Surface Flux Inhomogeneities at the Southern Great Plains Cloud and Radiation Testbed Site and Their Effects on Cloud Formation

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

Introduction

We use observations and a three-dimensional numerical model to study the effects of inhomogeneous surface fluxes on the boundary layer characteristics of a 300-km x 350-area in Oklahoma and Kansas. In particular, we consider the effects of spatially varying fluxes on the formation of boundary-layer clouds. We show that under the settled weather conditions prevailing during our case study days, the formation of boundary layer clouds was far more sensitive to spatially varying ambient meteorology than to spatially varying surface fluxes, even though surface fluxes varied significantly across the study domain. If the spatially varying surface flux values were replaced by reasonably accurate average values, then differences were readily observed, but only minor differences were found when the results were averaged over the full study domain. In light of these findings, we suggest that the importance of resolving surface fluxes in coarse resolution models such as single column models may be less than has been claimed on the basis of numerical studies and that this issue should be critically reexamined.

Observations

To determine flux values for the complete Cloud and Radition Testbed (CART) domain from a set of point flux measurements, we adopted a simple empirical approach that takes advantage of the extensive data collection network in CART. We sought a fit of the sensible and latent heat flux data to variables that were closely related to these quantities. For these variables, we chose the normalized difference vegetation index (NDVI) and the precipitation occurring over the 2-week period preceding the days on which we wished to calculate the fluxes. NDVI values were obtained from AVHRR (advanced very high resolution radiometer) satellite data at 1-km resolution. The average NDVI value was then computed for each CART grid element. (For our analysis, the CART domain is divided into grid elements 6.25 km on a side, corresponding to the resolution of a mesoscale model that we use for studies at this site.) Objectively interpolated precipitation fields were generated using the multiquadric basis function interpolation scheme of Nuss and Titley (1994) applied to data from the Oklahoma Mesonet, the Kansas State University network, National Weather Service sites, and Atmospheric Radiation Measurement (ARM) stations. Daily precipitation totals were then assigned to each grid point in the domain.

Three days with settled weather conditions were selected for study. Values of the sensible (H) and latent (L) heat fluxes averaged from 0930 through 1500 LST were calculated for each flux station for each of the three days. Each set (H and L) of daily averaged flux data was then fit to a bilinear equation using NDVI and the 14-day antecedent precipitation as the independent variables. The NDVI and precipitation values over the whole domain were then used to calculate daily average values of H and L at each grid point. This approach clearly has a number of limitations and cannot be used to obtain detailed information on the surface fluxes at any particular location. However, we were interested primarily in the sensitivity of the boundary-layer response to overall patterns of flux distribution over the CART domain, and the approach is sufficient for this need. Figure 1 shows the calculated distribution of sensible and latent heat fluxes over the CART domain for 28 July 1994. The spatial distribution of fluxes on all three days was similar.

Numerical Model

The mesoscale model used for our simulations was version 3a of the Regional Atmospheric Modeling System (RAMS) developed at Colorado State University. It was run in a nested configuration with three grids, with the innermost grid encompassing most of the CART area at a resolution of 6.25 km. The model was initialized with the output analysis fields from the National Weather Service' s ETA model and from additional information obtained from standard and supplemental rawinsonde soundings in the CART area. Soil

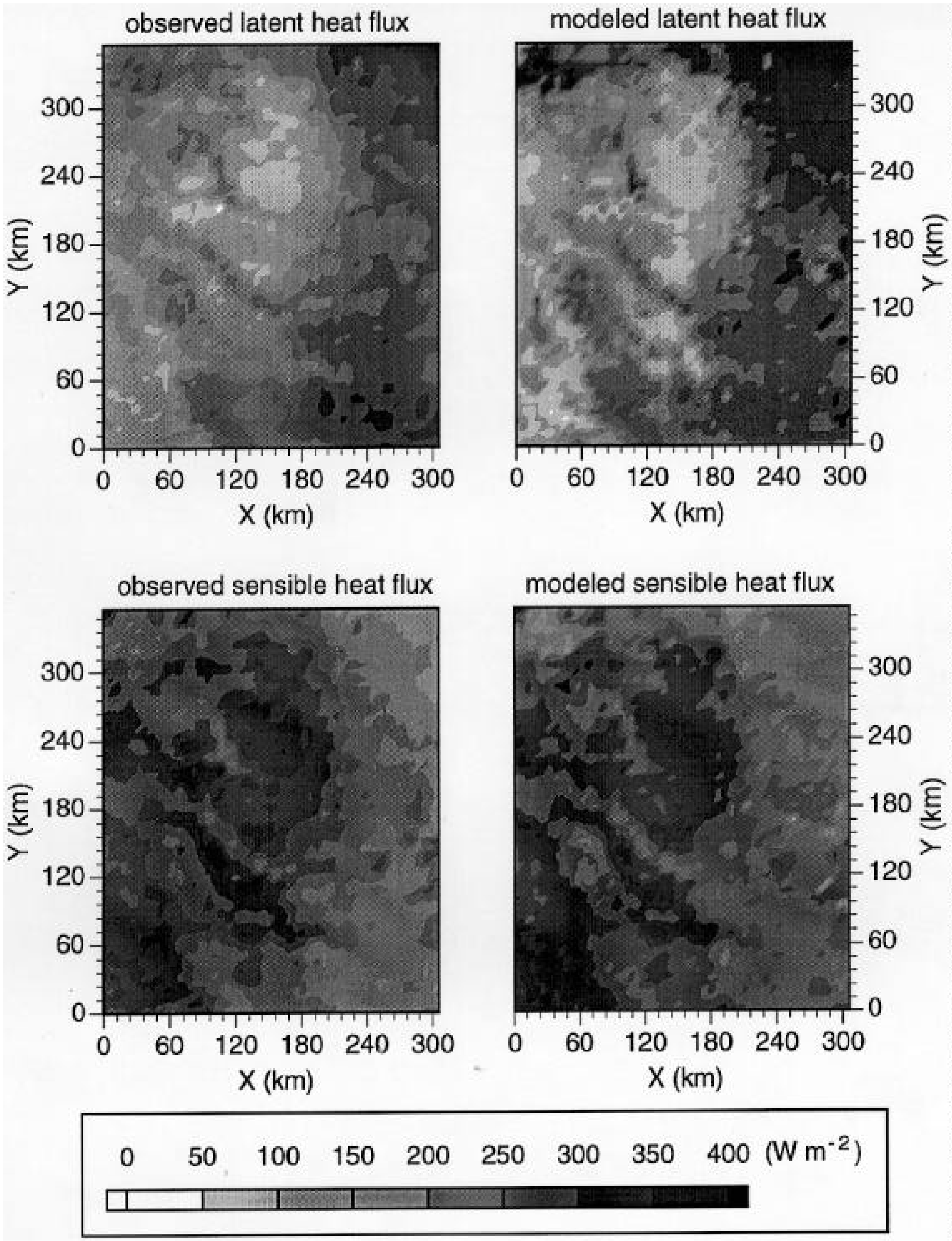

Figure 1. Distribution of averaged sensible and latent heat fluxes over the CART site on 28 July 1994, calculated from NDVI and antecedent precipitation values (left) and simulated with the mesoscale nodel (right).

moisture was used as a tuning parameter in the model and adjusted at each of the grid locations so that the patterns of sensible and latent heat fluxes produced by the model were similar to those derived by the empirical approach described above. Figure 1 also shows an example of sensible and latent heat flux values calculated with this method; the simulated flux values show close correspondence with the observations. For each case, the simulations began at 1200 GMT (0600 LST) and continued for 12 hours.

Cloud Parameterization Schemes

We selected four cloud parameterization schemes to calculate the fractional cloudiness that would occur over the innermost domain of the model on each of the three selected days. The cloud schemes are described by Kvamstϕ (1991), Sundqvist et al. (1989), Ek and Mahrt (1991), and Wetzel (1990) and have been compared elsewhere (e.g., Mock and Cotton 1995) and found to be reasonable indicators of cloud development. Our purpose was not to evaluate the relative merits of the schemes again, but to determine if the results of our numerical experiments would be sensitive to the choice of a particular parameterization method.

Results and Discussion

We performed two basic sets of simulations. In the first set, the full spatially varying pattern of surface fluxes was retained, and the response of the atmosphere to these lower boundary conditions was calculated. In the second set, the vegetation, soil type, and soil moisture were made uniform across the site, and the soil moisture was adjusted so that the simulated values of sensible and latent heat fluxes at each grid cell were close to the values obtained by averaging the inhomogeneous fluxes over the innermost model domain.

For each day and for each set of simulations, we calculated the fractional cloud cover at each grid point for the innermost domain of the model. Figure 2 shows an example of the observed and calculated patterns of cloud cover for 12 August. By comparing these figures, we can see that regardless of which flux distribution was used—spatially varying or uniform—cloud patterns similar to the observed ones are obtained in the numerical simulations. The simulations with the spatially varying fluxes do provide additional spatial details that are also seen in the satellite image, so if one is interested in localized effects of fluxes, their spatial variations must clearly be taken into account.

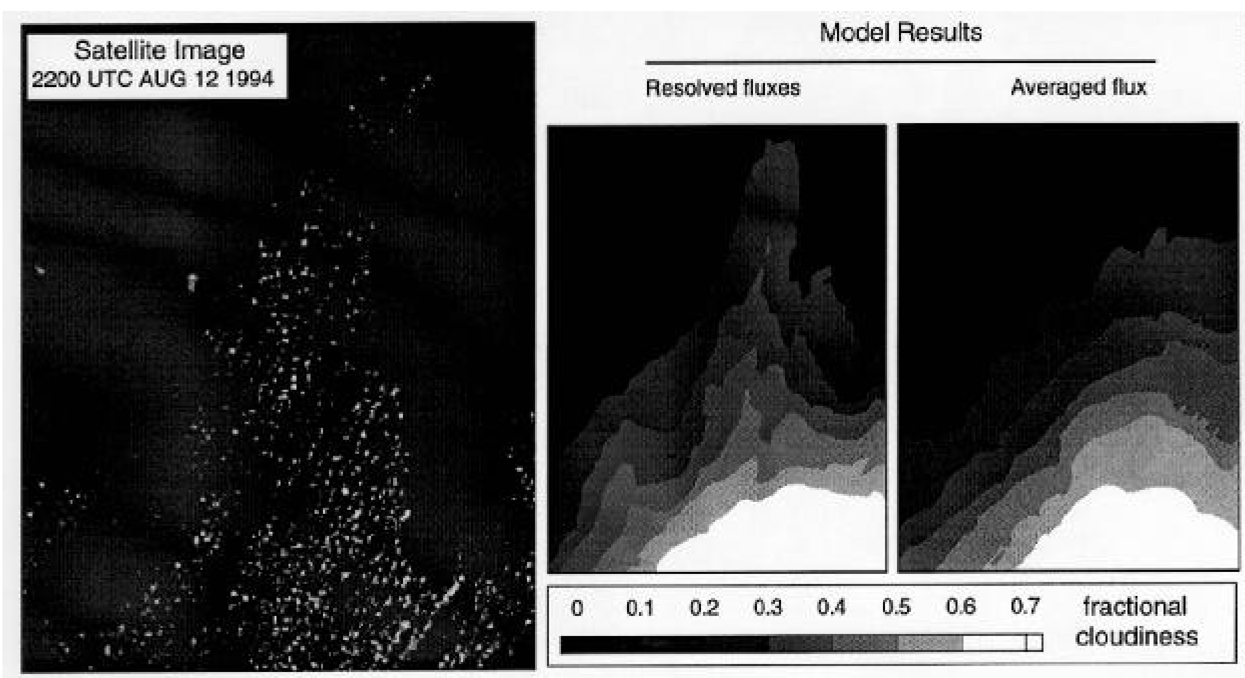

Figure 2. Observed (left) and simulated (Wetzel scheme) patterns of cloud cover for 12 August 1994 using spatially varying surface fluxes (middle) and uniform surface conditions (right).

However, there is little to distinguish between the results from the two sets of flux conditions if we sum the cloud fractions over the full computational domain (Table 1). This conclusion holds regardless of which cloud parameterization scheme was used.

The fractional cloud cover was also computed using the meteorological conditions that were obtained by averaging conditions over the inner domain of the model. At this scale, the atmosphere was sufficiently dry that the cloud fraction was quite small or zero for all four parameterization schemes and for both the spatially varying and uniform flux cases. This result emphasizes the importance of resolving the ambient meteorology at scales smaller than 300 km and suggests that a failure to do so can lead to poor predictions of cloud cover no matter how well the surface fluxes are resolved. We have also examined the temperature and moisture fields, averaged over the 300-km x 350-km CART domain and have compared the results obtained with uniform surface conditions and with spatially varying fluxes. The spatially varying surface fluxes produce substantial variations in potential temperature profiles, water vapor mixing ratio profiles, and mixed layer depths over the CART site, particularly on July 28 and August 12. Nonetheless, when an average is taken over the full domain, the resultant profiles are virtually indistinguishable from those obtained with uniform surface conditions. Thus, any mesoscale fluxes that may have arisen from flux inhomogeneities appear to have had little effect on the mean atmospheric state in these cases.

Acknowledgment

This research was supported by the Environmental Sciences Division of the U. S. Department of Energy under Contract DE-AC06-76RLO 1830 at Pacific Northwest National Laboratory under the auspices of the Atmospheric Radiation Measurement Program. Pacific Northwest National Laboratory is operated for the U.S. Department of Energy by Battelle. We would like to thank W. J. Shaw for developing the precipitation fields used in the flux analysis and X. Bian for his preparation and processing of most of the illustrations used in this paper.

References

Ek, M., and L. Mahrt, 1991: A formulation for boundary layer cloud cover. *Ann. Geophys* **9**, 716-724.

Kvamstϕ, N.G., 1991: An investigation of diagnostic relations between stratiform fractional cloud cover and other meteorological parameters in numerical weather prediction models. J. *Appl. Meteor.* **30**, 200-216.

Mock, D.M., and W.R. Cotton, 1995: Evaluation of fractional cloudiness parameterizations for use in a mesoscale model. *J. Atmos. Sci.* **52**, 2884-2901.

Nuss, W.A., and D.W. Titley, 1994: Use of multiquadric interpolation for meteorological objective analysis. *Mon. Wea. Rev.* **122**, 1611 - 1631.

Sundqvist, H., E. Berge, and J.E. Kristjansson, 1989: Condensation and cloud parameterization studies with a mesoscale NWP model. *Mon. Wea. Rev.* **117**, 1641-1657.

Wetzel, P.J., 1990: A simple parcel method for the prediction of cumulus onset and area-averaged cloud amount over heterogeneous land surfaces. *J. Appl. Meteor.* **29**, 516-523.

Table 1. Fractional cloudiness (percent) predicted by four parameterization schemes for two sets of simulations with spatially varying fluxes and uniform surface conditions.

		Fractional Cloud Cover (%)			
Date	Flux Distribution	Kvamstϕ	Sundqvist	Ek and Mahrt	Wetzel
7/28/94	Variable	26	16	19	19
	Uniform	22	12	16	16
8/9/94	Variable	15	9	11	14
	Uniform	14	8	11	14
8/12/94	Variable	23	16	17	22
	Uniform	25	16	18	23