Analysis of Fine Structures of Flows, Hydrography, and Fronts in Taiwan Strait

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LONG-TERM GOALS

The long-term goal of the project is to determine the fine structures of flows, hydrography, and fronts by analyzing a collection of in situ data and satellite data. The in situ data provide a dual purpose: the description of conditions as they exist, and the verification and validation of the results from the satellite data analysis and dynamical analysis.

OBJECTIVES

(1) To resolve the fine structures of the flow field, (2) To determine the hydrodynamics and hydrography across the fronts, and (3) To examine the effects of the Taiwan Island to the fine structures and fronts under different forcing conditions. The tasks serving these objectives include the analysis of observational data from moorings and cruises, the use of an inverse analysis and extraction of flow field using Synthetic Aperture Radar (SAR) for fine structures, and the analysis of AVHRR/MODIS SST and MODIS/SeaWiFS ocean color parameters in the identification of the fine structures.

APPROACH

1) Field data analysis. The field data are used to describe the fine structures of flows, hydrography, and fronts, and examine the effects of the bathymetry and morphology on the fine structures to achieve the objectives. The horizontal and vertical structures, the effect of various waters of contrasting characteristics under seasonal wind conditions, the effect of Taiwan Island, and the effect of the generally shallow strait with sharp depth changes at near the northeast and southeast openings of the strait are major targets. Recently measured CTD data and historical XBT/AXBT data are used to determine the vertical thermal structure in the study area. The historical data are obtained from NOAA archives, which are in the public domain.

2) Satellite images. Satellite SAR is the most powerful sensor for ocean remote sensing because of its all weather, all day abilities, and high spatial resolution. The spatial resolution of the state-of-the-art satellite SAR images reaches 20 – 30 m, and the swath width reaches 100 – 450 km. These specifications match the requirements for observing the ocean internal waves with a spatial characteristic scale within a range from 0.1 km to 10 km. The SAR images used for the project were taken by the ERS-1 and 2, the RADARSAT-1 and 2 satellites.

3) Data processing methods. TECPLOT and GIS software packages are used for the visualization of the results from the analyses of the in situ data. These results will serve not only for the description and quantification of the fine structures, but also for the validation and verification of the analysis of

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satellite data including the algorithms of the inverse analysis of flow field using the satellite SAR images. Commercialized image processing software packets will be used for imagery enhancement, orthorectification, filtering, and data extraction.

4) Theoretical analysis. 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 PI for research in University of Maryland. Zheng focuses on data collection, satellite image interpretation, and the theoretical analysis.

WORK COMPLETED

1) Data collection. CTD data measured by 189 casts at 55 stations along 5 transects in the southwestern Taiwan Strait in summer 2005 are collected. Preliminary data analysis has been completed.

2) Dynamical analysis. Dynamical analysis of bottom-topography-induced stationary IW in NSCS has been completed. 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.

3) Paper preparation. Based on the results, five papers (see **PUBLICATIONS**) have been prepared and submitted to international-circulated and peel-reviewed journals. Two of them are accepted and in press.

RESULTS

1) Cruise data collected.

The cruise was carried out by R/V Yanping 2 from July 4 to 15, 2005 [Chen et al., 2005]. As shown in Figure 1, the survey area covers a rectangular region of 130 by 160 km enclosed by lines linking four points from A1 (23.6390ºN, 117.8522ºE) clockwise in turn to A9 (22.5331ºN, 118.9277ºE), C9 (21.6730ºN, 117.9168ºE), and C1 (22.7979ºN, 116.7755ºE). The water depth varies from 25 m to 500 m. The purpose of this cruise observation is to collect the temperature and salinity profile data for understanding the three-dimensional (3-D) fine structure of the circulation. During the cruise observation, the survey area was scanned by 189 CTD casts at 55 stations along 5 transects. The horizontal resolution of observation grids is about 20 by 35 km.

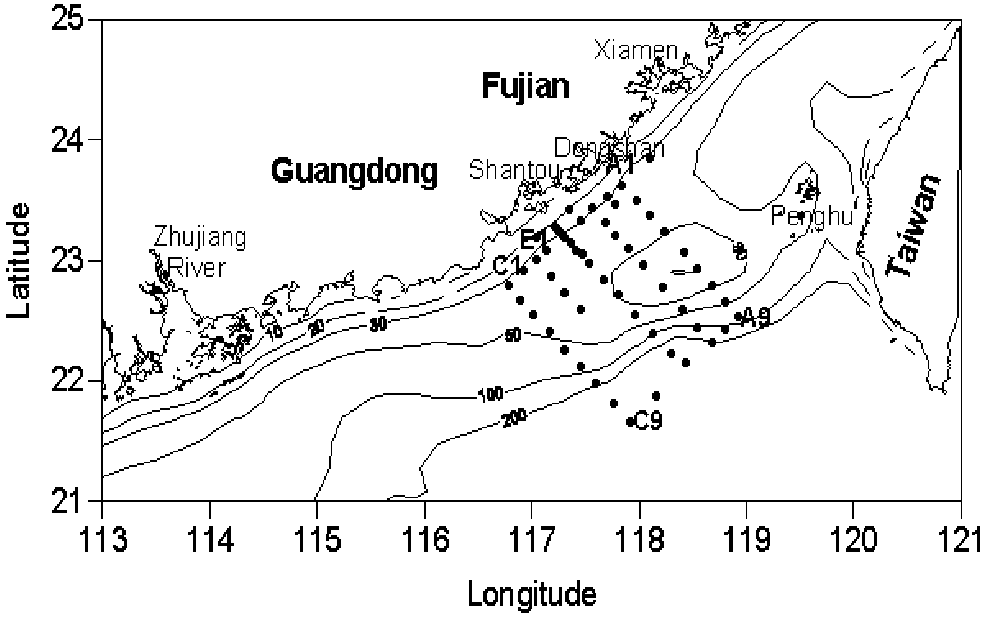

Figure 1. A map of study area. Codes represent CTD cast stations. Numerals on isobaths are in m.

2) Finding a low salinity tongue. Using the cruise data and interpolation methods, 2-D distribution maps of salinity at depths of 5, 10, 15, 20, and 30 m are generated as shown in Figures 2a-e. One can see that the most remarkable features are a low salinity tongue sandwiched by high salinity waters on both shallow and deep water sides. The low salinity tongue runs southwest-northeastward along 40-50 m isobaths. The tongue axis is located at an offshore distance of about 60 km and generally parallel to the direction of coastline. Defining 32 psu isohaline as the boundary of the low salinity tongue [Wu, 1989], the maximum width of the tongue at the surface layer (depth of 5 m) reaches 70 km. The water tongue tip reaches 23.2ºN, 118.3ºE. The water tongue root is located on the southwest side of the survey area, where the lowest salinity is only 27 psu, implying that the low salinity water originates from somewhere southwest of the survey area.

Vertically, at the 10 m layer, the water tongue keeps patterns similar to that at the surface layer. The location of water tongue tip keeps unchanged, but the width narrows to a maximum of about 45 km at the water tongue root. The lowest salinity increases 2.5 psu to 29.5 psu. The low salinity water exists even at the bottom layer (30 m), but cannot keep an entire tongue pattern below the 15 m layer. In other words, the low salinity water is mainly concentrated in the upper layer from the sea surface to about 10 m.

Horizontally, the salinity gradients can be calculated. Taking Figure 3b (10 m layer) as an example, along the west boundary of survey area, the salinity gradients reach 0.24 psu km^{-1} on the shallow water side, and 0.085 psu km^{-1} on the deep water side, respectively. This implies the existence of strong salinity fronts on the both sides of the low salinity tongue according to a generally accepted criterion of 0.018 psu km^{-1} for a salinity front [Zhuang et al., 2003]. Meanwhile, the existence of strong salinity fronts implies that a jet-like current has to serve as low salinity water supplier to maintain the existence of low salinity tongue [Zheng et al., 2004].

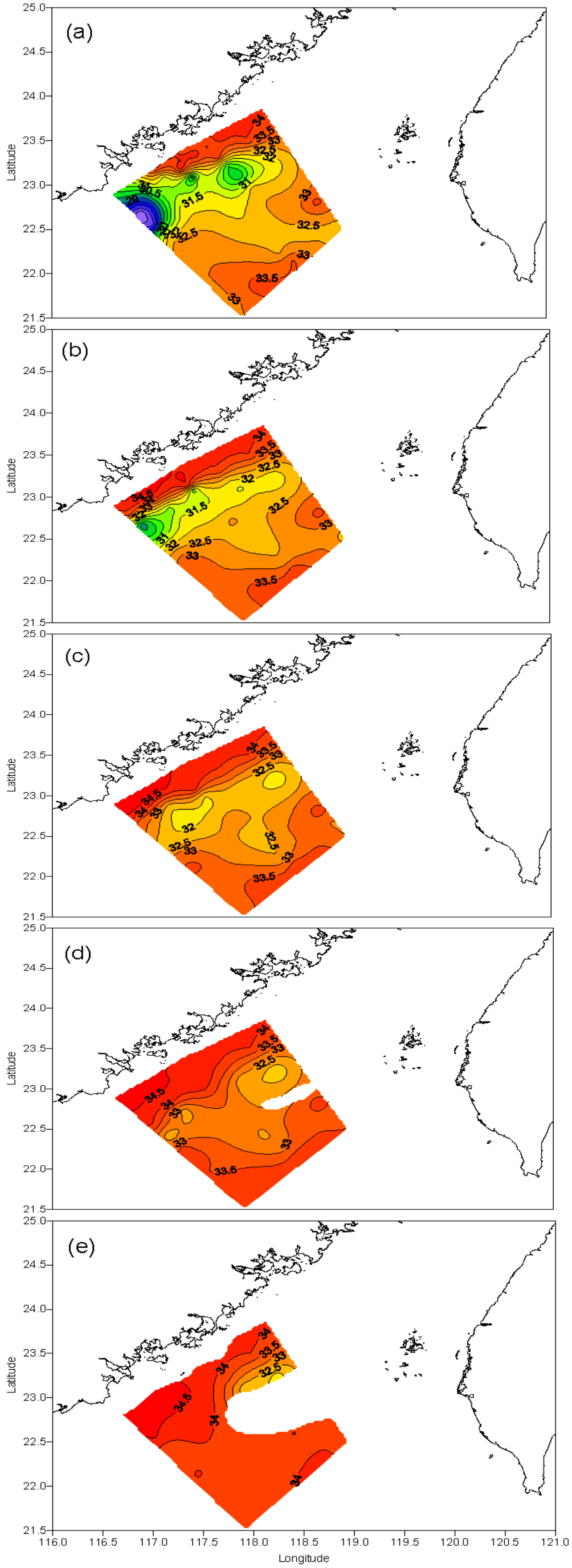

Figure 3. Two-dimensional distribution maps of salinity at depths of 5 (a), 10 (b), 15 (c), 20 (d), and 30 m (e) derived from the 2005 summer cruise data by interpolation methods.

3) Dynamical analysis of bottom-topography-induced stationary IW in Taiwan Strait. The satellite SAR images display wave-like patterns of the ocean bottom topographic features at the south outlet of Taiwan Strait (TS). Field measurements indicate that the most TS water body is vertically stratified. In order to explore the mechanisms and to determine the relations between the SAR imagery and the bottom features, a two-dimensional, three-layer ocean model with sinusoidal bottom topographic features is developed. Analytical solutions and inferences of the momentum equations of the ocean model lead to the following solutions. 1). In the lower layer, the topography-induced waves (topographic waves) exist in the form of stationary waves, which satisfy a lower boundary resonance condition $\sigma = kC_0$, here σ is an angular frequency of the stationary waves, k is a wavenumber of bottom topographic corrugation, and C_0 is a background current speed. 2). As internal waves, the topographic waves may propagate vertically to the upper layer with an unchanged wavenumber k, if a frequency relation $N_3 < \sigma < N_2$ is satisfied, here N_2 and N_3 are the Brunt-Wäisälä frequencies of middle layer and upper layer, respectively. 3). The topographic waves are extremely amplified if an upper layer resonance condition is satisfied. The theoretical SAR image of topographic waves is derived on the basis of current-modulated small wave spectra. The results indicate that the topographic waves on SAR images have the same wavelength of bottom topographic corrugation, and the imagery brightness peaks are either inphase or antiphase with respect to the topographic corrugation, depending on a sign of a coupling factor. These theoretical predictions are verified by field observations. The results provide a physical basis for quantitative interpretation of SAR images of bottom topographic waves in the stratified ocean.

IMPACT/APPLICATIONS

The results of this project will provide the users fine structures of ocean circulation in Taiwan Street, 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 ocean circulation in the Taiwan Street. The results will further reveal SAR imaging mechanisms and be used for SAR image interpretation.

RELATED PROJECTS

This project and the project of Grant Number N00014-05-1-0605 at the Louisiana State University (PI: Dr. Chunyan Li) are two separately funded components of the same project. The PI of this project serves as a PI for an ongoing ONR PO project titled "Satellite Synthetic Aperture Radar Detection of Ocean Internal Waves in the South China Sea". The study areas of two projects are immediately adjacent. Therefore, two projects sometimes share the same data resources of field observations.

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