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Seasonal variability in coastal fronts and its influence on sea surface wind in the Northern South China Sea

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ABSTRACT

High-resolution reanalysis data of Sea Surface Temperature (SST) show pronounced seasonal variations in oceanic fronts in the coastal area of the Northern South China Sea (NSCS), which are accompanied by the seasonality of monsoons. The NSCS oceanic fronts cover a wider area of the coastal sea in winter than in summer as strong winter monsoons progress. Nonetheless, the average SST gradients of the frontal area in both seasons are comparable. The response of surface wind to SST perturbations attributed to oceanic fronts in the NSCS coastal area has also been investigated by the observation data of satellite borne scatterometers and the simulation data of the Weather Research and Forecasting (WRF) model. Both the satellite observations and the simulations of the WRF model show apparent positive linear SST-wind coupling for most months in 2008, indicating the local influence of coastal SST fronts on the sea surface wind in the NSCS. The SST-wind coupling coefficients in the NSCS coastal sea are larger than those observed at mid-latitude oceans but smaller than those observed near equatorial oceans. It is also found that the influence of topography on the sea surface wind could be more important than that of the SST front at the southern end of the Taiwan Strait in winter. The transition of the monsoon could also affect the SST-wind coupling in the NSCS.

1. Introduction

For large scale ocean basins, Sea Surface Temperature (SST) perturbations are found to be negatively correlated with surface wind speed perturbations (Xie, 2004). Large-scale atmospheric circulation patterns change surface ocean temperatures through modulation of surface heat fluxes and surface mixed layer depth (Cayan, 1992). This is a one-way forcing of the ocean by the atmosphere. However, on smaller spatial scales between 100 and 1000 km, such as the mesoscale, the oceans drive an atmospheric response. In situ observations, satellite observations, and numerical simulations have consistently shown a positive correlation between surface wind speed and mesoscale SST variations (Small et al., 2008; Chelton and Xie, 2010).

An oceanic front is a typical mesoscale oceanic phenomenon identified by a discontinuity in temperature, salinity, or nutrient and chlorophyll *a* content (Belkin et al., 2009). SST perturbations associated with oceanic fronts can induce adjustment of the Marine Atmospheric Boundary Layer (MABL), and result in perturbations of the surface wind with enhanced winds over warm water and reduced winds over cold water. The responses of sea surface wind to SST perturbations over frontal areas are common in equatorial and mid-latitude oceans, including the eastern tropical Pacific (Wallace et al., 1989; Hayes et al., 1989; Chelton et al., 2001), the Kuroshio and its extension (Nonaka and Xie, 2003; Tokinaga et al., 2006), the Gulf Stream and its extension (Chelton et al., 2004; Song et al., 2006), the Brazil-Malvinas confluence in the South Atlantic (Tokinaga et al., 2005), and the Agulhas Current and Agulhas Return Current (O'Neill et al., 2005).

Previous studies have proposed several hypotheses to explain the mechanism of the surface wind response to oceanic SST fronts. One is the generation of hydrostatic pressure gradients through adjustments of the MABL mass fields (Lindzen and Nigam, 1987; Small et al., 2003; Song et al., 2006) and another is the stability-dependent modification of vertical mixing of momentum from aloft to the surface (Wallace et al., 1989; Hayes et al., 1989; Tokinaga et al., 2006). Tanimoto et al. (2011) proposed that both of these two mechanisms are active in the SST–wind interactions over a frontal area. Samelson et al. (2006) proposed an approximately linear relationship between the surface wind stress and the height of the MABL under a quasi-equilibrium condition, in which the MABL approximately comes into equilibrium with steady free-atmospheric forcing.

According to Yanagi and Koike (1987), oceanic fronts are classified into coastal water fronts, shelf fronts, and open ocean

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fronts. A considerable number of studies on the relationship between SST and sea surface wind have been conducted on the continental shelf and the open ocean fronts in the equatorial and mid-latitude oceans. However, studies on the modification of sea surface wind via coastal water fronts have rarely been reported.

The South China Sea (SCS) is an epi-continental marginal sea of the western Pacific Ocean and a Mediterranean-type basin dominated by the Asian monsoon, which blows northeasterly from October to April and southwesterly from May to September in the northern regions of the SCS. The active coastal fronts observed in the Northern South China Sea (NSCS) vary throughout the year due to the combined effects of reversing monsoon winds, variations in bathymetry, and the tide (Wang et al., 2001; Hu et al., 2003; Liu et al., 2010). These shallow and narrow coastal fronts are accompanied by marked seasonal variations in strength and coverage. Thus, SST–wind coupling over coastal fronts in the NSCS could vary from those over open oceans.

In the present study, the seasonal variations in a NSCS coastal front and its influence on the sea surface wind in the NSCS are investigated. The observation data and the model configuration are described in Section 2. The seasonal variability of the NSCS coastal front and the observed SST–wind coupling induced by the front are demonstrated in Section 3.1. The verification of our one-year simulation is presented in Section 3.2, and the simulation results are used to analyze the SST–wind coupling. The analysis results are discussed in Section 4. Section 5 summarizes the study.

2. Data and model configuration

2.1. SST and wind data

The Operational SST and Sea Ice Analysis (OSTIA; Stark et al., 2007) data are provided by the Group for High Resolution SST (GHRSST) pilot project, which was initiated by the Global Ocean Data Assimilation Experiment in 2000. OSTIA uses several kinds of satellite data from the GHRSST project, as well as in-situ observations, to determine the SST for the global ocean. The combination of multi-sources in the OSTIA data eliminates some abnormal perturbations and generates a smooth SST map, which can be conveniently used by atmospheric models.

The OSTIA SST has a resolution of 0.05° at daily intervals. The OSTIA dataset provides robust data and acceptable accuracy near shores, which enables it to identify coastal fronts in the NSCS. Xie et al. (2008) estimated five types of SST products of the GHRSST project and found that the OSTIA SST yields the smallest Root Mean Square Difference (RMSD) compared to the independent buoy and ship observations in the coastal and shelf seas around China.

The sea surface wind data used in this study were observed by Quick Scatterometer (QuikSCAT) and Advanced Scatterometer (ASCAT). Thus far, QuikSCAT provides a more extensive geographical and temporal coverage and higher spatial resolution of the ocean vector winds compared to those obtained by other spaceborne sensors (Chelton and Wentz, 2005). After QuikSCAT finished its mission in October 2009, ASCAT continues to provide global sea surface wind data. These two kinds of wind data have been widely used in previous studies on SST–wind coupling over open ocean fronts (Chelton et al., 2001; Nonaka and Xie, 2003; Tokinaga et al., 2006; Song et al., 2006; O′Neill et al., 2005, 2010; O′Neill, 2012).

The QuikSCAT data from 1999 to 2009 are distributed by Remote Sensing Systems (RSS). The ASCAT data from 2009 to 2011 are available from the Asia-Pacific Data Research Center. Despite missing near-shore data, the existing data covering the NSCS frontal area are sufficient to support the present study. Similar to previous studies, the analysis in this study that utilizes wind data is based on 10-m equivalent neutral winds. Equivalent neutral wind is the wind that would exist for an idealized condition at a given height if the atmospheric boundary layer was neutrally stratified.

2.2. Model configuration

The Weather Research and Forecasting (WRF) model with the Advanced Research WRF (ARW) dynamic solver (Skamarock et al., 2005) is used to confirm the response of sea surface winds to mesoscale SST perturbations over the NSCS coastal fronts. The WRF model has been used in previous studies to examine air–sea coupling processes over oceanic fronts (Song et al., 2009; O′Neill et al., 2010).

The WRF model in this study has two nested domains, D1 and D2, with horizontal resolutions of 18 and 6 km, respectively. The outer domain (D1) covers the NSCS while the inner domain (D2) focuses on the southern coastal area of China (Fig. 4A). Two-way nesting is applied to allow interactions between the two domains. This study used the simulation results of D2.

Two domains were initialized with the National Centers for Environmental Prediction (NCEP) operational analysis data. The lateral boundary conditions for D1 were updated by NCEP analysis data every 6 h to allow large-scale synoptic weather systems outside of the domain to propagate through the domain. Daily OSTIA SST data, which were updated every 24 h during the simulation periods, were used as the bottom boundary condition. The initial and boundary conditions were designed to obtain a realistic simulation result and to maintain consistency in the analysis of the observation and simulation results.

The simulation was performed using 43 vertical sigma levels including 25 levels below 1000 m. A fine vertical resolution was specified in the boundary layer to accurately simulate the vertical turbulent momentum exchange in the layer. The lowest level extends from the surface to a height of 12 m, whereas the highest level almost reaches a height of 20 km.

An improved Mellor–Yamada–Nakanishi–Niino (MYNN) level 3 scheme is employed to simulate the marine atmospheric boundary layer. This scheme is based on the original Mellor–Yamada level 2.5 turbulence closure model (Mellor and Yamada, 1982) and imposes additional restrictions to assure its reliability and numerical stability (Nakanishi and Niino, 2006). The Noah land surface model is also adopted in the simulation. The microphysical parameterizations include explicitly resolved water vapor, cloud, and precipitation processes. A modified version of the Kain–Fritsch scheme is used to represent the subgrid-scale effects of convection and shallow clouds.

The model was run for an integration period of one month, starting at 0000 UTC on the first day of the month and ending at 2400 UTC on the last day of the month. This process was conducted for the 12 months of 2008 to investigate the influence of fronts on sea surface winds during different seasons.

3. Results

3.1. Observation

3.1.1. Seasonal variability of the SST front

The monthly mean magnitude of the SST gradient was calculated using the OSTIA data from 2006 to 2011. The magnitude of the SST gradient can be regarded as an index of the strength of the coastal fronts. Therefore, maps showing the magnitude of the SST gradient were used to investigate the spatial distribution and seasonal variation of the SST front.