Surface circulation of the North Pacific derived from combining altimeter and drifter data

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Satellite altimeters can measure the sea-surface dynamic topography down to the oceanic mesoscale, but the information on the temporal mean topography is lost in the altimeter data processing. The sea-surface velocity may be divided into the temporal mean velocity and velocity anomaly. Velocity anomaly can be derived from sea-surface dynamic topography anomaly obtained from altimeter data with geostrophic approximation. The temporal mean velocity can be recovered by combining *in situ* surface velocities estimated from trajectories of surface drifting-buoys (hereafter, drifters) with velocity anomalies, as follows; at a point where a drifter measured the surface velocity, the temporal mean velocity can be estimated by subtracting the altimeter-derived velocity anomaly at that time from the drifter-measured instantaneous surface velocity (Fig. 1; Uchida and Imawaki, 2003). Sum of thus obtained mean and anomalies from altimeter data gives us a time series of the instantaneous velocity field.

The method is applied to the surface flow field of the North Pacific, using TOPEX/POSEIDON and ERS-1/2 altimeter data (CLS gridded data; Fig. 2), and WOCE-TOGA surface drifter data (Fig. 3) obtained from October 1992 through August 2001. The temporal mean velocity is estimated with a resolution of quarter degrees in both latitude and longitude.

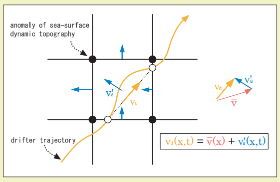

Fig. 1

Conceptual view of estimating the mean velocity $\bar{V}(x)$ by combining altimeter-derived velocity anomaly $V'a(x,t)$ and drifter-derived instantaneous velocity $Vd(x,t)$. If you have the drifter-measured velocity Vd at some point x at some time t, you can estimate the mean velocity $\bar{V}$ at that point, by combining altimeter-derived anomaly $V'a$ of sea-surface geostrophic velocity at that point at that time.

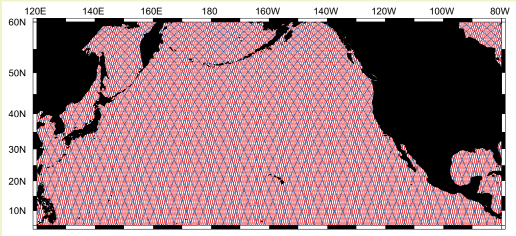

Fig. 2

Satellite tracks of TOPEX/POSEIDON (blue lines) and ERS-1/2 (red lines). We use the map of sea-surface height anomaly ζ prepared by the Collect, Localization, Satellites (CLS) in France from October 1992 to August 2001; the sea-surface height anomalies obtained by TOPEX/POSEIDON and ERS-1/2 were merged and gridded with a resolution of 0.25° latitud × 0.25° longitude globally every ten days, after removal of high frequency fluctuations including tides.

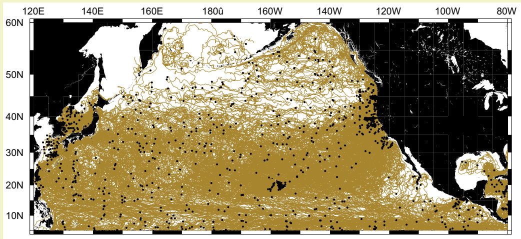

Fig. 3

Trajectories of all the drifters (about 1,600) during 1992--2001 used in the present study. Dots are starting points of each trajectory. Those drifter data were obtained by the Surface Velocity Program of WOCE and TOGA. Drifters were equipped with drogues centered at 15 m depth and tracked by satellites. The trajectories were smoothed by low-pass filter and sub-sampled every 6 hours.

The obtained mean velocity field (Figs. 4-7) clearly shows the general pattern of the North Pacific Subtropical Gyre, the Hawaiian Lee Counter Current (the eastward current), the Alaskan Stream (the narrow southwestward-flow) along the Alaska Peninsula, etc. Instantaneous velocities are estimated by summing up the temporal mean velocity and anomalies, every ten days during the eight-year period of 1993-2000 (Imawaki et al., 2003). The instantaneous flow field (Fig. 8) shows energetic variability of the Kuroshio Extension vividly, as shown by the **animation**. One of the interesting features is that the temporal mean Kuroshio Extension almost disappears just before the Shatsky Rise (at about 155-160° E), although the instantaneous Kuroshio Extension continues to flow down to the Emperor Seamounts (at about 170° E).

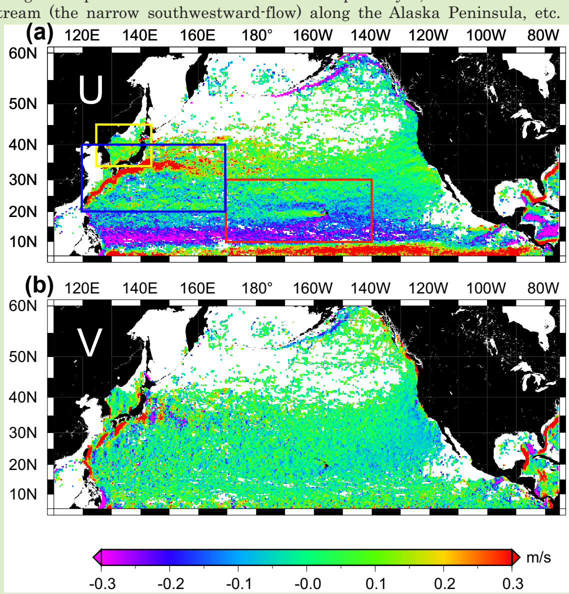

Fig. 4

Eulerian mean velocity field during 1993-2000 for (a) zonal and (b) meridional components in the North Pacific plotted with a resolution of quarter degrees in both latitude and longitude. An open box means that the temporal mean velocity is not estimated, because the number of drifter data in the box is less than three. The figure clearly shows the general pattern of the North Pacific Subtropical Gyre, including the Kuroshio, Kuroshio Extension, North Pacific Current, California Current and North Equatorial Current. Three boxes with thick lines indicate the areas for which the subsequent figures show the flow fields.

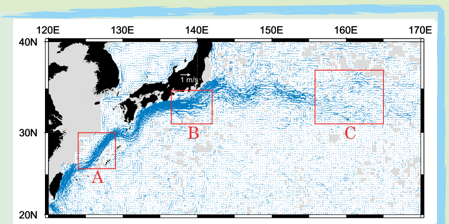

Fig. 7

Mean velocity field of the Kuroshio and Kuroshio Extension regions. The vector scale is shown by the white arrow in the upper middle. The Kuroshio Extension takes the stationary meander pattern, when leaving the Japanese coast. The mean Kuroshio and Kuroshio Extension are narrower and stronger than the climatological mean Kuroshio and Kuroshio Extension derived from historical hydrographic data averaged over several decades.

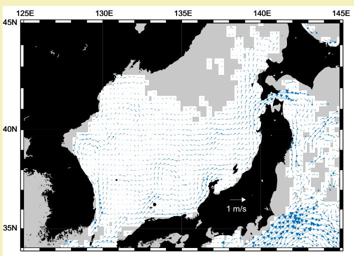

Fig. 5

Mean velocity field for the Japan Sea. The Tsushima Warm Current, East Korean Warm Current, Tsugaru Warm Current and Soya Warm Current are clearly seen.

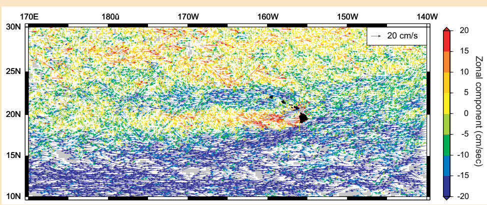

Fig. 6

Mean velocity field around the Hawaiian Islands. To the west of the Islands, the Hawaiian Lee Counter Current (the eastward current) is clearly seen along 19° N extending from 156° W to 177° W. At about 21° N in the western part, the weak eastward-flowing Subtropical Countercurrent is also seen.

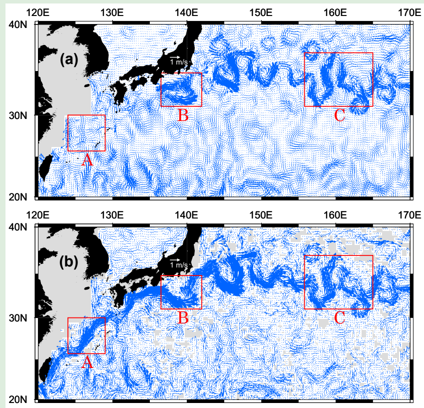

Fig. 8

Examples of (a) the altimeter-derived anomaly field of surface geostrophic velocity for the Kuroshio and Kuroshio Extension regions (on May 9, 1993), and (b) the instantaneous velocity filed obtained as the sum of Fig. 7 and the above. The boxes labeled A, B and C in those figures show three typical areas where contributions to the instantaneous velocity field are different between the mean and anomaly fields.

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[2] Hiroshi Uchida and Shiro Imawaki (2003) Eulerian mean surface velocity field derived by combining drifter and satellite altimeter data. *Geophysical Research Letters*, **30**(5), 1229, doi:10.1029/2002GL016445.