Title

Temporal and spatial variation of the Kuroshio in Tokara Strait observed by ferryboat ADCP

Members' names and affiliations

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Aim

Transverse-vertical structure and temporal variability of the Kuroshio current across the Tokara Strait during 2003–2012 measured by ferryboat acoustic Doppler current profiler (ADCP) with a 2-km horizontal resolution and a 2-day interval are presented. In the empirical orthogonal function (EOF) analyses of the cross-sectional velocity, the EOF3 mode (19.25%) exhibits a band-like structure, with a smaller horizontal scale than the first two EOF modes; such a band-like structure may be related to the wakes in the lee of the Tokara Islands.

For better understanding of the character of the island wakes behind the Tokara Islands captured by EOF3, we discussed with Prof. Xinyu Guo how to use the JCOPE-T ocean reanalysis data to examine the plain and vertical structure of the island wakes, including: (1) validation of ocean reanalysis data, and (2) surface pattern and vertical view of island wakes obtained from the reanalysis data.

Procedure

(1) **Validation of ocean reanalysis data.** We first compare the JCOPE-T reanalysis and ferryboat ADCP data for the time-averaged velocity structure of the Kuroshio on a transection through the Tokara Strait, and then, we examine their temporal agreement by the correlation analysis.

(2) **Surface pattern and vertical view of island wakes.** Previous studies revealed that area with negative Ertel's potential vorticity appears on the left side of a seamount, where high-wavenumber internal wave shears are remarkable, and the associated energy dissipation is strong. We examine this situation around the Tokara Islands using the JCOPE-T reanalysis data.

Results

To be consistent with observations, the JCOPE-T data was linearly interpolated to the ferry track. Next, the time frame of the JCOPE-T data was set to strictly coincide with the observational time; in this sense, the reanalysis data in the period when the observational data are missing were not used in the analysis. Considering that the direction of the current across the ferry track may differ from the JCOPE-T and ADCP data, we compared the absolute velocities on the transection but not cross-sectional velocities. In the time-mean vertical structure of the absolute velocity on the transection (Figure 1), both the observation and reanalysis demonstrate a multicore feature of the Kuroshio, including the countercurrent beneath the Kuroshio, though the current in the northern channel is excessive for the JCOPE-T data. The cause of the excessive northern Kuroshio core may be related to the overshooting of the Kuroshio, separating from the continental slope.

The JCOPE-T time series of volume transport through the Tokara Strait during 2003–2012 is shown in Figure 1c. The JCOPE-T reanalysis agrees well with observations but has a slightly smaller mean and variability. The JCOPE-T mean net volume transport through the Tokara Strait (excluding the Ohsumi Strait) is 20.41 ± 3.01 Sv, while the observed net volume transport by ferryboat ADCP is 23.03 ± 3.31 Sv. During the observational period, the JCOPE-T reanalysis captures the temporal transport variability well. The correlation coefficient between the observed and reanalyzed volume transports through the Tokara Strait is 0.68 (significant at the 95% confidence level).

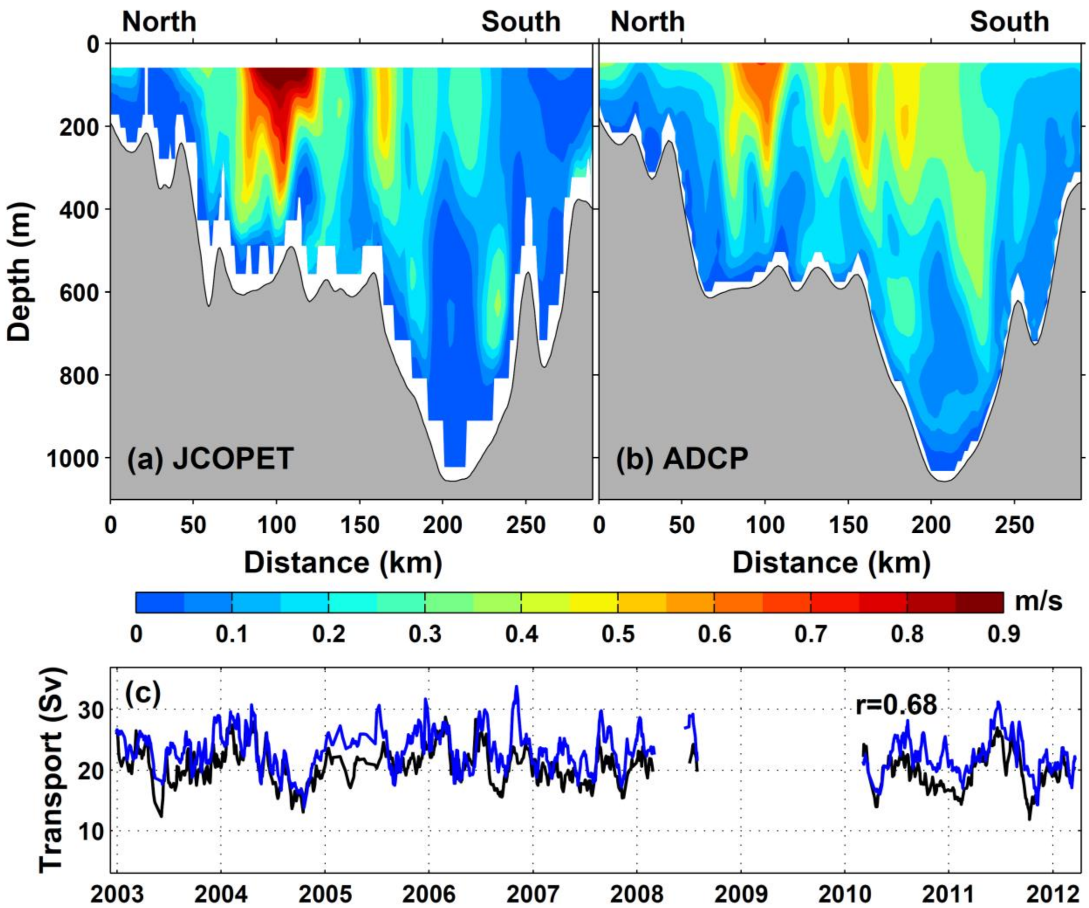

Figure 1. Mean absolute velocity on the transection for (a) JCOPE-T reanalysis data and (b) ADCP observation. The time frame spans the observational period during January 2003–March 2012. (b) Comparison of transport time series from the JCOPE-T reanalysis (black) with ADCP observation (blue). Coefficient correlation between two time series is given at the top right corner.

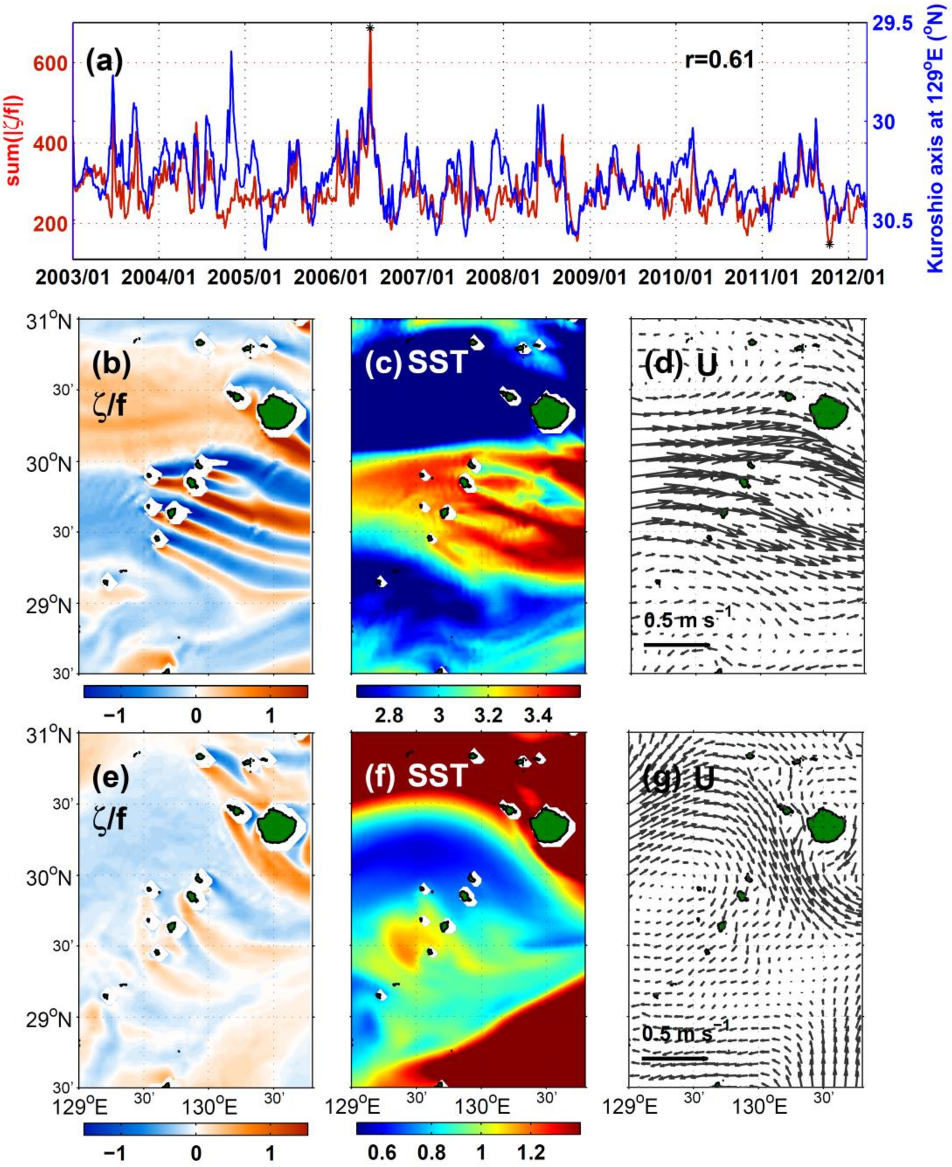

Figure 2. (a) Comparison of the sum of the absolute normalized surface relative vorticity ($|\zeta/f|$, red line) with the Kuroshio axis latitude at 129°E (green line) based on JCOPE-T data (r = 0.61 for the period January 2003–March 2012). (b)–(d) Instantaneous ζ/f, sea surface temperature anomaly, and sea surface current velocity for June 20, 2006, when the island wakes are strongest. (e)–(g) Same as (b)–(d) but for instantaneous distribution on October 19, 2011 when the island wakes are weakest.

Figure 2a shows the time series of the sum of absolute normalized relative vorticity along the ferryboat track (red lines, hereafter $\text{sum}|\zeta/f|$). This time series reveals that strong wakes with large amplitudes (> mean + std) tend to develop in summer (e.g., June–July). In contrast, weak wakes with small amplitudes (< mean – std) tend to occur in winter. Such a seasonal variation of island-induced wake intensity is closely associated with the location in the latitude for the Kuroshio at 129°E, as revealed in Figure 2a. The correlation between the $\text{sum}|\zeta/f|$ (red line) and the latitude of Kuroshio at 129°E (green line) is 0.68. In the following, we will show the surface patterns and vertical views of the strongest wake (on June 20, 2006) and the weakest wake (October 19, 2011), respectively, in the entire observation period.

Figure 2b shows the instantaneous ζ/f (surface relative vorticity normalized by f) on June 20, 2006, and it reveals that the anticyclonic and cyclonic vorticities are on the left and right side of the wake, respectively. As shown in Figure 2b, the area where ζ/f is less than –1 (equivalent to negative Ertel's potential vorticity) is present in the Tokara Strait where the Kuroshio current strongly interacts with the topography. Cold, thin streaks with lengths of about 50 km appear behind the islands on June 20, 2006 (Figure 2c). The water within the wakes is 0.3–0.5 °C colder than the surrounding waters. The lee of the islands is characterized by the return current against the incoming current (Figure 2d). Figures 3a, 3b, and 3c show the vertical views of relative vorticity, temperature, and velocity over the section, respectively. Behind the island, the multicore velocity structure of Kuroshio is more enhanced on June 20, 2006 than the mean state shown in Figure 1. Isotherms in the upper 100 m are domed behind the islands, indicating that upwelling and vertical mixing occur there.
Contrary to the situation shown in Figure 2b (June 20, 2018), Figure 2e shows that when the island-induced wakes become relatively weaker (October 19, 2011), the Kuroshio path clearly shifts northward. In this case, the concurrent distributions of relative vorticity and sea surface temperature do not change as much in the lee of the islands (Figure 2e–g). Additionally, the vertical sections of the relative vorticity, temperature, and velocity (Figure 3e–f) are comparable to the mean state displayed in Figure 1.

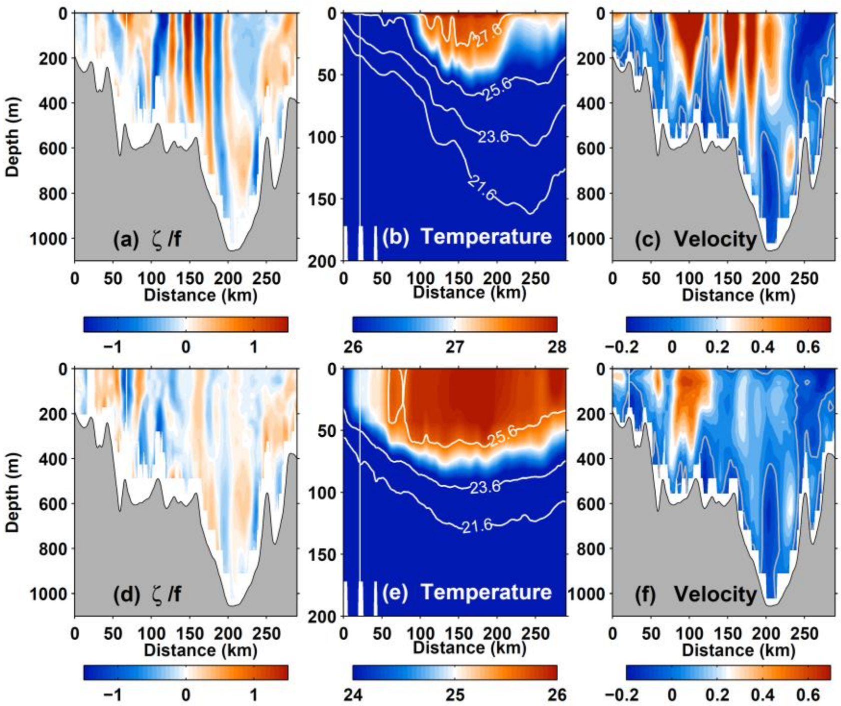

Figure 3. Vertical sections of (a) normalized relative vorticity ζ/f, (b) temperature, and (c) cross-sectional velocity on June 20, 2006 when the island wakes are strongest. (d)–(f) Same as (a)–(c) but for vertical sections on October 19, 2011 when the island

wakes are weakest. The white curves for temperature (b and e) and velocity (c and f) indicate isotherms from 21.6 °C to 27.6 °C with an interval of 2 °C, and zero velocity.

Publication/conference presentation

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Perspectives in future

I would like to thank the Lamer project for proving this chance to discuss with Prof. Guo about the usage of JCOPE-T reanalysis data. The high-resolution JCOPE-T data improved our understanding about the island wakes obtained from ferryboat ADCP data. In future studies, it will be important to combine the observational data with the JCOPE-T data for understanding the impact of island wake variations associated with the Kuroshio shape around the Tokara Strait on the surrounding ecosystem. Looking forward to joining the Lamer next year.