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FINE SCALE METEOROLOGICAL SIMULATIONS OF THE HOUSTON-GALVESTON METROPOLITAN AREA WITH LANDSAT-DERIVED HIGH-RESOLUTION LAND USE AND LAND COVER DATASETS

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1. INTRODUCTION

To characterize the effects of urbanization on the local atmospheric conditions, a fine scale meteorological modeling study that has a higher resolution than the current grid size, usually around at 4- or 5-km, would be necessary. Such a model would require an adequate description of the atmospheric dynamic/thermodynamic conditions as an input at around 1-km grid resolution. Meteorological modeling at 1-km resolution has been attempted by several researchers. However, one of the common concerns was the limited resolution and accuracy of the critical input data such as the land use coverage data. For example, the current USGS 25-category Land Use (LU) data and Land Cover (LC) data linked with the MM5 meteorological modeling system is roughly at 1-km resolution data elements but somewhat out-dated (with the reference year 1990). One of the problems with the data is that it uses only one urban category that does not distinguish among the built-up urban, residential areas, planted trees, road and pavement areas. Our previous experience in meteorological modeling for the Houston-Galveston Area (HGA) shows that present LU/LC data can describe the air-land surface exchange processes at best up to 4-km MM5 grid resolution and the 1-km grid meteorological simulation would not be possible because of the poor quality of the land use input data. Recently, with the support of the Texas Forest Service (TFS), Global Environmental Management (GEM) has generated highly accurate land use and land cover datasets separately for the Houston and the surrounding eight county areas using the 30 meter resolution LANDSAT satellite imagery and ancillary datasets of varying spatial resolutions for the reference year 2000 (Byun, 2004).

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The objective of this paper is to study the impacts of using the new LU/LC datasets on fine scale meteorological modeling. To fully exploit the advantage of the new LU/LC dataset, a comprehensive land surface model (NOAH LSM) is utilized. NOAH LSM provides evapotranspiration and moisture diffusion processes, which are critical to characterize vegetation impacts on the land surface process, while the simple slab soil model in MM5 represents such effects with soil moisture.

2. MODEL CONFIGURATION

In this study, MM5 Version3 Release 6 (MM5v3.6.0) (Grell et al., 1994) is used. The simulation period is from 22 Aug. to 02 Sep., 2000. Figure 1 shows the domain setup, with the grid configuration listed in Table1.

Table 1. Domain configuration.

Domain	# of x	# of y	Z level	dx, dy(km)
1	53	43	43	108
2	55	55		36
3	100	100		12
4	151	136		4
5	189	289		1

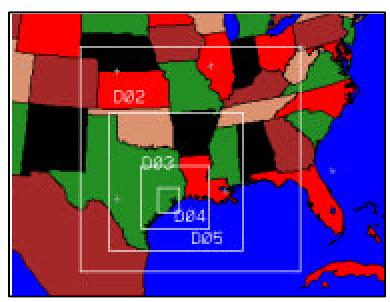

Figure 1. Domain setup.

MM5 physical options applied include: Grell cumulus scheme on the 108, 36 and 12 km domains, and no cumulus scheme on the 4 and 1 km domains; MRF PBL scheme; Dudhia simple ice microphysical scheme, cloud-radiation scheme and the NOAH LSM (Chen et al. 2001). The first guess and boundary conditions are from the NCEP Eta model. Upper-air analysis nudging of wind, temperature and water vapor is used without the surface analysis nudging. Observation nudging of wind was used in the 4- and 1-km domains. The focus of this study is on the treatment of the land surface processes. Before this study, we had done several sensitivity studies to improve the meteorological simulation in the surface temperature parameter. Modifications include: (1) adding canopy water in the urban area to account for the man-made vegetation evaporation processes; (2) inserting the emissivity value based on the land use type into NOAH LSM (Cheng and Byun, 2004). In this paper, all the modifications are applied to the NOAH LSM in the MM5 simulations.

MM5 simulations at 4- and 1-km resolution domains were evaluated with observation and wind profiler data. Figure 2 shows the locations of the available CAMS (Continuous Ambient Monitoring Station) sites which provide the observed surface wind and temperature information.

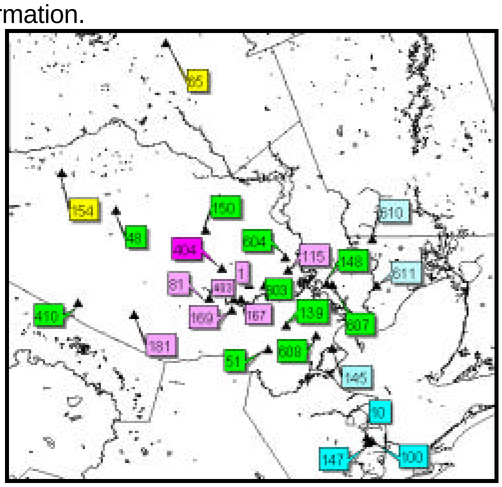

Figure 2. Location of the observation sites

3. DESCRIPTION OF LAND USE DATA

The sensitivity studies were designed to accommodate different land use data inside MM5. First, MM5 simulation was performed by utilizing the original USGS land use dataset. Figure 3 shows the dominant land use type of 4-km (panel (a)) and 1-km (panel (b)) resolution domain derived from the original USGS 25-category dataset. Although 1-km land use data does show more complicated information than 4-km land use data, the Houston urban area is still recognized as a large contiguous impervious area (shown in red color) which does not distinguish between urban, residential, planted trees and road information. To resolve more accurate and detailed Houston urban characteristic, an updated land use type within the eight county area surrounding Houston was produced using LANDSAT satellite imagery and ancillary datasets (GEM, 2003). Figure 3, panels (c) and (d) are the 4- and 1-km land use data derived from LANDSAT satellite imagery. Inside the Harris county area, the Houston urban area is composed of grass, trees and urban concrete structures; detailed information of which is indicated in the 1-km land use map especially. One noticeable difference between the two land use data is that most of the dry/cropland type in USGS land use data is replaced with the grass type in the LANDSAT LU data while the land surface parameters specified for MM5 simulations do not differ very much between the dry/cropland and grass land use types. The MM5 simulation (namely LANDSAT2000) was performed by replacing the original USGS 25-category data with the new LANDSAT LU data within the Houston eight county areas in the 4- and 1-km domains.

4. SIMULATION RESULTS

4.1 Surface Temperature

Figure 4 shows the spatial distribution of 1.5-m temperature derived from different MM5 simulations for Aug. 25th at 2000UTC. Simulations of the 4-km domain are similar with respect to the different utilizations of the LU data (panel (a) and (b)), because the resolution is too coarse to indicate effects of different land use datasets. In the 1-km domain simulation, using the new land use data shows a lower temperature prediction than using the USGS land use data. This is due to the fact that LANDSAT LU data provides more grass or tree areas than the USGS LU data causing the cooling effects.

Figure 5 is the scatter diagram of 2-m temperature prediction between CAMS data and MM5 simulations from 25 ~ 31 Aug. Panels (a) and (b) are 4km simulation results obtained by using USGS and LANDSAT land use data respectively. The scatter diagram show little difference between the two datasets, but utilizing the 1-km resolution shows definite improvement over the 4-km for both USGS (panel (c)) and LANDSAT (panel (d)) LU datasets. The 1-km simulation using LANDSAT LU data shows a few sites with worse under-prediction of minimum temperatures than the case using USGS LU data. On the other hand, the former shows better results with the observed maximum temperatures than the latter in spite of the generally lower overall domain wide temperature predicted. This demonstrates that the accuracy of the LANDSAT LU data benefits the proper simulation of land surface processes. Overall, the LANDSAT LU case shows slightly better agreement with observations than the USGS LU case. Some areas showing the under-prediction may be caused by the less representative emissivity values assigned to the grass land type in the Houston urban and residential areas. Further testing will be necessary to improve such lower temperature biases.

Simulation with the LANDSAT LU data show that Houston meteorology is much more affected by the vegetation and tree covers than the USGS LU data represents. Therefore, decreases in the simulated maximum 2-m temperature are observed at several CAMS sites. Figure 6 (panels (a)) is the time-series comparison of 2-m temperature between CAMS site 1 and 4-km MM5 simulations. Table 2 lists the land use type of CAMS site 1. At this site, the urban LU type specified in the USGS data is replaced with the grass LU type in the LANDSAT2000 simulation, which explains the drop in the maximum temperature in the 4-km simulation results. Time-series from 1-km simulation result (panels (b)) is better and closer to the observation than 4-km simulation at this site.

Table 2. Land use type of CAMS site 1.

CAMS	USGS		LANDSAT	
	4km	1km	4km	1km
1	Urban	Urban	Grass	Grass

4.2 Planetary Boundary Layer (PBL) Height

Similar to the spatial plot of 1.5-m temperature, the spatial plot of PBL heights from 1-km simulation on Aug. 25th at 2000UTC (Figure 7) shows lower PBL heights with the LANDSAT LU data than those with the USGS LU data.

5. CONCLUSION

Availability of the LANDSAT LU data provides a good opportunity to study the fine scale modeling. At the 4-km resolution, the use of LANDSAT LU data show minor improvements over the original USGS LU data when compared with the available measurement sites, since the resolution is still too coarse to indicate the finer-resolution land use data effects. However, at the 1-km resolution, the simulations show a significant improvement over the 4-km domain. The preliminary results show an obvious dropping in the maximum temperature if the urban land use type inside USGS LU data was replaced with the grass or vegetation-type inside LANDSAT LU data. This demonstrates a benefit of using LSNDSAT land use data in the fine-scale modeling.

With more detailed land use characteristics specified in the Houston urban area, fine scale (1-km) MM5 simulation gives a good performance and accurate prediction. Fine scale meteorological modeling is achieved with the updated and finer LU/LC data.

6. REFERENCES

Byun, D.W., S.-T Kim, F.-Y. Cheng, S.-B. Kim, A. Cuclis, N/-K. Moon, 2003: Information Infrastructure for Air Quality Modeling and Analysis: Application to the Houston-Galveston Ozone Non-attainment Area; *J. Environmental Informatics*, 2(2), 38-57.

Byun, D.W.; S.-T. Kim, B. Czader, D. Nowak, S. Stetson, M. Estes, 2004: Estimation of biogenic emissions with satellite-derived land use and land cover data for air quality modeling of Houston-Galveston ozone non-attainment area; *J. Environ. Manag. (submitted).*

Chen, F., and Dudhia, J., 2001: Coupling an advanced land surface-hydrology model with the Penn State-NCAR MM5 modeling system. Part I: Model implementation and sensitivity. *Mon. Wea. Rev.*, **129**, 569-585.

Cheng, F.-Y., D.W. Byun, and S.-B. Kim, 2003: Sensitivity study of the effects of land surface characteristics on meteorological simulations during the TexAQS 2000 period in the Houston-Galveston area, Extended Abstract. The 13-th Penn State/NCAR MM5 User's Workshop, Boulder, Co. June, 2003.

Cheng, F.-Y. and D.W. Byun, 2004: A sensitivity study on the effects of land surface characteristics on meteorological simulations in the Houston-Galveston area: Application of MM5 for the TexasAQS 2000 episode. *(Draft paper)*

Grell, G., Dudhia, J. and Stauffer, D.R. (1994): A description of the fifth-generation Penn State/NCAR Mesoscale Model (MM5). NCAR Tech. Note NCAR/TN-398+STR, 117pp.

GEM, 2003: Satellite Data Processing for Land Use and Cover Type Classification, Final Report, TFS-3-027, Prepared for the Texas Forest Service, July 8, 2003.

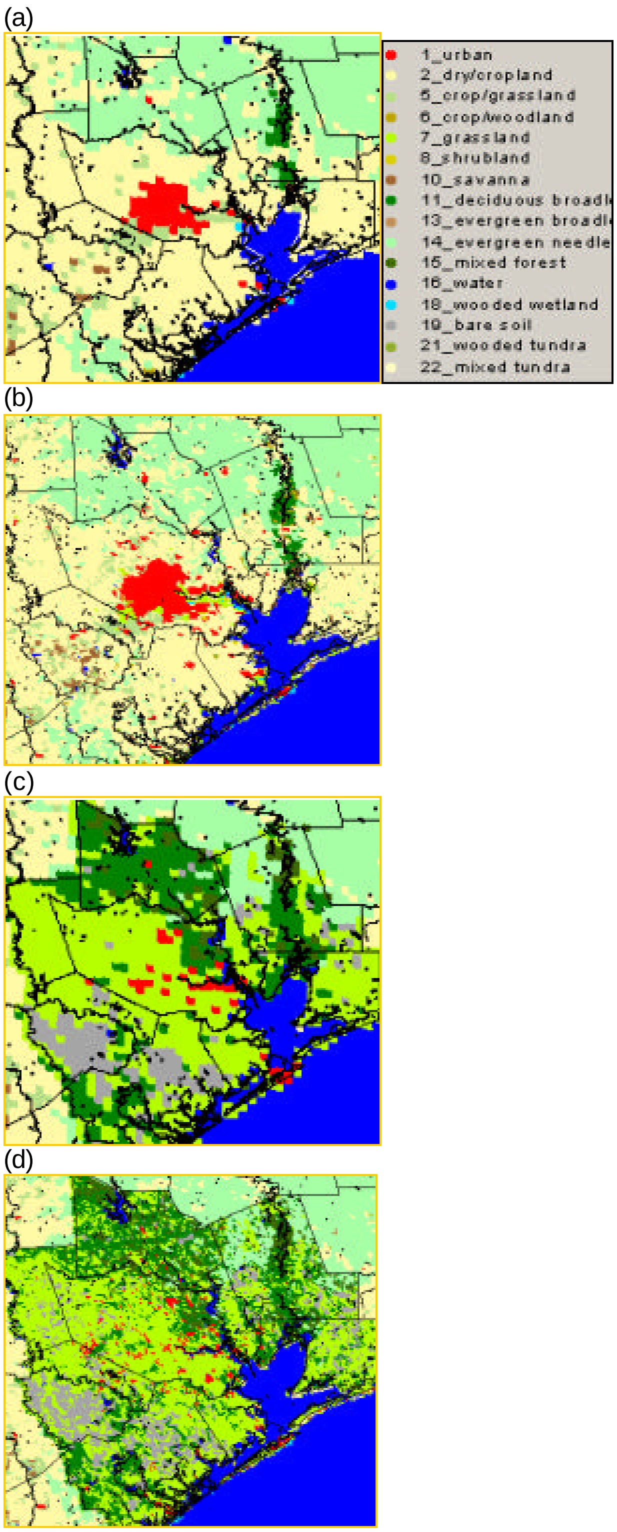

Figure 3. (a) 4-km (b) 1km Land use data derived from original USGS 25-category; (c) 4-km (d) 1-km land use data derived from LANDSAT satellite.

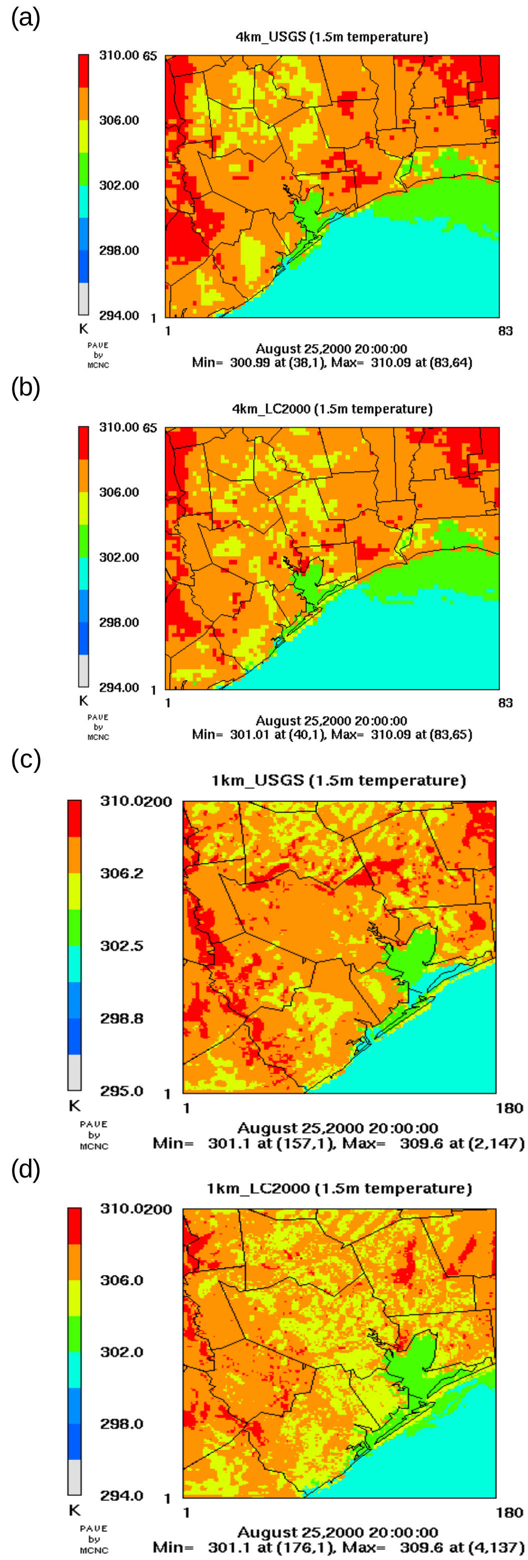

Figure 4. Spatial plot of 1.5m temperature derived from 4-km MM5 simulation with (a) USGS (b) LANDSAT data; and 1-km MM5 simulation with (c) USGS (d) LANDSAT data.

(a) (b) (c) (d)

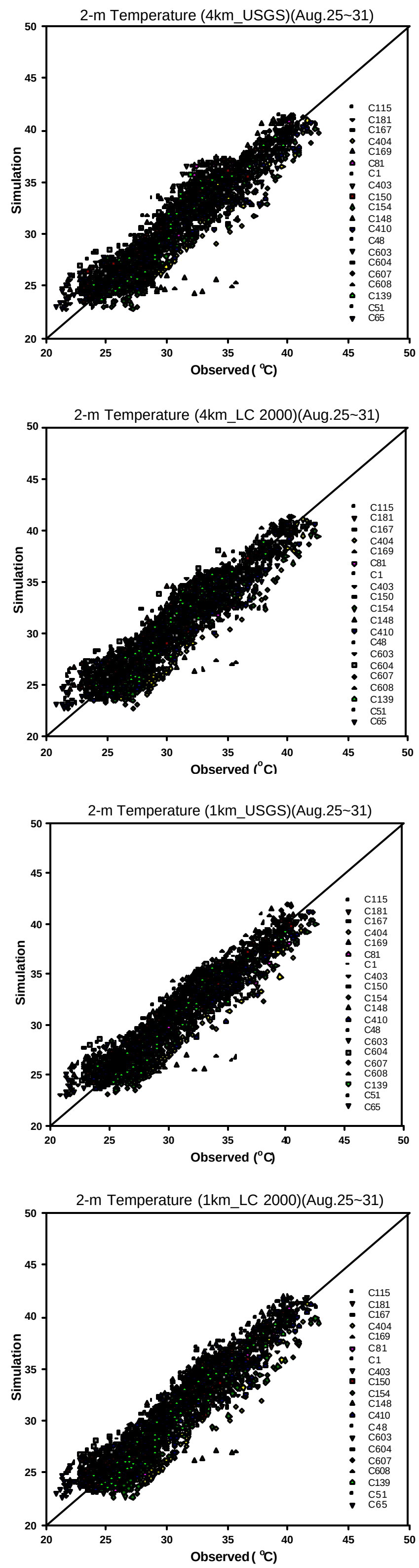

Figure 5. Scatter diagram of 2m temperature between CAMS and 4-km MM5 simulations using (a) USGS; (b) LANDSAT data; and 1-km MM5 simulations using (c) USGS; (d) LANDSAT data.

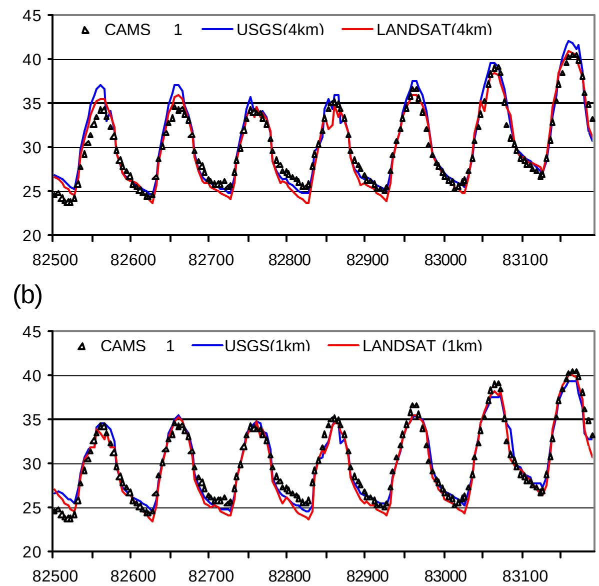

Figure 6. Comparison of 2-m temperature between (a) CAMS site 1 and 4-km MM5, (b) CAMS site 1 and 1-km MM5.

(a) (b)

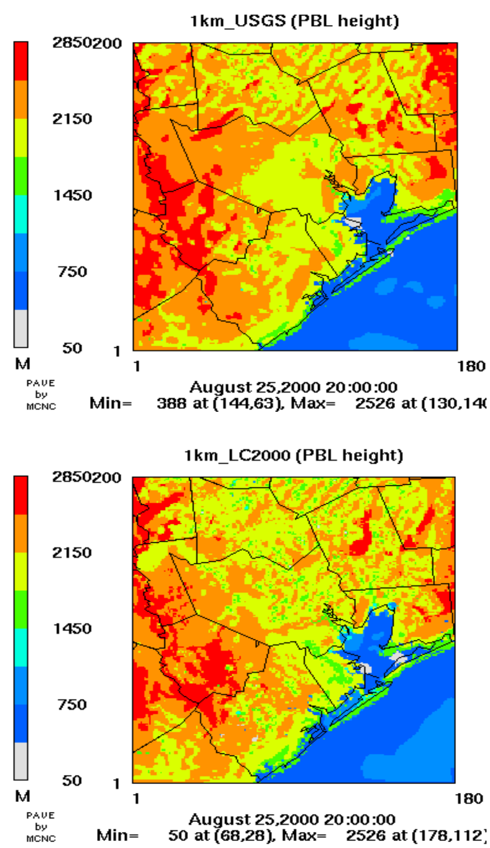

Figure 7. Spatial plot of PBL height from 1-km MM5 simulations by using (a) original USGS 25-category; (b) LANDSAT satellite land use data.