Contribution of the Internal Tide to the Altimetry Error Budget

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Introduction

Use of satellite altimeters to study sub-tidal phenomena (e.g., mesoscale eddies, inter-annual sea-level variability, etc.) is complicated by the presence of variations in sea-surface height caused by the astronomical tide. Present models of the long-wavelength barotropic tide are accurate to better than 1.5cm, root-mean-square average over the global ocean (70S to 70N). Over the continental shelves or complex bathymetry, the errors can be of larger magnitude and vary spatially on the same scales as the bathymetry. The sea-surface height perturbations caused by the shorter-wavelength internal tide can be as large as 8cm, depending on location, seasonal stratification, and, possibly, mesoscale currents. Accurate maps of the internal tide are not yet available globally, but as more accurate and higher-resolution studies of the mesoscale proceed, they must be corrected for tidal contamination.

This poster highlights recent work with high-resolution regional tidal models to:

- map the phase-coherent tidal contributions to sea-surface height,
- estimate and map the seasonal variability of tidal elevations.

A major challenge with the three-dimensional tidal modeling is to adequately validate the model results against altimetry and in situ measurements. Case studies of the Hawaiian Ridge and East China Sea illustrate modeled and observed tides and their variations.

Mapping the Internal Tide

Our efforts have focussed on data assimilative modeling to estimate and interpolate the internal tide in a dynamically consistent manner.

Numerical Modeling with PEZ-HAT

- Z-coordinate, three-dimensional, primitive equation model
- Simplified turbulence model
- Horizontal resolution: 1km to 4km
- Vertical resolution: 30m to 120m typical
- High-resolution bathymetry for realistic simulations
- Linearized model for data assimilation
- Nonlinear model for studies of tidal variability

Data Assimilation

- Based on weak-constraint variational data assimilation in the frequency-domain
- Extends OTIS (Oregon State Tidal Inversion Software) methodology to three-dimensional tidal model (PEZ-HAT)
- Assimilate coastal Doppler radar data in small, high-resolution domain
- Assimilate altimetry data in larger regional domains

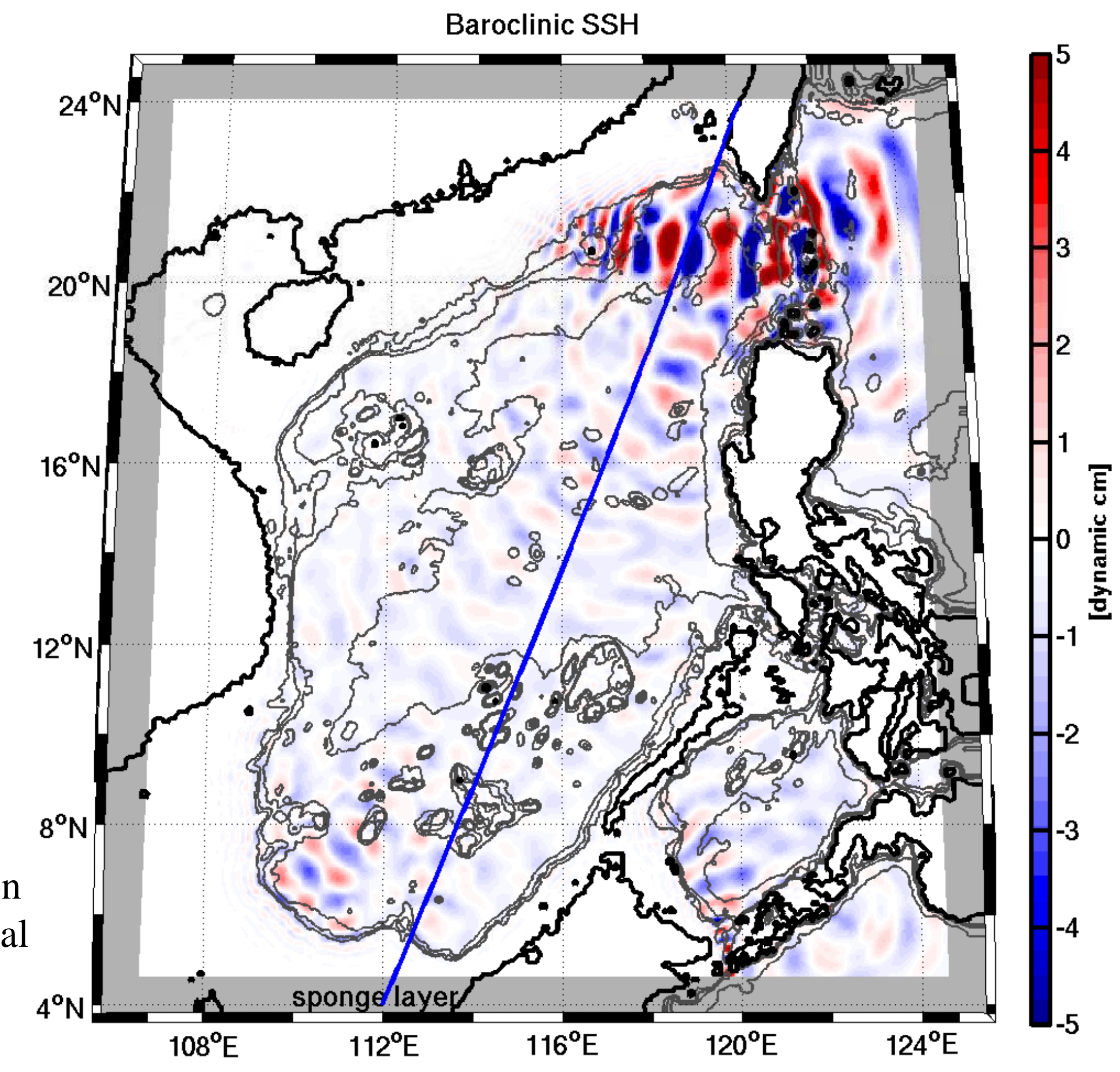

Figure 1: South China Sea Model Simulation
The baroclinic component of the M_2 tidal sea-surface elevation (in-phase component). Solid blue line shows T/P ground track 26, used in comparisons of along-track data, below.

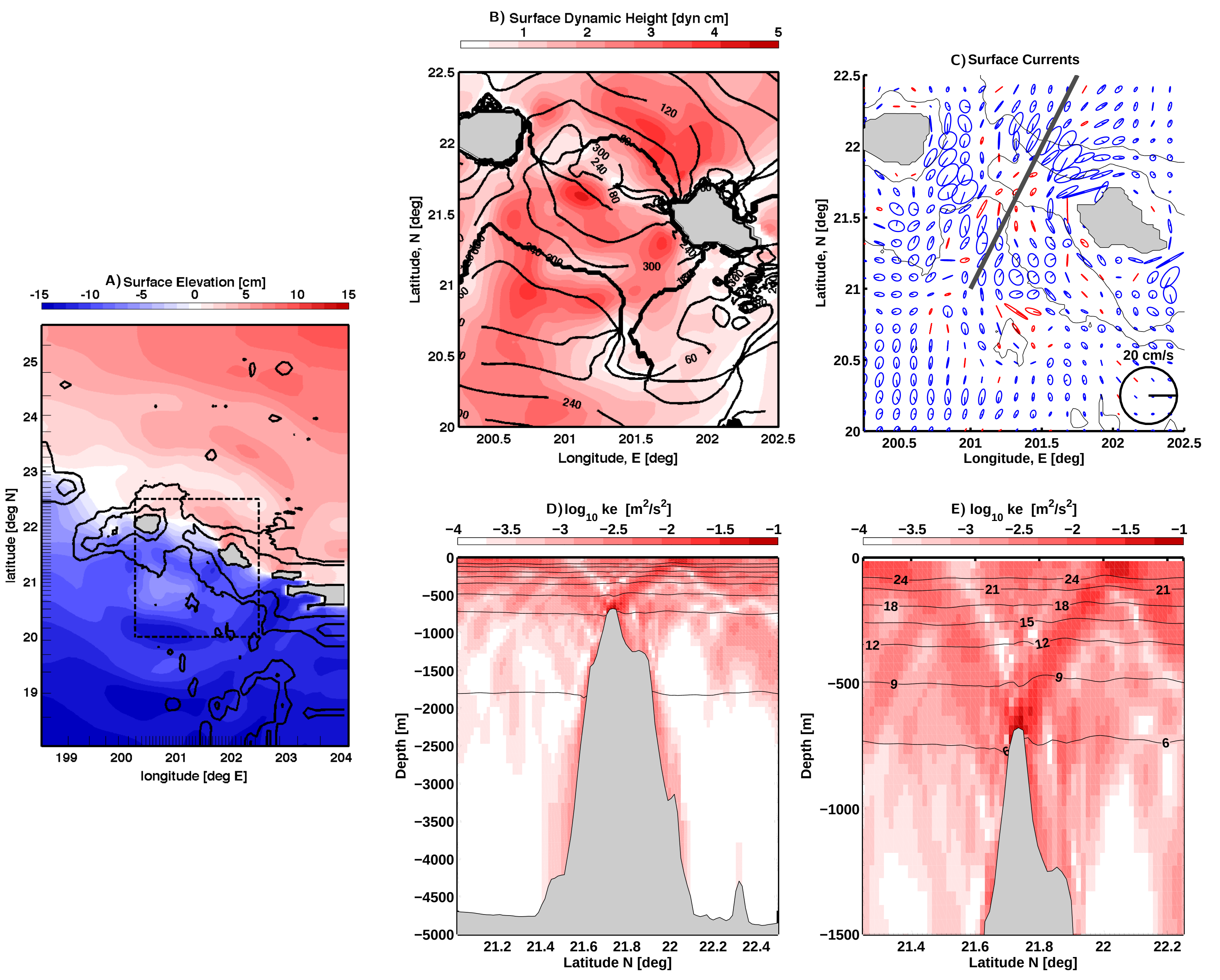

Figure 2: Data Assimilation Example: Kauai Channel, Hawaii
Example of data-assimilative tidal solution for a small domain in the Hawaiian Archipelago. The example shows the results of assimilating HF-radio Doppler surface currents into PEZ-HAT. Surface elevations due to the internal tide are $\pm 5\mathrm{cm}$, and they are not scale-separated from the mesoscale. The internal tide is generated between the islands of Kauai and Oahu, where the barotropic tidal flow encounters the topographic feature, Kaena Ridge. Satellite altimetry through the channel is in reasonable agreement with the data-assimilative solution; however, it would not be possible to infer the complete fields from the altimetry alone.

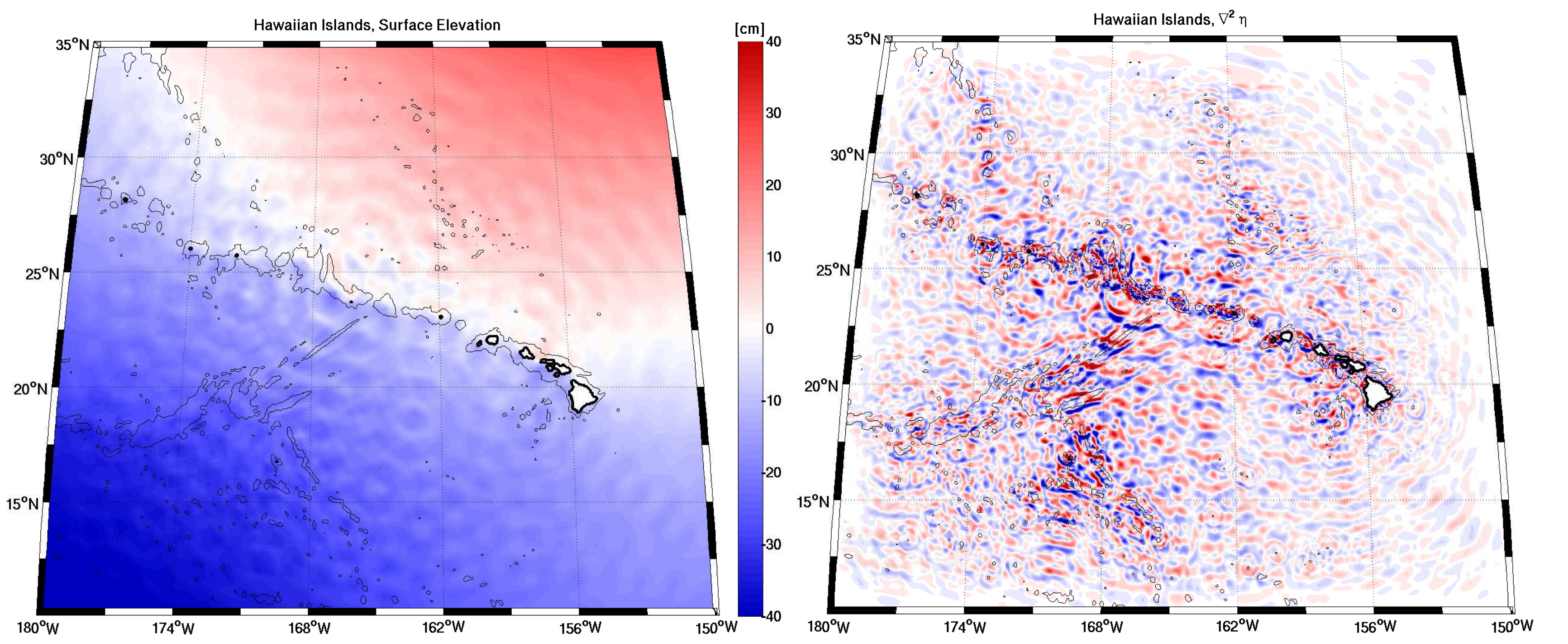

Figure 3: Data Assimilation Example: T/P Altimetry near Hawaiian Ridge
Left: Example of data-assimilative tidal solution for the Hawaiian Ridge. Root-mean-square misfit to T/P altimetry is approx. $0.94\mathrm{cm}$; only about 20% of the internal tide variance is explained in the data-assimilative solution. Most of the unexplained variance is at small scales near topographic features. Land is shown in gray, and the $3200\mathrm{m}$ isobath is contoured with the thin black line.
Right: The high-wavenumber components of the inverse solution are emphasized by plotting the Laplacian of the surface elevation, $\nabla^2\eta$. The T/P altimeter ground tracks are spaced too far apart to resolve most of the waves generated by small-scale bathymetry and seamounts. Synthetic data studies utilizing multiple altimeters (e.g., T/P, ERS, and GFO) indicate that the more dense coverage greatly improves estimates of derived quantities, such as the energy flux of the internal tide; however, achieving these gains requires longer time series than are presently available.

Temporal Variations of the Internal Tide

Observations

Seasonal changes in the internal tide are observable with satellite altimetry in a number of regions, such as the South China Sea.

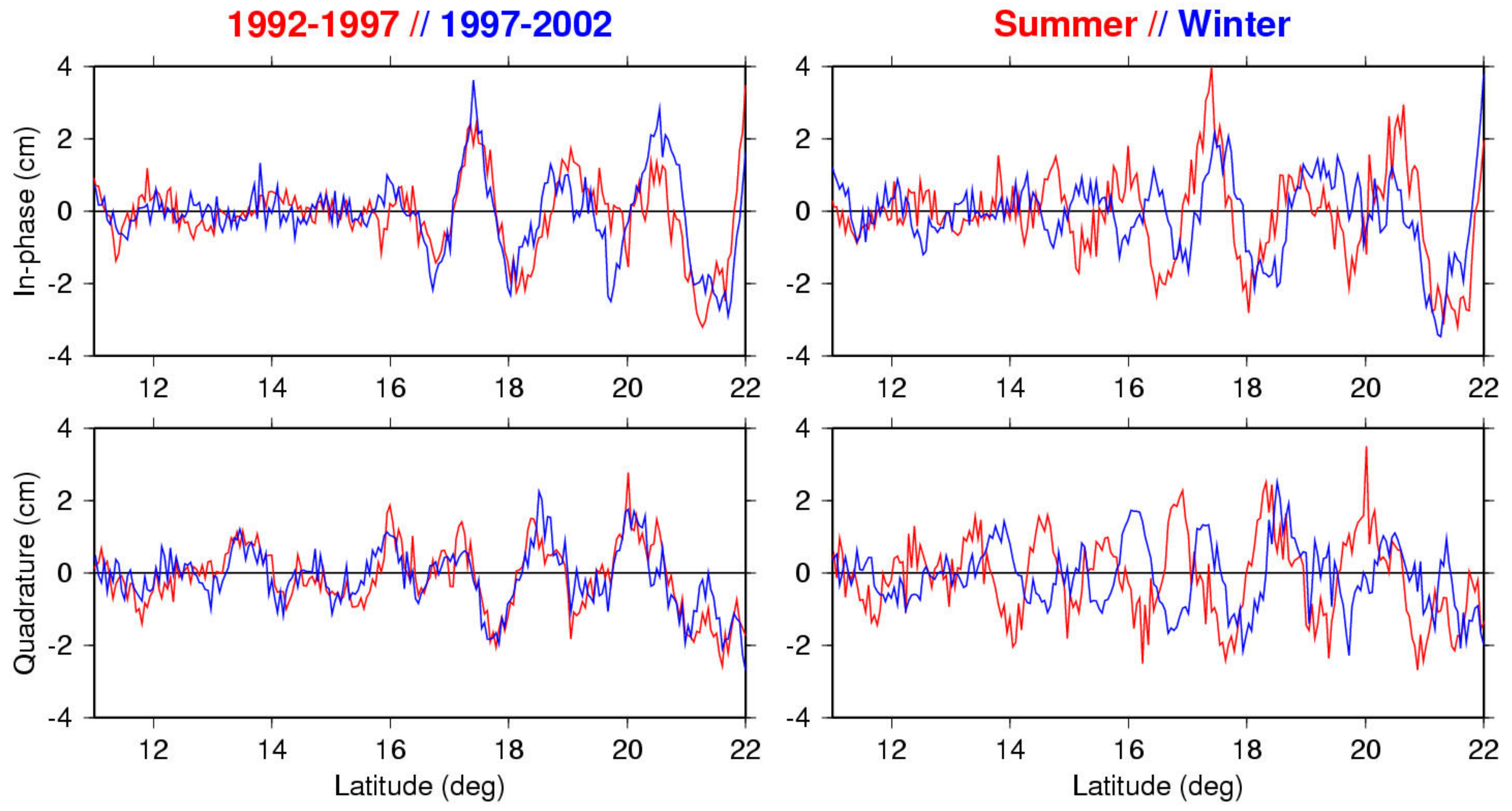

Figure 4: Observed Seasonal Variability of Internal Tide: South China Sea
Seasonal variability in the internal tide of the South China Sea is observable using T/P altimeter data. The figure shows high-passed SSH at the M_2 tidal frequency on the ground track in Figure 1.

Modeling Seasonal Variability in the Internal Tide

We have begun to model the temporal variability of the internal tide in a number of regions. In the South China Sea, where there is clear evidence of a seasonal cycle in the tides, the primary driving mechanism appears to be seasonal changes in the stratification and the location of the frontal boundary within Luzon Strait.

We are also investigating the interactions of the tide with the mesoscale, which creates tidal variations on shorter-than-seasonal time scales. Quantifying these interactions requires detailed observations or accurate simulations of the mesoscale. In the central Pacific, around the Hawaiian Ridge, we have used the SODA-POP ocean reanalysis to look at interactions with the large scale mesoscale (e.g., westward propagating nonlinear long Rossby waves). Here we have found that the propagating internal tides loses about 15% of its energy by mesoscale scattering once it is 300 to 500km from the Ridge.

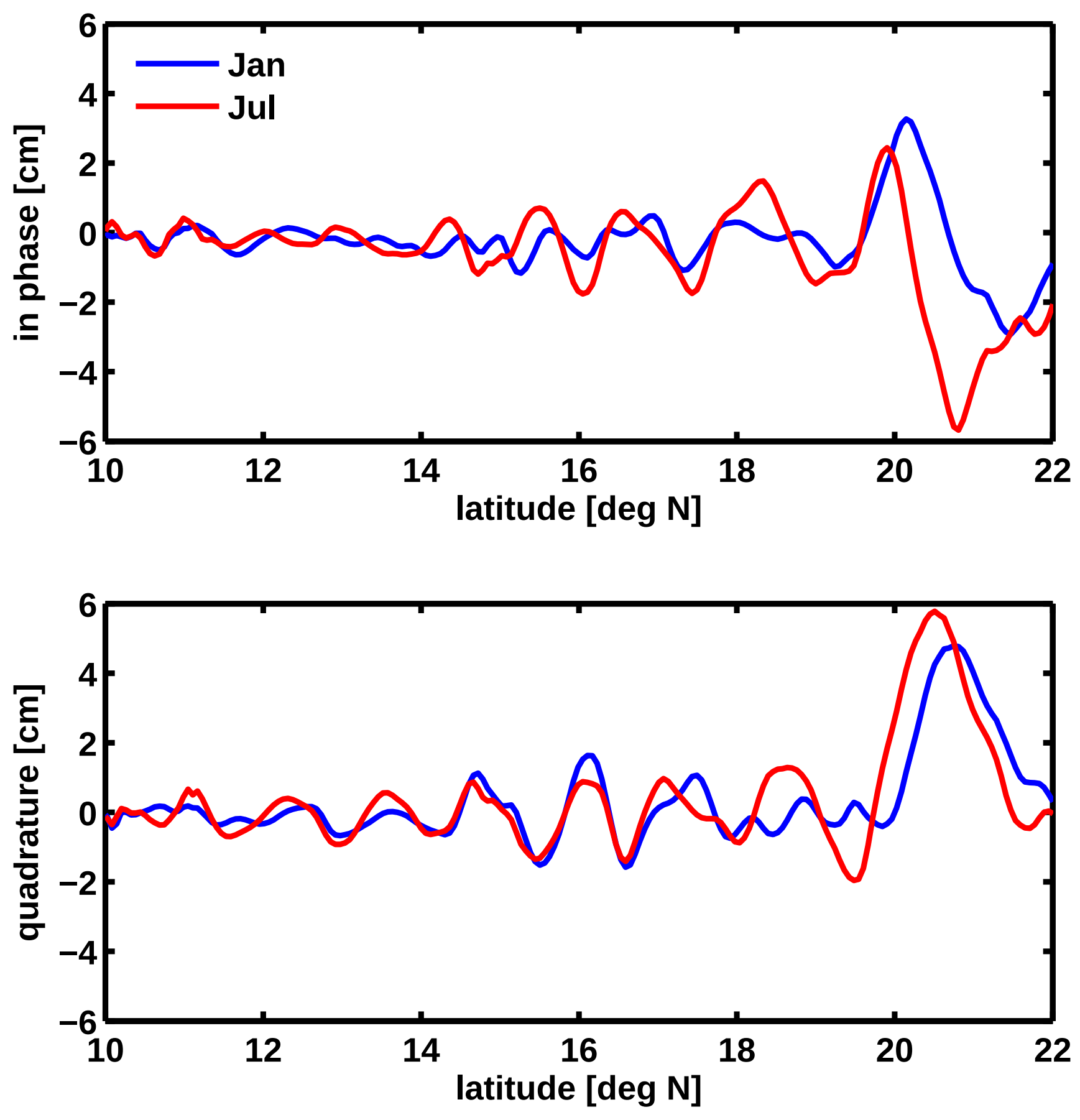

Figure 5: Modeled Seasonal Variability of Internal Tide: South China Sea
The figure shows seasonal changes in M_2 internal tide elevation along the same ground track as in Figure 4. Although there are some similarities between the observed and modeled seasonal changes, the model result is quite different overall. We hypothesize that better hydrographic data in the Luzon Strait is required to adequately model the internal tide in the South China Sea. Currently, the hydrography is extracted from the World Ocean Database, 1° objectively analyzed fields.

Future Plans

- Include non-traditional Coriolis terms in PEZ-HAT.
- Incorporate more realistic, KPP-like, boundary layer model.
- Perform additional regional simulations and data-assimilation experiments.

2008 Ocean Surface Topography Science Team Meeting
Nice, France
November 11–12, 2008

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