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 aforementioned 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 to

> (1) observe the part of the Kuroshio over the outer continental shelf of the ECS and thus quantify its entire transport (along with IES data simultaneously obtained in the Okinawa Trough), and
>
> (2) determine the relationship between the IES-measured characteristics of the Kuroshio off the shelf and its transport over the shelf in order to estimate its total transport for the 23-month 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 the IES array, in order to measure the Kuroshio flow over the outer shelf. At the shallower site (mooring A1), an ADCP housed in a Barnacle-shaped trawl-resistant bottom mount (Barny TRBM, Perkins et al., 2000) was deployed. At the deeper site (mooring A2), 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 (A2) 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 A1 and A2 was successfully made in November 2004, and a 13-month-long data set was obtained at mooring A2. Despite the successful recovery of the mooring at A1, 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 5-10 m to about 120 m off the sea floor at 4 m or 8 m vertical intervals with a sampling interval of 30 minutes.

Besides the principal investigators, three others are engaged in this work: Byung-Ho Lim (Graduate Student) at Seoul National University, and Dr. Jae-Hun Park (Marine Research Scientist) and Magdalena Andres (Graduate Student), both at the University of Rhode Island..

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 *R/V Tamyang.*

The ADCPs recorded vector current component profiles at 4 or 8 m vertical intervals together with near-bottom temperature and pressure. Data from the ADCPs were processed and analyzed to determine mean currents, tidal currents, and sub-tidal current and temperature fluctuations (Chang et al., 2004) to be combined with the IES data to quantify the Kuroshio transport and investigate its temporal variability. A data report describing the IES, ADCP and CTD data, together with their processing, has been completed (Andres et al., 2005).

Ancillary information on sea level, historical hydrographic data from the PN-line near the ADCP-IES 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

Spatial and temporal data gaps in the current velocity time series exist because of the limited vertical range of the ADCPs at both mooring sites and because data were obtained for less than the full duration of the IES deployments.

Available current records are from 146 m to 34 m at 4 m intervals for mooring A1 and from 275 m to 179 m depth at 8 m intervals for mooring A2. We applied two separate methods of spatial extrapolation to estimate the upper-water column velocities at these sites. In the first method ("horizontal-smoothing"), a two-stage OI (Optimal Interpolation) procedure was applied to the combined ADCP and IES data to map the stream function at each level down to 150 m depth and the velocity at that level was calculated from the horizontal gradient of its stream function. These velocities were used at levels where the ADCP data were lacking. In the second method ("vertical-extension"), the stream function was OI mapped only at 150 m depth. A GEM (Gravest Empirical Mode) lookup table was then employed to obtain profiles of specific volume anomaly δ from the stream function, and vertical current shear was determined from the horizontal gradient of δ. The resulting shears were used to extend the ADCP current measurements through the unmeasured (upper) part of the water column. Since ADCP measurements were obtained at the deeper site (A2) for 7 months longer than the measurements at the shallower site (A1), and since the velocities at the shallower site were usually small (<0.2 m/s), a modification of the horizontal-smoothing method was applied, in which the data from A1 were not used. Figure 1 shows the portion of the Kuroshio transport over the shelf and upper slope determined by these methods (blue, green and red lines). It is encouraging that these various methods agree very well, differing by < 1 Sv rms (i.e., < 4% of the total mean Kuroshio flow in the region).

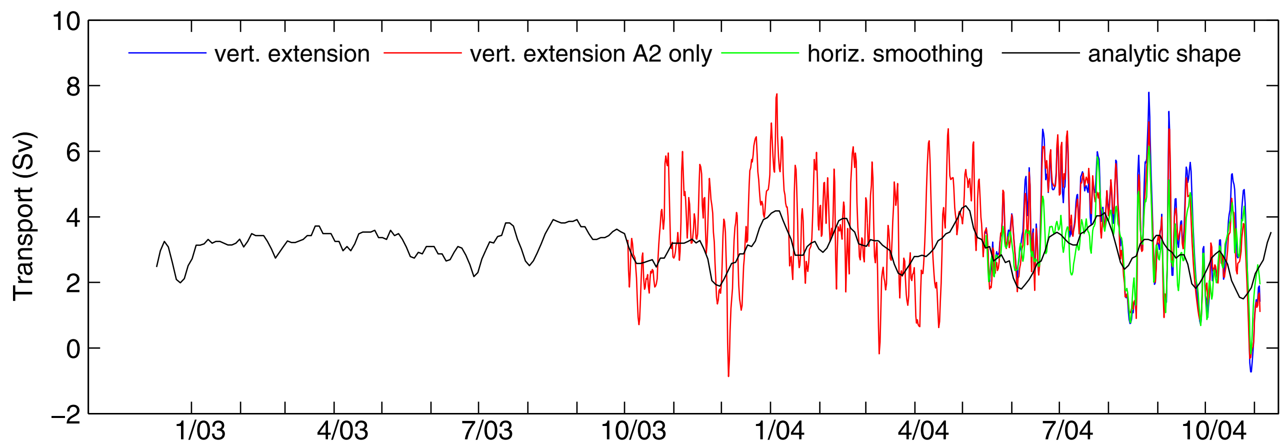

Figure 1. Shelf and upper slope transports determined from the horizontal-smoothing (green), vertical-extension (blue), vertical-extension without A1 (red), and analytical-shape (black) methods. Since all four methods produce similar transport estimates, we have confidence in these estimates.

We have also used the ADCP data in developing a viable method ("analytical-shape") for temporal extrapolation during the first ten months of the 23-month IES array deployment, a time when no ADCP data were available. We took the James et al. (1999) analytical form for the ECS Kuroshio velocity cross-section and adjusted it in position and strength for a least-squares fit, at each time step, to the IES-measured portion of the velocity field (20-day low-pass filtered, for stability). Figure 1 shows the resulting time series of estimated transport over the shelf and upper slope (black line). During the time in which data from the ADCPs were available, the analytical-shape method agrees well with the ADCP-determined transports, differing from them by < 2 Sv rms. We can therefore estimate the entire ECS Kuroshio transport during the full 23-month duration of the field study. For the results, see the Report on our related study, "Variability of the Kuroshio in the East China Sea, and its Relationship to the Ryukyu Current."

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 Japan/East 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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