Annual Report

LaMer, Ehime University

Date (16, 11, 2017)

To Director of LaMer

Principle Investigator:

Affiliation Ocean University of China

Position Graduate student

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Include the report on the result of the project/meeting in a separate sheet.

1. Project / Meeting title

The interaction of baroclinic tide and background current in the Kuroshio

2. Members of project / meeting

Name	Affiliation	Position	Contribution part
PI Jie Gao	College of Oceanic and Atmospheric, Ocean University of China	Graduate student	Data processing; Paper writing
Members Xinyan Mao	College of Oceanic and Atmospheric, Ocean University of China	Lecturer	Beneficial discussion
Xinyu Guo	Center for Marine Environmental Studies (CMES), Ehime University	Professor	Beneficial discussion

3. Contents (please write in separate sheet, A4-size, within 5 pages including figures and tables. Itemize “Title, members’ names and affiliations, aim, procedure, result, publication/conference presentation, perspectives in future”).

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Title

The interaction of baroclinic tide and background current in the Kuroshio

Members' names and affiliations

Name	Institution and Department	Employment position	E-mail
Jie Gao	College of Oceanic and Atmospheric, Ocean University of China	Graduate student	gaohexizi@163.com
Xinyu Guo	Faculty member of LaMer	Professor	guoxinyu@sci.ehime-u.ac.jp

Aim

This project aims to carry out cooperative research with Prof.Guo Xinyu of Ehime University on the generation and propagation of internal waves in the Tokara Strait.

Procedure

The principal investigator (PI) first gave an oral presentation "An introduction to internal wave", which has two parts: 1. The equation and approximations of internal waves; 2. Considering the influence of Kuroshio Current, the generation and propagation of internal wave in the Tokara Strait.

The PI also made several discussions with Prof. Guo Xinyu and Dr. Tsutsumi on the internal tides influenced by seasonal changes of Kuroshio Current and the calculation of barotropic and baroclinic tidal energy.

The PI will carry out further research with Prof. Guo Xinyu on the following subjects: 1. Combine the observed data with simulation data to analyze the generation and propagation of internal tide; 2. focus on the interaction of the Kuroshio Current and propagation of internal tides in the Tokara Strait; 3. Extend analysis area to the Luzon Strait.

Results

Our joint research of this year (2016) is focused on the study of internal tide in the Tokara Strait from simulation data in 2007 from JCOPET. Before simulation, we studied the theoretical background of internal waves.

First, we gave some approximations to solve the geophysical fluid dynamics equation and obtained the modal structure under different stratification. By giving basic equations and approximations, the theories of internal tide generation and propagation were clearly studied:

The frequency depends only on the orientation of the wave vector and not its magnitude. The frequency is therefore independent of the wavelength.

The group velocity is perpendicular to the wave vector and therefore in the direction of the fluid velocity. The vertical phase velocity is always opposite to the vertical group velocity.

In this research, model domain covers a longitudinal range from 127° E to 132° E, and a latitudinal range from 27° N to 32° N with a horizontal grid spacing of 1/36 degree, including the Tokara Strait(Fig 1). Numerical studies are carried out to investigate the nature and efficiency of the generation of internal tides by tidal flow and low-frequency flow (Fig 2) in the Kuroshio Current.

- The generation and propagation of internal tide

To qualify the internal tide generation, model data are used to compute the forcing term. $F(z) = 2\pi z N^2(z)\vec{U} \cdot \nabla H / H\omega_{M_2}$.where $\vec{U}$ is the barotropic tidal current, H is the water depth, and ω_{M_2} is the frequency of semidiurnal tide [Pichon et al., 2013]. The vertically integrated forcing term from surface to bottom, $\int_0^H F(z)dz$, provides evidence of a preferential site for the internal tide generation in the Tokara Strait (Fig 3).

Fig 4 shows the Profile of temperature, salinity, density, buoyancy frequency N^2 at 130.7°E，29.7°N. It is obviously that the maximum of buoyancy frequency appears at the thermocline.

In order to study the internal tide generating and propagating at Tokara Strait, we did harmonic analysis of the temperature. Fig 5 shows the amplitude and phase of M2 component at the transect of 130.7°E. As expected, the maximum of amplitude of baroclinic tidal signal does not appear in the surface, but near the thermocline and sea bottom. Internal tides are likely generated on the slope of seamount, propagated upward and downward. The group velocity (i.e. the direction of energy propagation) is perpendicular to the direction of phase propagation (i.e. parallel to co-phase contours), with opposing vertical components. Applying these theoretical results, we confirmed that internal-tide energy propagated along the beam.

- **Characters of baroclinic tide**

In this section, velocity and temperature data for February and November are used to investigate the characters of barotropic and baroclinic tides. The transect is at 130.7°E. The point are at 130.7°E，29.7°N.

The barotropic tidal signals at February and November (Fig. 6a&6b) were obtained with a filter to the JCOET hourly velocity output. The baroclinic tidal signals are also clearly visible on the Fig. 6e&6f. In this research, amplitude is defined by the largest vertical displace of isotherms in the Kuroshio Current (also the thermocline).

The baroclinic tides are evidently nonlinear at spring tide. They have asymmetric waveform although the barotropic tidal forcing has a symmetric sine shape. At neap tide, internal tide displacements are obviously weakened, but high-frequency waves are still clearly visible although their value is small (Fig. 7c&7d). The vertical distribution of baroclinic tide is influenced by low-frequency fluctuations.

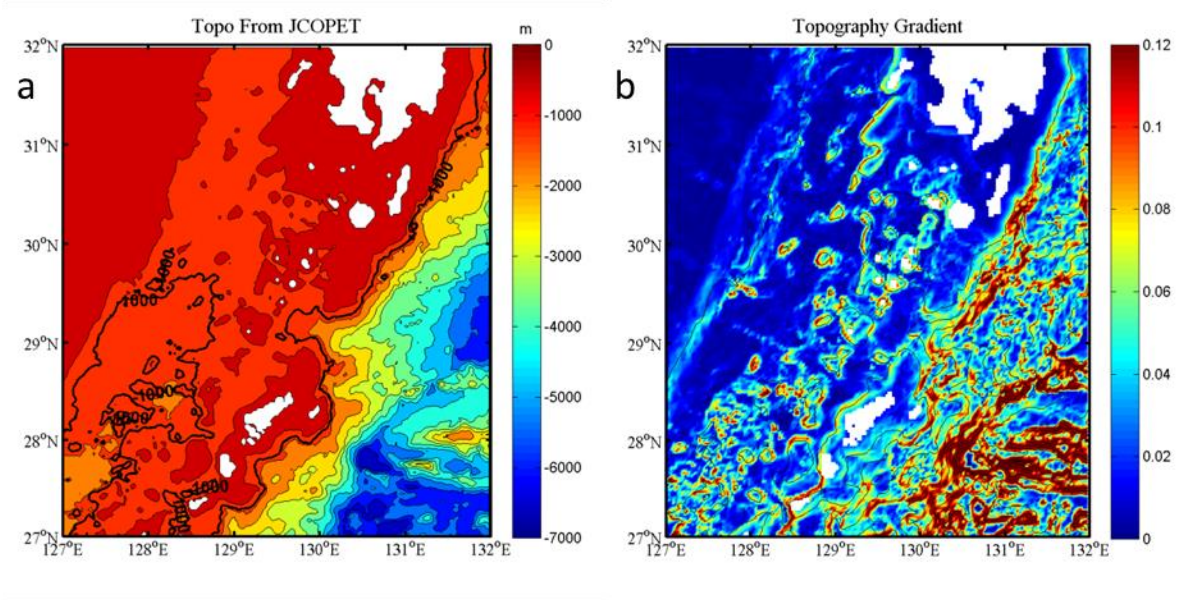

Fig 1. The topography and gradient of water depth in the model domain. Contour interval is 1000m(a).

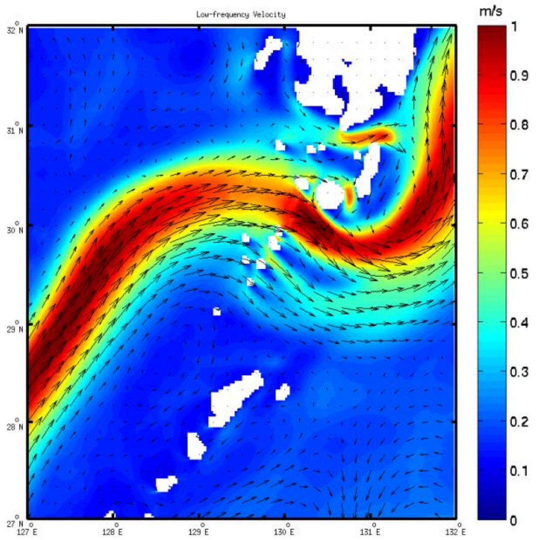

Fig2. Annual mean of surface velocity distribution at the Tokara Strait. The vectors are the surface low-frequency currents.

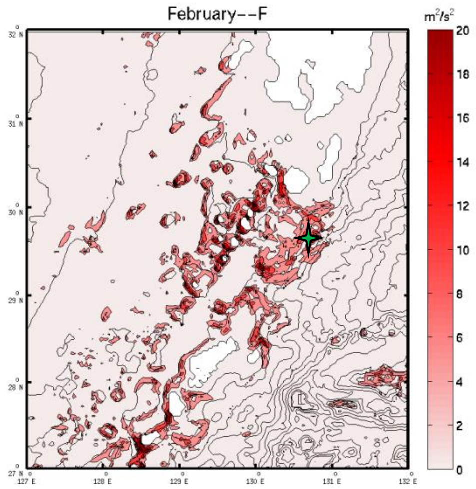

Fig 3. The forcing term F(z) for internal tides integrated from sea surface to sea bottom.

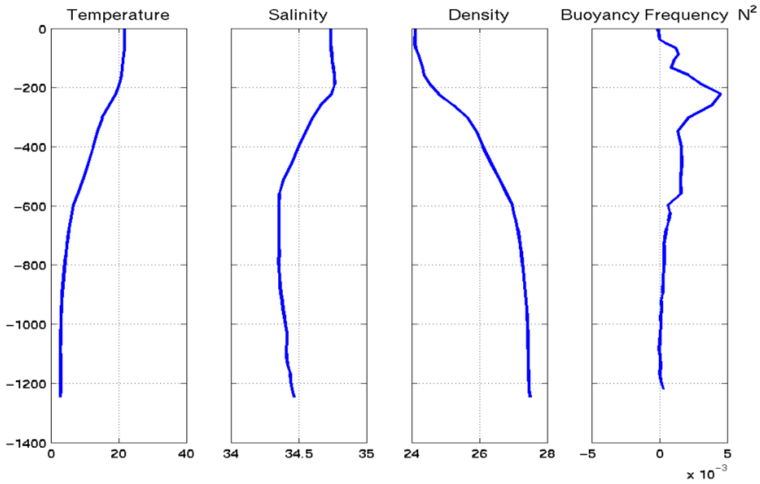

Fig4. Profile of temperature, salinity, density, buoyancy frequency N^2. The diamond marks the location of station(130.7°E，29.7°N) at Fig 3.

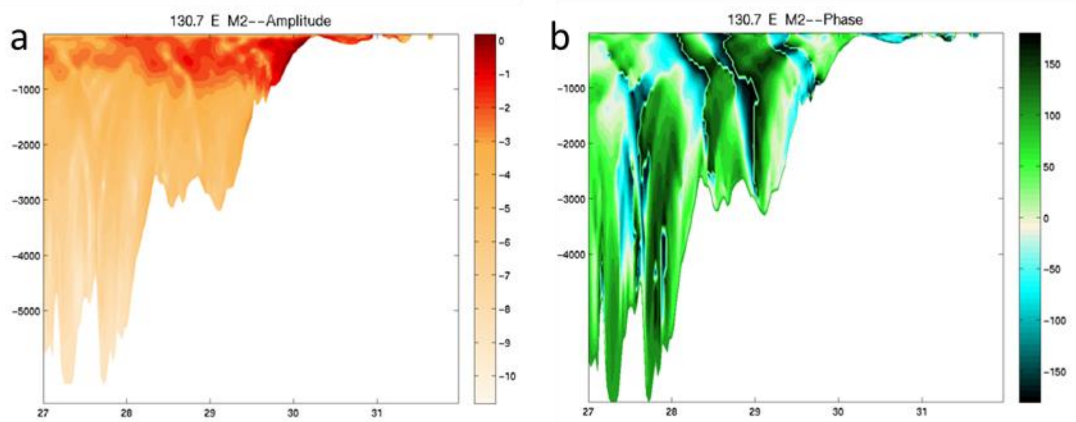

Fig 5. The amplitude (a) and phase (b) of M2 baroclinic tide along section of 130.7°E(0-3000m).

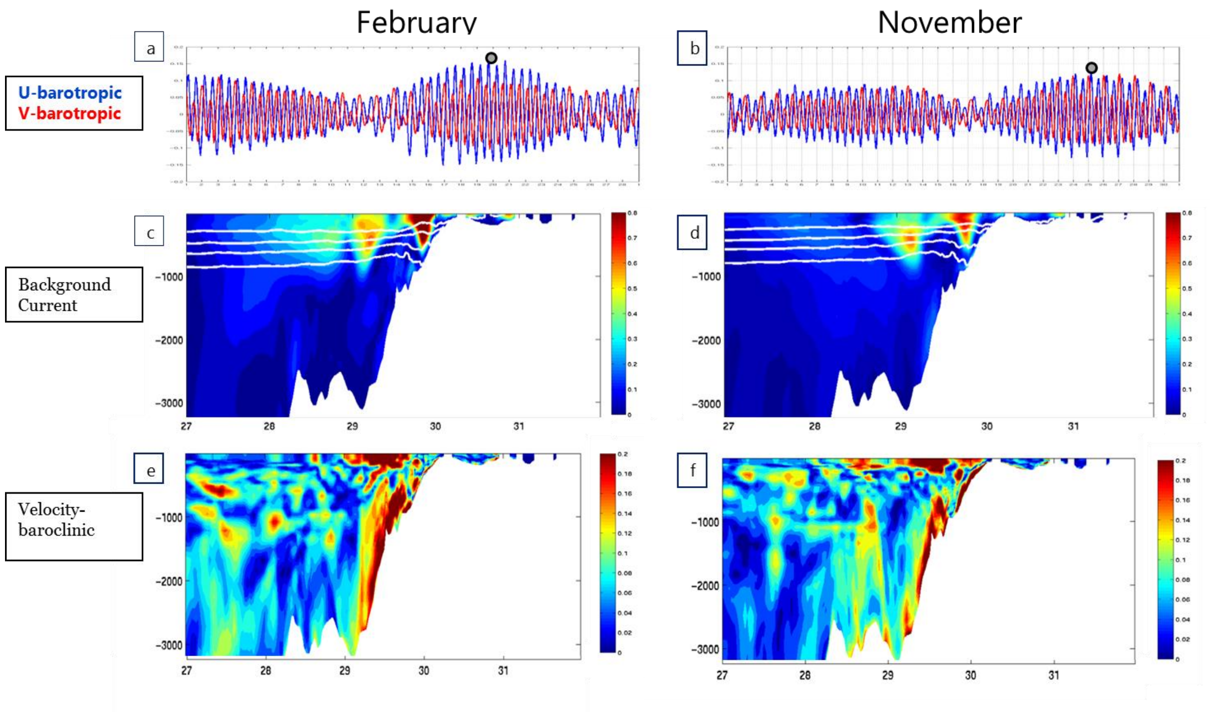

Fig 6. Time series of barotropic current velocity u (blue) and v (red) at the point (130.7°E， 29.7°N). The low-frequency velocity normal to section of 130.7°E; isotherm of 9/12/15/18˚C (white lines); The baroclinic zonal velocity along section of 130.7°E(0-3000m).

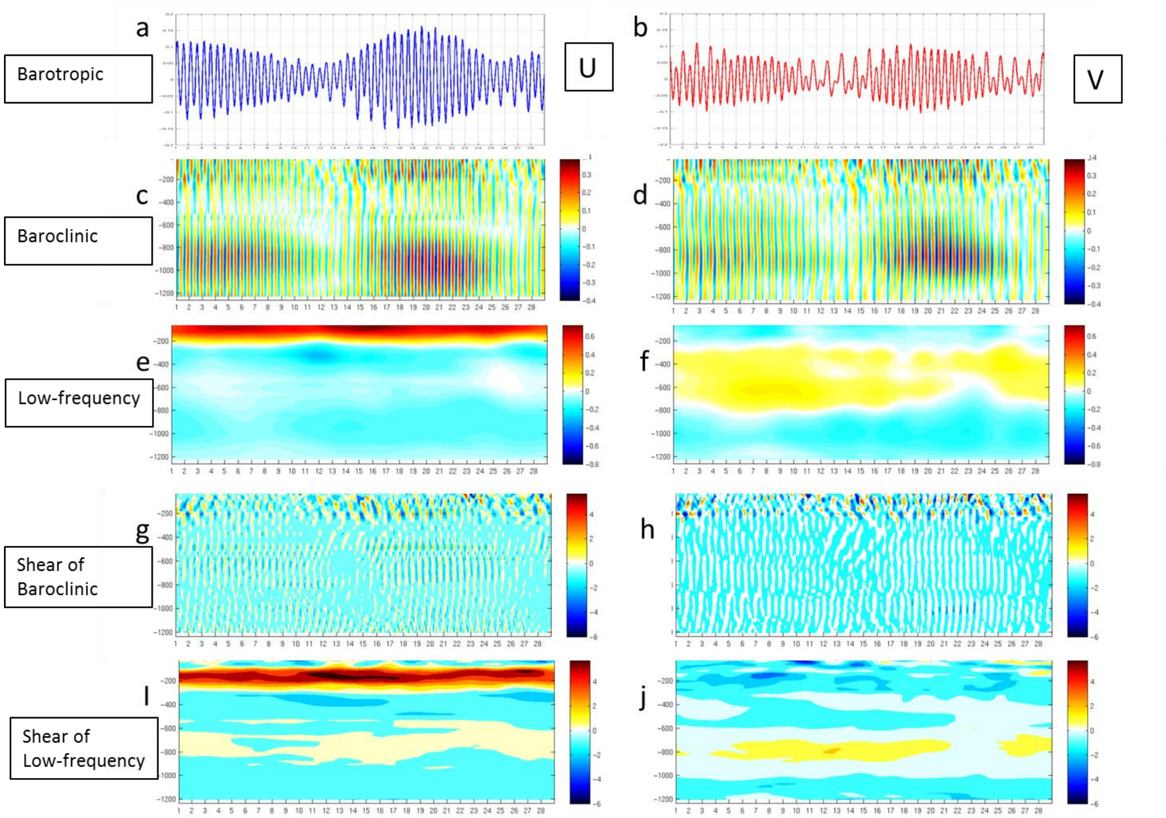

Fig 7. Time series of barotropic current meridional velocity u(a) and zonal velocity v (b)at the point(130.7°E， 29.7°N), the profile of baroclinic tide(c, d), low-frequency current (e, f), shear of baroclinic tide(g, h), shear of low-frequency(i, j).

References

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Gerkema T, Lam F P A, Maas L R M. Internal tides in the Bay of Biscay: conversion rates and seasonal effects. Deep Sea Research Part II: Topical Studies in Oceanography, 2004, 51(25): 2995-3008.

Publication/conference presentation

Publications:

Oral presentation:

Title: An introduction to internal wave

Lecturer: Jie Gao

Time: November15, 2016.

Location: Ehime University.

Perspectives in future

We expect great progresses **by using observation data.** B**y using numerical model POM, we will** focus **on how** Kuroshio Current **influences internal tide with a comparison with the** results **in the Luson Strait.**