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COMPARISON OF GROUND-DERIVED AND SATELLITE-DERIVED SURFACE ENERGY FLUXES FROM A SHRUB-STEPPE SITE

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COMPARISON OF GROUND-DERIVED AND SATELLITE-DERIVED SURFACE ENERGY FLUXES FROM A SHRUB-STEPPE SITE

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1. INTRODUCTION

Efforts to measure evapotranspiration (ET) remotely are common in agriculture, and the application of such data to irrigation scheduling is readily apparent. Extending this methodology to arid environments is primarily of use as a mechanism for validation of ET algorithms used in large-scale watershed and global climate change modeling efforts. To facilitate testing of the remote sensing method for ET, measurements of sensible and latent heat flux were made at four sites located on the U.S. Department of Energy's Hanford Site using a combination of lysimeter and Bowen Ratio Energy Balance (BREB) stations. The objective was to calibrate an aerodynamic transport equation that relates sensible heat flux to radiant surface temperature, and to map sensible heat flux using Landsat data.

The Hanford Site is located in southeastern Washington, with an areal extent of 1450 km^2 located from latitude 46° 18′ N to 49° 49′ N and longitude 119° 17′ W to 119° 52′ W. Geological features in the area consist of large flat areas with monoclinal escarpments and tilted basalt outcrops. Altitude ranges from a high of 1093 m at the top of Rattlesnake Mountain to a low of 92 m at the Columbia River.

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The Hanford Site is primarily a shrub-steppe grassland, dominated by sagebrush, bunchgrass and cheatgrass vegetation. Silt loam soils are found on the slope and at the base of Rattlesnake Mountain. The lower elevation areas of the Hanford Site are generally flat and contain soils classed as sandy loams and sands. The average annual rainfall is 160 mm, with precipitation occurring primarily in the cool season months. Typical bunchgrass and sagebrush communities along with BREB station and weighing lysimeter systems used in this study are visible in Figure 1.

2. SURFACE ENERGY AND RADIATION BUDGETS

The surface energy budget is commonly described as follows:

$$R_N - G - H - \lambda E = 0 \qquad (1)$$

where R_N = net radiation (the difference between incoming and outgoing radiation both long and short wave)
G = soil heat flux
H = sensible heat flux
λE = latent heat flux.

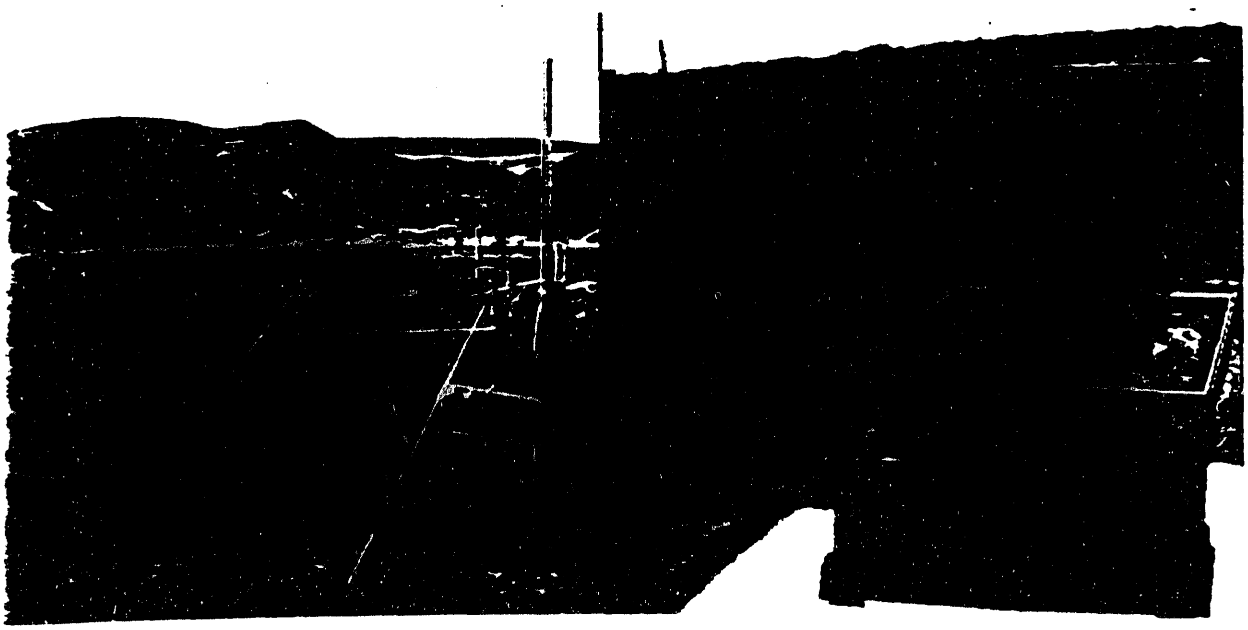

Figure 1. Bowen-Ratio station over bunchgrass and weighing lysimeter containing sagebrush.

Landsat TM data were used to estimate terms of the radiation budget at the surface. The May 8 and June 1, 1989, Landsat estimates of reflected short-wave radiation are moderately correlated (R^2=.77, all values are within 5 W/m^2 of the 1:1 line) with measurements using inverted Eppley pyranometers.

Estimates of net radiation were determined from satellite data (short- and long-wave-outgoing) and short-wave-incoming (pyranometer) and long-wave-incoming radiation [estimated from an air/temperature, vapor pressure relationship of Brutsaert (1982)]. These estimates were compared to measured net radiation values taken at the same time from four field sites (Figure 2). The correlation coefficients for estimated and measured net radiation values are 0.97 and 0.66 for May and May/June data, respectively. Atmospheric correction of both Landsat data sets was based on May 8,1989, radiosonde data only. The measured net radiation values are approximately 40 W/m^2 higher than the estimate from Landsat data. Field et al. (1992) showed a similar over estimation of net radiation by the net radiometers. A subset (42 by 18 km) of Landsat scene (path 44 row 28) encompassing the field observation sites was processed to show net radiation (Figure 3).

3. DEVELOPMENT OF RESISTANCE TERM FOR SENSIBLE HEAT TRANSPORT

The sensible heat flux equation as a resistance formulation is

$$H = \rho C_p \frac{T_s - T_a}{r_a} \qquad (2)$$

where ρ = density of air (kg m^{-3})
C_p = specific heat at constant pressure (J kg^{-1} K^{-1})
$T_{s,a}$ = temperature (°K) of surface and air.

The resistance term (r_a) is a function of wind speed, atmospheric stability, and surface roughness. Data collected between April 11 and May 9, 1988 at the vegetated sites were used to calibrate the resistance term of a sensible heat-flux transport equation for the two surface types. Data used to calibrate the equation were restricted to values obtained between 10:00 and 12:00 hours to approximate Landsat overflight time. Sensible heat flux density was derived as the available energy (R_N-G) minus the latent heat flux measured with the lysimeters. Radiant temperature was estimated by combining data from an IR thermometer viewing primarily canopy and soil temperature (thermocouple at 1-cm depth). Data sets collected during this time were used to determine values of the bulk Richardson number (Ri), stability functions, and resistance to heat transfer. Linear regression of measured and predicted sensible heat

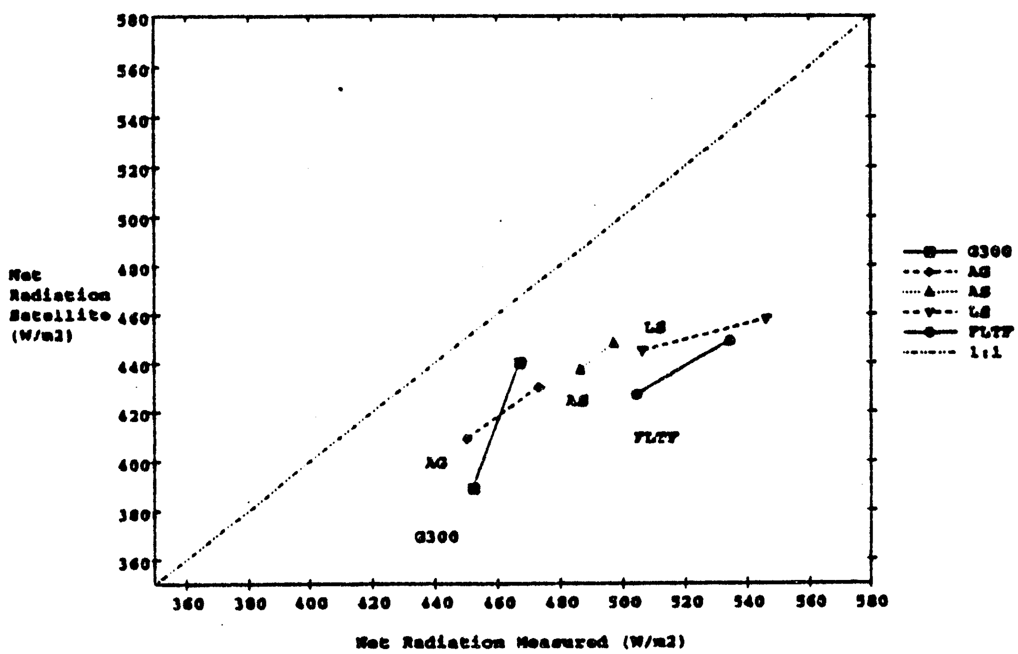

Figure 2. Comparison of measured net radiation with net radiation derived from Landsat data.

flux density gave R^2 values of 0.80 and 0.89 for the bunchgrass and sagebrush sites, respectively. This equation was then used with surface temperatures derived from Landsat satellite overflights in May 8, 1986 and May 8 and June 1, 1989, to generate estimates of sensible heat flux. The sensible heat flux density estimates were similar to sensible heat flux density values determined at the time of overflight with BREB stations, but exhibited significant scatter. Estimates of sensible heat flux ranged between 139 and 290 W/m^2, while measured values ranged between 166 and 287 W/m^2. Specifically for sensible heat transport, the resistance to heat transfer (sm^{-1}) is

$$r_a = \frac{\ln\frac{z - d_o}{z_{om}} + \ln\frac{z_{om}}{z_{oh}} - \Psi_h \cdot \ln\frac{z - d_o}{z_{om}} - \Psi_m}{\kappa^2 \mu} \qquad (3)$$

where z = height at the top of the canopy
z_o = roughness length for the soil or canopy
d_o = zero plane displacement height
ψ_h = stability correction function of heat
ψ_m = stability corr. function of momentum
κ, μ = von Karmon (0.4), windspeed.

The nine data points comparing BREB to satellite estimates of sensible heat flux are similar in magnitude but poorly correlated (Figure 3).

The scatter of this Landsat/Bowen ratio data set is only slightly more than that reported by Kustas et al. (1989) or Brunel (1989). Unfortunately, the method is not accurate enough to detect the difference (<50 W/m^2) between adjacent bunchgrass and sagebrush sites.

4. NDVI AND SOIL HEAT FLUX

A further complication was introduced by the highly variable soil heat flux term which is nearly equal to latent heat flux at three of four sites and varies more than sensible heat flux between the four sites. Pairs of data points obtained from five sites at Hanford at the Landsat overflight times of May 8, 1989, and June 1, 1989, are connected by straight lines (Figure 4). Using NDVI (normalized difference vegetation index) values obtained from three Landsat images and G values taken from five sites, we were unable to develop a predictive equation. The proposed NDVI-G relationships of Kustas and Daughtry (1990) and Moran et al. (1989) to predict soil heat flux as a function of NDVI are also plotted, but do not fit our data set. The K symbol in Figure 4 represents the high and low values of NDVIs reported by Kustas and Daughtry (1990). The symbols AG and AS represent the bunchgrass and sagebrush communities shown in Figure 1. Additional data points are from other Hanford Sites are explained in detail in Kirkham (1993). The May NDVI values are consistently higher than the June values, as expected, and G increases with decreasing NDVI. It appears that there may be a threshold NDVI value (with only one site Lower Snively (LS) with complete cheatgrass cover and having an NDVI greater than this value) where G is relatively constant because of litter accumulation.

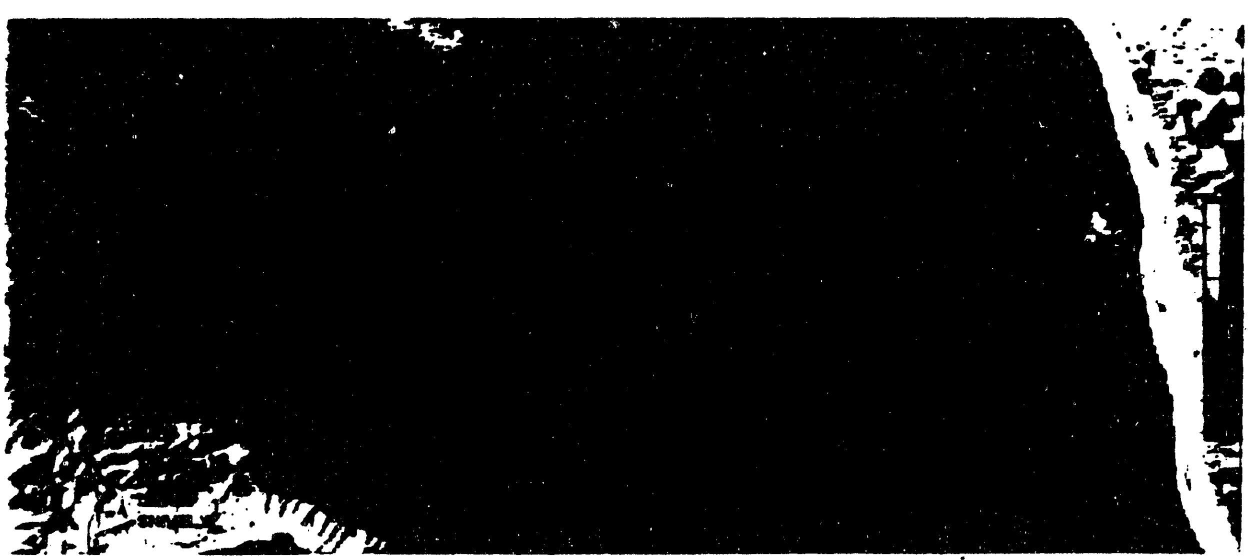

Figure 3. Net radiation calculated from Landsat 5 and surface observation data for May 8, 1989.

5. CONCLUSIONS

Use of remotely sensed data at arid, natural vegetation, sites can be used to map net radiation. To complete the energy balance and partition the available energy into latent and sensible heat flux, a method is needed to estimate G in highly variable surface litter areas. Furthermore, a simple resistance formulation of the sensible heat flux equation should only be used when looking for flux differences greater than 50 W/m^2. In arid and semi-arid areas, ground litter varies in responce to soil properties, plant community, and yearly climatic conditions. Estimates of G and, subseqently, H and LE, may require hyper-spectral data sets able to discern vegetation adsorption bands other than chlorophyll [i.e., lignin 2130 and 2270, and cellulose 2090 and 2270 nm, Roberts et al. (1993)], or the inclusion of climate-driven litter models.

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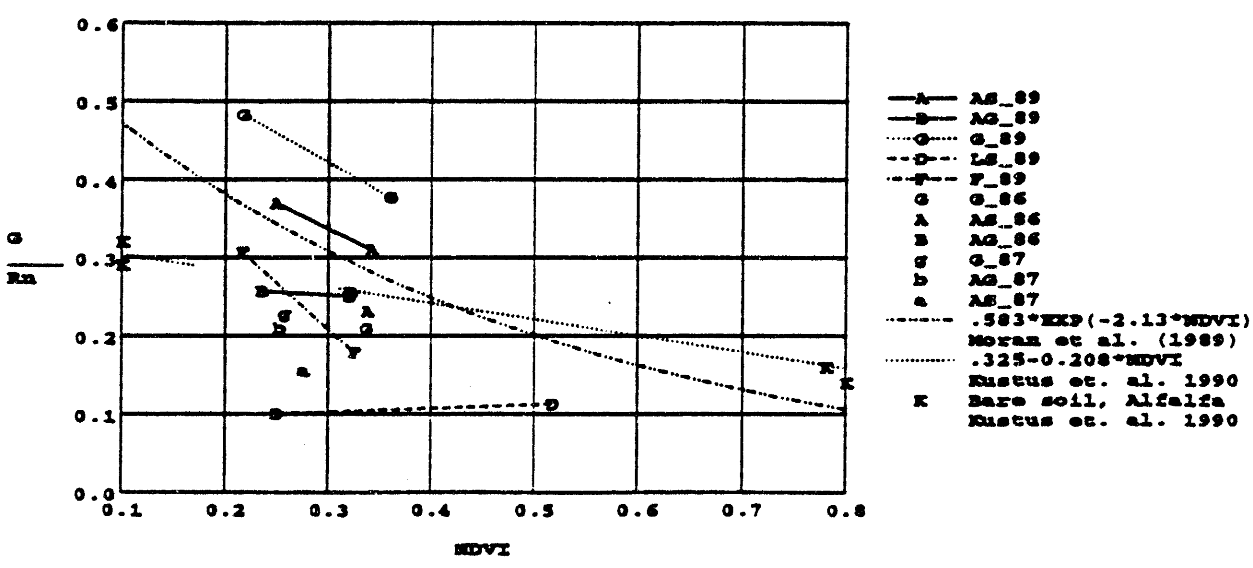

Figure 4. G/Rn compared with NDVI determined from Landsat for multiple sites and dates.

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