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A case of cold air outbreak over the Kuroshio region is simulated over an 8 day period using a state-of-the-art coupled atmosphere-ocean forecast model that includes assimilation of observations. During the event, maximum winds reach 20 m/s in agreement with observations and the air temperature drops over 10^{o}C, resulting in surface heat fluxes in excess of 1000 W/m^2.

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Cold air outbreak over the Kuroshio Extension Region

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Abstract-A case of cold air outbreak over the Kuroshio region is simulated over an 8 day period using a state-of-the-art coupled atmosphere-ocean forecast model that includes assimilation of observations. During the event, maximum winds reach 20 m/s in agreement with observations and the air temperature drops over 10°C, resulting in surface heat fluxes in excess of 1000 W/m^2.

I. Introduction

The northward flowing Kuroshio Current turns to eastward flow, leaving the coast of Japan near 35°N. It separates regions with large gradients in sea surface temperature over shorts distances, with cold sub-polar water masses to the north and warm subtropical water masses to the south. The subtropical gyre south of the Kuroshio extension is also an area where some of the largest sensible and latent heat fluxes can be observed. The annual mean is about 50 W/m^2 and 150 W/m^2, respectively [1]. However, during winter when dry, cold air masses are rapidly advected from the Asian continent, the sum of those heat flux components can exceed 1000 W/m^2. In this study we investigate such an event which started January 30, 2005 00UT and lasted through February 5, 00UT. Early coupled modeling studies of cold air outbreaks was done over the Gulf Stream area using a high-resolution boundary layer model [2] or two-dimensional models [3] and [4]. In this work we apply state-of-the-art three-dimensional models for both the ocean and the atmosphere and include assimilation of meteorological observations to get a realistic simulation of the event.

II. Observations

The event was observed by National Oceanographic and Atmospheric Administration's Kuroshio Extension Observatory (KEO), a buoy at 144.6°E, 32.4°N operating since June 2004. It is equipped to measure wind speed and direction, air temperature, relative humidity, rainfall, down-welling short wave and long wave radiation, and ocean temperature, salinity and currents close to the ocean surface and several subsurface levels. Fig. 1 shows the observed ocean temperature at 1 m (SST), the 2 m air temperature and their difference, and, in the right panel, the wind velocity components and speed at 10 m. During the cold air outbreak event, the winds are westerly at about 12 m/s on average, but reach 20 m/s. The air temperature dropped from being in equilibrium with SST to be nearly 10°C cooler compared to the time before the event. Measurements were taken at 10 min interval and hourly averages are shown in Fig. 1.

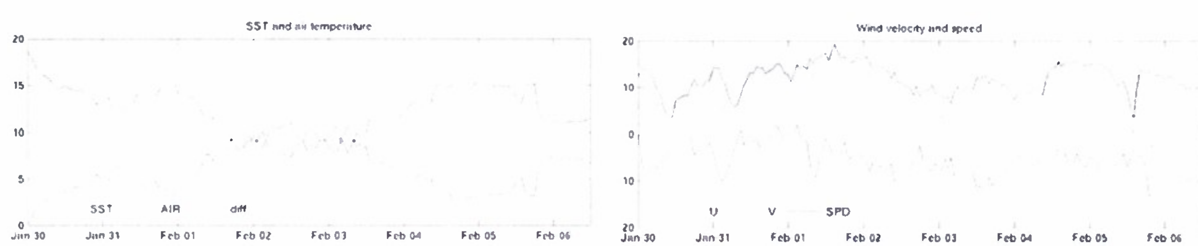

Fig 1. Observed SST and air temperature (left) and wind velocity components and speed (right) during the main cold air outbreak event.

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III. Coupled Ocean-Atmosphere Meso-Scale Prediction System

To interpret these measurements and assess how well the buoy data represents the air-sea interaction in the area, we apply the Naval Research Laboratory's Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS®) in a fully coupled mode with very high horizontal resolution. The non-hydrostatic atmospheric model is using 3 nested grids with resolutions of 27 km, 9 km and 3 km, respectively. All grids have 40 vertical levels. The atmospheric model is initialized using the Navy Operational Global Atmospheric Prediction System (NOGAPS), which also is used to provide boundary conditions during the simulation. The atmospheric model component is described in [5].

Details about the ocean model, the Navy Coastal Ocean Model (NCOM), is given in [6] . We use two-way nested ocean models. The larger model covers the area from 140°E to 155°E and 30°N to 42°N with a horizontal resolution of 1/16°, which is about 7 km, and 50 vertical levels. An inner nest with the same vertical levels and a horizontal resolution increased by a factor of three to 1/48° covers a region from 142°E to 150°E and 32°N to 38°N. It has 50 vertical levels, using a hybrid sigma-z vertical coordinate and a free surface. The initial fields and boundary conditions are provided from a western Pacific version of NCOM using 1/16 ° resolution. That model uses boundary conditions from a global NCOM model with 1/8° resolution model.

A 12 hour forecast is done using the coupled model, followed by an analysis that includes previous forecasts and data assimilation of new available observations. This 12-hour forecast/analysis cycle is repeated throughout the 8 days of simulation.

IV. Simulation Of Cold Air Outbreak

The coupled model was run to simulate the cold air outbreak event from 30 Jan to 6 Feb, 2006 using 12-hourly update cycles. The figures below show the location of the KEO buoy and a few examples of the information available from model simulations of the cold air outbreak event. Fig. 2 (left) shows the surface temperature (SST over oceans) minus the 2 m air temperature for February 2, 2005 00UT over the entire model domain covered by the 27 km grid. The model solution shows a large drop in air temperature over the Sea of Japan and over the Kuroshio region and the resulting large air-sea temperature difference caused by the cold air-out break.

Cold air propagates from the northwest with a maximum wind speed of 15-20 m/s in agreement with the KEO observations (Fig. 2, right). The wind field, shown on the 9 km grid, has sharp wind shear regions associated with the passage of fronts.

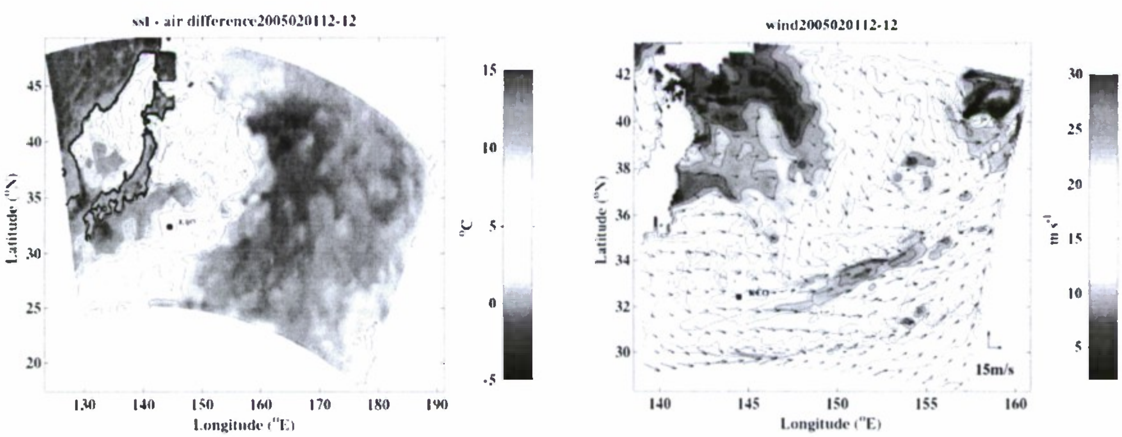

Fig 2. COAMPS atmospheric model surface fields on Feb 2, 2005 00UT Left: Surface temperature minus 2 m air temperature on the coarse model grid (27 km) showing large ocean atmosphere temperature differences over the Sea of Japan and over the subtropical gyre south of the Kuroshio Current. Right: wind velocity and wind speed at 10 m shown on nest 2 (9 km grid). The color represents the total wind speed.

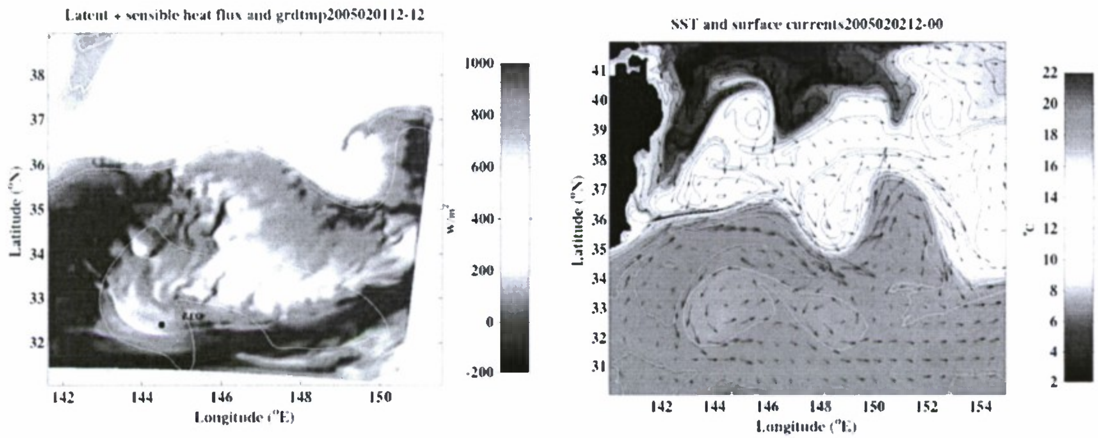

Fig 3. Left: The sum of latent and sensible heat flux from COAMPS atmospheric 3 km grid on Feb 2, 2005 00UT. Right: Sea surface temperature and current vectors from the 1/16° grid NCOM model

During this event the sum of the model latent and sensible heat fluxes exceeded 1000 W/m in the warm pool region including the KEO buoy location (Fig. 3, left). This is similar to those reported for the Gulf Stream region [3] where air-sea temperature differences exceeding 20°C have been observed [7]. Contours of SST on the atmospheric grid are shown in the figure and also in Fig. 3 (right) in color shading on the ocean model grid. It is clearly seen that the high heat fluxes are confined to the warm subtropical waters south of the Kuroshio front. Also note that a cyclonic cold core eddy is at the KEO buoy location (Fig. 3, right) during this time. This recirculation gyre is present during the entire model simulation.

The model simulation provides realistic air temperatures and winds over the KEO buoy (Fig. 4). The relative humidity is systematically underestimated in the model. The results in Fig. 3 are from on the 3 km atmospheric grid, but results on the coarser atmospheric grids are also in very good agreement with the buoy data.

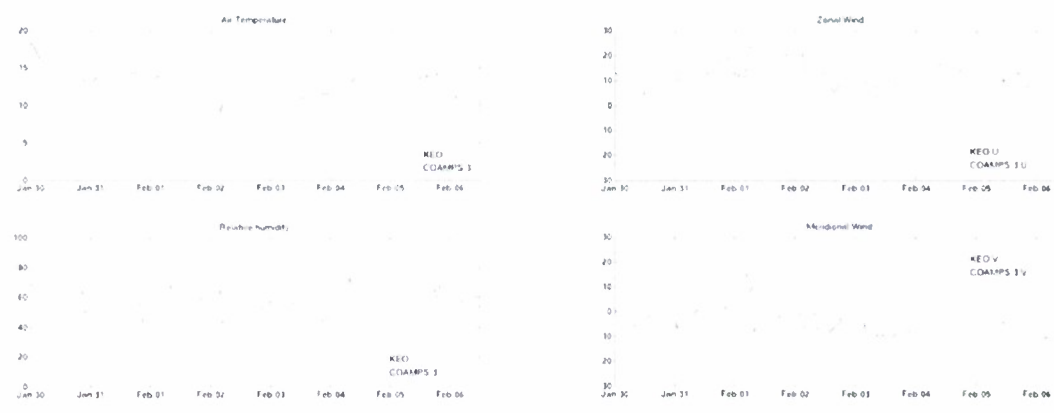

Fig. 5. Comparison of observations from the KEO buoy and COAMPS model, nest 3, for air temperature, relative humidity, zonal wind speed and meridional wind speed.

V. Discussion

The COAMPS model is a practical tool for assimilation of observations, performing atmospheric analyses and forecasting under extreme weather conditions. The system allows for computation of numerous atmospheric and oceanic variables that are not readily observed, and do it consistent with available observations. It provides the state and evolution of the atmosphere and ocean over the entire area of interest. Our model simulation is consistent with the observation in spite of the extreme conditions during the simulations period. The model solution shows very rapid motion of atmospheric fronts, high spatial and temporal variability of air-sea fluxes associated with cold air outbreaks.

With increasing resolution, model solutions resolve finer scale features that increase the variance of each quantity. In principle, the high model resolution should make point by point comparisons to station data like the KEO buoy more reliable, but that is to some extent offset by the increased variance.

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