Surface Fluxes Important to Cloud Development

F. J. Barnes and W. Porch
Los Alamos National Laboratory
Los Alamos, NM 87545

K. E. Kunkel
Illinois State Water Survey
Champaign, IL 61820

Introduction

To address some of the issues in scaling and averaging of measurements, U.S. Department of Energy laboratories funded under the Atmospheric Radiation Measurement (ARM) Program conducted collaborative field campaigns in June 1991 and 1992. We selected a site in Boardman, Oregon, with two distinct regions where the sensible and latent heat fluxes would differ sharply and where each region was sufficiently extensive enough to allow full development of boundary layers and use of aircraft-mounted instrument systems (Barnes et al. 1992, Doran et al. 1992). Measurements were clustered along a 16-km transect across adjoining irrigated farmland and semi-arid rangeland that allowed the collaborating teams to conduct a variety of studies relating to overall goals. The Los Alamos team focused on assessing the effects of different surface characteristics on fluxes of heat and water vapor.

Progress from the Boardman experiments and preliminary work at the Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site (see p. 3) has contributed to the ability to model and measure fluxes over a wide range of scales. Extrapolating surface flux measurements and exploring aggregation of measurements of fluxes and surface characteristics at different scales will be important at CART sites in order to model the influence of surface variability on cloud formation and radiative transfer. Our approach is unique in that it integrates modeling and diverse field methodologies as well as expertise in ecological and atmospheric sciences. This is important not only for the surface characterization and Surface Vegetation Atmosphere Transfer Scheme (SVATS) modeling that will be required for the CART sites, but also in the use of remote sensing tools to test the aggregation of tower flux measurements.

Fine Scale Variability in Fluxes Over Range and Farm

The Los Alamos team members focused on the following measurements over the course of the 3-week campaigns:

1. Intercomparison of micrometeorological instrument performance.
2. Determination of fine-scale variability of surface fluxes over dry grassland (1991) and farmland (1992) and its relationship to variability in surface soil moisture, crop type and leaf area index or biomass.
3. Comparison of spatially averaged optical measurements of heat fluxes and convergence with micrometeorological measurements, high-frequency Doppler acoustic measurements, and multi-spectral cloud images and cloud height measurements.
4. Determination of evapotranspiration (ET) from water balance estimates of 4 crops in the agricultural area and comparison to micrometeorological measurements of ET.

1991 Results

A survey of the rangeland site (Barnes et al. 1992) showed that one grass and two shrub associations were most important in spatial coverage of the transect area in the northern portion of the rangeland. The grassland areas were dominated by needle-and-thread, a perennial bunchgrass. Aboveground green vegetative cover on the grassland sites ranged from 20% to 40%. Biomass estimates for three sites in this community ranged from 13 to 55 g/m^2. The two shrub communities were dominated by either rabbitbrush or bitterbrush, with understories of needle-and-thread and/or cheatgrass. Overstory canopy cover on the shrub sites was about 14%. At the time of the study, the perennial grasses had largely completed vegetative growth and were starting to set seed, while the annual grasses were senescent with no green foliage evident. The shrubs were still in an active vegetative growth phase. Conditions across the rangeland were extremely dry. During the study period, gravimetric soil moisture determined on samples from 0 to 15-cm depth ranged from 1.1% to 4.1% volume, and from 2.5% to 6.4% volume in the 15- to 30-cm depth samples.

Mean latent and sensible heat fluxes were calculated for the shrub (4 sites) and grass (5 sites) communities. Mean maximum daily sensible heat fluxes for both communities ranged from 270 to 450 W m^{-2}, and about 45 to 80 W m^{-2} for latent heat fluxes. There was no discernible trend in the effect of vegetative cover type on the mean fluxes. Inspection of the daily flux rates for each site showed that the sensible heat flux rates were remarkably uniform among sites. However, the latent heat flux from the bitterbrush site was significantly ($P<0.01$) higher than over the other shrub sites. This trend cannot be explained by the effect of surface soil moisture, which tended to be lower at this site. Although the overall vegetative cover on this site was similar to the other shrub sites (14%), the dominant shrub species (bitterbrush) has a larger growth form and higher green biomass per shrub than the rabbitbrush growing on the other shrub sites. The potentially higher green biomass per unit ground area and deeper rooting (likely with a larger-sized shrub and resulting in the vegetation accessing soil moisture deep in the profile) could account for the higher ET from the site.

1992 Results

Results (Barnes et al. 1993) showed that eddy correlation measurements of sensible and latent heat fluxes over the farm were very sensitive to wind speed. ET determined from Bowen Ratio energy balance data was not as sensitive to wind speed. Preliminary water balance calculations suggest that differences in ET can be linked primarily to crop type. This may be a result of both leaf area index (LAI) and stomatal conductance differences between the crops. However, it is also possible that the assumptions in the water balance calculations heavily biased the results since micrometeorological methods of determining ET did not show clearcut differences between crops. Effects of crop type, LAI, and synoptic weather patterns on energy balance components will be further explored using the full micrometeorological data set on 15 fields. Hydrologic modeling of the agricultural area is underway and results will be compared with data obtained from aircraft-mounted flux instruments (Doran et al. 1992).

We have also applied techniques to provide spatially-averaged flux and wind convergence measurements and relate these to cloud variability. Results are summarized in Porch et al. (1992, 1993) and Porch and Shaw (1993). These measurements covered scales of hundred of meters over a dry grassland with high heat flux. The 1991 experiment focused on comparisons of wind convergence measured by optical cross-wind sensors in a 200-m triangle and vertical velocities measured with a high frequency Doppler acoustic sounder (Coulter et al. 1992). These measurements showed that vertical velocities were highly correlated with convergence. Also, when wind blew from the predominant wind direction (southwest to west), net divergence and downward vertical velocities were observed. Since net vertical velocities (either up or down) imply a net advective flux, it is important to determine how convergence changes under the wider variety of wind conditions observed in 1991.

In 1992, a second triangle with 400-m legs was added using optical turbulence saturation resistant systems, and we determined the short-term effect of passing clouds on surface heat flux. Results showed first that path-averaged optical heat flux determination allowed much faster determination of heat fluxes than can be obtained from a tower. Passing cloud shadow effects could be defined with high temporal resolution using optical turbulence-based heat flux and turbulent energy dissipation over paths of 100 to 150 m. Second, convergence of the wind into two triangles defined by optical cross-wind sensors is relatively independent of scale between 200 and 400 m. Though we were unable to determine a land-use-induced daytime convergence in the dry grassland, we were able to detect smaller scale topographic effects that may at times stimulate or inhibit cloud formation. We also showed that net divergence and downward velocities observed the previous year under relatively high wind conditions were not observed under light wind conditions in 1992.

Modeling of Surface Fluxes Over SGP CART

In 1992, we hosted Mr. Dean Jordan, a DOE Global Climate Fellow from the U. of Wyoming, for a 3-month practicum. His presence at Los Alamos gave us the opportunity to address the issue of modeling surface fluxes (using RAMS, the Regional Atmospheric Modeling System) at the SGP CART site ahead of schedule. Our objectives were to 1) use data bases currently available, characterize the soils and vegetation with maximum detail, and enter the data into the ARC/INFO Geographic Information System (GIS) software (Environmental Systems Research Institute, Redlands, California); 2) aggregate the surface features at different scales; and 3) compare results from modeling experiments with the surface features aggregated at different scales, using a control simulation with uniform vegetation and soils as the baseline. We made progress toward completing the first two objectives, as well as performing initial runs comparing the results from a uniform surface parameterization to a scenario with soils and vegetation aggregated into a few classes at 16-km resolution (Jordan et al. 1993).

Soil texture classes, obtained from Soil Conservation Service maps for Kansas and Oklahoma, were aggregated to eight soil texture classes. Careful checking across state lines, and with county maps was required to obtain a satisfactory map that could be digitized and imported in the GIS. Dr. R. McMillan (Atmospheric Turbulence and Diffusion Division, National Oceanic and Atmospheric Administration) provided us with an Advanced Very High Resolution Radiometer (AVHRR) image processed to show vegetation classification. This classification was aggregated into just three vegetation types, crop/mixed farming, tall grass/ pasture, and mixed woodland, plus open water. Both soil and vegetation layers were aggregated to various scales using the ARC/INFO resident algorithm (Figure 1). The control model run was parameterized with uniform crop/ mixed farming and sandy loam soil.

Initial conditions for RAMS were established with dry soils (20% field capacity) on the summer solstice. Initial atmospheric conditions were horizontally uniform with a vertical temperature and moisture profile typical of summertime conditions. The model was run through 24-h diurnal cycles, with energy and moisture fluxes, air and soil temperatures, and winds being generated by local conditions.

Results showed that spatial variability in surface characteristics, particularly vegetation type, had a strong influence on atmospheric boundary layer processes. Maps of surface temperature showed a strong correspondence to vegetation type, with localized cool areas over woodland/ open water, in marked contrast to the uniform temperature fields in the control run. Analysis of the results of the model runs is still under way.

From exploring aggregation at difference scales, we found that features can be eliminated, depending on the scheme and scale used (Figure 1). These differences in surface characteristics are often the very ones that induce localized sharp gradients in surface heating. Thus, the method of aggregating surface features for studying the effects of surface variability on mesoscale circulation needs to be carefully assessed.

References

Barnes, F. J., W. Porch, S. Tarbox, K. E. Kunkel, R. Scott, W. A. Dugas, R. Hicks, P. Larson, and C. Riemann. 1993. Energy balance components of irrigated crops in North-Central Oregon, *Fourth Symposium on Global Change Studies*, American Meteorological Society Annual Meeting, January 17-22, 1993, Anaheim, California. American Meteorological Society, Boston, Massachusetts.

Barnes, F. J., K. E. Kunkel, W. Porch, D. Cooper, L. Hipps, and E. Swiatek. 1992. Variability of surface fluxes over a heterogeneous semi-arid grassland. American Meteorological Society Annual Meeting, *Third Symposium on Global Change Studies*, pp. 63-67, January 5-10, 1992, Atlanta, Georgia. American Meteorological Society, Boston, Massachusetts.

Coulter, R. L., W. Gao, P. J. Martin, J. D. Shannon, J. C. Doran, J. M. Hube, W. M. Shaw. 1992. Evolution of the lower planetary boundary layer over strongly contrasting surfaces. *3rd Symposium on Global Climate Change Studies*, American Meteorological Society Annual Meeting, Atlanta, Georgia, January 5-10, 1992. American Meteorological Society, Boston, Massachusetts.

Doran, J. C., F. J. Barnes, R. L. Coulter, T. L. Crawford, D. D. Baldocchi, D. R. Cook, D. Cooper, R. J. Dobosy, W. A. Dugas, L. Fritschen, R. L. Hart, R. Hicks. L. Hipps, J. M. Hubbe, W. Gao, R. R. Kirkham, K. E. Kunkel, T. J. Martin, T. J. Meyers, W. Porch, J. D. Shannon, W. J. Shaw,

E. Swiatek, and C. D. Whiteman. 1992. The Boardman Regional Flux Experiment. *Bull. Am. Met. Soc.* **73**(11):1785-96.

Jordan, D. N., F. J. Barnes, and J. E. Bossert. Influence of Surface Spatial Scale on Regional Atmospheric Fluxes. Abstract, Eighth Annual U.S. Landscape Ecology Symposium, April 1993. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Porch, W., F. Barnes, M. Buchwald, W. Clements, D. Cooper, C. Doran, J. Hubbe, W. Shaw, R. Coulter, T. Martin, and K. Kunkel. 1992. Spatially averaged heat flux convergence measurements at the ARM Regional Flux Experiment. *Third Symposium on Global Changes Studies*, pp. 125-131. American Meteorological Society Annual Meeting, January 5-10, 1992, Atlanta, Georgia. American Meteological Society, Boston, Massachusetts.

Porch, W., F. Barnes, M. Buchwald, J. Stephens, and J. Archuleta. 1993. Application of spatially averaging optical techniques to the study of short-term flux changes associated with clouds. *Fourth Symposium on Global Change Studies*, American Meteorological Society Annual Meeting, January 17-22, 1993, Anaheim, California. American Meteorological Society, Boston, Massachusetts.

Porch, W., and W. Shaw. 1993. Application of optical remote sensing to the study of surface fluxes related to cloud formation. Optical Remote Sensing of the Atmosphere, Sixth Topical meeting, Optical Society of America, Washington, D.C., March 8-12, 1993, Salt Lake City, Utah.

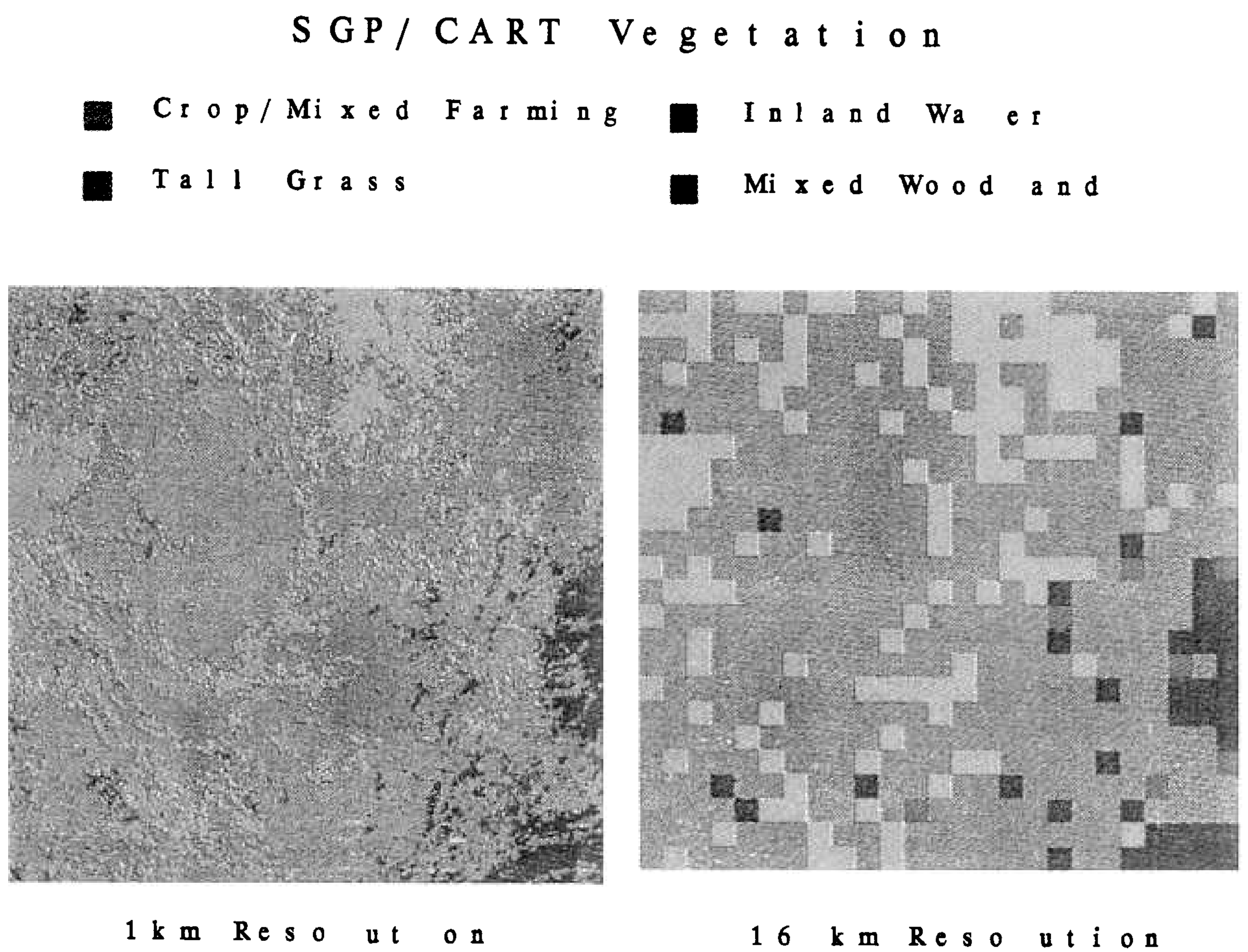

Figure 1. Vegetation classification at the SGP CART site, aggregated into three land use types, at 1-km and 16-km resolutions. Note differences in distribution and extent of inland water and woodland classes between the two scales of resolution.