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Scaling surface energy fluxes in a tall-grass prairie using large aperture scintillometer and MODIS data

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1. Introduction

Satellite remote sensing has been used to examine the cycling of mass and energy fluxes many times in the past. The primary problem with the comparison has always been the issue of validation of the fluxes derived from satellite platforms (Brunsell and Gillies, 2003). In recent years, the use of a large aperture scintillometer (LAS) has become a viable technique for directly measuring the sensible heat flux (H) at scales directly comparable to the satellite pixel.

We examine issues related to the use of the Moderate Resolution Imaging Spectroradiometer (MODIS) for determining water and heat fluxes in an ungrazed, annually burned tall grass prairie in at the Rannells Flint Hill Prairie Preserve Ameriflux site in Northeastern Kansas (Figure 1). We examine the impact of spatial variability in topography, moisture, surface vegetation and surface temperature on the determination of fluxes with MODIS. In addition, we investigate the representativeness of the eddy covariance measurements collected on top of a ridge compared to LAS measurements which includes flux contributions from an area of lower topography which has implications for the use of the Ameriflux network for validation of satellite derived fluxes.

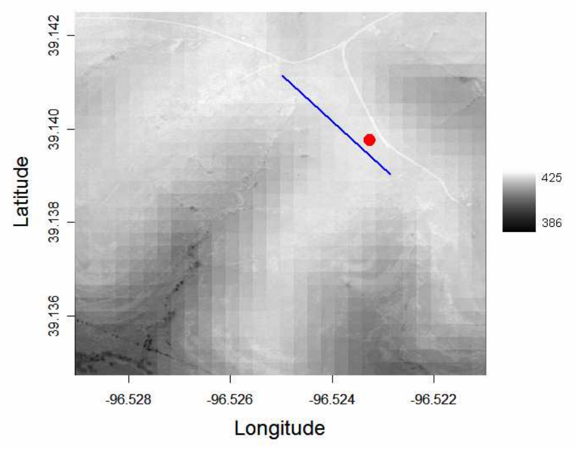

Figure 1. Digital orthophoto overlaid on digital elevation grid of the Rannells Ranch ungrazed Ameriflux site showing path length of the LAS shown (line), and eddy covariance station (point).

2. Field measurements

The Rannells site is approximately 5 km from Manhattan, Kansas and consists primarily of C4 grasses. The transmitter and receiver of the LAS are separated by approximately 300 m such that the path is perpendicular to the average wind direction. The LAS measures intensity fluctuations in the near infrared (880 nm). These fluctuations are due to changes in the refractive index of the atmosphere caused by turbulent eddies (Hill, 1992). The structure parameter for refractive index (C_n^2) can be related to the structure parameter for temperature (C_T^2). Assuming Monin-Obukhov theory applies, H can be derived. Therefore, the LAS gives us a spatially integrated H over the path length.

Figure 2 presents a comparison of the LAS and eddy covariance H measurements against the available energy measured at the eddy covariance tower for DOY 229-241 in 2005. At large values of available energy, the LAS results in a lower value of H. This is possibly due to variations in the footprints between the two measurements, and thus would represent the impact of spatially variable topography, soil moisture, vegetation as well as other

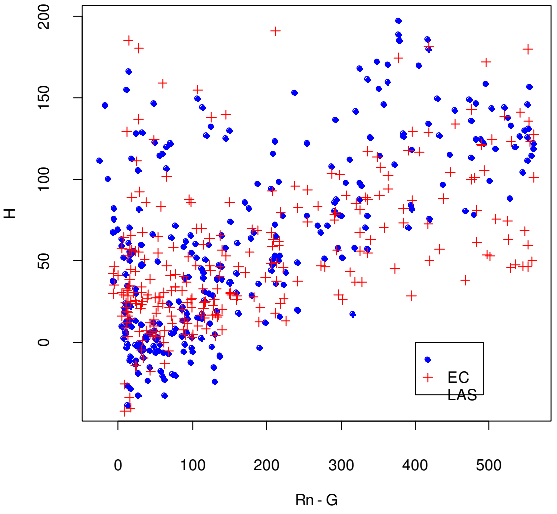

Figure 2. LAS and eddy covariance measurements of sensible heat flux as a function of available energy (Rn –G).

parameters.

3.0 Model and MODIS estimates

In order to determine water and energy fluxes from satellites, a modeling approach is necessary. Here, we use the 'triangle method' (Gillies et al., 1997) which relates the joint distribution of spatially variable fractional vegetation (Fr, derived from the NDVI) and surface temperature (Ts) to the fluxes. The assumption is made that the triangular shape (Figure 3) observed in Ts-Fr space is due to spatial variability in near surface soil moisture. This allows a physically based Soil-Vegetation-Atmosphere Transfer (SVAT) model to be iterated over all possible soil moisture (0-100%) and fractional vegetation (0-100%). The fluxes are determined via a regression between Fr, model output Ts and fluxes:

$$F_x = \sum_{i=0}^{3} \sum_{j=0}^{3} a_{i,j} Fr^i Ts^j$$

where F_x is the desired flux (sensible, latent, etc.) and a are the regression coefficients.

The SVAT model is a fully coupled surface-atmospheric boundary layer model that allows us to investigate the impact of surface heterogeneity. Combined with the remote sensing measurements, we have a framework for assessing the impact of various model assumptions on the spatially distributed fluxes. With the use of the LAS we can now 'validate' the fluxes and presumably the appropriateness of the assumptions.

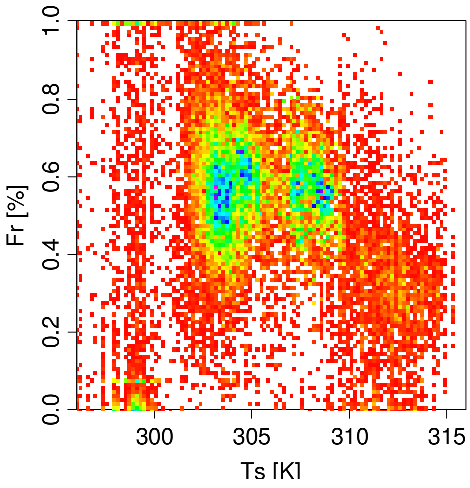

Figure 3. Joint density plot of surface temperature and fractional vegetation for Northeastern Kanas (DOY 229-241, 2005).

4. Results

One issue that can be examined is the assumption of horizontally flat surface. The variation in topography is probably the cause of disagreement between the eddy covariance and LAS measurements, and in order to determine the impact of assuming a flat pixel we model the diurnal cycle in the pixel and compare the results to the LAS. At the time of the satellite overpass, fluxes agree very well, but the overall correlation for the day is 0.7. This indicates that the ability to accurately simulate fluxes at the time of overpass does not correspond to accurate determination throughout the day.

A second issue that can be investigated is the use of temporally composited remote sensing data for estimation of fluxes. Maximum compositing of NDVI data is commonly performed in order to minimize the impacts of clouds. However, since the flux determination requires both vegetation and surface temperature data, the issue becomes the significance of a temporally composited radiometric temperature. As an example consider the following. NDVI was composited for 10 days using a maximum composite and the temperature is composited using the same overpass as the one that gives the maximum NDVI. This preserves the coupling between temperature and vegetation. However, the overall impact is to decrease the spatial variance in both fields, biasing towards higher NDVI and lower temperature measurements. Since the triangle method relates the joint variability in temperature and vegetation to the fluxes, the changes in input distributions impacts the fluxes as seen in Figure 4. Therefore, we recommend

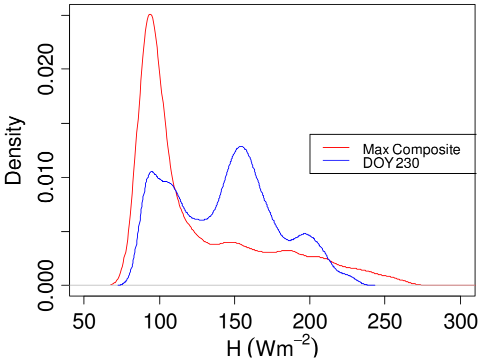

Figure 4. Impact of using temporally composited NDVI and Ts data on sensible heat flux (H).

avoiding temporally composited data for flux determination.

5. Conclusions

Through a combination of surface measurements, physically based modeling and remote sensing we are able to ascertain the spatial and temporal variability of land surface processes. We demonstrate that the location bias of eddy covariance towers (Schmid and Lloyd, 1999) has a direct impact on the ability to validate satellite remote sensing estimates of pixel scale fluxes. In addition, minor variability in topography, soil moisture and other controls also have significant impacts on the determination of areally averaged surface energy fluxes. This variation must be taken into account in order to truly determine spatially distributed fluxes with remote sensing.

6. References

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