ABSTRACT

As part of a project led by D. Stammer for assessing the qualities, relative merits, etc. of eleven global tidal models (Stammer et al., 1996; Ritman et al., 1994), harmonic constants of tidal currents derived from recent tidal models are compared to harmonic constants estimated from ocean acoustic tomography. Data from four acoustic tomography arrays deployed for various experiments over the past 30 years in the North Pacific and North Atlantic are used. As a measurement technique employing reciprocal acoustic signals that cycle through the water column and traverse O(500-km) distances, acoustic tomography offers a precision measurement of barotropic currents, tidal currents in particular. Barotropic tidal currents negligibly influence these measurements. Previous comparisons of tidal harmonic constants between models have shown that tomography can accurately measure the harmonic constants of at least the eight largest tidal constituents. While some of the tidal models are constrained by observations and some are hydrodynamically non-interactive, the tidal currents derived from models are constrained by measurements of tidal currents. The new comparisons between measured and modeled tidal harmonic constants are generally favorable, with most models being "right-side up". Small systematic differences between measured and modeled harmonic amplitudes and phases suggest some aspect of tidal modeling problem than a measurement problem. In any case, inssofar as these "spot" comparisons can determine, tidal currents derived from many of the modern global tidal models appear to be reasonably accurate, in the open ocean at least.

TIDAL MODELS

Currents corresponding to the tomography measurements were computed from eleven global barotropic models, with the GODAS model, or in a particular model was only computed for M2. Some of the model file sizes are rather large. Some models currently have a 1/12° resolution, with currents computed after the fact. Other models are hydrodynamic with currents computed as a part of the model solution. 

1) TPXO (Egbert/OSU) An assimilative barotropic tide model, hydrodynamic, with many analysis grids. 1/12° resolution.
2) STORMTIDE (Miller et al. 2012) A non-assimilative ocean circulation and tidal model, from which the barotropic tides are extracted. 1/8° resolution.
4) CISS (Cresswell and Hanke, DB) An assimilative barotropic tide model. 1/12° resolution.
5) LEEGED (Gifford/Leeds Univ, UK) A non-assimilative barotropic tide model, STM-1B. 1/8° resolution.
6) OTIS-G2N (Drown and Nycander 2013) A non-assimilative barotropic tide model. 1/12° resolution.
7) KEWIS (Schweiderska ca. 1980) From Schweiderska's classic paper. An assimilative barotropic tide model. 1/12° resolution.
8) GOT4.7 (Pilkey 2001) An empirical tidal analysis with many constituents. Currents computed post hoc by least-squares minimization of inventory and continuity equations. 1/2° resolution.
9) OTIS-ERB (Egbert, Ray, and Bills 2004) A non-assimilative barotropic model. 1/12° resolution.
10) HYCOM (Arbic et al, 2010; Shriver et al. 2012) Non-assimilative. Barotropic tides extracted from a model which includes many layers and atmospheric as well as tidal forcing. 1/12° resolution, subsampled to 1/4° resolution.
11) FES 2012 (Lyard/LEGOS, Carrere et al. 2012, FR) A hydrodynamic barotropic model with assimilation of altimeter data. Unstructured global mesh with resolution a few km in coastal regions to 25 km in the deep ocean. 1/10° resolution.

COMPARISONS TO EIGHT CONSTITUENTS: $M_2$ to $O_1$

The precision of the tomographic measurements allows the first eight tidal constituents to be resolved: $M_2$, $S_2$, $N_2$, $K_1$, $O_1$, $K_2$, and $S_2$. While the tomography results are limited on the spatial resolution and the constituents considered, the results indicate two points: First, the resolution of the tide currents appears to be about the same for all the constituents. Second, all the $M_2$ constituents indicate that the measured amplitudes are systematically smaller than modeled on some regions, particularly near Hawaii, but not uniformly across the region. The differences between models, demonstrate the precision of the observations.

TIDAL VORTICITY

By Stokes’ Theorem, integration of current around a closed loop is equal to the volume integral of vorticity. A small rectangle is oriented by the loops, primarily by tidal elevation stretching the vortex lines. To a resolution, currents can be modeled through the "tearing" (vertical) and through flow over varying topography. The dominant term to tidal vorticity is roughly in phase with elevation (Dushaw et al. 1997).

TIDAL ENERGY

Tidal energy flux around Hawaii shows that most of the tidal energy travels into the Hawaiian region. This result is mainly due to mesoscale activity. Harmonic constants from the Harmonic currents analysis to the tidal currents, mainly due to tidal forcing. In 1991, the HOME array was first deployed north of Hawaii for about 1 year, and then moved south of Hawaii for a year. The northern array suffered instrument failure, leaving only a single path with reciprocal transmissions. The southern array continued to function. The arrays were deployed to measure radiation of internal tides from the Hawaiian Ridge, hence the longest path of the array. The results reported here are for the path and the short path perpendicular to it.

TOMOGRAPHY BASICS

Sound travels faster in warm water than in cold water. By measuring the travel time of sound over a known path, the sound speed and thus temperature can be determined. Each acoustic travel time represents the path integral of the sound speed (temperature) and water velocity. As the sound travels along a ray path, it inherently averages these properties of the ocean, heavily filtering along-path horizontal scales shorter than the path length. A 1°C change in temperature roughly corresponds to a 4 m/s change in sound speed, although this scale factor is somewhat temperature dependent. Over a 1000-km range, a depth-averaged temperature change of 10°C is easily measured as a 20-m travel time change. (Mark, Worcester and Wunsch, 1995)

Sound travels faster with a current than against. By measuring the reciprocal travel times in both directions along a path, the absolute water velocity can be determined, and the effects of temperature can be excluded. Currents (1 cm/s) have a small but measurable sound speed (1 mm/s) change.

Sound speed is also weakly affected by salinity. A 1 PSU change in salinity roughly corresponds to a 0.1 m/s change in sound speed. The dependence of sound speed on temperature and salinity allows an accurate determination of the salinity fields and temperature during the experiment.

REFERENCES

