3.6 Evolution of the Lower Planetary Boundary Layer over Strongly Contrasting Surfaces

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INTRODUCTION

In a multilaboratory field study held near Boardman in northeastern Oregon in June 1991 and described in greater detail elsewhere (Doran et al., 1991), various properties of the surface and lower atmospheric boundary layer over heavily irrigated cropland and adjacent desert steppe were investigated in the initial campaign of the Atmospheric Radiation Measurement (ARM) program of the U.S. Department of Energy. The locale was selected because its disparate characteristics over various spatial scales stress the ability of general circulation models (GCMs) to describe lower boundary conditions, particularly across the discontinuity between desert (in which turbulent flux of heat must be primarily as sensible heat) and large irrigated tracts (in which turbulent flux of latent heat should be the larger term). This campaign of ARM seeks to increase knowledge in three critical areas: (1) determination of the relationships between surface heat fluxes measured over multiple scales and the controlling surface parameters within each scale, (2) integration of local and nearly local heat flux estimates to produce estimates appropriate for GCM grid cells of 100-200 km horizontal dimension, and (3) characterization of the growth and development of the atmospheric boundary layer near transitions between surfaces with strongly contrasting moisture availabilities. Although data analysis is still in a preliminary stage, some early results for some components of the experiment are of interest to the research community studying global climate change.

SITE DESCRIPTION AND SAMPLING LOCATIONS

The agricultural fields, irrigated by linear sprinkling systems rotating around a central pivot, are circular and about 800 m in diameter. A typical rotation rate is about 12 deg/hr, but irrigation is not continuous, as the farming company makes daily decisions about sprinkling on the basis of crop stage and ambient conditions. Potatoes, alfalfa, corn, and wheat are the dominant crops. Each circular field is essentially a homogeneous surface except for a bare sand road about 3 m wide leading to the pivot; wider sand roads encircle each field. The offset "cookie-cutter" arrangement of the circular fields leaves concave triangular areas of unused land, which tend to have vegetation similar to that of the desert but somewhat taller because the desert is grazed in the early spring. Overall, more than 10% of the agricultural area is uncultivated.

Surface and boundary layer properties over fields of corn and potatoes were intensively studied in the investigation component described here; the fields were located at the western or prevailing upwind edge of the farm. A layout of the intensive measurement area (known as site K in the overall experiment) is shown in Figure 1. Five sodars and minisodars were aligned across neighboring surface types (corn, wheat, irrigation byefflers) to measure availability and vegetative cover. One of the minisodars was designed for easy portability, and alternate locations are shown in the potato field and in the desert. The desert location where the rover minisodar was sometimes located is not drawn to scale, as it was 6-7 km from the core minisodar operations. Alternate locations are also shown for a three-axis minisodar system, which was operated as a row of three single-axis minisodars (vertical) in this ARM experiment. Three laser anemometers were operated essentially continuously in the potatoes, in the corn, and across their junction; the paths used during most of the experiment are shown in Figure 1. The paths are not precisely parallel because of the need to avoid a Bowen ratio station located in the potatoes and the desirability of orientation along radii from the sprinkler pivots to minimize down time during sprinkler passage. The central path was about 20% longer than the other paths because the laser transmitter and receiver, each atop poles of about 2.5 m, had to be located where the tires and sprinkler heads of the rotating irrigation system would not contact the instruments and the supporting guy wires. The laser equipment was normally bagged for 1-2 hr protection from spray during passage of the sprinklers. Other supporting instrument systems included (1) three tethersondes aligned along the prevailing wind (WSW) at sites in the desert, about 800 m into the irrigated area; and in the middle of the irrigated area (not shown); (2) a 12-m eddy correlation tower 800 m into the irrigated area; and (3) multiple levels of the not shown in the desert and in various irrigated fields, including the potato field investigated here.
RESULTS

Meteorological conditions during the three weeks of the field study were less than ideal for the experimental goals and plans. Tethersonde sites and minisodars were aligned along the normally prevailing flow (WSW) and the laser anemometer paths were oriented approximately normal to the expected flow. However, the WSW flow tended to be stronger than feasible for tethersonde operations (Doran et al., 1991), particularly over the desert. In addition, extensive cloudiness, virga and even light rain were more frequent than expected for a desert steppe; the reduction in heat loading to the surface by solar radiation on those occasions reduced the contrasts in turbulent heat exchanges over different surfaces.

One of the more revealing descriptors of the effects of contrasting surface characteristics is the vertical profile of the temperature structure parameter \( \left(C_T^2\right) \). \( C_T^2 \) is principally a function of the surface sensible heat flux \( H \) and the height above the surface. The near-surface portion of the profile is characteristic of \( H \) on the local scale, while higher portions of the profile reflect the average \( H \) over a larger area. It is hoped that the effect of averaging \( H \) over surfaces with very different typical values of \( H \) will produce a unique profile that will provide insight into the averaging process. The vertical profiles of \( C_T^2 \) derived from analysis of the acoustic signals reveal boundary layer growth and development, temporally through their individual evolutions and spatially along the vertical cross section produced from the aligned profiles.

Although analysis is still quite preliminary, selected cases reveal some interesting effects. On 18 June, surface winds were light and variable from SE through NE, with NNE winds aloft. Skies were overcast, primarily from cirrus. The rover minisodar was operating in the desert and was thus somewhat downwind of the irrigated area. The tethersonde at site K near the western edge of the irrigated area was operated, but the tethersonde in the desert was not. Results from the site K tethersonde runs at approximately 0800 and 1200 PDT are shown in Figures 2 and 3. Amplitudes of the acoustic signal returns, as yet unscaled to produce \( C_T^2 \) values, for the rover minisodar and a site K minisodar for approximately the same times are shown in Figures 4 and 5. At 0800, shallow inversions around 40 m and around 220 m were evident in the tethersonde profile. The site K minisodar signal exhibited structure there as well, reflecting turbulent exchange in the entrainment zones. The lower entrainment zone in the desert minisodar return was about twice as high and weaker. At 1200 a weak isothermal layer was apparent at about 60-80 m, with a stronger inversion around 190-210 m. The lower structure
Fig. 2: Results of the tethersonde run at 0800 PDT on 18 June 1991 at site K.

Fig. 3: Results of the tethersonde run at 1200 PDT on 18 June 1991 at site K.
Fig. 4: Amplitude of the acoustic signal returns from minisodars in the potato field (asterisks) and in the desert (squares) for 0800 PDT on 18 June 1991.

Fig. 5: Amplitude of the acoustic signal returns from minisodars in the potato field (asterisks) and in the desert (squares) for 1200 PDT on 18 June 1991.
was apparent in the minisodar signal at site K, but not in the desert; both sites reflected structure around 200 m.

Line averages of index of refraction structure function $CN^2$ over contrasting surfaces were produced through scintillation measurements with the laser anemometers over paths approximately 200 m long and 2 to 3 m high in corn, potatoes, and across the corn/potato interface. The variations in the path heights resulted from the slightly rolling surface of the fields. $CT^2$ and $H$ are related to $CN^2$, although the relationship is better understood for near neutral conditions or for a dry, unstable boundary layer (Wyngaard and Clifford, 1978) than for other conditions. The potato field was irrigated more regularly than was the corn field during the experiment, and the effective leaf area index of the potatoes was much greater. In addition, cool weather slowed the growth rate of the corn. One would thus anticipate that latent heat flux would be relatively more important (or sensible heat flux would be relatively less important) for the potato field than for the corn field. Indeed, the $CN^2$ values from the laser anemometer path in the potatoes were regularly less than from the path in the corn. The path across both crops usually indicated an intermediate value of $CN^2$, but analysis and understanding are complicated because the path included a dry, bare segment (the boundary road) of about 10 m between the fields. A plot of the laser anemometer signal variance for 18 June, not yet converted to $CN^2$, is given in Figure 6. Only the potato path laser operated during the night, and all lasers were shut down briefly before 0800 because of sprinkler operations. The laser variance for the corn path is markedly greater, while the variance for the mixed path laser variance is similar to but is generally greater than the variance for the potato path. The large changes in typical variance values are probably due to the periodic passage of layers of altocumulus and altostratus clouds that reduced the intensity of short-wave radiation received at the surface.

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**REFERENCES**


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