure estimated from the MERRA-2 reanalysis product.



Validation using barotropic tidal currents

The figures below illustrate comparisons between modeled and observed M_2 tidal currents. The observed currents are based on harmonic analysis of Global Drifter Program data (Elipot et al 2016) averaged within 500 km patches on a PixMap grid. The colorscale shows the error in the semi-major axis of the current ellipse.



Elipot, S. et al, 2016: A global surface drifter data set at hourly resolution, *J. Geophys. Res.*, 121, 2937–2966.

Summary

The new TPXO10 hydrodynamic prior model is much more accurate than the TPXO9 prior model, and, for several nonlinear tides, the TPXO10 prior model exceeds the accuracy of the TPXO9 data-assimilative (inverse) model. The model is much less dissipative in the deep ocean and we anticipate it will provide a better starting point for subsequent data-assimilative solutions. The tables below show errors (cm) compared to "Stammer Deep" reference tide gauges.

Tide	RMS Signal	TPXO9 Prior	TPXO10 Prior	TPXO9 Inverse
M_2	30.22	12.04	2.87	0.51
S_2	11.21	7.65	0.96	0.33
N_2	6.36	2.46	0.72	0.21
K_2	3.12	1.91	0.34	0.15
K_1	12.51	4.23	0.84	0.42
O_1	8.75	2.92	0.74	0.26
P_1	3.99	1.44	0.31	0.15
Q_1	1.79	0.53	0.18	0.14
M_4	0.22	0.34	0.17	0.04
MN_4	0.09	0.15	0.07	0.04

Tide	RMS Signal	TPXO9 Prior	TPXO10 Prior	TPXO9 Inverse
$2N_2$	0.80	0.86	0.32	0.45
L_2	0.75	0.51	0.25	0.22
Nu_2	1.13	0.52	0.14	0.10
Mu_2	0.95	0.38	0.22	0.11
T_2	0.63	-	0.45	-
$2Q_1$	0.25	0.12	0.05	0.06
OO_1	0.43	0.32	0.09	0.09
J_1	0.72	0.38	0.09	0.12
S_1	0.41	0.28	0.27	0.28
M_3	0.23	0.22	0.09	0.06
MS_4	0.12	0.19	0.08	0.04

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