Nonlinear Internal Waves in the South China Sea

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LONG-TERM GOAL

To study nonlinear ocean internal wave processes in the South China Sea (SCS) by using satellite synthetic aperture radar (SAR) imagery, in-situ data, and numerical models to understand the environmental effects (e.g. bottom topography, shoaling, mixing, and current/shear) on nonlinear internal wave generation, evolution, and dissipation.

OBJECTIVES

The objective of this study is focused on nonlinear internal wave and mesoscale feature (e. g. eddies, fronts) observations in the shelf-break region of the SCS. The effort is to support the Asian Seas International Acoustics Experiment (ASIAEX) for the ocean modeling and remote sensing. The task is concentrated on the collection and analysis of RADARSAT ScanSAR and mooring data in the SCS during ASIAEX-2001. Of particular interest is the generation of huge internal waves caused by the branch out of Kuroshio through Luzon Strait and its evolution and dissipation on the shelf break.

APPROACH

The approach is to use the SAR data in conjunction with the in-situ measurements from field experiments to calibrate and validate SAR imaging mechanism of nonlinear internal waves, and to integrate all data by wave model for data assimilation. A validated and calibrated algorithm and model can be very useful for understanding of shelf processes and for the applications of the internal wave effects on acoustic propagation. A parametric study for various environmental conditions to assess the nonlinear effects such as bottom topography (across critical depth), shoaling, stratification, and dissipation has been conducted. The generation and evolution of internal waves (elevation versus depression, and mode-one versus mode-two), and wave-wave interaction will be studied using satellite data in conjunction with in-situ data from the field experiments. All data will be synthesized/integrated by using numerical models (Liu et al., 1986; Liu, 1988).

The ASIAEX has been conducted in SCS in May 2001 and this joint experiment from US, Singapore, and Taiwan used three ships from Taiwan (R/V OR-1, OR-3, and Fisheries Researcher-1). The mooring deployments were done by the end of April, and SEASOAR surveys was carried out from April 29 to May 14. The intensive period of measurements was from May 3 to May 18. During the field test, a typhoon (Cimaron) was passing through ASIAEX area around May 12. Mooring recovery started after May 18 to 24. Numerical simulations will be performed by using observed internal wave field in deep water near the shelf break area as an initial condition to produce the wave evolution on the continental shelf and compare with the observations.

WORK COMPLETED

Satellite remote sensing is critical to several aspects of ASIAEX, including tracking the internal waves, and locating surface fronts and mesoscale features. In January 2001 ERS-2's gyro#1 failed. So, the quality of ERS-2 SAR is highly degraded and Taiwan ground station can no longer process SAR images during ASIAEX-2001. In replacement, all cloud-free SPOT images (60km * 60km) with 20m resolution were collected and processed in near-real time from Taiwan ground station. However, most of days during ASIAEX, the SPOT images were obscured by the cloud-cover and internal waves were visible only on May 7 and May 14, 2001.

Four RADARSAT ScanSAR images from May 2, May 9, May 18, and May 11 (replaced by June 4), 2001 have been ordered and collected during ASIAEX through RADARSAT International. On May 11, the SAR data were lost due to transmission problem. Most of oceanography data have been collected and are under processing. These SAR data have been used to compare with mooring data. Based on the preliminary observations from SEASOAR and moorings, the internal wave field was dominant in the ASIAEX area and its magnitudes were also larger than predicted from the pretest planning.

During ASIAEX-2001, many marine radar images from R/V OR-1 have been recorded from May 3 to May 10. The ship track was focused on the shelf break area in shallow water with a serpentine pattern for internal wave evolution. These marine radar, EK500 echo sounder, ship-board ADCP, and SEASOAR data will be very useful to combine with SAR and mooring data for internal wave evolution study in the shelf break area. These preliminary data sets have been compiled with special focus on internal wave study.

RESULTS

In summary, Figure 1 shows the internal wave distribution map in the ASIAEX area collected in May 2001 from RADARSAT ScanSAR images. The square box is the ASIAEX test area for reference. The green lines are internal waves for May 2, dark lines for May 9, and blue lines for May 18. The RADARSAT ScanSAR image (500km * 500km with 100m resolution) collected northeast of the South China Sea on May 9, 2001 shows large internal wave packets in the ASIAEX area. The squall lines with rain cells can also be clearly identified in the SAR image. Steve Ramp of NPS and David Tang of NTU have processed some of their mooring data. Since ScanSAR image is collected at GMT 21:57:34 on May 9, the large internal soliton with amplitude of 100 m near the mooring S7 in the SAR image can be identified on temperature data measured at GMT 22:00. In general, the internal solitons observed in the SAR images are consistent with those mooring data.

However, the internal wave field in ASIAEX area sometimes can be quite complicated. As shown in Figure 1 on May 18, besides the regular internal wave packet propagating in the west direction, there are second packets refracted and generated by Dongsha Island propagating to the north in ASIAEX area. These two wave systems were merged as a circle by the nonlinear wave-wave interaction. Two-dimensional wave pattern of this two-wave field is crucial for the interpretation of acoustic measurement.

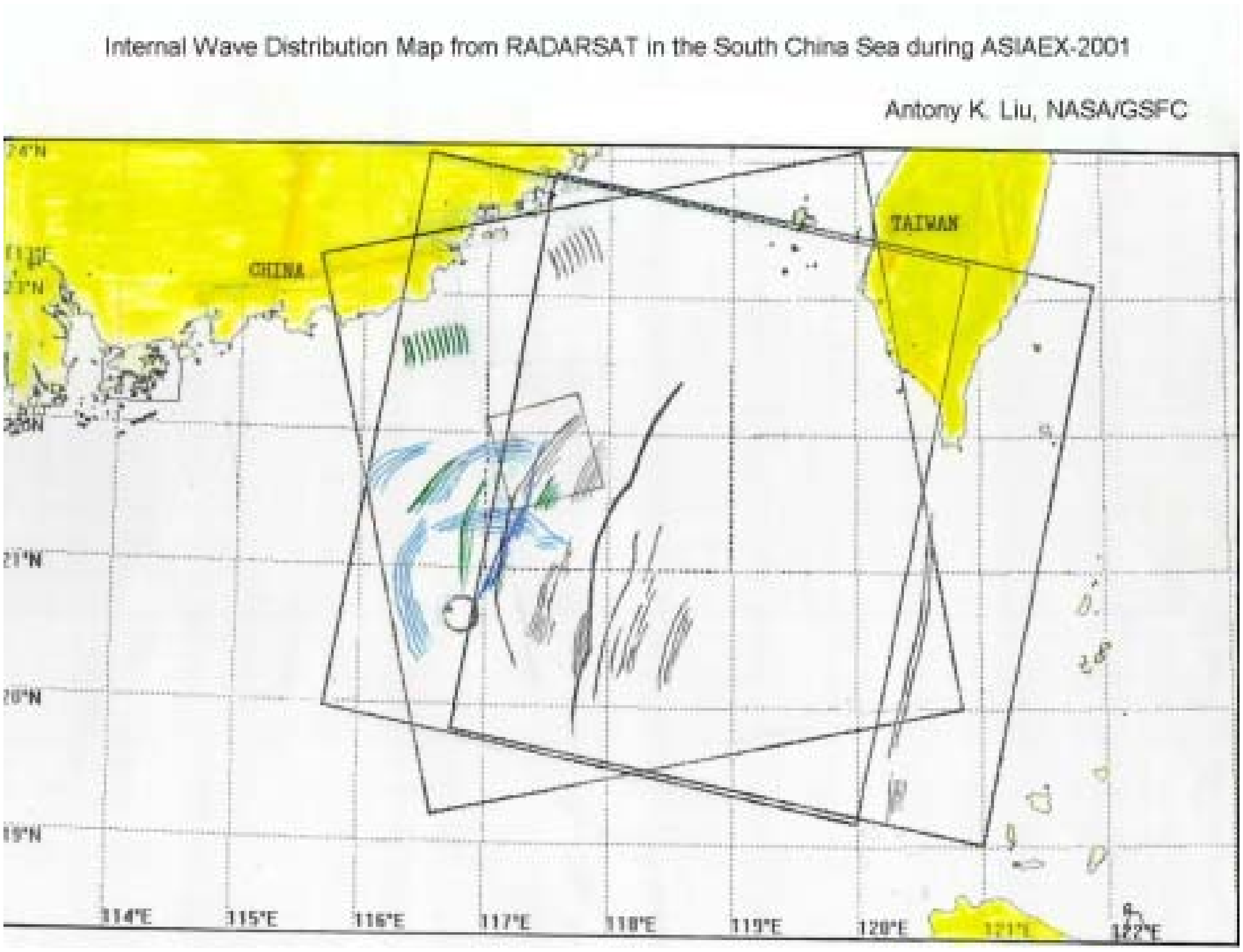

Figure 1. Internal wave distribution map in the ASIAEX area collected in May 2001 from RADARSAT ScanSAR images. The square box is the ASIAEX test area. The green lines are internal waves for May 2, dark lines for May 9, and blue lines for May 18.

The mesoscale variability, mean horizontal and vertical shears and varying stratification near the shelf-break are highly transient in April/May during the spring transition from winter monsoon to summer typhoon season. Therefore, the evolution of internal solitons in the ASIAEX test area at shelf-break is complicate in April/May with many interested features such as mode-two solitons. The solitons are in transient with continuous evolution and dissipation along the shelf. The impact on acoustic volume interaction is also quite interesting and significant. For the internal wave study, it is hoped that issues on generation, evolution, and dissipation in SCS can be addressed based on the data analysis of ASIAEX project. An ONR ASIAEX analysis workshop will be held from October 31 to November 2, 2001 to present preliminary results from the East and South China Sea field programs and develop strategies for further analysis of the data.

IMPACT/APPLICATIONS

It is clear that these internal wave observations in the South China Seas provide a unique resource for addressing a wide range of processes (Liang et al., 1995; Liu et al., 1996, 1998; Hsu and Liu, 2000). These processes are listed as follows: the generation of elevation internal waves by upwelling, the evolution of nonlinear depression waves through the critical depth, the disintegration of solitons into internal wave packets, internal wave breaking induced by solitons, the generation of mode-two internal waves, and internal wave-wave interaction. The inclusion of these physical processes is essential to improve quantitative understanding of the coastal dynamics. The ASIAEX has been conducted in the East and South China Seas in May 2001. One of the major tasks is to study the effects of large-amplitude internal wave packets on the propagation and scattering of sound.

TRANSITIONS

The internal wave evolution model developed by Dr. Antony Liu has been used in a NRL study of internal wave effect on acoustic propagation. Recently, the internal wave distribution maps from more than three hundreds of ERS-1/2, RADARSAT and Space Shuttle SAR images in the East and South China Seas from 1993 to 2000 have been compiled for ASIAEX field test planning and operation (Hsu et al., 2000). These internal wave distribution maps are the most recent and important information for future planning of internal wave related field tests in these areas. Near real-time processed SAR images can be very helpful for scientists on research ship to coordinate the survey strategy. Dr. Liu has actively participated in the field test and coordinates the joint efforts between participants from the US, China, and Taiwan. A validated and calibrated internal wave model can be very useful for understanding of shelf processes and for the applications of the internal wave effect on oil drilling platform, nutrient pump, sediment transport, and acoustic propagation.

RELATED PROJECTS

This study is jointly funded by ONR Physical Oceanography and Ocean Acoustics Programs for ASIAEX support. Dr. Antony Liu has participated in the field test stationed at Taiwan during the ASIAEX-2001. He has also established an internal wave project with the National Taiwan University as a part of Kuroshio Upstream Dynamics Experiment (KUDEX) funded by Taiwan's National Science Council. Hydrographic surveys by Taiwan's research ships with CTD casts, thermistor chains, acoustic echo sounder, marine radar, and ADCP have been conducted during ASIAEX-2001 by Prof. David Tang and Joe Wang of the Institute of Oceanography of the National Taiwan University and Prof. Ming-Kuang Hsu of the National Taiwan Ocean University. The SPOT images have been collected and processed in near real-time at the Taiwan ground station. RADARSAT ScanSAR images were ordered and processed through RADARSAT International as an approved research project. These in-situ measurements have provided a calibration on SAR observations and inputs for the numerical simulation of nonlinear wave evolution on the continental shelf.

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