Seasonal variation of the deflection angle of the wind-driven surface flow estimated from altimeters and long-range ocean radars

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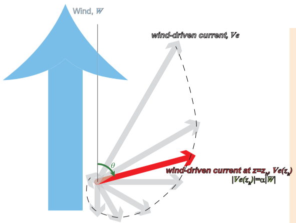
1. Introduction

The "Ekman spiral" is one of the most familiar subjects in textbooks, but its in situ profile with actual non-constant eddy viscosities is not well observed.

In this study, the wind-driven current component is estimated by combining two velocity data sets; ocean radars and satellite altimeters.

2. Method



Schematic plan view of wind-driven currents

Assume that the wind-driven current V_e at a fixed depth Z_h can be expressed by the linear transform of the wind $\boldsymbol{W}$ with the speed factor α and deflection angle θ.

For velocity component normal to a subsatellite track of altimeters, de-tided ocean Highr-Frequency (HF) radars' velocity V_h would be

$$V_h = V_g + V_e + \varepsilon_h$$
$$= V_g^{mean}(r) + V_a' + V_e + \varepsilon_h,$$

where

V_g^{mean} ; temporal mean geostrophic velocity,
V_g' ; temporal anomaly of the geostrophic velocity,
V_e ; wind-driven current
ε_h ; ocean radar noise

Since V_g' would be replaced by the altimetry-derived geostrophic anomaly V_a' (Tokeshi et al., 2007),

$$V_h - V_a' = V_g^{mean}(r) + V_e + \varepsilon_h + \varepsilon_a.$$

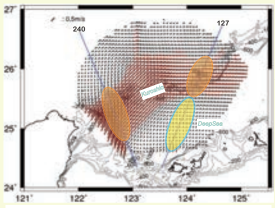
If the noises can be properly smoothed out, temporal variations of this term provides observations of V_e.

By the least square method and daily wind data $\boldsymbol{W}$, we can determine monthly values of $\alpha(T_i)$ and $\theta(T_i)$ (T_i=1,2,3...,12), together with the mean geostrophic current $V_g^{mean}(r)$ (Yoshikawa and Masuda, 2009).

3. Data

Ocean Radars) Daily averaged de-tided data in the Kuroshio upstream region from 2004/4 to 2007/12 on a 7km grid; provided by NICT and Nagoya Univ. For these radars, the observed current is considered to represent at a depth Z_h of a few meters.

Altimters) Regional along-track Jason-1 SSHA data, provided by the CTOH/LEGOS, France, for the tracks 127 and 240. Additional tidal corrections were performed by the harmonic analysis.



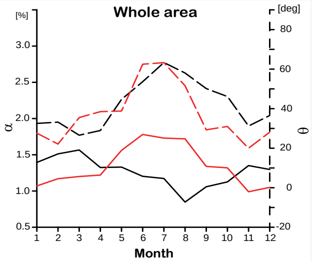
V_h^{mean} and the altimeter tracks; altimeter data in the circes were used.

Wind) Daily QuikSCAT SeaWinds data on a 0.5deg grid, provided by CERSAT.

Spatial Smoothing) In order to estimate V_e, V_h and V_a' should be properly smoothed to reduce noises $\varepsilon_h + \varepsilon_a$. In this study, both V_h and V_a' are spatially smoothed over 126km.

4. Results

4.1 Seasonal variations of α and θ



Seasonal variations of the estimated α and θ

In the left panel, estimated monthly α (solid line) and θ (broken line) are plotted. For reference, parameters estimated in the Tsushima Strait between Japan and Korea at 33.5-35N (using other ocean radars and sea level difference across the Strait measured by tide gauges) are plotted by the red lines.

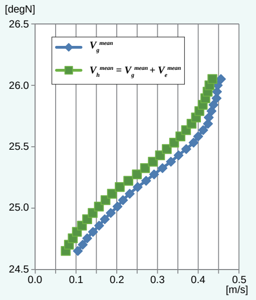
The variation of θ quantitatively coincides with that in the Tsushima St. Larger θ in summer would agree with a shallower Ekman depth due to stronger stratification, as was considered in the Tsushima St.

Meanwhile, the variations of α in two areas are similar in range (0.01-0.015) but opposite in phase. Although further studies are necessary to interpret this discrepancy, difference of the air-sea interaction in tropical/subtropical regions would contribute to this discrepancy, e.g. through changes of the wind drag coefficient C_D that depends on the stability of the atmospheric boundary layer.

4.2 Mean velocity

This study also provides along-track profile of the mean geostrophic current $V_g^{mean}(r)$. Note its difference from the mean ocean radar velocity $V_h^{mean}(r)$.

Not only the mean wind $\boldsymbol{W}^{mean}$, but also the wind anomaly $\boldsymbol{W}'$ produces the mean wind-driven current V_e^{mean} through seasonal variation of the deflection angle.



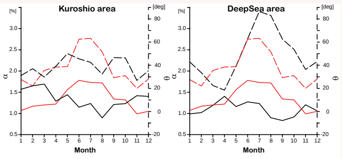
Mean velocity profiles along the 127 track.

5. Summary and Discussions

Wind-induced surface current is estimated by subtracting the altimetry-born geostrophic velocity from the ocean radar surface velocity. The speed factor α and deflection angle θ are determined by the least square method and daily wind $\boldsymbol{W}$ data, together with the mean geostrophic velocity V_g^{mean}, which has been lost in the altimeter data.

Seasonal variation of deflection angle θ ranges from 20 to 60 degrees, while that of the speed factor α remains within 1.0 to 1.5%. The former is in phase with the results in the Tsushima Strait around at 34N, but the latter is out of phase. Further studies are necessary, including discrepancy of the air-sea interactions in those regions.

The seasonal variation of θ is larger in the Deep Sea region than in the Kuroshio region (lower panels), although the division of the areas may reduce reliability of the results.



Variations in the Kuroshio (left) and Deep Sea (right) areas

Reference

Tokeshi et al., JO, 63, 711-720, 2007.
Yoshikawa and Masuda, JGR, 114, C12022, 2009.