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# A simulation study of mesoscale coastal circulations in Mississippi Gulf coast

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ABSTRACT

A numerical simulation of atmospheric mesoscale circulations in the Mississippi Gulf coast is carried out with non-hydrostatic WRF ARW meso-scale model to understand the flow and the boundary layer characteristics in the coastal environment. The model is used with three nested grids at 36, 12 and 4 km resolution covering the Mississippi Gulf coast and its adjoining regions for a typical summer period 01–03 June, 2006 having weak synoptic forcing. Results show development of sea-breeze circulation and formation of thermal internal boundary layer (TIBL) across the coast. The flow pattern shows regular occurrence of onshore winds in the day time and offshore winds in the late night/ early morning times. Simulated sea breeze extended horizontally up to 80 km inland and vertically up to 1 km. Height of the simulated internal boundary layer is 300 m near the coast and gradually merged with the mixing layer inland. Simulated winds and temperature distribution at the coast are found to agree with mesonet and upper air observations. Model simulated TIBL height is confirmed using observations from a boundary layer experiment. Performance of the Planetary Boundary layer (PBL) parameterization on the simulated circulation features is studied by conducting sensitivity experiments. The Yonsei University (YSU) nonlocal first order PBL scheme and a more complex Mellor–Yamada–Janjic (MYJ) TKE scheme are selected keeping the other model physics identical. Both the schemes have shown similar skills in simulating the mean characteristics of observed winds during sea breeze in the region. The YSU scheme shows improvement over MYJ in the simulation of internal boundary layer characteristics and the overall performance of predicted mean variables.

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## 1. Introduction

Meteorological conditions in the coastal regions are distinctly different from the inland regions. The flow pattern in coastal regions is determined by land–sea temperature contrast, complex terrain, shape of the coastline and land use heterogeneity. The primary forcing is the surface in homogeneity such as terrain and physiographic induced mesoscale systems (Pielke, 1984). These conditions affect various meteorological variables including convection, cloud formation and air pollution dispersion. Transport and diffusion of air pollutants in the coastal regions especially, is influenced by these circulations. Coastal regions are environmentally sensitive due to the location of industries with consequent elevated pollutant releases and the presence of complex meteorological circulations. It is essential to use detailed meteorological information in the dispersion models for improved estimates of transport and dispersion of pollutants. The essential phenomena that influence the atmospheric dispersion in coastal regions are the development of land–sea breeze and associated boundary layer alteration. There are

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numerous observational studies of significance to this phenomenon (e.g., Thara et al., 2002). The plume trajectory and ground level concentration are studied at several coastal sites in relation to the above effects (Venkatram, 1977; Jin and Raman, 1996). While the observational studies help to investigate the structure of the internal boundary layers at the coastal sites, modeling is essential to understand the mesoscale circulations spatially and temporally.

Coastal circulations, especially the sea-land breeze circulations have been studied extensively. Thermodynamic forcing that drives the circulation and its characteristics, including its initiation, inland penetration of the sea breeze front, the compensating return flow aloft and the broad scale of subsidence over the water as well as the formation of mixed layer over land have been studied in the past at several locations mostly through numerical simulation (Atkinson, 1981; Pielke, 1984; Simpson, 1994). Air pollution as a result of industrial activities, oil production in coastal regions is influenced by diurnal cycle of the land–sea breeze circulations. These mesoscale circulations tend to have fairly steady wind direction within the zone of circulation, but will vary dramatically beyond. Also they tend to be shallow flow so that the pollutants are trapped and do not mix well with the air above.

Recent development of three dimensional atmospheric models permits the study of these circulations in better detail. The evolution of these systems and their influence on the transport and dispersion of pollutants were studied using mesoscale models (Boybeyi and Raman, 1995; Lyons et al., 1995). Several theoretical and numerical studies dealt with the physics and characteristics of the sea breeze circulation and the effects of topography, synoptic forcing and latitude (Pielke, 1974; Dailey and Flovell, 1999). Thermal internal boundary layer associated with local circulation was numerically studied for onshore flows and coastal fumigation (Venkatram, 1977; Luhar and Sawford, 1988; Gryning and Batchvarova, 1990). The accuracy of simulating these topographic flows heavily depends on representing the terrain features accurately and on better representation of boundary layer exchange. Earlier works (e.g., Pielke et al., 1991) demonstrated the application of nonhydrostatic models with high horizontal grid resolutions. Several parameterization schemes for physical processes are introduced in the recent mesoscale models so that they are easily adaptable to different geographical regions and for studying various meteorological phenomena. The PBL parameterization is important in the simulation of lower atmospheric winds, temperature and humidity. Berg and Zhong (2005) have conducted a comprehensive study on the sensitivity of the high resolution mesoscale simulations to several available boundary layer parameterization schemes in the NCAR MM5 model. All the schemes, in spite of the complexity of formulation, were shown to give similar skill in predicting near-surface and boundary layer mean winds, temperature and humidity excepting a few differences. The Mississippi gulf coast is interesting due to its location on the east of complex Louisiana coastline in the Gulf of Mexico. The region is also important for air pollution studies due to the existence of several chemical industries, oil refineries and a major nuclear power plant. In the earlier studies (Croft et al., 2000; Hafner and Reddy, 2000) the significance of model domain on the convective initiation and land–sea breeze circulation for the Gulf coast region were studied using NCAR MM5 mesoscale model.

The objective of the present study is to understand the pattern of the coastal circulation and mean boundary layer structure in Mississippi Gulf coast using numerical model simulations. A high resolution nested grid mesoscale model Weather Research and Forecasting (WRF) is used for the study. In summer, high pressure system persists over the Gulf of Mexico leading to calm weather conditions. Under this weak synoptic forcing local scale circulations can prevail in the Louisiana–Mississippi coast. The land–sea temperature contrast is also significantly higher during summer and causes sea breeze induced convection and local thunderstorms. Hence the simulations are conducted for a summer period in June 01–03, 2006. The performance of the model is studied using two boundary layer parameterizations namely, the simple first-order nonlocal Yonsei University (YSU) scheme (Hong et al., 2006) and the more complex TKE based Mellor–Yamada–Janjic (MYJ) scheme (Janjic, 1990, 1996, 2002). Simulated model fields at the surface and at different levels are compared with observations from automated weather stations, Radiosonde upper air data besides boundary layer experimental observations available from the region.

## 2. Brief description of the model

The NCAR Advanced Research WRF ARW model (WRF version 2.2) based on Eulerian mass solver (Skamarock et al., 2005) is used to investigate the meso-scale wind flow pattern in the study area. WRF is the next generation mesoscale model designed for several applications such as research, operational regional weather forecasting, data assimilation, parameterized-physics research, driving air quality models, atmosphere-ocean coupling and idealized simulations. The model consists of fully compressible nonhydrostatic equations and the prognostic variables include the three-dimensional wind, perturbation quantities of potential temperature, geopotential, surface pressure, turbulent kinetic energy and scalars (water vapor mixing ratio, cloud water etc). The model vertical coordinate is terrain following hydrostatic pressure (eta coordinate) and the horizontal grid is Arakawa C-grid staggering. A 3rd order Runge–Kutta time integration is used in the model. The model has several options for spatial discretization, diffusion, nesting, lateral boundary conditions and physics parameterization.

### *2.1. Model domain and initial conditions*

The study region comprises the Mississippi Gulf Coast and its adjoining areas (Fig. 1A). WRF model is designed with 3 nested grids with horizontal resolutions of 36, 12 and 4 km (Fig. 1B). The 2nd and 3rd are two-way interactive grids. The outer domain was taken to cover the South-central US and the surrounding Atlantic Ocean to capture the dynamics that might influence the circulation in Mississippi. The inner finer grid (4 km) covers the Mississippi Gulf Coast off Louisiana above the Gulf of Mexico. The coarse domain has the size of 54 × 40 grid points while the finer domain has 187 × 118 grid points. All the domains contain 34 vertical levels with 10 levels in the lower atmospheric region (below 800 hPa). The USGS topography and vegetation data (25 categories) and FAO Soil data (17 categories) available at 30 sec resolution (~0.925 km) are used to define the lower boundary conditions. The