A Statistical Investigation of Internal Wave Propagation in the Northern South China Sea

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LONG-TERM GOALS

The long-term goal of this project is to predict the generation of internal waves over the ridges in the Luzon Strait and wave propagation across the northern South China Sea.

OBJECTIVES

The objective of this study is to provide a description of internal wave/tide propagation from the Luzon Strait to the edge of the continental shelf off China. Three issues are to be studied: 1) the relationship between the internal waves and the barotropic tides in the Luzon Strait, 2) temporal and spatial variations of internal wave properties during propagation across the deep basin of the northern South China Sea, and 3) wave transmission over the continental margin.

APPROACH

Guided by the characteristics of internal waves inferred from nonhydrostatic numerical simulation, time series analysis will be performed on simulated real-time data obtained from the Ocean Nowcast/Forecast System of Naval Research Laboratory during NLIWI. In the generation region, the study will estimate the energy conversion rate from the barotropic tides to baroclinic waves. Sources of the internal waves are to be identified. In the propagation region, waves will be traced back to the generation region to find the dependence of the amplitude of internal solitary waves on the conditions in the Luzon Strait.

WORK COMPLETED

Time series of oceanographic variables obtained from NRL simulation have been analyzed during periods of large internal wave energy flux. Internal waves flux generated from the east and west ridges in the Luzon Strait have been examined to determine the sources of internal waves. Wave propagation speed is calculated. A process study using a ridge of asymmetric slope with and without a mean current has been carried out to investigate the asymmetrical eastward and westward energy propagation from Luzon Strait.

RESULTS

Figure 1 is a time-longitude plot of the vertically integrated eastward energy flux at the diurnal period along 20.3°N. Two ridges are present in this section: one reaching the surface at 121.9°E (the east ridge) and a deeper one (1670 m below the surface) at 120.8°E (the west ridge). Internal wave energy is generated at the east ridge and propagates toward both east and west with the westward energy flux nearly twice the eastward energy flux. The westward propagating internal waves transmit across the west ridge into the deep basin of the northern South China Sea.

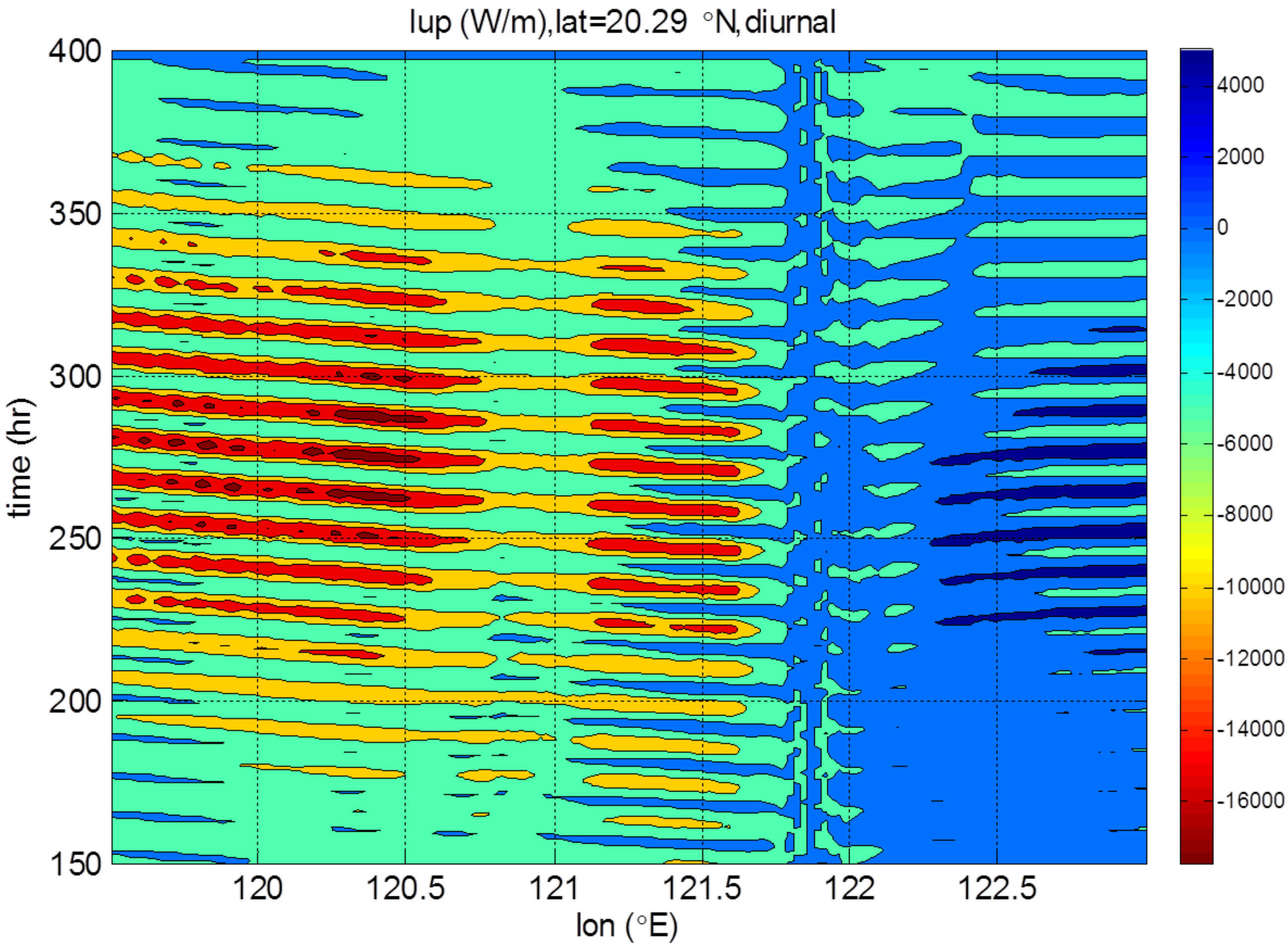

Figure 1. Contour plot of vertically integrated internal wave energy flux at the diurnal period along 20.3°N as a function of time and longitude. Time represents hours after 0 hr on July 1, 2006. Positive flux is toward east. The west ridge and the east ridge are located at 120.8°E and 121.9°E, respectively. Large internal wave energy flux emits from the ridge during a 5-day period between hours 208 and 330. The propagation speed is about 4.1 m/s. The maximum westward flux is about twice that toward east.

Figure 2 shows the east component of velocity along the same section covering one diurnal tide cycle from hour 257 to 277. Wave beams associated with the vertically propagating internal waves generated at the east ridge are clearly seen. For example, reflection of a downward wave beam toward the surface occurs between the west side of the ridge and 120.5° E. Since internal solitary waves develop only in a mode-1 wave structure, no internal solitary waves are possible east of 120.5°E. The result is consistent with satellite and mooring observations that no internal solitary waves are observed within a distance 100 km from the ridge. Some wave energy is generated by the west ridge as indicated by a weak wave beam from 800 m at 120.5°E. This energy contributes to the westward energy flux from the east ridge as shown in Figure 1.

At 20.3°N, the taller east ridge is the major source for both eastward and westward semidiurnal fluxes but nearly all westward energy flux from the east ridge is blocked by the west ridge (not shown).

At this latitude, the east ridge is the main source of the diurnal internal waves propagating into the northern South China Sea.

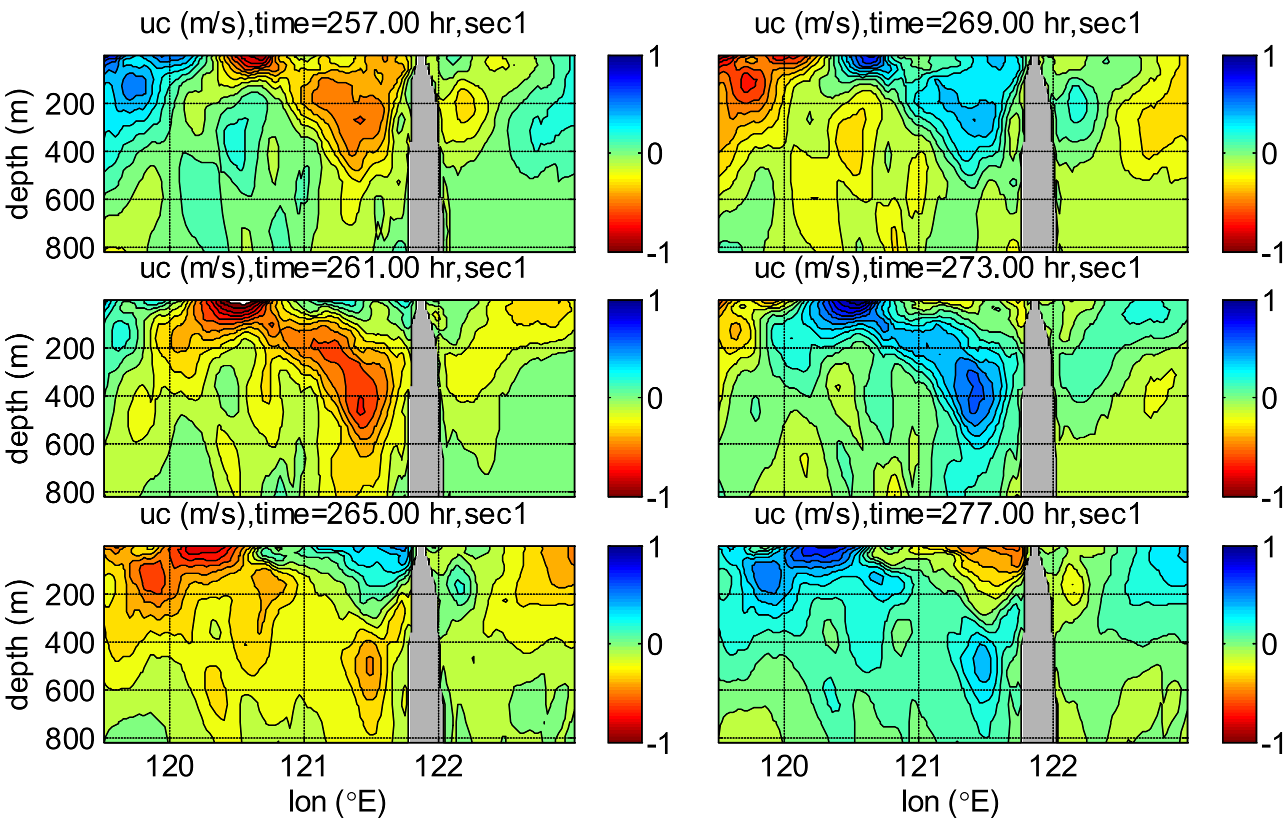

Figure 2. Contour plot of the eastward baroclinic velocity at the diurnal period in the zonal section along 20.3°N. The duration covers one diurnal cycle. The ridge is shaded. Internal waves originating from the ridge propagate along slant wave beams. The wave beam surfaces at about 100 km away from the ridge.

Energy propagation is of different characteristics along 21.3°N. In this section, the west ridge at 120.8°E is 315 m below the surface. The east ridge is at 121.6°E and is much deeper at 1106 m below the surface. In the plot of the vertically integrated internal wave energy flux (Figure 3), the east ridge seems to be the source of diurnal internal waves propagating toward east. Westward flux is generated mainly by the west ridge. However, the westward flux generated at the west ridge decays rapidly before reaching 119.5°E. In contrast, diurnal waves in the southern section could propagate farther westward into the South China Sea (Figure 1).

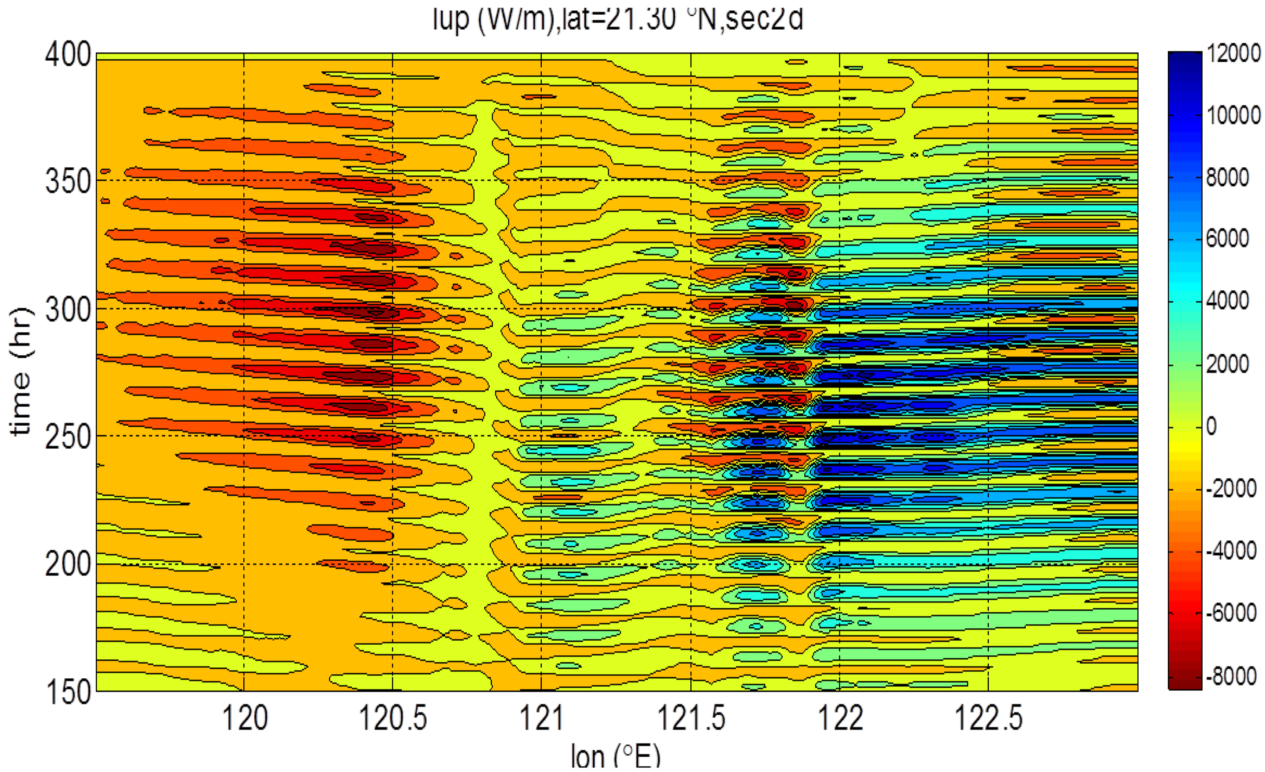

Figure 3. Contour plot of vertically integrated internal wave energy flux at the diurnal period along 21.3°N as a function of time and longitude. Time represents hours after 0 hr on July 1, 2006. Positive flux is toward east. The ridges are located at 120.8°E and 121.6°E. The maximum eastward flux is slightly larger than that toward west.

At 21.3°N, the west ridge is the main source of both the eastward and westward energy fluxes at the semidiurnal period (Figure 4). The westward energy flux is intermittent and is weaker than the westward diurnal energy flux from the southern section. Although at 1106 m below the surface, the east ridge efficiently blocks the eastward propagating semidiurnal waves except during periods of largest energy flux.

The following conclusions can be derived. At 20.3°N, the tall east ridge generates eastward and westward energy fluxes at both the diurnal and semidiurnal periods. The lower west ridge effectively blocks the westward internal wave energy propagation at the semidiurnal period, but allows transmission of diurnal waves into the South China Sea. At 21.3°N, the west ridge is the main source of westward internal wave energy flux at the semidiurnal period, and the westward diurnal waves generated by the west ridge decay rapidly. The lower east ridge generates only diurnal eastward internal waves; westward diurnal waves are blocked by the west ridge.

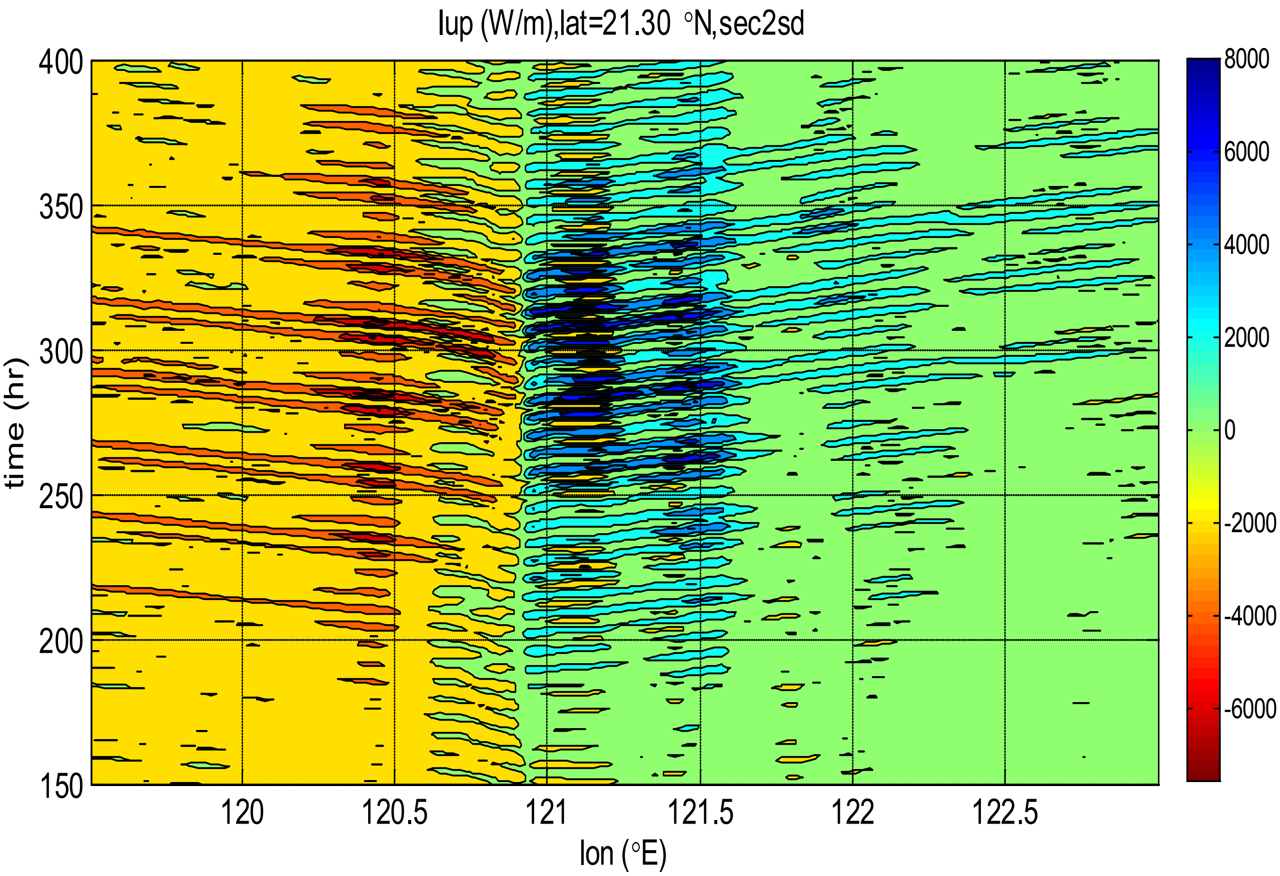

Figure 4. Contour plot of vertically integrated internal wave energy flux at the semidiurnal period along 21.3°N as a function of time and longitude. Time represents hours after 0 hr on July 1, 2006. Positive flux is toward east. The west ridge is located at 120.8°E, the east ridge is located at 121.9°E Internal wave energy flux at the semidiurnal period emits from the ridge toward west. The propagation speed is about 3.2 m/s, slightly slower than that of the diurnal waves. The eastward energy flux is much smaller than that at 21.3°N.

IMPACT/APPLICATIONS

This study suggests that both diurnal and semidiurnal waves are generated in the southern section of the tall east ridge. The westward propagating semidiurnal waves are blocked by the lower west ridge at this latitude but the diurnal waves are not affected. Consequently, the southern portion of the east ridge is the source of diurnal waves in the northern South China Sea. The westward propagating semidiurnal waves are mostly generated by the northern portion of the west ridge and are weaker than the diurnal waves originating at 20.3°N. The result is supported by observations that diurnal waves (24-h period or type-a waves) are stronger than the semidiurnal waves (12.42 hr period or type b waves) in the northern South China Sea (Ramp et al., 2004). Thus, the observed frequency of internal waves may depend not only on the topography of the ridge at the source but also on the lower ridges along the path of energy propagation.

The study indicates that internal wave propagation is reasonably described by the hydrostatic NRL model. Data from the NRL simulation could provide a comprehensive view of the internal wave field and the energy flux in the vicinity of the Luzon Strait and in the northern South China Sea. This approach would expand the description obtained from field observations with limited spatial and temporal coverage (e.g., Alford, et al., 2010) to include the effect of the Kuroshio.

RELATED PROJECTS

A student working on this project is supported by an accompanying Early Student Support award (Award Number: N00014-10-1-0470).

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Qian, H., P.-T. Shaw, and D. S. Ko (2010) Generation of internal waves by barotropic tidal flow over a steep ridge, Deep-Sea Research I, 57, 1521-1531. doi:10.1016/j.dsr.2010.09.001. [published, refereed]