Kuroshio Variability on the Shelf of the East China Sea

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LONG-TERM GOALS

To characterize and understand the dynamics of the time varying structure and transport of the Kuroshio in the East China Sea (ECS) in conjunction with the ONR-supported project, "Variability of the Kuroshio in the East China Sea, and its Relationship to the Ryukyu Current."

OBJECTIVES

Through the ONR-supported project, an array of eleven IESs (inverted echo sounders) was deployed in the ECS for nearly two years between December 2002 and November 2004 to study the spatio-temporal structure of the Kuroshio. The IES array was deployed in the Okinawa Trough at depths deeper than 500m. The Kuroshio, however, extends to the outer continental shelf. This NICOP project aims

(1) to observe the part of the Kuroshio over the outer continental shelf of the ECS to quantify its entire transport (along with IES data simultaneously obtained in the Okinawa Trough), and

(2) to determine the relationship between the Kuroshio axis position (from the IES data) and its transport over the shelf in order to estimate its total transport for the two-year period of IES deployment.

APPROACH

Two moorings equipped with acoustic Doppler current profilers (ADCPs, RDI Model WHS300) were deployed in October 2003 in the ECS at approximately 150 m and 280 m depths northwest of an IES array, in order to measure the Kuroshio flow over the outer shelf. At the shallower site (mooring K2), an ADCP housed in a Barnacle-shaped trawl-resistant bottom mount (Barny TRBM, Perkins et al., 2000) was deployed. At the deeper site (mooring K1), another ADCP housed in a subsurface foam buoy was moored 5m above the sea floor. One additional mooring was deployed close to the deeper site (K1) in May 2004 to enable us to obtain full-water-column current measurements using two ADCPs and a regular Aanderaa current meter. This additional mooring, however, was lost. Final recovery of the moorings K1 and K2 was successfully made in November 2004, and a 13-month-long data set was obtained at mooring K1. Despite the successful recovery of the mooring at K2, we failed to obtain the data for the first half of the 13-month-long mooring period due to failure of the data storage units. ADCPs were pre-set to record current speed and direction at elevations from 5-10m to about 120m off the sea floor at 4 m or 8m vertical intervals with a sampling interval of 30 minutes.

WORK COMPLETED

The field work consisted of four cruises to minimize loss of instruments in this intensively fished region: initial deployment, 2 turnarounds, and final recovery. The ADCP moorings were initially deployed in October 2003 and finally recovered in November 2004. Turnarounds of the moorings were made in November 2003 and May 2004. CTD casts were performed during each of the four cruises. The field operations were conducted using *R/V Onnuri* of the Korea Ocean Research and Development Institute (KORDI), *T/V Kagoshima-maru* of the Faculty of Fisheries, Kagoshima University, and *R/V Tamyang* of Pukyung National University. KORDI and Korea Science and Engineering Foundation supported this project by providing matching funds and providing ship-time on the *R/V Onnuri,* and *Tamyang.*

The ADCPs recorded current speed and direction profiles at 4 or 8 m vertical intervals together with near-bottom temperature and pressure. Data from the ADCPs are processed and analyzed to determine mean currents, tidal currents, and sub-tidal current and temperature fluctuations (Chang et al., 2004) that will be combined with the IES data to quantify the Kuroshio transport and investigate its temporal variability. A data report describing the ADCP and CTD data, together with the processing of the resulting data, is being finalized.

Ancillary information on sea level, historical hydrographic data from the PN-line near the ADCP-CPIES array, and satellite-derived sea-surface-height anomaly has been collected and partially analyzed to study the Kuroshio variability in the ECS and east of Taiwan, and long-term Kuroshio variability in the ECS. Submarine cable voltage data in the Korea Strait have been acquired during the period of ADCP-IES deployment that will allow us to investigate the relationship between the Tsushima Current entering the East/Japan Sea and the Kuroshio transport in the ECS.

RESULTS

Data gaps in the current time series exist because of the time between mooring recovery and re-deployment for mooring K1, and also due to the limited vertical range of WHS300 ADCPs for moorings K1 and K2. In the preliminary processing of current data, depth bins where the data return is less than 50% of the complete record were excluded. Available current records are then from 275m to 179 m depth at 8 m vertical intervals for mooring K1, and from 146m to 34m at 4m intervals for mooring K2. After correction for local magnetic variation and de-spiking of data, data gaps were filled by a tidal harmonic analysis for the tidal component and linear interpolation for the sub-tidal component of along- (Ur) and cross-shelf (Vr) currents.

The M2 tidal current velocity is dominant with a peak Ur of 11.5 cm/s at 254 m. The M2 amplitude decreases towards shallower depths with a minimum value of 6 cm/s at 174 m. Diurnal tidal velocities are weaker than 3 cm/s at all measured depths.

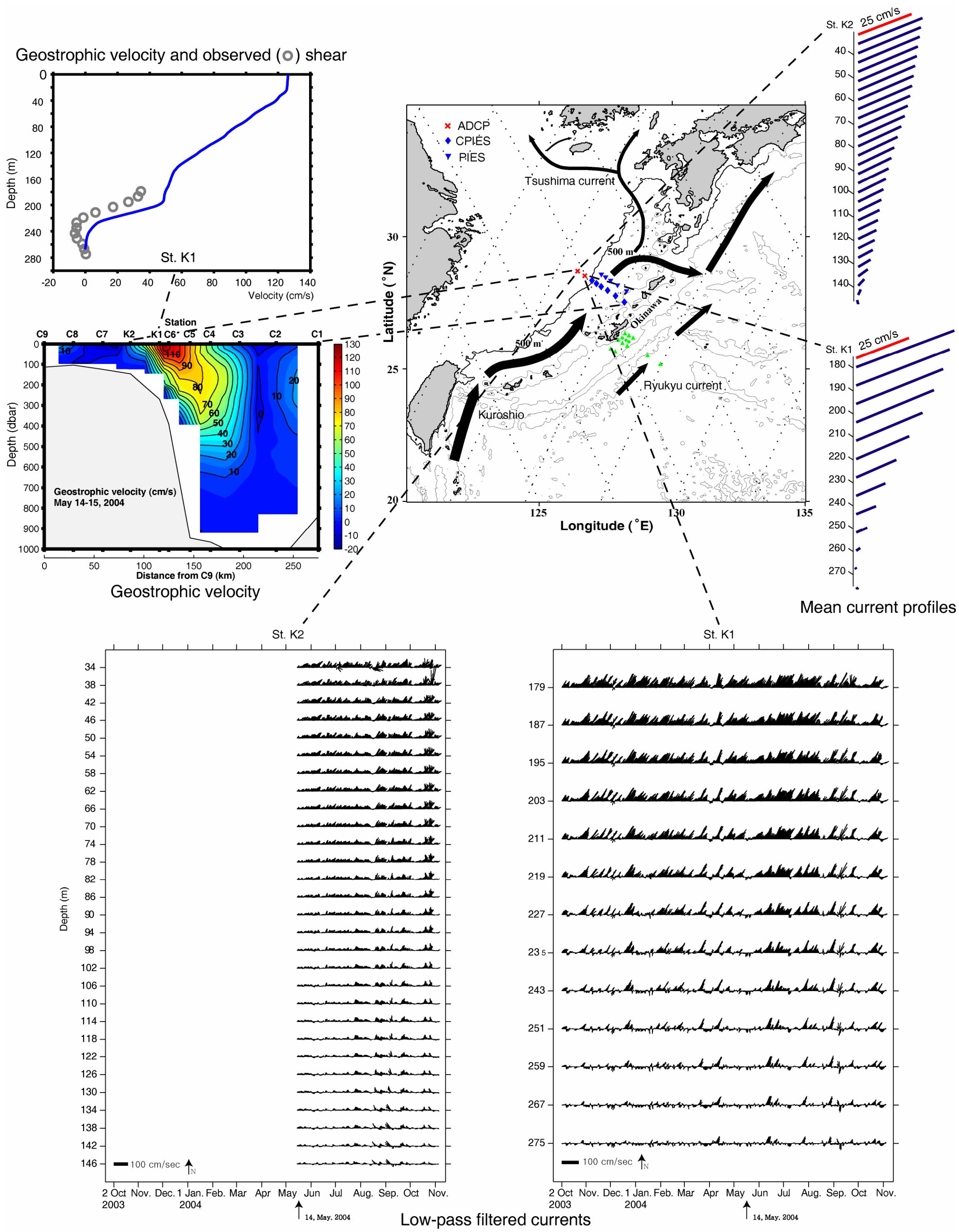

Figure 1. Positions of IES and ADCP moorings, mean and variability of observed ADCP currents, and geostrophic velocity section across the ADCP-CPIES array in May 2004 along with a comparison between the geostrophic and directly measured vertical current shear at K1.

Figure 1 shows positions of IES and ADCP moorings, mean current profiles (upper right) and vector current time series of low-passed 12-hourly currents (lower panel) at moorings K1 and K2, and geostrophic velocity section across the ADCP-CPIES array in May 2004 (upper left). Schematic paths of the Kuroshio, Ryukyu Current, and the Tsushima Current are denoted by arrows in the station map. Also shown is a comparison between the geostrophic current profile and observed daily mean currents at the time of the CTD survey in May 2004 (upper left). CTD stations occupied in May 2004 are close to two ADCP and six IES sites with additional shallow stations northwest of mooring K2.

Mean currents directed to the northeast decrease with depth, with peak values of 46.2 cm/s at mooring K1 and 30.6 cm/s at mooring K2 occurring at the uppermost bin depths (179 m for K1 and 34 m for K2). The mean current directions at both moorings with speeds greater than 10 cm/s are northeastward between 30° and 40° from north in the clockwise direction. Below the strong currents, the mean currents tend to veer in a clockwise direction at K1 and in an anticlockwise direction at K2 towards the sea floor resulting in an almost opposite direction for bottom currents, southwest at K1 and northeast at K2. Current fluctuations occur on multiple timescales from a few days to a couple of months. Currents at upper bin depths are predominantly to the northeast or north with temporal variations mainly arising from fluctuations of current speeds. There are few flow reversals at the upper bin depths, and these are short-lived. As the depth increases, the flow reversals become more frequent and persist for longer times. During the observation period, the currents at K1 were the strongest in summer (June and July) and weakest in fall and spring. Strengthening and weakening of the along-shelf current (Ur) at K1 appear to be associated with lowering and rising of bottom temperature, respectively, which occurred on two- and four-month time scales. These fluctuations are presumably due to the on-shore and off-shore migration of the strong core of the Kuroshio.

Prior to the quantification of the Kuroshio transport by combining ADCP with IES data, it is necessary to extrapolate the measured ADCP current profiles from 179 m to the surface at K1, and from 34 m to the surface at K2. This could be done by an analysis of geostrophic shear calculated from historical hydrographic data obtained regularly (four times a year) at the PN-line. According to Fig. 1, the geostrophic shear calculated from CTD data agrees well with the vertical shear of the observed currents. The other way to do this extrapolation is by using the fitted analytical form for the ECS Kuroshio given in James et al. (1999). We will attempt both methods.

The ECS Kuroshio comes from the region east of Taiwan. According to a long-term direct observation east of Taiwan, Kuroshio variability there is dominated by a 100-day peak related to Kuroshio meandering caused by westward propagating anticyclonic eddies from the interior ocean (Zhang et al., 2001). During low transport periods, the Kuroshio meanders offshore to flow northward along the eastern side of the Ryukyu Islands. These results imply a strong connection between the Kuroshio fluctuations east of Taiwan and those in the ECS. Also reports have been given of a close relationship between the 10-day low-passed Kuroshio transport and the sea-level difference east of Taiwan (Yang et al., 2001). We will investigate the relationship between the Kuroshio east of Taiwan and in the ECS by comparing the sea-level difference east of Taiwan and observed transport fluctuations of the Kuroshio in the ECS. We will also analyze sea-level data observed in the Ryukyu Islands to examine whether or not sea-level data could be used as an estimator of the ECS Kuroshio transport. For this purpose, we have been collecting and analyzing sea-level time series from the 1950s to 2003 or 2004 at Keelung and Kaohsiung in Taiwan and Ishizaki, Naha and Naze in the Ryukyu Islands.

IMPACT/APPLICATIONS

The results from this study should lead to advances in our understanding of western-boundary-current (WBC) dynamics, in particular the dynamics associated with spatiotemporal variability of meanders and bifurcations. This knowledge should be applicable to the Kuroshio at other latitudes, and also to other WBCs.

The NICOP project will also contribute to understanding penetration of the Kuroshio onto the continental shelf and the generation mechanism of its branch, the Tsushima Current. The directly observed Kuroshio transport in the ECS will also provide an opportunity, for the first time, to compare the Kuroshio transport in the ECS with the transport of the East/Japan Sea throughflow; the latter is being monitored by both submarine cable (Kim et al., 2004) and ship-of-opportunity (Takikawa et al., 2005).

RELATED PROJECTS

The University of Rhode Island was supported by ONR to deploy an array of IESs in the Okinawa Trough near the PN-line in a project titled "Variability of the Kuroshio in the East China Sea, and its Relationship to the Ryukyu Current." These instruments recorded the main part of the Kuroshio transport in the ECS. The array was deployed in December 2002 and recovered in November 2004, thus providing spatiotemporal structure of the Kuroshio for a two-year time period.

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PUBLICATIONS

Chang, K.-I., C.-S. Hong, M. Wimbush, and H. Ichikawa, 2004. Moored ADCP measurements on the continental slope of the East China Sea. *Proceedings of the Second PEACE (Program of the East Asian Cooperative Experiments)*. Nov. 25-26, Kyushu, Japan. [published]