Form 3

Annual Report

LaMer, Ehime University

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To Director of LaMer

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

1. Project / Meeting title

Sea-surface current features in the Gulf of Tonkin observed from altimetry satellite and high frequency radars

2. Members of project / meeting

Name	Affiliation	Position	Contribution part
PI Kim-Cuong Nguyen	VNU University of Science, Vietnam	Lecturer	Propose idea, supervise the work, write the final report.
Members Manh-Cuong Tran	Center for Oceanography, Vietnam	Researcher	Visit Japan, write a code, and process HF radar and satellite data
Thi Thu Mai Nguyen	VNU University of Science, Vietnam	Lecturer	Process HF radar and satellite data
LaMer Faculty member in charge Akihiko Morimoto	Ehime University, Japan	Professor	Supervise the computation, discuss, analyze the results.

3. Contents

SEA-SURFACE CURRENT FEATURES IN THE GULF OF TONKIN OBSERVED FROM ALTIMETRY SATELLITE AND HIGH FREQUENCY RADARS

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I. Introduction

The Gulf of Tonkin is located in the North West of the South China Sea, from 105ºo36'E to 109º55'E, extending from latitude 17ºN to latitude 21º52'N, with the area of about 160,000 km^2, the circumference of about 1,950 km. The Gulf of Tonkin is bordered by the North Vietnamese coast in the west, the Chinese coast to the north and Leizhou Peninsula and Hainan Island on the east. The waters of the Gulf of Tonkin mainly interact with the South China Sea through the south gate of the bay, which is about 230 km wide and more than 100 m deep. A small part of the water is exchanged through narrow Qiongzhou strait (18 km) and not deep (20 m). Due to the shallow depth of the Gulf, the circulation in the Gulf of Tonkin was formed mainly by the effects of the prevailing monsoon. However, with a relatively close association with the South China Sea on the south, the exchange of water through the bay also causes diversity in the distribution and fluctuation of seasonal flows in the gulf. This diversity is also influenced by air-sea interactions process, primarily thermal interactions.

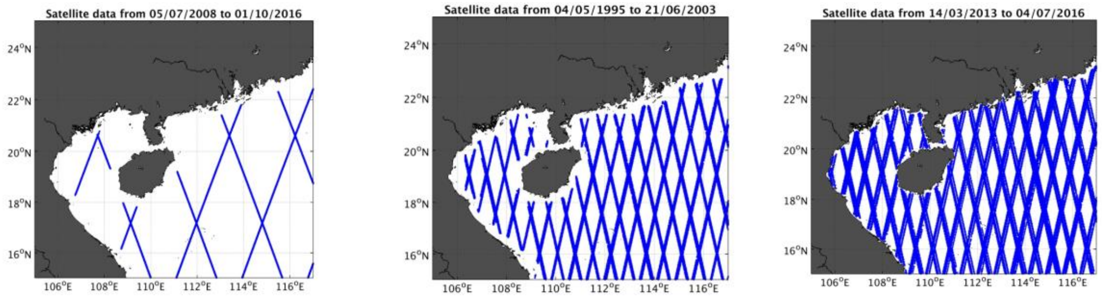
Although having numerous studies conducted by numerical model, the circulation in Tonkin gulf remains controversial due to the lack of observational data over the entire domain. The purpose of this study is to apply the technique of satellite altimetry data processing and the data from coastal HF radar for the analysis of Tonkin gulf circulation. The method is straightforward, firstly, we collect all the available satellite data, satellite-tracked drifter's data and the HF radar data. Secondly, the Lagrangian drifter data and the HF radar data can indicate the absolute sea surface current over large area. And if assuming sea state is geostrophic balance, we can get the sea surface current anomaly. Combining three data sources, we can calculate the sea surface current field in Tonkin Gulf (Uchida and Imawaki, 2003; Ambe et al., 2004).

II. Data and Method

2.1. Data sources

2.1.1. Satellite data

In this study, we use the satellite altimeters data from TOPEX/POSEIDON, ERS-2, Envisat and Jason 1 and 2, SARAL, which are downloaded from http://rads.tudelft.nl. We use only one source to download the satellite data for BIAS-control. Ito (2014) calculated the BIAS between these sources of satellite data in his dissertation, the average BIAS between ERS-2 and Envisat is 0.404m and between TOPEX/POSEIDON and Jason-1 is 0.098m. And no BIAS was found between ERS-2 and TOPEX/POISEDON after AVISO correct (Ito, 2014).



Jason and TOPEX/POSEIDON tracks ERS2 and Envisat tracks SARAL tracks

Figure 1. Satellite data tracks collected from 1995 to 2016

2.1.2. Satellite-tracked drifters

Satellite-tracked drifters have been collected from World Ocean Circulation Experiment (WOCE) -Tropical Ocean and Global Atmosphere (TOGA) Surface Velocity Program (SVP) (WOCE/SVP). The drifter data was interpolated along track and time every 6 hours. The figure 2 demonstrated the collected drifter data in northern South China Sea region and in Tonkin Gulf. Unfortunately, the data in Tonkin Gulf region is very limited.

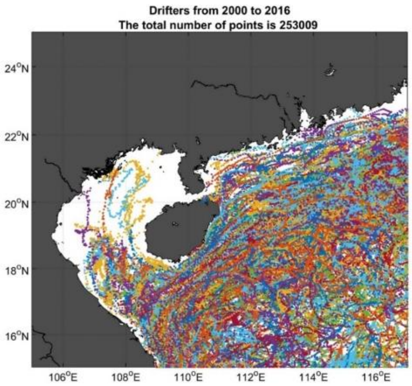


Figure 2. Drifter buoys in Tonkin Gulf and northern South China Sea region: 416 buoys with 253,009 observed points

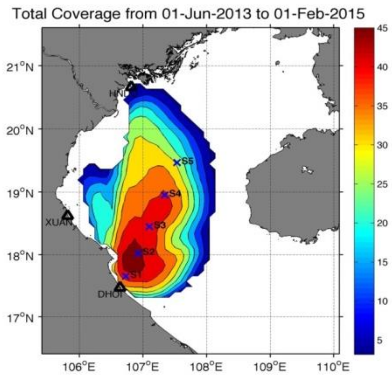


Figure 3. HF radar stations in Vietnam and total coverage (unit: %)

2.1.3. Wind data

We downloaded the re-analysis wind data from ECMWF Era-interim product, the data is 6-hours in time and in uniform gridded with the resolution of 0.125°x0.125°. The wind data is to evaluate the Ekman current by using empirical formula (Ito, 2014): $V_e = A.V_{wind}.\exp\{i(\theta-\psi)\}$ (1)

In which, Ve is Ekman current; A is wind magnitude; θ is the angle of wind relative to east (positive in the anti-clockwise direction); ψ is the angle relative to the downstream wind direction (positive in the clockwise direction) (Ito, 2014).

2.1.4. HF radar data

Since 2011, three long-range HF radar observation systems have been established along the coast of Vietnam in western of Tonkin Gulf. All three stations operate at 4.65 MHz with horizontal resolution of 5.825 km and azimuthal resolution of and 5° (figure 3). The HF radar measures the sea surface velocity component in the direction toward the radar, using the Doppler frequency shift of the radio wave backscattered by ocean surface wind waves, so that at least two radars are normally used to construct a total vector from each site's radial components. At the central data combining station, the radial vector maps from multiple radar stations are merged to create a total velocity vector current map.

2.2. Method

The mean sea surface current cannot be calculated directly from the satellite altimetry data due to large geoid errors and the irregular time and space sampling of the drifter data. In this study, we use the method from Uchida and Imawaki (2003), Ambe et al. (2004), Ito (2014) to calculate the mean current field in the Gulf of Tonkin. The method is written as following equation:

V(r,t) = Vm(r) + Va(r,t) (2)

In which, V(r,t) is the absolute current at position r and time t; Vm(r) is the mean sea surface current at the position r; Va(r,t) is the anomaly which is derived from the Sea surface Anomaly (SSHA) of altimetry data.

Firstly, data files were collected in the area range from 15° - 25°N, 105° - 117°E. The sea surface height anomaly (SSHA) can be calculated from the satellite data by using Optimal interpolation (OI) method by using covariance functions W(|R|) and noise σ_e (Ito, 2014):

$$W(|R|) = w_0^2 \exp\left\{-\left(\frac{|R|}{L}\right)^2\right\}; \sigma_e = \sigma\delta(\Delta t) \quad (3)$$

With Δt is the Dirac delta function, |R| is the distance from the satellite data and the position on the grid, L is the de-correlation length scale, w_o is the magnitude of the signal (L = 80 km, w_o = 5.4 cm) and magnitude of noise σ_e = 7.8 cm.

Assuming the ocean is geostrophic balance, the sea surface anomaly current Va is derived from the interpolated SSHA field over the entire domain. In addition, the V(r,t) is derived from the drifters and HF radar data at time t and position r. Since the drifters data are irregular in space and time, the mean sea surface current field can only be calculated where the data are sufficient enough. That is also the same with the HF radar data due to the gaps in the dataset. As we concern only the geostrophic current, the HF radar data and drifter data were average over 72 hours in order to remove the tidal signal and geostrophic components. In addition to that, we removed the wind effects on the current field by estimate the Ekman current using the empirical function (1) with the parameters A = 0.0406, ψ = 15° for the Tonkin gulf domain. All the data were interpolated on the grid of 0.25°x0.25° and were averaged to get monthly mean. After the sea surface current field Vm(r,t) is derived from this method, we can calculate the absolute current field V(r,t) by using the equation (2).

III. Results

3.1. Mean sea surface current of Tonkin Gulf

As can be seen from figure 4, the coverage of drifter data is limited in Tonkin Gulf. Therefore, we use the HF radar data as a solution to calculate the mean sea surface current field. In this study, the HF radar data is chosen from June 01st, 2013 to Jan 31st, 2015 for calculation of mean sea surface current in the Tonkin Gulf. The total current map from HF radar only cover nearly a half of Tonkin gulf region, we chose the area that cover more than 30% of the whole dataset. We also calculate the bias between HF radar geostrophic current and the geostrophic current derived from satellite data is about 6.11 cm/s.

The figure 4 demonstrates the mean current field in the northern South China Sea and in the Tonkin gulf calculated from this method. Although the results showing acceptable transitions in overall, there are some erroneous values at the southwest of Hainan Island due to the difference between HF radar data and drifters data. The errors are caused by the lack of drifter data in Tonkin gulf domain, and the region is also at edge of HF radar coverage. The mean sea surface current maps show that, the sea surface current velocity in the Tonkin gulf is smaller than in the upper part of South China Sea, the average velocity is about 20 – 40 cm/s. The current map also shows the flows from northeast to southwest and accelerates in the southern of Hainan islands with the average velocity about 30 – 40 cm/s. The flow, as shown in some previous studies, is one branch of Kuroshio current intrusion into South China sea. In the southern Hainan island, the flow diverse, one branch flows into Tonkin Gulf and one flows to the south.

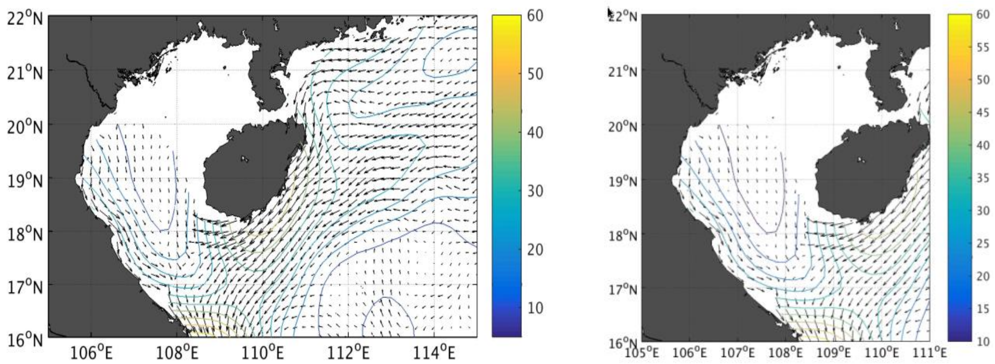


Figure 4: Mean sea surface current field in the northern South China Sea (left) and zoom on Tonkin gulf (right) (unit: cm/s)

3.2. Seasonal variations of sea surface current field

We examine the seasonal variation of sea surface current field in the Gulf of Tonkin using frequency analysis and the standard deviation normalized by monthly mean current of each season. Figure 5 shows the sea surface current map of winter season (January 2013) on the left and summer season (Jul 2013) on the right. Figure demonstrates the frequency analysis of winter season and summer season, below are the standard deviation normalized by seasonal mean current in winter and summer. The frequency of current is shown by different colors relatively: “highly stable” current is shown in red vector which is greater than 70% frequency; “stable” current is shown in blue vector which is higher than 50% but less than 70%; and “unstable” current which is shown in black color with frequency less than 50%. The vector of the map indicates the magnitude of the current field. In addition, the normalized current map indicates the greater variability of current velocity than the seasonal mean velocity by warmer color and less variability by cooler color.

In winter, the sea surface current velocity of Tonkin gulf is about 25 – 35 cm/s. In the middle of the gulf, the current mostly has northwest – southeast direction with the frequencies of more than 25%. The results clearly show there is a cyclonic eddy at around the latitude 19ºN. The figure 6 also shows that the current near Vietnamese coastal is more stable than offshore current. During this season, to the south at the mouth of the gulf, the jet from the north is highly stable running along the coast of Vietnam to the south.

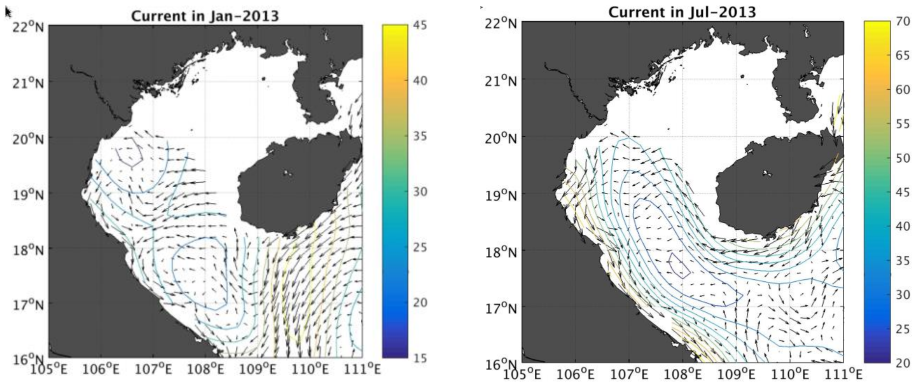
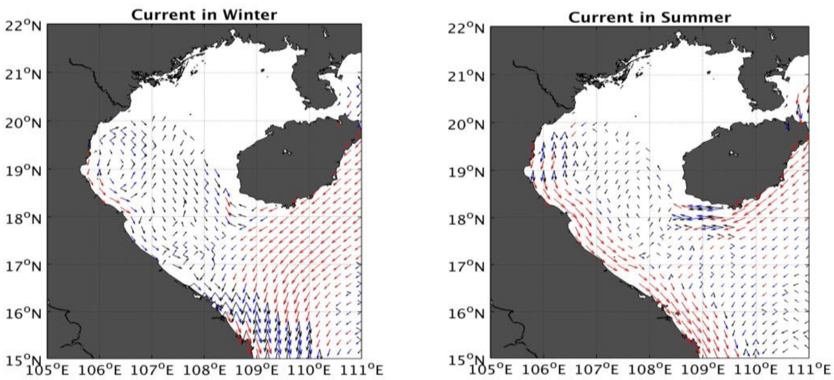
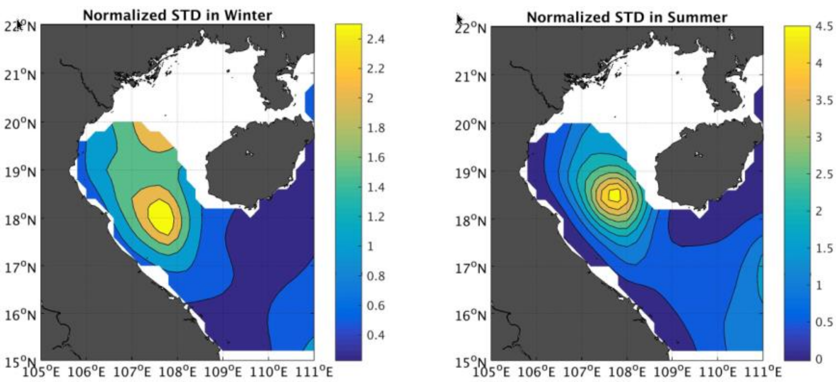


Figure 5: Monthly sea surface current field of the Tonkin gulf in winter (left) and in summer (right) (unit: cm/s)



(a) (b)



(c) (d)

Figure 6: Frequency analysis of the Tonkin gulf sea surface current field in winter (left) and in summer (right) (red: frequency greater than 70%, blue: frequency greater than 50% but less than 50%, black: frequency greater than 25% but less than 50%, the length of the vector indicates the magnitude of current velocity). Figure c,d is the standard deviation normalized by monthly mean sea surface current in winter (left) and in summer (right)

In summer, the sea surface current field has the different pattern. In the middle of the gulf near the Coast of Hainan Island, the current has southeast – northwest direction. This current converges then going up north then turns left at about 19 – 20ºN, making the current field in the gulf like a large scale cyclonic eddy. At the south of the gulf, the jet from the north split, one branch goes to the coastal of Vietnam then continue going south, the other, with higher velocity, turns right and joins the eastern current of the gulf going north, which is highly stable during this season. Another notable thing is the red vector and blue shading in the Vietnamese coastal in this season which indicates the highly stable coastal jet along the coast of Vietnam. From spring to autumn, the jet becomes stable, mostly in the middle of summer. There is also the significant of large volume of fresh water by Red river discharge, which could lead to the cause for this phenomenon. In overall, the current pattern in summer seems to be more stable than other seasons.

IV. Summary and discussions

The results from using satellite data combining with drifter data and HF radar data have demonstrated the sea surface current pattern in the Gulf of Tonkin and northern of South China Sea. In the northern part of South China Sea, there is a highly stable jet which originates from Taiwan Strait and Luzon strait in to the sea. In winter, the branch from Luzon strait becomes significant clear which indicates the intrusion from Kuroshio Current into South China Sea. The jet flows westward, runs along Hainan Island to the coast of Vietnam then going southward from autumn to spring. In summer, the jet diverse at the south of Hainan Island, joins the eastern current of the Gulf of Tonkin then turn left, follows the western boundary current of the gulf going south, making the current pattern a large scale cyclonic eddy on the gulf. The other is stable western boundary current during spring and summer in the Tonkin Gulf. The results also show that in summer, the sea surface current in Tonkin gulf is more stable than other seasons.

V. Perspectives in future

The result from this project is very interesting and it might be obviously evidences to show the insight of mechanism of general circulation in the Gulf of Tonkin. This work is promising to be published as a very good research paper. The authors will continue this investigation after the project finishes.

With this project, there were 2 bilateral visits between the members from VNU University of Science, Vietnam and Ehime University, Japan for discussing, working together, and presenting the researches to the colleagues. We do hope this collaboration between two universities will be further developed in the near future.

References

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