Mean and Temporal Variability in Kuroshio Geostrophic Transport South of Taiwan (1993–2001)

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Observations of the Kuroshio south of Taiwan have been carried out on a quarterly basis since late 1992 as part of the basin-wide High Resolution expendable bathythermograph/expendable conductivity-temperature-depth (XBT/XCTD) network. Mean geostrophic transport in the Kuroshio, 0–800 m, from 34 cruises is 22.0 Sv ± 1.5, consistent with previous results from moorings and geostrophic calculations in the upstream Kuroshio region. The mean core of the current has speed about 90 cm s⁻¹ and is located close to Taiwan. At this location the Kuroshio appears to be confined mainly to the upper 700 m, and there is no evident tight recirculation of the current. Eddy variability is substantial, and large eddies can be seen propagating westward for thousands of kilometers in TOPEX/Posidon altimetric data, impinging on the current and altering its structure and transport. The annual range in transport is about 8 Sv ± 6, with maximum in summer. Interannual variability is about 12 Sv ± 6, with transport maxima in 1995 and 2000 and a minimum in 1997–1998. Interannual variability in the upstream Kuroshio may be uncorrelated with that in the downstream region south of Japan, where the transport is much greater. Our quarterly sampling aliases high frequency variability of the current, and an improved boundary-current observation program would include more frequent transects and occasional deeper measurements.

Keywords:
- North Pacific
- subtropical gyre,
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- East Taiwan
  Current,
- geostrophic
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- high resolution
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  program.

1. Introduction

The Kuroshio, the poleward western boundary current of the subtropical North Pacific Ocean, has its origin in the westward-flowing North Equatorial Current (NEC). The NEC bifurcates at the Philippine coast (e.g. Nitani, 1972), with its northward branch (the Kuroshio) flowing along the continental margin of the northern Philippines (the Luzon Current) and Taiwan (the East Taiwan Current) before entering the East China Sea. The bifurcation of the NEC, and the distribution of its transport into poleward and equatorward branches (Qiu and Lukas, 1996), is of considerable interest in studies of seasonal to interannual climate variability. Important issues include the northward transport of heat by the subtropical gyre of the North Pacific (Roemmich et al., 2001) and the pathways of subducted thermocline water parcels originating in the subtropical gyre (Gu and Philander, 1997). At the NEC bifurcation, these waters may either turn poleward to complete the subtropical circuit via the Kuroshio, or equatorward via the Mindanao Current, carrying their subtropical properties and variability into the equatorial thermocline.

The present study addresses geostrophic transport and variability in the upstream portion of the Kuroshio south of Taiwan, during the period 1993–2001. Transport near the Kuroshio origin has received little attention relative to the downstream regions, which include the East China Sea, the flow adjacent to Japan, and the Kuroshio Extension. The Kuroshio has relatively low transport near its origin, being augmented along its path by additional flow from the east. Early studies of the upstream region were of short duration or from single realizations, and only within the last decade have sustained measurements been undertaken there. An array of current meter moorings was maintained in the Kuroshio east of northern Taiwan from late 1994 to mid-1996 (the PCM1 array, Johns et al., 2001). This array and a downstream counterpart—the 1993–1995 current meter moorings south of Shikoku, Japan (ASUKA array, Imawaki et al., 2001a)—form primary datasets for comparison with our results. It is of

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interest to describe the transport of the Kuroshio and its variability both along-current and in the time domain.

Observations of the Kuroshio near its source region south of Taiwan may have advantages over locations farther downstream. Beginning with the East Taiwan Channel (Fig. 1, E.T.C.), a ridge extending from northern Taiwan eastward to the southern Ryukyu Is., the Kuroshio’s path traverses a series of ridges upon entering and exiting the East China Sea. The East Taiwan Channel is nearly perpendicular to the Kuroshio path and has a sill depth of about 750 m (Smith and Sandwell, 1997). The ridges modify the Kuroshio structure and may promote mixing of water masses. Any deep flow is obstructed by the ridge and may be redirected eastward instead of entering the East China Sea. Although the ridge creates a choke point for the flow and provides a suitable location for moorings, strong bottom velocities can exist in the passages. These render reference level assumptions inaccurate (Liu et al., 1998) and the passages have complicated flow structures related to the bathymetry. The sharply curved continental margin just northeast of Taiwan appears to cause Kuroshio water to intrude onto the shelf (Qiu and Imasato, 1990; Hsueh et al., 1992). Mixing with shelf waters introduces relatively fresh waters into the Kuroshio in the East China Sea (Ichikawa and Chao, 2000). The transport of the Kuroshio in the East China Sea is apparently related to wind stress forcing in the latitude bands further south (Akitomo et al., 1996), since additional transport from wind forcing at the latitude of the East China Sea is constrained by topography to stay east of the Ryukyu Islands.

The present work analyzes an 8.5-year record (1993–mid 2001), including 34 realizations of an ongoing transect that crosses the Kuroshio south of Taiwan. The quarterly cruises, which are described in Section 2, allow an estimate of the mean geostrophic transport (Section 3), with error estimates based on the observed variability. A breakdown of the mean transport into water masses is also shown. Temporal fluctuations of transport on eddy time-scales, as well as the annual cycle and interannual variability are discussed in Section 4. Kuroshio variability in the context of the western Pacific current system is summarized in the concluding section. A strong focus of the present work is to determine how the time-series of western boundary current transport might be augmented in the future for more accurate estimation of interannual fluctuations.

2. XBT/XCTD Transects

Sampling was initiated in September 1991 on the SS CSX Enterprise (formerly the SS Sea-Land Enterprise), a container ship operating along a track from San Francisco to Honolulu to Guam to Kao-hsiung, Taiwan (PX44_Ka, Fig. 1). Near the western end, the ship track passes through the Bashi Channel, skirting the Kao-t’ai Shih shoal to the north (121.7°E), before reaching the 100 m isobath off the southern tip of Taiwan. Beginning in April 1999, the Enterprise’s western leg was altered to Guam-Hong Kong (PX44_HK). This track passes through the central Bashi Channel between Itbayat and Batan Islands. Cruise-to-cruise variability has been minimal along both the PX44_Ka and PX44_HK tracks. Both tracks will