Snow, Shrubs, Grasses, and Footprint Theory: Measuring Moisture and Energy Fluxes in Patchy Landscapes

J. E. Strack[1], G. E. Liston[1], C. A. Hiemstra[1], R. A. Pielke Sr.[1], and L. Mahrt[2]

[1]Department of Atmospheric Science, Colorado State University, Fort Collins, CO 80523-1371

[2]College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR 97331-5503

jstrack@atmos.colostate.edu

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1. Introduction

Shrublands cover a large fraction of western North America and are often partially masked by snow during the winter months. Due to the prevalence of this landscape it is important for weather and climate models to accurately simulate the exchange of energy between snow-covered shrublands and the atmosphere. In this study we test the ability of a modified version of the LEAF-2 (Land Ecosystem-Atmosphere Exchange Feedback) model (Walko et al. 2000) to simulate sensible and latent heat fluxes from a snow-covered mixture of shrubs and grass at North Park Colorado. The fluxes computed by the model using similarity theory are compared to those measured by tower-mounted eddy-covariance instruments that were installed at North Park during the 2002/2003 winter for the FLuxes Over Snow Surfaces (FLOSS) project.

When measuring sensible and latent heat flux from a tower within a heterogeneous landscape, one must consider which part of the landscape influences the flux sampled by the instruments. This variable landscape fraction, known as a footprint, is dependent upon wind direction, wind speed and atmospheric stability (thermal and mechanical). In this study we use a very simple footprint formulation, based only on wind direction, to estimate the upwind area sensed by the tower-mounted eddy-covariance instruments. The modified version of LEAF-2 is then used to simulate the fluxes of sensible and latent heat from this footprint, and the results are compared to those observed by the tower.

Our objectives were to:

- Estimate the footprint of the tower-mounted eddy-covariance instruments.
- Test the LEAF-2 simulated sensible and latent heat fluxes from the footprint against those actually measured at the tower.

2. Methods

We assumed the tower instruments sensed the area bounded by plus or minus the standard deviation of the hourly mean wind azimuth most strongly, and considered this to be the tower footprint (Figure 1). The shrub and grass fractions of this upwind area were calculated from a 1-m grid of observed vegetation types around the tower. The snow-covered fraction and average snow depth for the shrub and grass areas was derived from observations taken every 10 days during the FLOSS project. In addition, the average height and Leaf Area Index (LAI) for the shrubs and the grasses was estimated from observations taken near the tower.

These data were then used along with observations at the tower of solar radiation, longwave radiation, air temperature, relative humidity, wind speed, atmospheric pressure, and soil temperature to drive a single column version of the LEAF-2 model for both the grass and shrub landcover types within the footprint area. The single column version of LEAF-2 used in this study has been modified to include a snow and soil skin-temperature calculation (Liston et al. 1999) and a new age-dependent snow albedo formulation (Douville et al. 1995). More details on this modified version of LEAF-2 can be found in Strack et al. 2004.

The model was run for seven individual days ranging from 13 Jan. 2003 to 13 Mar. 2003 when all necessary data were available. The footprint was calculated every 5 min. based on the average wind direction and standard deviation during the preceding hour. The sensible heat flux was then calculated for both the grass and shrub areas within the footprint and the area-weighted average compared to the flux observed at the tower. A similar calculation was done for latent heat flux.

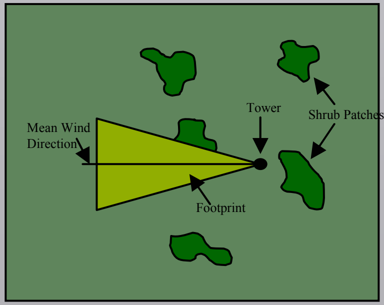

Figure 1: Schematic of the simple tower footprint.

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3. Results

The simulated versus observed sensible and latent heat fluxes are shown along with a photograph from the tower for each day the model was run (Figure 2a-g).

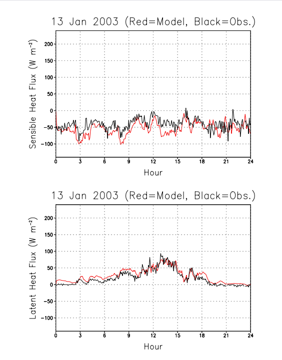


Fig. 2a

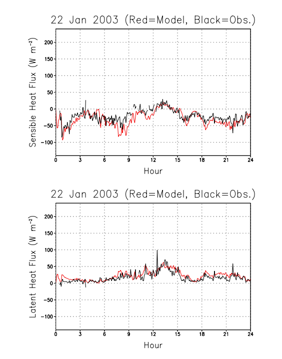


Fig. 2b

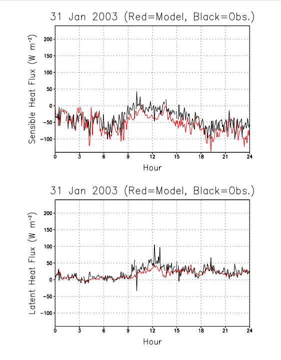


Fig. 2c

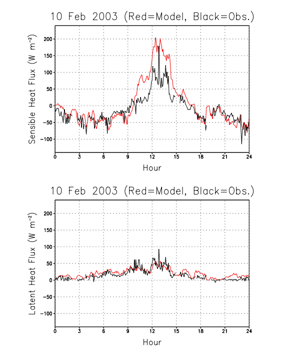
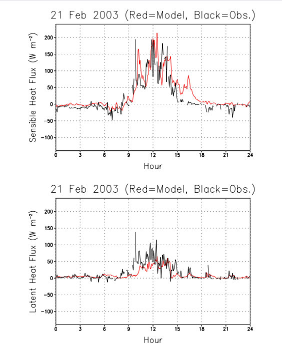


Fig. 2d



No photograph on this date.

Fig. 2e

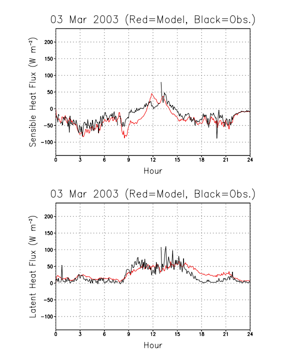


Fig. 2f

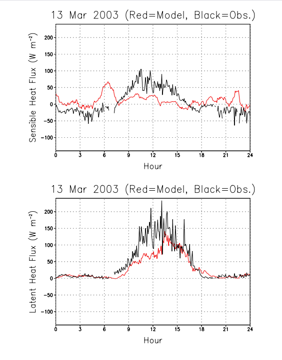


Fig. 2g

4. Discussion and Future Work

The model was able to simulate the diurnal cycle of both sensible and latent heat fluxes fairly well on most of the days. However, the magnitudes were in error by more than 10% at times. One likely reason for the magnitude errors is the overly simplistic footprint used in this study. When the footprint is wrong the observations at the tower are not representative of the area being simulated by LEAF-2, and thus the model fluxes will not be expected to match the tower fluxes.

Future work should include the construction of a more sophisticated footprint theory similar to one developed by Kaharabata et al. 1997 for the BOREAS study. This scheme takes into account the atmospheric stability and measurement height. However, it is not directly applicable to regions with very stable surface layer thermodynamic stability and low surface roughness such as North Park.

5. References

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