Satellite Synthetic Aperture Radar Detection of Ocean Internal Waves in the South China Sea

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LONG-TERM GOALS

The long-term goal of the project is to meet the goal of ONR DRI NLIW, which is to achieve the basic science understanding that leads to a predictive capability that will be able to tell when and where non-linear internal waves will occur and what effects they will have on the hydrodynamic and acoustic environment. This project focuses on the use of remotely sensed variables, together with models and in situ observation that can reproduce and predict the generation and structure of these waves, their evolution during propagation, and the processes controlling dissipation.

OBJECTIVES

1). To determine the statistical features of ocean internal waves in SCS. Interpreting ten years of satellite synthetic aperture radar (SAR) images, the statistical features of ocean internal waves in SCS will be determined. 2). To understand the effects of topography/thermocline on the evolution of solitary internal waves in SCS. 3). To explore the SAR imaging conversion mechanisms of internal waves.

APPROACH

In this research, the PI's use both *in situ* and remotely sensed data. For the remotely sensed data, the main source is the synthetic aperture radar (SAR) carried by various satellites, i.e., ERS-1/2, Radarsat-1/2 and Envisat. High resolution NOAA AVHRR data and SeaWifs, as well as data from Terra and Aqua satellites will also be used. Historical XBT/AXBT data will be used to determine the vertical thermal structure in the study area. The data will be obtained from NOAA archives, which are in the public domain. In addition, historical CTD data from NOAA-NODC as well as data from NLIWI program will be used in collaboration with the PIs from observational team.

For the analysis, for different features the PI plans to apply different data analysis methods, which best match the nature of these features. Two-dimensional Fourier transform is used to study wave number

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characteristics of internal waves. The HHT method developed by Huang et al. (1998) will be used to determine the variation of spatial phase of internal waves and to trace back to their generation locations.

The objectives of theoretical analysis are to understand the nature, physics, mechanism, and laws of variation of the studied process, to derive unknown geophysical parameters using parameters and information derived from SAR image interpretation as inputs, to analyze the relation between the studied process and the surrounding environment, and to predict the future development of the studied process.

Dr. Quanan Zheng serves as a lead PI and coordinates the project. Zheng will focus on data collection, satellite image interpretation, and the theoretical analysis. Dr. R. Dwi Susanto from LDEO, Columbia University, serves as a Co-PI. Susanto focuses on image processing, statistical analysis, and takes part in data collection and the theoretical analysis.

WORK COMPLETED

1). The statistical analysis of IW occurrence in the northern South China Sea (NSCS) has been completed using seven years of satellite SAR images from 1995 to 2001.

2). Nonlinear analysis of effects of shoaling thermocline on the IW generation has been completed. The role of Kuroshio playing in IW generation in the Luzon Strait has been analyzed using linear wave models and the Fourier transform methods. Dynamical analysis of bottom-topography-induced stationary IW in NSCS has been completed.

3). Analysis of variability of thermocline depth in SCS is still underway. More than 37,000 CTD casts in the SCS are being analyzed.

RESULTS

1). Statistical analysis of seven years of satellite SAR images from 1995 to 2001, statistics of IW occurrence in NSCS generate the following results.

a. Statistics indicate that 22% of IW packets distributed in the east of 118ºE obviously originate from the Luzon Strait, and 78% of IW packets west of 118ºE may propagate from the east or evolve from the solitons originating from the east boundary owing to the fission effect of shoaling thermocline (Figure 1, partially from Zhao et al., 2004).

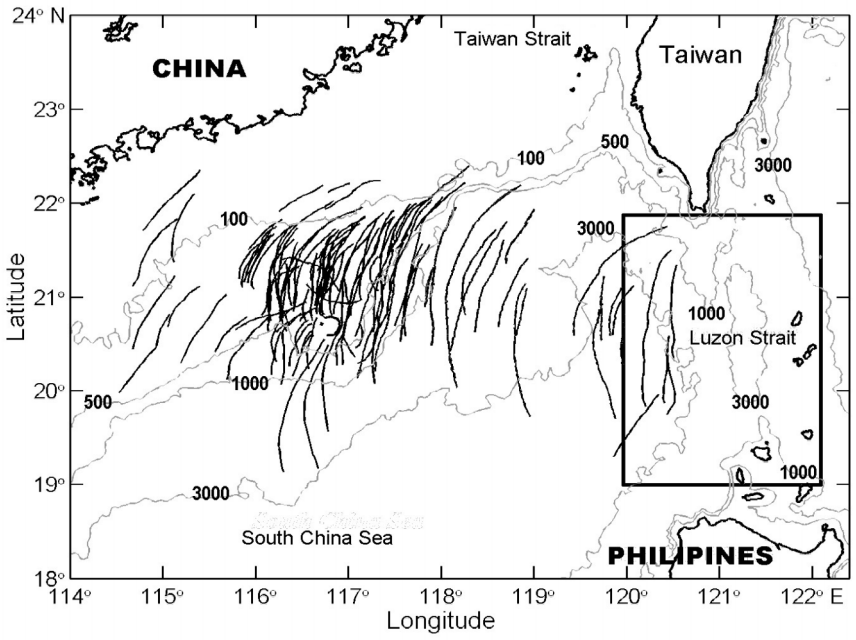
b. An interannual variability of IW occurrence frequency is apparent. The frequencies in 1995, 1998, and 2000 are 2 to 5 times higher than that in other years. This interannual variability implies that there are long-term and large scale processes modifying the SAR-observed IW occurrence.

c. A seasonal variability of IW occurrence frequency is also apparent. High frequencies are distributed from April to July and reach a peak in June with a maximum frequency of 20%. The low occurrence frequencies are distributed in winter from December to February of next year with a minimum frequency of 1.5% in February (Figure 2).

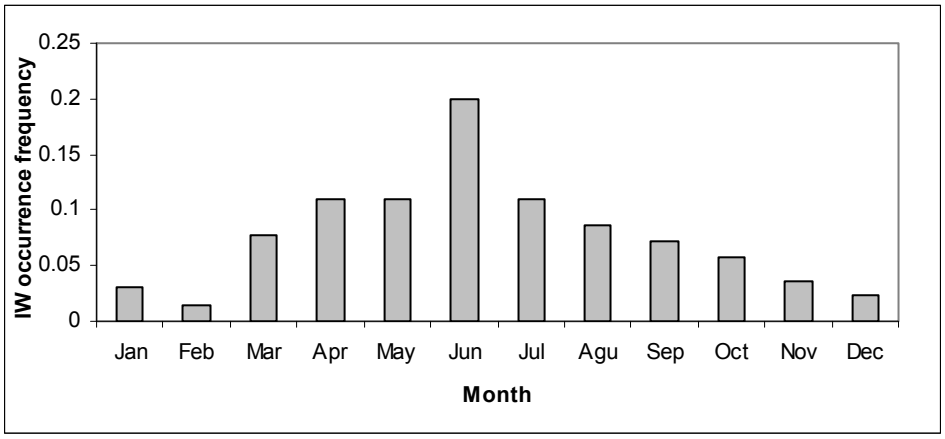
2). Nonlinear analysis of effects of shoaling thermocline on the IW generation indicates that the thermocline shoaling provides the forcing to soliton amplitude growth, so that the soliton amplitude growth ratio (SAGR) serves as a decisive factor for the IW occurrence frequency.

3). The role of Kuroshio playing in IW generation in the Luzon Strait indicates that for the western propagating disturbance, the Kuroshio west wing is unstable and the east wing is stable; while the reverse is true for the eastern propagating disturbance. The results are used to interpret satellite SAR images of the ocean internal waves, which are generated in the Luzon Strait and propagated westward.

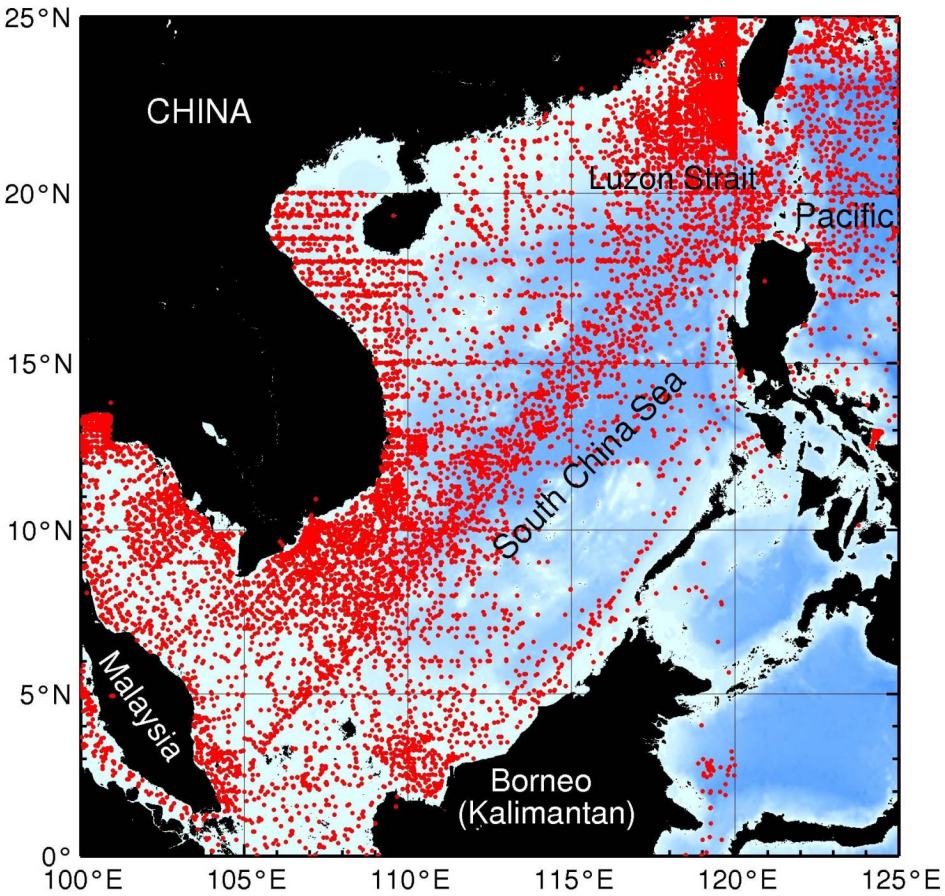
4). Reflection coefficient associated with thermocline depth variability in the South China Sea based on historical CTD data (Figure 3) shows two large circulations in the SCS and also upwelling jet across the Vietnam coast (Figure 4). We will further analysis all CTD data.



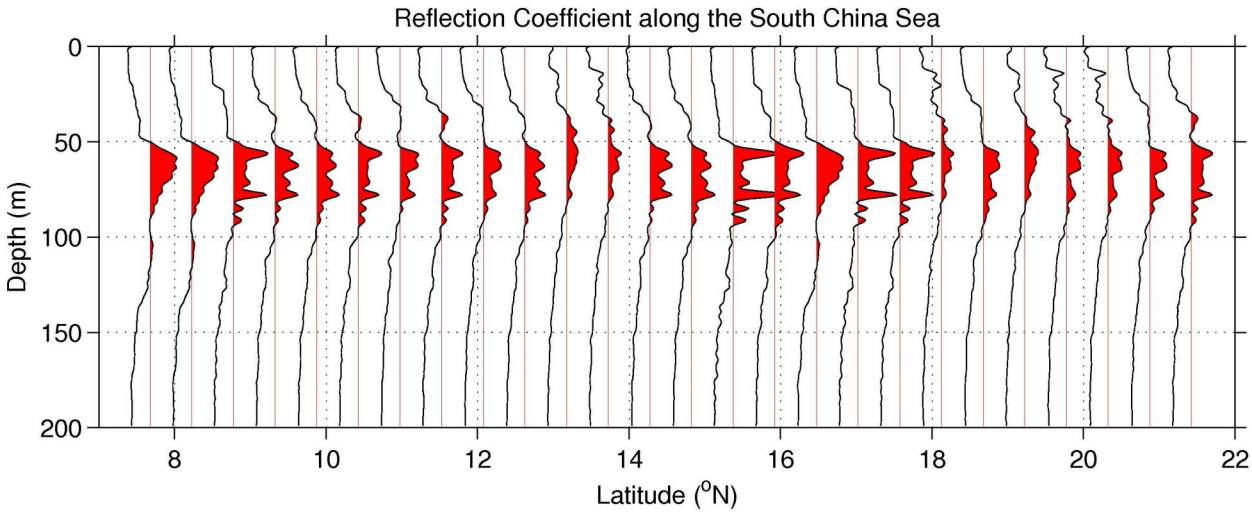
[Figure 1. A map of latitudinal distribution of IW packets in NSCS. Bold lines represent crest lines of leading waves in IW packets interpreted from SAR images. The rectangular box on the right defines an IW generation source region for the dynamical analysis, Zheng et al., 2007.]



[Figure 2. Monthly distribution of SAR-observed IW occurrence frequencies in NSCS, Zheng et al, 2007.]



[Figure 3. Historical CTD data in the South China Sea used for analysis of thermclonice depth variability. Susanto & Zheng (in preparation)]



[Figure 4. Reflection coefficient associated with thermocline depth variability in the South China Sea. Susanto & Zheng (in preparation)]

IMPACT/APPLICATIONS

The results of this project will provide the users a statistical outline of internal wave behavior and boundary conditions in SCS, and will benefit the broader oceanographic community, ocean engineering industries, underwater navigation and operational users. The results may also serve as a basis for empirical, theoretical, and numerical prediction models of internal wave behavior in SCS, and contribute to creation of a predictive system. The results will further reveal SAR imaging mechanisms and be used for SAR image interpretation.

RELATED PROJECTS

- ✓ Ongoing ONR PO project titled "Analysis of Fine Structures of Flows, Hydrography, and Fronts in Taiwan Strait". Quanan Zheng serves as a CO-PI. The study areas of two projects are immediately adjacent. Therefore, two projects sometimes share the same data resources of field observations.

- ✓ Ongoing multidisciplinary project supported by ONR-DRI to understand archipelago strait dynamics in the Mindoro Strait and adjacent straits within the Philippine region.

- ✓ Ongoing collaborative project (Indonesia-China-USA) to deploy an array of trawl- resistant, bottom mounted ADCP. Chinese PIs led by Prof. Guohong Fang of the First Institute Oceanography and US PI is Dr. Dwi Susanto and the Indonesian PI is led by Dr. Sugiarta (BRKP).

- ✓ Project supported by the ONR: N00014-04-1-0698; PI: Dwi Susanto on"An overview submeso-scale features in the Indonesian Seas has been completed. Some statistical and dynamical analyses have been applied to both Indonesian Seas and South China Seas; Hence we share authorships.

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