Westward-Propagating Wavelike Features in the East Sea using NOAA/AVHRR and TOPEX/ALT Data

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I. Introduction

Ever since the availability of Seasat altimetric data in 1974, altimetric data have been used in numerous researches on the global ocean circulation. More recently, the studies on global scale wave dynamics, particularly the low-frequency motions, have been actively conducted using sea level anomaly data from TOPEX altimeter which has been operational since September 1992. All these studies were carried out in the open ocean with large spatial scale. On the contrary, the East Sea is a small semi-enclosed marginal sea. Studies on the spatial and temporal variability of sea level anomaly using altimeteric data in a small basin have been confined to the ground tracks. The horizontal SST(Sea Surface Temperature) structure of the East Sea exhibits two-dimensional turbulence and various dramatic structures driven by eddies or fronts. These features of SSTs should be also detected at SSHA(Sea Surface Height Anomaly) fields from TOPEX altimeter data. To relate SST variations to SSHA, spatial and temporal anomalies of SST fields(SSTA) are derived, and then the two fields are used to investigate temporal variations of the spatial structure.

II. Data

Semi-monthly averaged SST maps were precisely made using all the available NOAA/AVHRR data for six years from 1990 to 1995 based on the better cloud detection methodology. Twenty to forty images, or over fifty images in extreme cases due to specific climatological conditions over the East Sea in monsoon season and winter, are used to make a SST map during a semi-month. RMS errors with the dataset itself are assessed mostly below 1.0℃ and approximately 1.5℃ to 2.0℃ in the frontal area and around mesoscale eddies. To obtain SSHA fields, a mean of 100 TOPEX cycle data for 3 years from October, 1992 to September, 1995 was taken and then subtracted from each altimetric data whose tidal signals were removed.

III. Propagation of Wavelike Features

III-1. Wavelike feature of SSHA

Fig. 1 shows time series of sea level anomalies along the longest track of TOPEX in the East Sea from the beginning of 1993 to early September 1995(TOPEX cycle 11-111). It is evident that a SSHA higher than neighboring spatial points gradually propagates from the northeast to the southwest along the track. The propagating speed of this wavelike SSHA amounts to approximately 0.7km/day up to 1.0km/day on an average. It is difficult to understand 2-D spatial propagation with only this plot along a track, so that zonal-time datasets were reconstructed to obtain temporal variations of sea level anomalies.

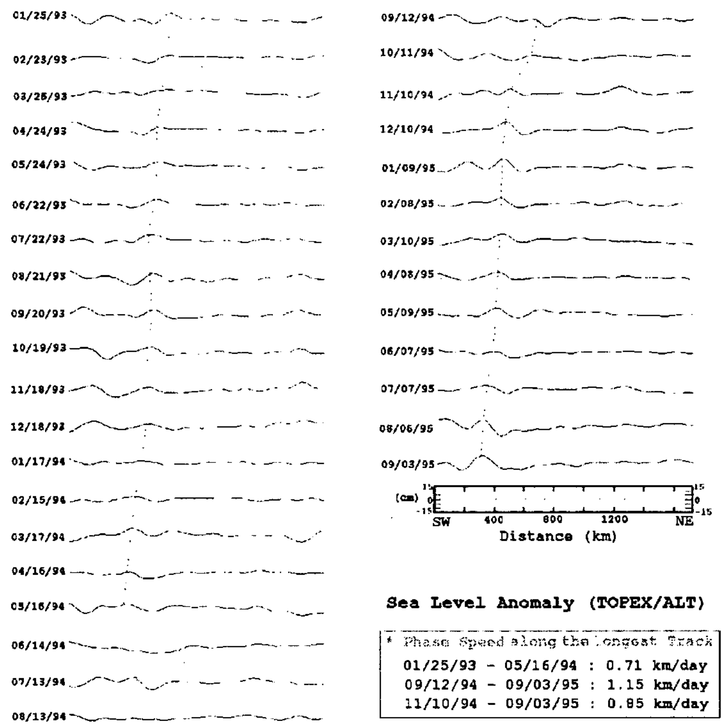

Fig. 1 Sea level anomalies along the longest track of TOPEX in the East Sea

1) Zonal-Time Autocorrelation of SSHA

In order to investigate the temporal variation of SSHA fields, the time series of SSHA data at several latitudes between 36°N and 46°N were made. Two-dimensional trend of the SSHA fields was removed by regressing them to 2-D spatial plane equation. The zonal-time autocorrelation functions for the SSHA fields show an anisotropy with respect to each dimension, the main axes of which incline to the left side on the base of the zero zonal lag line. This inclination means that the mean patterns of SSHA on each latitude proceed gradually westward(minus zonal lags) in time. The phase speed of westward propagating sea level anomaly may be inferred from the extent of the inclination. The propagation speed at lower latitude such as 36°N or 37°N has larger values of over 2 km/day than that of the central part of the East Sea(0.5-1.2 km/day). The reason for this small speed in the central part is not clear, however it may result from numerous spatial scales of motions including both large-scale meandering and small-scale frontal eddies around the strong thermal frontal zone. These mesoscale eddies with a few tens of kilometer scale would reduce the inclination by contributing to the autocorrelation.

Two-dimensional zonal-time autocorrelation function is a good estimator of a propagation of wavelike-features, but provides an information only along fixed spatial lines. It is necessary therefore to examine whether this temporal variations can be observed in the entire horizontal domain or not. Thus, three-dimensional autocorrelation functions were computed to study the temporal variation of the two-dimensional spatial SSHA patterns in the following section.

2) Three Dimensional Autocorrelation of SSHA

Prior to computing three-dimensional zonal-meridional-time lagged autocorrelation functions, the SSHA data were resampled in a square box 37°N, 130°E to 42°N, 139°E. The three-dimensional autocorrelation functions for SSHA within the subdomain as a function of increasing time lag are presented in Fig. 2. The central correlation peak in zonal-meridional lag distance space proceeds gradually toward minus zonal lag, which means that the SSHA at each grid point exhibit similar features of their own in the westward direction. The westward propagation phase speed of the SSHA features was approximately 0.82 km/day. In addition the the westward component, the 3-D autocorrelation function also represents a slight northward displacement of the central peak at a speed of approximately 0.136 km/day. This component is about 16% of the westward propagation speed. This suggests that the propagation of wave-like features is primarily confined to the zonal direction.

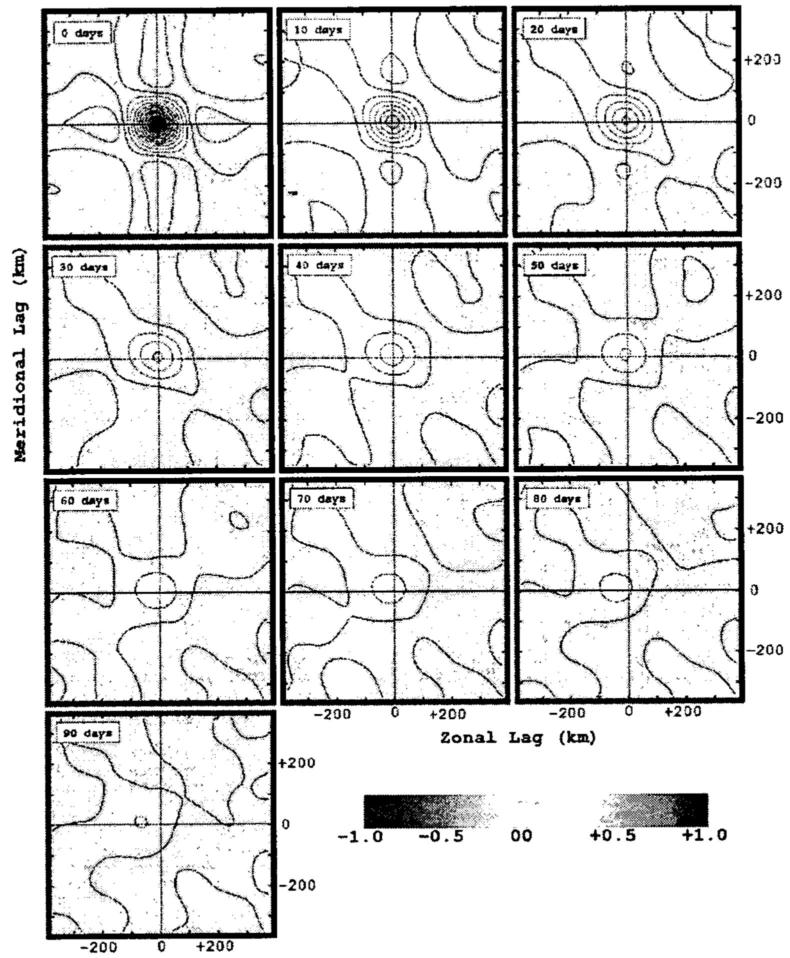

Fig. 2 Three-dimensional autocorrelation functions of SSHA

III-2. Wavelike feature of SSTA

In order to determine temporal variations of spatial features in the SSTA fields, two and three-dimensional autocorrelation functions were computed. Similar to the SSHA case, the linear trend of SST fields within the analysis domain was removed to get sea surface temperature anomalies with zonal and time axes.

1). Zonal-Time Autocorrelation of SSTA

Fig. 3 shows the zonal time-lagged autocorrelation functions along several latitudes from 35°N to 46°N. It reveals inclinations toward positive and negative zonal lags as temporal lags increase. Most of latitudes except in the central part of 37°N, 39°N, 40°N show westward shifts of SSTA in time. The eastward components in the central part of the East Sea may come from more complex SST structure in the Tsyshima Warm Current region which includes not only small-scale eddies but also the large meandering of the Warm Current. The predominant westward propagating features are found in the northern part of the polar frontal zone from 41°N to 44°N. The approximate phase speeds of he westward propagating components for each latitude is about -1.40 km/day, but down to -0.62 km/day if the eastward components are included.

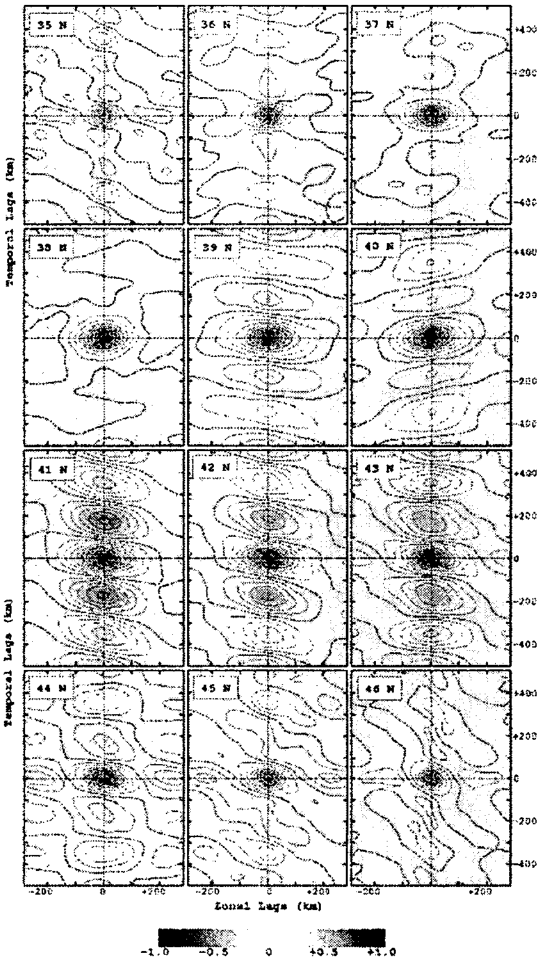

Fig. 3 Two-dimensional time-zonal autocorrelation functions of SSTA along each latitude

2). Three Dimensional Autocorrelation of SSTA

To examine wavelike features, three-dimensional autocorrelation was computed in the central domain of the East Sea identical to the resampling domain of the SSHA analysis. The correlation value itself diminished over the entire domain with time, and the central correlation peaks gradually moved westward along minus zonal lag axis. This clearly shows the westward propagation of approximately 87 km in 105 days, which corresponds to the phase speed of 0.83 km/day. In addition to this westward propagation, the central correlation peak is shifted northward by 17 km in 105 days with a phase speed of 0.16 km/day. The initial central peak gradually propagates westward away from the original location, and the correlation minimum occupies the original zero lag position in 180 days or 195 days, though the statistical significance is very low. The fact that the sign of correlation changes in half a year implies that the characteristic period of averaged SSTA variability is about one year(365 days). It means that the SSTA fields also have a characteristic seasonal variation with one-year period similar to the SST fields.

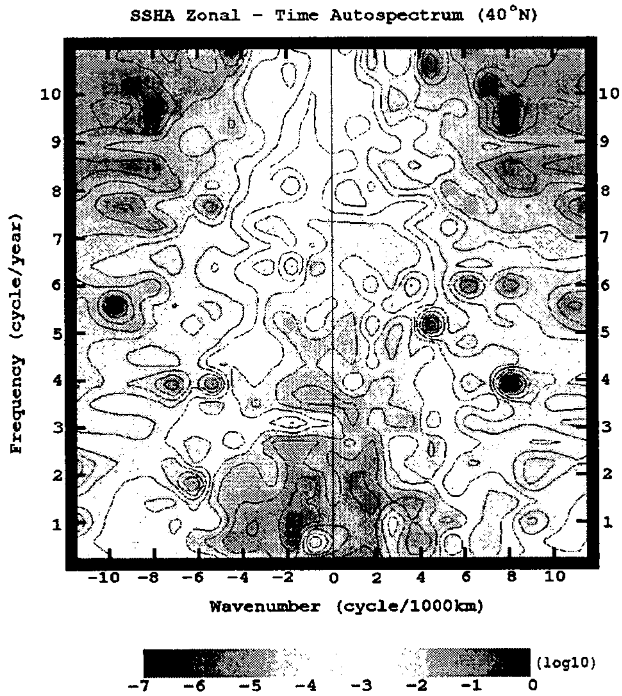

Fig. 4 Zonal-time autospectrum of SSHA along 40°N

III-3. Spectra of Maximum SST front and SSHA

The westward propagating features are relatively well seen both in the sea level anomalies from TOPEX altimeter data and the sea surface temperature anomalies than the eastward propagating components. As another evidence for the westward propagating wave-like features, the magnitude of the maximum horizontal gradient(the polar front) apparently moves westward along the zonal line with a propagation speed of approximately 1.2 km/day. Two-dimensional autospectrum for the zonal-time maximum front shows that the wavenumber with the largest spectral density moves to the west at the most dominant frequency(σ_1) of 1 cycle/year than the eastward movements. The phase speed of the westward propagating features is about -1.48km/day(σ_1/k_1). This speed shows good agrrement with values of the previous calculations for SSHA and SSTA.

The correlation itself gives only a dominant mean feature among the various phenomena included the dataset, on the other hand the time-zonal autospectrum reveals an information about each individual feature as well. So, the two-dimensional zonal-time autospectrum was computed along 40°N to examine the complex wave-like features as an example. The autospectrum in Fig. 4 clearly shows two dominant peaks. The first maximum spectral energy density is observed in the west, and the second in the east, showing two signals running in the opposite directions. The fact that the first maximum is located at the minus wavenumber indicates the dominant motion should proceed to the west with a speed as

-1.31km/day. The eastward component of the second maximum is observed at higher frequency than the first maximum, so that the propagation speed may be expected to be larger than the westward component. The average phase speed by zonal-time autospectra computed along every latitudes from 36°N to 45°N amounts to approximately -1.2 km/day, which falls in the range of those of the previous results.

In the present study, the westward or eastward propagating wave-like features are investigated in several statistical ways. The fact that the propagating features were observed both in SSTA variability and in SSHA variability, makes it possible to suppose that the two fields are closely related to each other. If correct, only SST anomalies can be used to provide informations about the wavelike features.

IV. Summary and Conclusion

Semi-monthly averaged sea surface temperature distributions were made using NOAA/AVHRR data for six years from 1990 to 1995. To relate SST variations with SSHA, spatial and temporal anomalies of SST fields were derived, and then two fields were used to investigate temporal variations of the spatial structures in the East Sea. Time variation of SSHA and SSTA in the East Sea showed a characteristic westward propagation similar to wavelike features. This propagation is convinced in several ways by the results from analyses by statistical methods as well as the dataset itself. As a result of tracking the maximum fronts with time and space, the maximum front near 138°E appeared to propagate westward at 1.2 km/day speed. These westward propagating features were also detected in the two-dimensional autospectra of a time series of maximum horizontal gradient magnitudes. Its maximum energy moves to the minus wavenumber domain, which means a westward direction. To clarify this propagation, the TOPEX altimeteric SSHA data as well as SSTA were used in the spectral analysis and autocorrelation study. The two dimensional time-zonal autocorrelations along every integer latitude also exhibits westward propagation. Similarly, the three dimensional autocorrelation also represents the westward propagation of the horizontal SSHA as well as SSTA at a speed of approximately 1-2 km/day.

Accordingly it indicates that the SSTA variations with time has a close relation with the temporal variations of sea level anomaly, which can give an implication of a certain interrelation between the SSTA with the underlying baroclinic eddy-like features in the East Sea. It suggests a possibility that the westward propagation phenomenon may be an indirect evidence of the baroclinic Rossby wave which was not observed in the East Sea so far. Halliwell and Cornillon(1991) found that the SST anomaly features propagated westward in the Sargasso Sea using the six year SST data of 1982 through 1988, and mentioned that SST anomaly features propagated westward in a manner consistent with theoretical zonal dispersion properties of first-mode baroclinic Rossby waves, suggesting that the anomalies may be coupled to a field of wavelike eddies. However it is not clear in this study whether the Rossby waves can directly account for the westward propagation because of the complex circulation in the East Sea. Thus, other studies such as numerical model experiments should be preceded to simulate and interpret systematically these wavelike features in the East Sea.

References

Halliwell, G. R. JR. and P. Cornillon, 1991, Westward-Propagating SST Anomaly Features in the Sargasso Sea, 1982-88, J. Phys. Oceanogr. Vol.21, p635-649.