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Spectra of the deep currents southeast of Okinawa Island

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Abstract : The kinetic energy spectra are shown with three current meter records obtained above the continental slope southeast of Okinawa Island from November 1991 to September 1992. The mean velocity is almost parallel to isobaths except just above the bottom where it is indistinguishable from zero. The eddy kinetic energy is higher than the mean kinetic energy. On most time scales it is higher in the along-isobath than cross-isobath directions. The dominant eddy kinetic energy range shifts toward shorter time scales with increasing depth.

1. Introduction

There are many studies on the low frequency fluctuations with long-term current meter records (e.g., MODE group, 1974; LUYTEN, 1977, 1982; RICHMAN *et al.*, 1977; SCHMITZ, 1978; WUNSCH, 1981; FU *et al.*, 1982; IMAWAKI and TAKANO, 1982). These studies show marked spatial inhomogeneity in properties of the eddy field depending on the depth and geographical location. In the MODE region the mesoscale (20 to 150 days) fluctuations are dominant at 4000m depth, while the secular scale (longer than 150 days) fluctuations are dominant at 500m depth, but at a site near the Gulf Stream in the POLYMODE region the mesoscale fluctuations are dominant at both 600m and 4000m depths (SCHMITZ, 1978). At a deep layer in the western North Pacific, the eddy field is characterized by three time scales; annual scale with zonal dominance of the eddy activity, temporal mesoscale with meridional dominance and monthly scale with horizontal isotropy, and about two thirds of the eddy kinetic energy is contained in the temporal mesoscale (IMAWAKI and TAKANO, 1982). Eddy resolving gyre-scale numerical models (e.g., HOLLAND and LIN, 1975a, b; SEMTNER and CHERVIN, 1992) also show marked spatial inhomogeneity in eddy properties, which seem to be controlled by the eddy-mean flow interaction and the upper, lower and lateral boundary processes.

Three current meter moorings were deployed to the southeast of Okinawa in November 1991 and recovered in September 1992 by the R/V Shijian of the State Oceanic Administration in the framework of a Sino-Japan cooperative study. It is a preliminary step toward clearer understanding of the current structure above the continental slope in the region around the Ryukyu Islands where so far there have been very few long-term current measurements. The present paper describes low frequency fluctuations which other papers (TAKANO *et al.*, 1994; YUAN *et al.*, 1994, 1995) are not concerned with.

2. Velocity data

The locations of three moorings OA, OB and OC are shown in Fig. 1 with the bottom topography. Six time series of velocities from moored current meters (Aanderaa RCM-5) with sampling intervals of one hour were obtained, but usable series longer than one month are only three; at 1890m depth at OB, 2000m and 4500m depths at OC (hereafter abbreviated to OB (1900), OC (2000) and OC (4500)). The details of the current measurements and some results are given in another paper (TAKANO *et al.*, in preparation).

Figure 2 shows stick diagrams of the daily mean deviations of the 25-hour running mean velocities from the velocities averaged over the whole measurement periods at OB(1900), OC

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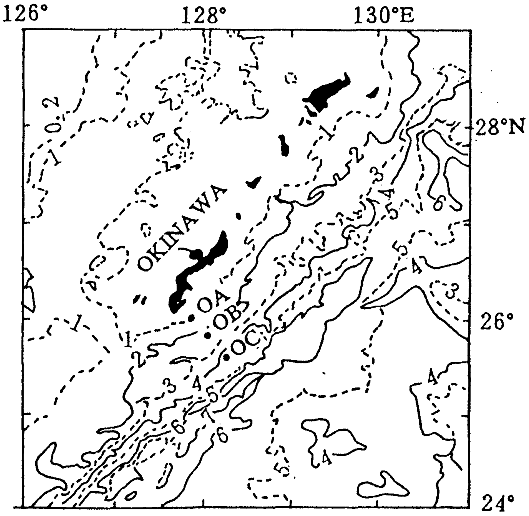

Fig. 1. Locations of moorings OA, OB and OC with bottom topography (depth in km).

(2000) and OC (4500). At OB (1900), the speed and direction of the deviations frequently change with time, except for the first two months when the southwestward deviation is prevailing. The maximum magnitude is smaller than 10 cm/s. It is still smaller at OC(4500) and the direction is more variable than at OB (1900). At OC (2000) the maximum magnitude is more than 10 cm/s. The deviations are better organized, which are directed mostly to the south to southwest in November 1991 and after May 1992, and to the north from December 1991 to April 1992. As expected, they appear to be parallel rather than perpendicular to isobaths.

3. Low frequency fluctuations

Eddy kinetic energy spectra

The Godin filter (GODIN, 1972) suitable for dealing with low frequency fluctuations (IMAWAKI, 1986) is first applied to the data to remove the tidal and inertial oscillations, and then the time series subsampled at intervals of 1 day are analyzed. Table 1 shows statistics of the data after low-pass filtering. On account of topographic directivity at the mooring sites and apparent dominance of the along-isobath component of velocity in Fig.2, the velocity is broken down into two components in the along- and cross-isobath directions (45° and 315° from the north). The eddy kinetic energy of the two components are denoted by subs A and C as K_{EA} and K_{EC}. The mean current is indistinguishable from zero at OB (1900), northeastward with a speed of 2.9 cm/s at OC(2000), and south-southwestward with a speed of 1.3 cm/s at OC (4500). The eddy kinetic energy is much higher than the mean kinetic energy at OB (1900), and about two times larger at OC (2000) and OC (4500).

The raw spectra of the first 256-day records are calculated with FFT and smoothed over four

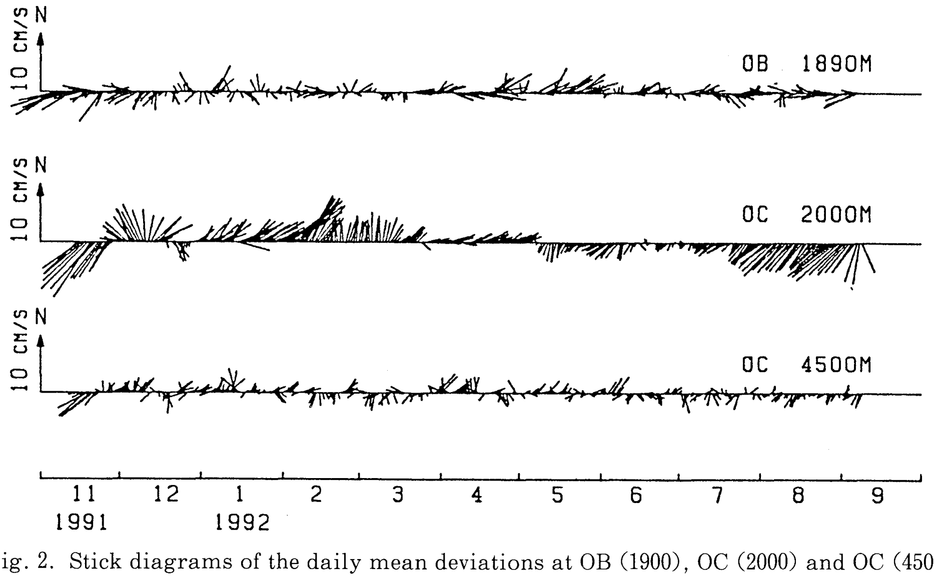

Fig. 2. Stick diagrams of the daily mean deviations at OB (1900), OC (2000) and OC (4500).

Table 1. Along- and cross-isobath components (U,V) of time-average velocity at OB and OC, variances S_U^2, S_V^2, mean and eddy kinetic energies K_M, K_E and the ratio K_E/K_M.

Location		Water depth(m)	Meter depth(m)	Length (days)	U (cm/s)	S_U^2 (cm²/s²)	V (cm/s)	S_V^2 (cm²/s²)	K_M (cm²/s²)	K_E (cm²/s²)	K_E/K_M
OB	25°48′ N 128°03′ E	2020	1890	307	−0.03	5.7	0.09	2.9	(0.005)	4.3	(800)
OC	25°34′ N 128°20′ E	4630	2000	298	2.9	18.7	0.08	2.5	4.3	10.6	2.4
			4500	298	−1.2	2.6	−0.7	1.1	0.9	1.8	1.9

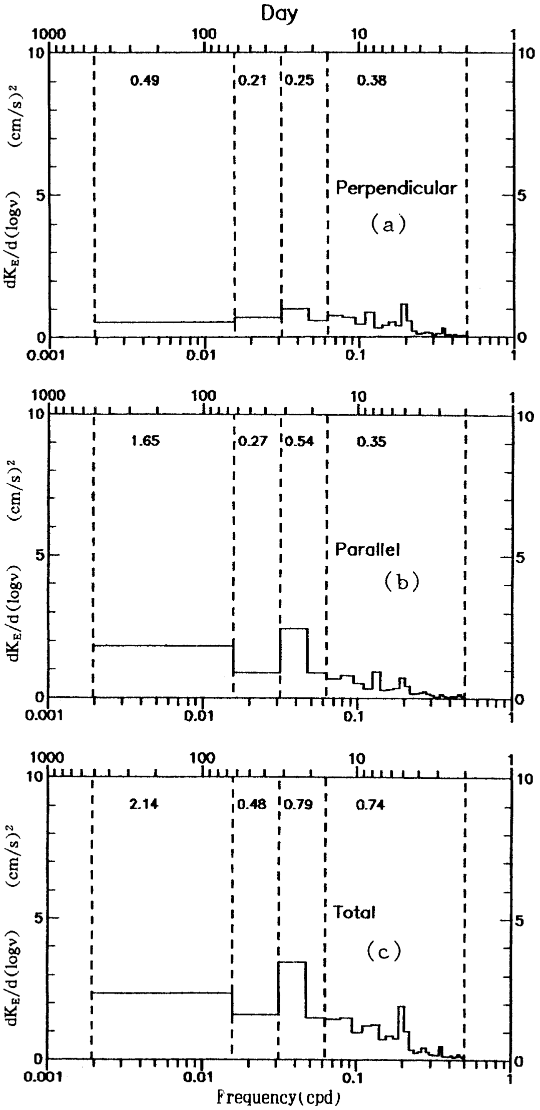

Fig.3. Frequency (ν) spectra for the low-frequency eddy kinetic energy per unit mass at OB (1900) in variance-preserving form. (a) cross-isobath spectrum; (b) along-isobath spectrum; (c) total spectrum.

period bands; 2–16 days, 16–32 days, 32–64 days and 64–512 days. The spectrum freedom is 8. The 95% confidence limits are 0.46 to 3.67 times the individual estimates. The spectra are plotted in variance-preserving form in Figs. 3 to 5, where the energy per unit mass is shown in each period band. Table 2 lists the ratio of the kinetic energy in each band to the total energy integrated over the four bands, and the ratio K_{EA}/K_{EC}.

The upper panel of Table 2 shows that at OB (1900) and OC (2000) more than half of the total eddy kinetic energy is in the band of 64–512 days. While only 3% of the total energy is in the band of 2–16 days at OC (2000), about half of the total energy is in the band of 2–16 days at OC (4500). In IMAWAKI and TAKANO (1982), however, a very small fraction of the total eddy kinetic energy is in the band of 2–16 days at 5000m depth at a site 6200m deep. At OB (1900) where the bottom is 2020m deep, 18% of the total energy is in the band of 2–16 days. The kinetic energy on scales longer than 32 days amounts to 63% of the total energy at OB (1900), 85% at OC (2000) but only 30% at OC (4500). These figures might indicate that the dominant energy range shifts toward shorter time scales with increasing depth, in particular, near the bottom. This agrees with a result by SCHMITZ (1978) in the MODE region, but does not with another result of his at a site near the Gulf Stream.

The lower panel of Table 2 shows that the eddy activity is more enhanced in the along-isobath direction than in the cross-isobath direction except at OB (1900) and OC (2000) in the band of 2–16 days where it is almost isotropic. At OC (2000) far from the sea surface and the bottom, the K_{EA} is monotonically increased with period and much larger than the K_{EC} on time scales longer than 32 days. At OB

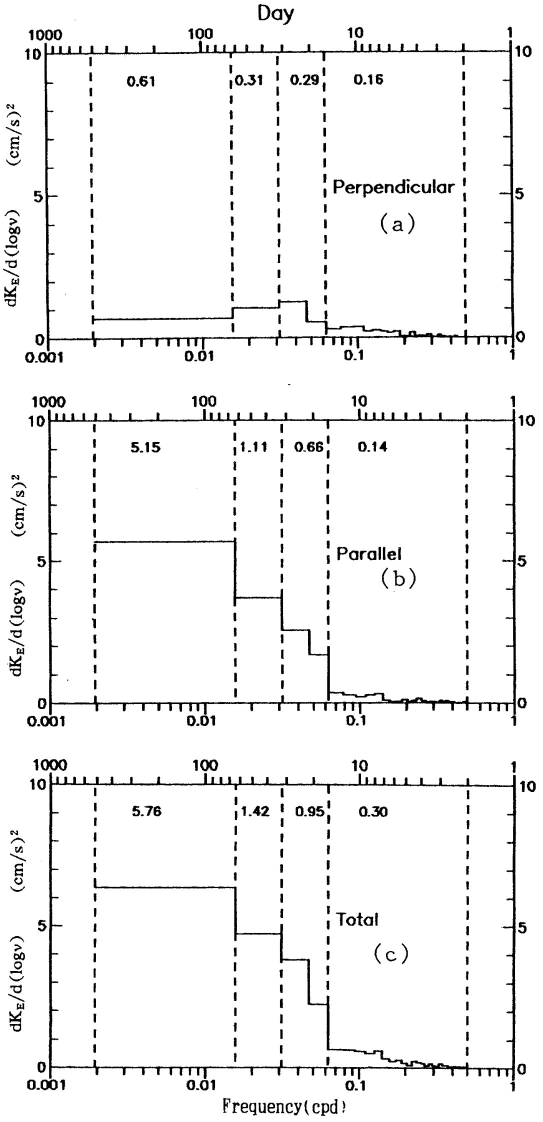

Fig.4. Same as Fig. 3 except for OC (2000).

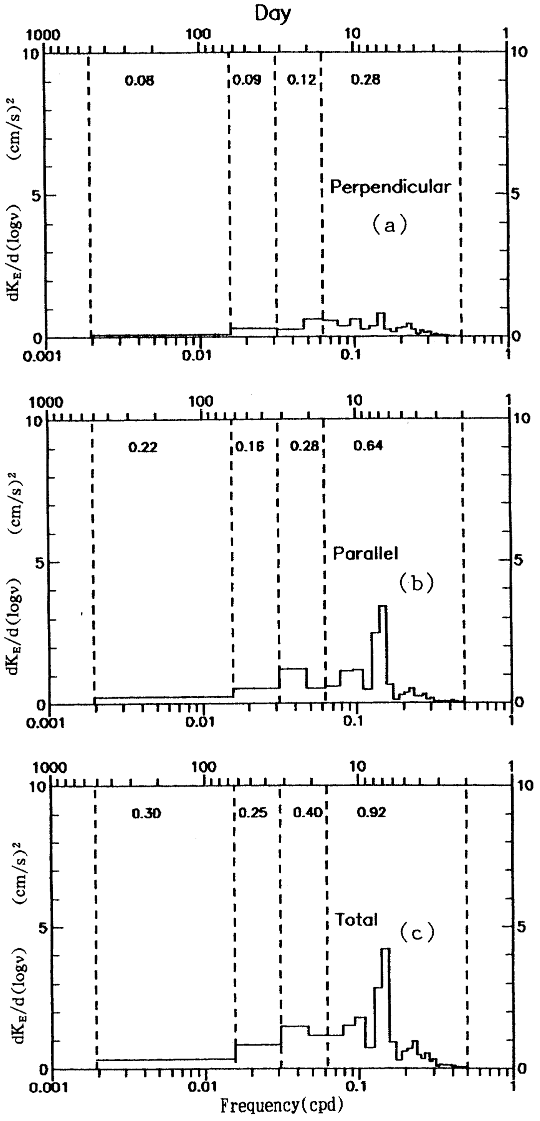

Fig.5. Same as Fig. 3 except for OC (4500).

Table 2. Ratio(%) of the kinetic energy in each period band to the total kinetic energy (upper panel) and ratio K_{EA}/K_{EC} (lower panel).

	Period (days)			
	2–16	16–32	32–64	64–512
OB(1900)	18	19	12	51
OC(2000)	3	11	17	68
OC(4500)	49	21	13	16
OB(1900)	0.92	2.2	1.3	3.4
OC(2000)	0.87	2.3	3.6	8.4
OC(4500)	1.3	2.3	1.8	2.8

(1980) near the bottom, the ratio KEA/KEC at each period band and its increase or decrease with period are similar to those at OC (4500). This suggests the importance of the location relative to the bottom. If both K_{EA} and K_{EC} are integrated over the four period bands, the ratio of the former to the latter is 2.1 for OB (1900), 5.2 for OC (2000) and 2.3 for OC (4500).

Maximum entropy energy spectra

The maximum entropy spectra (MCDONOUGH,

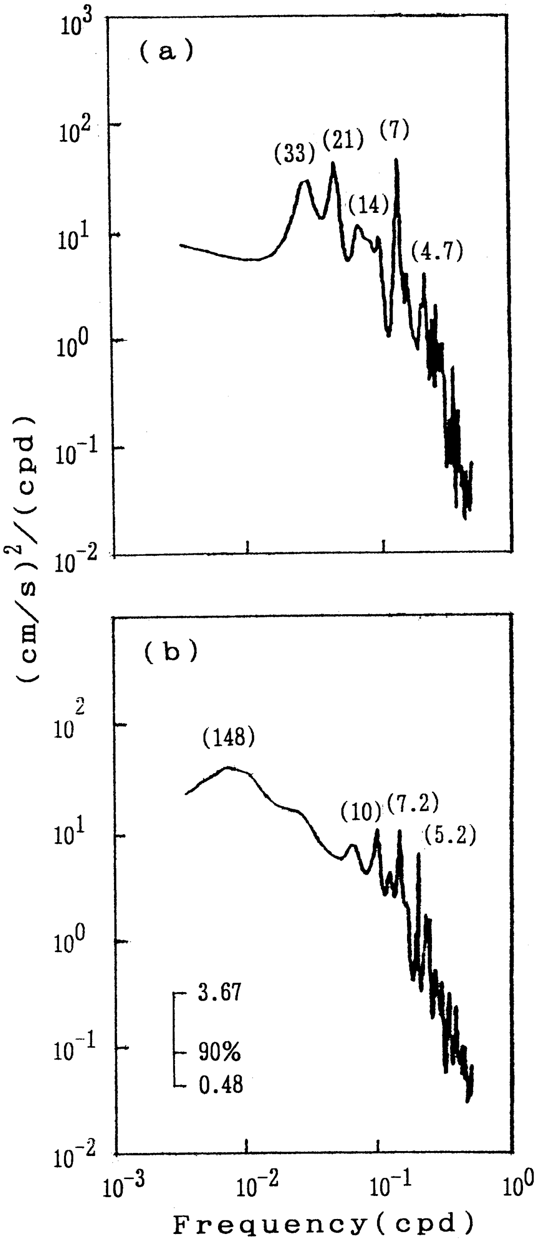

Fig. 6. Maximum entropy spectral estimates at OC (4500). (a): clockwise, (b): anticlockwise. Numerals in parentheses indicate periods (in days) at nearby peaks.

1974) with a degree of freedom of 6 show many small peaks on the time scales of 3 to 148 days, but under the 90% confidence limit only two at OC (4500) are significant (Fig.6); one at 7-day period in the anticlockwise spectrum and the other at 5-day period in clockwise spectrum. This is consistent with previous results that the kinetic energy is mostly contained in shorter time scales at deeper layers.

The squared coherence between two of the three series of velocities is estimated, which is all under the 90% confidence level. There is no significant coherence.

4. Remarks

As preliminaries, a small number of current meters were deployed at an area where the bottom topography is well oriented. The data retrieval rate was unexpectedly poor. Although solid conclusions are not drawn from such a limited amount of data, spatial inhomogeneity of the eddy activity above the continental slope southeast of Okinawa is shown with spectral analysis.

The dominant energy range appears to shift toward shorter time scales with depth, in particular, near the bottom, while the total eddy kinetic energy considerably decreases with depth.

Except at OB (1900) and OC (2000) for the band of 2–16 days, the K_{EA} is much larger than the K_{EC}. The ratio K_{EA}/K_{EC} depends on the location and the time scale. If the spatial scale of the fluctuation is much larger or much smaller than the characteristic scale of the bottom topography, the ratio K_{EA}/K_{EC} will be little affected by the bottom topography. If both are of the comparable order of magnitude, it will be seriously affected and the directivity of the eddy kinetic energy will be enhanced. Since the spatial scale is related with the time scale, there might be some relationship between the optimum time scale for a large K_{EA}/K_{EC} and the characteristic scale of the bottom topography. This scale-selective mechanism of the energy partition in the along-isobath and cross-isobath directions seems to be dependent on the height above the bottom.

More current meter data are expected to provide further information on the distribution of the eddy kinetic energy as a function of depth and time scale and its directional repartition relative to the bottom topography.

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