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Barotropic and baroclinic volume transports of the Kuroshio estimated by IES measurements

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Abstract

Temporally averaged volume transports of the Kuroshio, south of Japan, were estimated by use of Inverted Echo Sounders and Current Meters. The barotropic and baroclinic modes of the transports were primarily introduced and the corresponding velocity components were defined. Their typical length scales across the Kuroshio of the transports were almost the same of 150 km and the barotropic transport of the Kuroshio was estimated at about 40 Sv. The length scales of the velocity components parallel with the Kuroshio flowing direction were clearly different between the barotropic and baroclinic modes, and they were estimated at 100 km and 150 km, respectively, though both of the modes were indicating the same features of coastally trapped distributions across the Kuroshio.

Key words: *barotropic transport, baroclinic transport, IES, Kuroshio, ASUKA*

1. Introduction

In physical oceanography, strong current systems, e.g. Gulf stream, the Kuroshio, Brazil Current, etc., are studied with enormous interests, because they are not only physically interesting themselves but also their effects are extended to miscellaneous fields from navigations to global climate changes. ASUKA group carried out intensive hydrographic observations of the Kuroshio, and the results allow us to analyze the structures of the velocity profiles which tightly be related to the Kuroshio volume transport.

For investigating the characteristic features of the Kuroshio transport, we elementarily applied its vertical modes to the horizontal velocity vertical profiles that are estimated as geostrophic flows modified by current velocity values at reference depths. With the geostrophic balance approximation, the component is separated into two kinds of vertical modes. One is a barotropic mode, having a constant value vertically, and another is a baroclinic mode, corresponding to the condition of isobaric and isopycnic surfaces inclined.

The Kuroshio is the western boundary current of the north Pacific and is affected by global environment, in particular, the north Pacific wind fields. In general, a barotropic mode is related to temporally fast phenomena, order of 10s days, and a baroclinic mode slow, order of seasons, years or more. In this study, we attempt to understand the Kuroshio from the viewpoint of the transport simply separated into barotropic and baroclinic modes.

2. Data and Analyses

In order to estimate the water mass and heat transports of the Kuroshio and its recirculation, intensive hydrographic observations named Affiliated Surveys of the Kuroshio off Cape Ashizuri (ASUKA)[1] were carried out from October 1993 to November 1995 in the south of Japan (Fig. 1). Inverted Echo Sounders (IES) analyzed in this study were deployed at ten stations, but the instrument moored at ES05 was not recovered. Details of the current meter (CM) and IES observations are described in other articles[2), 3)].

The IES measures a round-trip acoustic travel time between the sea floor and the sea-surface. The time is a depth integral of the inverse of the sound speed. Travel time variations reflect the depth variations of the main thermocline well, and are made possible to estimate the variations of vertical temperature profiles through a Gravest Empirical Mode (GEM) method[4]. Time series of dynamic height vertical profiles are evaluated by state equations at the IES stations (ES01-10). We also obtain the time series of velocity components normal to the observation line from the

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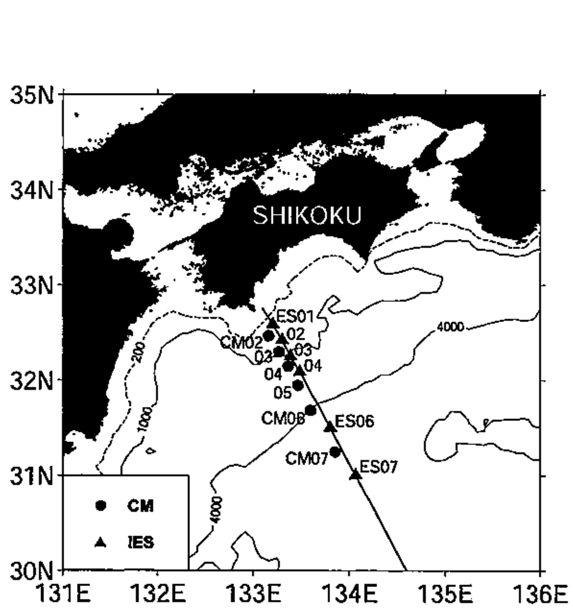

Fig.1 ASUKA observation line and locations of stations. Solid circles indicate moored Current Meter (CM) stations and solid triangles indicate Inverted Echo Sounder (IES) moored at bottom. Isobaths of 200, 1000 and 4000 m are also shown.

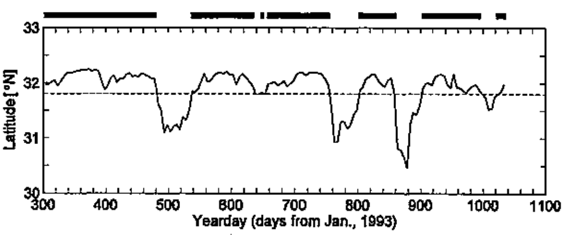

Fig.2 Time series of the Kuroshio axis position at 650 m depth inferred from the 7℃ isotherm. The thin dotted line indicates the position of 31.8° N. Upper thick solid lines indicate periods of the alongshore path.

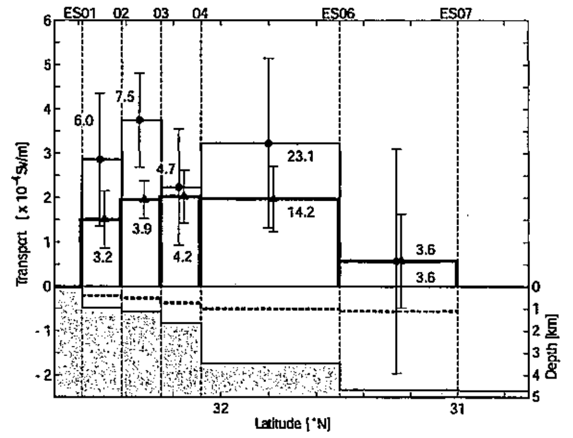

Fig.3 Volume transports per unit width across the ASUKA line between every adjoining IES stations. The positive value means eastward transport and Sv means $10^6 m^3 s^{-1}$. These are temporally averaged values during the Kuroshio flowing alongshore. Thin lines indicate barotropic transports and thick lines show indices of baroclinic transports. The values of transports for each section, described in the figure, are expressed in Sv unit. The lower broken line indicates the depth of node for estimated baroclinic mode and the schematic bottom topography is also shown.

current meters located between every IES stations. Then, we obtain vertical profiles of the components normal to the line by calculating geostrophic flows with referenced velocity values measured by CMs deployed at sub-thermocline depths. We define the vertically integrated value of the component as the barotropic volume transport per unit width (BT), and the value of BT divided by the water column height as the barotropic velocity component (V_{BT}). When we subtract V_{BT} from the profile of the component normal to the line, we obtain the profile of a baroclinic velocity component, of which vertically integrated value is zero. Since this profile basically indicates the first mode of the baroclinic structure, we integrate the profile from the depth of the nil component value to the surface and then define the integrated value as (the index of) the baroclinic volume transport per unit width (BC). The depth of the nil component value is considered as node of a first baroclinic mode. The baroclinic velocity component (V_{BC}) is defined as the value of BC divided by the depth of the node.

3. Results

The Kuroshio almost flows alongshore during the observation periods, but it sometimes leaves far from the coast[2]. In this study, we analyze the results during the Kuroshio flowing alongshore, its axis located north of 31.8° N (Fig. 3). About 75 % long of the observation period is analyzed. The referenced latitude is, however, slightly southward compared to the value adopted by Takeuchi et al.[5], this difference affects the results almost not at all.

Figure 3 shows the temporally averaged barotropic and baroclinic volume transports per unit width; hereafter we redefine them as BT and BC, respectively. Their values are

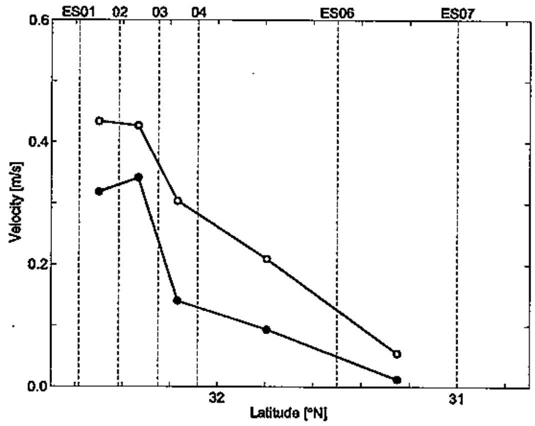

Fig. 4 Barotropic and baroclinic velocities across the ASUKA line. The positive value means eastward component normal to the line. Solid and open circles indicate barotropic and baroclinic velocities, respectively.

distinguished between the coast and ES06. The area is considered as that of the Kuroshio. The former indicates the coastally trapped structure in the coast and the characteristic length scale is estimated at about 50 km, though it substantially keeps the value from the coast to ES06. The sum of BT north of 31.5° N (ES06) is estimated at about 40 Sv. In contrast, the latter keeps almost constant values between the coast and ES06, where is the area of the Kuroshio flowing, and the characteristic length scale is estimated at about 150 km.

4. Discussion and Summary

The length scales of the barotropic mode and the baroclinic mode across the Kuroshio are almost the same of 150 km, when we discern the Kuroshio from the view point of mass transport. However, another length scale of 50 km, which is introduced from the distribution of barotropic mode along the line, suggests the some differences between the barotropic and baroclinic mode. The characteristic features of V_{BT} and V_{BC}, which are simply obtained from BT, BC and their typical thickness, are considered to be related to the dynamical features of the Kuroshio. Both of them denote the typical coastally trapped structures across the Kuroshio, and the length scales, e-holding scales, of V_{BT} and V_{BC} are about 100 km and 150 km, respectively (Fig. 4).

We estimate the distributions of the Kuroshio mass transport across the ASUKA line. These are primarily separated to barotropic and baroclinic components. Their length scales are almost the same. In contrast, these of velocity components are clearly different for each other, though they indicate to have the similar coastally trapped distributions across the Kuroshio.

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