Larval dispersal in the Seto Inland Sea analyzed with a 3-D Lagrangian particle tracking

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Abstract. In order to investigate influences of the Kuroshio path on interannual variability of circulations and associated larval dispersal in the Seto Inland Sea (SIS), Japan, an extensive offline Lagrangian particle tracking is conducted with a decade-long oceanic reanalysis based on a JCOPE2-ROMS double nested downscaling system. The persistent clockwise overall circulation in the SIS is found to be dominant, largely affected by the distance to the Kuroshio axis from Capes Toi, Ashizuri, and Sionomisaki. The larval dispersal generally occurs eastward, mainly induced by the clockwise SIS circulation and thus the transient Kuroshio path plays a substantial role. In summer, the eastward larval dispersal is pronoucedly altered by locally-developed gyres due to so-called "cold dome" formed at depth. In winter, many of the larvae released from the Iyo Sea are transported rather westward due to the northerly winter monsoon.

Keywords: the Seto Inland Sea, Kuroshio, Larval dispersal, Lagrangian particle tracking

1. Introduction

Spatiotemporal variations of the Kuroshio drifting off Shikoku Island, Japan, are recognized to influence on the estuarine circulation in the SIS (Komai *et al*, 2008). In general, ambient currents passively transport marine larvae that are responsible for maintaining the ecosystem in the SIS. Therefore, the coastal dispersal of the larvae in the SIS is influenced by the transient impact from the Kuroshio through its seasonal and interannual variability. We thus conduct a double-nested high-resolution SIS modeling based on a JCOPE2-ROMS oceanic downscaling system for consecutive ten years from 2004 through 2013. An offline Lagrangian particle tracking is then carried out with the ROMS reanalysis to emulate the pelagic larval dispersal in the SIS. Primary objectives of the present study are to investigate correlation between transient variability of the Kuroshio path off Shikoku and associated volume transport in the SIS (hereinafter refered to as *the SIS through flow*), and effects of the Kuroshio-affected through flow on the larval dispersal. Analyses are performed with the Lagrangian probability density functions of the particles released in the SIS.

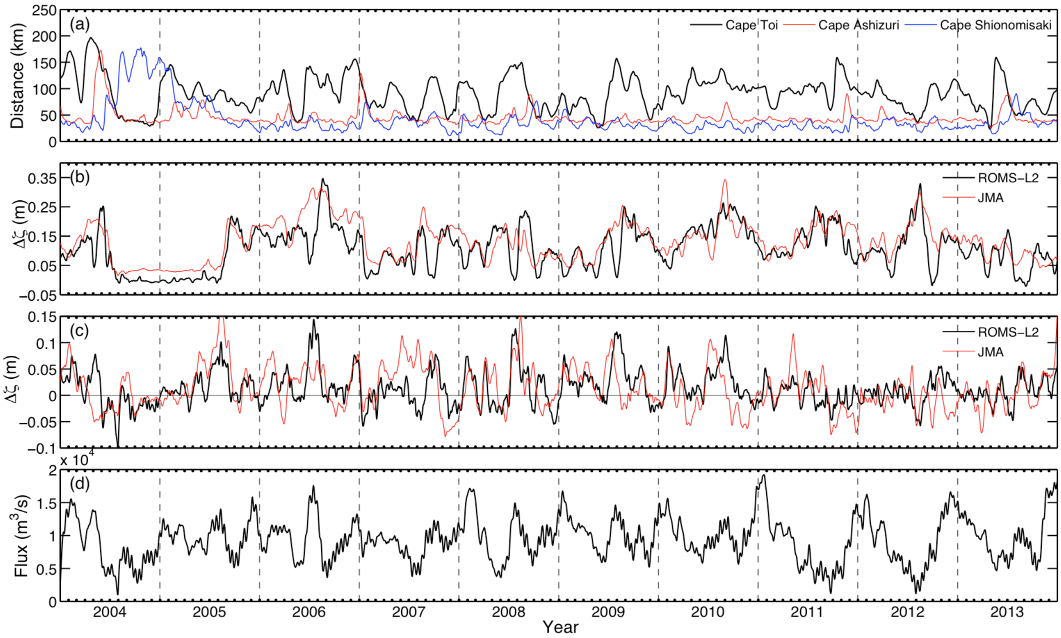

Fig. 1 : Time series of (a) the distance from Capes toi, Ashizuri, Shionomisaki to the Kuroshio main axis for the ROMS-L1, (b) the difference of the sea surface height (SSH), $\Delta\zeta$, between Kushimono and Uragami for the ROMS-L2 and the JMA in-situ data, (c) $\Delta\zeta$ between Uwajima and Shirahama for the ROMS-L2 and the JMA *in-situ* data, (d) the volume flux at the Kii Channel for the ROMS-L2 (outgoing flow is set as positive).

2. Numerical model

Double nested ROMS domains are configured with a 1-way offline nesting technique, embedded in the JCOPE2 reanalysis. Horizontal grid resolutions are consecutively refined from about 10 km (JCOPE2), 2 km (the outer ROMS-L1 domain) to 600 m (the inner ROMS-L2 domain). The outermost boundary and initial conditions are provided by the daily-averaged 3-D product from the JCOPE2 reanalysis that is then projected on to the ROMS-L1 perimeters. Tides are imposed on the ROMS-L2 boundaries, and monthly-averaged discharges from major rivers in each domain are considered. The four-dimensional TS-nudging with the nudging strength of 1/20 day^{-1} is introduced in the ROMS-L1 model toward the 10 day-averaged JCOPE2 temperature and salinity fields for enhanced reproducibility of the Kuroshio path (e.g., Uchiyama *et al*. 2012). Furthermore, the 20 day-averaged SST and SSS computed from the JCOPE2 are applied for the surface flux restoration, so as to avoid long-term drift and bias caused by erroneous surface fluxes from the COADS05 monthly climatology field and the JMA GPV-MSM atmospheric reanalysis. The computational period is chosen for a 10-year period from Jan. 1, 2004 to Jan. 31, 2014.

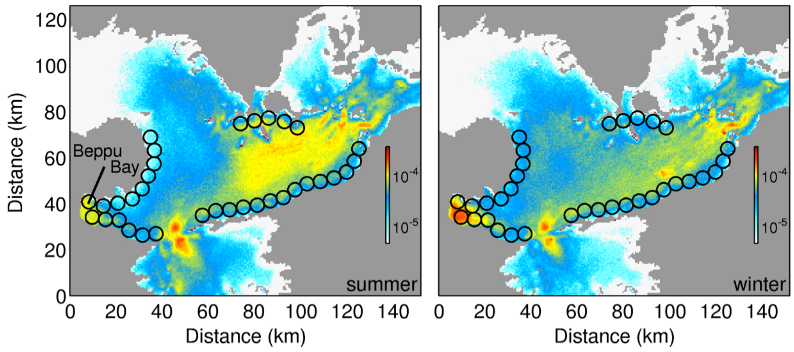

Fig. 2 : Lagrangian PDFs for the particles released in the Iyo Sea in summer (left) and winter (right) after the advection time of 30 days. Open circles indicate all the release patches deployed in the Iyo Sea.

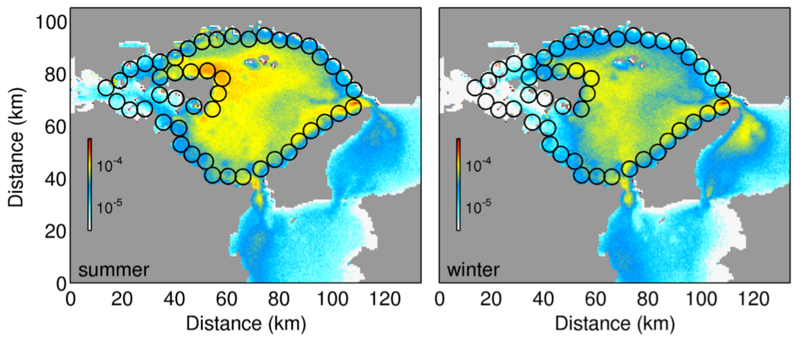

Fig. 3 : Same as **Fig. 2** but in the Harima Sea.

3. Effects of Kuroshio path on subtidal circulations in the SIS

The Kuroshio runs in the south of Shikoku with inter- and intra-annual variability associated with straight or meandering path. These patterns are generally described in terms of the distance from capes on the southern shores to the Kuroshio axis (**Fig. 1a**). Cape Toi in Kyushu Island, Cape Ashizuri in Shikoku Island, and Cape Shionomisaki in Honshu Island are indicative locations that measures the path. For the 10-year period, except for the large meander occurred in 2004, the distance from Cape Toi is more variable than those from the other two capes. The sea surface height (SSH) difference ($\Delta\zeta$) between Kushimoto and Uragami has widely been used as an index to evaluate how the Kuroshio path is near the shore or far to the sea off the southern coast of the Kii Peninsula (**Fig. 1b**), showing a good agreement with the JMA reanalysis. The volume flux (the SIS through flow, **Fig. 1d**) positively correlates with $\Delta\zeta$ between Uwajima and Shirahama (**Fig. 1c**) while negative correlation in $\Delta\zeta$ between Kushimoto and Uragami is apparent. These results suggest that the Kuroshio path varies mostly near the Bungo Channel (the western opening) compared to that near the Kii Channel (the eastern opening), responsible for changing the amount of the overall clockwise (positive) SIS through flow significantly.

4. Larval dispersal simulation

A three-dimensional Lagrangian particle tracking is then carried out with the modeled SIS circulation field. About 100 Lagrangian particles are equally distributed and released from the 34 patches in the Iyo Sea and the 48 patches in the Harima Sea at z = -0.5 m at 24-hour intervals from 2004 until 2013, and are integrated over the advection time of 30 days. **Figures 2** and **3** show Lagrangian PDF, the probability density function of particle displacement after a given advection time (Mitarai *et al*., 2008), in summer and winter in the Iyo Sea (**Fig. 2**) and the Harima Sea (**Fig. 3**). In summer, the larvae released from the Iyo Sea are transported eastward due to locally-developed anticyclonic gyre associated with the subsurface cold dome structure, while in winter, many of them are transported rather westward due to the northerly winter monsoon. In the Harima Sea, the larvae released in summer are trapped by a well-developped cyclonic gyre to remain in the source area, while in winter, the persistent eastward transport is predominant due to the clockwise SIS through flow energized by the Kuroshio drifting (**Fig. 1d**).

References

[1] Komai, K, Hibiya, T, Ogama, T, Influence of the kuroshio Meander/Straight on Flow in the Seto Inland Sea, J. JSCE Ser. B, Vol.64, No.3, pp.165−179, 2008.

[2] Uchiyama, Y., Kuriyama, T., Miyazawa, T., Impact of the Kuroshio Paths on Oceanic and Estuarine Circulations in and around Seto Inland Sea, J. JSCE Ser. B2 (Coastal Engineering), Vol.68, No.1, pp.441−445, 2012.

[3] Mitarai, S., D. Siegel, J. Watson, C. Dong, and J. C. McWiliams, Quantifying connectivity in the coastal ocean with application to the Southern California Bight, J. Geophys. Res., Vol.114, C10026, doi:10.1029/2008JC005166, 2009.