Seasonal Variability of the Internal Tide in the South China Sea

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Summary

- A coherent low-mode internal tide has been observed in the South China Sea using TOPEX/POSEIDON altimetry.
- The free surface amplitude of the internal tide is approximately 3cm, and its phase is coherent between multi-year records.
- Harmonic analysis over seasons (summer and winter) reveal a seasonal cycle in the internal tide as it propagates south and west into the South China Sea.
- We hypothesize that the seasonal cycle is caused by changing stratification at the generation site in the Luzon Strait, and we are examining this hypothesis with numerical model simulations of the northern South China Sea and western Philippine Sea.
- Model simulations of the surface barotropic tide in the Taiwan Strait on the Asian continental shelf show substantial disagreement with observations.
- Work is ongoing to improve the performance of the 3-D model in this setting.

Abstract

The coherent low-mode internal tide has been observed in the South China Sea. The TOPEX/POSEIDON (T/P) data indicate that the free-surface expression of the internal tide is approximately 3cm near the Luzon Strait, and there is a seasonal cycle in the phase of the internal tide as it propagates south and west into the South China Sea. Satellite images of sea-surface temperature and in situ observations of stratification suggest that changes in the internal tide may be caused by the seasonal cycle of stratification at the generation site in the Luzon Strait, and we are examining this hypothesis with numerical model simulations of the South China Sea. Preliminary simulations have shown a sensitivity to conditions at the generation site, but quantitative agreement with the altimetry is lacking.

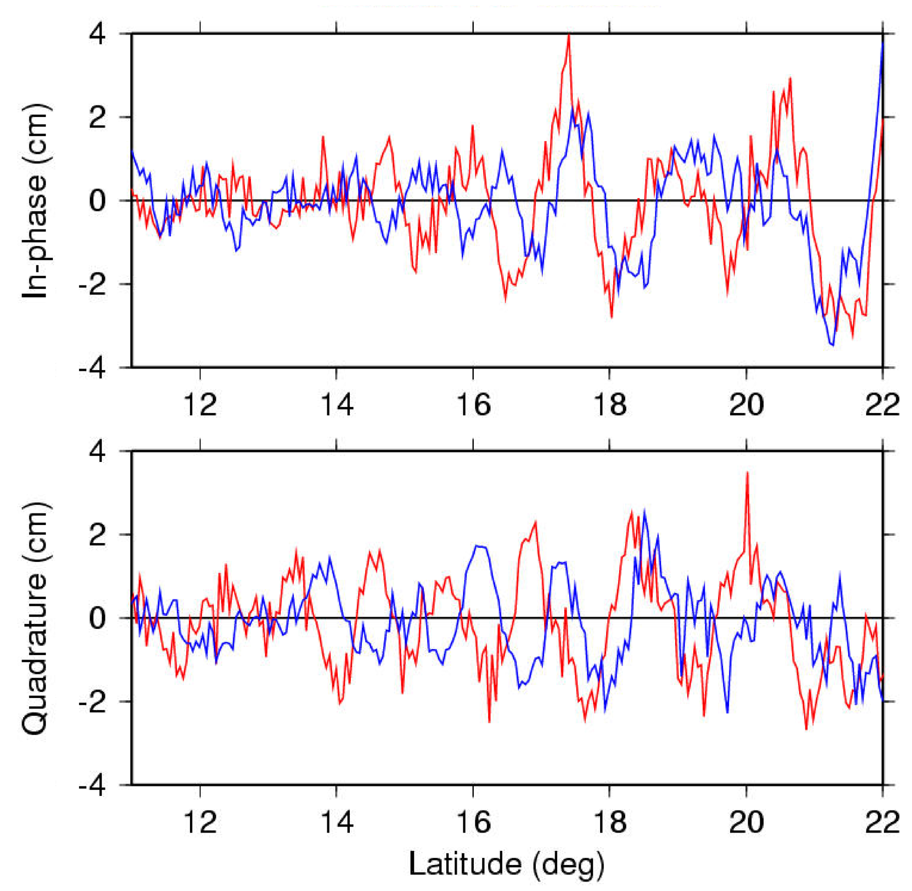

Figure 1: High-Pass T/P Data in the South China Sea
Seasonal variability in the internal tide of the South China Sea is observable using T/P altimeter data. The figure shows high-passed SSH at the M_2 tidal frequency on the ground track in Figure 2. Harmonic analysis over December-February (red) and June-August (blue) are shown.

Observations

There is a seasonal cycle in the coherent low-mode internal tide in the South China Sea.

Harmonic analysis of TOPEX/POSEIDON data indicate a seasonal cycle of the internal tide in the north-central South China Sea. Figure 1 shows the in-phase (top) and quadrature (bottom) components of the harmonically analyzed and high-passed altimtery data along the ground track shown in Figure 2. Overall, the internal tide amplitude is approximately 1cm larger in winter (red) than in summer (blue). Also, there is a phase offset approaching 180° near 17°N, approximately 400km south of the generation site in Luzon Strait. The high-passed amplitude and phase are stable (coherent) when subsets of the 1992 to 2002 analysis period are compared (not shown). In other words, no long term trend in the internal tide is present.

The large-amplitude internal tide is generated in the Luzon Strait.

In situ observations have shown that the Luzon Strait is a significant generation site for the internal tide. Field studies have recorded large amplitude internal waves and solitons which propagate westward from the Strait into the South China Sea.

The preliminary model solution shown in Figure 2 shows the generation and propagation of the internal tide in terms of the steric height. The largest amplitude waves propagate zonally, and they slow down and shorten when they encounter the continental shelf of Asia.

Note that the general orientation of the waves is oblique to the satellite ground track. The amplitude of the internal waves which propagate to the southwest in the model is only about 1/2 to 2/3 the amplitude seen in Figure 1.

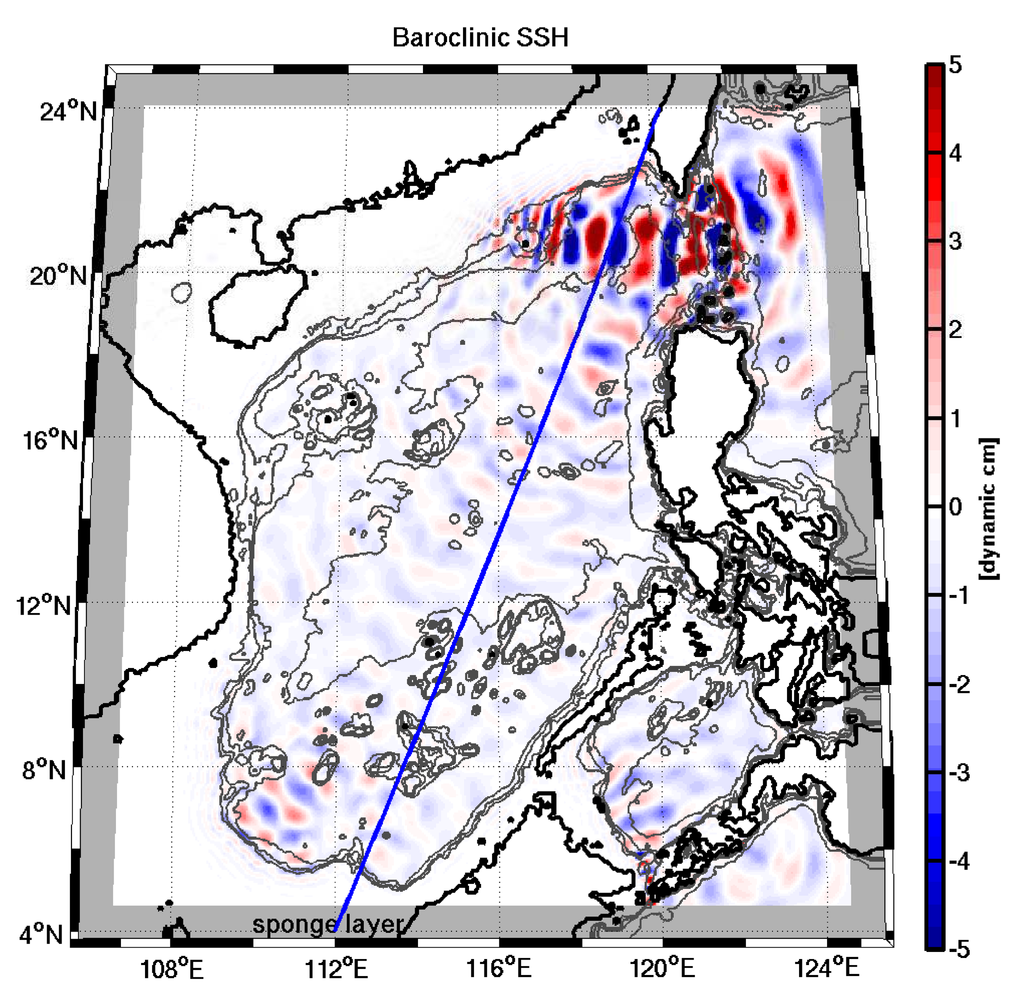

Figure 2: South China Sea Model Simulation
The baroclinic component of the modeled M_2 tidal sea-surface elevation (in-phase component). Solid blue line shows T/P ground track used in Figure 1, above.

Hypothesis: Seasonal variability in stratification at the generation site is responsible for the seasonal cycle of the internal tide.

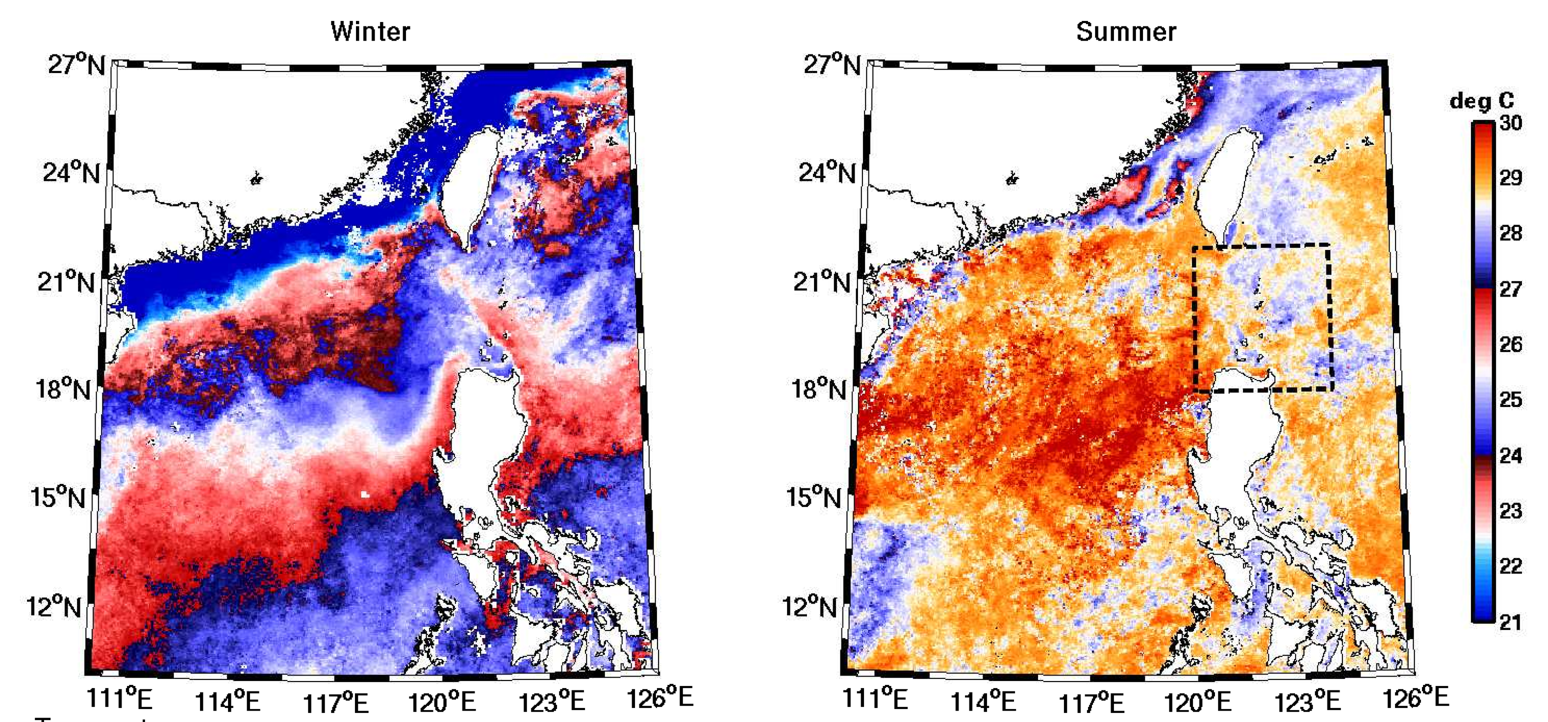

Figure 3: Sea-Surface Temperature
Monthly average SST at 4km resolution from the MODIS/Aqua satellite is shown for February and July, 2004 (`http://poet.jpl.nasa.gov/`). During winter, water from the Kuroshio (Japan Current) partially enters the South China Sea from the Philippine Sea. The dashed line shows the region of ARGO float data used for the water mass analysis shown in Figure 4.

Figure 3 illustrates the difference between summer and winter sea-surface temperature (SST) in Luzon Strait. During the winter, an SST front forms between Philippine Sea and South China Sea water masses, which extends across Luzon Strait. The position of the front is variable, but it is typically well-defined during winter. In contrast, during the summer, the SST is much more uniform and the position of the front, if any, is ambiguous.

As shown in Figure 4, the seasonal cycle and extremal water mass properties are not well represented in climatologies. Instead, individual hydrographic casts must be used to define the subsurface stratification. Initial model simulations, such as that shown in Figure 2, utilized seasonal stratification defined by the NODC's World Ocean Atlas (WOA).

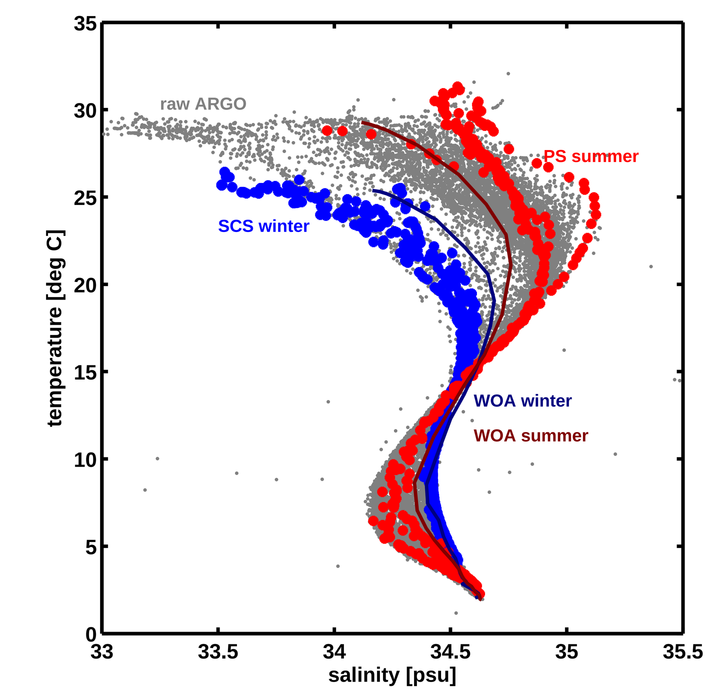

Figure 4: Temperature-Salinity Relations
Water mass properties have been derived from ARGO profiling floats in the vicinity of Luzon Strait. The most extreme contrast is between South China Sea water in winter (SCS, blue) and Philippine Sea water in summer (PS, red).

Model Results

PEZ-HAT model details for the present study:

- 3-D, Boussinesq, hydrostatic, primitive equations model, mostly following MOM3 numerics;
- Horizontal resolution of 5km, partial-cell topography, and 30 vertical levels;
- Sponge layers for baroclinic velocity and tracers at open boundaries;
- Open boundary conditions on horizontal transport, elevation, or their combination via Flather boundary conditions;
- For tidal studies, the model is spun-up and fields are harmonically analyzed; and
- Only M_2 open boundary and astronomical forcing is used.

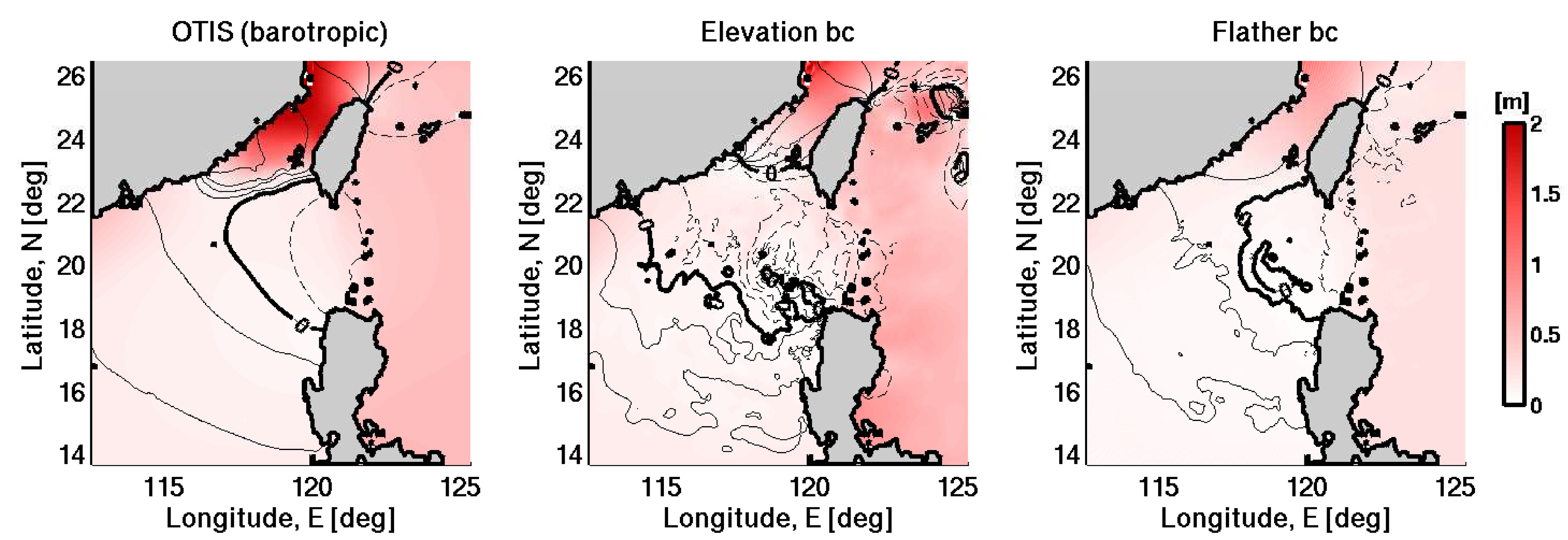

Figure 5: Model Comparison
The M_2 surface elevation and phase from the 2-D barotropic data assimilating OTIS model (left) is compared with two versions of the 3-D non-data assimilating PEZ-HAT model using prescribed elevation (center) and Flather (right) boundary conditions. Phase is contoured every 30deg, with negative phase indicated by dashed lines. Prescribed transport boundary conditions (not shown) are visually indistinguishable from the Flather boundary conditions.

Because the baroclinic tide is generated by the interaction of the barotropic tide with topography in Luzon Strait, the model must accurately reproduce the barotropic tide.

Figure 5 compares PEZ-HAT tidal elevation with the results of OTIS, a 2-D, barotropic, data-assimilating tidal model. It can be seen that the barotropic tide is not well-reproduced by the non-data assimilative model, PEZ-HAT. *Current efforts are directed towards understanding and improving the performance of the 3-D model in this setting.*

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