STUDY OF MESO-SCALE COASTAL CIRCULATIONS IN MISSISSIPPI GULF COAST WITH MESONET OBSERVATIONS AND MODELING

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1. INTRODUCTION

Land and sea breeze are important mesoscale phenomena in coastal regions that effect lower atmospheric wind flow, convection and air pollution dispersion. Temperature contrast across land-sea interface and shape of coastline determine these circulations. The Mississippi Gulf coast is interesting due to its location off the Lousiana complex coastline and many industries. Several meso-net observing networks exist in the region (White and Finney, 2005) and provide vital data to study the observational aspects the diurnal land-sea breeze circulations and also support model verification. Numerical models are extensively used to study the characteristics of these meso-scale circulations (e.g., Pielke et al, 1991; Simpson, 1994 among several others). In the earlier studies (Hafner and Reddy, 2000) the significance of model domain on the convective initiation and land-sea breeze circulation for the Gulf coast region are studied using NCAR MM5 model. In the present work land and sea breeze circulation in MS coastal region are simulated using WRF model, the meso-net observations in the region are used data assimilation and model validation. Observations from a boundary layer experiment are also used to compare the simulated vertical atmospheric structure near the coast

2. NUMERICAL EXPERIMENTS

Numerical simulations are conducted with the NCAR Advanced Research WRF ARW model (WRF version 2.2) (Skamarock et al., 2005) for the summer period 1-3, June 2006 and for 28-30, 2007.Atmospheric boundary layer experiment was conducted at MS Gulf coast between June 25-28, 2007. These observations along with meso-net observations in the region are used to validate model results. Three nested grids with 54x40 grid points (36 km grid spacing), 109x76 grid points (12 km grid spacing) and 187x118 grid points (4 km grid spacing) and with 34 vertical layers are used in the model (Fig 1). The area of interest is the inner fine grid (4km) covering the MS Gulf coast. The NCEP FNL analysis data at 1x1 degree resolution is used for initial and boundary conditions. FDDA observation nudging is performed for 12 hours using the NCEP ADP surface / upper air observations along with data from meso-net towers (Newton, Calhoun, Pascagoula, Agricola, Port Sulphur, Manchac, Hammond, and Franklinton St Joseph).

Model physics options selected are WSM3 class simple ice scheme for microphysics, YSU scheme for PBL turbulence parameterization, 5-layer soil model for ground temperature prediction, Kain-Fritisch scheme for convection, RRTM for long wave radiation and Dudhia scheme for shortwave radiation processes.

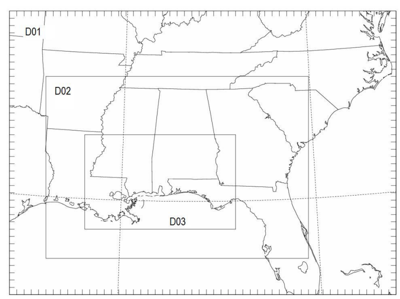

Figure 1. Model domains in WRF model

3. RESULTS

3.1 Horizontal circulation

Simulated surface winds (10 m level) are easterly over the south east US and westerly / south westerly winds prevail at 500 hpa level in the western parts of this domain. Sea level pressure pattern shows high pressure over North Atlantic Ocean and moderate pressures over the Gulf of Mexico. Simulated horizontal wind vectors at 10 m level on June 01 are shown in Fig.2 (a,b,c,d) corresponding to 06:00, 12:00, 16:00, 20:00 LST.

During the morning time the surface wind over Mississippi and Louisiana is northerly. It gradually becomes north-westerly offshore and gains in

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strength especially in parts of Mississippi and Louisiana coastal plains indicating prevalence of land breeze circulation. The surface wind at the coast turns southerly around 11:00 LST indicating development of sea breeze. Sea breeze penetrates inland up to 80 km and the maximum wind speed increases to about 5 ms^{-1} near the coast at 16:00 LST. Surface flow induced by sea-breeze is southerly to south-westerly over the region and has accelerating winds. Simulated surface circulation pattern on the next day revealed recurrence of land-breeze with northwesterly winds in early morning time (5:00 LST), and sea-breeze around the local noon with southerly winds. Results indicate diurnally recurring onshore and offshore flows during the simulated summer period over the Mississippi Gulf coast and its adjoining areas.

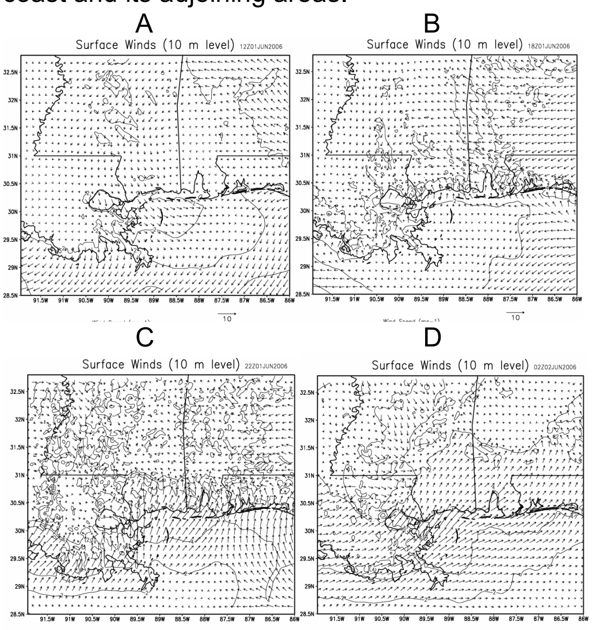

Fig.2 Simulated horizontal wind vectors at 10 m level for Domain 3 on June 1 A) 6:00 B) 12:00 C) 16:00 and D) 20:00.

Flow up to 1 km above ground level (AGL) (Fig. 4) is influenced by this circulation, land breeze in the morning time and sea breeze in the afternoon are noticed. Above 500 km the flow is relatively free from topographic effects. Circulation at 2 km a.m.s.l is not influenced much by topographic effects and is well defined by the large-scale flow.

3.2 Vertical circulation

Structure of the coastal circulation across Mississippi coast is analyzed using cross-section of circulation vectors i.e. the plot of u (ms^{-1}) and w (ms^{-1}), potential temperature in south-north direction at 89^o W and between 30^o N and 32^o N latitudes. Circulation near the coast line (grid point =100) shows development of a sea-breeze front with ascending winds at the leading edge, return flow aloft and subsidence behind the front. Sea breeze cell is seen to extend up to 2 km AGL and associated horizontal circulation prevails up to a height of about 1200 m above ground level. Converging motion at lower levels up to 800 m AGL, diverging motion at the upper levels and strong vertical winds are seen at the location of the sea breeze front. Maximum convergence, divergence and vertical motion associated with sea breeze front are -97.0e-05 s^{-1}, 62.0e-05 s^{-1}, 69 dPa s^{-1} respectively and the maximum vertical motion associated with sea breeze front is about 69 dPa s^{-1}

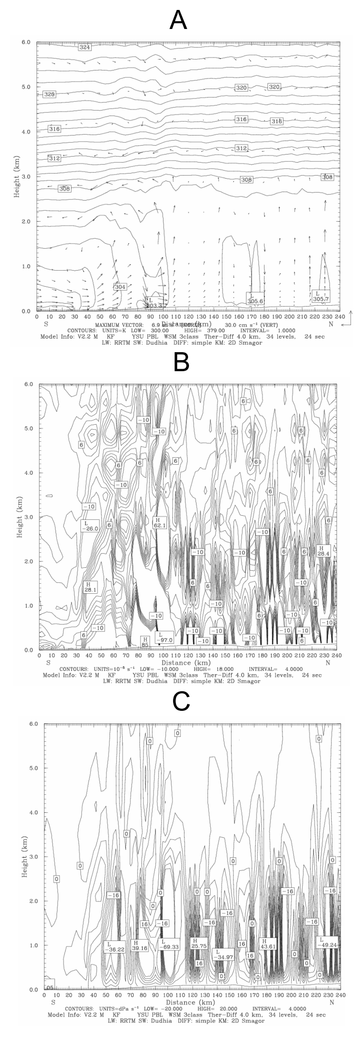

Fig. 7 Vertical section of a) potential temperature b) divergence (1.0e-05 s^{-1}) and c) vertical motion (dPa s^{-1}) across the coast at 16:00 LST.

3.3 Comparison of simulated variables

Model results are evaluated with observations of air temperature, surface wind from meso-net stations and with Radiosonde vertical profiles at a few locations.

After the first few hours of spin-up time, model values show good comparison with diurnal surface observations at Pascagoula meso-net station located at 5 km distance from the coast and at Newton located far inland. Both observations and model values at Pascagoula indicate increase in wind speed, decrease in air temperature and shift in wind direction around the noon time indicating sea-breeze onset. A shift in wind direction from 275° (northwesterly) to 200° (southerly/ southwesterly) is found both in the model values and observations. The model could reproduce the observed trends of the surface variables both at Pascagoula and Newton locations.

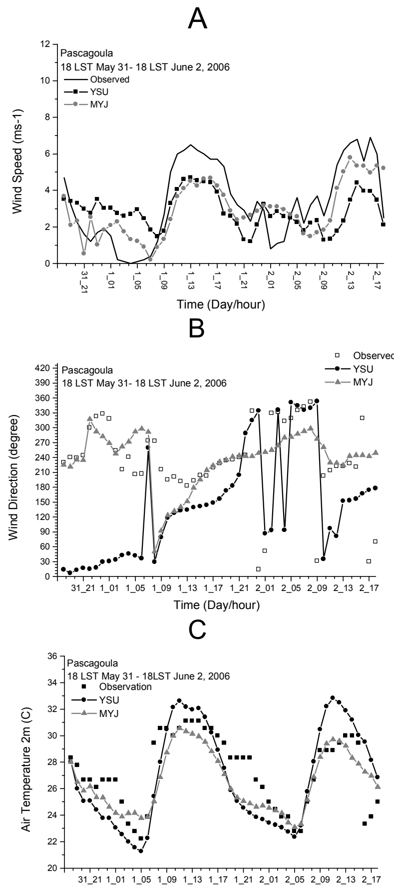

Fig. 8 Simulated and observed Wind speed (A), Wind direction (B) and 2m Air Temperature (C) for the model grid at Pascagoula station on June 1, 2006

A qualitative agreement of the model parameters for wind and temperature with radiosonde data is seen. The profiles show increasing potential temperature (inversion), increasing wind speed with height. Simulation shows slightly larger gradients of the above quantities in the lower atmosphere. In the convective unstable conditions during day time the above parameters are expected to be nearly constant with height in the mixed boundary layer. Model produces well mixed boundary layer during daytime as seen from the profiles at 13:00 LST and predicts a mixing layer of height of 800 m. Simulation also shows an unstable layer of about 300 m height above ground level (AGL) indicating development of TIBL near the coast.

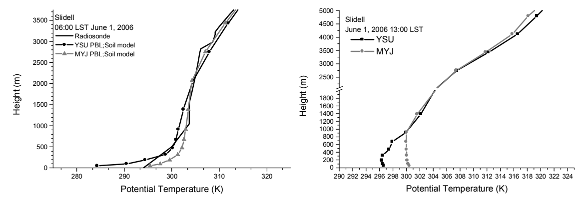

Fig. 9 Simulated and observed vertical profiles of potential temperature at Slidell a) at 07:00 LST b) 13:00 LST

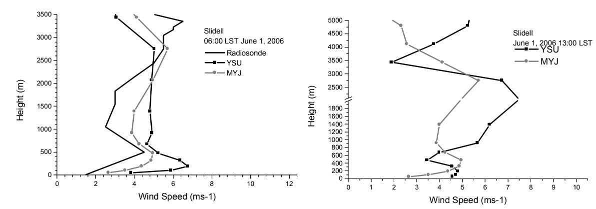

Fig. 10 Simulated and observed vertical profiles of wind speed at Slidell a) at 07:00 LST b) 13:00 LST

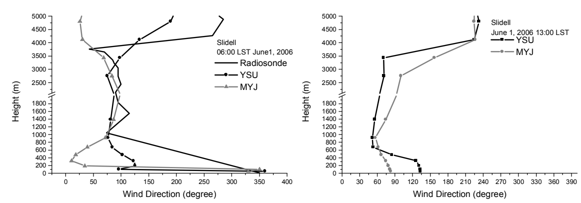

Fig. 11 Simulated and observed vertical profiles of wind direction at Slidell a) at 07:00 LST b) 13:00 LST

A detailed statistical analysis of observed and model predicted parameters at standard pressure levels of 925 hpa, 850 hpa, 500 hpa (Anthes et al, 1989) is performed using 14 upper air station data. The correlation, root mean square error (RMSE) and bias are found as (0.985, 16.81, 0.256) for temperature, (0.478,14.36, -2.39) for humidity, (0.544, 2.43, -0.423) for wind speed and (0.41,83.2,-1.762) for wind direction respectively.

3.4. Mixing Height across the coast

Boundary layer height is an important parameter as it represents limiting region of the boundary layer heating, convection, pollutant mixing and low level circulation. Sea breeze alters the stability structure over land. A shallow boundary layer near the coast and deep boundary layer in the inland region are seen. The region of low mixing height along the coast (thermal internal boundary layer) is seen to extend horizontally up to 30 to 40 km inland at 16:00 LST (Fig 12).

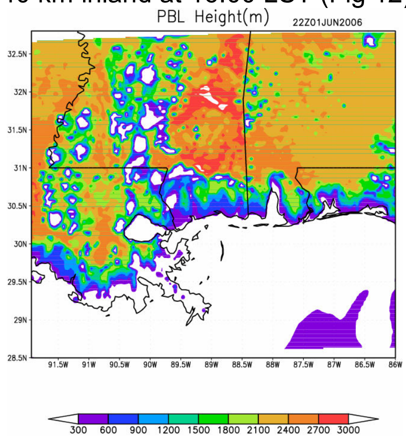

Figure 12. Mixing layer height in the model 3rd domain

Vertical profiles of temperature collected using GP Sonde during a boundary layer experiment on June 28, 2007 (Fig.13) provide indicative information on the PBL structure near the coast during sea breeze time. A developing boundary layer with stable atmosphere above 100 m AGL in the morning time. With daytime heating a shallow unstable layer marked with steep lapse rate is seen up to 300 m AGL and a mixed layer up to 500 m AGL at 13:00 LST (Fig 15b). The vertical growth of TIBL identified from the base of the lowest inversion is about 300 m at 13:00 LST. In the present simulations the PBL height is seen to gradually vary from a low value of about 100 m at the coastline to a higher value of about 2000 m on the land.

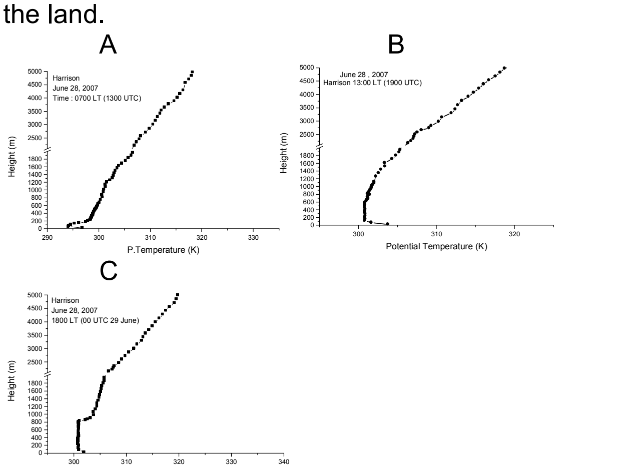

Figure. 13 Vertical profiles of potential temperature from GP Sonde at Harrison

4. CONCLUSION

The simulation study has shown consistent occurrence of sea-land breeze mesoscale circulations along the MS Gulf coast. Significant onshore flow during day time and off-shore flow during late night / morning times are seen from simulation. A fully developed sea breeze occurrence in the south-southwest direction is seen at 11:00 LST and is confirmed with surface observations. Strength of simulated sea breeze winds is about 5 ms^{-1}. Horizontal and vertical extents of sea breeze from the simulation are noticed as 100 km inland and vertically up to 1 km height. A shallow thermal internal boundary layer is seen to form near the coast during the sea breeze time which is confirmed from experimental observations. Simulated TIBL height varied along the coast and is about 300 m at Harrison located at a distance of 15 km from the coast. Model results showed observed trends in the surface and upper air variables in the region indicating the applicability of model generated meteorological fields for dispersion studies.

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