1.4 High Resolution Lidar Evaporative Fluxes Over Corn and Soybean Crops in Central Iowa During SMACEX

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Introduction

The Soil Moisture-Atmosphere Coupling Experiment (SMACEX) was conducted in the Walnut Creek Watershed near Ames, Iowa over the period from June 15-July 11, 2002. A main focus of SMACEX is the investigation of the interactions between the atmospheric boundary layer, surface moisture and the vegetative state. The Los Alamos Raman Lidar collected data over fields of soybeans and corn, with mutually supporting measurements by the NRC Twin Otter atmospheric research aircraft, the Utah State University Piper Seneca remote sensing aircraft, two elastic Lidars, and an array of eddy covariance towers in the nearby fields. The aircraft and lidar provide a high resolution mapping of the evaporation rate over the fields and the changes between them. Figure 1 is an aerial photograph of the site taken during a period with little or no vegetation. It can be seen that the site is not uniform, the lighter area of the photograph being slightly higher in elevation (and thus dryer) than the surrounding areas. The effect of the surface variability on the evaporative fluxes remains to be seen. The effect of a growing canopy that eventually covers the region with a leaf area index of 3 or more on the spatial variability will also be examined.

During the field campaign, the lidar operated daily during daylight hours. During the first 2-1/2 weeks of the experiment, there were no precipitation events in the project area. Nevertheless, there was vigorous growth by the dominant crops of corn and soybeans, creating large changes in surface roughness and in the canopy contribution to evapotranspiration. This presentation will provide a mapping of the evaporative fluxes that existed during the field campaign, with a comparison to the topology of the local area. The comparison will be made over an extended dry-down period as the corn grew rapidly.

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The typical maximum horizontal range for the lidar is approximately 700 meters when scanning, with a corresponding spatial resolution of 1.5 meters over that distance. The upper scanning mirror allows three dimensional scanning in 360 degrees in azimuth and ±22 degrees in elevation. The uncertainty in the water vapor mixing ratio is typically measured to be less than 4%. Details of the instrument, data collection, and determination of water concentration may be found in Eichinger et al. [1999].

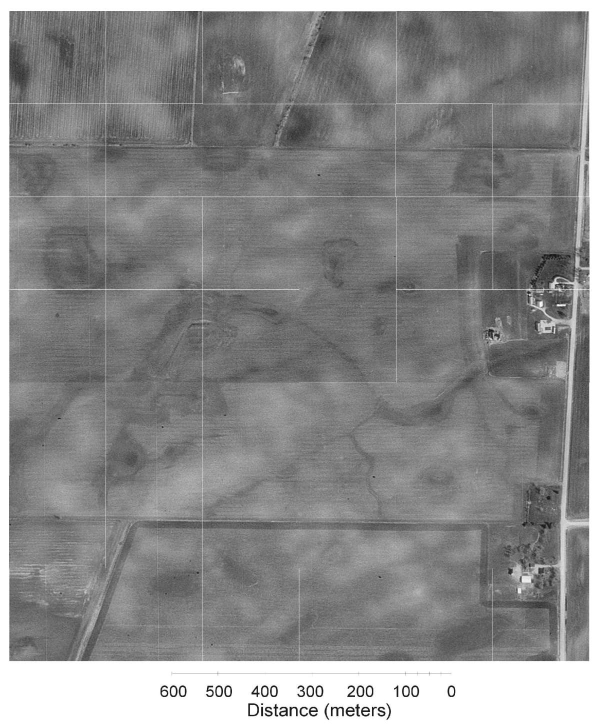

Figure 1: A composite of aerial photos of the fields in the vicinity of the lidar site.

Lidar Derived Flux Method

High-resolution water vapor concentrations from the lidar will be processed to determine the spatially resolved evapotranspiration rate [Eichinger et al. 2001]. The water vapor concentration in the vertical direction can be described using Monin-Obukov Similarity Method (MOM) [Brutsaert, 1982]. With this theory, the relationships between the properties at the surface and the water vapor concentration at some height, z, within the inner region of the boundary layer is:

$$q_s - q(z) = \frac{E}{L_e k u_* \rho}\left[\ln\left(\frac{z}{z_{ov}}\right) + \psi_v\left(\frac{z}{L}\right)\right] \quad (1$$

where the Monin-Obukhov length, L, is defined as:

$$L = -\frac{\rho\ u_*^{\,3}}{kg\left[\dfrac{H}{Tc_p} + 0.61\,E\right]} \quad (2)$$

z_{0v} is the roughness length for water vapor, q_s and T are the surface specific humidity and temperature, q(z) is the specific humidity at height z, H is the sensible heat flux, E is the latent heat flux, O is the density of the air, L_e is the latent heat of evaporation for water, and u_* is the friction velocity [Brutsaert, 1982], k is the von Karman constant, taken as 0.40, and g is the acceleration due to gravity. O_v is the Monin-Obukhov similarity function for water vapor and is calculated as:

$$\psi_v\left(\frac{z}{L}\right) = 2\ln\left[\frac{(1 + x^2)}{(1 + x_{ov}^2)}\right] \quad (3)$$

where :

$$x = \left(1 - 16\frac{z}{L}\right)^{1/4} \quad (4)$$

for unstable conditions, and where x_{ov} represents the function x calculated for the value of z_{ov}. These relations are valid in the inner region of the boundary layer where the atmosphere reacts directly to the surface. This region is limited to an area between the roughness sublayer (the region directly above the roughness elements) and below five to thirty meters above the surface (where the passive scalars are semi-logarithmic with height). The vertical range of this layer is highly dependent upon the local conditions. The top of this region can be readily identified by a departure from the logarithmic profile near the surface.

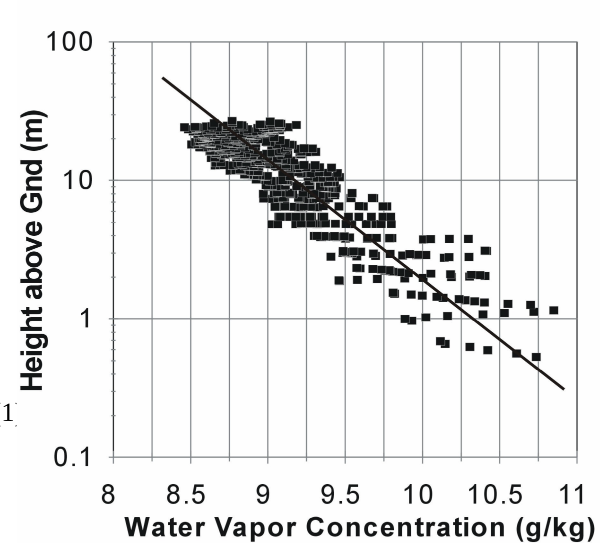

Figure 2: The profile of water vapor concentration with height taken from the vertical scan shown in figure 3. The data is taken between 225 to 250 m from the lidar.

Figure 2 is an example of a water vapor profile with a logarithmic fit during a period of strong convection showing a logarithmic relationship at least to 25 meters above the surface. Suggestions have been made that the atmosphere is also logarithmic to higher levels and may integrate fluxes over large areas [Brutsaert, 1998].

The method rearranges (1) into a linear form

$$q(z) = -Mz' + c \quad (5)$$

where M is the slope of the fitted function (M = E /(L_e k u_*O)), z' is a reduced height parameter [z' = ln(z-d_o) - O_v((z-d_o)/L)], and c is a regression constant (c = Mln(z_o) + q_s). Measurements for the slope are made based upon a least squares fit to several hundred measurements of water vapor concentration. Having determined M from the slope of the fitted line, the flux is then

$$E = L_e\ M\ k\ u_*\ \rho \quad (6)$$

where u_* and L are obtained from local measurements.

The flux estimation method used assumes that in some region, taken for this experiment to be 25 meters in size, the slope of the water vapor concentration in the z direction can be determined from a curve fit using all of the measurements of the water vapor concentration above that region. This assumes horizontal homogeneity inside the region and with the region immediately upwind, that the aggregate of the values constitutes a measurement of the average condition over the region, and that the slope in water

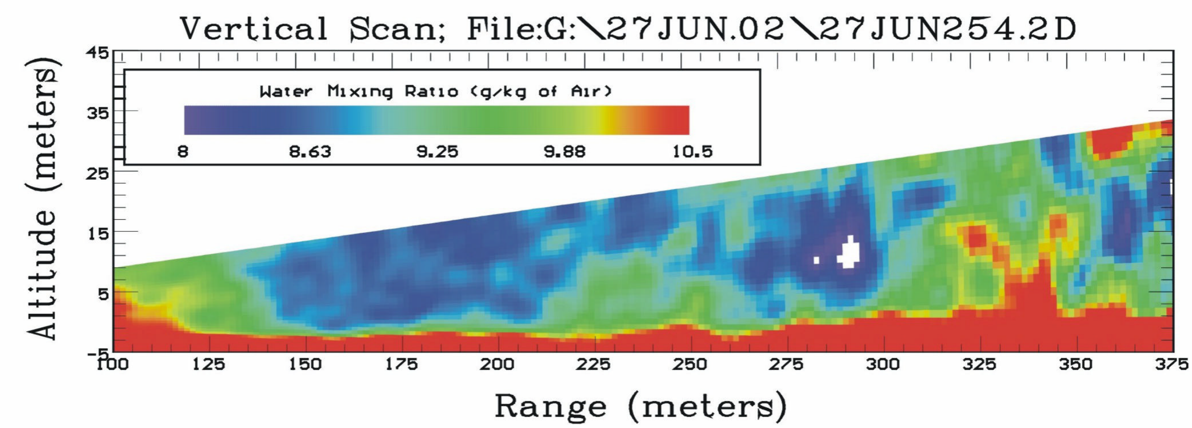

Figure 3: A vertical scan showing the water vapor concentration in a vertical plane above the corn canopy. The day is strongly convective.

vapor concentration is the result of conditions inside that region. The analysis methodology described above is executed along each azimuth angle for each incremental distance.   Within each 25 meter cell, all of the data values are averaged. From these 25 meter cells, a contour map is made from the data.

Most of the previous work to obtain evaporative fluxes from the lidar was done over sites that were level and in which the geometry between the lidar and the canopy top was well known. Thus the sites were ideal in that they were horizontally homogeneous, but also in that the height of a particular lidar measurement above the canopy was easily and well determined. Thus it would be expected that this technique should reproduce fluxes as measured by other techniques. Gradient methods for determining fluxes are well established [Stull, 1988, Brutsaert, 1982]. The lidar method is unique in that it uses a large number of measurements to determine the vertical water vapor gradient. The extension of the method to rough terrain presents issues relating to assumptions of horizontal homogeneity as well as the determination of the surface location (with respect to the lidar) and the direction of the normal to the surface.

Figure 3 is a typical scan from the Raman lidar showing the water vapor concentration in one vertical plane at the SMEX site. The intense red color at the bottom is a result of the attenuation of the laser beam by the ground, bushes, or trees and by the fluorescence of the organic compounds in the canopy. The attenuation of the laser beam reduces the intensity of the nitrogen and water vapor signals, but fluorescence increases the intensity of the water vapor signal at 273 nm relative to the nitrogen signal at 263 nm. Since the water vapor concentration is found from the ratio of the two signals, the algorithm produces an apparent large water concentration inside plant canopies. While the values are spurious, they are useful in identifying the canopy surfaces.

For this experiment, the lidar had a nominal 1.5 meter range resolution. In other words, at every 1.5 meters along each of the lidar lines of sight that make up figure 3, a measurement of the water vapor concentration was made. Each of these measurements is used to build up a two dimensional plot of water vapor concentration. The SMACEX site is far from ideal in the sense that it is not horizontally homogeneous and the height above the canopy of a given measurement varies considerably and is not dependent upon geometry alone.

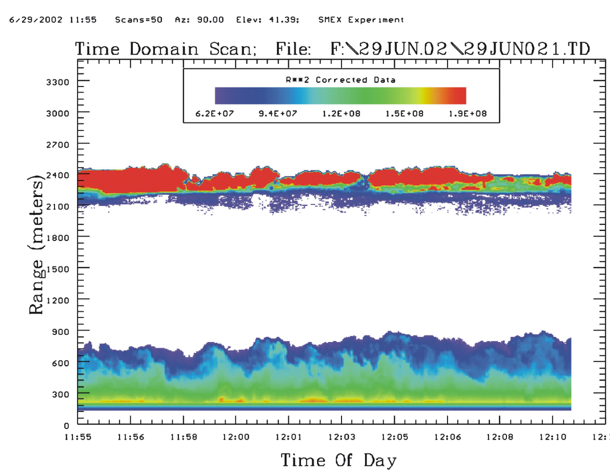

Figure 4: A plot showing the variations in the height of the boundary layer with time. The plot covers a period of about 15 minutes near noon.

The goal is to examine the response of the atmosphere to the change in surface roughness and canopy over time. The degree to which the canopy will decrease the spatial variability of evaporation is an indicator of the relative contributions of canopy and soil moisture/type. To further investigate land surface-atmosphere coupling, data from the elastic lidars can give information on the response of the atmosphere over the region. The depth of the boundary layer and entrainment zone are indicators of the surface heat fluxes. From the scanning lidar, these can be measured in great detail as a function of distance from the lidar out to about 5 km. Figure 4 is an example of the boundary layer height with time over the lidar site.

Between the lidar and other remote sensors, the range of spatial and temporal scales necessary to investigate the local impact of landscape heterogeneity is well measured.

References

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