Coastal surface currents northeast of Taiwan detected by along-track altimetry data

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1. Introduction

Recently, monitoring currents in the East China Sea (ECS) becomes a big issue from the viewpoints of both fisheries and marine pollution.

The Kuroshio and the Taiwan Warm Current (TWC) are most important factors for oceanographic conditions in the southern ECS. However, their effects have not been fully studied yet due to insufficient data. For example, it is not yet confirmed whether the TWC exists in winter.

Even if we use satellite altimetry data, we would encounter two problems in the ECS.

1. **Resolution of the sea surface height anomaly (SSHA) field interpolated from the altimetry data is too low to describe such fast and/or small-scale variations as the Kuroshio and the TWC.**
2. **Mean current is missing, which is essential to discuss existence of the TWC and strong variability of the Kuroshio.**

Therefore, in this study, we use along-track altimetry data to avoid interpolation across subsatellite tracks, altough location and direction of the obtained velocity are limited. At first, temporal mean current is determined by combined use of surface drifter data. Then, variations of the currents northeast of Taiwan are discussed, with further aid of High Frequency (HF) radar data.

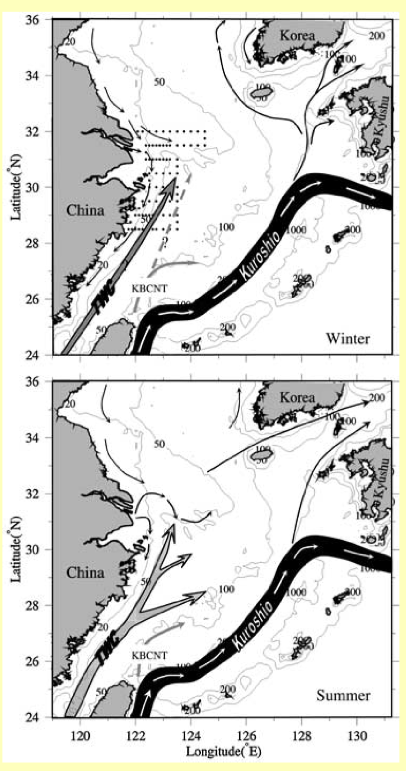

Fig.1-1: Schematic view of the winter- and summer-time regional circulation patterns in the East China Sea. (after Zhu et al., 2004).

2. Method & Mean Velocity

The method of estimating mean velocity is based on Uchida and Imawaki (2003), but modified for the along-track data (Fig. 2-1).

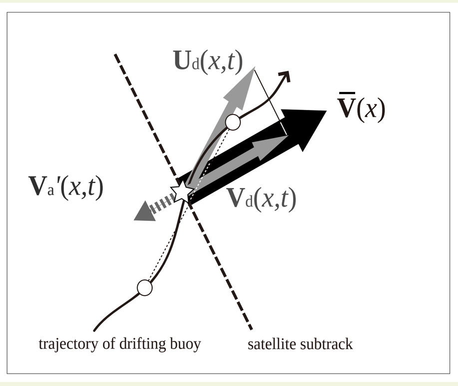

Fig.2-1: Schematic diagram for estimation of mean component $\overline{V}(x)$ from drifter velocity Ud and altimetry geostrophic anomaly component Va'.

1. The drifter velocity $U_d(x,t)$ is estimated when and where a drifter crosses a subsatellite track (x,t). U_d is calculated from data longer than two days or 1.5 times Rossby radius. U_d is further used to obtain velocity component V_d normal to the track.
2. The temporal anomaly geostrophic current $V_a'(x,t)$ is estimated from altimetry data. V_a' is subtracted from U_d to obtain the mean component $\overline{V}(x)$.
3. For surrounding points $(x+dx, t+dt)$, $\overline{V}$ is also used as a less reliable estimate. In this study, reliability $G(dx,dt)$ is set as the Gaussian function with decorrelation scales of the Rossby radius and the inertial period.
4. Using many drifters, $\overline{V}(x)$ is statistically averaged with weight of reliability $G(dx,dt)$.

DATA

Satellite Altimeters (T/P, Jason-1)
- along-track SSHA provided by AVISO, France (DT-SLA Ref)
- tidal components removed by harmonic analysis
- spatially smoothed with approximately Rossby radius

Surface Drifters
- position data every 6 hours provided by AOML, USA
- moving average with 30 days
- 1992/10- 2006/01

HF radar systems on Ishigaki and Yonaguni Islands
- gridded surface velocity field provided by NICT, Japan
- geostrophic component estimated by Tokeshi et al. (2007)
- 2001/07-2005/02

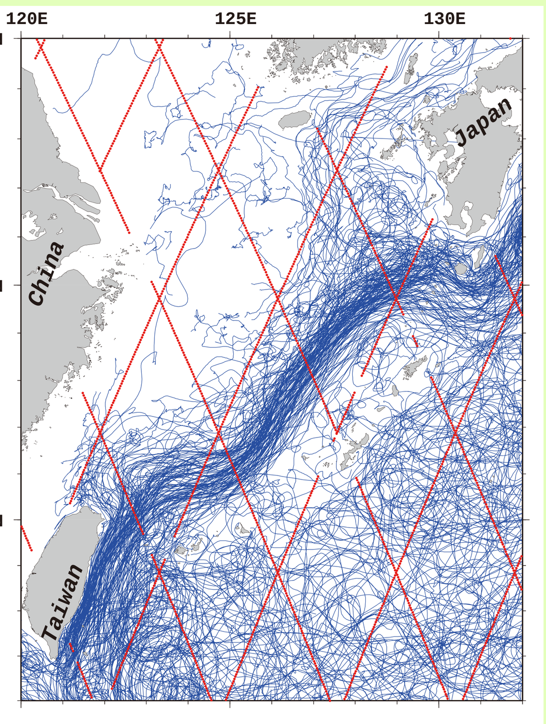

Fig.2-2: Trajectories of drifters and subsatellite tracks

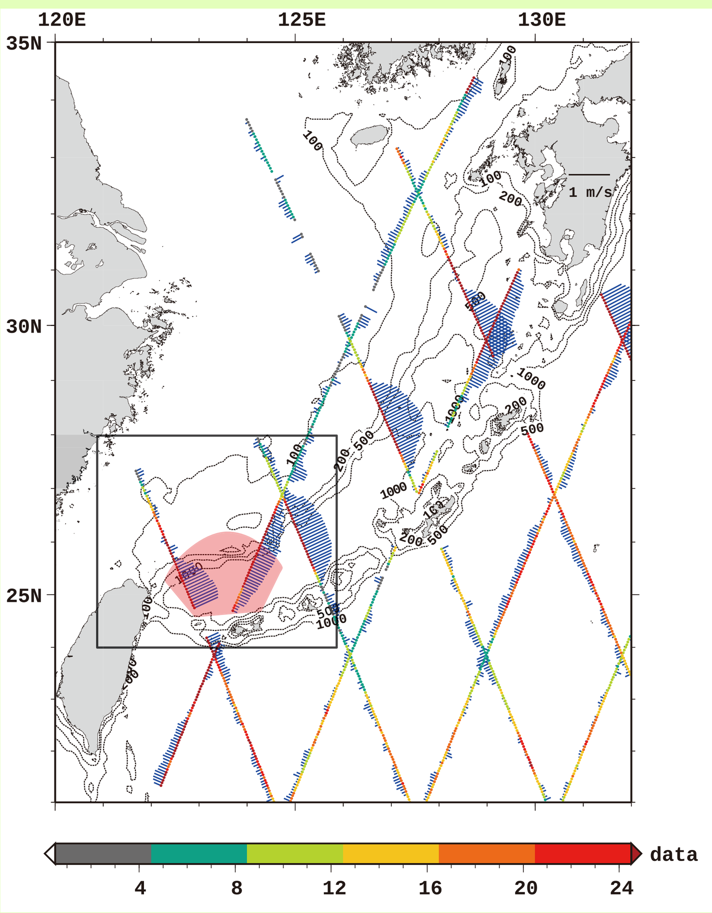

Fig.2-3: Estimated 13-year mean velocity. Colors indicate the number of data used.

Estimated 13-year mean velocity along each track is plotted in Fig. 2-3. The velocity is evaluated by comparing with 3.5-year mean HF velocity in the upstream region (Fig. 2-4). Although these velocity profiles are not in complete agreement, they agree within their estimated errors.

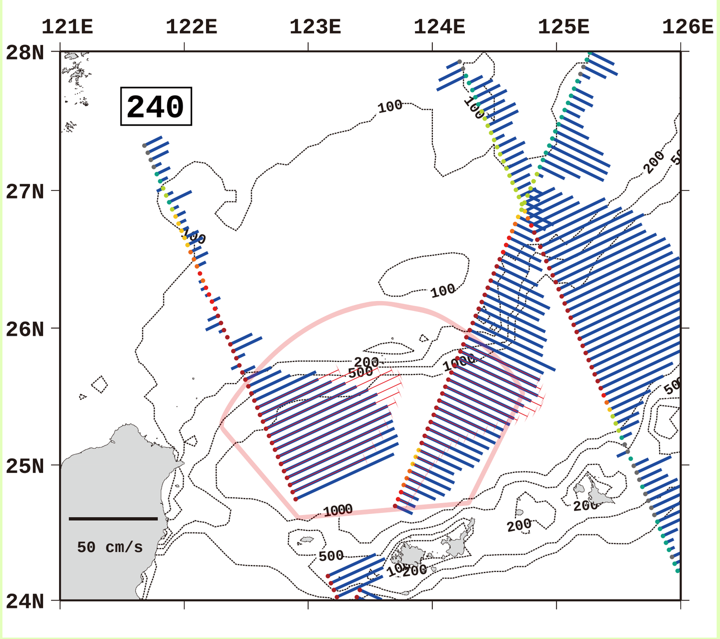

Fig.2-4: 3.5-year mean velocity component normal to the track. The HF velocity is also plotted with red arrows.

In Fig. 2-4, three sections along the track 240 are recognized to be the northeastward currents in the coastal region (shallower than 200m). Referring to Fig. 1-1, we recall them as

1. north branch of the TWC at 27.5N (approx. 50-m depth)
2. south branch of the TWC at 26.5N (approx. 100-m depth)
3. Kuroshio Branch Current (KBC) at 25.8N (at the continental shelf edge; 200m)

3. Seasonal variations

By adding temporal anomaly to the mean determined above, time series of velocity component normal to the track is determined. In this study, we first focus on longer-term variations of the TWC and KBC described above.

Fig. 3-1 shows 13-year time series of 3-month averaged surface velocity along the track 240. Both north (27.5N) and south (26.5N) branches of the TWC are recognized in the figure, with repeated strengthening/weakening. Meanwhile, the KBC around 25.8N is found higly variable; its direction is sometimes reversed.

Strengthening and weakening of the TWC are more clearly described in Fig. 3-2, which shows the monthly averages over 13 years. The north branch of the TWC is pronounced only in spring and summer (March-September). On the contrary, the south branch is recognized both in summer (June-July) and in winter and spring (December-April), with slightly shifting its position.

It is also noteworth that southwestward current at 26N appears only in summer when the north branch of the TWC is strong.

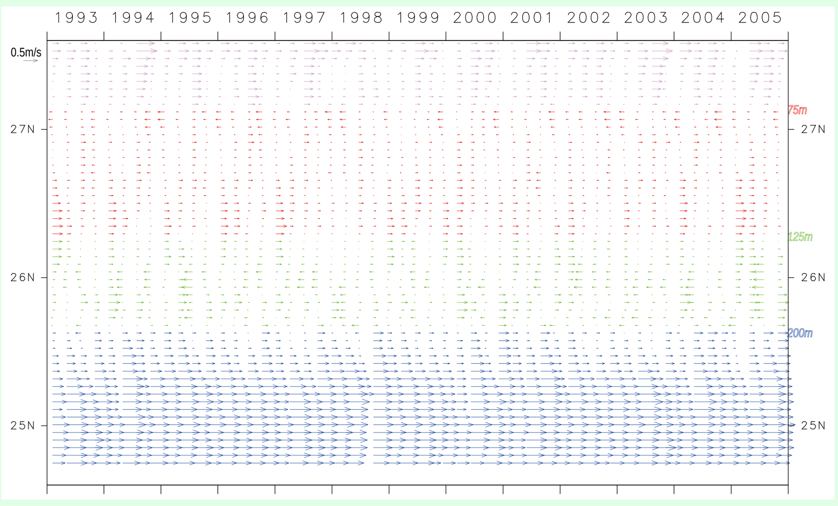

Fig. 3-1: Time series of 90-day averaged velocity componennt normal to the track 240. Arrows are colored in blue, green, red and pink, if the depth of the points is deeper than 200m, 125-200m, 75-125m and shallower than 75m, respectively. A rightward arrow indicates northeastward flow.

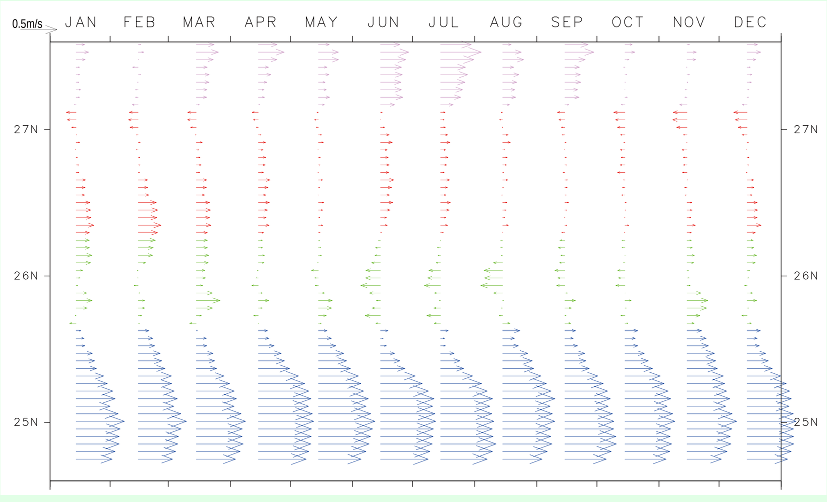

Fig. 3-2: Monthly averages obtained by folding 13 years of the altimetry data.

4. Intra-seasonal variations

Seasonal variations described above, however, would not be measured by a single observation since intra-seasonal variability is quite high as shown in Fig. 4-1. Even in May and August, the north brance of the TWC may reverse the direction.

In the previous section, the southwestward current at 26N is related with the stronger north branch of the TWC. Strong reversed KBC at 26N occured in mid June and mid August in Fig. 4-1, and consequently the north brance at 27.5N was strengthened approximately 20-30 days later, suggesting presence of temporal lags that cannot be resolved in Fig. 3-2.

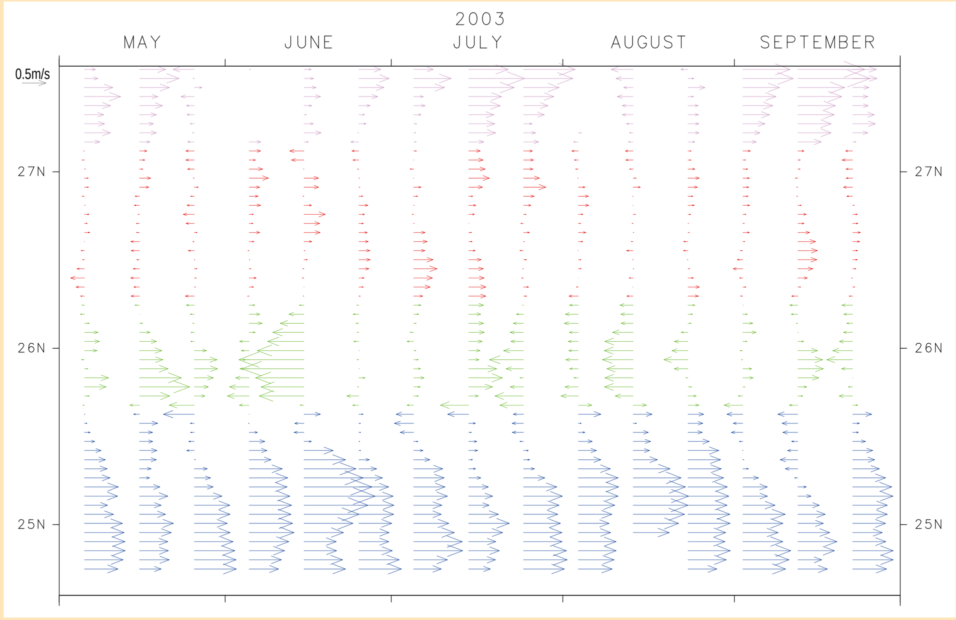

Fig. 4-1: Surface velocity component normal to the track 240 in mid 2003, plotted every 10 days.

When the reversed KBC occured at 26N, northeastward velocity to the north of 25N was strengthened. Use of the HF radar data reveals that this northern strengthening is caused by northward movement of the Kuroshio axis (Fig. 4-2). Furthermore, the wider SSHA field (Fig. 4-3) suggests that the movement of the Kuroshio axis is affected by mesoscale eddies east of Taiwan and south of the HF observational area (Ichikawa, 2001). These mesoscale eddies may also induce variations of the TWC successively.

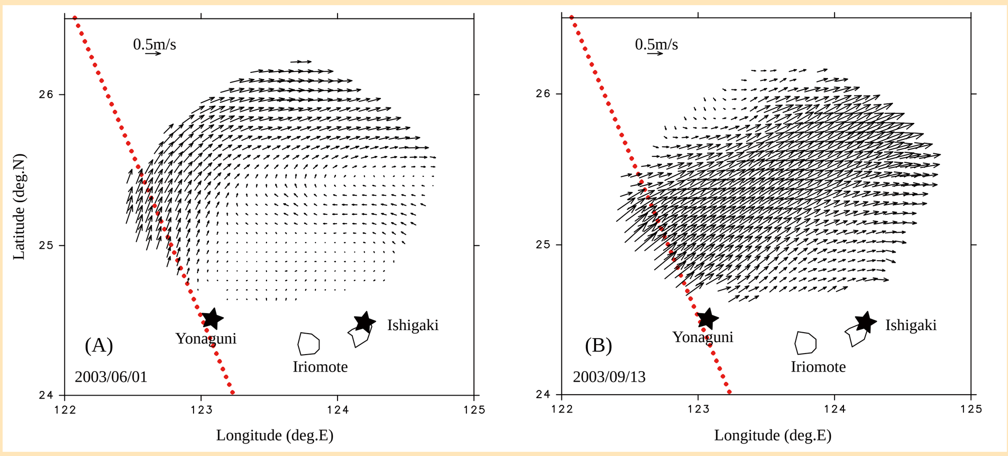

Fig. 4-2: The surface geostrophic velocity estimated from the HF data on 1/June/2003 (A) and 13/Sept/2003 (B).

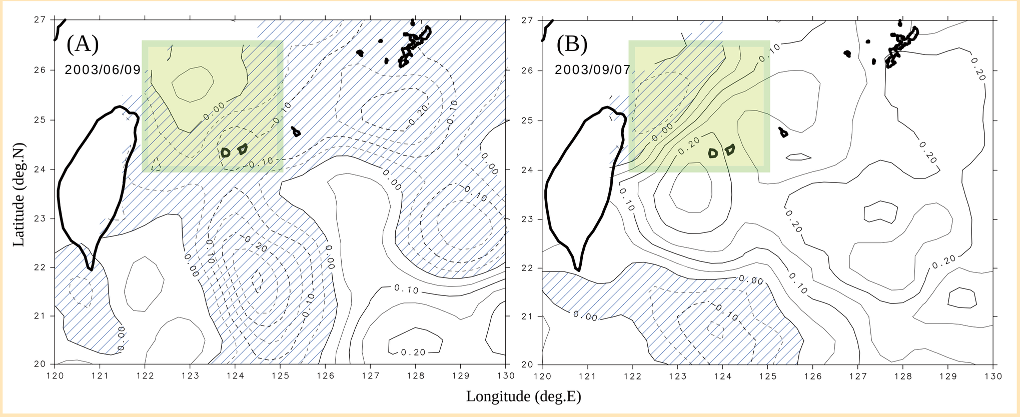

Fig. 4-3: The SSHA field on 9/June/2003 (A) and 7/Sept/2003 (B) interpolated from Jason-1, ERS-2 and Envisat data. Negative values are shaded. Green squares indicate the area shown in Fig. 4-2.

5. Summary

Using along-track altimetry data and surface drifters data, coastal surface currents northeast of Taiwan is described with high spatial resolution along subsatellite tracks. North branch of the TWC that flows at 27.5N in a shallow region tends to be strong in spring and summer. Meanwhile, southern branch of the TWC at 26.5N that flows at approximately 100-m depth exists even in winter. Those seasonal variations of the TWC are, however, easily masked by intra-seasonal variations. The intra-seasonal variations also dominates the KBC near the continental shelf edge, which seems to be related with movements of the Kuroshio axis to the south.

References

Ducet, N. and P.Y. Le Traon (2000): Global high-resolution mapping of ocean circulation from TOPEX/Poseidon and ERS-1 and -2. *J. Geophys. Res.*, **105(C8)**, 19,477-19,498.

Ichikawa, K. (2001): Variation of the Kuroshio in the Tokara Strait induced by meso-scale eddies. *J. Oceanogr.*, **57(1)**, 55-68.

Niiler, P.P., N.A. Maximenko, G.G. Panteleev, T. Yamagata and D.B. Olson (2003): Near-surface dynamical structure of the Kuroshio Extension. *J. Geophys. Res.*, **108(C6)**, 3193, doi:10.1029/2002JC001461.

Pazan, S. E., and P. P., Niiler (2001): Recovery of near surface velocity from undrogued drifters, *J. Atmos. Oceanic Technol.*, **18**, 476-479.

Uchida, H. and S. Imawaki (2003): Eulerian mean surface velocity field derived by combing drifter and satellite altimeter data. *Geophys. Res. Letts.*, **30(5)**, 1229, doi:10.1029/2002GL016445.

Tokeshi, R., K. Ichikawa, S. Fujii, K. Sato and S. Kojima (2007): Estimating the geostrophic velocity obtained by HF radar observations in the upstream of the Kuroshio. *J. Oceanogr.*, in press.

Zhu, J., C. Chen, P. Ding, C. Li and H. Lin (2004): Does Taiwan warm current exist in winter?, *Geophys. Res. Letts.*, **31**, 12302, doi:10.1029/2004GL019997.