10.15 ANNUAL AND INTERANNUAL VARIABILITIES OF EAST ASIAN MONSOON REVEALED BY SPACEBASED OBSERVATIONS

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1. INTRODUCTION

A significant portion of the world's population is under the influence of monsoon changes. Understanding of physical processes governing the evolution of Asian monsoon is not only important for regional climate variation, but also crucial to global climate variation. Besides bringing rain to land, monsoons also change ocean currents, ocean upwelling, and coastal ecology. Over land the consequences of monsoon are, perhaps, well observed, but the ocean observations are still very sparse. Spaceborne microwave scatterometers and radiometers observe ocean surface with high spatial and temporal resolution, which provides an unprecedented opportunity to explore variability at the sea surface on various time scales.

2. DATA

The scatterometers on the European Spacecraft ERS-1/ERS-2 and the National Aeronautics and Space Administration Scatterometer (NSCAT) measure ocean surface wind speed and direction under both clear and cloudy conditions. The surface winds are derived from the scatterometers and interpolated to 0.5° and twice daily through a successive correction method (Tang and Liu 1996). Special Sensor Microwave/Imager (SSM/I) provides wind speed and integrated water vapor at daily and 0.25° resolution (Wentz 1996). The SSM/I wind vectors are derived by combining satellite measured wind speed with European Centre for Medium-Range Weather Forecasts (ECMWF) analyses (Atlas et al. 1996). The Topex/Poseidon altimeter measures sea level change along ten-day repeated ground-tracks, and the data are interpolated to 1° and 3 day resolution (Fu et al. 1994). The 1° and 7-day composite SST is compiled by blending Advanced Very High Resolution Radiometers (AVHRR) data with in situ measurements (Reynolds and Smith 1994). Latent heat flux is computed from wind speed and integrated water vapor from SSM/I and SST from AVHRR (Liu et al. 1994). Precipitation rate is derived by the Global Precipitation Climatology Project, which combines the satellite estimates from SSM/I and rain gauge analyses at 2.5° resolution and monthly average.

3. ANNUAL VARIATIONS OF THE SOUTH CHINA SEA MONSOON

In November, South China Sea (SCS) is dominated by the northeasterly winter monsoon, which causes positive (cyclonic) curl of wind-stress in the central basin, with a stronger center west of Luzon Island and a weaker center east of Vietnam (Fig. 1). Strong negative curl of wind stress is found along the southeast coast of China. In the following month, negative sea level changes are observed in the central basin, stretching from Luzon to Vietnam, and positive sea level changes are found in the coastal regions in the north and in the south. The sea level changes lead to two cyclonic gyres of geostrophic current, one west of Luzon and the other off the southern tip of Vietnam.

Significant negative correlations between the curl of wind stress and sea level change, with the stress

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curl leading by a month, are found in the central part of the SCS (Liu and Xie 1999). The negative correlation is consistent with a simple Ekman pumping scenario. Cyclonic winds drive surface divergence and upwelling in the ocean; the rise of the thermocline causes lower sea levels. Anticyclonic winds cause higher sea level change and anticyclonic currents.

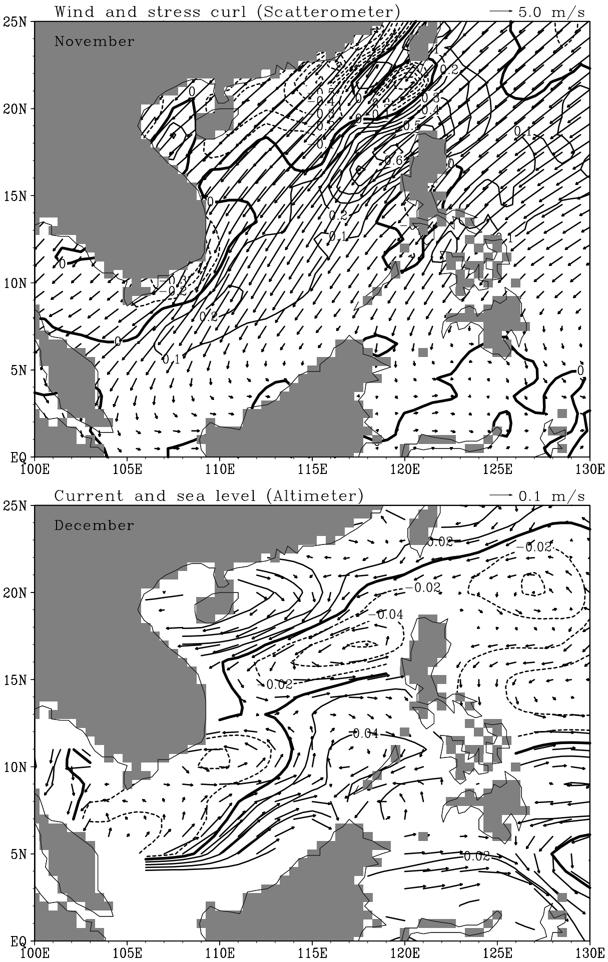

Figure 1: The climatological wind and curl of wind stress in November (a), and sea level change and geostrophic current in December (b).

4. INTERANNUAL VARIATIONS OF THE SOUTH CHINA SEA MONSOON

During the strong Pacific cold events (1988/89, 1995/96, and 1998/99), the SCS winter monsoon, represented by strength of the northeasterly wind over the northern part of SCS, is abnormally strong (Fig. 2a). Both zonal and meridional wind have negative anomalies during those winters, which coincides with the Pacific cold events as referred from strong easterly wind anomalies in the equatorial western and central Pacific. During the strong winter monsoon years, water vapor in the central SCS basin is high which indicates very wet winters and it is negatively correlated with that in the central and eastern equatorial Pacific (Fig. 2b). Weak latent heat flux during the strong winter monsoons with the lowest value in spring (Fig. 2c) is associated with the reduced air-sea moisture contrast in the central basin due to high water vapor content and low SST (except the winter of 1998/99). It suggests that the anomalous high moisture during these winters is brought in by the winter monsoon outside of the SCS basin.

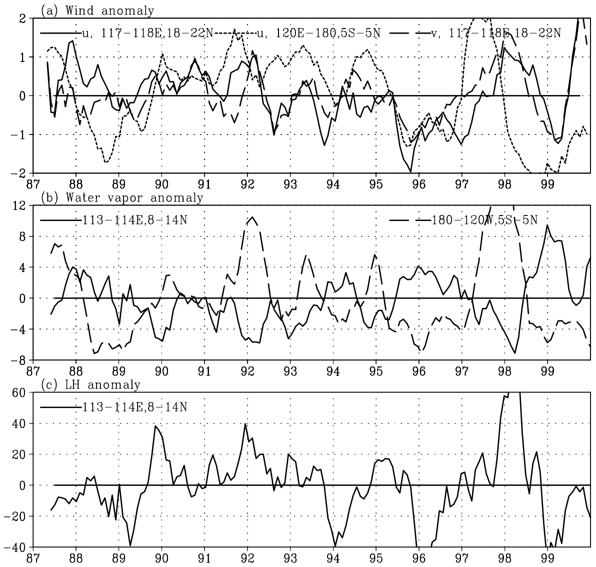

Figure 2: Time series of (a) zonal wind and meridional wind anomalies averaged over the northern SCS (117°E-118°E, 18°N-22°N) and equatorial western and central Pacific (120°E-180°, 5°S-5°N), (b) integrated water vapor anomalies averaged over the the central SCS basin (113°E-114°E, 8°N-14°N) and central to eastern Pacific (180°-120°W, 5°S-5°N), and (c) latent heat flux anomalies averaged over the central SCS basin.

During the winters of the peak Pacific warming in 1982/83, 1991/92, and 1997/98, the SCS winter monsoon is weaker than normal. Strong westerly and southerly wind anomalies occur in the northern SCS in winter, several months after the major westerly wind anomalies in the equatorial western and central Pacific (Fig. 2a). Water vapor in the central SCS is low during the winters of peak Pacific warming events (Fig. 2b). The strong latent heat flux (Fig. 2c) is associated with the anomalously dry atmosphere over the warm ocean surface which strengthens the moisture contrast between ocean and atmosphere.

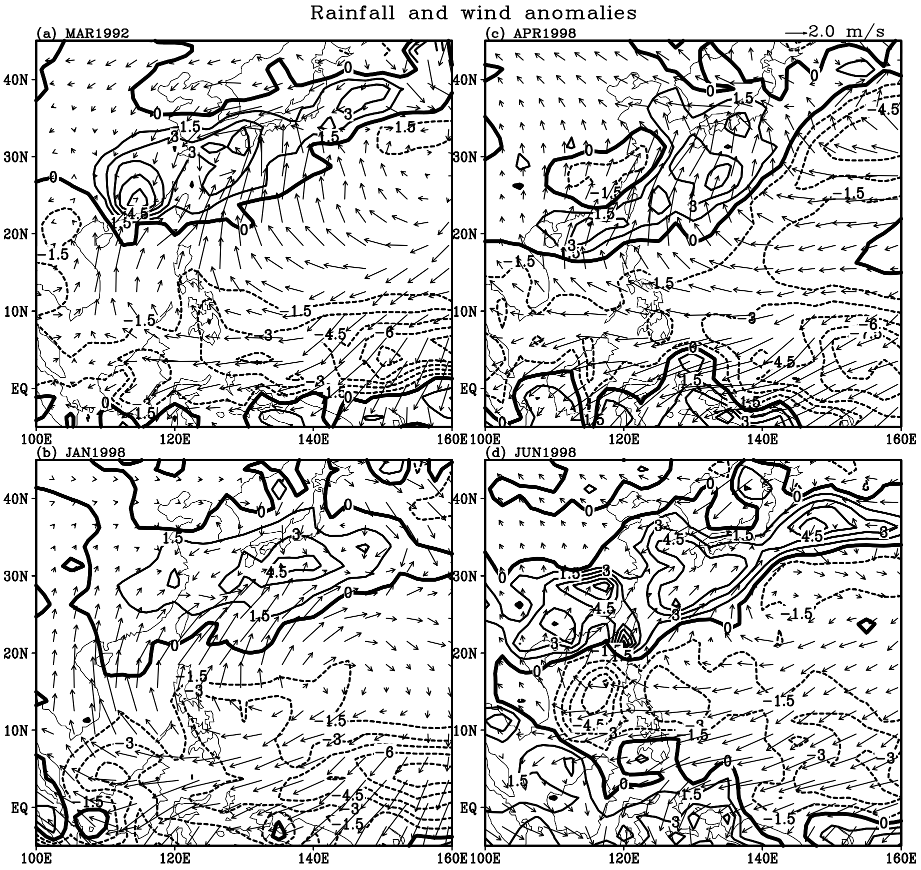

Figure 3: Precipitation (contour) and wind (vector) anomalies over the east Asian monsoon and western Pacific regions during (a) March 1992, (b) January 1998, (c) April 1998, and (d) June 1998. Contour interval of the precipitation rate is 1.5 mm/day.

5. IMPACT OF ANTICYCLONIC WIND OVER PHILIPPINES ON EAST ASIAN MONSOON RAINFALL

The northern winter in the east Asian monsoon area is dominated by dry northerly or northeasterly wind. During the Meiyu-Baiu season (May-June), a southwest-northeast oriented rain band accompanied by warm and moist southerly wind extends from southern China to southern Japan. During the winters of Pacific warming events, the anticyclone over Philippine Sea persists to the next spring (Wang et al. 2000). For the extremely strong ENSO event such as 1997/98, the anticyclone even survives to the summer of 1998. The wind anomalies exert significant impact on the east Asian winter and pre-monsoon rainfall. Winter and spring become anomalously wet in southeast/east China and southern Japan following the Pacific warming (displayed in Fig. 3). Onset of the Meiyu-Baiu is earlier than non-ENSO years. More intense rainfall is expected during the pre-monsoon season. The precipitation anomalies bear similar spatial pattern with the climatological Meiyu-Baiu rain band. The rain band is associated with the wind convergence. The southern branch of the anticyclonic circulation is correlated with divergence and anomalously dry condition. The results concur with previous studies of ENSO impact on East Asian climate (e.g., Zhang et al. 1996, Tao and Zhang 1998).

6. SUMMARY

The spacebased observations by microwave scatterometers and radiometers are analyzed to reveal the annual and interannual variabilities of East Asian monsoon. Significant negative correlation between curl of wind stress and sea level change in the central part of the SCS basin is consistent with seasonal changes of Ekman pumping following the monsoons. In the deep basin, positive stress curl causes upwelling, lower sea level, and cyclonic geostrophic current in winter, and negative stress curl causes higher sea level and anticyclonic geostrophic current in summer.

The SCS winter monsoon is stronger and wetter during the Pacific cold events, whereas during warm events it is weaker and dryer than normal years. During the spring and summer following the Pacific peak warming, The anticyclonic anomalies over Philippines induces earlier onset of Meiyu-Baiu and more intense rainfall. The anomalous rain band associated with wind convergence bear similar spatial pattern with the climatological Meiyu-Baiu polar front.

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