Study of Nonlinear Internal Waves at South China Sea Applying NRL Ocean Nowcast/Forecast System

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LONG-TERM GOALS

This work aims to understand the mechanism related to the generation and propagation of large-amplitude nonlinear internal waves (NLIWs) at South China Sea (SCS). Applying the knowledge leaned to improve Navy ocean prediction capability.

OBJECTIVES

The first objective of this effort is to develop a high resolution ocean model to study the large-amplitude nonlinear internal waves at northern South China Sea applying a Naval Research Laboratory (NRL) Ocean Nowcast/Forecast System (ONFS) (Ko et al., 2008). The second objective is to provide internal waves prediction to sport the ONR NLIWI field experiment. The third objective is to collaborate with other NLIWI PIs to resolve issues on the generation and propagation mechanism related to the tidal forcing, ocean topography and ocean stratification using model and observation data. The finally objective is to use observation data to evaluate the model capability to predict large-amplitude internal waves at SCS and apply the result to operational application.

APPROACH

To achieve the objectives a high resolution ocean model which covers the NLIWI experiment area were first developed. The model coverage includes the northern South China Sea, the Luzon Strait and part of Philippine Sea (Figure 1). The Navy Coastal Model (NCOM, Martin, 2000) was applied for the modeling. NCOM has been in operation at NAVO on a global scale (Barron, 2004) and on a relocatable regional scale. Necessary modifications were made to improve prediction on the large-amplitude internal waves at SCS. A large scale ocean model covering East Asian marginal seas and West Pacific Ocean are also developed to provide open boundary conditions to the high resolution internal wave prediction model. Three years of model simulation were conducted with a realistic forcing in coincide with the period of NLIWI field experiment such that the field observations and satellite remote sensing data are available to evaluate the model. Once it is shown that model can predict large-amplitude internal waves at SCS with accuracy, model is applied to conduct a series twin experiments to resolve issues related to the generation, propagation of large-amplitude internal waves in relation to the ocean topography, tides, ocean stratification and ocean currents. The knowledge leaned are applied to improve the model internal waves prediction capability for a transition to the operation.

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14. ABSTRACT
This work aims to understand the mechanism related to the generation and propagation of largeamplitude nonlinear internal waves (NLIWs) at South China Sea (SCS). Applying the knowledge leaned to improve Navy ocean prediction capability.

15. SUBJECT TERMS

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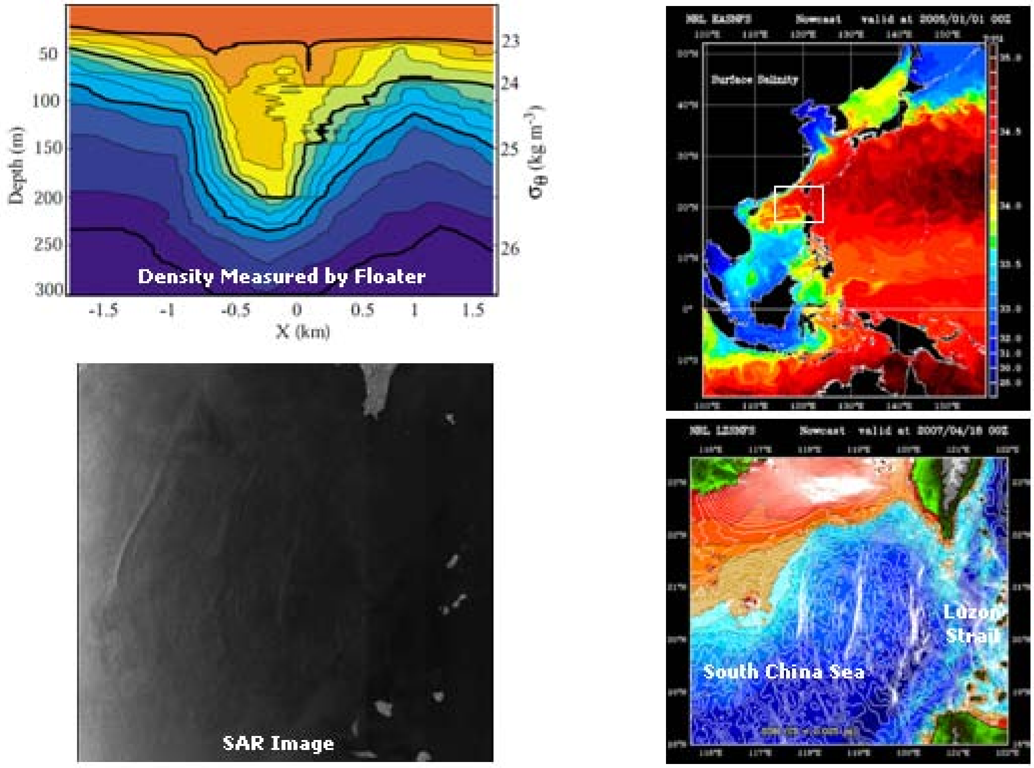

Figure 1. Internal wave at South China Sea have an amplitude over 200 m (top-left) and externs over 200 km (bottom-left). The coupled NRL Ocean Nocast/Forecast System with nested grid (right) is used to study the internal waves.

WORK COMPLETED

The coupled ocean model based on NCOM were developed during the previous years. The model predictions were used to support the NLIWI SCS field experiment. It was reported that the model predicted time being and location of the large-amplitude internal waves at SCS are fairly accurate and the model prediction has been used for cruise planning. The model performance in predicting the large-amplitude internal waves were evaluated against field observation and satellite remote sensing data (Figure 2). The evaluation shows that the model can predict large-amplitude internal waves, particular the timing, with accuracy (Chao, 2008).

A series of twin experiments were conducted applying the model. A twin experiment with different ridge heights at Luzon Strait was performed to study the influence of the ridges on the internal wave generation and propagation in collaboration with NLIWI PIs Y.-S. Chao of University of Maryland, and R.-C. Lien of University of Washionton and P.-T. Shaw of North Carolina State University. The result of study was published in an article in Journal of Oceanography at FY08.

A twin experiment was conducted, with and without the Kuroshio, to assess the influence of the Kuroshio on the internal waves generation and propagation at the Luzon Strait and the South China Sea in collaboration with postdoc S. F. Lin. The result of the study was presented at 2008 Ocean Science Meeting.

An article on the internal waves at South China Sea was prepared and submitted to be published at 2008 Naval Research Laboratory Review Book.

In collaboration with NLIWI PIs P.-T. Shaw and S.-Y. Chao finished a study on the generation of internal solitary waves in the northern South China Sea. An article was prepared and submitted to the Journal Geophysical Research for publication.

Provided the model outputs to A. C. WarnVarnas of NRL to study the parameter ranges encountered in South China Sea solitary wave predictions. Result of study was presented at 2008 Ocean Science Meeting.

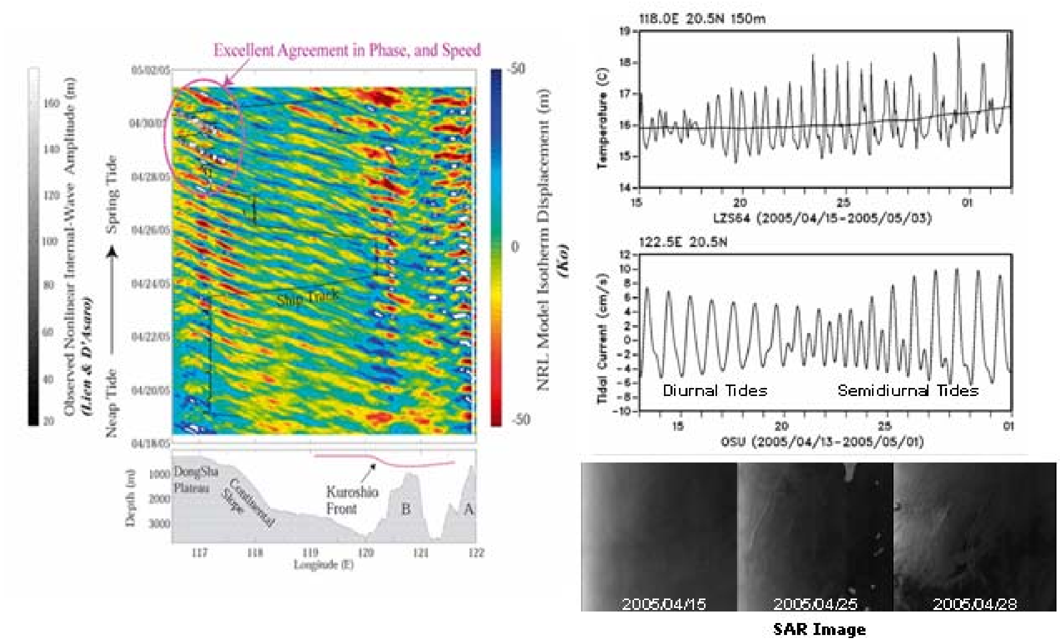

Figure 2. Comparison of model predicted internal waves at South China Sea with shipboard observation (left). Comparison of model prediction with corresponding tidal current and satellite synthetic aperture radar (SAR) images (right).

RESULTS

From the model experiments, we identified the mechanism that is reponsible for the large-amplitude non-linear internal waves generation at the South China Sea. The strong barotropic tides at Luzon Strait interact with the undersea ridges and are coverted into internal tides. Propagating away from the ridges, the internal tidal wave steepens, which transforms the internal tide to an internal tidal bore. The internal tidal bore evolves into a large-amplitude, internal solitary wave as it propagates further away from the ridges. If the tide is strong, the solitary wave may develop into a packet of internal solitary waves (Figure 3). The east ridge in the middle reaches of Luzon Strait is the major internal wave generation site where the internal tidal energy flux diverges (Fig. 3). There is a secondary generation site at the northern shallow reaches of the west ridge south of Taiwan. The internal tidal energy generated at middle reaches of the east ridge propagates westward into the deep, northern, South China Sea and dissipates on the shallow shelf. The west ridge in the middle portion of Luzon Strait blocks part of incoming internal tidal energy from the east ridge (Chao et al., 2007).

The barotropic tides are the major forcing that generates the internal waves in the South China Sea. Without the tide, internal energy can be generated by the frontal instability of the Kuroshio, but this energy is very weak and does not propagate. The semidiurnal tide is more effective than the diurnal tide in generating the large-amplitude internal waves (Fig. 3). Although the strength of the semidiurnal and diurnal tides are about equal in the South China Sea, the semidiurnal tides, with a shorter wave length and more rapid variation, more easily convert the barotropic tide into internal tides that evolve into large-amplitude internal waves. Concurrent satellite synthetic aperture radar (SAR) images and shipboard observations from NLIWI suggested that this is the case (Figure 2).

A twin experiment was conducted to assess the impact of the Kuroshio (Figure 4) on the generation and propagation of the internal waves at SCS. As shown in Figure 5, the vertical integrated zonal energy flux of the internal tides is larger for the cases with a presentation of Kuroshio (red) compared to the one without the Kuroshio (black). This is mainly due to a stronger stratification at the ridges with Kuroshio impinging on the Luzon Strait. Shaw et al (2008) also suggested this is the case based on the non-hydrostatic model simulations using different stratifications or density profiles. There are differences on the direction of the tidal energy flux (Figures 5 & 6) between two cases. It indicates that the horizontal inhomogeneous stratification due to Kuroshio and mesoscale eddies plays an important role in the propagation of the internal wave energy at SCS by refraction.

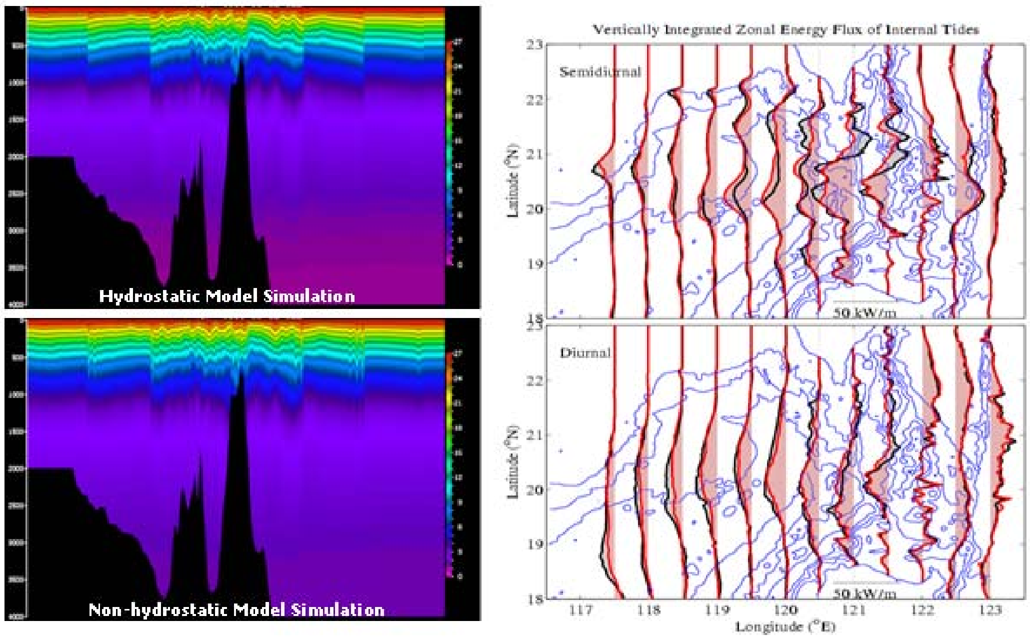

Figure 3. Simulation of the internal waves generation and propagation with hydrostatic and non-hydrostatic models (left). The energy flux of the inter tides (right). Red and black correspond to results with and without west ridge blocking.

A few conclusions can be made based on the numerical study of the internal waves at the SCS we have conducted. The operational ocean model, NCOM, is capable to produce the large-amplitude internal waves although it may not produce the waves in detail. The tidal forcing and topography data base applied are adequate for the application. The prediction on the time being of the internal waves at SCS is very accurate. The predicted internal wave amplitudes, however, are in general smaller compared to the field observations. The under-prediction on the internal wave amplitude is largely due to insufficient model resolution and in part due to the hydrostatics assumption applied in NCOM. The ocean stratification plays an important role in the generation and propagation of the internal waves. The accurate prediction in the time being and location of the large-amplitude internal waves by the model suggested that the stratification produced in the model by assimilation of the satellite data, and with surface forcing from Navy weather forecast models (NOGAPS and COAMPS) is fairly good.

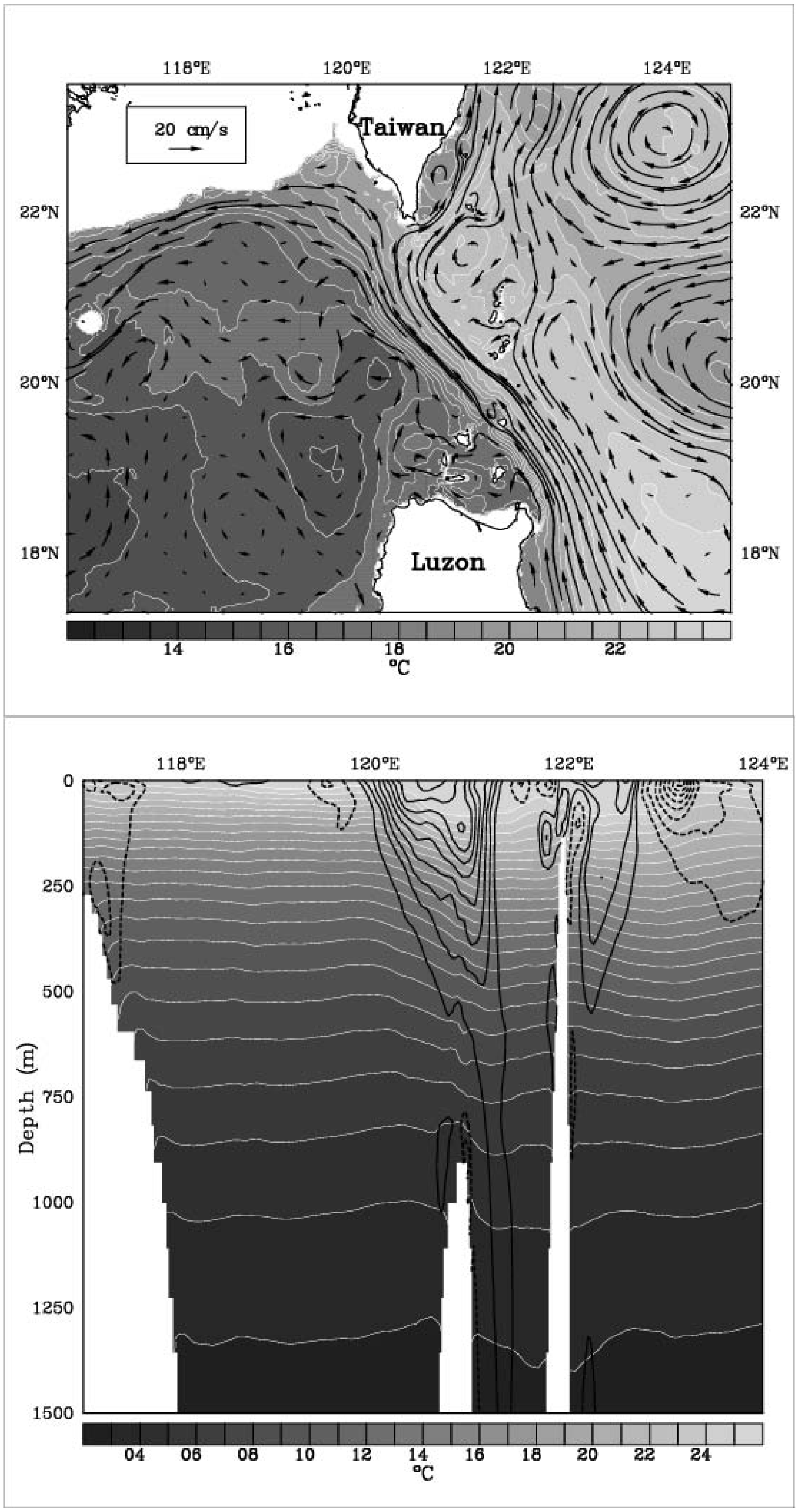

Figure 4. Kuroshio at Luzon Strait (top) and the zonal cross-section of temperature and velocity at 21N (bottom) from a high resolution Luzon Strait ocean model.

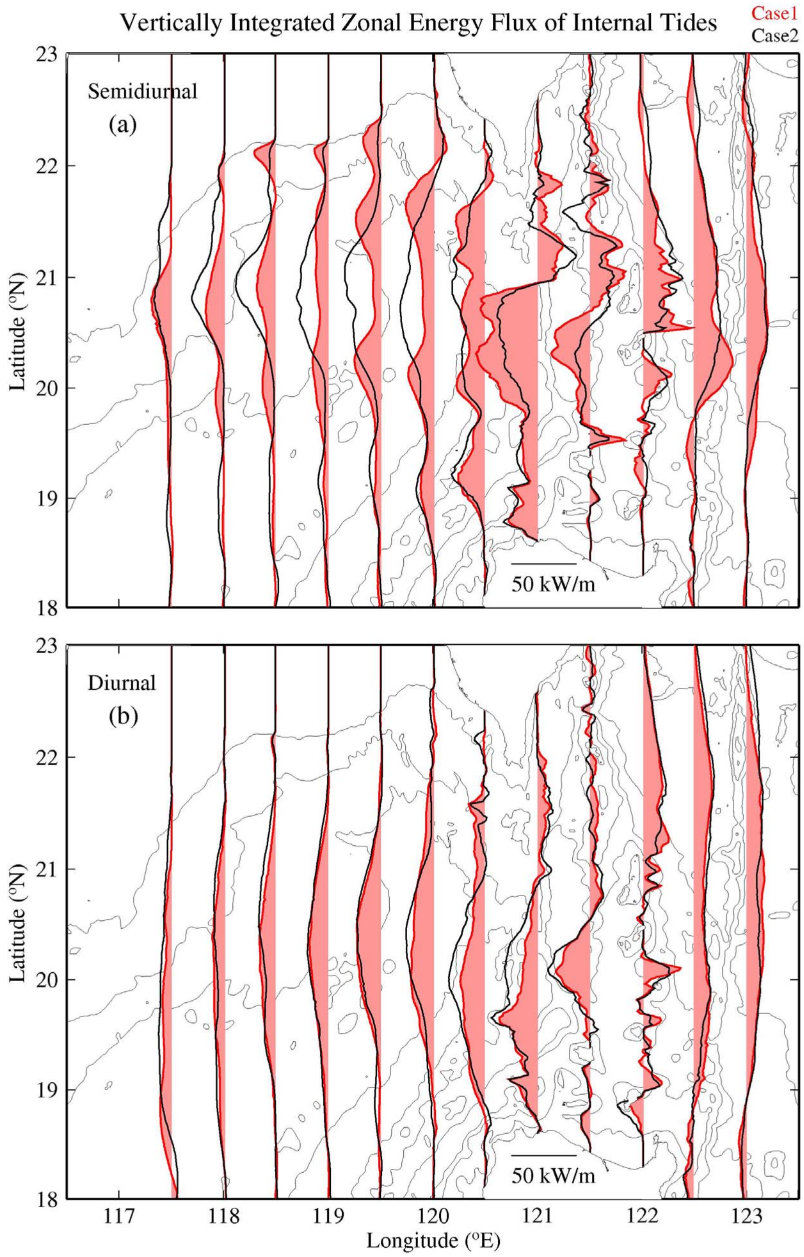

Figure 5. The vertical integrated zonal internal tidal energy flux from a model simulation with Kuroshio (red) and from a model simulation without Kuroshio (horizontal homogenous stratification) (black).

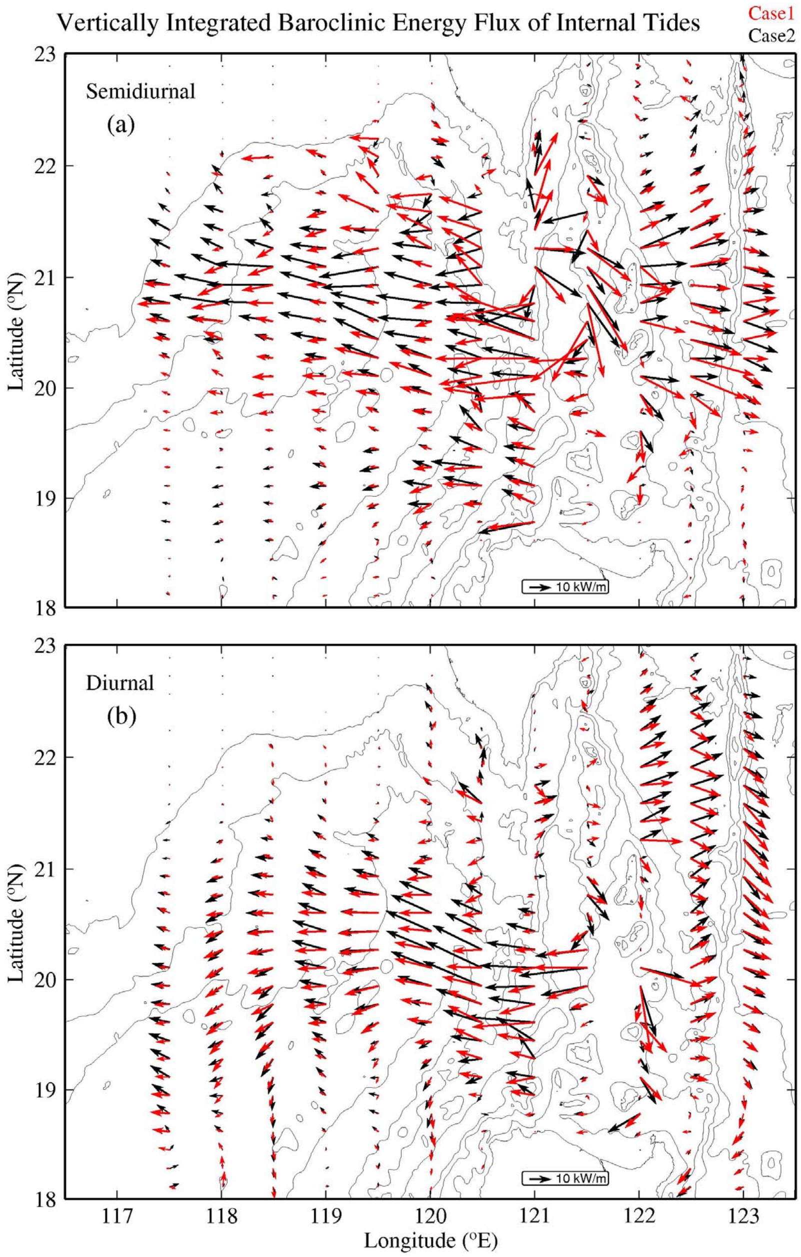

Figure 6. The vertical integrated internal tidal energy flux from a model simulation with Kuroshio (red) and from a model simulation without Kuroshio (horizontal homogenous straitification) (black).

IMPACT/APPLICATIONS

The results outlined above are applied to develop a "large-amplitude internal wave warning system for the South China Sea" in transition to NAVO for operation.

RELATED PROJECTS

NRL 6.4 Small Scale Oceanography Project (PI/POC – Rick Allard) – Transition of the large amplitude internal wave warning system for the South China Sea to NAVO is conducted under this project.

REFERENCES

[r.1] Ko, D.S., P.J. Martin, C.D. Rowley, and R.H. Preller, A real-time coastal ocean prediction experiment for MREA04, *J. Marine Systems*, 69, 17-28, 2008.

[r.2] Martin, P.J., Description of the Navy Coastal Ocean Model Version 1.0, Tech. Rep. NRL/FR/7322-00-9962, 42 pp., 2000.

[r.3] Barron, C.N., Kara, A.B., Hurlburt, H.E., Rowley, C., Smedstad, L.F., Sea surface height predictions from the Global Navy Coastal Ocean Model (NCOM) during 1998–2001. J. Atmos. Ocean. Technol. 21, 1876–1893, 2004.

PUBLICATIONS

[p.1]- Chao S.-Y., D. S. Ko, R.-C. Lien, and P.-T. Shaw, Assessing the west ridge of Luzon Strait as an internal wave mediator, J. Oceanogr., 63, 897-911, 2007. [published]

[p.2]- Ko, D. S, S. Y. Chao, P. T. Shaw, and R. C. Lien, Influence of the Kuroshio on the internal waves generation at the Luzon Strait, AUG Ocean Sciences Meeting, 2008. [published]

[p.3]- Ko, D. S., P. J. Martin, S. Y. Chao, P. T. Shaw, and R. C. Lien, Large-Amplitude Internal Waves in the South China Sea, NRL Review Book, 2008. [submitted]

[p.4]- Shaw, P.-T., D. S. Ko, and S.-Y. Chao, Generation of internal solitary waves in the northern South China Sea, J. Geophys. Res., 2008. [submitted]

[p.5]- WarnVarnas, A. C., J. Hawkins, S. Chin-Bing, D. King, E. Coelho, D. S. Ko, and K. Lamb, Parameter ranges encountered in South China Sea solitary wave predictions, AGU Ocean Science Meeting, 2008. [published]