Zonal distribution features of high frequency planetary waves in the oceans derived from satellite altimeter data

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Abstract

Based on TOPEX/Poseidon (T/P) and ERS-1 and 2 satellite altimeter data between October 1992 and December 2000, high frequency oscillations with periods less than 150 d are analyzed and their spatial distributions are described. The ratio, instead of the energy itself, of the energy corresponding to certain frequency band from power spectrum relative to the total energy in the 20~143 d range is analyzed. The results show that the period of the most energetic oscillations in this band increases with latitude from about 1 month near the tropics to about 4 months near 30°, in agreement with the latitudinal dependency of the phase speed of westward propagating long Rossby waves,which dominate the variability in those latitudes.As a result,the global spatial distributions of the period of the dominant oscillations are largely zonal, with relatively small differences between different ocean basins. It suggests that the oscillations with periods around 60 d are mainly associated with planetary Rossby waves except the often regarded as tidal aliasing.

Key words: zonal distribution features, Rossby waves, altimeter

1 Introduction

The availability of nearly 9 a of high quality sea level anomaly(SLA) data from satellite altimeters makes it now possible to estimate the dominant signals of variability in the global ocean more accurately than was previously possible. Moreover, merging the T/P and ERS-1 and 2 altimeter data through an advanced global objective analysis can greatly improve our ability to accurately estimate oceanic variability compared with using a single altimeter (Boulager and Menkes, 1995). The altimeter data reveal the dominant role of planetary Rossby waves in oceanic variability and the propagation speed of these waves can be compared with theory(Chelton and Schlax, 1996; Cipollini et al.,1997). Previous studies using altimeter data focus on the analysis of regional(Ducet et al., 2000; Fu et al., 2001; Gtill, 1982; Hirose and Ostrovskii, 2000) or global(Killworth et al., 1997; Kuragano and Kamach, 2000) variabilities, and, to a large extent, focus on the long-term time scales. A few studies focus on high frequency variations, such as the 25-d period of oscillations in the Argentine Basin (Li et al.,2002), or 1 month period of oscillations in the Pacific north equatorial region(Liu and Wang, 1999). The oscillation with the period of 90 d is discussed(McPhaden, 1991) with 3 a of SLA data and focus on the tropical Pacific. Studies of the time-space scales of oceanic

variability(Polito and Cornillon,1997;Polito et al.,2001) are often based on decorrelation calculations using 3~4 a of data. Here, full spectral analyses of longer records are made in order to try to discuss the following questions: what are the dominant high frequency signals in the global ocean? and what are their spatial distributions? Can all the signals with the period near 60 d be simple and often regarded as tidal aliasing?

2 Results and discussion

The analyzed global altimeter data are from October 22,1992 to December 29,2000 with a space resolution of (1/2)°×(1/2)° (The original data were (1/4)°×(1/4)°)(Boulager and Menkes,1995) so that 3 000 d long time series are available at each grid point. Each time series is divided into 3 pieces, three power spectra (PS) are calculated at each grid point, and then averaged for improving its reliability. Only os cillations with periods less than 150 d, that is high frequency planetary waves, are considered here.

Since the propagation of planetary waves in the above range of frequencies is limited to low and mid-latitudes (White and Heywood, 1995), we mainly focus here on the area between 40°S and 40°N.From the averaged PS at each grid point, the period corresponding to the most energetic peaks within the above high frequency band is identified;the spatial distribution of those peaks are shown in Fig.1. Since the ocean variabilities are corresponding to the red-spectrum, that is, it has more energy at lower frequency in the PS, the zonal structure is still striking. In the north tropical Pacific area of(4° ~8°N,120°~150°W), the 1-month period signal is dominant; such oscillations associated with tropical instability waves due to the large-scale shear of the zonal equatorial current system are well known (Liu and Wang, 1999; Wunsch,

1991; Wunsch and Stammer, 1995). Otherwise, the dominant period increases from the equator to the mid-latitude zones. Also note that the 2-month period oscillations dominate coastal regions, possibly due to tidal aliasing and altimeter accuracy problems there. However, it is also likely that short-term wind-driven variations are important and often observed in shallow regions.

Calculations of the statistical significance of the dominant peaks indicate that almost all the peaks are significant within at least 80% confidence intervals and much of the low and mid-latitude peaks are significant within 90% ~95% confidence intervals (not shown). As typical examples,the PS at four different latitudes in the Pacific Ocean are shown, as well as 90% confidence intervals for the most energetic peaks (see Fig.2). These four locations represent the tropical east Pacific, with a peak period of 34 d and other energetic peaks with periods of 20~50 d (see Fig.2a), the western North Pacific near the origin of the Kuroshio, with an eminent peak period of 61 d (see Fig.2b), and the central South and North Pacific Ocean, with peak periods of 91 d (see Fig. 2c) and 143 d (see Fig. 2d), respectively.

The most energetic peak of PS is related to the wave of a certain frequency. It is more reasonable to analyze the energy of a frequency band for the research of planetary waves. However, the energy of a frequency band changes so much for different locations, for example, they are always much higher along the Kusoshio,the Gulf Stream and the Arctic Circumpolar Current than those in other regions. The previous works which focus on the spatial distributions of energy show the active regions of the global ocean. But the information of the Rossby waves is lost at the point of low energy. Here the relative energy is introduced as follows. We divide each spectrum into four frequency bands corre sponding to 20~48, 50~71, 77~100 and
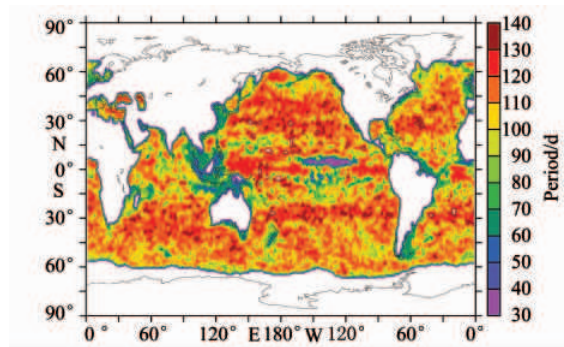
Fig. 1. Spatial distribution of the periods of the
most energetic peaks obtained from power spectra of
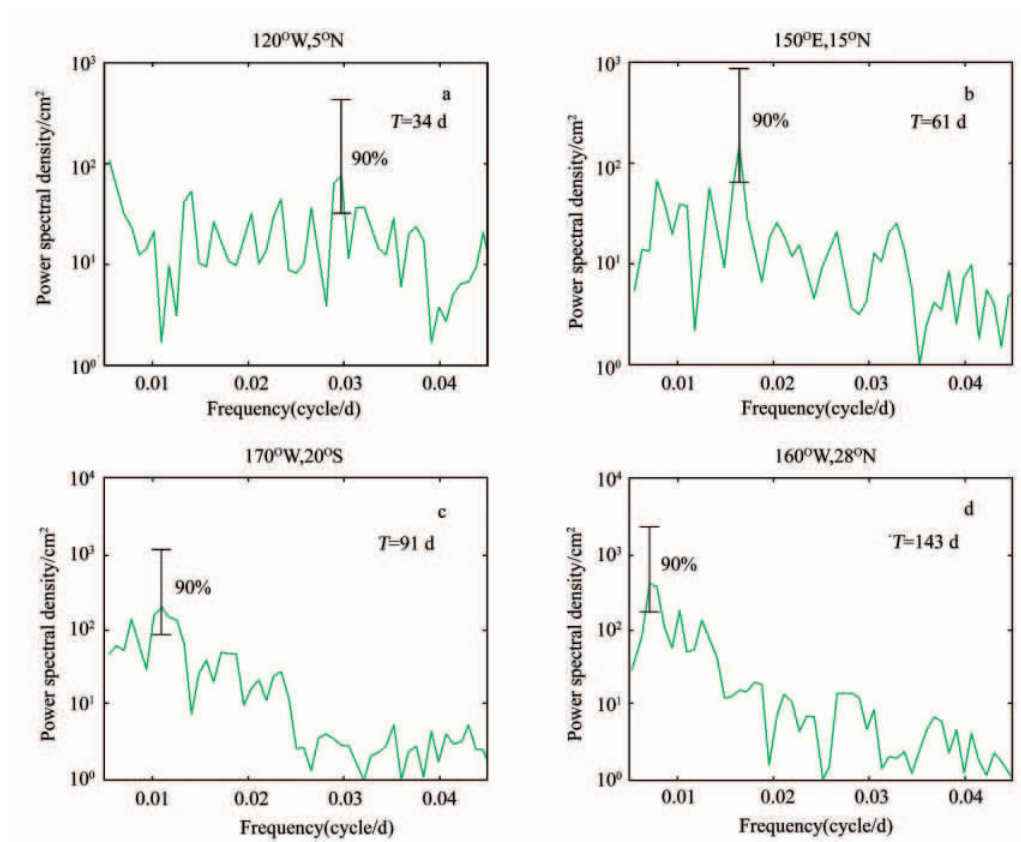over 8 a of altimeter data and shown on a 2°×2° grid.

Fig. 2. The power spectral density at four different points (the location is indicated at the top of each panel).
A vertical error bar indicates a confidence interval of 90%.

111~143 d periods(which represent about 1-, 2-, 3-, and 4-month oscillations) and calculate the energy in each band relative to the total energy in the 20~143 d range, E_t. These ratios, $E_1/E_t, E_2/E_t, E_3/E_t$ and E_4/E_t are shown in Fig.3. The 1-, 2-, 3- and 4-months oscillations dominate the energy around 7°N(S), 14°N(S), 21°N(S) and 28°N(S), respectively. Energy in the tropical ocean from 8°S to 8°N, with 1-month period oscillations, is partly the result of the tropical instability waves and strong air-sea interactions (Wunsch and Stammer, 1995). However, from the tropics to the mid-latitudes the shift of energy to longer scales seems to be consistent with the behavior of long Rossby waves.In the high frequency ranges discussed here, the wave length of long Rossby waves decreases with increasing latitudes, but the phase speed of the waves decreases much faster with increasing latitudes (Chelton and Schlax,1996;Yu et al.,1995), so the dominant period associated with Rossby waves should increase from low to high latitudes.For example, if we make a rough estimate of scales from the data,we find a typical wave length and speed of 800 km and 0.14 m/s at 15°N, which corresponds to a period of about 2 months, and a wave length and speed of 550 km and 0.05 m/s at 35°S which corresponds to a period of about 4 months, in agreement with Fig.3. Zonally averaged energy ratios are shown in Fig.4. An interesting phenomenon is the asymmetry of the energy ratio between the Northern and Southern Hemispheres, such that oscillations with periods of 1 and 3 months are relatively more energetic in the Northern Hemisphere while oscillations with periods of 2 and 4 months are more energetic in the Southern Hemisphere. The meridional asymmetry of tropical instability waves is known(Wunsch, 1991), but further study of this asymmetry in mid-latitudes and how it may relate to meteorological differences or oceanic stratification differences

are beyond the scope of this study.

Another question is whether the period of the dominant oscillations increases continuously with latitude. Let

$$A_k(x,y)=\frac{PSD_k(x,y)}{\sum_j PSD_j(x,y)},$$

$$B_k(y)=\frac{1}{1440}\sum_{i=1}^{1440} A_k(x_i,y),$$

$$C_k(y)=\frac{\mathrm{d}}{\mathrm{d}T}B_k(y),$$

where $PSD_k(x,y)$ is the power spectrum density corresponding to a certain period number k; T is period. From the distribution of $C_k(y)$ (see Fig.5), it is obvious that the period of the dominant oscillations increases continuously with latitude. That the peak corresponding to the period of 60 d exists at all latitudes suggests that it is tidal alaising,but the oscillations around 14°N(S) are Rossby waves except tidal aliasing.

Because of the long repeat cycle of the altimeters, analyses of high frequency oscillation using altimeter data may not be simple and often regarded as tidal aliasing, in particular, for periods around 60 d(Killworth et al., 1997; Schlax and Chelton, 1994; Stammer, 1997). And the wave amplitude with periods around 60 d is 10 cm or so near 14°N(S) while the tidal aliasing is 2~3 cm. The zonal distribution features also suggest, however, that high frequency oscillations in this range are mainly associated with planetary Rossby waves around 14°N(S) in most of the open ocean.For the coastal regions where tidal aliasing may affect the accuracy of analysis, further research is needed.

3 Conclusions

The present work focuses on high frequency variabilities and their spatial distributions in the global ocean,as obtained from spectral anal-
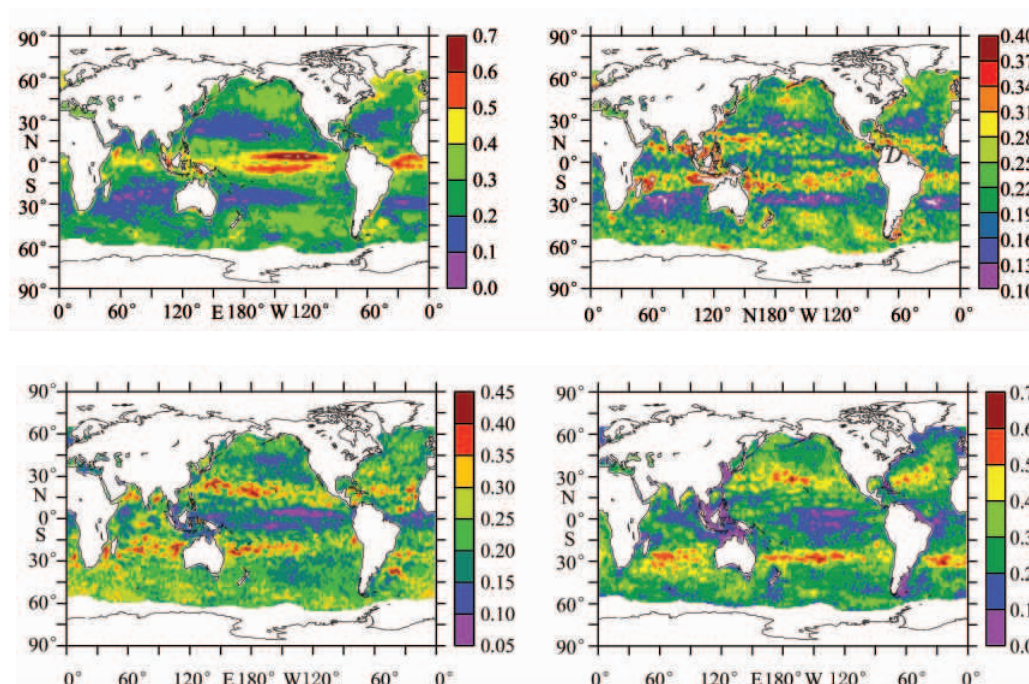
Fig. 3.   Global distributions of the energy at four period bands (from top to bottom):
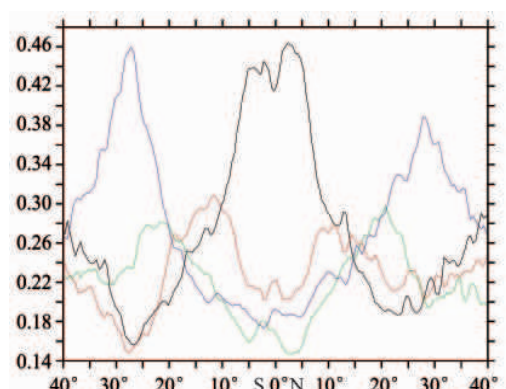20~48, 50~71, 77~100 and 111~143 d, relative to the total energy.

Fig. 4. Zonally averaged distributions of the energy ratio
(the same as in Fig. 3).

Fig. 5.   The distribution of $C_k(y)$.

yses of more than 8 a of altimeter data. These relatively short-period oscillations are strikingly zonal in their dominant periods, and seem to closely relate to the latitudinal changes of the phase speed of the long Rossby wave. The period of the most energetic peaks in the data in-
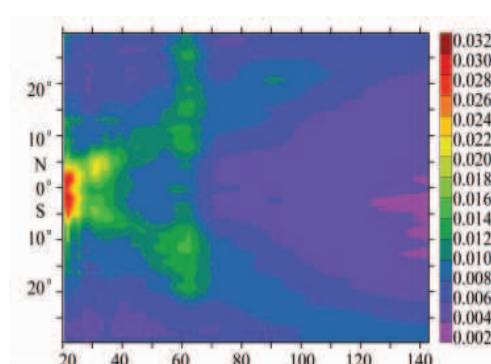
creases from about 1 month near the tropics to about 4 months in mid-latitudes. More work is needed to asses high frequency variability in coastal regions where problems associated with tidal aliasing and altimeter data errors are larger.

The oscillations with periods around 60 d

may not be regarded as tidal aliasing, especially around 14°N(S). And the energy ratio is asymmetrical between the Northern and Southern Hemispheres.

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