The Boardman ARM Regional Flux Experiment

J. C. Doran
Pacific Northwest Laboratory
Richland, WA 99352

In June 1991, a field campaign was conducted to study the effects of sub-grid scale variability of surface sensible and latent heat fluxes on surface boundary layer properties and to provide data with which to address the problem of extrapolating from a limited number of local measurements to obtain areal-averaged values of fluxes appropriate for use in general circulation models (GCMs). Participants in the campaign included DOE's Argonne National Laboratory, Los Alamos National Laboratory, Pacific Northwest Laboratory, the National Oceanic and Atmospheric Administration's Atmospheric Turbulence and Diffusion Division, and several other collaborators.

We sought an experimental site in which surface fluxes of sensible and latent heat could be expected to differ sharply from one surface to another (with each surface of order 10 km in length) but would show relatively minor variations over any particular surface. With such a site, we hoped to see a clear signature of the effects of surface inhomogeneities, test one or more parametric schemes relating turbulent fluxes to vertical gradients of mean quantities, evaluate methods of measuring surface fluxes over inhomogeneous terrain, examine the variation of surface fluxes over a range of scales, and establish procedures for extrapolating flux values from smaller scales to larger ones.

The site chosen for the experiment was located near Boardman, in northeastern Oregon, and is shown schematically in Figure 1. A large, sagebrush steppe area

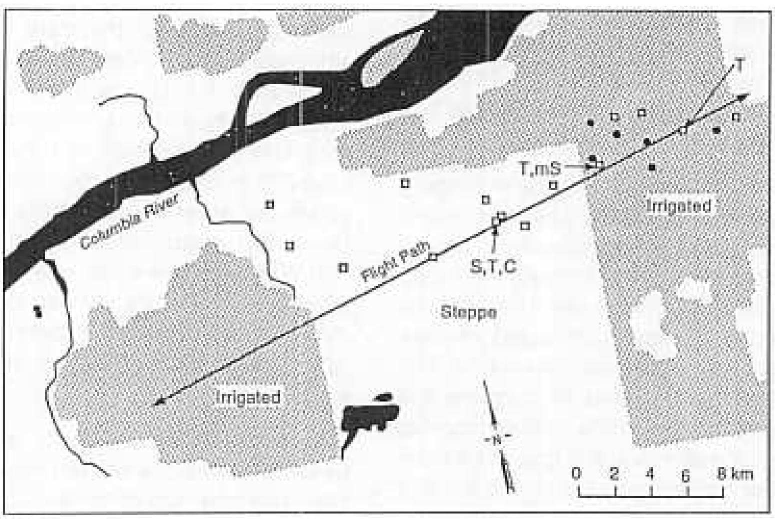

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Figure 1. Schematic Diagram of Experimental Area. Black areas are bodies of water, stippled areas are irrigated farmland, and the remaining area is steppe. Squares are eddy correlation instruments, circles are Bowen ratio energy balance stations, D denotes three-component Doppler sodar, T marks locations of tethered balloon launches, C is the location for the convergence measurements, and S shows location of mini-sodars for measurements of internal boundary-layer development. The primary flight path for the instrumented aircraft is also shown.

is bordered on the east, northeast, and west by extensive areas of irrigated farmland. The terrain is generally flat to gently rolling with a slight tilt toward higher elevations to the south. The prevailing winds are from the west southwest; such winds traverse extended areas of alternating warm, dry surfaces and cooler, wetter ones.

Surface fluxes of sensible and latent heat were measured using both eddy correlation instruments and Bowen ratio energy balance stations. Most of the eddy correlation instruments were also equipped with fast response UV or IR hygrometers. The steppe flux stations were distributed to sample conditions in the three primary steppe plant communities, while the farm sites were located on the downwind side of fields containing the principal crop types grown in the experimental area. Bowen ratio energy balance stations were located at six additional sites in the irrigated areas and one site in the steppe region. The locations of the various instruments are also shown in Figure 1. This distribution of flux measurements provided extensive coverage of both the semiarid and wetter regions over a path approximately 40-km long and 6-km wide.

A mobile flux platform (Crawford and Dobosy 1992) was flown on a single-engine aircraft during 91 hours of measurements over the course of the experiment. This instrument package enabled the aircraft to measure mean wind speed and direction, temperature, and humidity; turbulent fluctuations of wind speed, temperature, moisture, O_3, and CO_2; and ground radiating temperatures. The most common flight path was along the line of ground-based flux instruments shown in Figure 1.

At a steppe site, triangular arrays of laser space-averaging and large optic saturation resistant cross-wind and optical turbulence sensors were used to measure the index of refraction structure function C_n^2 and the spatially averaged horizontal wind speed across the optical path. The structure function provides a measure of the path averaged sensible heat flux for comparisons with point measurements. The spatially averaged winds can be used to measure the convergence or divergence of the winds in the triangular area bounded by the optical paths, and this quantity can be related to the presence of convective cells during the day or general subsidence at night. Another laser anemometer array was located near the dry-wet transition zone at a height of 3 m and with path lengths of several hundred meters. One path was entirely over a corn field, a second was over a potato field, and a third spanned portions of both fields, with approximately equal lengths in each field. This arrangement provided a combination of measurements of line averages of heat fluxes over separated crops as well as an integrated value over two crops.

Because the temperature structure parameter C_T^2 is principally determined by the surface sensible heat flux and the height above the surface, differences in area-averaged fluxes should result in changes in the shape of the vertical profile as it "sees" larger and larger scales. To this end, vertical profiles of C_T^2 were determined by five sodars and minisodars located within neighboring surface types characterized by different moisture and vegetation.

On five days, tethered balloons were flown at three sites to record vertical profiles of wind speed and direction and wet and dry bulb temperatures to altitudes of ~1 km. The sites were a steppe site, a farm site approximately 800 m east of the boundary between the steppe and farmland, and a second farm site approximately 6.5 km east of the boundary. For westerly winds, this provided an opportunity to sample a relatively deep boundary layer characteristic of conditions over semiarid terrain; a boundary layer strongly modified by flow over cooler, wetter surfaces; and a transition zone between these two conditions.

Although data processing and analysis are still in a relatively early stage, it is possible to make some general observations about the data that were collected. The anticipated differences in the sensible and latent heat fluxes over the steppe and farmland were readily discerned by both the ground and airborne instruments. Maximum daily sensible heat fluxes over the steppe ranged from 275 to nearly 500 m², while latent heat maxima were nearly an order of magnitude lower. Over the irrigated farmland, measured latent heat fluxes reached as high as 600 W/m², with sensible heat fluxes on the order of 100-200 W/m². Figure 2 shows an example of fluxes measured during a two-day period over a steppe site and over a wheat field; the differences in flux characteristics are evident.

Differences in the mean as well as turbulent variables between the steppe and farmland areas were also discernible. Surface radiating temperatures showed marked changes of 20 K or more, and air temperature and moisture differences were found as well. It may be possible to detect thermally induced circulation patterns from the aircraft data during periods of lower wind speeds,

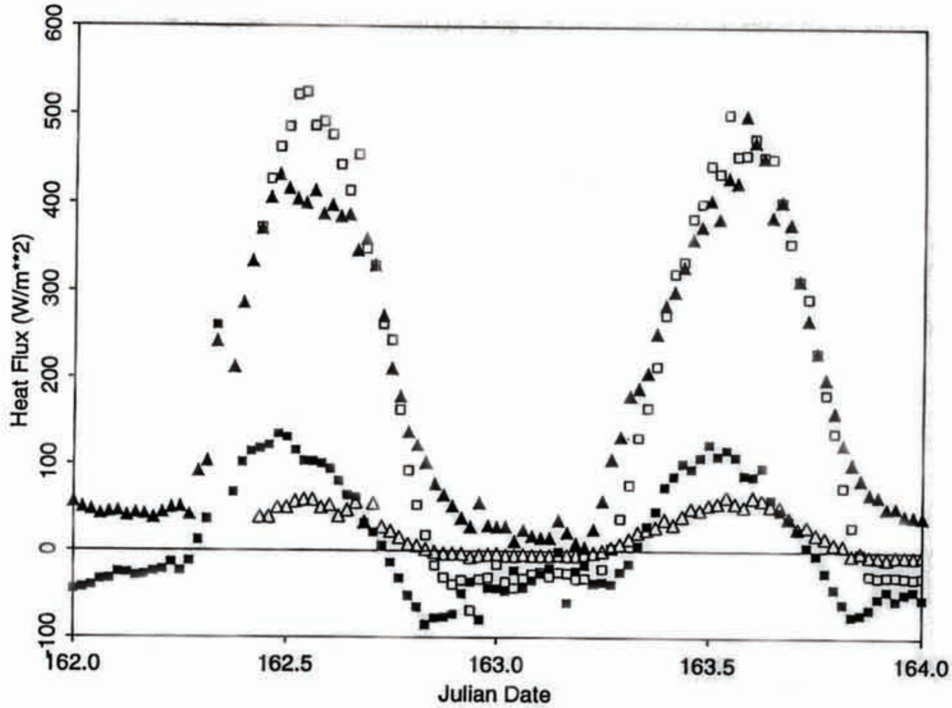

Figure 2. Sensible and latent heat fluxes over steppe and irrigated wheat field for 11-12 June 1991. Open symbols are values for steppe and filled symbols for farmland. Squares denote sensible heat values; triangles indicate latent heat values.

particularly at low flight altitudes. There is some limited evidence for a tendency to form a "farm breeze" from the cooler, irrigated area toward the steppe. We hope to be able to evaluate the relationships between measured surface fluxes over an area and the area-averaged vertical gradients in wind speed and temperature that have been used in GCMs to estimate these fluxes.

Reference

Crawford, T. L., and R. J. Dobosy. 1992. A Sensitive Fast-Response Probe to Measure Turbulence and Heat Flux from Any Airplane. *Boundary-Layer Meteorology 59:257-278.*