ANNUAL SIGNAL MODULATION OF THE KUROSHIO THROUGH-FLOW VOLUME TRANSPORT SOUTH OF JAPAN LEADING WEST PACIFIC PATTERN

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ABSTRACT

For better understanding of interactions between the Kuroshio south of Japan and the climate system in the North Pacific, variations of the satellite-derived eddy-removed volume transport of the Kuroshio through-flow (*KTVT*) south of Japan in 1993 – 2007 and the West Pacific Pattern index (*WPPI*) are compared with each other. Both of *KTVT* and *WPPI* with longer periods than 8 months have dominant components with about annual period. They have a maximum in every winter while their amplitudes change year by year. By the cross correlation analysis of their around annual period components, we found that interannual variations of *WPPI* in May and October lead to *KTVT* by 41-month while those of *KTVT* in February and August lead to *WPPI* by about 4 years, suggesting that the interactions between annual period components of *WPPI* and *KTVT* are dominated by seasonal different mechanisms.

1. INTRODUCTION

A mechanism underlying the seasonal and interannual variations in weather and climate system has been studied using various kinds of climate indices such as the Arctic Oscillation Index. In the climate system, the Kuroshio south of Japan is considered to play an important role through transporting a large amount of heat which is released to the atmosphere in the Kuroshio Extension region. However, the seasonal and inter-annual variations of the Kuroshio transport have not been elucidated yet due to large fluctuations caused by the recirculation eddy to the south of Shikoku and mesoscale eddies from the east. Under this situation, the relation between the variations of Kuroshio transport and climate system has also not been clarified yet.

For estimating the variations of the net volume and heat transports of the Kuroshio through-flow south of Japan by reducing the dominant recirculation and eddy components, we conducted the moored array observation for two years from July 2004 to October 2006 in the north of 30°N along an observational line for the Affiliated Surveys of the Kuroshio off Cape Ashizuri (ASUKA, [1]), and along the 30°N line from 135°E to 142°E. Combining these mooring observation data with the satellite altimeter data, [2] estimated a long time series of the volume transport of the Kuroshio through-flow across the ASUKA-line of which variance is much smaller than previous time series obtained by [1]. This time series enables us to examine the relation among the variations of the Kuroshio transport and various kinds of climate indices. Reference [2] indicated that the wind forcing produces the interannual (4-year period) variation in the volume transport of the Kuroshio through-flow.

Various kinds of monthly Northern Hemisphere teleconnection indices have been calculated by Climate Prediction Center (CPC), the National Weather Service at National Oceanic and Atmospheric Administration, by applying the Rotated Principal Component Analysis technique to monthly mean standardized 500-hPa height anomalies obtained from the Climate Data Assimilation System (CDAS), the National Centers for Environ-mental Prediction (NCEP) / the National Center for Atmospheric Research (NCAR) Reanalysis Project, in the analysis region of 20^{o}N - 90^{o}N from January 1950 to December 2000 [3]. One of the indices called the West Pacific pattern represents a primary mode of low-frequency variability over the North Pacific in all months. During winter and spring, it consists of a north-south dipole of anomalies, with one center located over the Kamchatka Peninsula and another broad center of opposite sign covering portions of south-eastern Asia and the western subtropical North Pacific. Therefore, its strong positive or negative phase is reflected to pronounced zonal and meridional variations in the location and intensity of the entrance region of the Pacific (or East Asian) jet stream. These anomalies show a strong northward shift from winter to summer, which is consistent with the observed northward shift of the East Asian jet stream [4]. From these facts, we could infer that the West Pacific pattern has a close relation with the volume transport of the Kuroshio through flow.

In this paper, for better understanding of interaction between the Kuroshio south of Japan and the climate system in the North Pacific, time series of around annual period components of the satellite-derived eddy-removed volume transport of the Kuroshio through-flow (*KTVT*) south of Japan in 1993 – 2007 and the West Pacific Pattern index (*WPPI*) were compared with each other. We found that interannual variations of *WPPI* in May and October lead to *KTVT* by 41 months and those of *KTVT* in February and August lead to *WPPI* by about 4 years.

2. DATA AND METHOD

Time series of *KTVT* estimated by [2] and *WPPI* produced by CPC are shown in Fig. 1. *KTVT* with longer periods than 8 months has a maximum in every winter (January, February or March) and a minimum in every summer (July, August or September) while its amplitude changes year by year. The contribution to the total variance of KTVT with periods longer than 8 months from components with periods around annual period (8- 18 months) is estimated to 75 %.

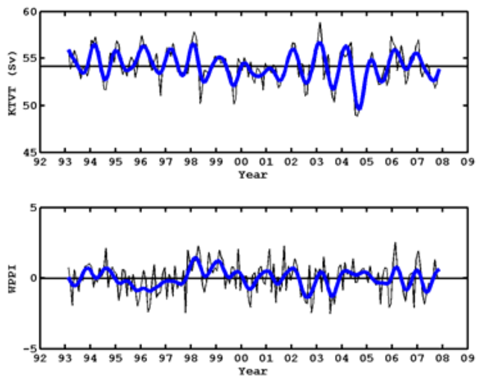

Figure 1. Time series of monthly means (black curve) and variation components with period longer than 8 months (blue curve) of KTVT (top panel) and WPPI (bottom panel).

We can see that the annual period component of *WPPI* has a maximum in every winter (from November to March) and a minimum in every summer (from June to September) except in 1993 to 1996 and 2000 while its amplitude changes year by year. The contribution to the total variance of *WPPI* with periods longer than 8 months from components with around annual (8 - 18 months) periods, quasi-biennial (18-60 months) periods, and periods longer than 60 months are estimated to 50 %, 29 % and 21 %, respectively.

We extracted the around annual period components of *KTVT* and *WPPI* by the band-pass filter with half-power periods at 8 and 18 months, and examined the relation between them not by the wavelet analysis but by the correlation analysis due to a shortage of available data duration length.

3. RESULTS

The cross-correlation function, R_{KW}, between *KTVT* and *WPPI* is found to have statistically significant maxima of -0.729 at lag (L) = -19 months (*WPPI* leads *KTVT*) and -0.725 at L = 65 month (*WPPI* delays to *KTVT*). This result may indicate that, while *WPPI* affects more directly to *KTVT* after 19 months, *KTVT* has some feedback processes affecting to *WPPI* after 65 months. It should be mentioned here that *KTVT* is found not to have a close relation with annual period components of the Multivariate ENSO Index (MEI, [5]), the Arctic Oscillation (AO) Index, and the Pacific Decadal Oscillation (PDO). This is mainly due to the facts that these climate indices have the maxima and minima in different months every year while *KTVT* has the maximum in every winter and the minimum in every summer.

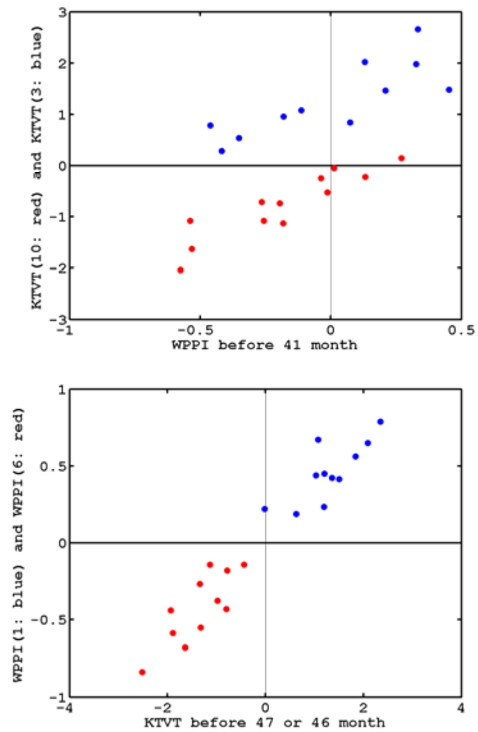

Figure 2. Top panel: KTVT in March (blue) and October (red) as a function of WPPI in October or May, before 41 months. Bottom panel: WPPI in January (blue) and June (red) as a function of KTVT in February before 47 months or August before 46 months.

For better understanding of the relations between amplitude modulations in *KTVT* and *WPPI*, we calculated another kind of cross correlations for various lags between *KTVT* and *WPPI* in selected month of every year. For example, KTVT time series in all January from 1993 to 2007 and WPPI time series in all February from 1993 to 2007 are compared for one month lag.

By this analysis, we found that interannual variations of *KTVT* in March and October are closely associated respectively with *WPPI* in October of 4-year before and May of 3-year before, both in 41-month before. On the other hand, interannual variations of *WPPI* in January and June are closely associated respectively with *KTVT* in February, 47-months before, and August, 46-months before (Fig. 2).

4. DISCUSSION AND CONCLUSION

We found that, for annual period component, inter-annual variations of *WPPI* in May and October lead to *KTVT* by 41 months while those of *KTVT* in February and August lead to *WPPI* by about 4 years. This difference could be associated with the seasonal difference of the dominant mechanism underlying the interaction between annual period variations of *WPPI* and *KTVT*.

Annual period variation of *KTVT* is considered to be associated with the oceanic annual signal which is dominated by the annual variation of the North Pacific jet stream in the key area far from Japan, and propagates to the south of Japan after a long trip. Present results suggest that, in the key area, the oceanic eddy caused by the wind stress curl or the wind stress curl itself is much stronger in May and October than in other months corresponding with *WPPI*, and it takes 41 months to propagate to near Japan.

It should be noticed here that, when monthly *WPPI* and *KTVT* stay around the annual mean value apart from their annual maxima and minima, they may have interannual components with periods longer than 18 months because their interannual components are not fully removed by the 18-month period half-power high-pass filter. Therefore, there is a possibility that the phase delay of monthly *KTVT* in March or October to monthly *WPPI* in October or May is associated only with the interannual component of *WPPI* leading to that of *KTVT* by about 4.5 years.

Both of *KTVT* and *WPPI* have the maximum in winter and the minimum in summer. *KTVT* in February and August have close relations respectively with *WPPI* in January and June of 4 years later, suggesting that the modulation of annual signal in *KTVT* may be not the result but the origin of modulation of annual signal in *WPPI*. The variation of heat transport accompanied by *KTVT* is considered to affect the amount of the sea surface heat flux in the Kuroshio Extension region, and then the atmospheric circulation which dominates the variation of the North Pacific jet stream and *WPPI* through dynamics not specified yet. Present results suggest that the response of the atmospheric circulation to *KTVT* through the ocean surface heat flux in the Kuroshio Extension region might be much more sensitive in February and August than in other months. It may be an important fact that the surface heat flux in the Kuroshio Extension region is maximized in winter and minimized in summer.

It should be noticed here that the phase lag of about 4 years between monthly *KTVT* in February or August and monthly *WPPI* in January or June are nearly coincident with the dominant period of variation in the wind forcing indicated by [2]. This suggests that interannual variation of wind forcing could play some roles in the dynamics underlying the influence of *KTVT* on *WPPI*.

For better understanding of the ocean-atmosphere interaction dynamics connecting *KTVT* and *WPPI*, we must keep the continuous monitoring of *KTVT* and the surface heat flux in the Kuroshio and Kuroshio Extension region, and elucidate the role of the heat flux variations above the Kuroshio and Kuroshio Extension region in the atmospheric circulation dynamics by using numerical models and observational data. As variations of air temperature and precipitation anomalies in the North Pacific are associated well with *WPPI*, we should be able to predict them with some certainties from present *KTVT*. This is one of the possible societal benefits from the proposal mentioned in [6].

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