Barotropic and Baroclinic Tides in the Philippine Seas - a Modeling Study

Bin Zhang[1], Enrique Curchitser[1], Julia Levin[1], Hernan G. Arango[1]

[1]Institute of Marine and Coastal Sciences, Rutgers University

Introduction

The Sulu and Celebes are two marginal seas in Southeast Asia confined within the Philippine Archipelago. They connect to the South China Sea and Western Pacific Ocean through numerous straits and inner seas. Tides play an important role in the mixing and dynamics of this region. Strong internal waves, due to the density structure, are prevalent in these seas. The barotropic and baroclinic tides are simulated using the Regional Ocean Modeling System (ROMS) in a regional model of the Philippine Archipelago. The baroclinic energy flux and its divergence is investigated. The tides are strongly affected by the complex bathymetry and the many island passages.

Model Description

A regional, 5km grid of the Philippine Archipelago is configured with ROMS. The model is initialized with HYCOM global (1/12°) resolution. HYCOM daily forecasts are imposed at the open boundaries. The tidal forcing (K1, P1, O1, Q1, K2, S2, M2, N2) is from OTPS. The surface atmospheric forcing is from NOGAPS (0.5°x0.5°, 3 hourly). The model is run for one year starting March, 2007.

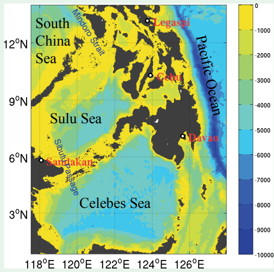

Figure 1: Model domain and bottom bathymetry

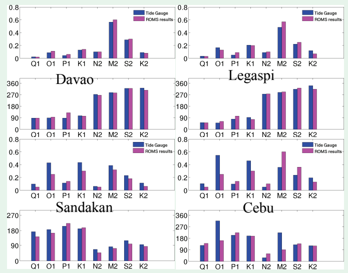

Figure 2: Amplitude and phase of the tidal components from ROMS and 4 tide gauges

Barotropic Tides and Comparison to Observations

A least square analysis is used in ROMS to calculate tidal harmonics at each time step. The tidal harmonics are compared against tide gauges (**Fig. 2**), TOPEX/Poseidon data (**Fig. 3**) and OTPS (**Fig. 4**). The agreement is good everywhere except inside the Archipelago and Bohol Sea. This may be explained by the smoothed bathymetry and lack of resolution. The RMS between ROMS and altimetry is 6.1cm for M2 and 5.9cm for K1.

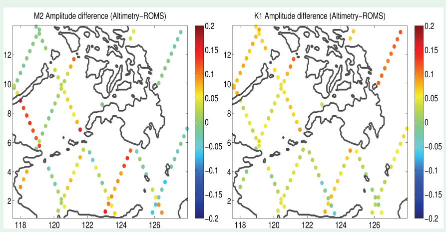

Figure 3: Tide amplitude differences between ROMS results and Topex/Poseidon data.

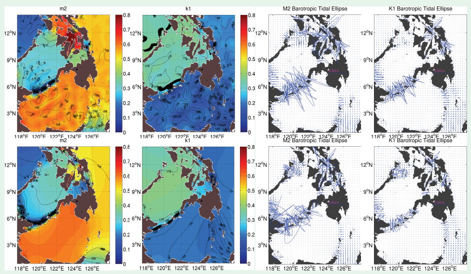

Figure 4: Comparison between ROMS (top) and OTPS (bottom).

Depth Dependent Tidal Ellipse

The baroclinic tidal ellipses (**Fig. 5**) show strong internal tide activity in regions of steep bathymetry (near the straits). Internal tides are observed at both sides of the straits. For example, in the Sulu bank and Kepulauan Sangihe Strait, the baroclinic velocity exceeds 10cm/s . **Figure 6** shows the major axes of tidal ellipses and phase along a section through the Sibutu Passage. It shows the path of the internal tide propagation.

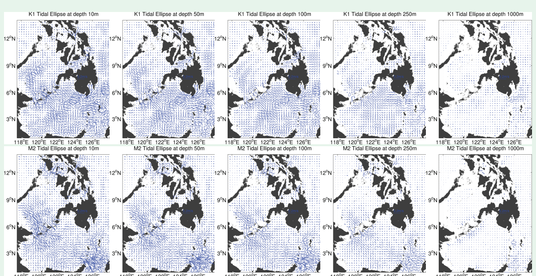

Figure 5: Baroclinic tidal ellipse at different depth for M2 and K1

Surface Manifestation of Baroclinic Tide in Sulu and Celebes Seas

Usually, movement of isopycnals are highly correlated with strong baroclinic tides. However, their effects can also be observed at the surface. In the model, these effects can be observed in the cotidal chart (**Fig. 4**). This chart shows how the surface elevation is modified by the internal tides. This propagation (**Fig. 7**) is shown for the Sulu Sea time series with an average speed of 2.5 m/s, which is close to the soliton wave dispersion.

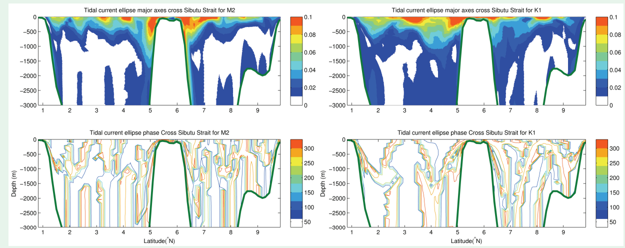

Figure 6: Profiles of major ellipse axes of baroclinic tides through the Sibutu Passage in the Sulu and Celebes Seas.

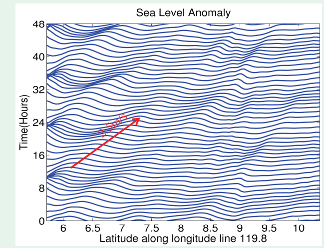

Figure 7: Surface feature of baroclinic tide propagation in the Sulu sea.

Baroclinic Energy Flux, Divergence and Seasonal Variations

The baroclinic energy flux is defined as $\frac{1}{T}\int\int u' p' dt dz$, where u' is baroclinic velocity, and p' is the baroclinic pressure, $p' = P(s) - \int_0^{-1} P(s) H_z ds / \int_0^{-1} H_z ds$. A harmonic analysis is carried out on the baroclinic velocity and pressure, so that the baroclinic energy flux for a specific tide component is expressed as function of amplitude and phase of the baroclinic velocity and pressure: $u_0' p_0' \cos(\varphi_u - \varphi_p)$. The maps of convergence and divergence of baroclinic energy flux can be used to determine where the generation and dissipation of baroclinic tides are taking place (**Fig. 8, middle**). Examples of monthly variations of the energy flux for M2 are shown in **Figure 8, right**. In the Celebes Sea, these variations are mainly due to changes in stratification.

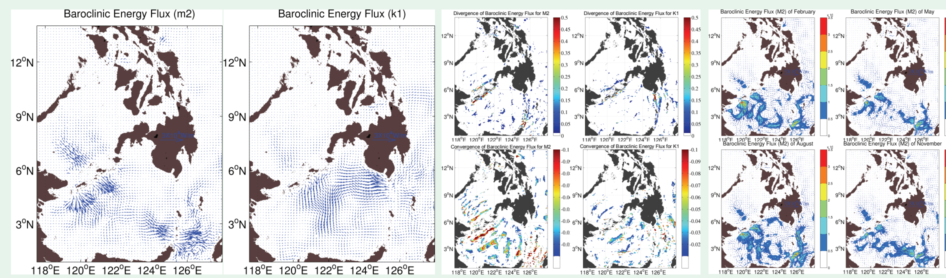

Figure 8: Baroclinic energy flux, its convergence, divergence and seasonal variations.

Conclusions

- The marginal seas in the Philippine Archipelago are characterized by strong barotropic tides at almost all the island passages. The baroclinic tides are weaker and generated by the steep and tall bathymetry in these areas.
- In the model, the resulting tidal currents are dominated by surface intensified baroclinic tides in the Celebes and Sulu basins. Barotropic tides dominate the connecting straits.
- Baroclinic tide energy dissipation occurs mostly in the deep ocean.
- Changes in stratification are due to the seasonal monsoon effect on the baroclinic energy flux in the Celebes Sea and nearby Pacific Ocean. No seasonal variability is observed in the Sulu Sea's baroclinic energy flux.

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