JP2.7 ON THE ADDED VALUE OF HIGH−RESOLUTION REMOTELY SENSED SOIL MOISTURE DATA IN A MESOSCALE MODEL

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1. INTRODUCTION

The Southern Great Plains Hydrology Experiment conducted in the summer of 1997 (SGP−97) had as one of its scientific objectives to examine the effect of soil moisture on the evolution of the atmospheric boundary layer and clouds over the Southern Great Plains during the warm season. Through the use of data from this experiment and numerical modeling, the effects of soil moisture heterogeneity on the planetary boundary layer (PBL) can be investigated.

During SGP−97 special data were collected to determine the effects of soil moisture on the PBL. An L band passive microwave radiometer known as ESTAR (Electronically Scanned Thinned Array Radiometer) was flown on a P−3 aircraft and used to measure surface (0−5 cm) soil moisture. These soil moisture data have an effective resolution of 800 m and cover an area approximately 10,000 km^2 over Oklahoma and Kansas. Another helpful data source flown on the P−3 was the LIDAR Atmospheric Sensing Experiment (LASE, Browell et al. 1997) which provided water vapor profiles and PBL depth along the P−3 flight path. Other special data available during SGP−97 included ARM−CART (Atmospheric Radiation Measurement Cloud and Radiation Testbed) and Oklahoma Mesonet data.

The ESTAR data are used here in a mesoscale model to show the effects that detailed soil moisture has on the PBL. Comparing model experiments that include the high resolution soil moisture data from ESTAR and runs that do not include ESTAR against the special SGP−97 data shows the added value of small scale soil moisture variations on the PBL. Model simulations are also performed using climatological values for soil moisture, soil moisture output from an offline (external to the MM5) land−surface model, and a land surface model coupled directly to the mesoscale model. This work addresses the importance of soil moisture on atmospheric structure and demonstrates the impact that different soil moisture data have on a mesoscale model solution.

Determining the effects that soil moisture has on the PBL, as well as the scale of these effects, is important in discerning what data may improve numerical model forecasts. Satellite data from the National Aeronautic and Space Administration's (NASA) Aqua Advanced Microwave Scanning Radiometer (AMSR) currently provides ~60 km resolution soil moisture data. Knowledge of the scale of the PBL response to soil moisture would be helpful in determining the possible benefits of using currently available soil moisture data in numerical models and the added value of higher resolution data.

2. CASE DESCRIPTION

The period 12 UTC 11 July to 00 UTC 13 July 1997 was chosen for this boundary−layer study because synoptic−scale ridging was occurring over the central United States, creating generally cloud−free and weak synoptic forcing conditions. This paper focuses on the daytime PBL structure on 12 July 1997.

3. MODEL AND METHODOLOGY

The nonhydrostatic PSU/NCAR mesoscale model MM5 (Grell et al. 1994) v3.3 is used to simulate the period 12 UTC 11 July to 00 UTC 13 July 1997. As shown in Fig. 1, four one−way nested domains are used at 36, 12, 4, and 1.3−km resolutions. The two coarser, outer domains are integrated for 36 hours (from 12 UTC 11 July to 00 UTC 13 July), the 4−km domain is run for 24 hours (from 00 UTC 12 July to 00 UTC 13 July), and the 1.3−km domain is run for 12 hours (from 12 UTC 12 July to 00 UTC 13 July). There are 62 vertical sigma layers, with the first layer 30 m AGL (Above Ground Level), 50−m resolution through the lowest 2 km, and the model top at 50 hPa. On the 36 and 12−km domains Four Dimensional Data Assimilation (FDDA) is applied above the boundary layer to provide improved lateral

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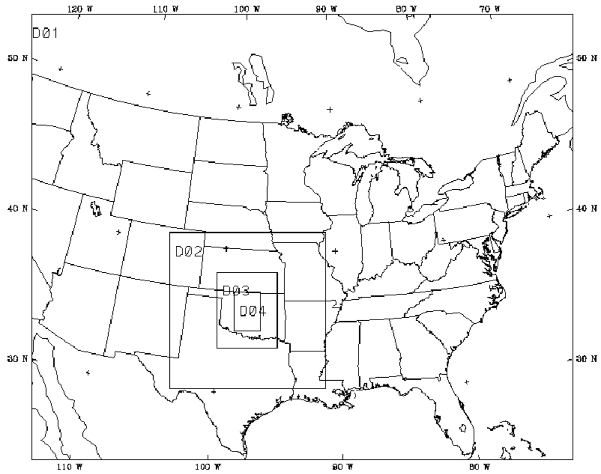

Figure 1. Locations of the 36−km (D01), 12−km (D02), 4−km (D03), and 1.3−km (D04) MM5 model domains.

boundary conditions for the finer two domains where no FDDA is applied.

The PBL depth is determined by the height at which the turbulent kinetic energy (TKE) falls below a threshold value. The PSU 1.5−order TKE parameterization scheme (Stauffer et al. 1999, Shafran et al. 2000) is used to predict TKE.

The MM5 traditionally uses soil moisture based only on landuse type and time of year (warm−season or cold−season) and force−restore land surface physics (Slab model). A land surface model, Parameterization for Land−Atmosphere−Cloud Exchange (PLACE, Wetzel and Boone 1995) is run with 36−km resolution offline (external to MM5) for the 6−week time period prior to the initial time of the MM5 model. The offline PLACE was forced by the observed meteorological conditions throughout this period. A comparison between the soil moisture contents given by the offline PLACE and ESTAR is shown in Fig. 2 and there is good agreement between the two data sources. Note that the PLACE data (36−km resolution) and the ESTAR data (800−m resolution) are first averaged to the 4−km MM5 grid, and then averaged east−west across the ESTAR swath.

4. EXPERIMENTAL DESIGN

A control run labeled Experiment (Exp.) Climo is performed using climatological soil moisture values based on landuse type (Grell et al. 1994). In another experiment the offline PLACE soil moisture values are averaged over the two−day MM5 period and used instead of the default

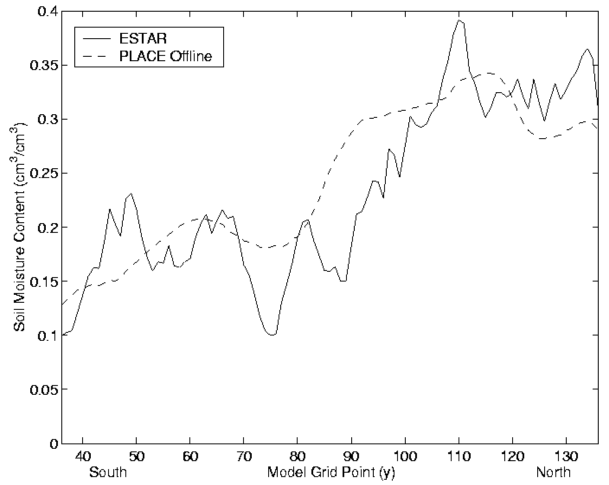

Figure 2. Offline PLACE vs. ESTAR soil moisture contents for 12 July 1997. Each model cell y−value represents an east−west 4−km grid average across the width of the ESTAR data area.

climatological soil moisture values; the PLACE values are scaled to be similar in magnitude to the climatological values but they include additional spatial structure (Exp. PLACE). The fine−scale ESTAR soil moisture data are introduced into the model in Exp. ESTAR but due to its limited spatial availability the offline PLACE values are used outside the ESTAR region.

In another set of experiments, the PLACE land−surface model is coupled directly to MM5 (inline), allowing interaction between these two components throughout the modeled time period. This coupling allows for a time−varying soil moisture that responds to modeled atmospheric changes and in turn atmospheric conditions reflect the time−varying soil moisture and vegetation fluxes.

5. RESULTS

In this preprint the 4−km MM5 results are shown because the areal extent and resolution of the ESTAR data first become significant in this domain.

5.1 Analysis of Horizontal Structure

Comparison of Exps. PLACE and ESTAR results reveal that different fields are affected on different scales by the finer scale soil moisture data (4−km average derived from the 800 m ESTAR data). The area with ESTAR soil moisture coverage has much greater heterogeneity in sensible and latent heat fluxes than this same

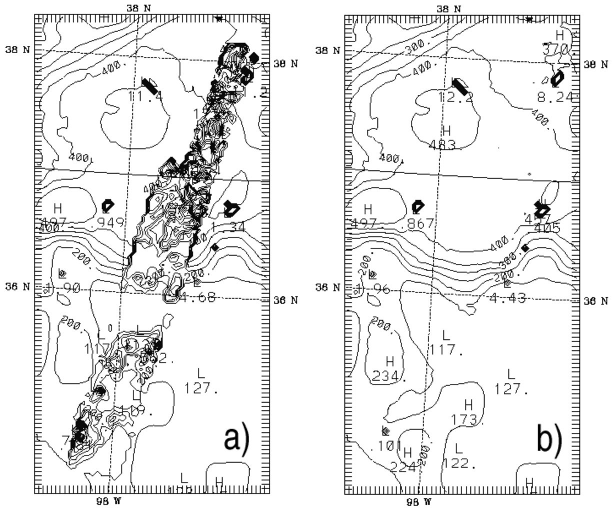

Figure 3. Model−predicted latent heat flux at 18h (18 UTC 12 July 1997) for the 4−km domain a) Exp. ESTAR and b) Exp. PLACE.

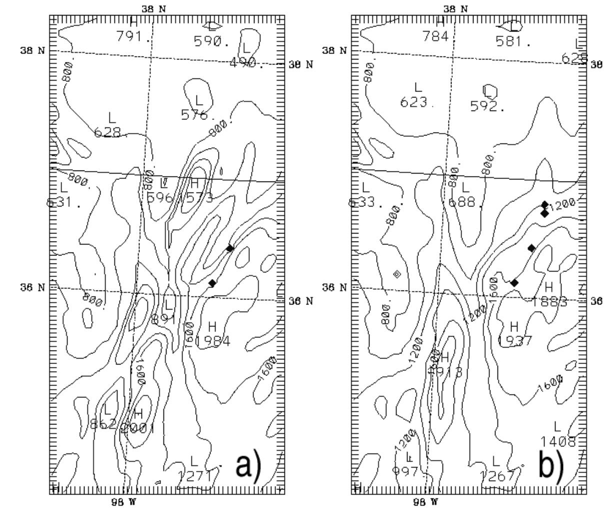

Figure 4. Model−predicted PBL depth at 18h (18 UTC 12 July 1997) for the 4−km domain a) Exp. ESTAR and b) Exp. PLACE.

area when using the offline PLACE soil moisture data derived from 36−km data. This allows the ESTAR area to be clearly visible in the horizontal plot of latent heat flux in Fig. 3. The PBL depth in the ESTAR region also shows increased variability but on a significantly larger scale (Fig. 4). Latent and sensible heat fluxes are strongly dependent on local soil moisture availability whereas the PBL structure is affected also by the size of the eddies and advection. These findings indicate that high resolution soil moisture results in increased heterogeneity in model fields with the scale of the response being much larger in the atmospheric boundary layer than in the surface fluxes.

5.2 Analysis of Vertical Structure

The ~18 UTC 12 July 1997 flight path of the P−3 aircraft which made the LASE measurements of PBL height and moisture profiles is shown in Fig. 5. Along this flight path all three model experiments produced a surface superadiabatic layer which is consistent with the sounding taken at the ARM−CART Central Facility (not shown). The model cross section for Exp. ESTAR (Fig. 6) also shows that the inversion at the top of the PBL is weak and so additional heating may significantly deepen the PBL, and that north−south variations in sensible heating may result in large spatial variations in PBL depth.

A comparison of the PBL depth as indicated by the LASE data (Fig. 7) with that predicted by the model (Fig. 8) shows good qualitative agreement with PBL depths near the southwest end twice as deep as those on the northeast end in Exps. ESTAR and PLACE.

The observed PBL depth is just under 1000 m at the northeast end, and as one moves southwest there is a ~1400 m maximum, a ~1000 m minimum and finally a ~2500 m maximum at the extreme southwestern end. All three model runs in the figure show increased PBL depth at the southern third of the cross section but Exp. Climo underestimates the difference in PBL depth between the two ends of the cross section whereas Exps. PLACE and ESTAR more closely parallel the observed structure. In addition, Exp. ESTAR shows a more pronounced secondary maximum consistent with the observations. Thus climatological soil moisture results were furthest from the observations with the runs including offline PLACE data improving the fit to observational data and the addition of the ESTAR data further improving the results.

The water vapor mixing ratio observations in the PBL along this cross section (not shown) indicate that Exp. Climo is too moist with values about 2 g kg^{-1} too high in the drier southwestern portion of the cross section and about 1 g kg^{-1} too high in the moister northeastern portion of the cross section. Experiments PLACE and ESTAR are generally dryer along this cross section with values about 2 g kg^{-1} lower than Exp. Climo in the southwestern portion of the cross section and about 1 g kg^{-1} lower in the northeastern section thus making Exps. PLACE and ESTAR similar to observations.

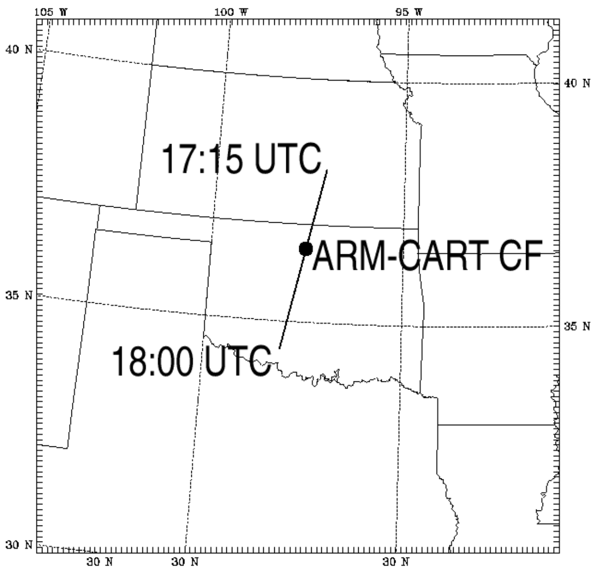

Figure 5. Flight path of the P−3 on 12 July 1997 starting at 17:15 UTC in the north and extending to the southern end of the path around 18:00 UTC. Note that this flight path is located near the eastern boundary of the ESTAR data swath shown in Fig. 3a. The location of the ARM−CART Central Facility (CF) is also labeled.

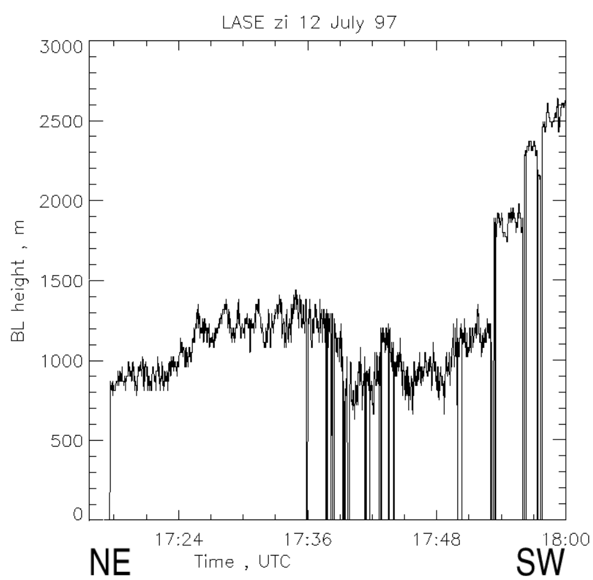

Figure 7. LASE observed PBL depth over P−3 flight path for ~18 UTC 12 July 1997 shown in Figure 5.

5.3 Surface Flux Analysis

Sensible and latent heat fluxes were measured at the surface throughout the daytime period at multiple sites within the model domain. Six flux measuring sites within the ESTAR area were chosen to validate the model results with and without ESTAR. The comparison indicates that

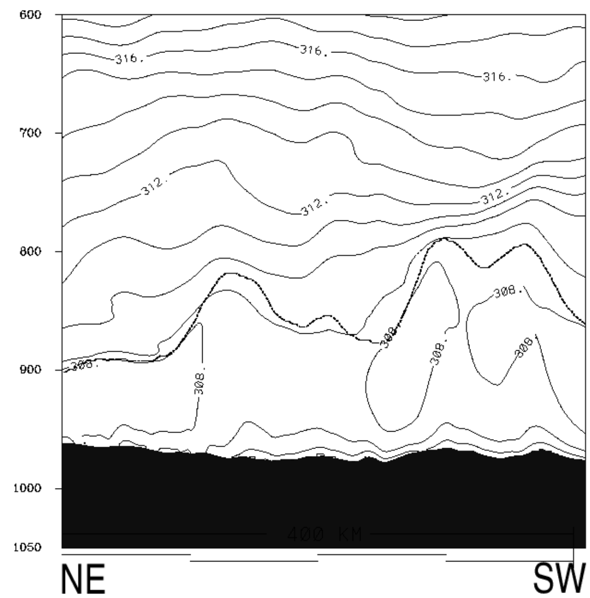

Figure 6. Model−predicted potential temperature (contour interval 1 K) for Exp. ESTAR at 18h (18 UTC 12 July 1997) along P−3 flight path shown in Fig. 5 (with northeast [NE] and southwest [SW} ends labeled). Dashed line indicates model predicted PBL depth.

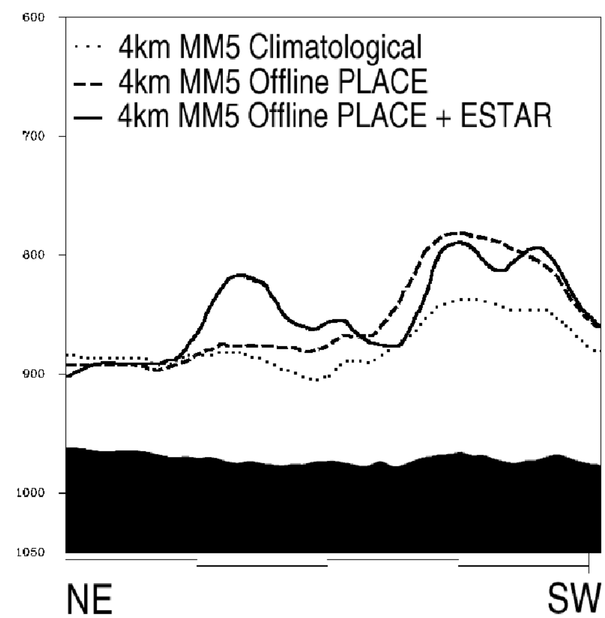

Figure 8. Model−predicted PBL depths at 18h (18 UTC 12 July 1997) along the P−3 flight path for Exps. Climo, PLACE, and ESTAR.

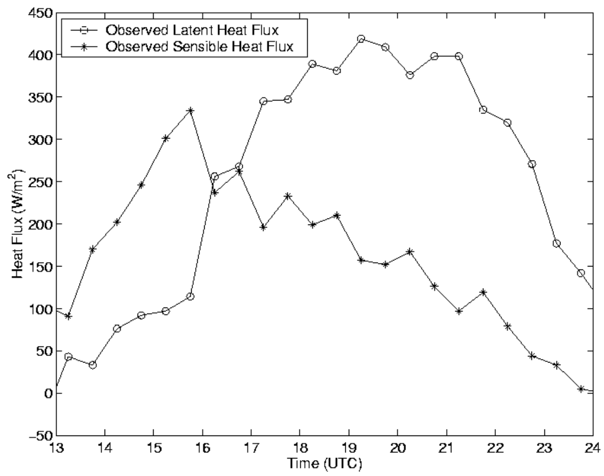

Figure 9. Observed surface heat fluxes for 12 July 1997 at LW07 (within the Little Washita River Basin).

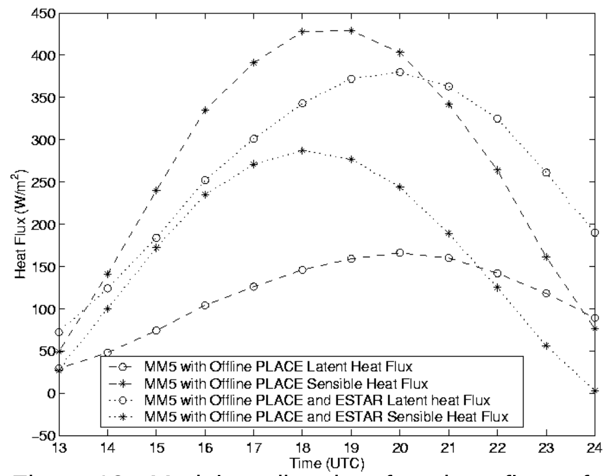

Figure 10. Model predicted surface heat fluxes for 12 July 1997 at LW07 for Exps. PLACE and ESTAR.

the ESTAR data consistently improves the predicted fluxes. Heat flux site LW07, located in the southern portion of the ESTAR data region in the Little Washita River Basin and its observations are shown in Fig. 9. Notice that from 17 UTC until the end of the day the latent heat flux was observed to be higher than the sensible heat flux (i.e. Bowen ratio < 1). The model results for this location (Fig. 10) indicate that Exp. PLACE showed sensible heat flux larger than latent heat flux (Bowen ratio > 1) for much of the period, contradictory to observations. The addition of the ESTAR data resulted in a Bowen ratio less than unity after 17h (17 UTC), which is consistent with the observations.

6. CONCLUSIONS

In general, the addition of the high−resolution soil moisture data had a positive impact on the mesoscale model results when using the force−restore model. The MM5 generally showed good agreement with observations along the P−3 flight path, with improved north−south variations seen for PBL depth in Exp. ESTAR as compared to Exp. PLACE. The model surface fluxes were also improved when ESTAR data were added.

The surface latent and sensible heat fluxes showed responses on or near the same scale as the soil moisture data whereas the PBL structure responded on much larger scales.

7. ACKNOWLEDGMENTS

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