The Sensitivity of Flux Parameterizations to Surface Characteristics

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The problem of measuring or calculating appropriate surface heat and moisture fluxes for use in general circulation models (GCMs) and single-column models (SCMs) is an important one. This is particularly true at Cloud and Radiation Testbed (CART) sites, where an accurate treatment of the surface boundary conditions is essential if SCMs are to be used to study cloud and radiation processes in detail. For this discussion, three issues will be considered:

1. From measurements of surface fluxes at a finite (and relatively small) number of points, such as will be available at the CART site, how can one interpolate/extrapolate to get the average flux over an area covered by an SCM or a GCM grid cell?
2. How are fluxes parameterized in models? Are these parameterizations consistent with what is known about the behavior of the planetary boundary layer (PBL) over inhomogeneous terrain? Can one deduce the correct average surface fluxes from knowledge of averaged boundary layer quantities such as mean winds or temperatures at a model level?
3. How much does it matter if fluxes are not correctly parameterized? What might some of the consequences be if the flux values used in models are incorrect?

To address these questions, some results from both observations and model simulations will be described. These results show differences in boundary layer properties over adjacent areas with differing surface characteristics. Such differences can have important consequences for the determination of area-averaged flux values from point measurements.

Several laboratories carried out measurement programs for the Atmospheric Radiation Measurement (ARM) Program in the springs of 1991 and 1992 in northeastern Oregon near the town of Boardman. The region is characterized by two distinct surface types—dry sagebrush and grassland steppe and heavily irrigated agricultural areas.

The winds during the 1992 experiment had three principal patterns. In the first pattern, the winds were moderately strong (up to 10 m/s near the surface) from the west-southwest and persisted through most or all of the day. In the second pattern, winds would start out from the west-southwest in the morning at speeds of 4-7 m/s, decrease, and around 1100 PST would shift and blow out of the north or even northeast. In the third pattern (which happened once) the winds were west-southwest for almost the whole day but the speeds were only 3-7 m/s. Winds from the west or southwest blew first over a dry fetch of ~18 km before blowing over the instrumented farm site.

Despite the relatively small scales of the adjacent disparate surface types, it was possible to detect differences in the boundary layer characteristics over the wet and dry areas for all three wind patterns. For strong wind cases, increased evaporation produced cooler temperatures over the irrigated area than over the dry area in the lowest 50-100 m. For lighter winds, the temperature contrasts near the surface were smaller but temperature differences could still be seen over depths of several hundred meters. The winds over the dry area were stronger, primarily due to the lower roughness length in that region. However, the reduced wind speeds over the farm were also consistent with the development of a weak secondary circulation arising from the thermal contrasts between the two surface types. On the day with the third wind pattern described above, additional suggestions of the development of a "farm breeze" were seen in the wind speed and direction profiles obtained from three sodars operated during the experiment.

From the results of the Boardman experiment, it is apparent that in calculating fluxes over different areas or in interpolating fluxes from point values to area averages, knowledge of the soil properties (vegetation, soil moisture, soil type, etc.) is a necessary but not sufficient condition. One may also have to take into account the variations in the wind, temperature, and cloud fields that help determine the surface fluxes. Even over a scale as small as that for Boardman, with an experimental domain less than 30-km long, such factors were found to vary substantially and had significant influences on the local flux values. Over a CART site, the scales will be larger and the effects may be greater.

Possible effects of heterogeneity in subgrid-scale surface properties can also be simply illustrated by considering results from some two-dimensional simulations carried out with the Colorado State University Regional Atmospheric Modeling System (RAMS) nonhydrostatic mesocale model. The issue addressed in these simulations is the consistency of the parameterizations used in GCMs or SCMs when the model resolution is insufficient to explicitly account for subgrid-scale variations in surface fluxes. In the simulations, the average soil moisture over the modeling domain (200 km in extent) was held fixed. A central 100-km region was then modified so that half of the region was wetter than the average and half was drier by the same amount. The dry and wet halves were broken up into patches ranging from 12 to 50 km in size, and the order in which the ambient wind blew over the dry and wet patches was varied. In one case, a 50-km dry patch was encountered first and, in the other case, a 50-km wet patch was first. Contour plots of the resulting distributions of horizontal wind speeds and of mixing ratios are shown in Figures 1 and 2, respectively.

The figures clearly show that the responses of the boundary layer in the two cases differ. Because the differences in sensible heat fluxes over the wet and dry areas generate secondary circulations, the spatial variations of the wind and moisture fields change substantially as the orientation of the different surface types relative to the mean wind is changed. Averages of wind speeds or mixing ratios over the 100-km central region differ as well. Temperature fields are similarly affected.

Two conclusions may be drawn from this example. First, properties of the boundary layer derived from averages of the surface conditions will not, in general, be the same as the average of the conditions derived over two different surfaces. Second, the order in which the individual patches are encountered may also be important. These findings are consistent with results obtained from the Boardman experiments. The implication for SCMs is important: to handle surface inhomogeneities correctly, one must know not only the percentages of each land surface type, but the characteristic sizes of the patches and their orientation relative to the prevailing winds.

How much does it really matter if the flux distributions are not treated correctly in the models? There are at least three reasons why a knowledge of the details of the boundary layer structure may be important for issues of concern to the ARM Program. First, the surface energy budgets are obviously dependent on the surface characteristics and the local meteorological conditions, which include the properties of the boundary layer. The surface energy budget, in turn, determines the surface temperature and the longwave radiation from the surface. Second, the height of the boundary layer and the distribution of aerosols and moisture in the boundary layer can clearly play an important role in the radiation budget; these distributions are determined largely by the turbulent mixing of heat, momentum, and moisture in the boundary layer, which, in turn, depend on the surface fluxes driving them. Finally, local "hot spots" may tend to favor the formation of cumulus clouds preferentially in some areas of the CART domain and not in others. All of these boundary layer features must be represented properly in SCMs and GCMs if their treatments of clouds and radiation are to be tested and improved.

Acknowledgment

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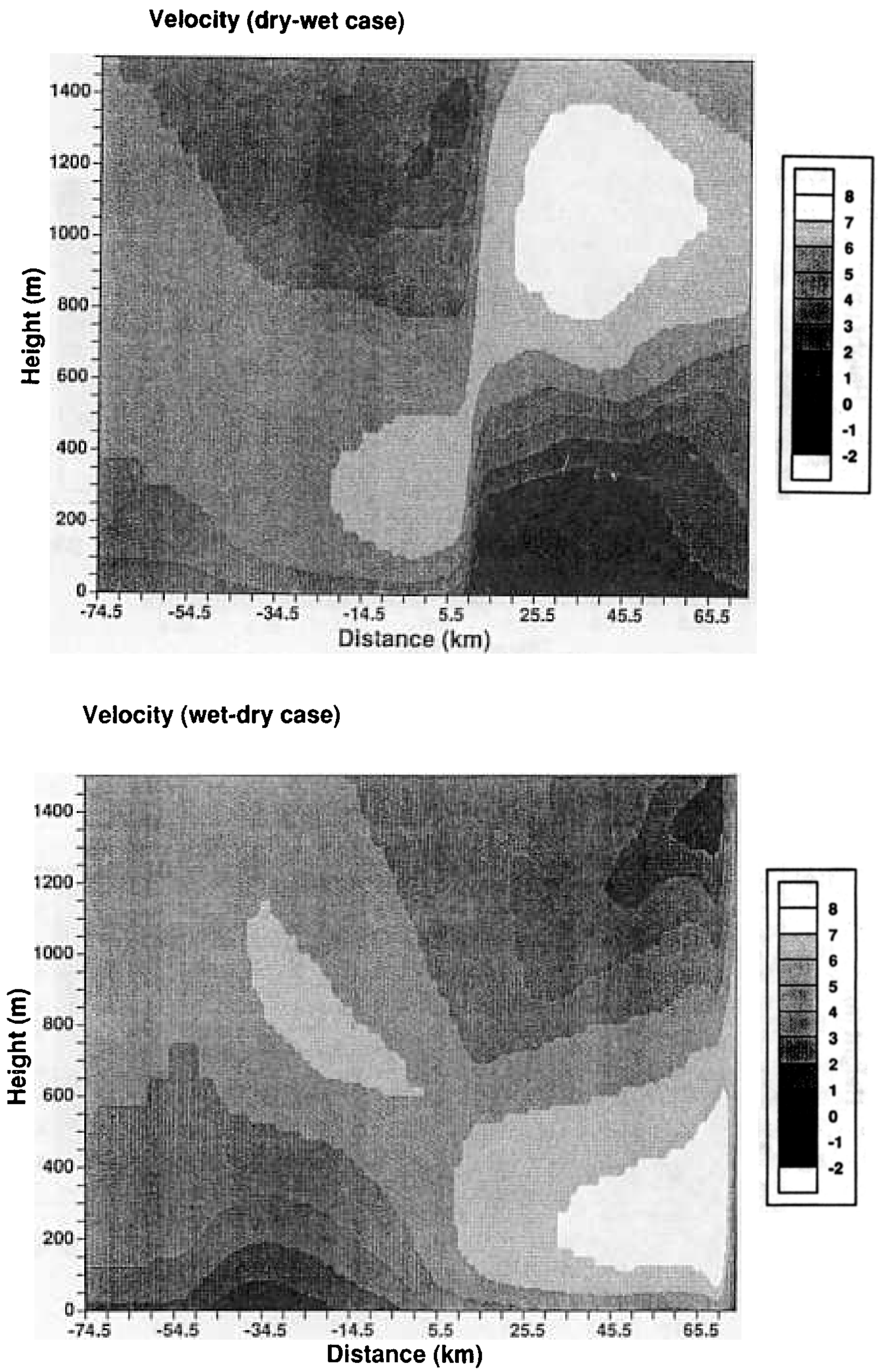

Figure 1. Contour plots of simulated variations in the u-component of velocity over dry-wet and wet-dry surfaces.

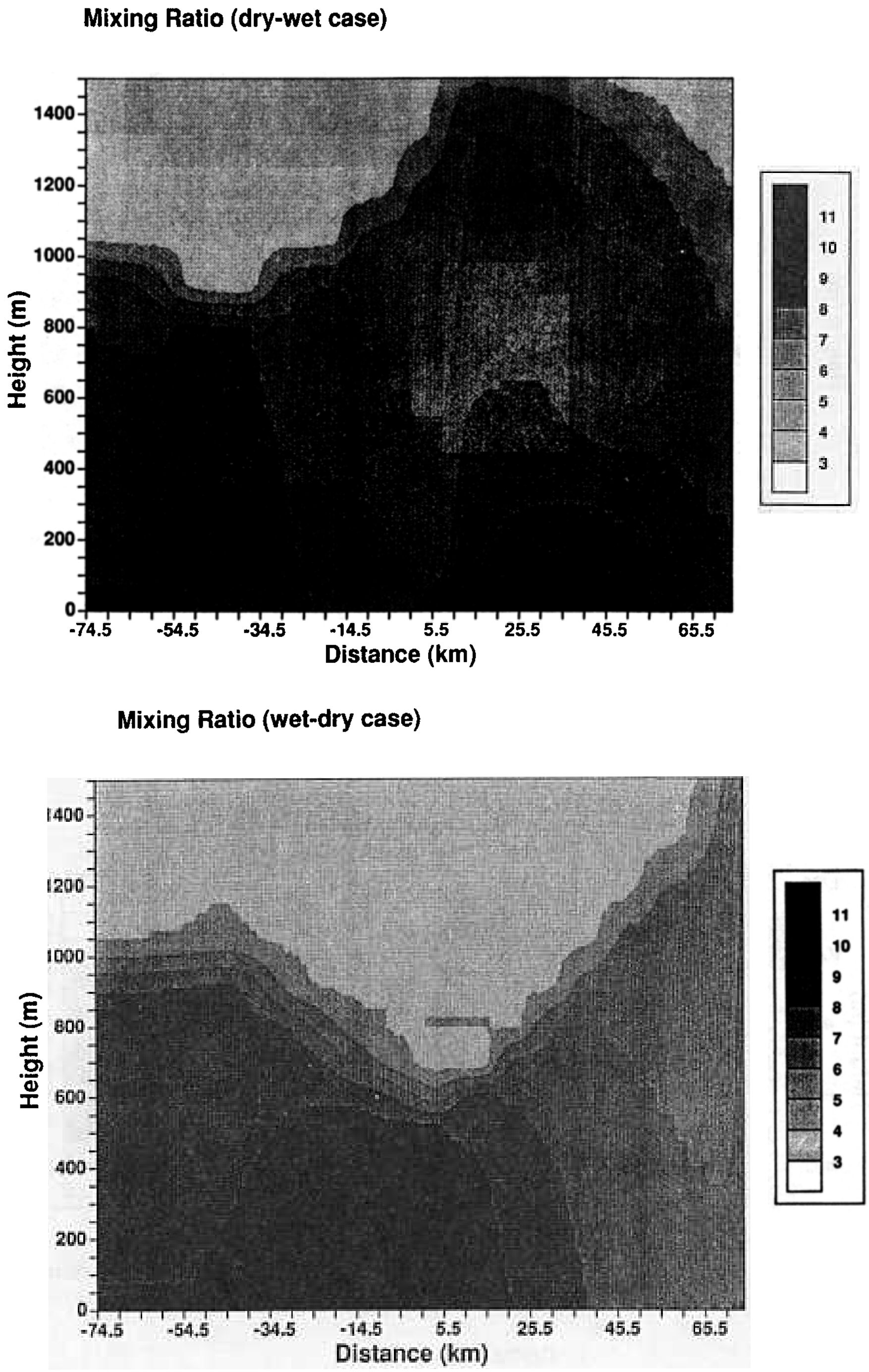

Figure 2. Contour plots of simulated variations in mixing ratios for flow over dry-wet and wet-dry surfaces.