Remote Sensing of Surface Fluxes Important to Cloud Development

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The lower boundary of the GCM (general circulation model) modeling domain, the earth's surface, exerts a strong influence on regional dynamics of heat and water vapor, and the heterogeneity in the surface features can be responsible for generating regional mesoscale circulation patterns. Changes in the surface vegetation due to anthropogenic activity can cause substantial changes in the ratio of sensible to latent heat flux and result in climate changes that may be irreversible. A broad variety of models for representing energy fluxes are in use, from individual leaf and canopy models to mesoscale atmospheric models and GCMs. Scaling-up a model is likely to result in significant errors, since biophysical responses often have nonlinear dependence on the abiotic environment. Thus, accurate and defensible methods for selecting measurement scales and modeling strategies are needed in the effort to improve GCMs.

There are few data sets that detail the fluxes, soil and vegetative characteristics, and topographic and landscape features over broad spatial and regional scales. Yet if we are to arrive at a functional average of the soil and vegetation properties over a GCM grid cell, such data sets of interrelating variables must be obtained in order to determine the appropriate scale for the measurements of these features at other sites and to estimate inherent variability and uncertainty in measurements made at different scales. Finally, to avoid the errors that are inherent in transferring across scales, a formulation of processes across a grid cell requires simplifications in modeling at larger scales that must be validated from detailed "bottom-up" mechanistic studies and bounded by sensitivity tests.

To address some of these issues in scaling and averaging of measurements, a collaborative field campaign was conducted in June 1991 by the DOE laboratories funded under the ARM program. We selected a site with two distinct regions where the sensible and latent heat fluxes would differ sharply and where each region was sufficiently extensive for full development of boundary layers and for utilizing aircraft-mounted instrument systems (Doran et al. 1992). The overall measurement transect (about 16-km long) at the site had adjoining irrigated and semi-desert rangeland sections that allowed the collaborating teams to conduct a variety of studies relating to the overall goals.

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

1. intercomparison of micrometeorological instrument performance
2. determination of fine-scale variability of surface fluxes over dry grassland and its relationship to surface soil moisture variability
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 height measurements

4. examination of variability in surface fluxes over the semi-arid grassland region and relationship to surface variability in vegetation and soils
5. Determination of evapotranspiration (ET) from water balance estimates of four crops in the agricultural area and comparison to micrometeorological measurements of ET.

Data analyses for items 1, 3, and 4 have been initiated and results to date are briefly summarized below. Completion of analyses and utilization of results from other collaborating laboratories will allow us to assess various averaging methods for determining fluxes over inhomogeneous terrain at different scales.

A qualitative survey of the rangeland site (Figure 1) showed that one grass and two shrub associations were most important in spatial coverage of the transect area in the north. The grassland areas were dominated by needle-and-thread (*Stipa comata*), a perennial bunchgrass. Site 2 was severely overgrazed and dominated by an annual grass, cheatgrass (*Bromus tectorum*), with needle-and-thread as a sub-dominant component. 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/m². The two shrub communities were dominated by either rabbitbrush (*Chrysothamnus nauseosus*) or bitterbrush (*Purshia tridentata*), with understories of needle-and-thread and/or cheatgrass.

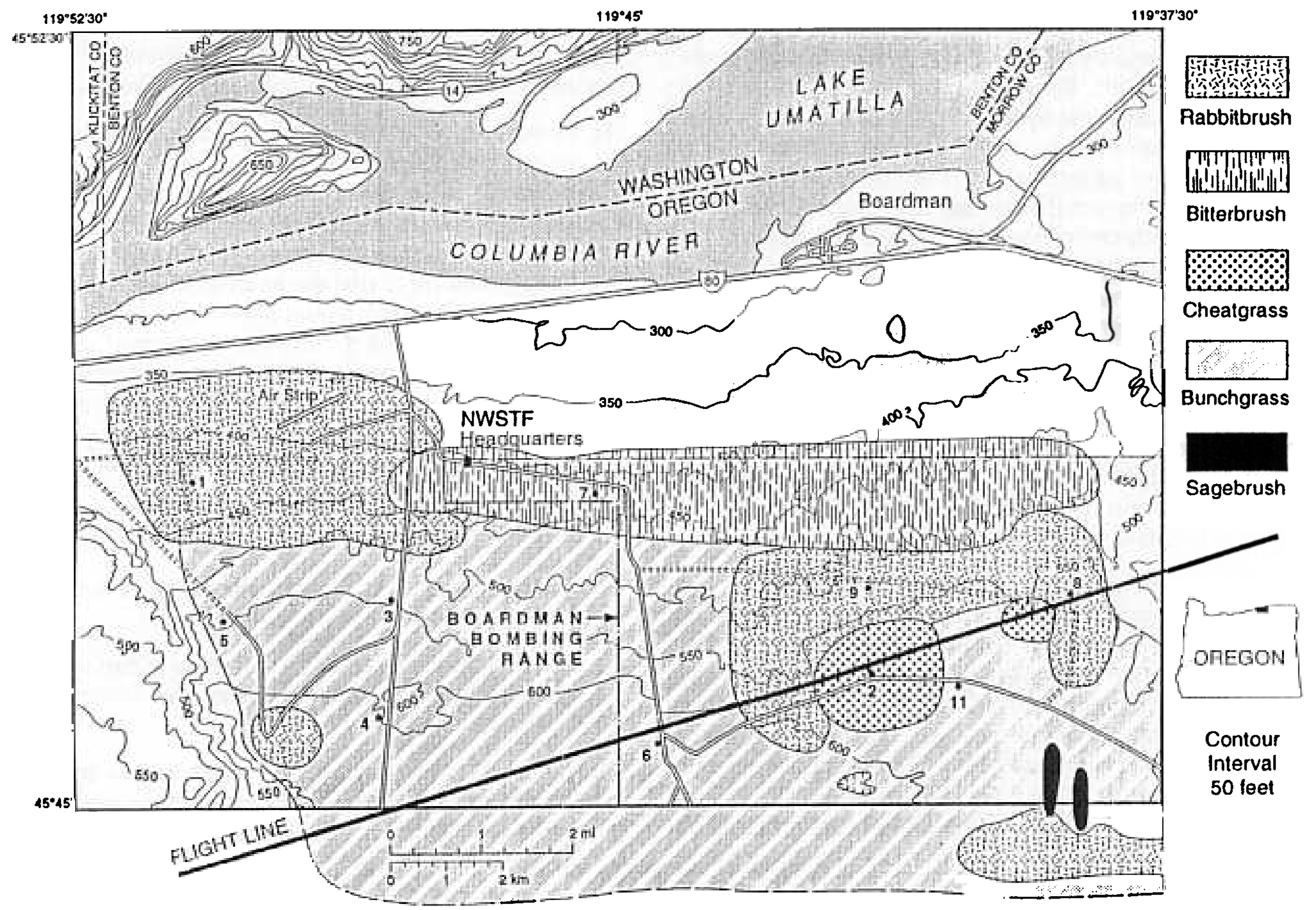

Figure 1. Rangeland site at Boardman, Oregon. Sites of flux stations are numbered.

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 heat and sensible heat fluxes were calculated for the shrub (four sites) and grass (five sites) communities; examples for four consecutive days are presented in Figure 2 (Barnes et al. 1992). Mean maximum daily sensible heat fluxes for both communities ranged from 270 to 450 W/m², and about 45 to 80 W/m² 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 depth (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. Other ecological factors that may be relevant to site differences are being examined.

In the grassland region (Site 2), a triangle of path-averaging optical anemometers was constructed (Figure 3). The optical turbulence used by these instruments to measure the path-average winds compared well with heat flux measurements during the convective portion of the day (Porch et al. 1992). The convective conditions were associated with heat fluxes above about 100 W/m².

Two types of optical cross-wind sensors were used along each leg of the triangle. One system, laser space averaging (LSA) system, used a visible HeNe laser beam. The other system, saturation resistant (SRU), used an infrared light emitting diode and larger optics and was subject to optical turbulence saturation on the warmer days. A weather

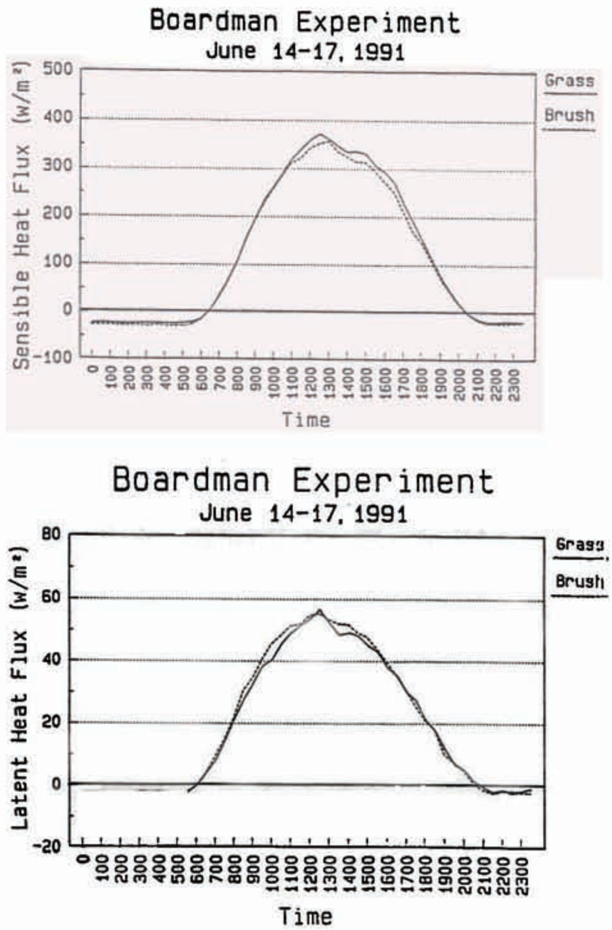

Figure 2. Mean sensible and latent heat fluxes over grass and shrub communities.

station cup vane anemometer was also located at each corner of the triangle (WSN).

These systems combine to provide three estimates of the triangle scale convergence. Figure 4 shows comparisons of these convergence estimates with vertical velocities (w) determined at a 35-m height from a high-frequency Doppler sodar (1-minute averages). On June 10, the winds were predominantly from the north, which is associated with positive wind components from the optical cross-wind sensors defining a northeast component (east path). On June 16, the wind direction was from the southwest, which gives negative wind components for the east path.

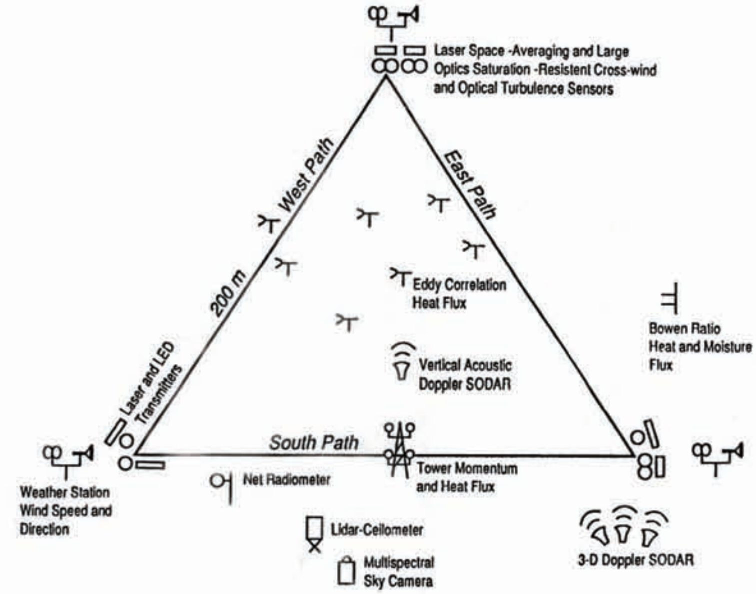

Figure 3. Instrument deployment at triangle of path-averaging optical anemometers at Site 2.

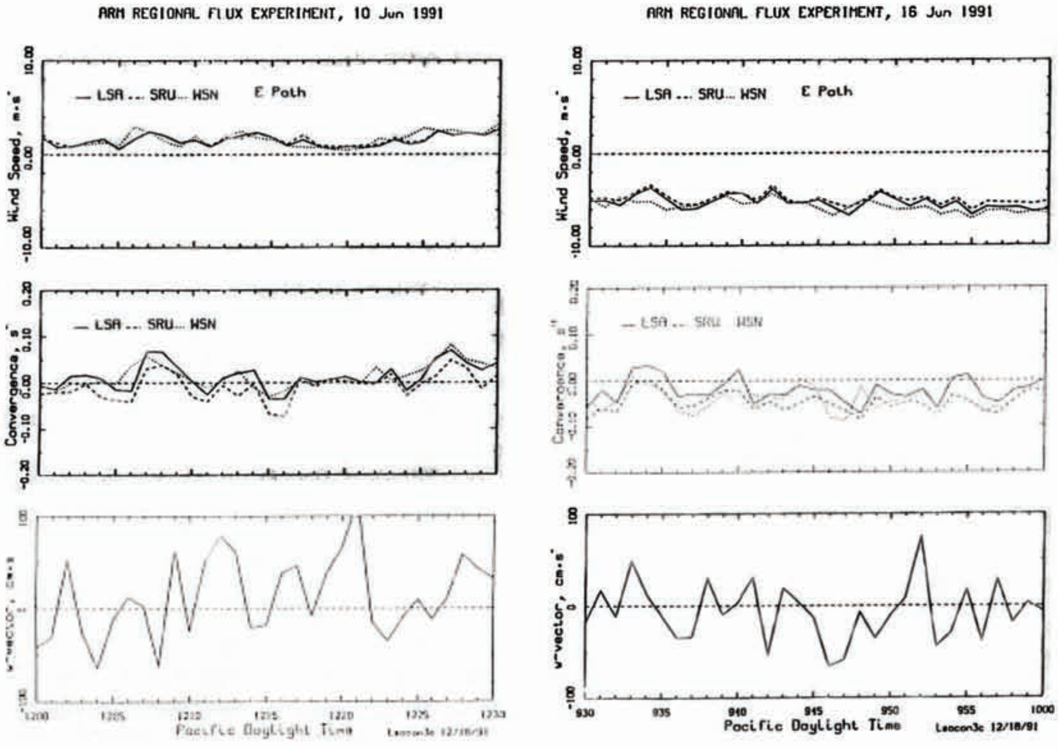

Figure 4. Comparison of convergence estimates with vertical velocities (w); LSA-HeNe laser system, SRU = saturation resistant system, WSN = weather station anemometer.

Comparison of the convergence and w for the two days shows an apparent effect of topography on the vertical component of the wind. The topography of the region slopes down to the Columbia River in the region with an aspect ratio of about 1%. Winds from the southwest (the predominant wind direction in the region) were associated with downward vertical velocities at the triangle and net divergence. The relationship between surface fluxes and fluxes measured by the aircraft is affected by vertical velocities between the surface and the aircraft. This relationship is different over a nonsloping surface with the same horizontal wind components. These measurements will aid in the interpretation of the effects of gentle topographic slopes on larger scale flux profiles needed for climate models.

As the analyses on all measurements taken over both farm and rangeland sites are completed, we will concentrate on evaluating averaging techniques for moving from point measurements to regional estimates of fluxes. Mesoscale models will be used to simulate the observations and to aid in designing measurement campaigns at future ARM sites.

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