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DESIGN AND EVALUATION OF THE COUPLED MM5/TOPLATS MODELING SYSTEM FOR A TEXAS AIR QUALITY EXCEEDANCE EPISODE

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1 INTRODUCTION

Phase II of the Advanced Texas Air Quality Model (ATAQM) has been implemented for the Texas Natural Resources Conservation Commission (TNRCC) to support simulations of the August 25-31, 1998 ozone-exceedance episode in the 8-county Houston-Galveston Non-Attainment Area. ATAQM is a new, state-of-science modeling system that should significantly improve upon recognized deficiencies in current meteorological modeling systems used to drive air quality models in support of State Implementation Planning. ATAQM Phase II consists of the Fifth-Generation PSU/NCAR Mesoscale Model Version 3 (MM5v3); the TOPMODEL-based Land Atmosphere Transfer Scheme (TOPLATS; Famiglietti and Wood, 1994; Peters-Lidard et al, 1997) land surface hydrology model; and a Sea-Surface Atmosphere Transfer Scheme (SSATS). The TOPLATS model is driven with both in situ and remotely sensed estimates of key meteorological variables, including solar radiation and precipitation, and the SSATS model is driven with observed Sea Surface Temperature (SST) data from a combination of in situ (NOAA PORTS) and remotely sensed (CoastWatch AVHRR products) sources. The modeling system is fully documented at http://www.emc.mcnc.org/projects/TNRCC-projects/tnrcc_public.html. Below, we discuss the model configuration and results for the episode.*

2 APPROACH

2.1 TOPLATS Configuration

The TOPLATS Study Domain (TSD) for this project was set by mosaicking 8-Digit Hydrologic Unit Code watersheds provided by the National Hydrography Dataset (NHD) (USGS, 2001). This domain was chosen to include all watersheds that contain areas of Harris County (Houston), Texas as well as all counties that border Harris. Using this one-county buffer region as a guideline, the domain to model for TOPLATS was set as a large portion of the Eastern Coastal Plains of Texas with an area of approximately 96,000 square kilometers. The region covers an expanse from Matagorda Bay in the most southern point (28.07 N) to near Waco, Texas in the north (31.81 N), and from Lake Charles, Louisiana in the east (93.01 W) to the suburbs of Austin, Texas at the westernmost location (97.37 W)(Figure 1).

The region chosen for this project is much larger than those typically used in previous TOPLATS studies, and is only possible due to the parallel techniques and high performance I/O that have been implemented as part of this research (Coats et al., 1999; Peters-Lidard et al., 1999). The TOPMODEL concept assumes that base flow is the same throughout the watershed of interest, and when the watershed is much larger than 500 square kilometers in area, this assumption may be invalid. Therefore for a large region such as the HGA study requires, the domain is subdivided into smaller watersheds suitable for TOPLATS. In total the region has been divided into 173 watersheds (Figure 2), each of which has watershed-specific parameters required for TOPLATS.

Parameters for TOPLATS were estimated using readily available Digital Elevation Model (DEM), landcover and soils databases. TOPLATS was then "spun-up" for the period January 1-August 24, prior to coupling, using observed forcing data, including NEXRAD WSR88D precipitation, observed solar radiation, and observed surface-station meteorology including wind-speed, temperature, relative humidity, etc. More details about the TOPLATS databases and spin-up are available online at:

http://www.emc.mcnc.org/projects/TNRCC-projects/ATAQM/ataqmII_report1.pdf

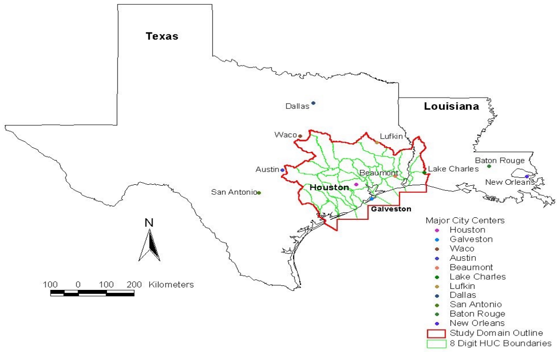

Figure 1. Houston-Galveston study region.

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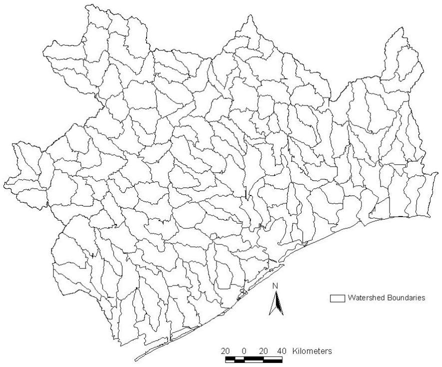

Figure 2. Houston-Galveston study region delineated watershed boundaries.

2.2 *MM5 Configuration*

MM5 was configured using a 36-12-4km nested model with 43 half-sigma layers in the vertical. The MM5 domains are shown in Figure 3.

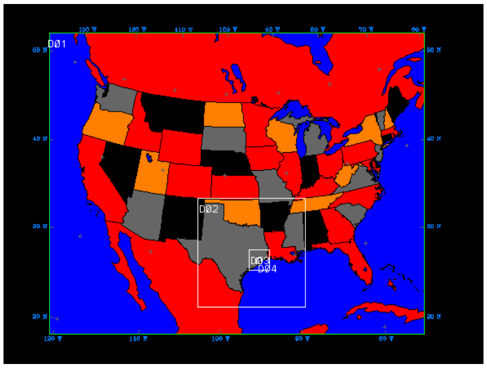

Figure 3. 36, 12 and 4 kilometer MM5 modeling domains, D01-03. D04 was not used.

The physics options chosen for this initial implementation are shown in Table 1.

Table 1. MM5 v3.4 Physics Options

Parameterization	Scheme Used
Explicit Moisture	(36,12, 4 km) Reisner-1
Convection	(36,12 km) Kain-Fritsch
Boundary Layer	(36, 12, 4 km) Blackadar with SMRAQ Modifications
Longwave Radiation	(36,12 km) RRTM (4 km) LWRAD
Shortwave Radiation	(36, 12, 4 km) Dudhia
Shallow Convection	None

Other schemes exist within MM5 that were not fully coupled with TOPLATS for this project, but could be coupled in the future. Two in particular are the Medium-Range Forecast (MRF) boundary layer scheme, and the Rapid-Radiative Transfer Model (RRTM), a longwave radiation parameterization scheme. The Blackadar-based high-resolution PBL scheme (HIRPBL, Grell et al., 1995) for planetary boundary layer (PBL) processes was used instead of the MRF scheme because applications at MCNC showed that PBL heights were often too high in MRF-based runs, and that the sea breeze was often too strong. This could have detrimental effects on photochemical simulations. Because the RRTM was released too late in the project to develop the coupling interface, the Dudhia (Dudhia et al., 1989) LWRAD scheme was used for longwave coupling on the 4 km grid, while the RRTM was used for the 36 and 12 km grids.

A large number of meteorological modeling data types were considered for use in the project, and many of them were utilized for developing MM5 initial, boundary, and FDDA fields; for driving TOPLATS; or for case analysis. A particular dataset issue relevant to MM5 was the lack of availability of ETA analysis fields for the first part of the episode, August 25-28, 1998. Therefore, the episode was run as two segments.

The first segment was run from August 25, 00Z through August 28, 12Z, (1998) and was based on GDAS initial fields. Since the initial fields were available only at 12-hourly intervals, we ran the 36-km/12-km grids (2-way nesting) twice. The first pass used analysis nudging at 12-hourly intervals. These results were then fed into INTERPB to produce 3-hourly REGRID style fields. These fields were fed back through RAWINS and INTERPF, and the results were used to nudge MM5 with 3-hourly analysis fields. The second segment was less complicated. We used ETA analysis fields (these fields were missing for the first part of the episode, thus leading to the procedures described above) for the second segment, which went from August 28, 12Z through 00Z August 31, 1998. These 3-hourly fields were fed into REGRID, then RAWINS, INTERPF, and finally MM5. For all these runs the 36/12-km grids were run in 2-way nested mode, while the 4-km grid was either a one-way or two-way nest.

3 RESULTS

Extensive evaluation against screen-level observations and GOES cloud imagery indicates that the 3-D coupled TOPLATS/MM5 (aka “coupled” or “c2”) modeling system performance is superior to that obtained from the original MM5 modeling system using the SLAB (5-layer Dudhia, aka “vanilla” or “van”) land surface model. For example, the diurnal 2-m temperature cycle and error statistics for the episode are shown in Figure 4.

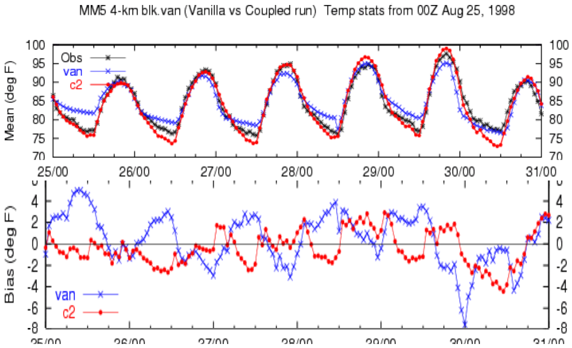

Figure 4. Average 2-m temperature observed at in-situ meteorological stations and modeled with MM5/SLAB ("Vanilla" or "van") and MM5/TOPLATS ("Coupled" or "c2").

Although the diurnal 2-m temperature cycle is clearly improved relative to the original modeling system, the 2-m humidity and 2-m wind results are strongly sensitive to lower limits imposed on wind speed and friction velocity within the HIRPBL scheme, and have a diurnal cycle. To further explore this sensitivity, a number of experiments were set up to examine the impacts of coupling, grid boundary conditions, and the lower limits to wind speed and friction velocity. These experiments will be discussed in more detail at the conference.

For example, Figure 5 illustrates the episode average daytime bias in humidity for nine cases, which can be contrasted with the nighttime humidity bias (not shown). In Figure 5, the best performance is for the no-lower limit coupled case, with a general trend of improvement in the coupled model relative to the original or "vanilla" model. However, this trend is exactly the opposite at nighttime, with increasing bias in the coupled model, and degradation of results when the wind speed lower limits are removed.

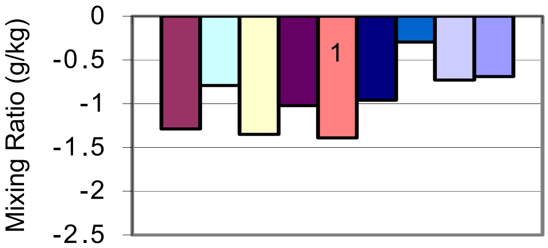

Figure 5. Daytime average bias in mixing ratio (q) for the nine cases described in the text.

Analysis of nighttime bias in the V-wind helps explain the differences in performance in the mixing ratio. The highest magnitude V-component bias occurs for the same cases for which the highest magnitude nighttime mixing ratio bias occurs, which suggests that the bias may be related to the inability to represent the sea-breeze/land-breeze at nighttime.

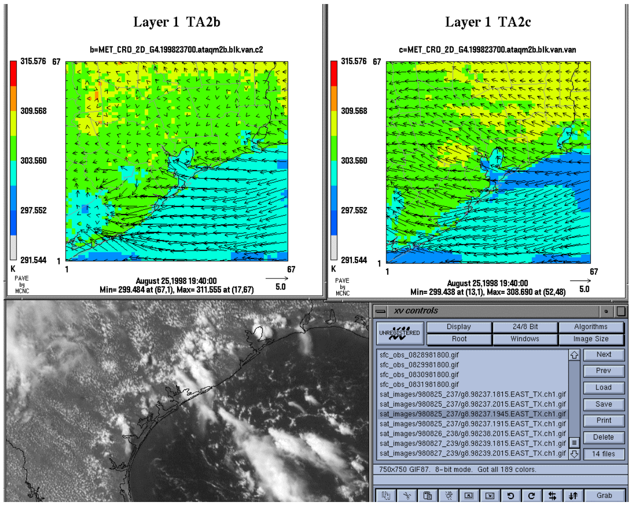

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Figure 6. TOPLATS/MM5 (left) and SLAB/MM5 (right) modeled 2-m air temperature (TA2) and winds (vectors), along with GOES imagery verifying the formation of convective clouds along the sea breeze convergence zone.

Other than the comparisons with station data screen-level variables, comparisons with GOES visible and IR data indicate superior performance in the coupled modeling system. For example, as shown in Figure 6 for August 25, 1998 at 1940UTC, the TOPLATS/MM5 results clearly resolve the daytime convective cloud development along the sea breeze convergence zone, as seen in the GOES imagery. The model results demonstrate the impact of the cloud development on the 2-meter air temperature, and underscore the importance of the GOES radiation data used to force TOPLATS in these simulations.

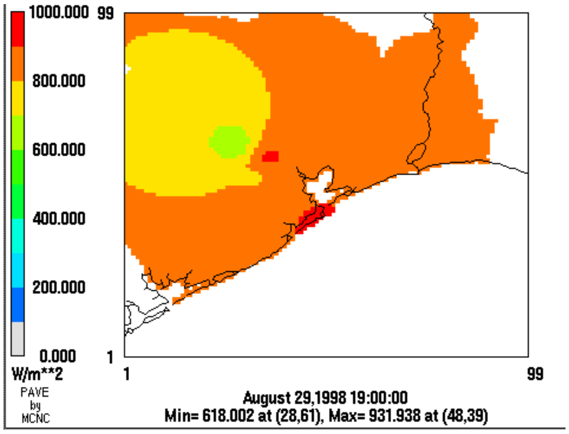

Figure 7. Interpolated solar radiation station data.

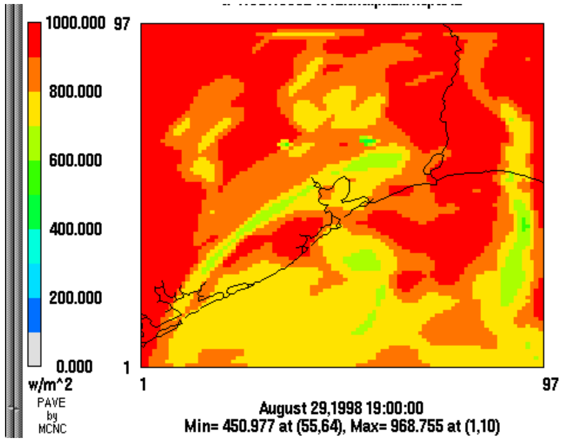

Figure 8. MM5-simulated solar radiation.

In addition to the results in Figure 6, further results with TOPLATS underscore the importance of GOES radiation products in the coupled modeling system; in particular, our analysis reveals significant differences in solar radiation from sparse surface observations (Figure 7), from MM5/SLAB simulations (Figure 8), and from GOES Surface Radiation Budget (SRB) products (Figure 9).

For example, analysis of August 29, 1998 at 19:00 UTC indicates upwards of 200 Wm^{-2} low biases in the station data in some locations. Overall, it is seen that the scarcity of stations with RSD measurements in the HGA domain leads to a nearly uniform interpolated field at locations far away from the stations. The MM5-calculated values for the same period show significant areas of lower radiation values associated with spurious clouds produced by the simulation. Of particular concern are linear areas associated with clouds at the northern and eastern boundaries of the domain.

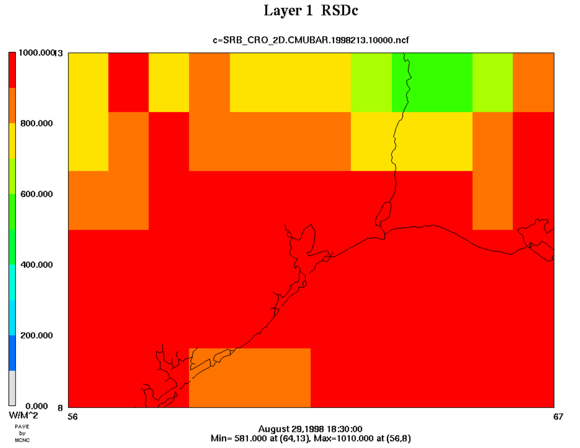

Figure 9. GOES SRB Product.

Although the native spatial resolution of the SRB data (approx. 0.5 deg) is coarser than MM5 (4 km), the SRB data is able to resolve much more spatial detail than the available station data. Second, the values in and around Galveston Bay are generally 200-300 Wm^{-2} higher in the SRB data compared to the MM5 output due to the presence of spurious clouds in the MM5 simulation without TOPLATS. Finally, the low values observed at a station to the northwest of Houston are not verified by the SRB data, suggesting a problem with the station data.

4 CONCLUSIONS

Extensive evaluation against screen-level observations and GOES cloud imagery indicates that the ATAQM system performance is superior to that obtained from the original MM5 modeling system, using the SLAB land surface model. ATAQM simulations without the GOES Surface Radiation Budget (SRB) products indicate that the downward shortwave observations have the largest impact on the modeling system. Further, although the diurnal 2-m temperature cycle is clearly improved relative to the original modeling system, the 2-m humidity and 2-m wind results are strongly sensitive to specification of lower limits to wind speed and friction velocity in the model. The two approaches are essentially equal in their abilities to predict wind speed. The MM5/SLAB model is better at predicting mean wind direction, due to the slightly greater counter-clockwise bias in the MM5/TOPLATS/SSATS. The MM5/TOPLATS/SSATS model is better at predicting mixing ratio, due to its better daytime performance. Further, cloud development along the sea breeze convergence zone and the diurnal cycle of PBL development in the vicinity of the Houston heat island are better represented in the MM5/TOPLATS/SSATS modeling system.

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6 REFERENCES

Coats, C. J., Jr., A. Trayanov, J. N. McHenry, A. Xiu, A. Gibbs-Lario, and C. D. Peters-Lidard, 1999: An Extension of the EDSS/Models-3 I/O API for Coupling Concurrent Environmental Models, with Applications to Air Quality and Hydrology, Paper J10.6, *Preprint volume: 14th Conference on*

Hydrology, American Meteorological Society, Dallas, Texas.

Dudhia, J., 1989: Numerical study of convection observed during the winter monsoon experiment using a mesoscale two-dimensional model. J. Atmos. Sci., 46, 3077-3107.

Famiglietti, J. S. and E. F. Wood, 1994: Application of Multiscale Water and Energy Balance Models on a Tallgrass Prairie. Water Resources Research, 30(11): 3061-3078.

Grell, G. A., J. Dudhia and D. R. Stauffer, 1995: A Description of the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5). NCAR Technical Note TN-398+STR.

Kain, J.S., and J.M. Fritsch, 1993: Convective parameterization for mesoscale models: the Kain-Fritsch Scheme. Meteor. Mono. 24, No. 46, Amer. Meteor. Soc., Boston.

McHenry, J. N., C. D. Peters-Lidard, C. J. Coats, K. Alapaty, S. Fine, A. Trayanov, and F. Pan, 1999: Preliminary Results of Coupling a 1-D Column Version of the PSU/NCAR MM5 with a Data-Assimilating Version of the TOPLATS Land-Surface Hydrology Model. *Preprint volume: 14th Conference on Hydrology, American Meteorological Society, Dallas, Texas.*

Peters-Lidard, C. D., J. N. McHenry, C. J. Coats, A. Trayanov, S. Fine, K. Alapaty, and F. Pan, 1999: Re-Thinking the Atmospheric LSP Problem from a Hydrological Perspective. *Preprint volume: 14th Conference on Hydrology, American Meteorological Society, Dallas, Texas.*

Peters-Lidard, C. D., E. Blackburn, X. Liang and E. F. Wood, 1998: The Effect of Soil Thermal Conductivity Parameterization on Surface Energy Fluxes and Temperatures. J. Atmos. Sci., 55 (7), 1209-1224.

Peters-Lidard, C. D., M. S. Zion and E. F. Wood, 1997: A Soil-Vegetation-Atmosphere Transfer Scheme for Modeling Spatially Variable Water and Energy Balance Processes, J. Geophys. Res., 102 (D4), 4303-4324.