Effects of Surface Heterogeneity of the CART Site on the Potential for Deep Convection

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Introduction

A number of investigators have suggested that precipitation can be affected by subgrid-scale land use inhomogeneities (Chen and Avissar 1994; Segal et al. 1995; Avissar and Liu 1996; Lynn et al. 1998). Although the evidence is based largely on numerical simulations with little or no real data used for verification, it seems plausible that under conditions of unstable stratification, even relatively weak and local perturbations to the atmospheric structure might be sufficient to trigger the development of convective storms. In our current study, therefore, we looked for evidence that subgrid-scale inhomogeneities in surface conditions can affect the occurrence of convective rainfall and that the effect is a significant one when averaged over a domain a few hundred kilometers on a side.

Site, Date, and Models

Our area of interest encompasses most of the Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) and is approximately 10^5 km^2 in size. Large areas of the CART are planted in winter wheat and those areas are harvested by early summer, leaving extensive areas of stubble or bare soil. Much of the remainder of the site is covered with native grasses or agricultural crops that are still growing actively in July and August. The substantial differences in surface cover lead to correspondingly large differences in the fluxes of surface sensible and latent heat over the CART; within the CART, regions with fluxes of similar magnitudes have characteristic scales of 50 km or more.

We have developed a technique that uses CART data and the Simple Biosphere Model (SiB2) (Sellers et al. 1996) to calculate surface fluxes from a knowledge of vegetation, soil, and meteorological conditions over the CART (Doran et al. 1998). These fluxes can be used to specify lower boundary conditions in the mesoscale model we use for numerical simulations. For our mesoscale model we used the Regional Atmospheric Modeling System (RAMS) (Pielke et al. 1992) with two interactive nested grids. The inner grid, which covered most of the CART, had a grid spacing of 12.5 km and a domain size of 306.25 km x 356.25 km. In our study, then, subgrid-scale refers to scales significantly smaller than this domain size. The RAMS model was modified so that its surface flux conditions, derived from the observations and our implementation of the SiB2 model, could be specified explicitly.

Approach

Two conditions necessary for the development of convective storms are the presence of an unstable stratified atmosphere and some triggering mechanism that sets off the convective process. Upward vertical motion resulting from convergence driven by differential heating and cooling over spatially varying land surfaces has been suggested as one possible mechanism. However, our earlier work (Zhong and Doran 1998) suggested that such motions are likely to be quite small over the CART. Thus, we decided instead to focus on the state of the atmosphere. Our approach was a modification of that used by Segal et al. (1995) for a somewhat larger-scale problem. They argued that atmospheric stability, as measured by the lifted index (LI), might be changed sufficiently as the surface sensible and latent heat fluxes changed so that deep convection would be more likely to develop in areas with one set of conditions than in another. We hypothesized that this effect might be seen with the subgrid-scale variations in surface conditions found in the CART. The LI is defined as the temperature difference between the 500-hPa ambient temperature and the temperature of a parcel of air that is lifted dry adiabatically until it becomes saturated and then follows a saturated adiabat to the 500-hPa level. The saturation adiabat for the parcel is found from the wet bulb potential temperature of the average lifting condensation level (LCL) for the mixed lowest 1000-m layer of the atmosphere.

Although Peppler and Lamb (1989) found that precipitation amounts were not well correlated with indices such as LI, Segal et al. (1995) were not concerned with actual rainfall amounts but only with the instability of the atmosphere as reflected in LI. Similarly, we were interested in the location and not the intensity of precipitation. Specifically, we wished to determine whether those locations would occur preferentially in areas of the CART with larger instability and what effects surface fluxes might have on the stability. Peppler and Lamb also found that the K index, which indicates the probability of thunderstorm development (George 1960), yielded significantly better correlations with rainfall totals than LI. The K index is defined by $K = (T_{850} - T_{500}) + T_{d850} - (T_{700} - T_{d700})$, where T is the temperature, numerical subscripts refer to pressure levels in hPa, and the d subscript means a dew point temperature. The probability of a thunderstorm occurring in an area ranges from 0% for $K < 15$ to near 100% for $K > 40$. We discuss this index below as well.

Case Selection and Analysis Procedure

For our studies, we adopted a three-step procedure. First, we examined maps of the precipitation over the CART for 55 days during July and August of 1995 to identify days on which the precipitation patterns over the CART were suggestive of airmass thunderstorms rather than synoptically driven storm systems. For these days, we made two sets of simulations with the RAMS model, one with spatially varying fluxes and a second with spatially uniform fluxes. For each of the simulations, we then calculated the LIs from the model-generated meteorological fields. The spatial distributions of LI for each day and for each set of surface conditions were computed for 1200 Local Standard Time (LST). We assumed that this time was representative of the pre-storm environment because in all cases essentially no rainfall was measured over the CART for the preceding six hours but it began to rain sometime in the following three to six hours. Finally, we compared the patterns of LI (and changes in LI when the distributions were changed from spatially varying to uniform surface fluxes) for each day with the patterns of observed precipitation that developed in the afternoon and early evening hours to determine 1) if the locations of precipitation initiation was well-predicted by LI at these spatial scales, and 2) whether the changes in LI values caused by local flux variations were significant and led to a more reliable indication of where precipitation would first develop.

Results and Discussion

Representative results for the stability and precipitation analyses are summarized in Figures 1 through 3. In each figure, the top two panels show the precipitation for 1500-1800 LST and 1800-2100 LST, the first six hours during which the isolated precipitation events occurred. The middle two panels show contours of the LI computed using uniform surface fluxes (left) and the corresponding LI contours computed using spatially varying fluxes (right). In the bottom row, the left panel shows contours of the latent heat fluxes that were used when variable surface fluxes were specified for the model. Finally, the right panel in this row shows contours of the mean vertical velocity at a height of 750 m above ground level (AGL), computed from the model using spatially varying surface fluxes. The times for all of the panels in the figure, with the exception of the first two showing precipitation, are 1200 LST.

The results for our six cases can be divided into three categories; each illustrated by Figures 1 through 3. In the first category (Figure 1, July 8), the distribution of surface fluxes seems to modify the LI pattern sufficiently so that precipitation occurs in a region of enhanced LI. A second category (Figure 2, July 21) is one in which the precipitation again tends to begin in areas with the largest negative values of LI but the LI pattern is rather insensitive to the details of the spatial distribution of the surface fluxes. In the third category (Figure 3, July 13), the precipitation does not start in or near the areas with the most negative values of LI. The LI distribution may again show some small response to the specification of the surface fluxes but it is not enough to alter the lack of a correlation between precipitation and large magnitudes of LI in these instances. In our study, only one day fell into the first category, three were in the second category, and two were in the third.

We have also looked at the spatial variations in vertical velocity, w, over the domain (Figures 1 through 3) to see if there was any relationship between regions of larger upward motion and areas of precipitation. As anticipated, no clear relationship was found. We also carried out an analysis for the K index similar to that done for LI. We found that K and LI were both useful indicators of the location of precipitation events. We also found, however, that our calculated K distributions were virtually identical when we used spatially varying or uniform surface fluxes in our simulations. This was expected because K is defined in terms that are insensitive to local surface conditions but are more closely related to larger scale weather patterns.

Conclusions

The results of our study suggest, then, that the subgrid-scale variations in land use properties over the SGP CART are normally unlikely to modify the atmospheric stability sufficiently to significantly enhance the likelihood of convective precipitation. Under the right circumstances, such as those of July 8, exceptions may occur. Our sample of events, albeit limited, indicate that such circumstances are

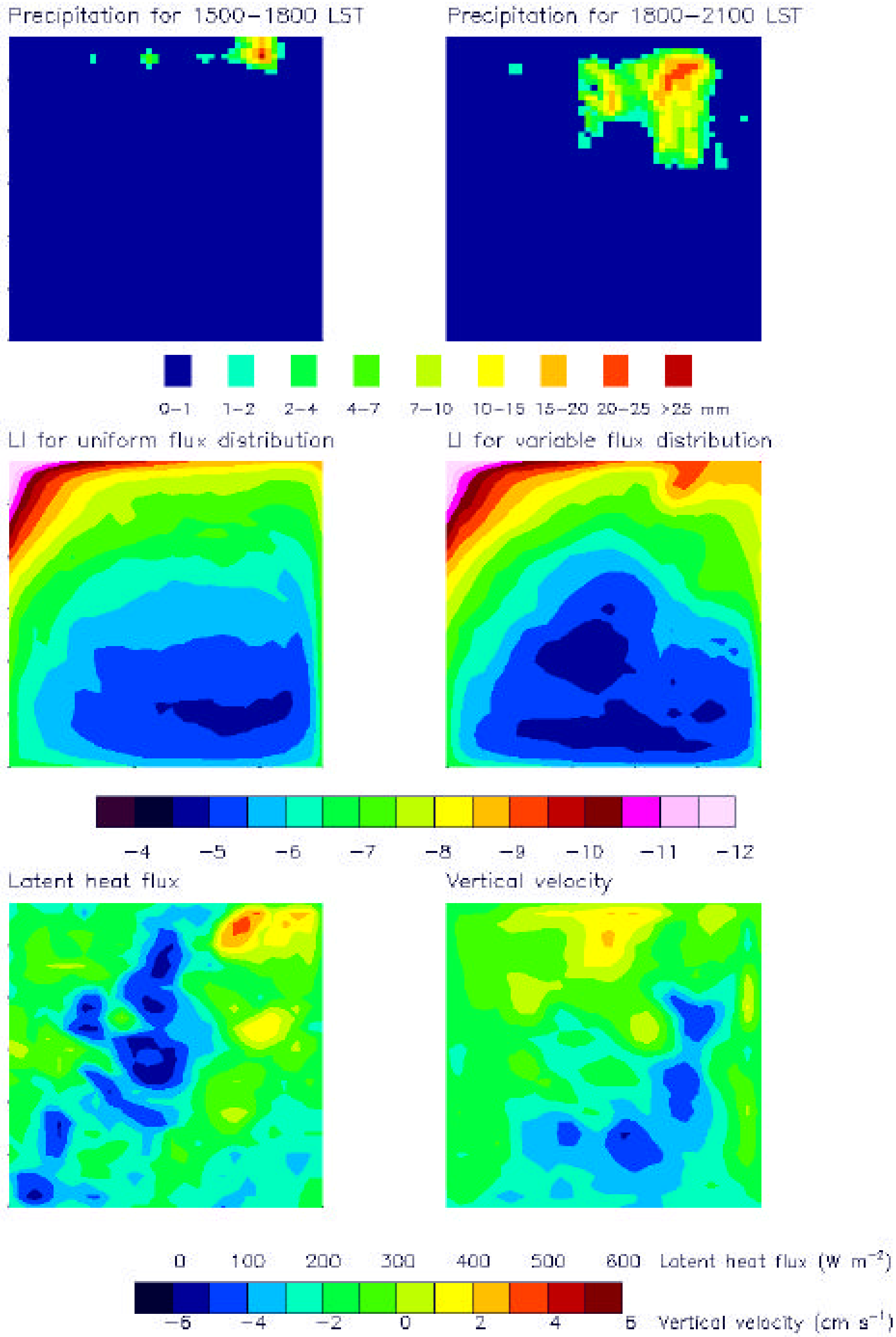

Figure 1. Maps of the cumulative precipitation totals (top row), LI distributions simulated using uniform and spatially varying sensible and latent heat fluxes at 1200 LST (middle row), and contours of surface latent heat fluxes and vertical velocity at 750 m AGL at 1200 LST (bottom row) for July 8, 1995.

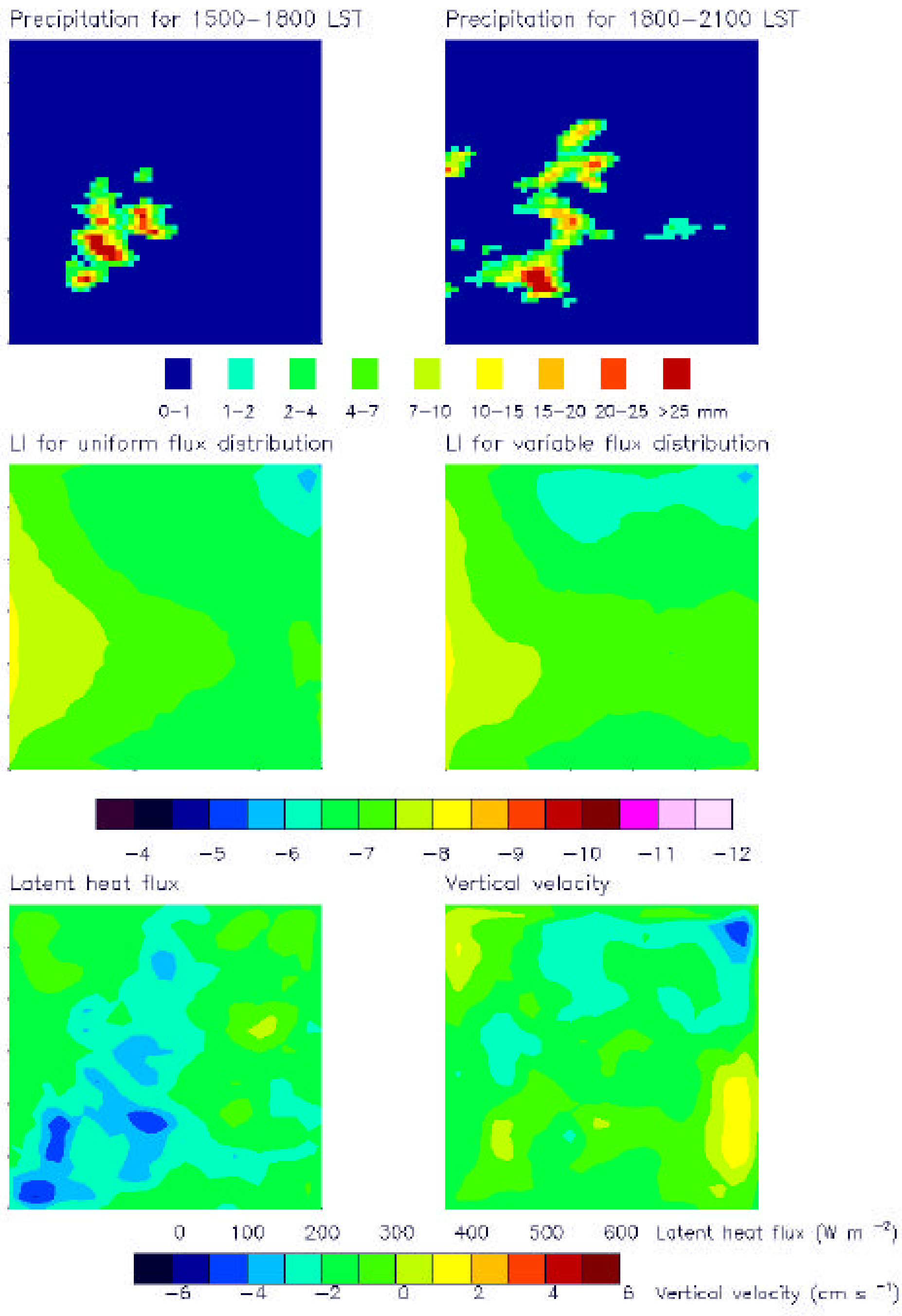

Figure 2. As in Figure 1 except for July 21, 1995.

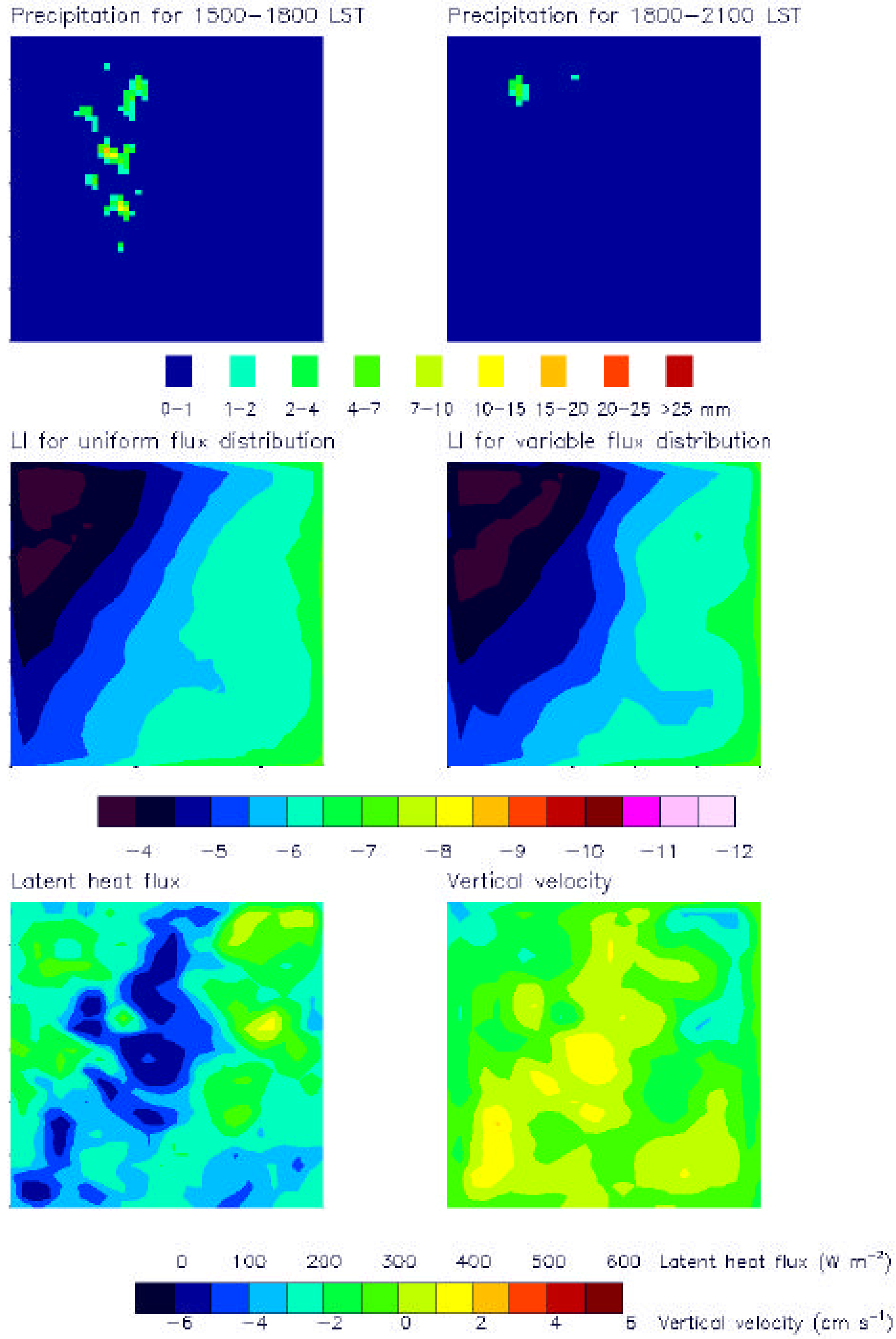

Figure 3. As in Figure 1 except for July 13, 1995.

apt to occur infrequently (one case out of 55 days examined). Instead, larger-scale influences (including land use features, but on scales of hundreds of kilometers or more) appear to be much more important in determining atmospheric instability and thunderstorm formation, at least in this part of the world.

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