Impact of Tidal Forcing on Western Boundary Currents

Patrick Timko[1], Brian K. Arbic[1], Luis Zamudio[1], Jospeh K. Ansong[1], Maarten C. Buijsman[2], Jay F. Shriver[3], and Alan J. Wallcraft[1]

[1]Affiliation not available
[2]University of Southern Mississippi
[3]US Naval Research Laboratory Stennis Space Center

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Abstract

Ocean General Circulation Models (OCGM) have been used for ocean forecasts and reanalysis in the past; successfully reproducing realistic large scale features such as Western Boundary Currents (WBC) which evolve slowly in time. Recent developments of three dimensional OCGM's include the incorporation of tidal forcing embedded in the numerical integration. With the inclusion of higher frequency tidal forcing it is now possible to study the impact of tides on the larger scale features of the ocean reproduced in the OCGM's such as WBC's through comparison of simulations with and without tides. We compare two 1/12.5° simulations of the Hybrid Coordinate Ocean Model (HYCOM) and report on differences in the mean position, transports, and warm/cold core eddy production in the Gulf Stream and Kuroshio Current and their extensions across the Atlantic and Pacific Oceans.

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[1]Welsh Local Centre, Royal Meteorological Society, [2]Department of Earth and Environmental Sciences, University of Michigan, [3]Centre for Ocean-Atmospheric Prediction Studies, Florida State University,
[*]corresponding author email: ptimko@umich.edu, [4]Dept. of Mathematics, University of Ghana, [5]University of Southern Mississippi, Stennis Space Center, [6]U.S.Navel Research Laboratory, Stennis Space Center

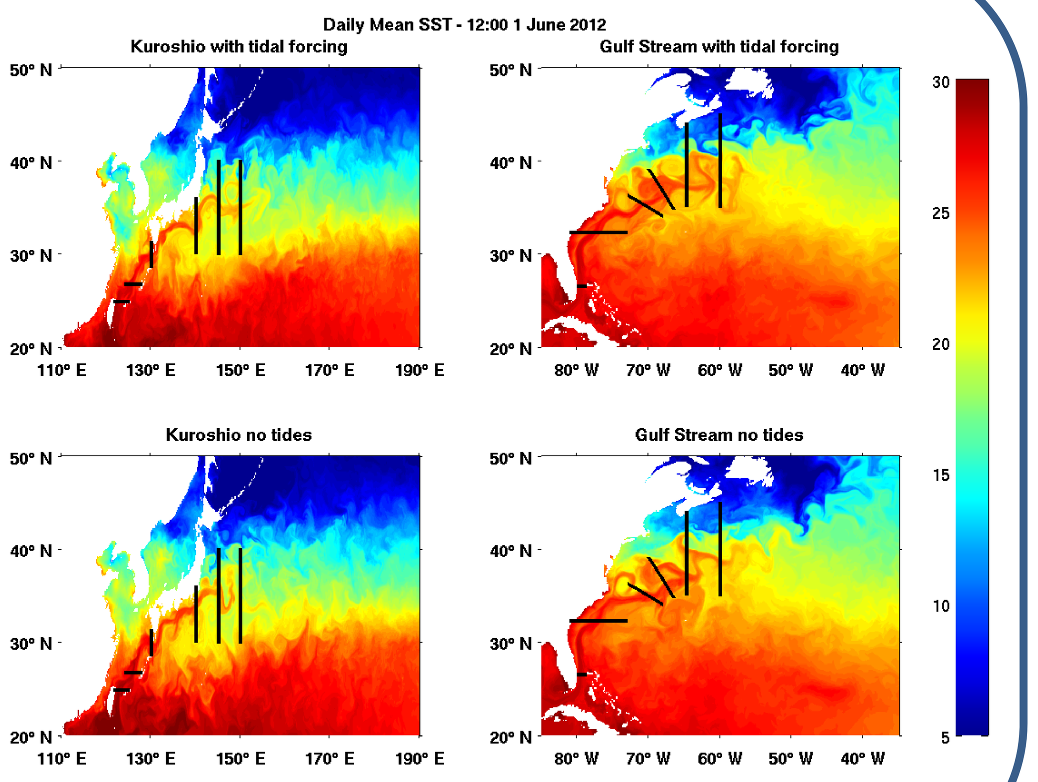
Background and Motivation

Shown in the figure to the right, a comparison of two global HYCOM simulations (Ngodock et al. 2016) with and without tidal forcing indicates differences in Sea Surface Temperature (SST) in regions of the Western Boundary Currents and their extensions.

We wish to quantify these differences in terms of:

- volume transport
- location of the current core
- warm/cold core eddy formation

Daily averaged fields from the 3-dimensonal HYCOM simulations are executed at a horizontal resolution of 1/12.5° with 41 vertical hybrid layers.The Navy Global Environmental Model (NAVGEM; Hogan et al., 2014) provides the atmospheric forcing and the simulation with tides includes constituents M_2, S_2, N_2, K_1, and O_1.



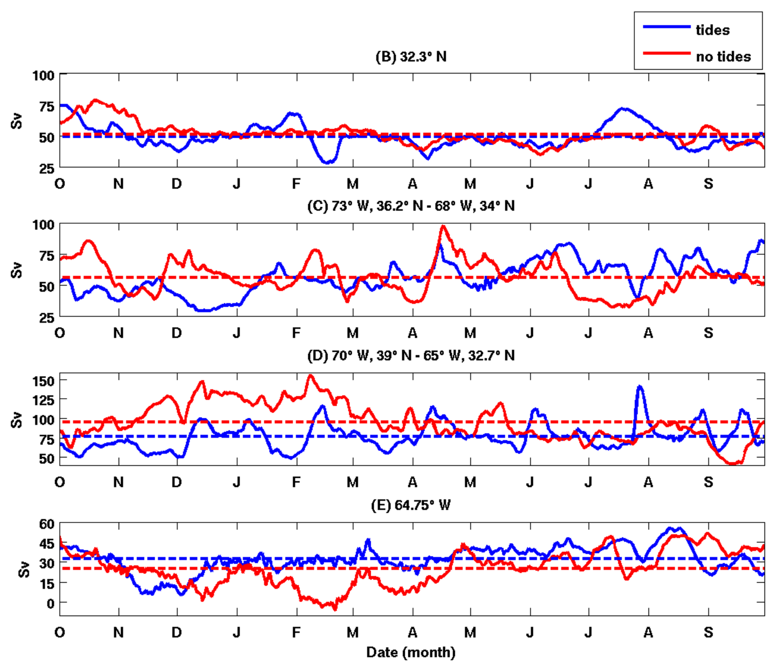
Impact of Tides on Volume Transport

With the addition of tidal forcing differences in the daily averaged transport (bottom right figure), normal to the transects shown as black lines in the figure above, between the surface and 500 m depth can be as large as 83 Sv in the Gulf Stream and 30 Sv in the Kuroshio (not shown).

The average transport over the year of simulation (Oct. 2011 – Sept. 2012) is shown in the tables to the right and below. Typically we find that differences in the average transport values are small (± 1 – 10%) in regions near the coastline where the geostrophic balance is expected to be the leading order solution. Once the western boundary currents separate from the coast we find that the tidal forcing increases (decreases) the transport in the extensions of the Gulf Stream (Kuroshio) by 25 – 70% (4 – 40%).

	Kuroshio											
	Volume Transport (Sv) to 500 m											
	24.9° N		26.7° N		130.1° E		140° E		145° E		150° E	
	Tides	No Tides	Tides	No Tides	Tides	No Tides	Tides	No Tides	Tides	No Tides	Tides	No Tides
mean	22.8	23.6	27.3	26.1	26.0	28.1	37.9	36.7	37.3	43.7	41.1	42.9
std	2.7	3.3	2.7	3.4	3.7	3.2	4.8	5.1	6.0	6.9	7.2	9.3
	Volume Transport (Sv) to 2000 m											
mean	26.0	26.8	31.1	29.8	30.3	33.1	51.9	49.9	45.1	57.9	52.7	59.7
std	3.0	3.8	3.5	4.1	4.2	3.8	9.2	9.8	12.8	11.6	13.7	20.5
	Volume Transport (Sv) to 5000 m											
mean	26.0	26.8	31.1	29.8	30.3	33.1	51.9	49.9	29.7	49.5	39.7	55.2
std	3.0	3.8	3.5	4.1	4.2	3.8	9.5	10.0	23.1	18.1	25.3	39.4

Gulf Stream Transport



	Gulf Stream											
	Volume Transport (Sv) to 500 m											
	26.5° N		32.3° N		73° W, 36° N - 68° W,34°N		70° W, 39° N - 66° W,35°N		64.75° W		60° W	
	Tides	No Tides	Tides	No Tides	Tides	No Tides	Tides	No Tides	Tides	No Tides	Tides	No Tides
mean	24.6	24.9	49.0	51.0	55.8	56.1	76.3	95.5	32.2	25.1	29.1	23.3
std	1.9	1.9	9.3	8.4	13.0	13.3	16.8	24.0	10.1	13.2	5.4	6.0
	Volume Transport (Sv) to 2000 m											
mean	26.7	27.1	74.0	76.7	115.6	113.4	158.1	195.8	41.5	27.6	39.6	27.0
std	2.2	2.1	24.5	22.3	28.7	27.5	32.2	45.8	23.4	28.3	12.7	13.3
	Volume Transport (Sv) to 5000 m											
mean	26.7	27.1	59.2	61.4	183.3	186.0	261.5	326.9	30.9	21.4	48.3	28.5
std	2.2	2.1	36.6	34.5	35.8	47.4	52.4	69.1	39.4	50.4	25.0	23.6

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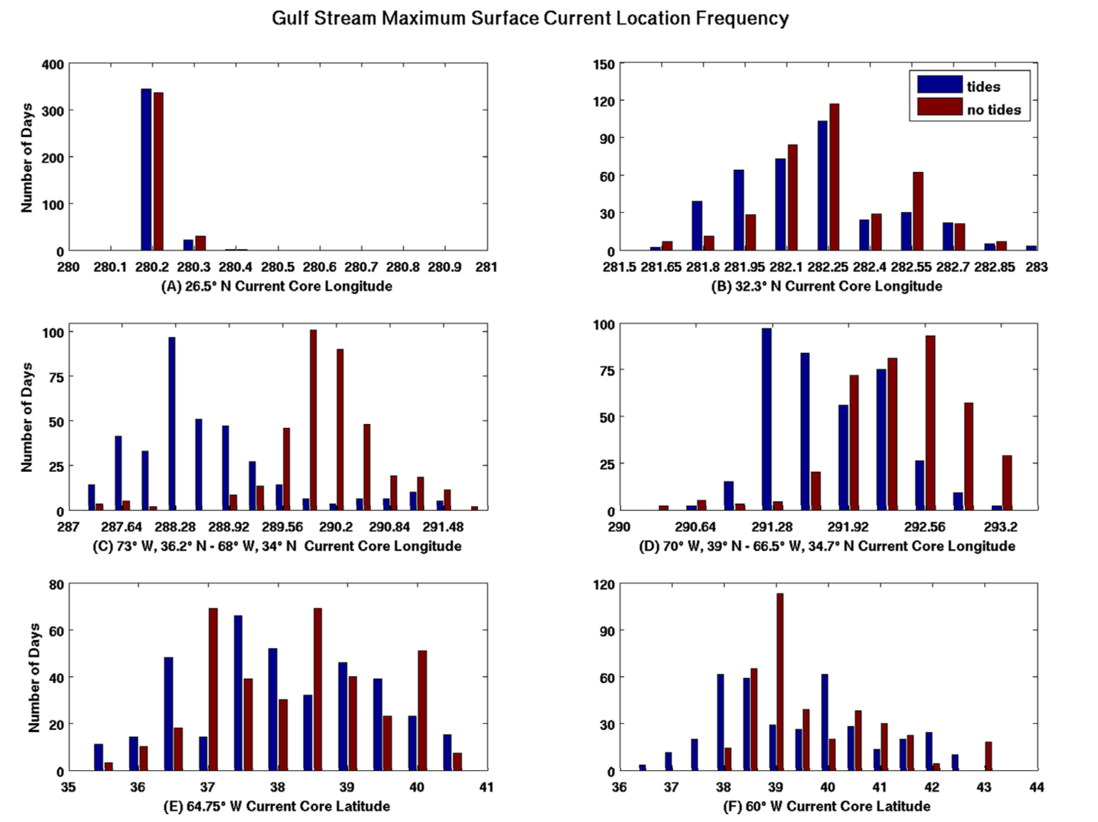
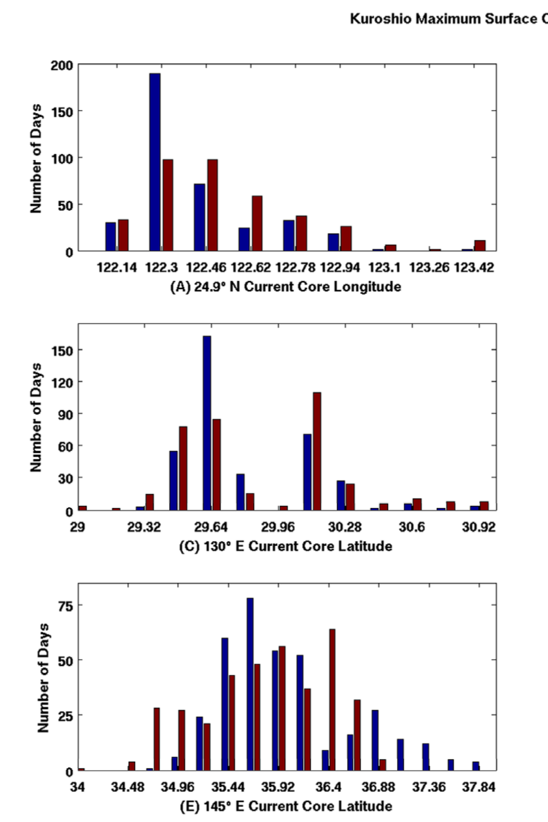
Ngodock, H.E., Souopgui, I., Wallcraft, A.J., Richman, J.G., Shriver, J.F., Arbic, B.K., 2016, On improving the accuracy of the M2 barotropic tides embedded in a high-resolution global ocean circulation model, Ocean Modelling 97, 16 – 26, doi:10.1016/j.ocemod.2015.10.011.

Impact of Tides on Location

The figures below show the latitude/longitude of the daily averaged current maxima across each of the transects (shown as black lines in the figure to the left). The largest differences in the mean and median of the surface current core location occur on the transects that are oriented from northwest to southeast and lie on the geodesics that extend from Bermuda to Chesapeake Bay (Panel C in Figure below left) and Montauk Point (Panel D in Figure below left). With the addition of the tidal forcing we find that the surface current core shifts towards the northwest by approximately 1.5° in longitude towards Chesapeake Bay and 0.6° in longitude towards Montauk Point. The inclusion of tidal forcing also reduces the kurtosis of the distribution of the surface current core location at the above mentioned transects and the transect at 60° W. Indicating fewer outliers in the distribution of the current core at these locations.

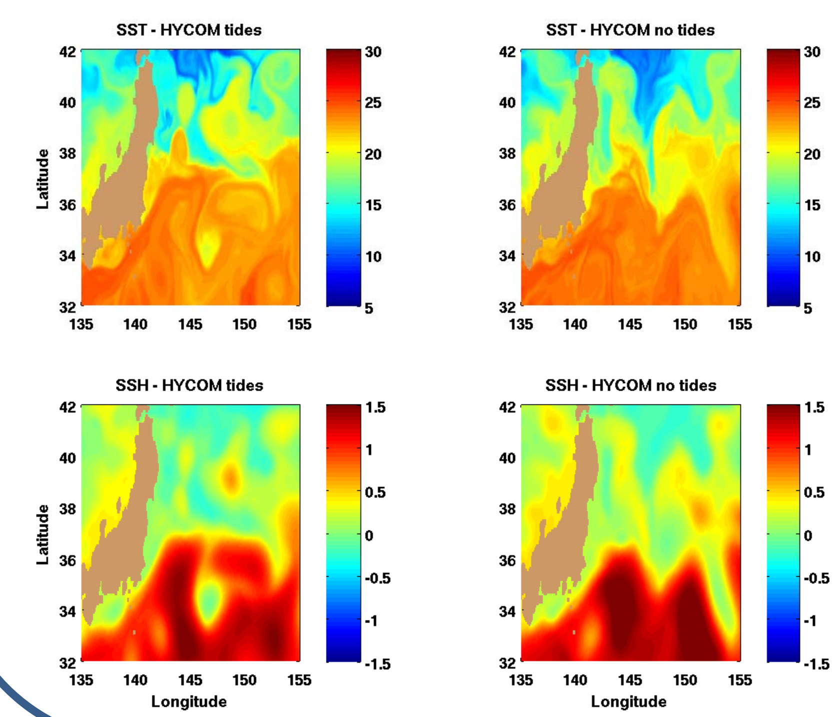
For the Kuroshio (Figure below right) the mean of the surface current core location at 140° E and 150° E shifts southwards by 0.4° and 0.3°, respectively, although there is no significant change in the median location. The location of the Kuroshio at 130° E exhibits a bimodal distribution. With the addition of tidal forcing the location of the surface current core appears to exhibit more variability. There is also greater variability in the surface core location at 24.9° N, 145° E with the kurtosis of the distributions increasing by 3.6 and 2.3, respectively at these locations. At 140° E and 150° E kurtosis values decrease by 3.2 and 2, respectively





Warm/Cold Core Eddy Production

The figure below shows an example of a warm core eddy (39° N, 148.5° E) and cold core eddy (34.5° N, 146.5° E) that appear in the simulation with tidal forcing but are absent when HYCOM is executed with no tides.



Other examples of differences in warm/cold core eddies exist between the two simulations. At time of publication of this poster we have not completed an exhaustive comparison of the number of eddies that form within the two simulations in the regions of the western boundary currents and their extensions.

Summary

Our preliminary comparison of the impact of tidal forcing on western boundary currents indicates that tides have a small, but measurable, impact on the location of the current core and volume transport in coastal regions where the leading order solution is provided by the geostrophic balance. Larger differences in the location of the Gulf Stream and Kuroshio and volume transport occur once the currents have separated from the coast and the assumption of geostrophic balance no longer applies. Additional work is necessary to compare the solutions to ocean reanalysis and observations to quantify model skill in terms of current core location, transport and warm/cold core eddy production.