Space Observation of the Coupling Between the Atmosphere and Asian Marginal Seas

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1. Introduction

The advance of spacebased microwave sensors that measure ocean surface wind vector [Liu, 2002] and sea surface temperature (SST) [Wentz, 2002], under both clear and cloudy conditions, night and day, open new opportunity of studying ocean-atmosphere coupling in the Asian marginal seas. The recent improvement in the spatial resolution of scatterometer winds [Tang et al., 2003] pushes the applications to coastal oceans. Examples of the manifestation of the coupling, as the correlation between SST and surface wind, in the Asian coastal ocean and marginal seas will be presented. Two perspectives – one with the atmosphere and the other with the ocean as the driving force, will be discussed.

2. Wind Forcing in South China Sea

The ocean will respond to surface wind and thermal forcing by changing SST and dynamic topography, which are observed by spacebased radiometer and altimeter. Liu et al. [1994], using measurements by the Special Sensor Microwave/Imager, clearly demonstrated a negative lag correlation between surface winds and SST in annual and interannual time scales over most of the global oceans. High winds increase evaporative cooling, and decrease mixed layer heat content and SST.

Dynamic coupling should be manifested through lag correlations between the curl of wind stress (CWS) and dynamic topography and between CWS and SST. Waves and current advection often obscure direct observations of such simple correlations in open oceans. South China Sea (SCS) is semi-enclosed, where such negative lag correlations were observed in annual time scale using only spacebased data [Liu and Xie, 1999]. Lin and Liu [2003] have also observed patches of lower SST after the passage of a tropical cyclone in SCS, which are largely caused by wind-driven Ekman pumping and vertical mixing in the ocean. Such cooling was also simulated by numerical models [Chu et al., 1999] in the same area.

In the center of the SCS basin, the winter monsoon causes positive CWS (cyclonic circulation), divergence of surface water, upwelling of cold water, depression of sea level and SST. The summer monsoon, with negative CWS, causes opposite responses. Fig. 1 shows the winter wind forcing and subsequent oceanic responses, derived

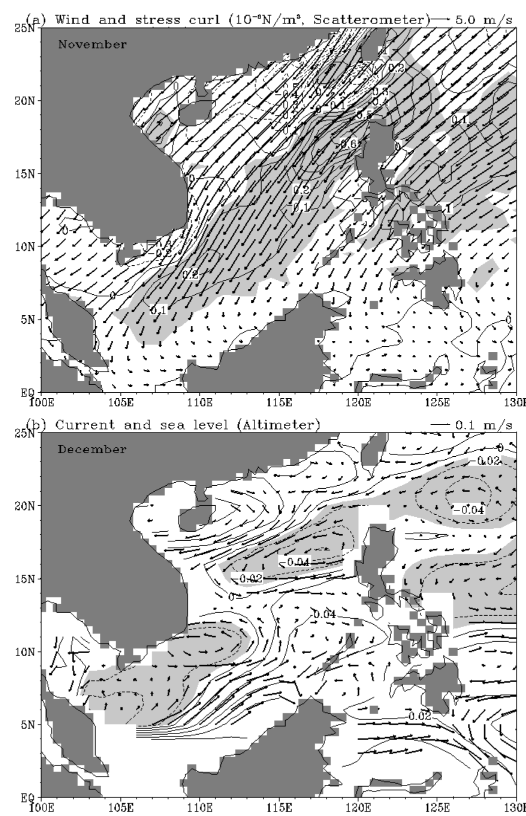

Fig. 1: Monthly average of curl of wind stress and wind vectors derived from 5 years of ERS1 scatterometer data (a); sea level changes and geostrophic currents derived from 9 years of Topex/Poseidon sea level (b) one month later.

from climatological data. In Fig. 2, the anticyclonic circulation in the center of the basin during summer is punctuated by a wind jet branching off from the South Vietnamese coast, causing positive CWS, low sea level and SST, two months later. It is suggested that the wind jet is influenced by the land topography of South Vietnam [Gordon Xie, personal communicating].

3. Ocean Forcing in East China Sea

Liu and Xie [2002], in their study of double intertropical convergence zone (ITCZ), presented observational evidence of two major mechanisms by which the ocean drives the atmosphere. When the ocean is warm and SST is above deep convection threshold (around 26-27°C), surface winds from different directions converge to the local SST maximum, driven by pressure gradient force. The local maxima of wind convergence and SST are approximately collocated. The stronger ITCZ occurs when the northerly trade winds meet the southerly trade winds over warm water. The weaker ITCZ occurs over cooler water and is caused by the deceleration of the surface winds as they approach the cold upwelling water near the equator. Decreases in vertical mixing and increases in vertical wind shear in the atmospheric boundary layer are suggested to be the causes of the deceleration of the trade winds as they move from warmer to colder water.

The relation between wind shear and atmospheric density stratification (stability) has been well known and discussed in turbulence transfer textbooks. A review on atmospheric stability driven by wind shear and buoyancy is given by Liu et al. [1979] and others. The change in wind shear in the boundary layer was used by Xie et al. [1998] to explain the coherence between SST and surface wind in the tropical instability waves (TIW) - the westward propagating temperature front of the cold tongue. Liu et al. [2000] validated this model with rawinsonde measurements of a research cruise across the TIW, and with the phase difference between spacebased wind and SST measurements. Surface wind convergence is at quadrature with SST. Similar ocean driven coupling over cool water which results in positive contemporary correlation between wind speed and SST appears to be much more prevalent. It was observed in the cold patches behind typhoon passages [Lin et al., 2002] and even over Gulf Stream rings [Park and Cornillon, 2002].

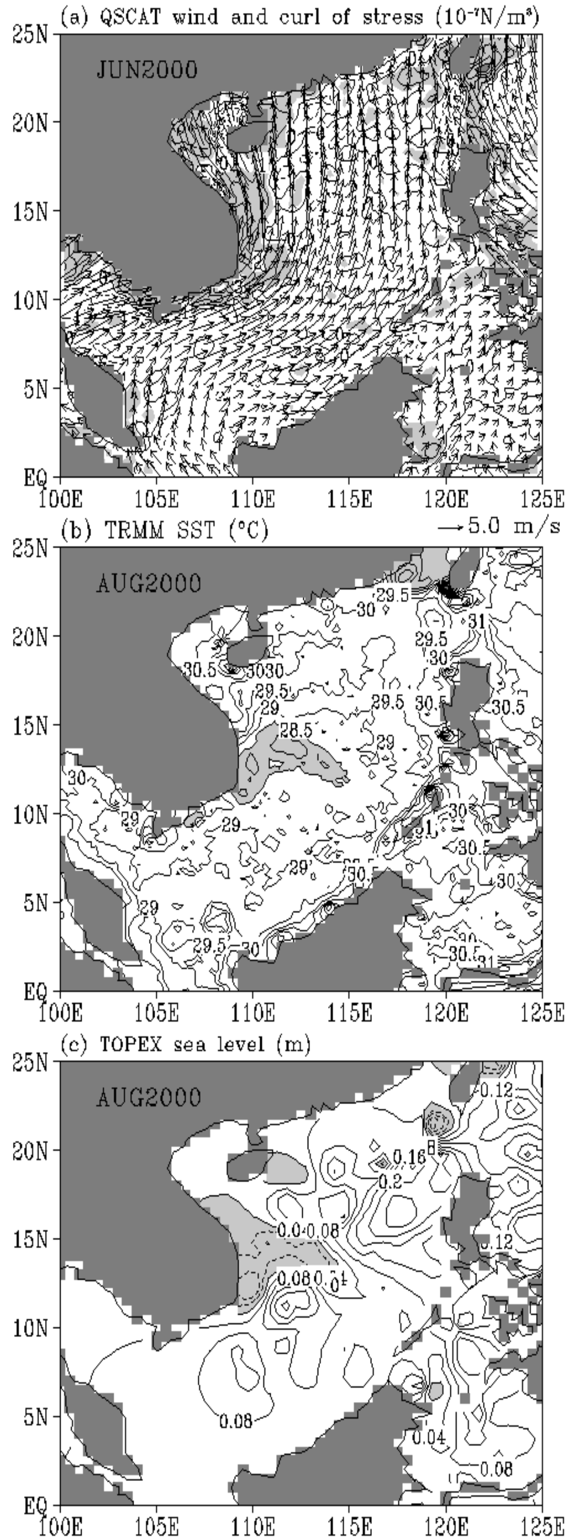

Fig. 2 Curl of wind stress and wind vector derived from QuikSCAT (a); sea surface temperature from TMI (b), and sea level changes from Topex/Poseidon (c).

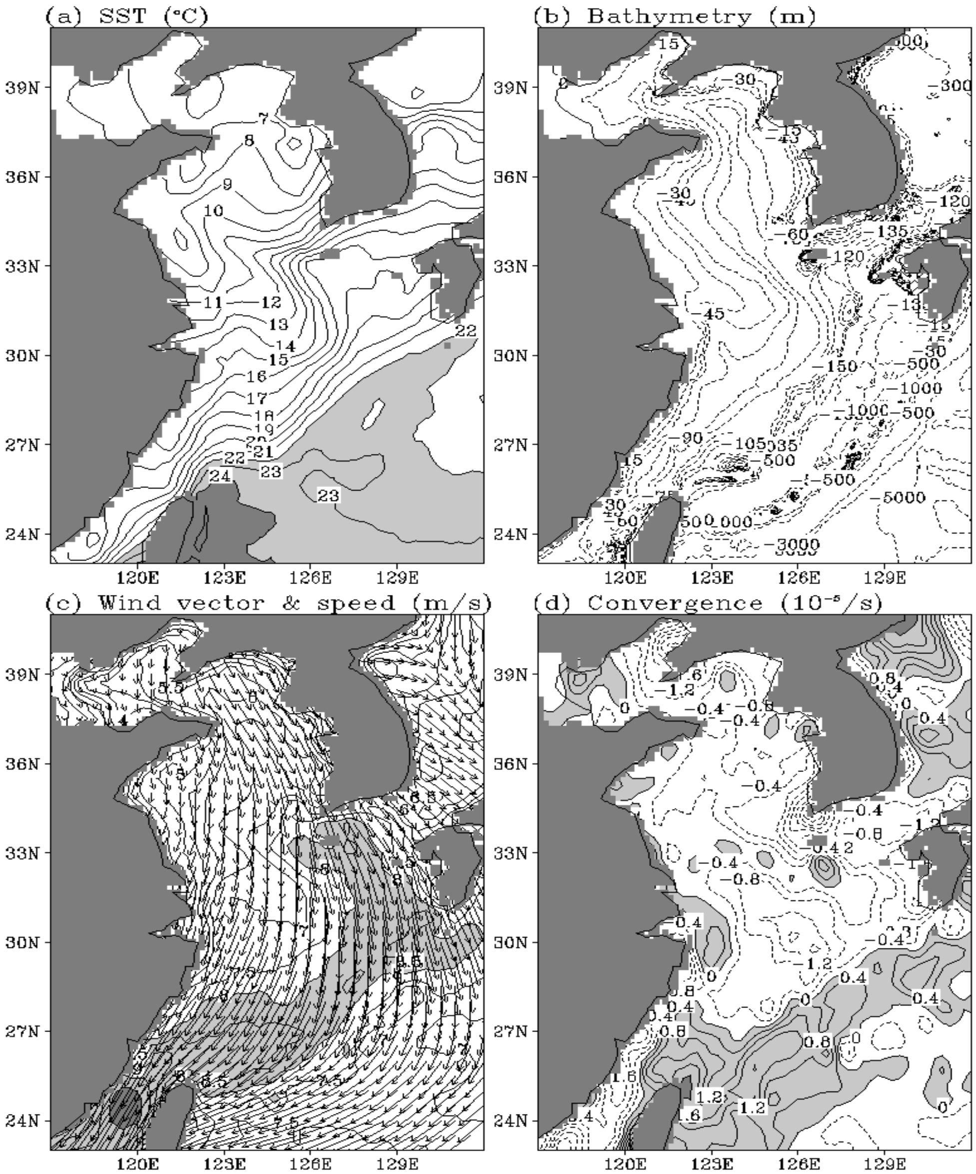

Fig. 3: Sea surface temperature measured by the microwave imager of the Tropical Rain Measuring Mission (a), bottom topography (b), wind vector denoted by arrows superimposed on isotach of wind speed derived from QuikSCAT (c), and wind convergence derived from QuikSCAT (d). Areas with sea surface temperature over 22°C, wind speed over 8 m/s, and positive convergence, are shaded.

The ocean driven coupling is evident during winter and spring in the vicinity of East China Sea. Fig. 3a shows a strong warm tongue stretching from Cheju Island of South Korea, through the Yellow Sea to the Bohai Bay. It is separated from a similar warm tongue in East China Sea to the south by a cold tongue. Fig. 3b shows that, in the East China Sea, the warm tongues lie over deep channels. As suggested by Xie et al. [2002], under intense winter cooling, deep-water cools much slower because of thermal inertia, than shallow water, and hence stay warmer. Vertical mixing is a strong determining factor of bathymetric effect on SST. Fig. 3c shows that the warm and cold tongues are co-located with high and low winds in the East China Sea, but the convergences are located at the front where the SST gradient is strongest. There is strong wind jet blowing along the Kuroshio front, most probably driven by cross-front pressure gradient. Fig. 3d shows that the location of convergence with respect to the SST fronts reveals the role played by the two mechanisms. Chen et al. [2003] shows that the ocean circulation cell and biological pumping associated with this frontal wind jet were simulated by a coupled model.

4. Availabilty of Vector Winds

Near-real-time and uniformly gridded QuikSCAT wind data can be assessed through http://airsea-www.jpl.nasa.gov/seaflux. The standard data have 25-km resolution and are not available within 30 km from land. There is on-going effort to improve the quality of higher resolution (12.5 km) wind products derived from range-compressed backscatter and fill in the 30-km data gap over coastal ocean (see http://airsea-www.jpl.nasa.gov/cos).

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References

Chen, D., W.T. Liu, W. Tang, and Z. Wang (2003): Air-sea interaction at oceanic fronts: a mechanism for frontogenesis. Presented at the Ocean Vector Science Team Meeting in Oxnard, CA.

Chu, P.C., S. Lu, and W. T. Liu (1999): Uncertainty of South China Sea prediction using NSCAT and National Centers for Environmental Prediction winds during tropical storm Ernie, 1996, J. Geophys. Res., 104(C5), 11,273-11,289.

Lin, I-I, W.T. Liu, C.-C. Wu, J.C. Chiang, and C.-H. Sui, 2002: Space-based observations of modulation of boundary layer winds by typhoon-induced upper ocean cooling. *Geophys. Res Lett*., in press.

Lin, I-I, and W.T. Liu, 2003: Oceanic biological response to a typhoon. Proc. 12th Conf Satellite Meteor. And Oceanogr. Amer. Meteor. Soc., Boston, in press.

Lindzen, R.S., and S. Nigam, On the role of sea-surface temperature gradients in forcing low-level winds and convergence in the tropics. *J. Atmos. Sci.*, **44**, 2440-2458, 1987.

Liu, W.T. (2002): Progress in Scatterometer Application, 58, 121-136.

Liu, W.T., and X. Xie, (1999): Spacebased observations of the seasonal changes of South Asian monssons and ocanic responses, Geophys. Res. Lett., 26(10), 1473-1476.

Liu, W.T. and X. Xie, 2002: Double Intertropical Convergence Zoens – a new look using scatterometer. *Geophys. Res. Lett*., 29(22), 2072, doi:10.1029/2002GL015431

Liu, W.T., K.B. Katsaros, and J.A. Businger, 1979: Bulk parameterization of air-sea exchanges of heat and water vapor including the molecular constraints at the interface. J. Atmos. Sci., 36, 1722-1735.

Liu, W.T., A. Zhang, and J.K.B. Bishop (1994): Evaporation and solar irradiance as regulators fo sea surface temperature in annual and interannual changes, J. Geophys. Res., 99 (C6), 12,623-12,637.

Liu, W.T., X. Xie, P.S. Polito, S. Xie, and H. Hashizume, 2000: Atmosphere manifestation of tropical instability waves observed by QuikSCAT and Tropical Rain Measuring Missions. *Geophys. Res. Lett*., **27**, 2545-2548, 2000.

Park, K-A., and P. Cornillon, 2002: Stability-induced modification of sea surface winds over Gulf Stream rings. *Geophys. Res. Lett.*, 29(24), 2211, doi:10.1029/2001GL014236i Wentz, F.J., C. Gentemann, D. Smith, D. Chelton (2000): satellite measurements of sea surface temperature through clouds, Science, 288, 847-850.

Tang, W., B. Stiles, and W.T. Liu (2003): Evaluation of high-resolution coastal winds, presented at the Ocean Vector Wind Science Meeting in Oxnard, CA.

Wentz, F.J., C. Gentemann, D. Smith, D. Chelton (2001): Satellite measurements of sea surface temperature through clouds, Science, 288, 847-850.

Xie, S.-P., M. Ishiwatari, H. Hashizume, and K. Takeuchi, Coupled ocean-atmosphere waves on the equatorial front. Geophys. Res. Lett., 25, 3863-3866, 1998.

Xie, S.-P., J. Hafner, Y. Tanimoto, W.T. Liu, H. Tokinaga, and H. Xu, 2002: Bathymetric Effect on the Winter Climate through the Sea Surface Temperature in the Yellow and East China Seas. Geophys. Res. Lett., 29(24),2288, doi:10.1029/2002GL015884..