INTERACTIONS WITH EDDIES IN THE UPSTREAM OF THE KUROSHIO AS SEEN BY THE HF RADAR AND ALTIMETRY DATA

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ABSTRACT: The long-range High-Frequency (HF) ocean radar system has observed surface velocity field in the upstream of the Kuroshio north of Ishigaki Island and east of Taiwan since 2001. Applying a new method to extract geostrophic velocity component from the HF surface velocity data with the aid of satellite-born wind data, time series of daily surface geostrophic velocity field has been determined. Despite limited width of the study area of the HF radar, analysis of the sea surface height anomaly determined from the satellite altimetry data in a wider area can provide estimated dates of arrival of mesoscale eddies in the study area of the HF radar. Variations of the Kuroshio position and strength are studied in detail for these cases of interaction with mesoscale eddy, although number of occurrence of direct interaction with the Kuroshio in the study area is not statistically enough. For example, when an anticyclonic eddy approaches to the Kuroshio, the Kuroshio axis is found tend to move northward, keeping away from the approaching eddy from the east.

KEY WORDS: HF radar, satellite altimetry, Kuroshio, mesoscale eddy

1. INTRODUCTION

Satellite altimetry has revealed that active interaction of the Kuroshio with mesoscale eddies in its upstream region plays important role to downstream variations of the Kuroshio such as its volume transport estimated from tide gauge records (Ichikawa, 2001). However, observations of the Kuroshio itself by the satellite altimetry are actually limited by mainly following two reasons. At first, loss of the temporal mean due to contamination of the geoid error makes it difficult to separate variations of the Kuroshio and adjacent mesoscale eddies (*e.g.* Ichikawa and Imawaki, 1994). The other reason is that spatial and temporal resolutions of the sea-surface height anomaly (SSHA) field obtained by the altimetry is too low to observe fast-moving phenomena such as the Kuroshio meanders (*e.g.* Ichikawa *et al.*, 1995), since the field is generally produced by interpolation of along-track altimetry data during a period over 10 days.

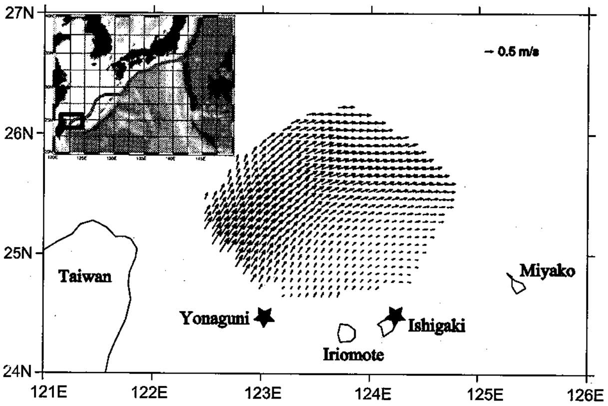

Figure 1. The study area of the long-range HF radar system. Locations of the HF radar (star marks) and 3.5-year mean surface velocity. Reference velocity of 1m/s is plotted at the top right corner.

Recently, a method has been established to obtain geostrophic surface velocity from the long-range High-Frequency (HF) radar data developed and distributed by National Institute of Information and Communications Technology (NICT), Japan (Tokeshi *et al.*, 2006). The HF radar has higher resolutions in both space and time than the satellite altimetry and not confined to the temporal anomaly, although the study area is limited (Fig. 1). In this study, variations of the Kuroshio observed by the HF radar are examined in detail, together with description of mesoscale eddies in a wider area obtained by the altimetry data.

2. DATA

Surface vector velocity on a 7-km grid is provided by NICT every 0.5 hour from July 2001 to January 2005. Tidal current component determined by the harmonic analysis is first removed and then daily-mean HF velocity field is determined. Finally, the Ekman current component estimated from satellite-born daily-mean wind data is removed (Tokeshi *et al.*, 2006).

Altimetry data sets of T/P, Jason-1, ERS-1, ERS-2 and Envisat used in the present study are distributed by AVISO (AVISO, 1996; Le Traon *et al.*,1995; Le Traon and Ogor, 1998). From all these altimetry data, the SSHA field is determined on a 0.25-degree grid by an optimal interpolation every 9.92 days (a repeat cycle of T/P). The optimal interpolation used in the present study is the same as that described by Ichikawa (2001).

3. RESULTS

In the present paper, two typical cases are described as an example of variations of the Kuroshio induced by interaction with mesoscale eddies.

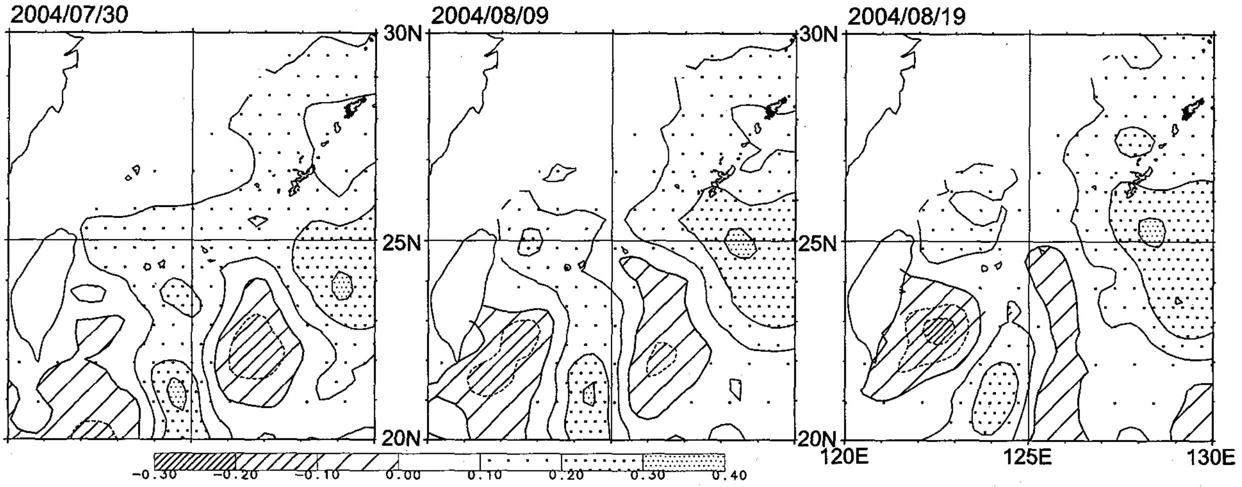

Figure 2. The SSHA fields on 30 July, 9 August and 19 August, 2004. Contour interval is 0.1m and positive (or negative) values are shaded with dots (or lines).

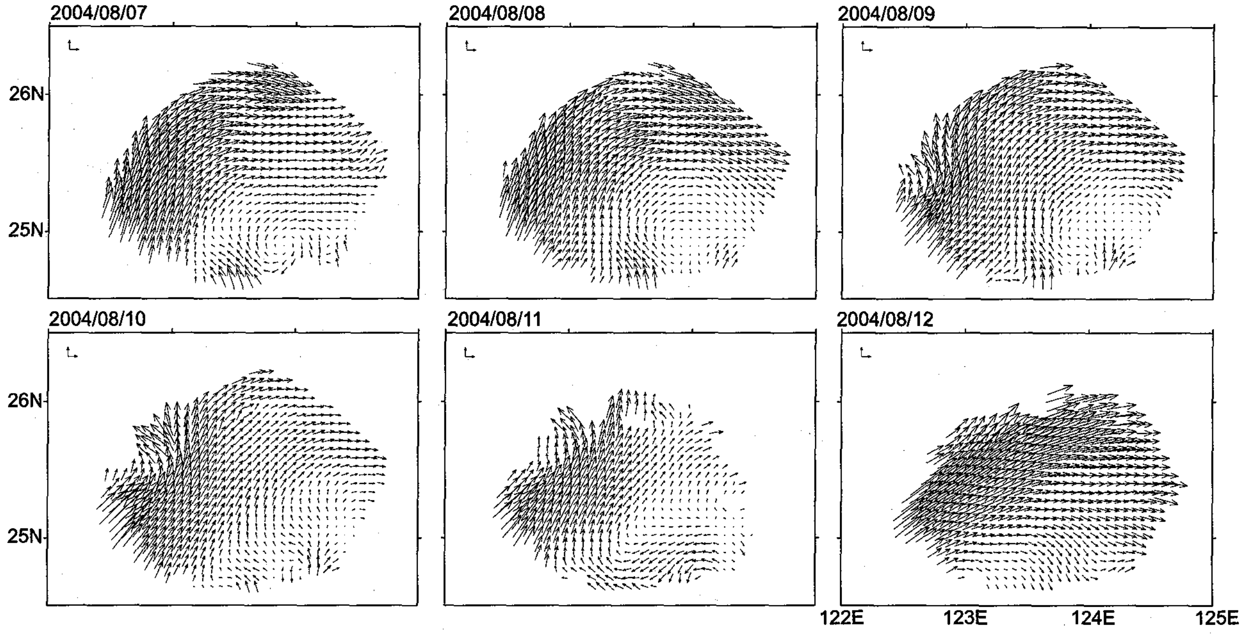

Figure 3. The daily-mean HF velocity in early August, 2004. Reference velocity of 0.5m/s is shown at the top left corner of each panel.

EARLY AUGUST, 2004

Figure 2 shows the SSHA field in early August, 2004. Around 25N, westward propagation of positive SSHA approaching to the Kuroshio is recognized, although most of it seems dismissed on 19 August.

The surface velocity field observed by the HF radar (Fig. 3) clearly shows presence of an anticyclonic eddy at 25N in early August. Meanwhile, the Kuroshio axis to the north of it is recognized to be shifted northward with respect to the 3.5-year mean in Fig. 1. Note that the Kuroshio shifted southward on 12 August when effect of the anticyclonic eddy was not present.

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In March, 2002, the area of the positive SSHA elongated along the Kuroshio axis steadily increased in the study area of the HF radar (Fig. 4). In this case, however, the SSHA was not originated from the east as in early August, 2004 (Fig. 2), but was induced by merging of the westward SSHA to the south of Taiwan at around 21N.

During this period, series of advection of anticyclonic eddies are recognized in the HF surface velocity field in Fig. 5. An anticyclonic eddy centred at (24.7N, 123E) on 13 March moved downstream to (25.2N, 124.2E) on 17 March. Meanwhile, another anticyclonic eddy appeared

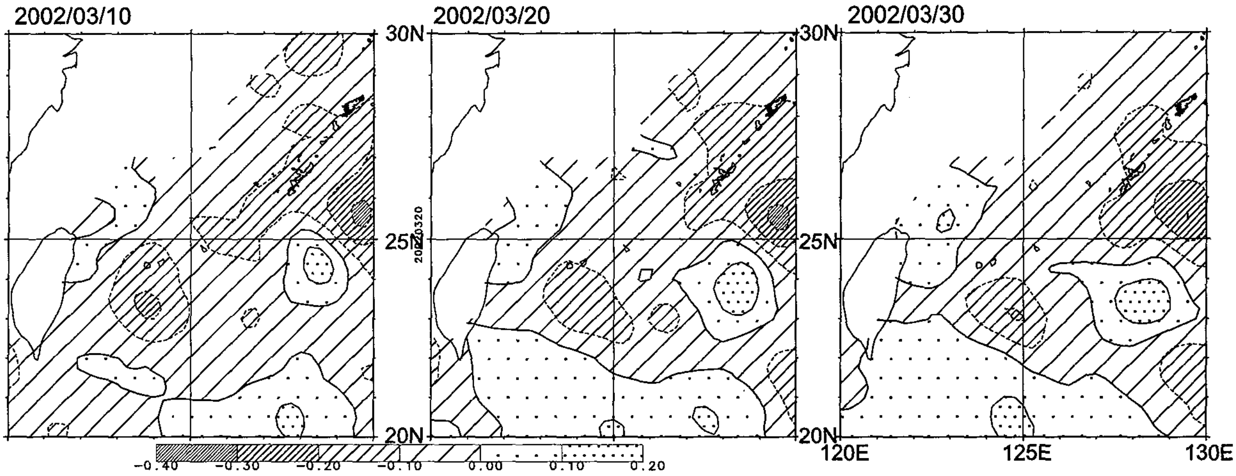

Figure 4. The same as Fig. 2 but on 10, 20 and 30 March, 2002.

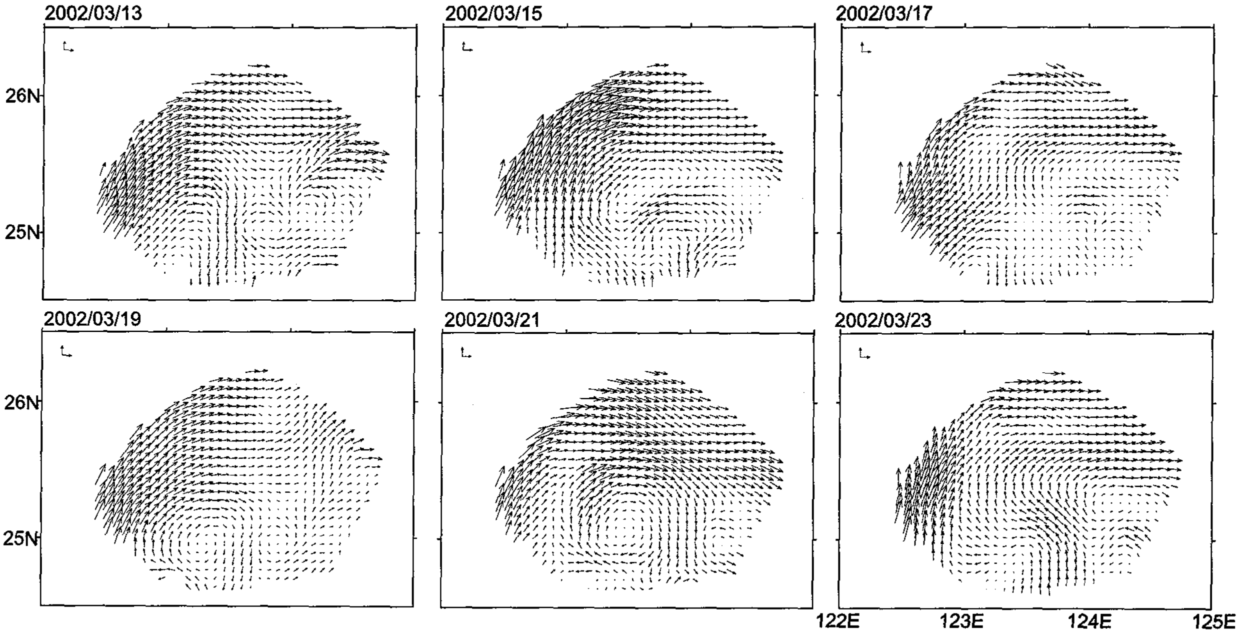

Figure 5. The same as Fig. 3 but in mid March, 2002. Panels are shown with 2-day interval.

on 17 March at (24.7N, 123E) which also moved downstream to (25N, 123.3E) on 19 March, to (25.1N, 123.5E) on 21 March, and to (25.3N, 124.3E) on 23 March. Note that the axis of the Kuroshio during these events was generally shifted northward than the mean in Fig. 1.

4. CONCLUSION

Use of the HF radar data together with the altimetry data provides more comprehensive description on variations of the Kuroshio by interaction with mesoscale eddies. For example, the northward shift of the Kuroshio axis is found when an anticyclonic eddy is approaching to the Kuroshio. More statistical treatment is being conducted.

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