Importance of the spatial resolution of sea-surface-temperature data in meteorological modeling

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Abstract

Mesoscale meteorological or air quality impact assessment models are constrained by surface boundary conditions such as emissions, deposition, sea surface temperature etc. Most models employ either weekly, monthly or climatological mean values for these forcing functions.

Sea-surface temperature (SST) is a key component of the atmosphere-ocean system that drives convection over the open ocean and induces sea breeze circulation (i.e. strength, inland penetration of sea breeze fronts etc) close to land. Large number of SST datasets are currently available from a relatively coarse spatial resolution of a 1 degree to finer resolutions of several kilometers. Moreover, one can use climatological means or diurnally varying SST in MM5 modeling. As a part of air quality modeling analysis, we employed MM5 meteorology using FDDA over Thailand. We performed MM5 simulations over this region using two sets of SST data – the FNL data (1^ox1^o every six hours) and the RTG SST data (0.5^ox0.5^o every day). We are also employing the MODIS SST data (4.5 km x 4.5 km, twice daily) to drive MM5 although the results from that experiment are preliminary. In this paper, we analyze the MM5 output employing these datasets and make comparisons of model predictions with surface observations. We will assess how the spatial and temporal resolution of the underlying SST data affects convection and sea-breeze circulation over the two regions of interest. Since major pollution events in many developing countries occur over coastal regions, the important role of SST in the coastal mesoscale circulation and regional air quality would aid in addressing many scientific and regulatory questions.

1. Introduction

Half the world's population lives within 60 miles of a water body. Many major metropolitan areas of the world that are mostly responsible for rising levels of air pollution are situated close to oceans. Meteorology near the coastal regions is thus important in many global regions because of its influence on the transport and subsequent local and regional distribution of air pollution from these urban centers. Understanding the meteorology of the coastal zone combines knowledge of the interaction of marine and land atmosphere boundary layers, air-sea interaction, large-scale atmospheric dynamics, and the circulation of the coastal ocean [Rogers, 1995]. The thermal contrast between the land and sea creates the land-sea breeze, coastal atmospheric fronts, coastal ocean currents and upwelling. The convergence of marine air over the coastline can result in strong convection with heavy precipitation.

One of the geophysical parameter that is critical in meteorology near coastal regions is the sea surface temperature (SST), which influences to a large extent the air-sea interactions. Rogers [1995] points out that many of the uncertainties in our understanding of coastal meteorology are the consequence of our lack of understanding of air flow in complex terrain, and the effect of horizontal inhomogeneities on the air flow, coastal ocean currents and interactions between the air and the sea.

In a study to simulate sea breeze in a complex coastal environment over the Lower Fraser Valley, British Columbia, Cai and Steyn [2000] demonstrated that a reliable modeling study depends on correct simulation of local surface fluxes and also on elevated layers transported from remote areas. Meteorological predictions over coastal regions have become important because of their implications in air pollution transport. Observations during the Indian Ocean Experiment (INDOEX) indicated pollution transport over distances of 500-1000 km. For example, Mohanty et al. [2001] conducted a numerical experiment to study the role of land-air-sea interaction on the circulation pattern over the Indian Ocean during INDOEX. They concluded that the deep offshore plume-like penetration can be a cumulative effect of local as well as large scale features linking to topography and SST gradients.

In this study MM5 simulations were carried out with FDDA in order to drive a diagnostic meteorological model (CALMET) and subsequently and air pollution dispersion model (CALPUFF) [Scire, 2000a,b]. Here we present results from two sets of simulations during the first week of June, 2002. These simulations differ from each other with respect to the SSTs employed as lower boundary conditions.

2. Data and Model Configuration

The MM5 modeling in this study included totally four domains. All four domains were two-way nested. Geographical locations of the domains are presented in Figures 1. The center of the coarse domain (Domain 1) was located at 12.6^oN, 100^oE. The Lambert Conical Conformal (LCC) map projection was used in the model coordinates with the standard latitudes at 5^oN and 30^oN. The total area of Domain 1 was about 6.5×10^6 km^2. The grid spacing was 81 km. The second-nesting domain (Domain 2) covered almost all of Thailand with a grid size of 27 km. The third and the fourth nesting-domains (Domains 3 and 4) were selected based on the needs of CALMET modeling and were more or less centered on the location of the facility. The grid spacings of these domains were 9 km and 3 km, respectively. In the

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vertical direction, there were 32 sigma levels from the surface to 100 hPa.

The MM5 model was run in the non-hydrostatic mode. The simple ice explicit moisture scheme that represents microphysics parameterizations was used in all domains. The Grell cumulus parameterization scheme [Grell et. al., 1996] was used for convections in Domains 1 and 2, while explicit convection was carried out for Domains 3 and 4. The Gayno-Seaman scheme was used for planetary boundary layer parameterization. The cloud radiation scheme was used for radiation cooling of the atmosphere. The five-layer soil model was used to predict soil temperatures.

MM5 was initialized using the large-scale analysis data from NCEP at NCAR. The NCEP Final Analysis (FNL) data archived at NCAR exists every 6 hours at a spatial resolution of 1^{o} x 1^{o} at 21 standard pressure levels under 100 hPa. The data include two-dimensional variables including sea surface temperature and sea level pressure, and three-dimensional variables of temperature, geopotential height, U and V components, and relative humidity. Sea surface temperature (SST) data was available from two other sources – Real Time Global SST (RTG SST) analysis from NOAA (0.5^{o}x0.5^{o} resolution) [Thiébaux et al., 2001] and MODIS (Moderate Resolution Imaging Spectroradiometer) from NASA (4km resolution). MM5 now has an option to vary the lower boundary condition with respect to time. Hence we employed this option to provide a realistic representation of the time variation of the lower boundary condition. For the FNL dataset, the lower boundary conditions were updated every 24 hours with the 0Z SST values from FNL data used throughout the day. Moreover, the SST data was interpolated to the four domain grids prior to the start of the simulation. This assures that the spatial lower boundary condition comes from the original FNL dataset. Alternatively, MM5 interpolates the lower boundary on the fly. In that case, the lower boundary values for domains 2 through 4 come from those integrated in domain 1 and may not be the original FNL values.

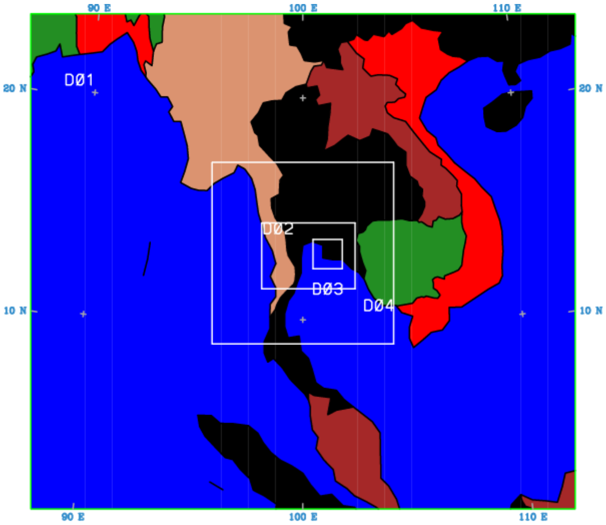

Figure 1: Domain configuration over Thailand for MM5 simulations

A comparison between the FNL, RTG and MODIS SST data over Southeast Asia is presented in Figure 2 for two days one each in October and January. The figure is just for illustrating the differences in the spatial resolution of the three datasets. Acquisition and processing of the June 2002 data from MODIS is presently underway and hence we have not included that data here. As seen from Figure 2, all three datasets capture the general horizontal patterns of SST over the region. In general, relatively high SST values (302-304 K) are observed over the equator and colder water temperatures (298-299 K) into the subtropics. SST values exceeding 303 K over the ocean west of Indonesia are observed on January 1, 2002 in the RTG and MODIS data but are conspicuously absent in the FNL dataset. Moreover, SST below 296 K is observed in the MODIS data in the South China Sea in January. One key feature of this comparison is that the spatial resolution of the SST data becomes very important close to land-ocean boundary. Because of the coarse resolution of the FNL data, a model grid point along the coastline can pick up either the land or the ocean temperature. Thus, having a finer spatial resolution of the SST data to force the lower boundary condition would be valuable in MM5 to represent the coastal mesoscale dynamics.

We employed four dimensional data assimilation (FDDA) in Domain 1 to force the model integration to the fields from the FNL data. Only three-dimensional FDDA was carried out since the surface observations were with a time resolution of 6 hours. We assume that the surface observations provided at NCAR are already incorporated in the FNL analysis and hence an additional analysis would not be required. Winds, temperature and moisture were nudged to the observed values every 6 hours.

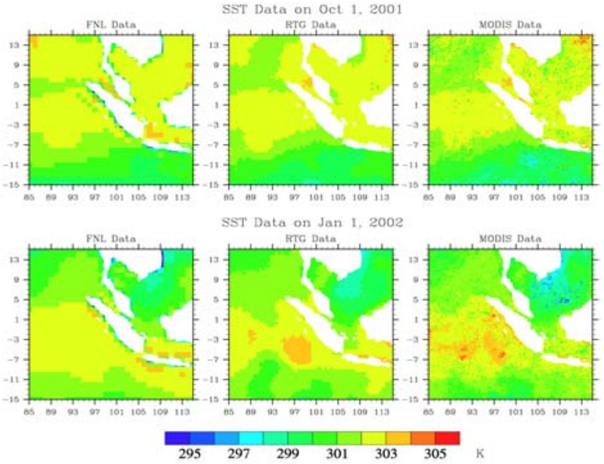

Figure 2: Comparison of FNL (1^{o}x1^{o}), RTG (0.5^{o}x0.5^{o}) and MODIS (4km x 4km) SST data over Southeast Asia for October 1, 2001 (top panel) and Jan 1, 2002 (bottom panel).

3. Results

Two sets of MM5 simulations were performed for a period May 31, 2002 to June 10, 2002 over the domains described in Figure 1. Both simulations were identical except the SST data ingested in the simulations. However results from these two simulations exhibit quite a bit of differences. These can be seen in Figure 3.

A snapshot of the horizontal distribution of winds and precipitation across Domain 3 is presented in Figure 3. The data presented is on June 3, 1300 local time, 78 hours after start of the simulation. A clear disparity is evident in the top and bottom panel of the figure. The precipitation obtained from the FNL SST (top panel) differs substantially from that in the simulation with the RTG SST (bottom panel). For example, the FNL simulation predicts precipitation mostly in the southwest region of the model domain in amounts between 2 and 8 mm/hr. Rainfall in the excess of 16 mm/hr is also predicted by MM5 over Bangkok. However there is little evidence of any predictions over the Pataya region of Thailand.

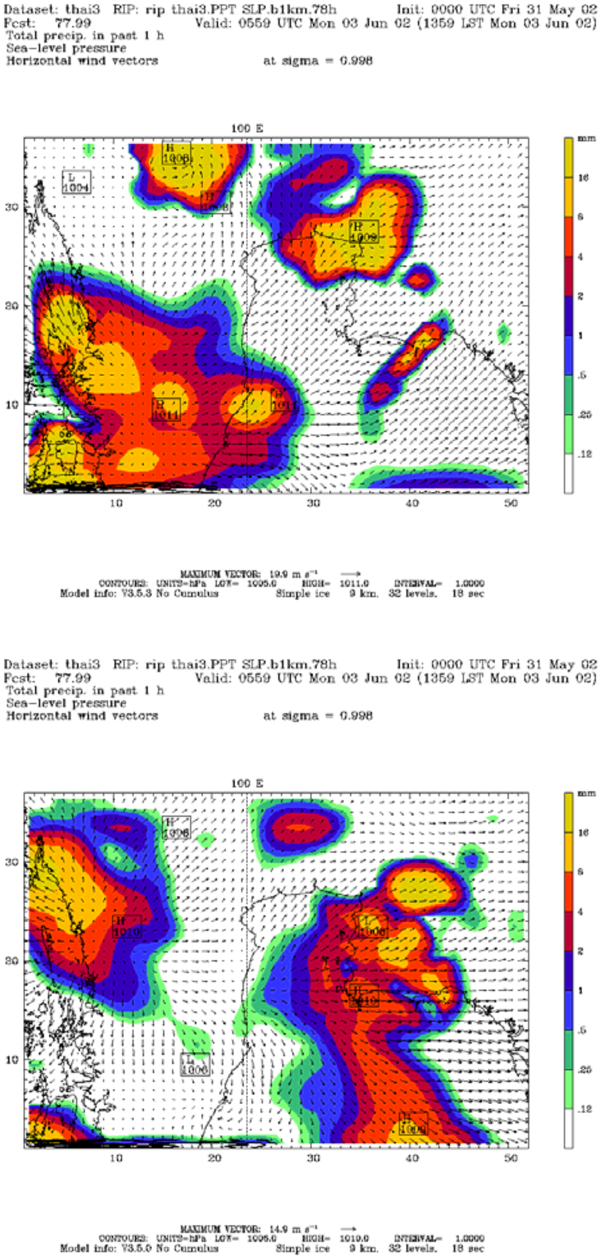

Figure 3: Snapshot of mesoscale hourly precipitation amounts predicted by MM5 in Domain 3.at local time 1300 June 2, 2002. FNL SST (top panel) and RTG SST (bottom panel).

In contrast, precipitation forecast from the simulation with the RTG SST shows an altogether different pattern. The precipitation predictions in the southwest region of the model domain are absent in this simulation altogether. However, strong precipitation occurs over the Pataya region of Thailand and also over the northwestern portions of the domain.

As with precipitation, the wind fields also exhibit differences. Differences in mesoscale circulation as well as effects of insitu convection may be contributing factors to the differences in the simulated winds. It should be noted that in both cases, convection was calculated explicitly in the model.

To explore more the differences in the predicted wind speeds between the two simulations, we present a time series of the wind speeds at four stations in Thailand. This is presented in Figure 4. In Figure 4, the Domain 4 MM5 winds are plotted. The observed wind speeds at these stations are also plotted in the figure. It should be noted that although the stations are quite close to each other, there are subtle differences in their time series. For the most part, winds from both simulations seem to be quite similar to each other and somewhat different from the observations. However, there are small differences such as the beginning of day 4. While the simulation from FNL SST predicted higher wind speeds, the RTG SST calculations were lower and closer to observations at the top three locations. However, there are other instances (noon on day 7), when both simulations deviate from observations. Model simulated winds in all plots seem to be very similar because of the proximity of all stations. A wide network of stations is required to carry out an exhaustive analysis.

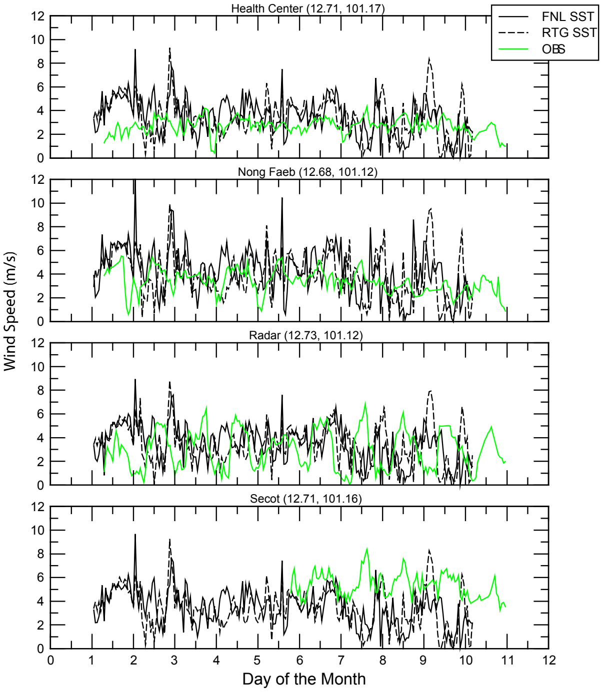

Figure 4: Time series of MM5 predicted and observed wind speeds at four locations over southern Thailand. The names and coordinates (latitude, longitude) of the stations are given above each plot. The data is presented for the first ten days of June 2002.

4. Conclusions

In this paper, we studied the effect of how a spatially resolved sea surface temperature data can influence MM5 predictions on coastal mesoscale circulation. Our preliminary results indicate a substantial difference in the predicted precipitation rates and wind patters over the simulated domains. The implications of these results in subsequent air quality studies can be tremendous. With the increasing applications of satellite derived products on much finer scales, realistic predictions of coastal meteorolgy will become important in the future. A promising start will be to incorporate the MODIS SST in MM5 to investigate the similarities and differences between predicted precipitation and wind fields. Along with the SSTs, it would be worthwhile to examine the effect of model grid resolution on the MM5 predictions. An exhaustive analysis with surface and upper air data should also be conducted for model validation. These studies will eventually aid in understanding the export of air pollution to the regional and global atmosphere.

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