The Alongshore Tilt of Mean Dynamic Topography and Implications for Nearshore Circulation and Regional Vorticity Balance

Christoph Renkl and Keith R. Thompson

Department of Oceanography, Dalhousie University, Halifax, Canada

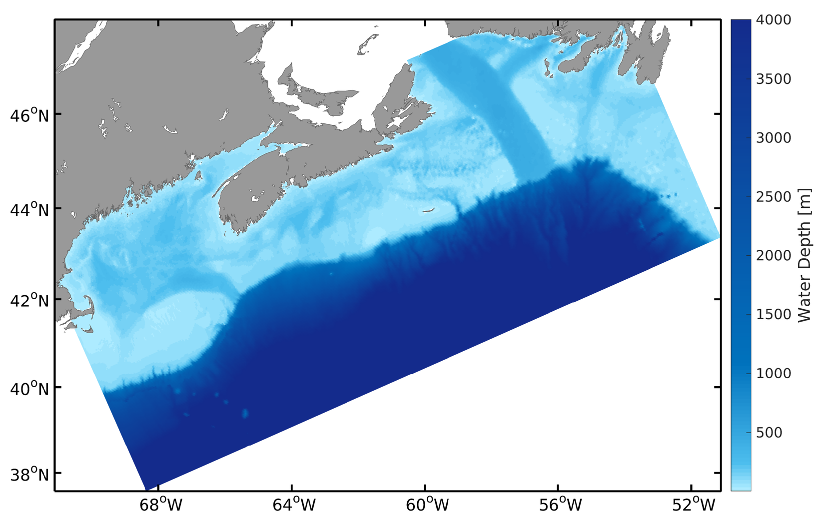
1. Background and Objectives

Coastal tide gauge observations in combination with the latest generation of geoid models are providing observations of the alongshore tilt of mean dynamic topography (MDT) with unprecedented accuracy. Additionally, high-resolution ocean models are providing better representations of nearshore circulation and the associated tilt of MDT along their coastal boundaries.

- Can we predict realistic estimates of the alongshore tilt of MDT using a high-resolution ocean model?
- How sensitive are the predictions to different model configurations?
- What does the tilt of MDT tell us about the circulation, both nearshore and offshore?

2. Model and Observations

Gulf of Maine and Scotian Shelf Model (GoMSS)



GoMSS model domain and bathymetry.

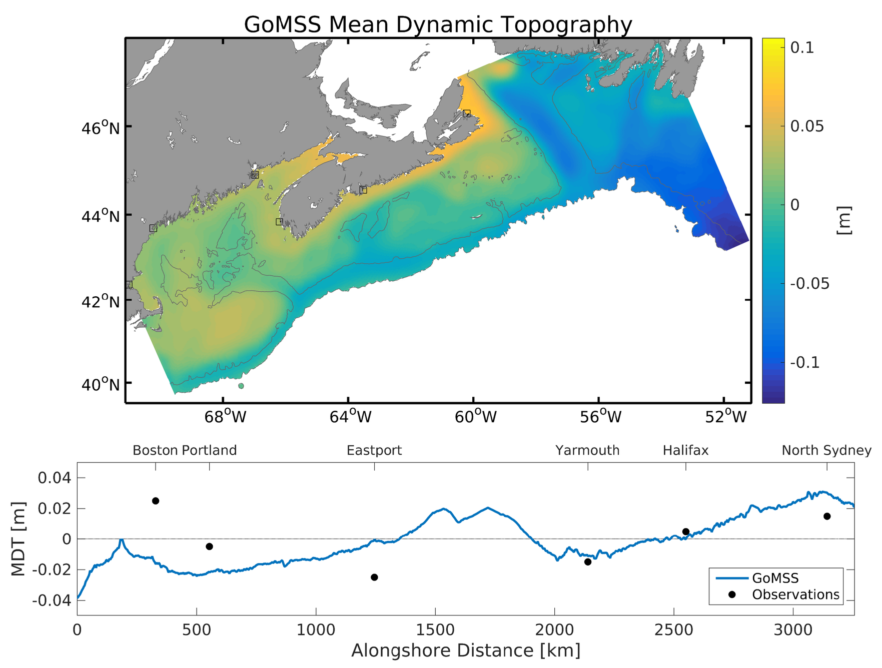
- NEMO v3.6
- 1/36° grid spacing
- 52 z-layers
- HYCOM open boundary forcing
- CFSR surface forcing
- No tides

(Katavouta et al., 2016)

Observations

Independent estimates of MDT are based on hourly sea level observations at 6 tide gauges referenced to the Canadian Gravimetric Geoid model (CGG2013). In our area of interest, the uncertainty of the geoid model is 2–3 cm (Huang and Véronneau, 2013).

3. Comparison with Observations



Upper Panel: GoMSS mean dynamic topography on shelf for the period 2010–2012 (mean removed).

Lower Panel: Modelled and observed alongshore MDT (respective means removed).

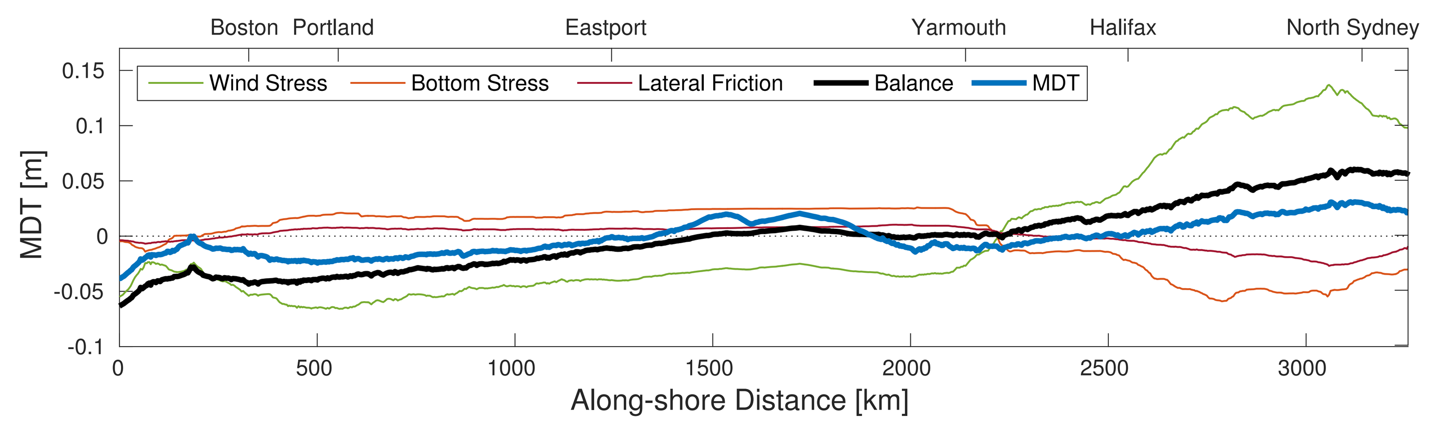
Overall, the predictions of MDT are in reasonable agreement with the observations.

4. Momentum Balance

Alongshore integration of the depth-averaged steady horizontal momentum equation

$$g\frac{\partial \eta}{\partial s} = \frac{\tau_s^w}{\rho H} + \frac{\tau_s^b}{\rho H} + F_s^l - \frac{g}{H}\int_{-H}^{0}(z+H)\frac{\partial \epsilon}{\partial s}\,dz + ADV \qquad (1)$$

yields respective contributions of each component to the alongshore MDT:



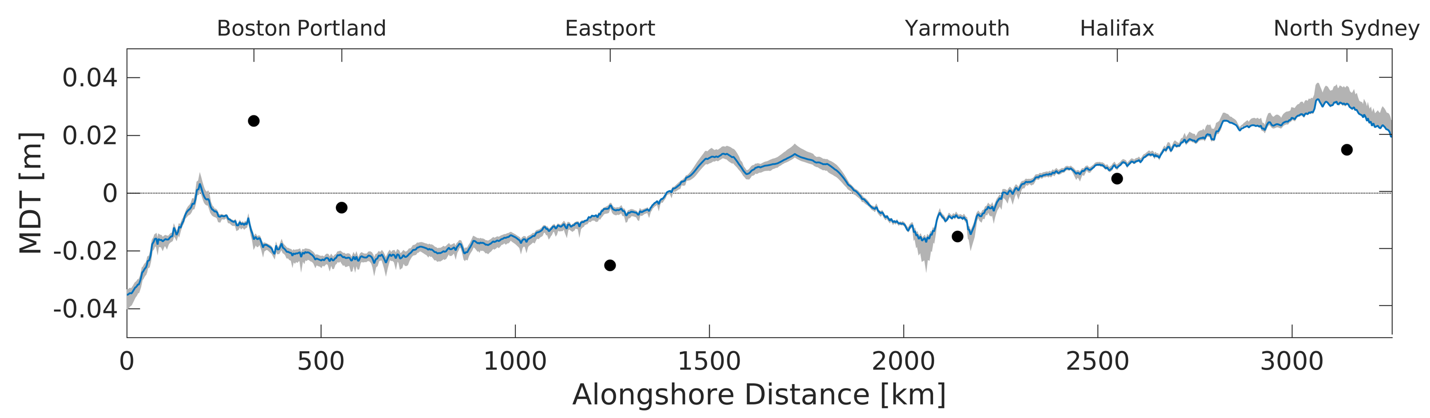
Components of the alongshore integrated momentum equation.

As expected, the alongshore tilt of MDT, $\frac{\partial \eta}{\partial s}$, at the coast is balanced by the sum of the alongshore wind stress, $\frac{\tau_s^w}{\rho H}$, bottom, $\frac{\tau_s^b}{\rho H}$, and lateral friction, F_s^l.

5. Sensitivity Analysis

Sensitivity of the predictions of alongshore tilt of MDT with respect to

- Lateral boundary condition
- Lateral eddy viscosity
- Wind stress in proximity to coast
- Upstream open boundary forcing



Alongshore mean dynamic topgraphy for 2010 of the GoMSS base run (blue) and the range of the sensitivity runs (gray). Black dots show the observations.

Surprisingly, none of the factors above affect the alongshore tilt of MDT:

Changes in lateral friction due to different boundary condition or modified eddy viscosity are compensated by equal changes in bottom friction.

Increased coastal wind stress is compensated by an equal increase of the sum of bottom and lateral friction.

Enhanced inflow at the upstream open boundary leads to an increased MDT over the downstream shelf. The Nova Scotia Current is enhanced, but the alongshore tilt of MDT is unaffected.

6. Dynamical Interpretation

Following Stewart (1989), we perform an area integral of the steady vorticity equation:

$$\oint_C \left(\vec{u}\zeta_a - \nabla\cdot\overline{T}\right)\cdot\vec{n}\,ds = \int_A \underbrace{\zeta_a\left(\nabla\cdot\vec{u}\right)}_{\text{upwelling}}\,dA \qquad (2)$$

with absolute vorticity $\zeta_a = \zeta + f$ and the kinematic stress tensor $\overline{T}$.

The offshore boundary of the area is chosen be in a quiescent region such that the line integral along that boundary becomes negligibly small. At the coast, the first term under the integral on the LHS vanishes. Additionally, the stress gradient at the coast is equal to the alongshore gradient of MDT and is related to the vorticity flux into the interior (Stewart, 1989).

It follows that the alongshore tilt of MDT is a measure of the area-integrated flow across isobaths which leads to vortex stretching.

7. Conclusions and Further Work

- The alongshore tilt of MDT of GoMSS is in reasonable agreement with observations
- Predictions are relatively robust to changes in lateral boundary conditions, eddy viscosity as well as local forcing
- Modification of the upstream open boundary forcing does not affect the tilt
- At the coast, the alongshore tilt of MDT is balanced by the sum of wind stress, bottom, and lateral friction
- On a regional scale, the tilt can also be related to the circulation offshore (through area-integrated upwelling)
- Both views (local vs. regional) are consistent and complementary.

In the future:

- Potential seasonal bias in GoMSS
- Influence of tides and waves
- Possibility of monitoring nearshore and shelf circulation with tide gauges

References

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Contact: christoph.renkl@dal.ca

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