JP.2.7 Sverdrup Transport Calculation Using Satellite Scatterometer Wind Product in the North Pacific

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1.Introduction

Information of volume transport in the ocean is one of essential factor to investigate heat transport as well as simply investigate the ocean circulation. This ocean circulation play an important role for making the state of climate (*Vonder Hear and Oort*, 1973), particularly, in the subtropical gyre, it largely affect to the state of climate since the heat transport toward north is much larger than the other latitudes. In addition, transports of the western boundary current, such as the Kuroshio and Florida Current, are known to highly correlate with the heat transport (*Chen et al*., 1992). Thus, it will be important to accurately estimate the volume transport in the subtropical gyre.

Geostrophic volume transport in a gyre is estimated by wind data based on Sverdrup relation (*Leetma et al.* 1977). Sverdrup Balance is a vorticity equation derived in the steady state (Sverdrup, 1947).

$$\beta V = f \frac{\partial w}{\partial z} \qquad \text{--- (1)}$$

where V is the meridional volume transport, f is the Coriolis parameter, β is the meridional derivative of the Coriolis parameter, ρ is the oceanic density and w is vertical velocity. Further, by integrate (1) to the depth which the vertical velocity vanishes, we get the following equation:

$$\int_{-H}^{0} V dz = \frac{1}{\beta\rho}(\nabla \times \tau) + \frac{1}{\rho f}\tau^{x}$$

namely,

$$M_G = M_S - M_E \qquad \text{--- (2)}$$

This equation means that the geostrophic volume transport (M_G) is proportional to the Sverdrup transport (M_S) minus the Ekman transport (M_E). In the steady state, the oceanic response for the wind forcing can be examined (*Hautala et al.* 1994). That is, we estimate the meridional transport indirectly from wind data by adapting this formulation.

We calculate the Sverdrup transport using scatterometer wind product of ERS-1/2 (the first and second European Remote Sensing Satellite. These products were reported to have good relationship to in-situ measurement (TAO buoy) data (Graber et al., 1996), meaning sufficient reliability. However, in the mid- and high-latitude regions, it is difficult to clarify the reliability of these gridded data products because there are few *in-situ* measurement data in such regions except near-shore areas. For example, at 45°N in the North Pacific, the wind-stress products estimated by ERS-1/2 data differ from the objectively analyzed wind products by 0.01-0.02 N m^{-2}. Wind-stress curl calculated by the spatial derivative has difference by the value of 1.0-2.0 x 10^{-8} N m^{-3} at 30°N, corresponding to the core zone of the subtropical gyre, so that the difference in wind-stress curl field is expected to affect the estimation of wind-driven volume transport.

In this study, we focus on the reliability of our product constructed by ERS-1/2 data in terms of estimation of wind-driven transport and its comparison with the objectively analyzed products: ECMWF (European Center for Medium-range Weather Forecasting) and NCEP (National Center for Environmental Prediction). We also construct another satellite scatterometer wind product by Qscat/SeaWinds (QuikSCAT launched in June 1999). Furthermore, as another method of verification of our products, we compare the estimated geostrophic transport with the one obtained by the historical hydrographic data based on WOA98 (World Ocean Atlas '98) by application of (2).

2. Data

Four different data sets are used to calculate the wind-driven transports. Wind data from Satellite scatterometer, ERS-1/2 in1992-2000 and QSCAT in 2000, are gridded through the adoption an averaging method using weighting function varying with space and time. This

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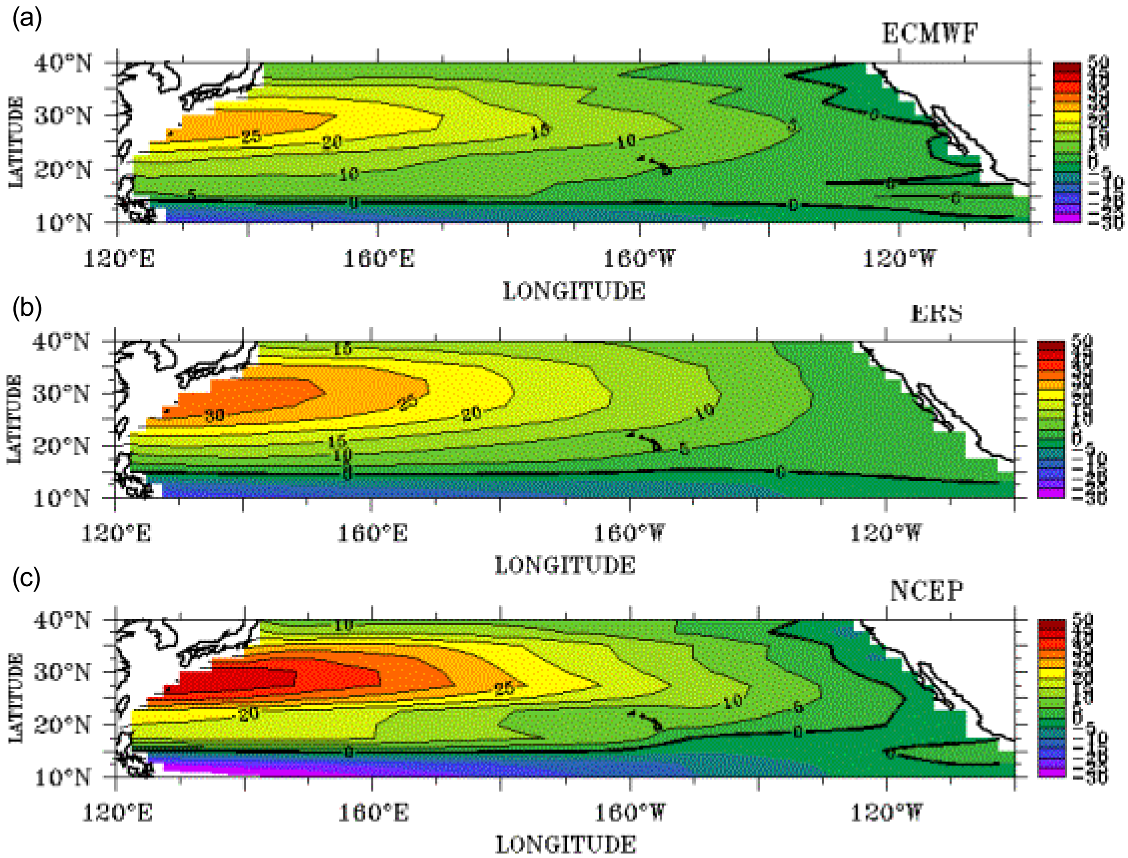

Fig.1 Distribution of zonally-integrated meridional Sverdrup transports which are calculated from different wind products (a:ECMWF, b:ERS-1/2, c:NCEP). Unit of contour is 1.0 x 10^6 m^3 s^{-1} (Sv)

procedure is similar to that by Kutsuwada(1998), who constructed NSCAT (NASA scatterometer) data on board the ADEOS (Advanced Earth Observing Satellite launched in August 1996) data in 1996-97, and also described in Kubota et al.(2002). The wind-stress vector is calculated by the bulk formula with the drag coefficient depending on only wind speed (Large and Pond, 1981).

The objectively analyzed wind-stress products (ECMWF and NCEP) are also constructed in 1992-2000. Calculation procedures are the same as those for the scatterometer products.

Finally, the WOA98 data set is used for calculation of the geostrophic flow field. Volume transport at each grid is estimated by vertical integration of the geostrophic currents from the sea surface to sigma- t=27.0 surface.

3. Mean field

Zonally-integrated Sverdrup transport fields calculated by the three products(ERS-1/2, NCEP and ECMWF) represent the similar features to each other (Fig.1). However, the values are different between the objective analyzed products, particularly south of Japan. The integrated Sverdrup transports at 137°E are listed in Table.1. The value of 32 Sv (x $10^6 m^3 s^{-1}$) for the ERS-1/2 product is 5 Sv larger than the ECMWF's and 10 Sv smaller than the NCEP's. Figure 2 shows the mean field of wind-stress curl which is the parameter of Sverdrup transport. Totally, the magnitude for the ERS-1/2 product is larger than ECMWF's and smaller than NCEP's. In the NCEP field, large negative curl is found around 155°W and 125°W, where there are no similar feature in the ERS-1/2 field. Also in the region of 160°E-170°W, two fields are different: the ERS's is significantly smaller than the NCEP's Note that there are clear discrepancy between the ERS's and NCEP's fields near the eastern boundary, where the latter exhibits abnormally large positive curl.

Table.1 Zonally-integrated meridional Sverdrup transport at 135E during 1992-99. Unit is 1.0 x 10^6 m^3 s^{-1} (Sv)

ERS-1/2	ECMWF	NCEP
32	27	42

Figure 3 shows a zonal profile of the meridional Sverdrup transport minus the Ekman transport, namely the

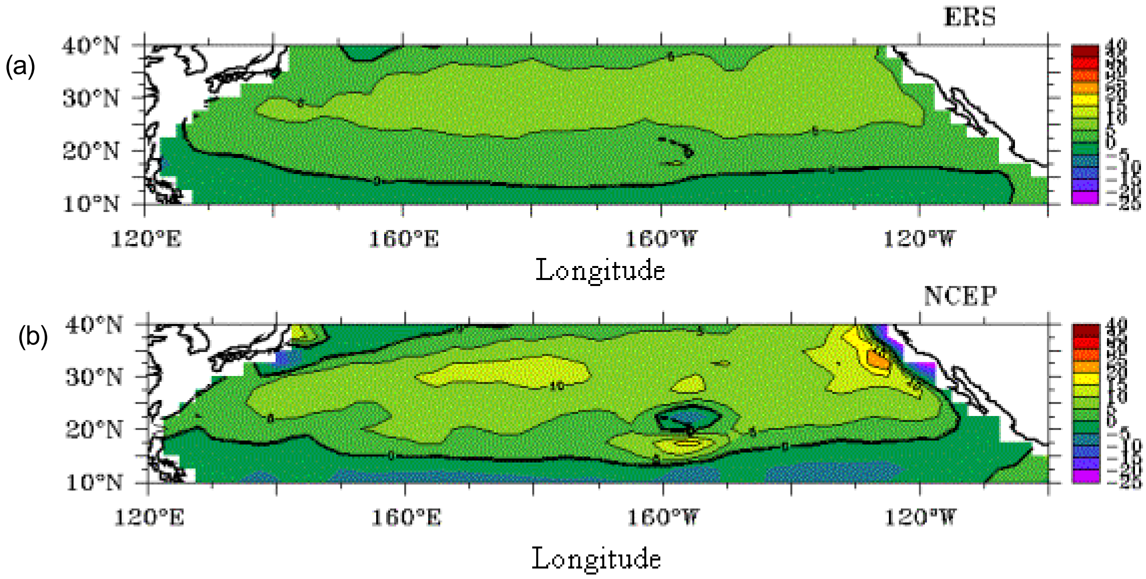

Fig.2 Distribution of wind-stress curl fields (a:ERS-1/2, b:NCEP). Unit of contours is 10^{-8} N m^3.

geostrophic volume transport. These are compared with the values obtained from the historical oceanic measurement data (WOA98). The geostrophic volume transport estimated by the ERS-1/2 product is smaller than the NCEP's and larger than the ECMWF's, reflecting the differences in the wind stress curl field. Even if the measured transports are larger than the all estimated ones in the eastern portion, they are closest to the ERS's in the western portion. We can see that the maximum of southward transport in the measured field is found at 135°E. This means that the value at 135°E corresponds to volume transport of the western boundary current. The transport by the ERS-1/2 product is 36Sv, which is 7 Sv larger than the ECMWF's and 10 Sv smaller than the NCEP's. On the other hand, the transport by WOA98 is 41Sv between the ERS-1/2's and NCEP's. The Sverdrup balance in the interior region east of 135°E is examined by the zonal slope of the integrated transport. The slopes by the ERS-1/2, ECMWF and NCEP products are 0.33, 0.28 and 0.45Sv/2.5deg, respectively. The ERS-1/2's slope is closest to the one by the WOA98 (0.35). In order to examine what longitudes this discrepancy is affected by, we notice the zonal profile of volume transport (not zonally-integrated) at each longitude(Fig.4). Note that the transports are low-pass filtered by 20-degree running means to remove short-scale signals or noise. In the central Pacific region of 150°E-160°W, the estimated value by the ERS-1/2's is close to the measured one by the WOA98. However, east of 160°W, the difference between the ERS's and WOA98 attains to remarkably 0.2 Sv, while the NCEP's is rather closer to the measured one.

In summary, wind-driven volume transport estimated by the ERS-1/2 product is most similar to the measured transport by the historical hydro- graphic data, and the similarity depends on the longitudinal domain and reference level for vertical integration (*Hautala et al.* 1994). It is necessary to investigate spatial features and their comparison in more detail.

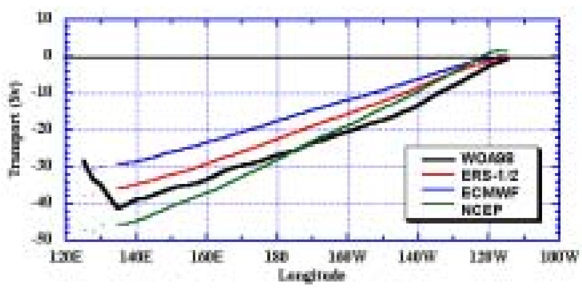

Fig.3 Zonal profiles of zonally-integrated geostrophic transport in a zone of 25-30° N. Red, blue and green lines are estimated values by wind products of ERS-1/2, ECMWF and NCEP, respectively. Black line is one obtained from historical hydrographic data (WOA98).

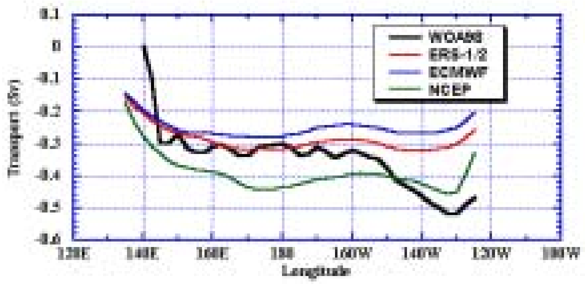

Fig.4 Zonal profiles of meridional geostrophic volume transports at each longitude in a zone of 25-30°N. All the values are low-pass filtered by 20-degree running means.

4. Monthly field

In the barotropic model, the oceanic response to any wind forcing in the mid-latitude around 30°N is accomplished within one month. Based on this assumption, we focus seasonal variation of zonally- integrated Sverdrup transport at 135°E.

Figure 5 shows a time series of monthly Sverdrup transport in 1992-99 which is estimated from three wind products. The ERS's transport is always smaller than the NCEP's, and the difference tends to be relatively large in winter season from December to February. When we notice a dependency of the difference between these data on the transport magnitude, we can find that it becomes larger as increase of the transport magnitude with correlation coefficient of 0.6 (Fig. 6). Wind data in strong range (>about 15 m s^{-1}) obtained by ERS-1/2 can have the relatively large errors (See Graber et al., 1996). Even if there can be, more or less, errors in the strong wind range in the NCEP's product, the difference in the large transport range shown in Fig. 6 may be due to less reliability in our ERS product.

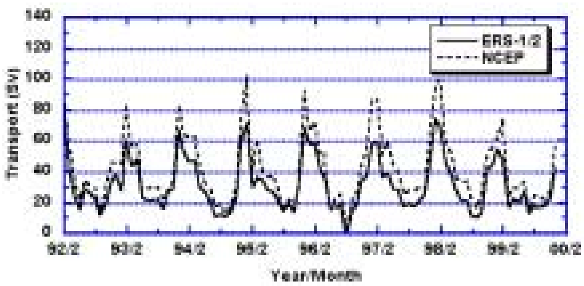

Fig.5 Time series of the zonally-integrated Sverdrup transports, corresponding to the western boundary current, in a zone of 25-30° N. Solid and dashed lines are estimated by the wind products of ERS-1/2 and NCEP, respectively.

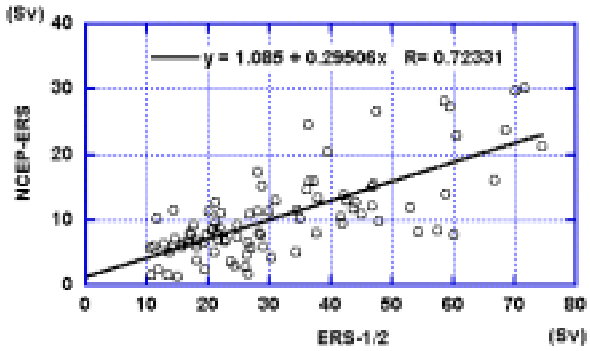

Fig.6 Scatter diagram between the zonally-integrated Sverdrup transport estimated by ERS-1/2 product and its difference with that estimated by the NCEP product.

5. Summary and Discussion

The Sverdrup transport in the subtropical gyre calculated by our ERS-1/2 product reveals the value between those for the two objectively analyzed products (NCEP and ECMWF). The zonally- integrated Sverdrup transport, corresponding to the transport of western boundary current, is different from the products by 5-10 Sv. In the examination of geostrophic transport, the wind-driven geostrophic transport in a zone of 25°-30°N estimated by ERS-1/2 product is closest to that obtained by the historical hydrographic data based on WOA98. On the other hand, the latter value is highly sensitive to the selection of integration depth, corresponding to the bottom of the wind-driven layer. Thus, it will be necessary to examine about this problem including comparison for other latitudes in future studies.

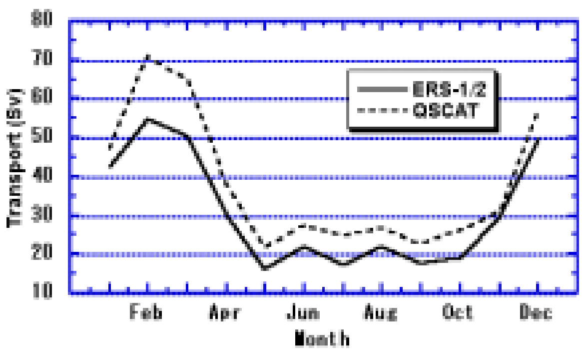

Fig.7 Annual time series of the zonally-integrated Sverdrup transports corresponding to the western boundary current, in a zone of 25-30° N. Solid and dashed lines are estimated by the wind products of ERS-1/2 and QSCAT/SeaWinds, respectively.

Figure 7 shows time series of monthly Sverdrup transports in 2000. In this figure, the estimation by the new satellite-derived product(Qscat) is also over-plotted. The transports by the ERS-1/2 are large in winter and small in other seasons with the amplitude of 20Sv. These are both smaller than the Qscat's by 15 Sv in February and by 5 Sv in summer. Further, the annual amplitude for the Qscat's is about 28 Sv, which is considerably larger than the ERS's. On the other hand, the monthly values for the NCEP's are closer to the QSCAT's. This may suggest that the ERS's values have been underestimated, particularly in February. Unfortunately, this comparison is limited to the only one year (2000), because of the avail- abilities of the wind products. The intercomparison between the Qscat and NCEP products need to be made for other region in detail.

Remote sensing satellite scatterometers, ERS-1/2 and Qscat/SeaWinds, have supplied much information over the world ocean during a long time for us Validation studies for the wind products will be required for various time and space ranges in future studies.

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