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Surface-Layer Response Over Shrub-Steppe Canopy During Springtime

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1. INTRODUCTION

The exchange of energy and trace gases between the atmosphere and heterogeneous surfaces is gaining increasing attention in the scientific community. Modeling efforts on scales from individual fields to the entire globe are including or requiring increasingly detailed descriptions of surface exchange processes. Numerous models have been developed relating energy fluxes (including radiative terms) among the soil, plant, and atmosphere components of a surface system (e.g., Shuttleworth and Gurney, 1990; Sellers et al., 1986). These types of models have been tested primarily over agricultural surfaces (e.g., Ham and Heilman, 1991; Sellers and Dorman, 1987). Some testing has been performed over the more widespread natural plant communities (e.g., Nichols, 1992; Sellers and Dorman, 1987). If current models can be shown to be successful over heterogeneous and sparse canopies of the natural landscapes, or if alternate forms can be developed, the benefit to regional and global-scale climate-change research will be considerable.

Whether the intent is to estimate evapotranspiration from remotely sensed radiative data or otherwise improve the lower boundary representation in atmospheric simulations, increased knowledge is needed of the effects of various surface types and the behavior of the boundary layer that interacts with them. One such heterogeneous surface that is wide spread in the semi-arid west is the shrub-steppe consisting of a sparse shrub overstory and an extensive grass understory. It is the largest of the grassland classes in the western United States, accounting for almost 645,000 km^2 (Risser et al., 1981).

An observational study of surface energetics and atmospheric response was undertaken in 1992 to provide data for model application to semi-arid climates and for the evaluation of various models. Measurements of surface-layer turbulence, canopy energetics, and soil heat and moisture budgets were made over a mixed shrub-steppe surface containing predominantly sagebrush, cheatgrass, and bare sandy soil. The observation periods spanned the 1992 spring season. The objectives of this field study were to quantify surface-layer fluxes over a mixed canopy in a semi-arid climate, to quantify canopy and soil energetics during the transition from moist winter conditions to dry summer conditions, and to investigate parameterization of surface exchange processes in a mixed-canopy setting. In this paper, we present an overview of the observational study and a discussion of the closure of the observed energy budget.

2. STUDY OVERVIEW

2.1 Site

The study site is located on the U.S. Department of Energy's (DOE) Hanford Site in south-central Washington, near the 1600-m arc of the Diffusion Grid. This part of the grid provides a 4-km^2 area that is uninterrupted by paved roads, excavation, buildings, or significant variation in the vegetation association. This site provides over 1000 m of uniform fetch over the study area for winds having a westerly component.

The study area is covered by an *Artemisia tridentata/Poa sandbergii* (big sagebrush/Sandberg's bluegrass) vegetation association (Figure 1). The association consists of three elements: 1) an overstory of shrubs, 2) an understory of grasses and forbs (herbaceous plants that are not grasses), and 3) patches of bare sandy soil. Total shrub canopy coverage, measured using the line intercept technique, is 12%. (Shrub density was 21 shrubs/100 m^2 and average shrub height was 1 m.) Canopy coverage of the understory element (Table 1) was measured using a modified Daubenmire technique (Daubenmire, 1968). Total understory canopy coverage ranged from 49% to 68%. As the 1992 growing season progressed, percent canopy cover of forbs at this low-elevation site decreased as water availability decreased and plants senesced.

Table 1. Percent canopy cover of understory vegetation at the measurement site on three dates in 1992.

Species	March 24	April 15	May 15
Cheatgrass	43.0	41.0	64.0
Sandberg's Bluegrass	7.0	2.0	3.0
Forbs	10.0	6.0	1.4
Total	60.0	49.0	68.4

The bare soil fraction, calculated as the residual of the sum of overstory and understory fractions, ranges from 20% to 39%. This calculation is assumed to yield slight underestimates of the bare fraction because some fraction of understory canopy is covered by overstory canopy, but we have not quantified this fraction. As an alternate technique for estimating fractional coverage of the elements, we performed a visual classification of the elements in a photograph (similar to Figure 1) taken from a 100-ft tower adjacent to the study site, and estimated fractional coverages to be 25% overstory, 60% understory, and 15% bare.

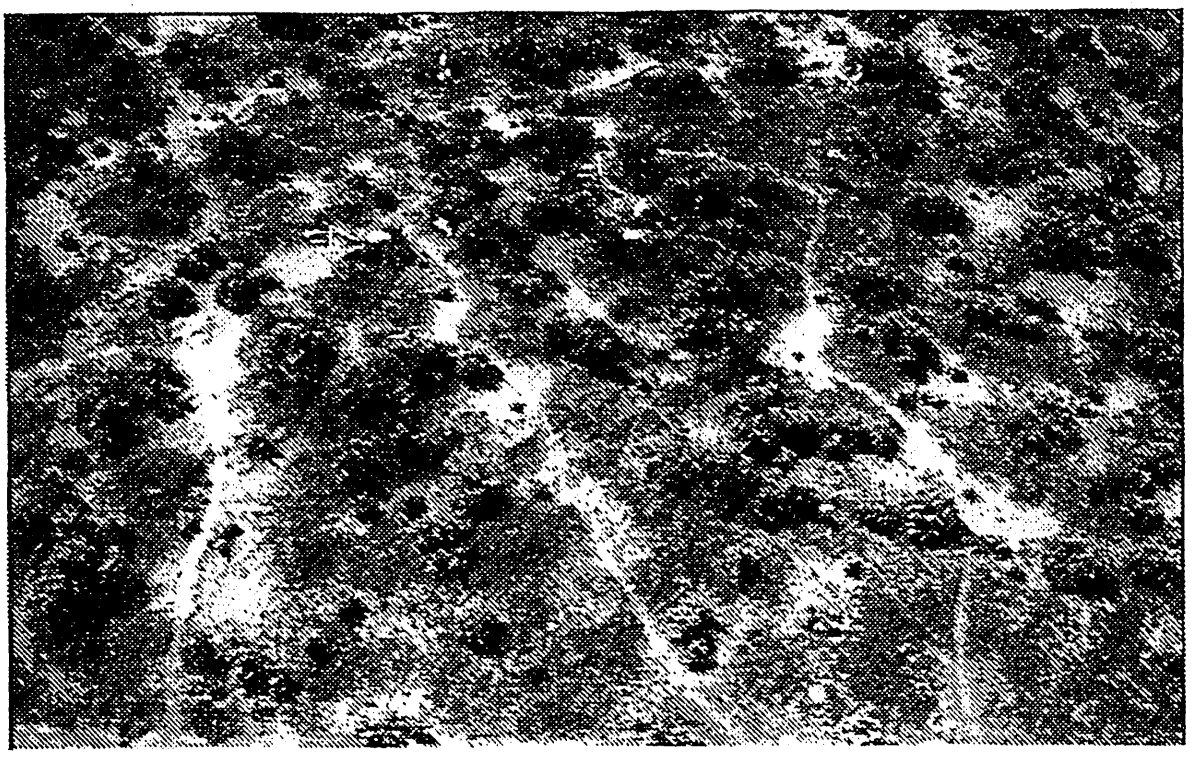

Figure 1. Tower photograph of the big-sagebrush/Sandberg's-bluegrass vegetation association found on the Hanford Diffusion Grid on the west side of the 1600-m arc, taken May 5, 1992.

2.2 Instrumentation

Surface energy budget components were measured in each of the three primary vegetation association elements (surface cover types): sagebrush, grass, and bare ground. In each of these cover types, continuous measurements were made of the soil temperature profile in the top 5 cm, soil heat flux at 5 cm, reflected short-wave radiation, and net all-wave radiation. In the two vegetated cover types, leaf temperatures and canopy air temperature were also measured. Surface temperatures were obtained with nadir infrared thermometers (view angle of 15 degrees) positioned 2 m above the respective surface. Soil samples were taken to a depth of 70 cm three times during the season for each surface element.

A suite of fast-response sensors deployed at a height of 6 m measured surface-layer sensible- and latent-heat fluxes using the eddy correlation technique. Three wind velocity components and the virtual temperature were measured using an Applied Technologies sonic anemometer, sampled at 10 Hz. This sensor was triggered by the data acquisition system to maintain temporal correlation with the other turbulence sensors. Also sampled at 10 Hz were the water vapor signal from an open-path infrared-absorption hygrometer (Auble and Meyers, 1992) and a platinum resistance thermometer.

As 1-Hz reference data, wind speed and direction were measured using a propeller-vane sensor and wet- and dry-bulb temperatures were measured using aspirated/shielded thermistors. Radiosondes measured thermodynamic variables to 300 mb at dawn and midday on selected days. The site is also 1600 m from the Hanford Meteorological Station 400-ft tower where mean wind measurements at 50, 100, 200, and 400 ft are taken.

2.3 Experiment

The study was conducted as three approximately 1-week intensive observation periods (IOPs) that spanned the spring-season drydown of the shrub-steppe system. These periods encompassed the following dates:

IOP1	March	19-28
IOP2	April	10-21
IOP3	May	8-14

Days suitable for comparison across IOP were chosen based on absence of clouds, suitability of wind direction, and functionality of all instrument systems. The following days were chosen to represent their respective IOPs: IOP1, March 20, March 21; IOP2, April 15, April 18; IOP3, May 9, May 11. The cloud interruption of the April 18 net radiation is greater than desired but in the interest of identifying at least two comparison days from each IOP, it is included.

3. ENERGY BUDGETS

The surface energy budget data collected for the three surface types were used to calculate the amount of energy available at each of the surface types for heat

flux and evapotranspiration to the atmosphere. We calculate the available energy, E, as

$$E = Rn - G - Gs$$

where Rn is the net radiation, G is the soil heat flux measured at 5 cm, and Gs is the soil heat storage in the top 5 cm. We present these values along with the sensible and latent heat fluxes and their sum for April 15 and May 11 (Figure 2). On April 15, the latent heat flux accounts for about 25% of the total turbulent flux while on May 11 it accounted for less than 10%. In both of these cases, the total heat flux at midday is bracketed by the lesser available energy over the bare ground and the greater available energies over the vegetated surfaces. Available energy over the bare ground is lower because of both lower net radiation (higher albedo and temperature) and higher soil heat flux.

The combined effect of the available energy at all the element surfaces in the "footprint" of the surface layer measurements should balance the total heat flux measured there. As an initial means of combining the effects of the three surface types, for evaluation of budget closure, we weight the available energy according to the fractional coverage of the respective surface type. We have two sets of fractional coverage estimates, *in situ* canopy sampling numbers and image-based numbers. These two weightings of available energy are presented with the total turbulent flux for April 15 and May 11 (Figure 3). We note that the scheme giving greater weight to the bare ground better balances the turbulent energy, at least during the midday and afternoon hours, and comment that gradations of canopy characteristics could result in biases not accounted for in our fractional coverage estimates. Moreover, the assumption that such weightings are invariant under wind and solar angle (for example) is dependent on the degree to which our point measurements are representative of their entire element. One possible mechanism that would draw the turbulent flux values toward the bare-ground values of available energy during the midday hours is that the sparse fringes of the grass element behave more like bare ground under high sun angles when the blades are less efficient at shading the ground, effectively increasing the fraction of bare ground. This line of reasoning would be consistent with the difference in the *in situ* and image-based estimates of bare ground fractional coverage since the latter technique posed difficulty in proper inclusion of the fringes or sparse

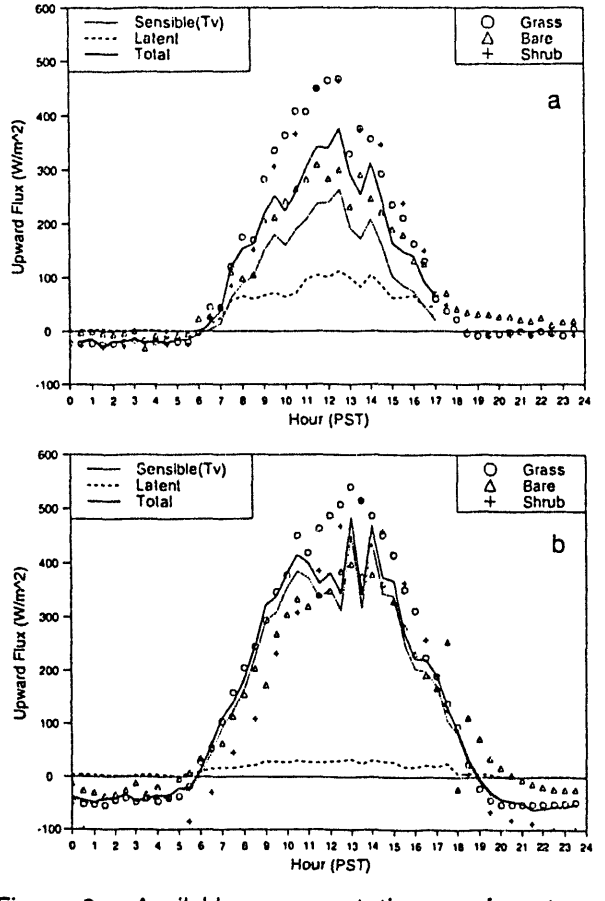

Figure 2. Available energy at three surface types (symbols) superimposed on sensible- and latent-heat flux and their sum (lines) for a) April 15, and b) May 11, 1992.

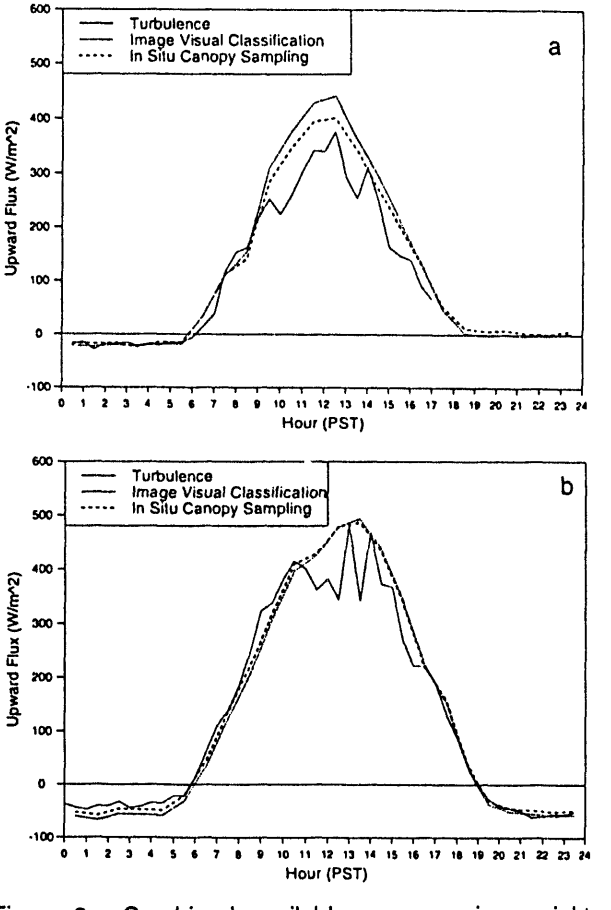

Figure 3. Combined available energy using weights based on *in situ* and image estimates of surface type fractional coverage, superimposed on the sum of sensible- and latent-heat flux for a) April 15, and b) May 11, 1992.

grass canopy in the bare category. Nichols (1992) and Kustas (1990) partition Rn between soil and canopy based on estimates of leaf area index and a parameter to account for sun angle. In this case it may be necessary to apply a sun-angle factor to each canopy leaf area index individually and then to the shrub fractional coverage to account for its shading of the other elements.

In addition to sun angle, wind speed may modify the effective fractional coverage of the different surface types. We note, for example, that on April 18 (not shown), when winds were higher than on April 15, the turbulent fluxes are closer to the higher available energies over vegetation than over bare ground.

4. CONCLUSIONS

The available energy over the vegetated elements exceeded that over the bare soil during all stages of the drydown. However, the available energy over bare soil was closer to the midday turbulent fluxes in all stages. During the first two IOPs, the latent heat flux accounted for between 25% and 35% of the total turbulent heat flux; by the third IOP, it accounted for only 10%. In this final stage of the drydown, the differences between available energies over the bare ground and over the vegetation were about half the size of the corresponding differences during the first two stages.

Combinations of the available energies based on fractional coverage of the three elements yielded good agreement with the surface-layer fluxes. Discrepancies were noted primarily during hours of high sun angle.

Future work includes examination of schemes for combining available energies of the individual elements and comparison with models of energy partitioning such as those of Shuttleworth and Gurney (Nichols, 1992) and Sellers et al. (Sellers and Dorman, 1987).

5. ACKNOWLEDGMENT

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6. REFERENCES

Auble, D. L. and T. P. Meyers, 1992: An open path, fast response infrared absorption gas analyzer for H_2O and CO_2. *Bound.-Layer Meteor.*, **59**, 243-256.

Daubenmire, R., 1968: *Plant Communities, a Textbook of Plant Synecology.* Harper & Row, New York.

Ham, J. M. and J. L. Heilman, 1991: Aerodynamic and surface resistances affecting energy transport in a sparse crop. *Ag. and Forest Meteorol.*, **53**, 267-284.

Kustas, W. P., 1990: Estimates of evapotranspiration with a one- and two-layer model of heat transfer over partial canopy cover. *J. Appl. Meteorology*, **29**, 704-715.

Nichols, W. D., 1992: Energy budgets and resistances to energy transport in sparsely vegetated rangeland. *Ag. and Forest Meteorol.*, **60**, 221-247.

Risser, P. G., E. C. Birney, H. D. Blocker, S. W. May, W. J. Parton, and J. A. Wiens, 1981: *The True Prairie Ecosystem.* Hutchinson Ross Publishing Company, Stoudsburg, Pennsylvania.

Sellers, P. J. and J. L. Dorman, 1987: Testing the simple biosphere model (SiB) using point micrometeorological and biophysical data. *J. Climate and Appl. Meteor.*, **26**, 622-650.

Sellers, P. J., Y. Mintz, Y. C. Sud, and A. Dalcher, 1986: The design of a simple biosphere model (SiB) for use within General Circulation Models. *J. Atmos. Sci.*, **43**(6), 505-531.

Shuttleworth, W. J., and R. J. Gurney, 1990: The theoretical relationship between foliage temperature and canopy resistance in sparse crops. *Q. J. R. Meteorol. Soc.*, **116**, 497-519.

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