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Comparisons of Ocean Currents Observed from Drifters and TP/ERS in the East Sea

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Abstract : Ocean currents estimated from sea height anomalies derived from inter-calibrated TP / ERS are compared with daily mean currents measured with satellite-tracked drifters. The correlation coefficient between the geostrophic current from TP / ERS and surface current at 15 m depth from drifter tracks was found to be about 0.5. Due to the limitation of satellite ground tracks, small scale eddies less than 80 km are poorly resolved from TP / ERS. One of the interesting results of this study is that coastal currents along the eastern coast of Korea were well reproduced from sea height anomalies when the coastal currents were developed in association with eddies near the South Korean coast. The eddy kinetic energy (EKE) estimated from drifters, TP / ERS, and a numerical model are also compared. The EKE estimated from drifters was about 22 % higher than EKE calculated from TP / ERS. The pattern of low EKE level in the northern basin and high EKE level in the southern East Sea is shown in the EKE estimates derived from both the drifters and TP / ERS.

Key words : East Sea current, drifter, TP / ERS, eddy.

1. Introduction

Since the Geosat altimeter mission in late 1980 (1985~1989) and much improved TOPEX / Poseidon (hereinafter TP) altimeter mission launched in 1992, many studies have been carried out to compare the sea level height measured from the satellite altimetric missions with the observed ocean circulation (Stammer and Wunsch 1994; Park and Gamberoni 1995; Grundlingh 1995; Teague *et al.* 1995; Hernandez *et al.* 1995). However, Blayo *et al.* (1997) showed that just one altimetric mission is not enough to resolve mesoscale features in the ocean. Subsequently, techniques for merging data from two or more altimetric missions have been developed by Le Traon *et al.* (1998) and Le Traon and Ogor (1998), using the TP as a reference to ERS-1 and -2 (hereinafter ERS). Ducet *et al.* (2000) compared the eddy kinetic energy (EKE) calculated from the merged TP / ERS sea level anomalies with the EKE from drifters and current meters. They found good agreements between the former and the latter. Using their global EKE maps produced from TP / ERS, they were able to demonstrate the very detailed ocean circulation features and the seasonal variations of EKE, which had never been possible before at a basin scale.

Encouraged by the findings of Ducet *et al.* (2000), this study attempted direct statistical comparisons of circulation and EKE estimated from merged and inter-calibrated TP / ERS and those measured with drifters in the East Sea. In spite of its small size, the East Sea has many circulation features of the ocean basin; it contains the western boundary current, fronts, and eddies of many scales (Lee *et al.* 2000). Therefore, the East Sea

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can serve as a useful area in testing ocean circulation features derived from altimeter missions.

The data used in this study are described in section 2. The visual comparisons of sea level anomaly fields from the merged TP / ERS and the drifter tracks are presented in section 3.1. In Section 3.2, the statistical analyses are performed for the correlation between the geostrophic currents derived from the TP / ERS and the surface currents observed with the drifters. Binned (0.5° × 0.5°) EKE are compared in section 3.3 and discussions with summary are followed in section 4.

2. Data

Drifter data

Satellite-tracked drifters report their positions to NOAA satellites 6-8 times per day depending on their latitude. The details of water-following characteristics of the World Ocean Circulation Experiment / Surface Velocity Program (WOCE / SVP) type drifter and position processing by the Global Drifter Center were described by Poulain *et al.* (1996) and Lee *et al.* (2000). U.S. Navy also deployed surface-type drifters without drogues. All Navy drifters were calibrated to 15 m depth using the relationship of undrogued drifter to wind by Pazan and Niiler (1999). High frequency noises arising from position errors, and inertial and tidal motions were removed by applying a low-pass filter. The cut-off frequency of the low-pass filter is about 1.1 cycles per day, thus eliminating the motions with frequency higher than diurnal tide.

The energetics and dynamic analysis of surface currents observed with the drifters deployed in the East Sea are found in the paper by Lee *et al.* (2000). Since most of the drifters in the East Sea were deployed after 1995, the comparisons of surface currents observed with drifters and the geostrophic current calculated from TP / ERS were performed for a 5-year period from April 1995 to January 2000. Total of 240 drifter tracks were used for the comparison.

TP/ERS data

The sea height anomalies derived from merged and inter-calibrated TP / ERS are available on-line from the University of Colorado (CCAR) and from the Archiving, Validation and Interpretation of Satellites Oceanographic data - Centre National d'Études Spatiales (AVISO-CNES). Each archiving center uses slightly different scheme for inter-calibration of TP and ERS. Visual comparison of several cases indicated that the sea level anomaly fields from AVISO-CNES match better with drifter tracks. For example, the separation point and pattern of the coastal currents in spring of 1998 are not reproduced by CCAR products, while they are well resolved by the AVISO-CNES sea level anomaly fields (Fig. 1). Therefore, this study utilized the AVISO-CNES data. The ground tracks of TP and ERS in the East Sea are shown in Fig. 2. The details of data processing and

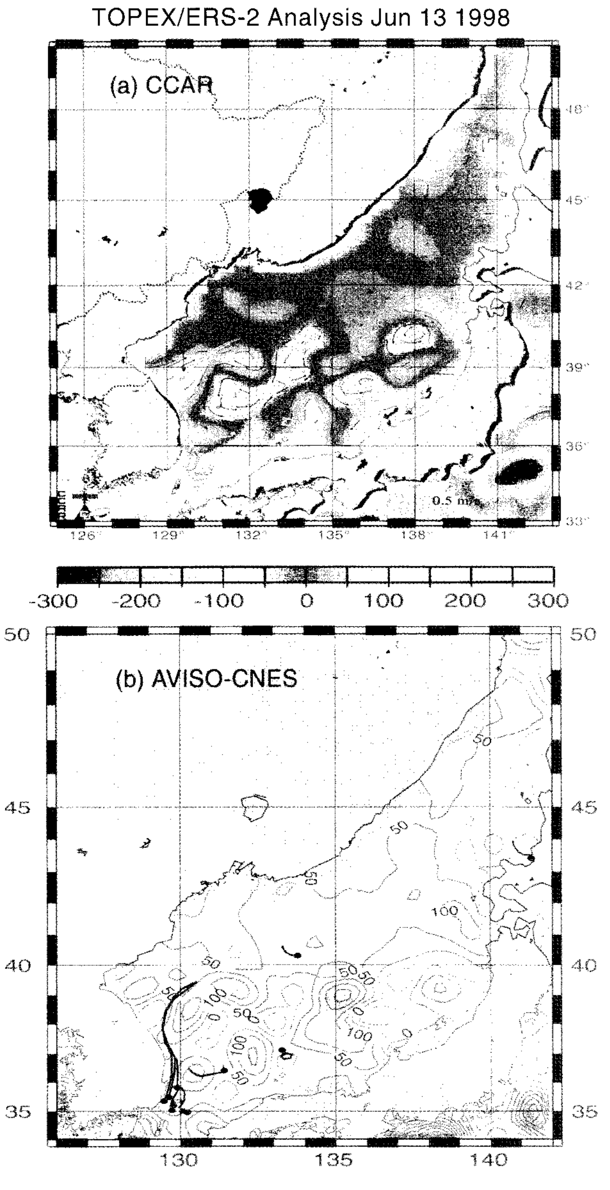

Fig. 1. TP/ERS sea level anomaly from (a) CCAR (University of Colorado) and (b) AVISO-CNES with ten-day long drifter tracks centered on June 13, 1998 (black dots indicate starting points).

inter-calibration scheme of TP and ERS were given by Stum *et al.* (1998).

3. Results

Drifter tracks and sea level anomaly fields

Coastal currents and large eddies were successfully reproduced from the sea level anomaly fields derived from TP/ERS (Fig. 3a and 3b). When warm eddy was developed near 38°N off the coast of South Korea the northward coastal current was observed(Fig. 3a), but when cold eddy was developed the southward coastal current was observed by drifters (Fig. 3b). The northward coastal current, the East Korean Warm Current, appeared to have large temporal changes in association with the presence of the eddy formed between Ulleung Island and the eastern Korean coast. Determination of the seasonality and dependency of the East Korean Warm Current on this eddy, which was named as Ulleung Warm Eddy (Lie *et al.* 1995) requires further observational study. Although it was difficult to resolve small scale motions from merged TP/ERS (Fig. 4), sea levels calculated from merged

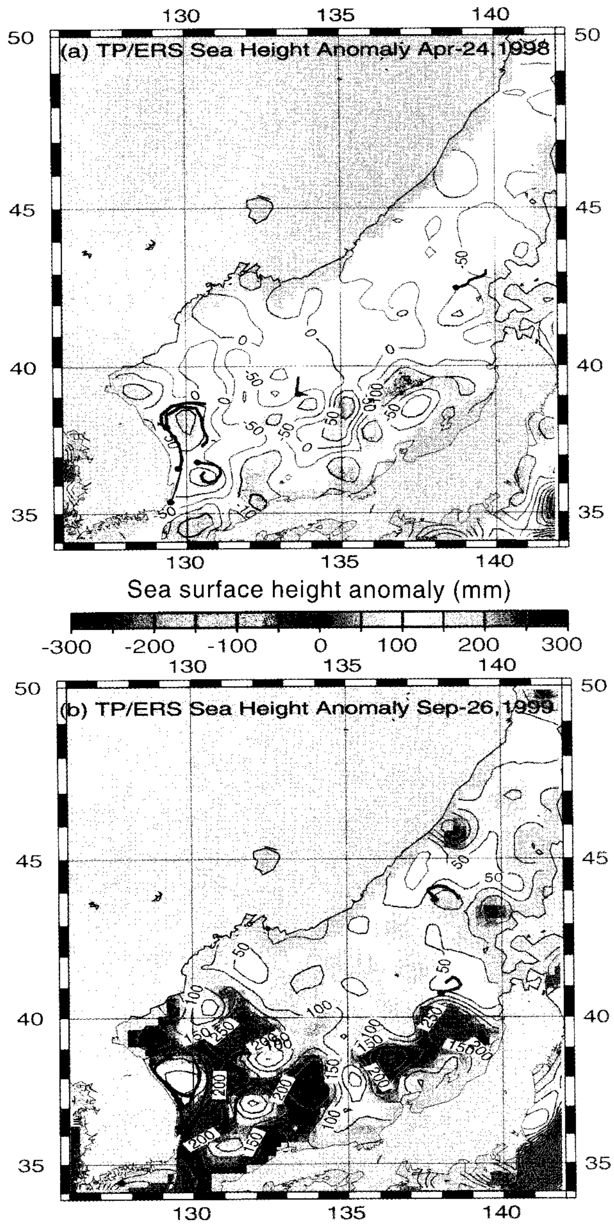

Fig. 3. TP/ERS sea level anomaly on (a) Apr. 24, 1998 and (b) Sep. 26, 1999.

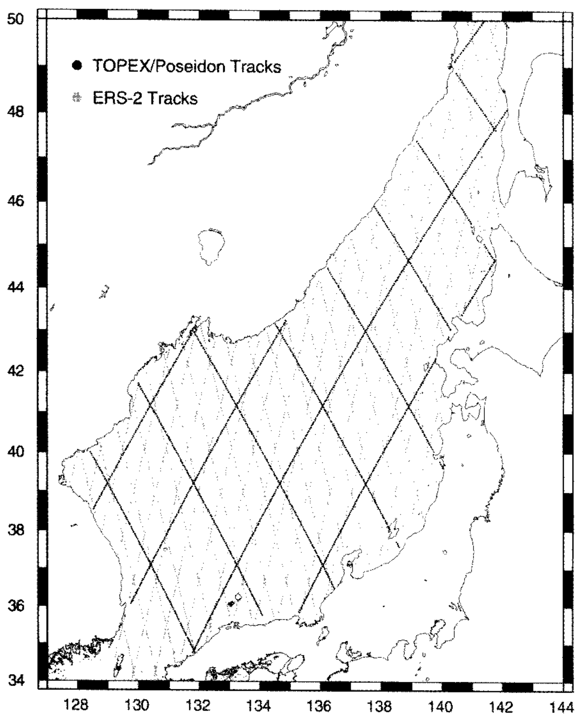

Fig. 2. Ground tracks of the TOPEX/Poseidon (black lines) and of the ERS-2 (gray lines).

TP/ERS seem to resolve many mesoscale eddies with size larger than ERS track distance of 80 km. Discrepancies between observed currents with drifters and geostrophic currents derived from the sea level anomalies could be attributed to the ageostrophic currents, especially in the northern East Sea (Lee *et al.* 2000), and the mean currents that could not be estimated from the sea level anomaly fields.

Geostrophic current

The geostrophic currents were calculated using following equation:

$$\vec{U}_g' = -\frac{g}{f}\cdot\nabla\eta'$$

where $\vec{U}_g'$ denotes the geostrophic velocity anomaly, η' is the sea level anomaly from TP/ERS, and f is the Coriolis parameter. AVISO-CNES sea level anomaly data are on a regular quarter-degree-resolution grid with 10-day interval. The geostrophic currents were compared with the currents observed with the drifters for before-and-after three days from the date of AVISO-CNES sea level anomaly field. The correlation coefficient was about 0.5, and the regression relationship between the geostrophic currents and the drifter currents was

$$\vec{U}_g = 0.75\times(\vec{U}_{drifter}) + (4.7\vec{i} + 3\vec{j})$$

where $\vec{i}$ and $\vec{j}$ denote unit vectors in east-west and north-south direction, respectively. Approximately 3,700 pairs were compared for this study.

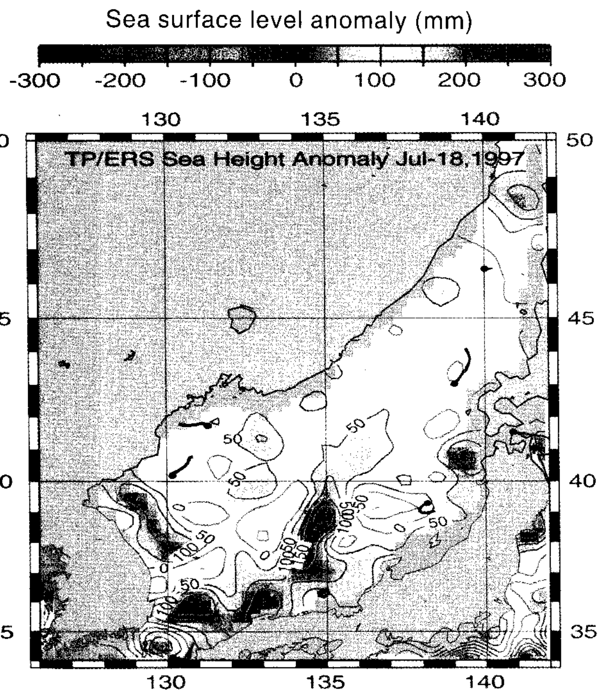

Fig. 4. Small scale features and ageostrophic current in the northern basin are not well resolved by TP/ERS sea level anomaly on July 18, 1997.

Scatter plots of geostrophic and drifter currents are shown in Fig. 5. Both components of the currents are shown more scattered in the northern East Sea (the sea north of 40°N) where ageostrophic wind-driven current were observed frequently (Lee *et al.* 2000) than in the southern East Sea (the sea south of 40°N).

Eddy Kinetic Energy

The EKE was calculated at each grid using the geostrophic currents estimated from TP/ERS. The EKE based on the currents observed with the drifters was calculated in 0.5°×0.5° bins. For the comparison between

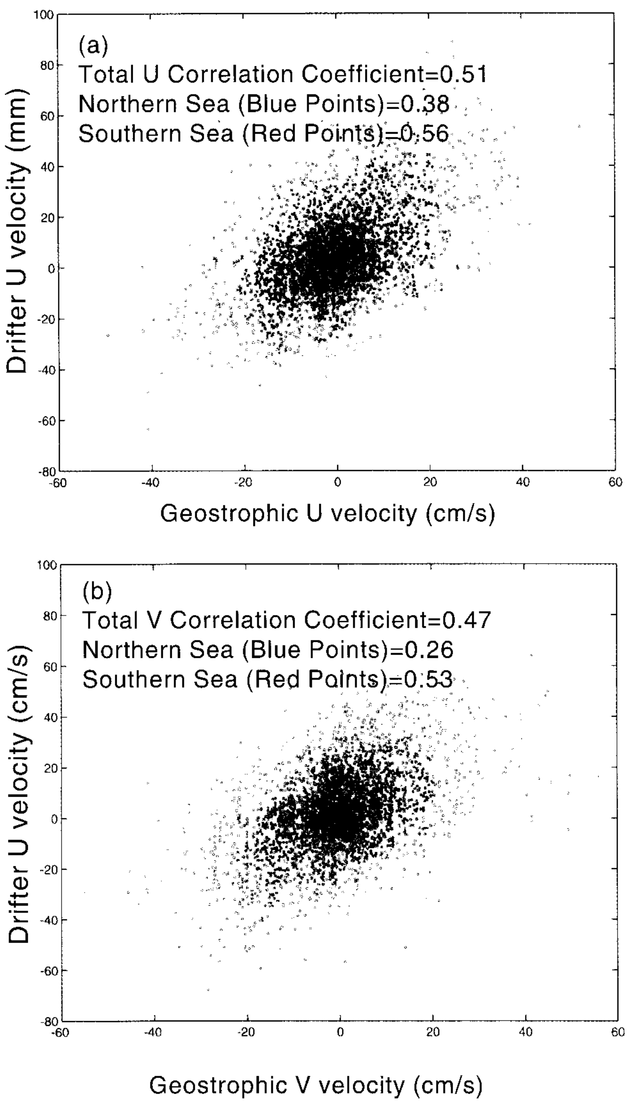

Fig. 5. Scatter plots of (a) east-west component and (b) north-south component of currents from drifters and TP/ERS. The boundary for the northern and the southern East Sea is 40°N.

the geostrophic EKE and the observed EKE, the square roots of EKE,

$$\sqrt{EKE_g} = \frac{1}{\sqrt{2}}\left|\vec{U}_g\right| \quad and \quad \sqrt{EKE_{drifter}} = \frac{1}{\sqrt{2}}\left|\vec{U}_{drifter}\right|$$

were calculated and compared in Fig. 6. The EKE measured by drifters is the sum of geostrophic EKE and ageostrophic EKE which is mostly from wind-driven current.

$$EKE_{drifter} = a \times EKE_g + EKE_{ageostrophic},$$

and the regression was

$$\sqrt{EKE_{drifter}} = \sqrt{1.22 \times EKE_g + 94}.$$

The nonlinear regression was performed using MATLAB optimization toolbox. The offset of 94 cm^2/s^2 is wind-driven ageostrophic eddy energy. The EKE levels observed with drifters was 22 % higher than calculated from TP/ERS. This could be explained by the track resolution of altimeter satellites. Ducet *et al.* (2000) found that levels of EKE calculated from merged TP/ERS were 30 % higher than those calculated from TP alone.

The patterns of low eddy energy in the northern basin, high eddy energy in the southern basin and v-shaped low EKE pattern caused by the Yamato Rise are shown in Fig. 7. In the northern East Sea, small eddies about 70-80 km size were observed by drifters (Lee *et al.* 2000), but these small eddies were not shown in TP/ERS EKE map. The high EKE of the Donghan Bay (the area along 39°N near the North Korea coast) was shown in EKE map of both TP/ERS and drifters. The high eddy energy area in the Yamato Basin showed undulating pattern that was not related to topography but possibly related to changes of polar frontal path. The largest eddy energy areas were found in the southern Ulleung Basin and in the eastern Yamato Basin. Since the error in sea level anomalies was large in the coastal region, coastal currents such as the Liman Current along

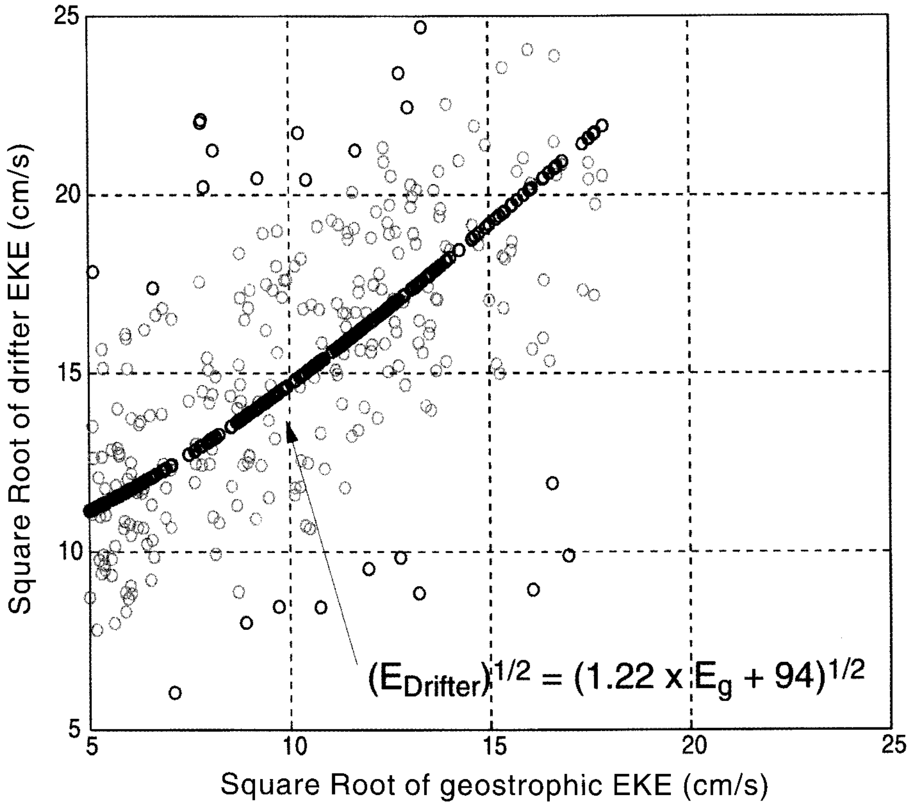

Fig. 6. Scatter plot for square root of eddy kinetic energy estimated from drifter and TP/ERS. Only gray points were used for the regression

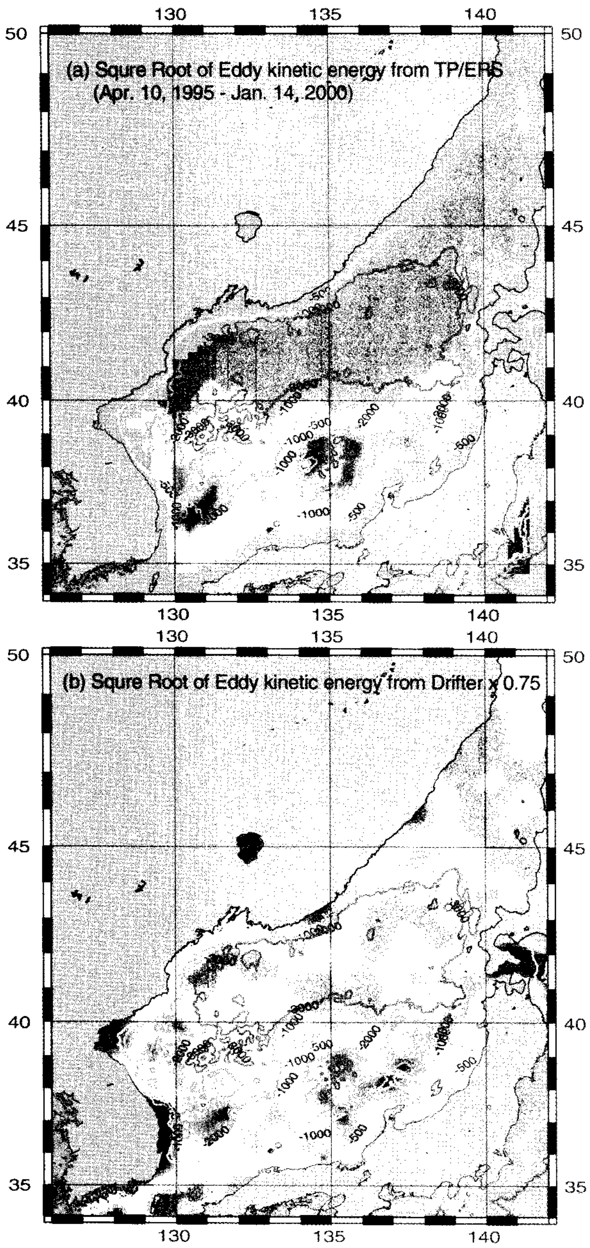

Fig. 7. Eddy kinetic energy calculated from (a) TP/ERS sea level anomaly and (b) drifter observations. Colors are eddy kinetic energy and contours are bottom topography.

the Siberia coast are not shown in EKE map of TP / ERS. In the case of numerical model (Hogan and Hurlbut 2000), the large EKE areas were formed by the topography, but the observations from both drifters and TP / ERS show little relationship with topography except in the area near the Yamato Rise.

4. Summary and discussion

The geostrophic currents from the sea level anomalies estimated from merged and inter-calibrated TP / ERS and the observed currents with the satellite-tracked drifters were compared in this study. It was found that the small scale features with size shorter than the track distance of 80 km and the coastal currents could not be successfully resolved from TP / ERS. However, the sea level anomaly fields and the drifter tracks matched very well for large eddies and along the sub-polar front. The correlation coefficient between geostrophic currents and the currents observed with the drifters was about 0.5, and the correlation was better in the southern East Sea than in the northern East Sea. The different correlation in the southern and northern basin was due to the small scale eddies and the ageostrophic wind-driven currents found in the northern sea (Lee *et al.* 2000). The mean magnitude of geostrophic currents computed from the sea level anomalies was about 75 % of the currents observed with the drifters.

It was found that satellite eddy maps in two dimensions are useful products that account for about 80 % of the observed currents. The patterns of EKE calculated from TP / ERS and EKE measured with drifters were similar, except for in areas near the coast and in the northwestern East Sea where small eddies were observed by drifters.

Blayo *et al.* (1997) reported that the assimilation of TP sea level anomaly into the numerical model was not successful for the mesoscale features. However, this study demonstrated that the eddies with size larger then 80 km and the frontal features could successfully be reproduced from the sea level anomalies derived from the merged and inter-calibrated TP / ERS. This study also showed that it is possible to simulate more realistic circulation features of the East Sea by assimilating sea level anomalies derived form inter-calibrated TP / ERS into a numerical model.

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