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A topographic Rossby wave off Ashizuri Point*

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Abstract: A current measurement was carried out at a station on the continental shelf off Ashizuri Point in Shikoku, Japan from September to December, 1981. The current velocity fluctuation with a period of 10.6 days was prominent in the upper and lower layers. This fluctuation, more remarkable in the lower layer than in the upper layer, is considered to be due to a bottom trapped topographic Rossby wave whose wave length is 66.8 km and whose phase speed is 7.3 cm s^{-1}.

1. Introduction

It has been widely known that the persistent low frequency variabilities in sea level and horizontal velocities with periods of several days exist along the Japanese coast. SHOJI (1961) and ISOZAKI (1969) pointed out that a sea level variation propagates from north to south along the Pacific coast of Japan Island looking the coast to the right hand. ENDO (1968) found that sea level variabilities have periods of 15 days along the Pacific coast and of 7.5 days along the Japan Sea coast. KUBOTA et al. (1981) analyzed current velocity data along the Fukushima coast and confirmed the existence of periodical fluctuation whose period was about four days and whose amplitude was about 20 cm s^{-1}. That current fluctuation propagated southward with a phase speed of about 1 m s^{-1}. KUBOTA (1982) showed that such fluctuations were due to the second or third mode shelf waves and discussed a generation mechanism of shelf waves by the wind. So far the low frequency variabilities along the Japanese coast have been attributed to the topographic long Rossby wave with wave length of several hundreds or thousands kilometers. However, it has been never discussed the existence of topographic Rossby wave with short wave length of several tens of kilometers along the Japanese coast yet.

In the present study I shall analyze the current velocity data obtained on the continental shelf off Ashizuri Point in Shikoku, Japan from September to December, 1981, and discuss the characteristics of low frequency current fluctuation with periods of about 10 days.

2. Observation and data processing

The current measurement was carried out at Stn. T-1 (32°39′06″N, 132°51′27″E, 135 m deep) on the continental shelf off Ashizuri Point in Shikoku, Japan as shown in Fig. 1. Two Aanderaa RCM 4 current meters were moored 30 m below the sea surface (hereafter referred

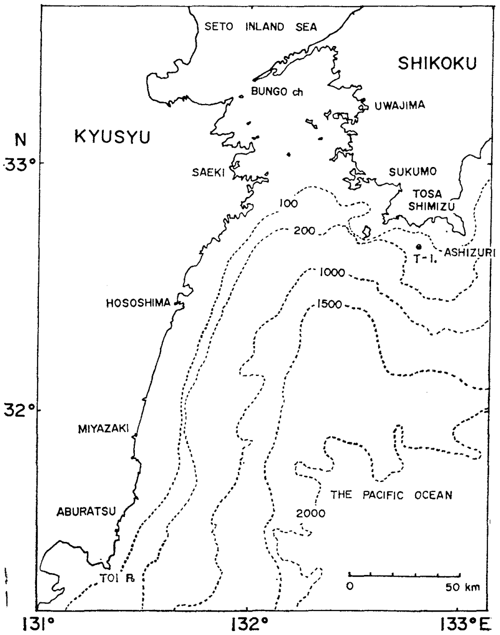

Fig. 1. Current measurement station. Numbers show depths (m).

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to as upper layer) and 35 m above the bottom (hereafter referred to as lower layer). Water temperature, salinity, current direction and speed were recorded every 15 minutes from September 16 to December 23, 1981.

The vertical profiles of water temperature, salinity and density at Stn. T-1 on September 17, 1981 are shown in Fig. 2. The prominent density stratification existed 50–70 m below the sea surface, so that the current meters were set above and below pycnocline. At first, one-hour average data were obtained and all data were processed by a Cosine-Lanczos filter ($p=0.6$ and a half power point is 2.2 days) in order to cut off short period fluctuations mainly due to semi-diurnal and diurnal tidal currents and internal oscillations. The low-passed data prepared in this way will be discussed as basic data set. The eastward and northward components of the low-passed velocity data and water temperature data are shown in Fig. 3. Salinities in both layers are nearly constants throughout the observation period and are not shown here. The raw

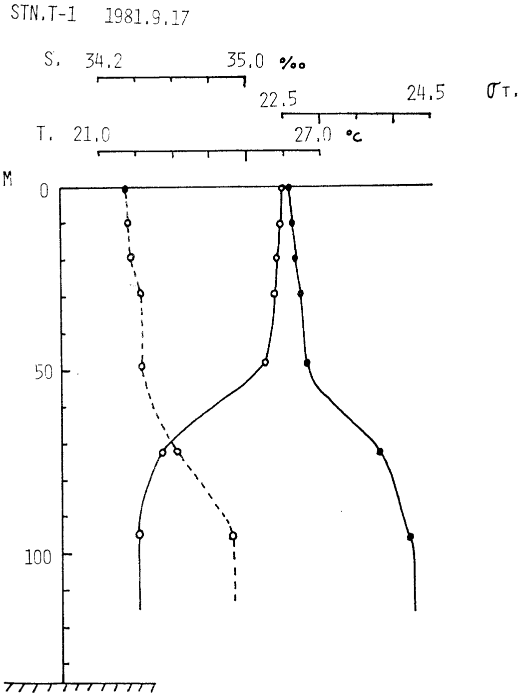

Fig. 2. Vertical profile of water temperature (open circle and solid line), salinity (open circle and broken line) and density (solid circle and solid line) at Stn. T-1 on September 17, 1981.

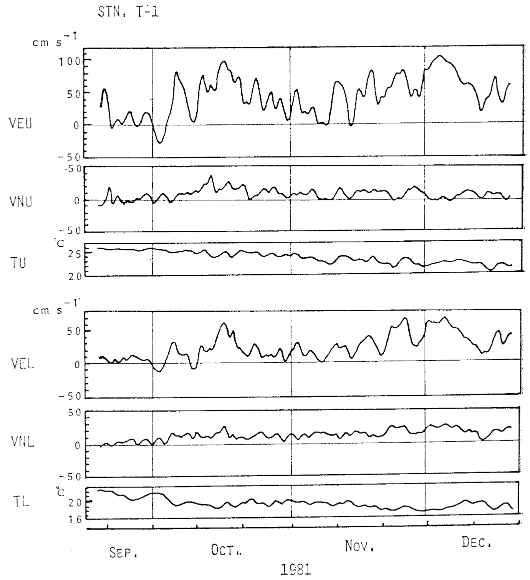

Fig. 3. Low-passed eastward (VE), northward (VN) velocity components and water temperature (T) in the upper (U) and lower (L) layers.

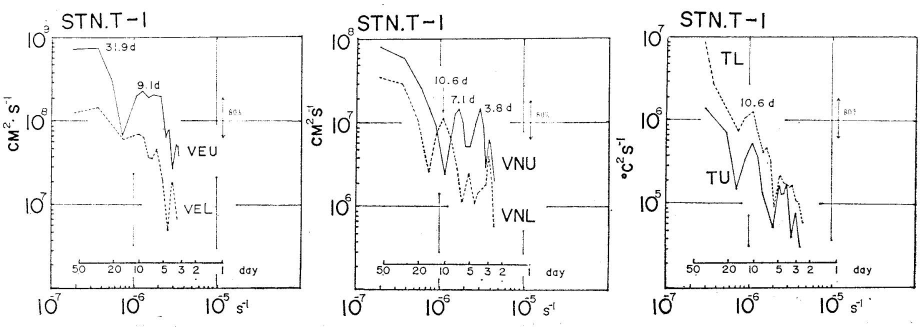

Fig. 4. Power spectra for the eastward velocity (left), northward velocity (center) and water temperature (right) in the upper and lower layers.

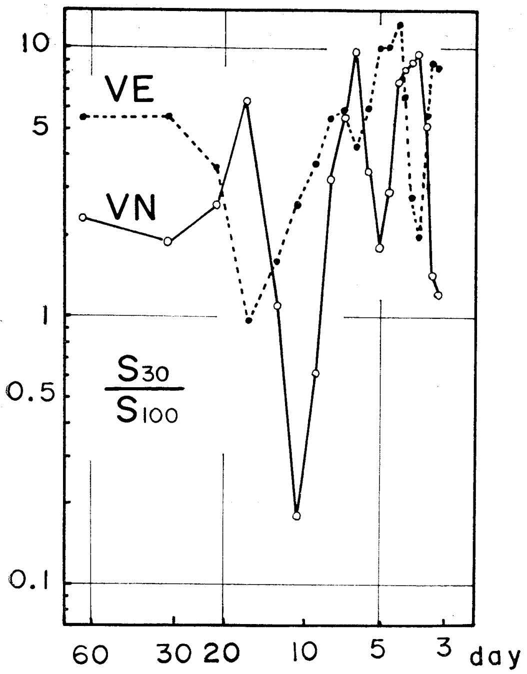

Fig. 5. Ratio of energy of current velocities at 30 m and 100 m depths from Stn. T-1.

data are shown in a previous paper (YANAGI, 1984). The low-passed eastward component is stronger in the upper layer than in the lower layer. On the other hand, the northward components in both layers have almost the same magnitude. We can easily identify in Fig. 3 the dominant variations with periods of several to several tens of days. The spectra for the eastward and northward velocity components and water temperature in both layers are presented in Fig. 4. The fluctuations with periods of around 10 days are dominant in all data. The energies of velocity fluctuations are larger in the upper layer than in the lower layer except for a period of 10.6 days in the northward velocity component. In Fig. 5 are plotted the ratios of the energy in the upper layer to that in the lower layer for the eastward and northward components. While low and high frequency fluctuations are more energetic in the upper layer, intermediate frequency fluctuations of periods around 10 days are more energetic in the lower layer. Water temperature fluctuations are stronger in the lower layer than in the upper layer. The fluctuation with a period of 10.6 days is dominant in both layers. The coherence and phase difference between the fluctuations of the northward velocity and water temperature in the lower layer are shown in Fig. 6. A high coherence square of 8.2 is observed for the fluctuation of a period of 10.6 days with phase difference of around 180°. This fact shows that the water temperature decreases when the northward current is strong in the lower layer.

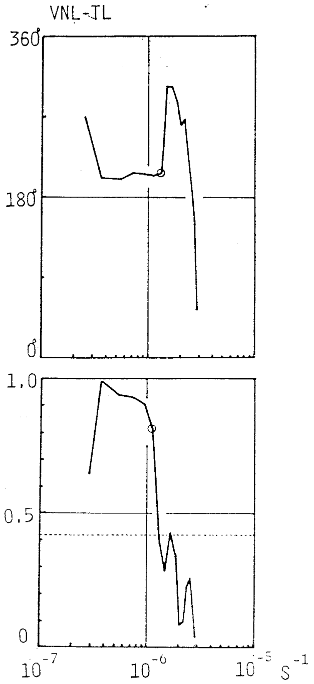

Fig. 6. Phase difference (upper) and coherence square (lower) between the fluctuations of the northward velocity and water temperature in the lower layer at Stn. T-1. Open circle denotes the fluctuation of period of 10.6 days and broken line a confidence limit of 90 %.

Then I shall investigate the characteristics of 10.6-day fluctuation for the water temperature and for the northward component velocity in both layers.

3. Discussions

The current velocities averaged over the observation period and the current ellipses with a period of 10.6 days in both layers are shown in Fig. 7. The average speed in the upper layer is about 1.5 times as large as that in the lower

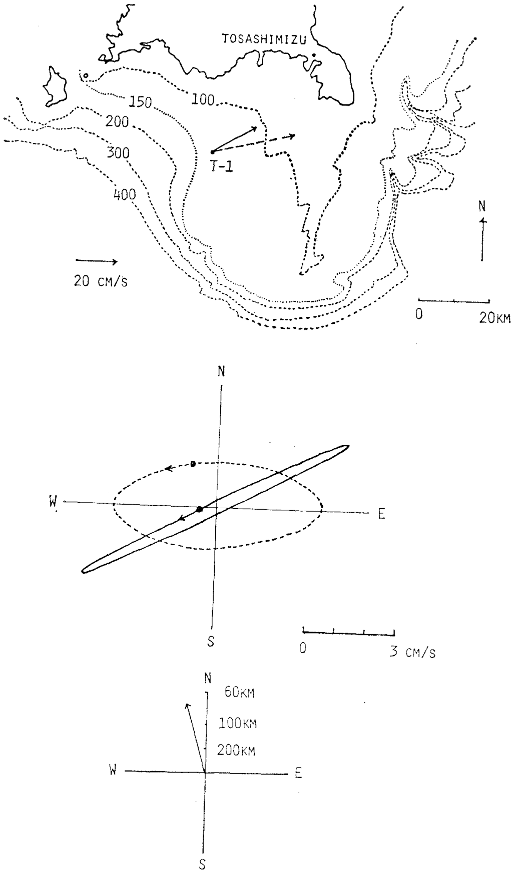

Fig. 7. *Upper panel*: Mean velocity vector in the upper layer (broken arrow) and that in the lower layer (solid arrow). *Middle panel*: Current ellipse with a period of 10.6 days in the upper layer (broken line) and that in the lower layer (solid line). Open circle on the ellipse denotes the phase at the beginning of current observation and arrow the direction of rotation. *Lower panel*: Wave number vector for bottom trapped topographic Rossby wave of period of 10.6 days.

layer. On the other hand, the amplitude of current ellipse with a period of 10.6 days in the lower layer is larger than that in the upper layer. More energetic velocity fluctuation in the lower layer suggests the existence of bottom trapped topographic Rossby wave (TOMPSON and LUYTEN, 1976).

Internal divergence parameter ε_i is defined as

$$\varepsilon_i=\left(\frac{f}{N}\cdot\frac{L}{D}\right)^2. \qquad (1)$$

Here f denotes Coriolis parameter ($7.8\times10^{-4}\,\mathrm{s}^{-1}$ at 32.6°N), N the Brunt-Väisälä frequency, L the horizontal scale and D the depth. Average Brunt-Väisälä frequency at Stn. T-1 estimated from Fig. 2 is $1.3\times10^{-2}\,\mathrm{s}^{-1}$, which gives $\varepsilon_i=0.03$ for $L=100\,\mathrm{km}$ and $D=2{,}000\,\mathrm{m}$. RHINES (1970, 1977) showed that the topographic Rossby wave tends to be bottom trapped mode in the case of $\varepsilon_i\ll1$. He gives the horizontal velocity component of bottom trapped topographic Rossby wave V by

$$V=V_0\cosh\left(\frac{\kappa N}{f}\right)z. \qquad (2)$$

Here κ is the horizontal wave number, z the vertical coordinate increasing upward from the bottom and V_0 velocity at the bottom. From Eq. (2) the ratio of kinetic energies at depth z_1 and z_2 is

$$R=\left[\frac{\cosh\left(\dfrac{\kappa N}{f}z_2\right)}{\cosh\left(\dfrac{\kappa N}{f}z_1\right)}\right]^2. \qquad (3)$$

If the physics of topographic Rossby wave holds good and z_2 is larger than z_1, R is smaller than 1.0. For evaluating R by the observation, the northward component is used because it should be less contaminated by nonlinear effect and the average flow. The ratio of kinetic energies of the northward velocity fluctuation of period of 10.6 days estimated from Fig. 5 is 0.19 at depths of 30 m and 100 m. The wave number κ and wave length obtained from Eq. (3) are $0.094\,\mathrm{km}^{-1}$ and 66.8 km, respectively. The phase velocity $C=\omega/\kappa$ of this topographic Rossby wave is 7.3 $\mathrm{cm\,s}^{-1}$. The direction of the wave number vector θ counted anticlockwise from the east is derived from FOFONOFF's (1969) formula,

$$\tan 2\theta=\frac{2S_{uv}}{S_{uu}-S_{vv}}. \qquad (4)$$

Here S_{uv} the cospectrum between the eastward and northward components, S_{uu} and S_{vv} are autospectra of the eastward and northward components, respectively. The wave number vector for the bottom trapped topographic Rossby wave with a period of 10.6 days can be estimated from Eqs. (3) and (4) and is plotted in Fig. 7.

The wave number vector is nearly along the isobathes and its phase propagates looking the coast to the right hand. The principal axis of current ellipse is nearly perpendicular to isobathes in the lower layer.

Acknowledgements

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足摺岬沖の地形性ロスビー波

柳　哲雄

要旨: 四国の足摺岬沖の大陸棚上で1981年9月～12月，長期測流観測を行った。水深60m付近に存在した密度躍層の上，下に流速計は係留された。上・下層の流速・水温とも10.6日周期の変動が卓越したが，下層のこの周期の運動エネルギーは上層のそれより大きく，波長66.8km，位相速度$7.3\,\mathrm{cm\,s^{-1}}$の海底捕捉地形性ロスビー波によってもたらされたと推定される。