OS41A-06 Model-Data Comparison of Flow over Realistic Topography in a Region with Coastal Submarine Canyons

John M. Klinck
Center for Coastal Physical Oceanography
Old Dominion University

Barbara M. Hickey
School of Oceanography
University of Washington

Michael S. Dinniman
Center for Coastal Physical Oceanography
Old Dominion University

Susan E. Allen
Department of Earth and Ocean Sciences
University of British Columbia

Objective: Compare observed circulation to the numerically modeled flow over realistic topography in a region with coastal submarine canyons.

Background

Submarine canyons along continental shelf edges are important topographical features that can have large impacts on coastal processes.[1] There has been much effort expended in trying to understand interactions of flow with the steep and variable topography found along the shelf edge and slope in coastal regions. Some success has occurred; however, most of these studies have involved symmetric structures configured to represent generic submarine canyons. Since the flow is so strongly influenced by the bathymetry, we decided to simulate flow in an area off the coast of Washington centered on Astoria and Willapa Canyons. We have an extensive velocity and temperature data set in Astoria that was obtained at small enough spatial and temporal scales to resolve the time-dependent circulation over and in the canyon.

[1] Hickey, Proc. Hawaiian Winter Workshop 1995.

Model Experiment

- Rutgers/UCLA Regional Ocean Model System (ROMS).
  - Parallel primitive equation model derived from the serial S-Coordinate Rutgers University Model (SCRUM).
  - Free surface and vertical s (terrain-following) coordinate.
- Domain: U.S. West Coast centered on Astoria and Willapa Canyons; 83km (lon) x 100km (lat)
- Resolution: $\approx$ 300m (lon) x 420m (lat) horizontal; 16 depth levels
- Bathymetry: Gridded field derived from digitized NOAA bathymetry charts. (Figure 1)
- Dissipation: Laplacian horizontal mixing and K profile parameterization (KPP) vertical mixing scheme. [2]
- Boundary Conditions: "Modified" Orlanski for North and South open boundaries; Zero gradient condition for West open boundary; free slip for East closed boundary. No sponges or forcing applied at open boundaries.
- Initial Stratification: Analytical approximation to a hydrographic section (T and S) obtained off the shelf near Astoria canyon in May 1983. Full non-linear equation of state used.
- Pressure Gradient Error: Checked by running simulation with zero wind stress. Maximum errors $\leq 10\%$ of forced values after 6 days.

[2] Large et. al., Rev. Geophys. 1994.

- Forcing:
  - Wind Stress: Applied as a body force over the top three layers of the model (concentrated towards the surface). Three simulations:
    - Constant upwelling (southward) winds for 10 days.
    - Generic upwelling event: Constant upwelling winds of 5 m/s for first 10 days. Ramped up to 10 m/s over the next two days and then down to zero over the next three days.
    - Realistic upwelling event: Constant upwelling winds of 5 m/s for first 5 days. Varied over next 10 days to match data.
  - Heat and fresh water flux: Set to zero

Model Parameters	
Quadratic Bottom Drag Coefficient	3.0×10^{-3} (dimensionless)
Horizontal eddy viscosity (A_m)	10.0 m^2 s^{-1}
Horizontal diffusivity coefficient (A_m)	5.0 m^2 s^{-1}

Steady Wind Forcing - 0.05 N m^{-2} (southward) for 10 days

- 50m Flow (Figure 2): Over all the canyons and only somewhat affected by the bathymetry.
- 150m Flow (Figure 3): Strong jet along shelf break, strong cyclone in Astoria canyon, weaker cyclone over the head of Willapa canyon
- 250m Flow (Figure 4): Cyclone over all three canyons (weak over Guide though)
- An extensive set of velocity and temperature data is available in Astoria Canyon from six mooring deployed from May to August 1983 (Figure 5) with the available time series varying from two weeks to three months.
- Observed mean flow (23 May - 3 June: Figure 6):
  - Flow above canyon turned slightly shore-ward by the bathymetry
  - Cyclone in the canyon that is much swifter near the head (stations A6,234m and A7,230m) than in the center (A3,210m).
- Mean model flow:
  - Vectors of model flow interpolated to same points as the observations (Figure 7) match observations reasonably well and show same pattern of upper circulation turned slightly by the canyon and deeper flow in the form of a cyclone
  - Magnified images of flow in the canyon (Figure 8a and 8b): Show that the vectors are fairly representative of the entire pattern but match could be improved (or worsened) with a slight shift in the location of the stations with respect to the cyclone.

Considering all the important processes that are simplified or missing in this simulation (non-representative constant wind stress, no buoyancy flux, open boundary conditions, inexact stratification, no tides, etc.), the match between the model circulation in the canyon and the mean observations is quite remarkable and shows how important the bathymetry is to the simulated flow.

Generic Upwelling Forcing

- Wind held at 5 m/s (southward) for 10 days, increased to 10 m/s (southward) over two days and then relaxed to zero over three more days.
- Observations show that during each upwelling event:
  - At maximum upwelling (determined by temperature), up-canyon flow is observed at most stations below the canyon rim.
  - As upwelling weakens, the circulation below the canyon rim changes from up-canyon to down-canyon on the north side and to stronger up-canyon flow on the south side.
- Model flow at maximum upwelling (Figure 9a): Not necessarily just up-canyon at all the moorings, but is not down-canyon at any of them
- Model flow as wind relaxes (Figure 9b): Circulation does become down-canyon on the north side and more strongly up-canyon on the south.
- However, while the phase of the model response seems to match the observations, the magnitude of the variations in the temperature signal is too small:
  - Observations (Figure 10) show fluctuations of as much 0.5 deg C for a single upwelling event.
  - Model temperature time histories (Figure 11) show more of a constant upwelling with much smaller variations due to the wind variability.

Realistic Upwelling Forcing (26 May - 4 June)

- Wind held at 5 m/s (southward) for 5 days then varied to match observed winds over a 10 day period (Figure 12).
- Circulation in the canyon at maximum upwelling (Figure 13a) and as the wind relaxes (Figure 13b) is similar to the generic upwelling event.
- Upper lever model response to the wind seems to have the same time scales as the observations: along-shore velocity fluctuations at A7,89m
  - Model: Maximum correlation (r = 0.81) with the wind at a lag of 1.0d (N.B. Model data only saved at 0.5d intervals)
  - Observations: Maximum correlation (r = 0.62) with the wind at a lag of 1.25d
- Time series of temperatures (Figure 14) show some temporal correspondence with the observations (Figure 10), but do have some problems
  - Magnitudes of the variations are too small:
    * Model vertical velocities are large enough to create (by advection) the correct amplitude in the temperature response.
    * Estimated vertical velocities in the canyon from observations are up to 50 m/d (upward) and 90 m/d (downward). Model vertical velocities are at least as strong as the observations.
    * Some other process must be limiting the model temperature variations.
  - Correlation between the model and observed temperatures (during the period when the realistic winds are blowing) at A7,89m is quite good (r = 0.90).
  - Correlation at A7,169m and A3,210m is not nearly as good and it appears that the model is still not fully spun up. However, if we remove the linear cooling trend from the model data, the correlation of the left over fluctuations to the observations is again quite good (r = 0.86 and r = 0.87 respectively).

Conclusions

- The mean circulation in Astoria Canyon can be simulated remarkably well using constant wind stress as the only surface forcing.
- The model response to transient wind events appears to be in phase with observations. However, the amplitude of the variations is too weak.
- Much work remains to be done on diagnosing the cause of the small amplitude in the response to transient winds. Possible reasons include:
  - Lateral Viscosity and Diffusivity
  - Lack of tides
  - Advective effects (model resolution, numerical scheme)
  - No Surface Heat and Fresh Water Fluxes
- It is important to accurately represent the complex bathymetry in the region in order to create a realistic simulation.

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