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Impact of the AVHRR sea surface temperature on atmospheric forcing in the Japan/East Sea

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Abstract. The impact of high resolution sea surface temperature (SST) data on the atmospheric forcing in the Japan/East Sea (JES) is investigated using a high-resolution mesoscale atmospheric model. We use the Advanced Very High Resolution Radiometer (AVHRR) Pathfinder SST (PFSST) and the operational NCEP (National Center for Environmental Prediction) global SST analysis (NCEPSST) as the lower boundary conditions for two numerical experiments. A sharp SST gradient associated with the subpolar front in JES, well-resolved by PFSST, has a significant influence on both synoptic scale and monthly mean surface winds and heat fluxes in JES. These results have an important implication for research related to coastal atmosphere and ocean circulation and air-sea interactions.

Introduction

The oceanic subpolar front in JES separates the warm subtropical water entering from the Tsushima Strait and the cold subarctic water. It is also referred to as the Polar Front [*Isoda et al.,* 1990]. Associated with the subpolar front is a strong SST gradient located near 40°N in JES. It is the most pronounced feature in the wintertime in JES. The SST front is shown clearly in the high-resolution (9 km) AVHRR data, but largely missing in the low-resolution (2.5°) NCEP global gridded SST analysis field (Plate 1, interpolated to the model grids). The wintertime atmospheric circulation in JES is dominated by Siberian cold-air outbreaks and their interaction with the complex coastal terrain in the region. The winter storms develop usually as synoptic-scale (at about 4-7 days interval) extratropical cyclones over the Asian Continent and propagate eastward to the northern Pacific. Cold and dry air protrudes behind an atmospheric surface cold front. Occasionally mesoscale cyclones develop or strengthen over the ocean in JES. Whether the SST spatial patterns in JES have any influence on the atmospheric circulation, however, is largely unknown. The main objectives of this study are (1) to examine the impact of a large SST front on the atmospheric circulation in JES and (2) to test the sensitivity of numerical simulation of weather systems to spatial resolution of the SST field.

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Data and Model

To test the sensitivity of the atmospheric circulation to SST forcing in JES, we use the operational NCEP SST [*Reynolds and Smith.,* 1994] and PFSST [*Kilpatrick et al.,* 2001] as the lower boundary conditions for two model experiments. The temporal resolution is 5 days for PFSST and 1 day for NCEPSST, respectively. The spatial resolution is 9 km for PFSST and 2.5° for NCEPSST. The daily NCEPSST data is produced using a 7-day running mean. We composite the twice-daily PFSST data into 10-day images, which are produced every 5 days centered on the date of interest, to minimize the number of missing data points due to clouds. Our main focus is the SST impact on atmospheric circulation of synoptic and monthly time scales. The 5-day update of PFSST is adequate for this study.

Because of the large SST gradient from west to east during the winter season, there are semi-permanent low-level clouds over the warm water in the eastern JES. Simple spatial interpolation will not yield realistic SST patterns over the large data gaps in the Pathfinder data, especially when sharp gradients exist near the boundaries of missing data regions. To circumvent this problem, we construct a blended product from PFSST and NCEPSST to fill the data gaps. We first generate a difference field between PFSST and NCEPSST (ΔSST = PFSST - NCEPSST). We then fill the gaps in ΔSST by averaging eight closest grid points surrounding each missing ΔSST point starting in the region with the least missing data. We apply this procedure iteratively until all missing data points are filled. We then add the ΔSST to NCEPSST to get a new SST at the missing

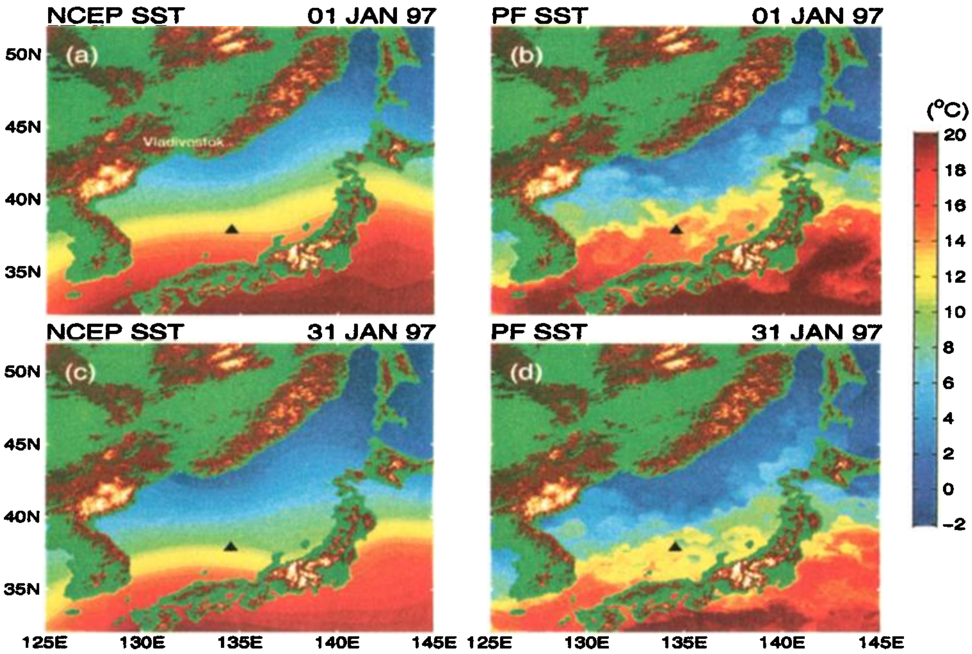

Plate 1. The NCEP global SST analysis (NCEPSST) and AVHRR Pathfinder SST (PFSST) for 1 January 1997 (a and b) and 31 January 1997 (c and d). The PFSST images are 10-day composites centered on the dates indicated. The black triangle indicates the location of the JMA moored buoy (21002) in JES.

data points originally in PFSST. This blended product is now referred as PFSST for simplicity.

We use the Penn State University/National Center for Atmospheric Research atmospheric nonhydrostatic mesoscale model (MM5) [*Dudhia,* 1993] to characterize the mesoscale structures of atmospheric synoptic forcing, especially for Siberian cold-air outbreaks off the coastal region near Vladivostok and in the vicinity of the subpolar SST front in JES. Our general approach is to use a nested-grid model to cover a large area in the outer domain and still resolve the fine mesoscale features in the inner domain. We use grids with 45 and 15 km grid spacing for the outer and inner domains, respectively. The outer domain covers a large portion of the Asian Continent and the northwestern Pacific Ocean (not shown). The 15-km grid inner domain covers the JES region (Plate 1). We use the European Center for Medium-range Forecast (ECMWF) global analysis fields to initialize MM5 and provide continuous lateral boundary conditions. The outer domain is run in a four-dimensional data assimilation (FDDA) mode to provide the best possible boundary conditions for the inner domain. The inner nested domain is run in a forecast mode with no FDDA.

Results

The atmospheric circulation is dominated by three major extratropical cyclones associated with wintertime cold-air outbreaks and four weak synoptic disturbances over the JES region during January 1997. The MM5 simulations captured the observed structure and evolution of the cold-air outbreak events over the JES region. The model simulations have been validated with both satellite and in situ observations including the Japanese Geosynchronous Meteorological Satellite (GMS-5) infrared cloud top temperature and water vapor images, the NASA Scatterometer (NSCAT) surface winds, and surface measurements from stations near the coastal regions and the JMA moored buoy at (37.9°N, 134.5°E, Plate 1). The model simulated storm tracks closely matched satellite observed center locations of the storms from the infrared and water vapor images. Detailed descriptions of the weather systems in January 1997 are given in *Chen and Zhao* [2001].

To investigate the impact of the SST forcing on the atmospheric circulations in JES, we first examine two different SST fields. The main difference between NCEPSST and PFSST is the sharp SST gradient associated with the subpolar front as shown in Plate 1. The subpolar front shifts southward from the beginning to the end of January 1997 while SST decreases in the entire JES, which is typical for the winter season.

Fig. 1 shows a time series of NCEPSST and PFSST comparing with in situ measurements from the JMA buoy at 2-m depth. PFSST is very close to the observed SST at the JMA buoy, whereas NCEPSST is about 2-3°C too low. The buoy is located southeast of the SST front where NCEPSST smoothes out the sharp gradient because of the low spatial resolution.

The winter storms usually develop over the Asian Continent and move across JES within 12-24 h. To examine whether the SST pattern in JES can influence the storm track and intensity, we conduct two MM5 experiments using PFSST and NCEPSST as the lower boundary conditions, respectively. The differences in surface wind and temperature fields for the two simulations are compared with the JMA buoy data (Fig. 2).

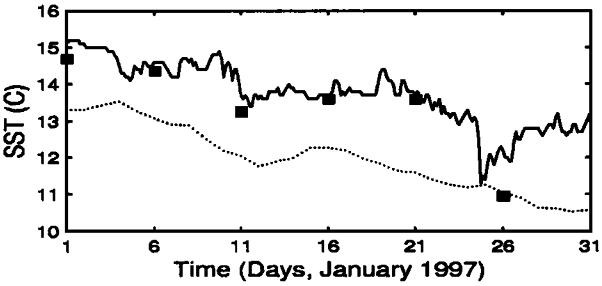

Figure 1. Time series of the JMA buoy-measured SST at 2 m depth (solid line), NCEPSST (dashed line), and 10-day composite PFSST (square) at the buoy location (37.9°N, 134.5°E) for January 1997.

There are seven high-wind events during January 1997. The main storm centers are located outside, mostly north, of JES in most cases. Only two storms (5-6 and 13-14 January) develop and intensify within JES. The surface wind gusts were up to 20 m s^{-1} in both NCEPSST and PFSST simulations, which is close to, but slightly underestimate, the observed 25 m s^{-1} at the JMA buoy during the first storm on 1 January. The simulated air-sea temperature difference reached 10-20°C behind the surface cold front similar to the observed value (cf. Figs. 1 and 2b). These extreme conditions induce strong surface heat and momentum fluxes. The high spatial resolution PFSST has a significant impact on the development and evolution of two storms that occurred on 5-6 and 13-14 January. Both storm centers pass through and strengthen over the SST front in JES, unlike all others that form over the Asian Continent and propagate downstream. For the 5-6 January storm, the PFSST simulation reproduced the 22 m s^{-1} surface wind peak, whereas the NCEPSST run failed to capture the strength of the storm (Fig. 2a). *Chen and Zhao* [2001] compares the model simulated storm structures with observations. They show that the PF-SST run produced a more realistic storm development in terms of vertical structure and storm location compared with the buoy measurements and satellite cloud top temperatures than the one using NCEPSST.

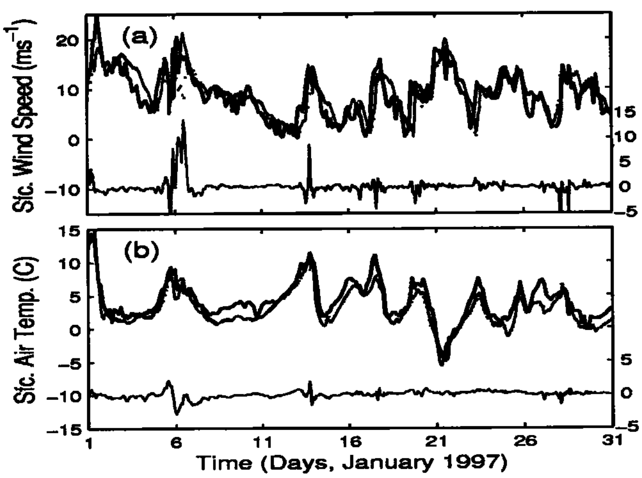

Figure 2. Time series of (a) surface wind speed and (b) air temperature measured at the JMA buoy 21002 (thick solid line) and from two MM5 simulations for PFSST (thin solid line) and NCEPSST (dashed line). The difference fields between the two simulations are plotted at the bottom of each panel (right axes with the same units).

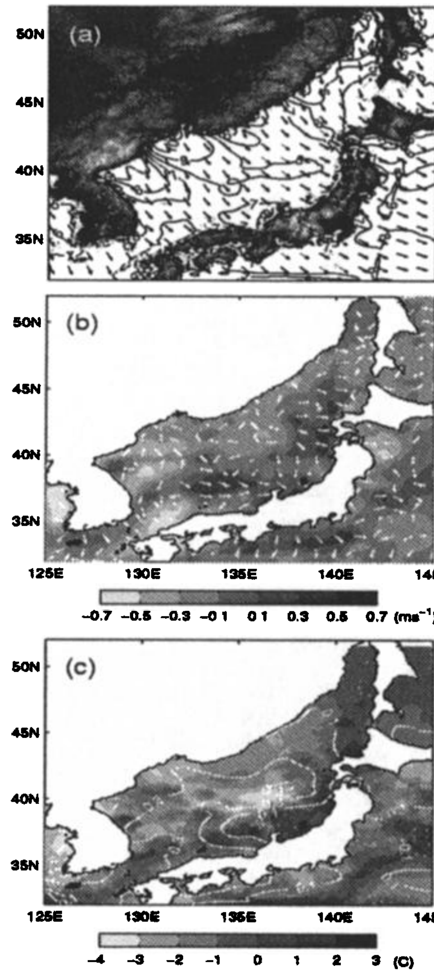

Figure 3. (a) Model simulated monthly mean surface wind speed (contours) and direction (arrows) using PFSST, (b) difference (PFSST-NCEPSST) fields of wind speed (shaded) and direction (arrows), and (c) difference fields of SST (shaded) and SLP (contours).

Fig. 3a shows the monthly surface winds simulated with PFSST forcing, which compares well with the NSCAT data [*Kawamura and Wu*, 1998; *Chen et al.*, 2001]. The surface winds and rainfall patterns were greatly modulated by the complex coastal terrain surrounding JES. Enhanced valley winds associated with the storms near Vladivostok were very persistent. There are several local minima downstream of the high mountains on the west coast. On the monthly mean time scale, the subpolar front in PFSST enhances the sea level pressure (SLP) gradient (Fig. 3c) which is largely responsible for the increase of monthly mean surface wind by about 10-15% (close to 1 m s^{-1}) on the warm side of the SST front (Fig. 3b).

The impact of the SST on surface turbulent (sensible + latent) heat flux is shown in Fig. 4. Generally, the high flux values are over the warm side of the SST front, except for the coastal region near Vladivostok where the strongest surface wind is located. The turbulent heat flux increases rapidly as the cold air moves from west to east across the SST front and then decreases further

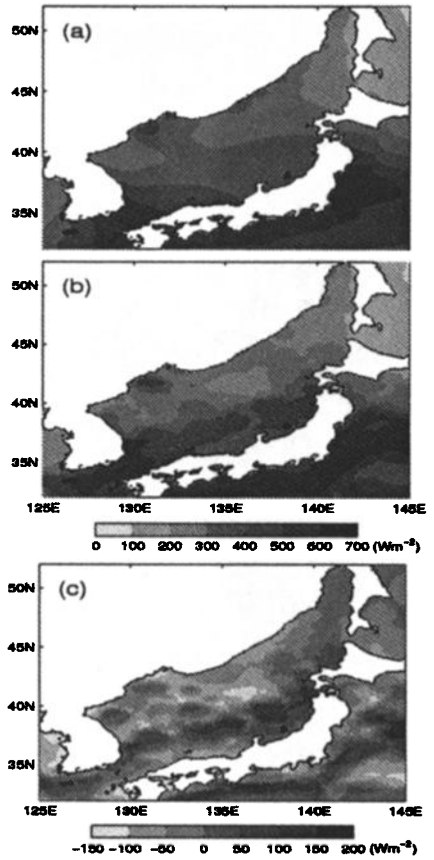

Figure 4. Model simulated monthly mean surface turbulent (sensible + latent) heat fluxes for (a) NCEPSST, (b) PFSST, and (c) difference (PFSST-NCEPSST) field.

downstream when the air temperature achieves equilibrium with the SST close to the west coast of Japan (Fig. 4b). This feature does not exist in the NCEPSST simulation (Fig. 4a). The difference in monthly mean surface turbulent flux between the two simulations is as high as 150 W m^{-2} in some locations (Fig. 4c). The pattern of the difference fields in sensible and latent heat fluxes are very similar to the total of the two, which closely match the SST difference (Fig. 3c).

Conclusions

The impact of the subpolar SST front observed by the PFSST on the atmospheric circulation in JES is examined. The atmospheric properties near the ocean surface including mean sea-level pressure, surface winds, and turbulent heat fluxes show a significant difference using PFSST and NCEPSST as lower boundary conditions in the atmospheric model. The high spatial resolution PFSST improves model simulation of winter storms in JES, especially those developed in JES, and has a significant impact on the atmospheric forcing on the monthly time scale. The atmospheric forcing associated with the winter storms in JES are known to induce strong oceanic response and possibly are responsible for variations in ice cover [*Martin et al.*, 1992] and formation of the JES Proper Water [*Kawamura and Wu*, 1998]. Accurate representation of SST can improve the surface winds, temperature, sea level pressure, and latent and sensible heat fluxes calculations that are crucial for understanding of air-sea interactions in JES.

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