Using ARM Data to Evaluate the Significance of Mesoscale Fluxes for Climate Modeling

J. C. Doran and S. Zhong
Pacific Northwest National Laboratory
Richland, Washington

Background

Numerous numerical studies of the response of the atmosphere to spatially varying fluxes of sensible and latent heat have been reported in the literature. These studies typically have found that significant secondary circulations are generated when strong contrasts in the surface flux values occur over adjacent regions of a modeling domain, with consequent implications for boundary-layer depth and structure, cloud formation, and precipitation. Our studies using data from the Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site, however, suggest that the significance of these effects for the performance of single-column models or climate models has been overstated by the specialized conditions assumed in these numerical studies. We present examples of our results using CART data and we examine the reasons for the differing conclusions between our own and previous studies.

Approach

The approach in our latest study can be summarized as follows:

1. Use CART data and the Simple Biosphere Model (SiB2) to estimate spatial and temporal patterns of surface fluxes over the CART site.

2. Select 15 days in July 1995 with large flux contrasts and light to moderate winds—conditions that should be conducive to producing significant mesoscale fluxes.

3. Use a mesoscale model (RAMS) to simulate the response of the atmosphere using both SiB2-estimated spatially varying surface fluxes and spatially uniform fluxes equal to the domain-average values.

4. Compare domain-averaged quantities such as mixed-layer depths, potential temperature profiles, mixing ratio profiles, and cloud fractions for the two sets of flux conditions.

Figure 1 shows examples of simulated profiles of potential temperature and water vapor mixing ratio for some of the days examined in our study. The results of our tests for the full set of 15 days are that, averaged over the CART domain, only small differences can be discerned in these quantities.

Sensitivity Tests

To investigate why the flux patterns at the CART site fail to produce significant mesoscale flux effects, comparisons were made among four simulations with four different combinations of flux patterns and ambient winds: a checkerboard flux pattern with light winds (0.5 m s^{-1}); a checkerboard flux pattern with ambient winds similar to those found on July 12 (a day with large flux contrasts); the SiB2-estimated flux pattern for 12 July with light winds (0.5 m s^{-1}); and the SiB2-estimated flux pattern for 12 July with actual ambient winds.

For the checkerboard flux pattern, we used a 4 x 4 grid pattern, with each segment 75 km wide and 89 km long. In each segment, we assumed a sinusoidal flux variation with time with maximum flux values occurring at 1200 LST. The “dryer” segments were specified to have maximum sensible and latent heat values of 450 W m^{-2} and 125 W m^{-2}, respectively, while the “wetter segments had maximum and minimum sensible and latent heat values of 150 W m^{-2} and 375 W m^{-2}, respectively. These values result in maxima and standard deviations of sensible and latent heat fluxes that are similar to those found using the SiB2 model for conditions on 12 July 1995. Thus, the checkerboard patterns provide total amounts of heat and moisture to the atmosphere that are similar to those found at the CART site but the spatial distributions are very different. In addition, we are able to test the sensitivity of the results to the assumed ambient wind conditions.

The vertical velocity distributions and flux profiles were then compared for the four cases and the results are shown in Figure 2. As can be seen, when very light winds and highly idealized flux distributions are assumed, substantial

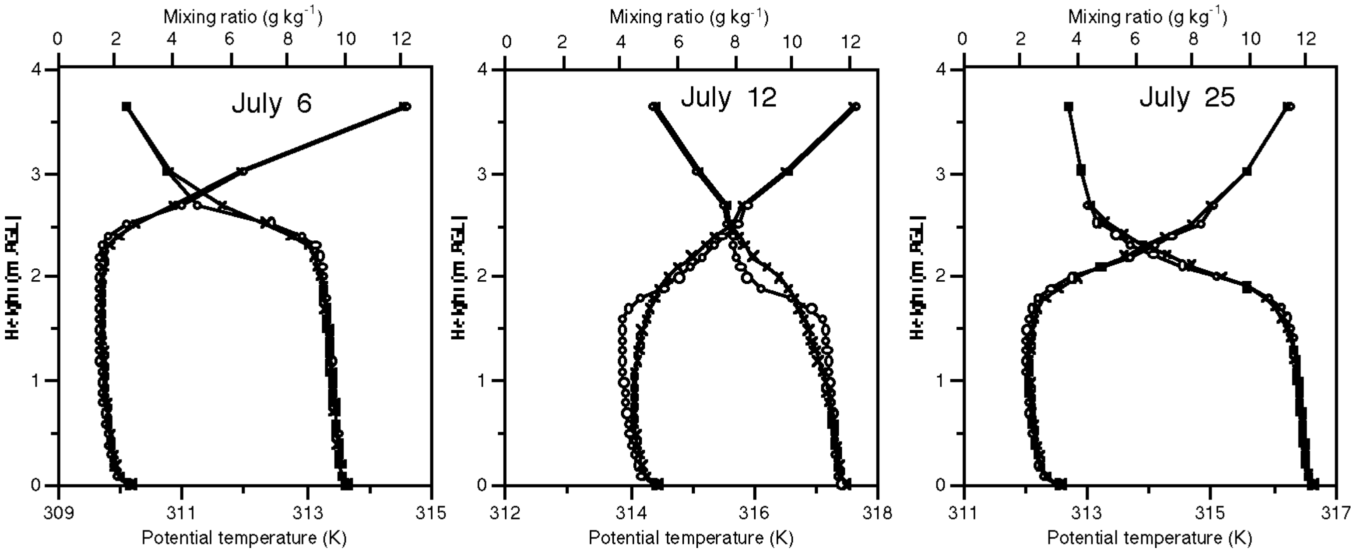

Figure 1. Simulated profiles of potential temperature and water vapor mixing ratio for 3 days using spatially varying (open circles) and uniform (crosses) surface fluxes.

vertical velocities can be found in the modeling domain. In contrast, when more realistic flux distributions and more commonly occurring wind values are used in the simulations, the large vertical velocities (and their associated mesoscale fluxes) are effectively eliminated.

Precipitation

We are currently examining the sensitivity of convective precipitation to the spatial distribution of fluxes. Simulations are done using either the Grell or Kuo cumulus precipitation parameterization schemes. Again, the results for spatially varying and uniform flux conditions are being compared. Although there are some differences in the simulated cumulative rainfall, they appear to be small compared to the differences between observations and simulations.

Conclusions

For single-column modeling studies of the SGP CART site, and for other climate modeling studies using grid spacing on the order of a few hundred kilometers, it is unlikely that attempts to include mesoscale flux effects will result in significant improvements in model performance for typical mid-latitude conditions. Previous numerical studies that have claimed more substantial contributions from mesoscale fluxes have typically used surface and meteorological conditions that are unlikely to be found in nature on a regular basis. Thus, their applicability to real-world conditions appears to be quite limited.

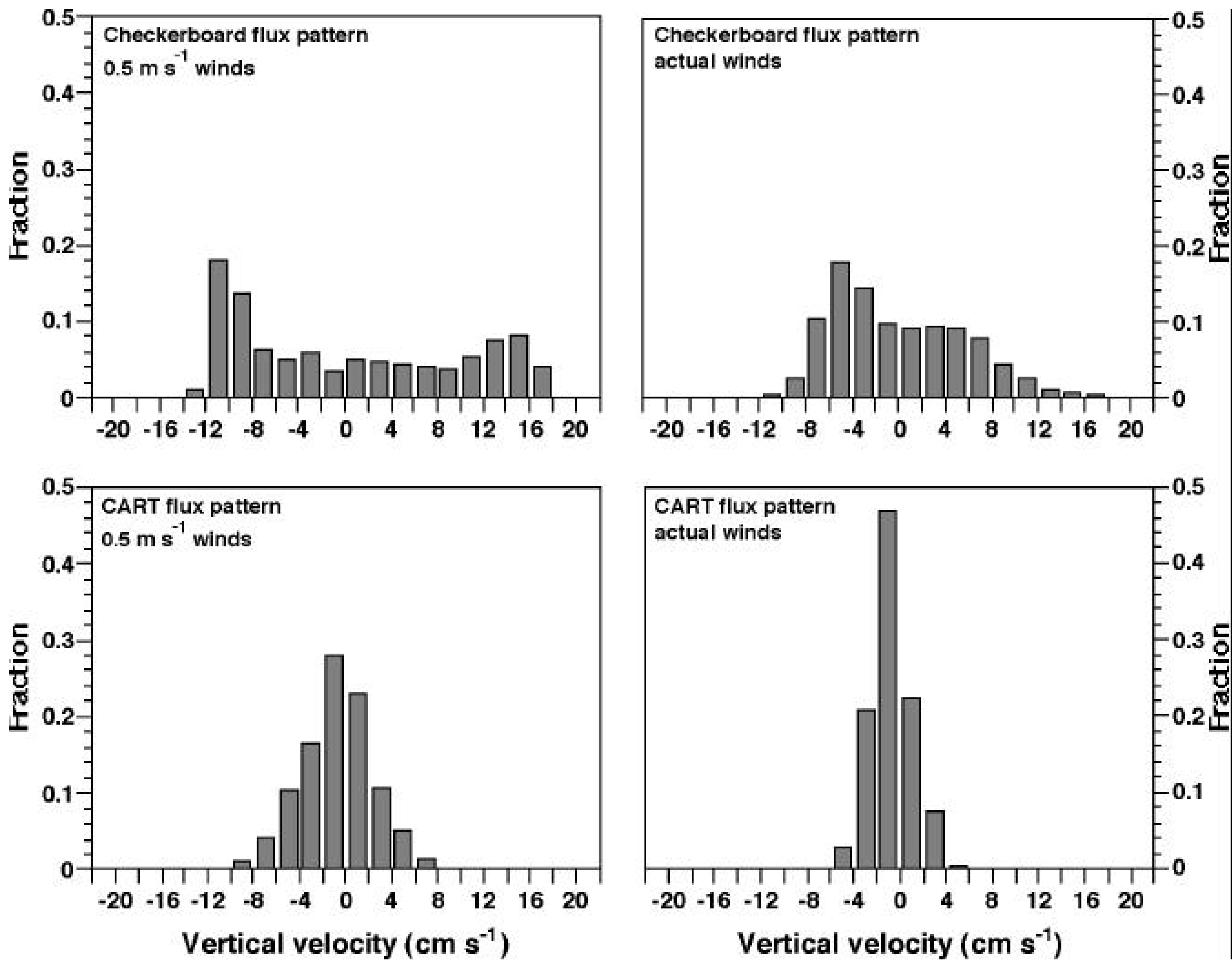

Figure 2. Distributions of simulated vertical velocities over the CART at 1400 LST and 1500 m above ground level for four cases: 1) checkerboard pattern with an ambient wind speed of 0.5 m s^{-1}, 2) the checkerboard pattern with winds similar to those found on July 12, 3) the SiB2-derived CART flux distribution of July 12 with winds of 0.5 m s^{-1}, and 4) the SiB2-derived CART flux distribution of July 12 with the actual wind values.