Cloud and Radiation Testbed Area-Representative Values of Surface Heat and Upwelling Radiation Fluxes Derived from Measurements by Ground Networks, Unmanned Aerospace Vehicles, and Polar Orbiting Satellites

W. Gao, J. Qiu and R. L. Coulter
Environmental Research Division
Argonne National Laboratory
Argonne, Illinois

Introduction

Estimating surface radiation and heat flux values representative of an area of several hundred kilometers (comparable to the size of grid cells used in general circulation models) is a complex problem. Because only a limited number of ground stations can be deployed in a field study to measure point values of the surface fluxes, differences between "area-representative" values extrapolated from the point measurements and the true surface fluxes representative of the area can introduce uncertainties in estimating the atmospheric radiation and energy balance, because surface fluxes are used as an important surface forcing within the column above the studied area.

To address the issue of determining surface fluxes representative of the area (about 350 x 400 km) of the Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site of the Atmospheric Radiation Measurement (ARM) Program, the multichannel, high-resolution remote sensing data from the advanced very-high resolution radiometers (AVHRRs) on board National Oceanic and Atmospheric Administration (NOAA) polar-orbiting satellites are used to aid in the analyses of spatial variabilities to extend the observations from ground stations across the SGP CART site.

Effective use of remote sensing data is largely dependent on reliable inversion methods to estimate surface parameters that determine spectral reflectances and thermal emissions measured by the AVHRR sensors' on board satellites (Gao 1993; Gao and Lesht 1997). In addition to the necessary correction of satellite data for atmospheric attenuation, scattering, and emission, a reliable surface radiation transfer model is also used to simulate surface scattering and bidirectional reflectance effects caused by vegetation and other surface covers and to infer broadband surface albedo. Satellite-data-derived surface parameters, combined with surface meteorological data, are incorporated into a surface energy transfer model to simulate surface heat fluxes. The combined system for atmospheric and surface radiation transfer and surface energy balance is used to estimate surface albedo, surface temperature, and sensible and latent heat fluxes at a spatial resolution of a satellite pixel (1 km), their spatial variations, and their area-representative values. Here we present a few examples of results obtained by using this combined inversion system.

Surface Albedo and Upwelling Radiation Fluxes

Approximately 20 ground flux stations with the Solar and Infrared Radiation Observing System (SIROS) and energy balance Bowen ratio (EBBR) and eddy correlation systems have been established within the SGP CART area to measure surface radiative and heat fluxes. Figure 1 shows surface shortwave broadband (0.3-3.0 µm) albedo measured by SIROS at selected locations during the summer of 1996. Narrowband spectral reflectances in the visible and near-infrared regions were also measured at the SIROS stations during a one-week field experiment with a handheld multispectral radiometer. The narrowband reflectance data were incorporated into the surface bidirectional reflectance model to calculate broadband surface albedo. As shown in Figure 1, values of the model-calculated surface albedo exhibit a trend similar to the measurements, with the exception of fluctuations in measured 1-minute average albedo that may be caused by passing scattered clouds.

Figure 2 shows the upwelling shortwave radiation fluxes measured by several different platforms on October 11, 1995, during the ARM Enhanced Shortwave Experiment (ARESE). Measurements made with an unmanned aerospace vehicle (UAV) flying at altitudes of about 800-1,800 m along a

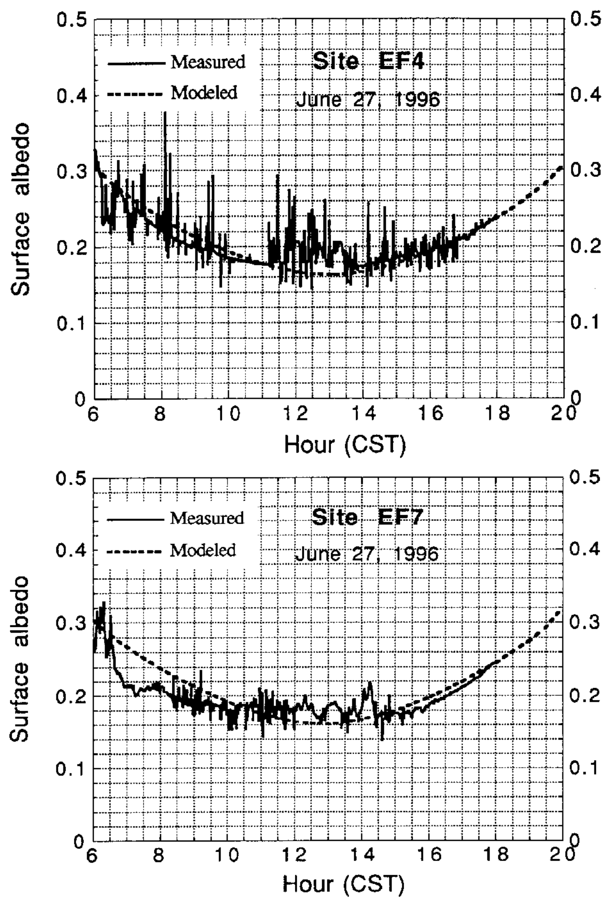

Figure 1. Measured and modeled values of surface albedo for SIROS stations EF4 and EF7 on June 27, 1996.

horizontal transect of about 180 km in the western part of the CART area show large fluctuations in upwelling flux, which seem to be correlated with the spatial variations in surface vegetative and soil conditions indicated by the AVHRR-derived normalized difference vegetation index (NDVI) for pixels along the UAV flight track. The UAV-derived flux variation along this track, about half the scale of the CART site, appears to be larger than the variation among five SIROS stations available for the period of the UAV flight. The satellite-derived AVHRR measurements along the UAV track have a spatial variation closely matching the UAV-measured flux variations. These AVHRR data are being used to simulate the surface albedo and upwelling fluxes along the UAV flight track (Qiu and Gao, this proceedings).

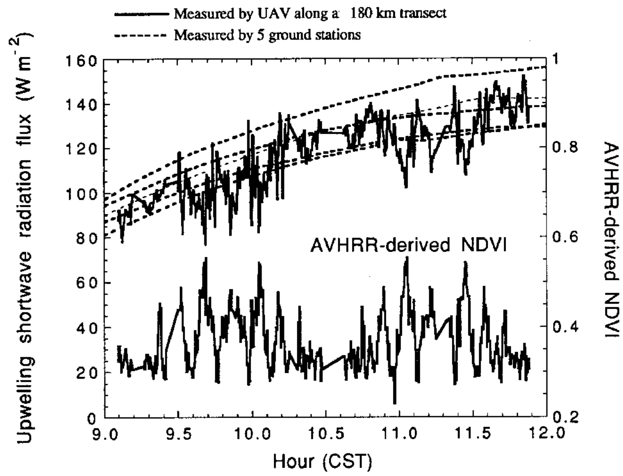

Figure 2. Upwelling shortwave radiation fluxes measured by an unmanned aerospace vehicle (UAV) at five ground SIROS stations on October 11, 1995, in comparison with the normalized difference vegetation index (NDVI) derived from AVHRR channel 1 and 2 reflectances for the UAV flight track of about 180 km.

Surface Heat Fluxes

Figure 3 shows the surface latent (LE) and sensible (H) heat fluxes, net radiation (R_n), and soil heat flux (G) measured at the ten EBBR stations within the CART site. The spatial variabilities in these fluxes among the EBBR stations are fairly large for LE, H, and G, but are relatively small for R_n. Because the EBBR sites all sample pasture or grassland conditions and may be unrepresentative of a large portion of the CART area, satellite observations of the surface spectral vegetation index, NDVI, and surface temperature (T_s) at a 1-km spatial resolution from AVHRRs on the NOAA-12 and NOAA-14 satellites provide a much more complete coverage of the surface conditions.

A modeling method (Gao 1995) that combines high-resolution satellite observations and limited ground measurements to estimate the area-representative surface fluxes was extended to include the distribution of soil moisture. The information on the spatial variability of soil moisture was inferred from the combined visible and thermal infrared remote sensing data on the basis of the hypothesis that the increase in AVHRR-derived T_s for a given NDVI is caused by the decrease in the soil moisture. The spatial distribution of soil moisture derived at a 1-km resolution shows some correlation with the

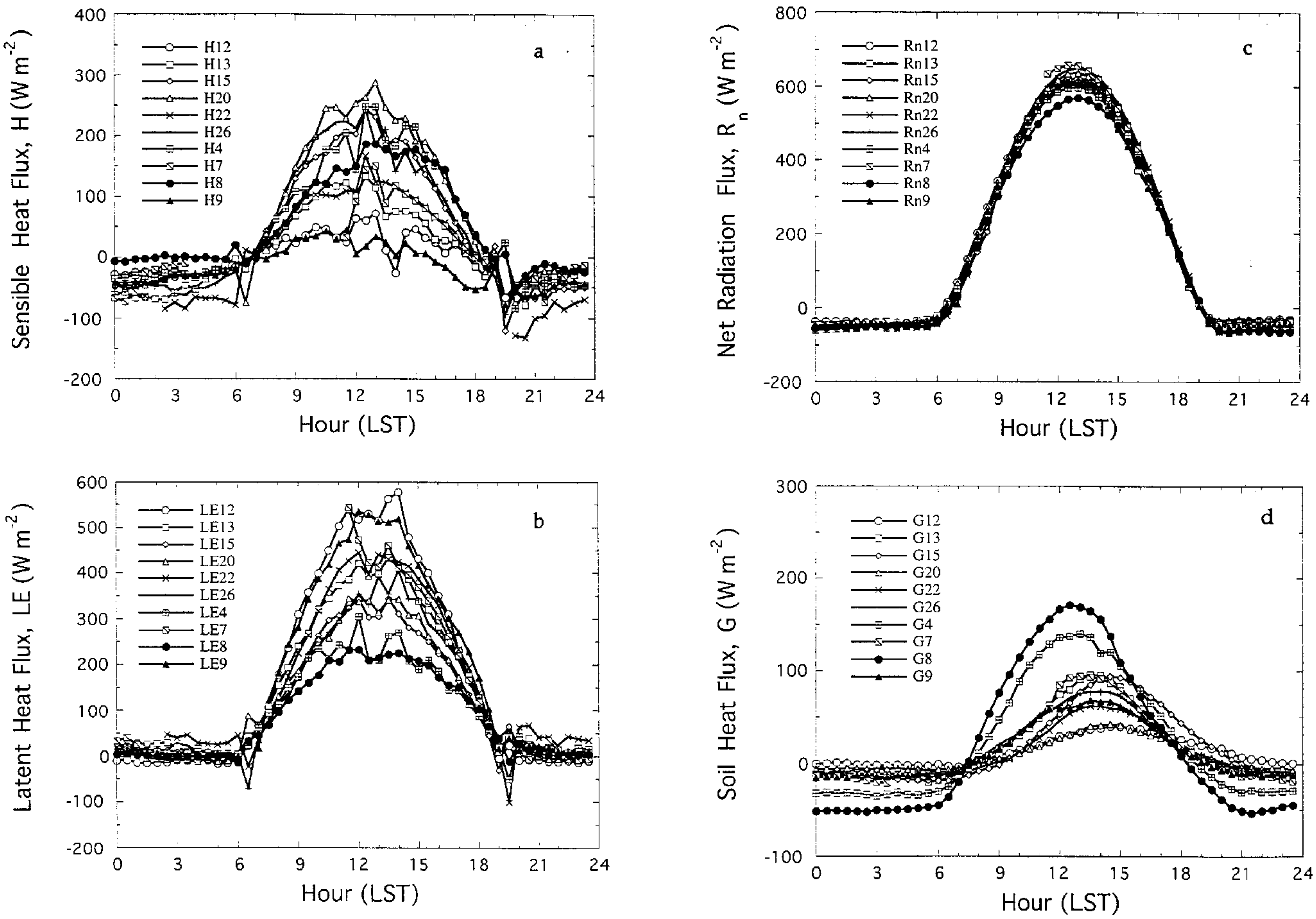

Figure 3. Diurnal changes of (a) sensible heat flux, (b) latent heat flux, (c) net radiation flux, and (d) soil heat flux measured on July 12, 1995, at the ten EBBR stations (indicated by different station identification numbers).

accumulated previous rainfall amount measured at the 58 Oklahoma Mesonet stations. By including a determination of the soil moisture distribution, the current version of the model can be used for operational calculations of surface fluxes with the AVHRR data and limited ground data. The minimal input data include AVHRR NDVI, T_s, mean wind speed, mean air temperature, mean humidity for the whole region of interest (when mesoscale horizontal gradients are not significant), and total solar radiation (single-point data can be used for clear days; knowledge of the spatial variation is required for cloudy days).

The calculated surface fluxes for clear sky conditions were evaluated with measurements at each EBBR station. The near-surface temperature and humidity calculated with estimated surface sensible and latent heat fluxes show a good agreement with their corresponding values independently measured at the 58 ground stations. Figure 4 compares the CART-representative surface fluxes, derived as average values of fluxes modeled for all pixels within the CART site, with the average fluxes from the EBBR stations for two clear days in summer and fall. The CART average R_n was close to the EBBR-derived average value, while the CART average LE was lower than the EBBR-derived average on July 12 but higher than the EBBR average on October 14. It is likely that as the surface conditions at the EBBR stations changed with the season, the representativeness of the EBBR fluxes for the whole CART area also changed. The modeling of regional fluxes with satellite observations can account for a more complete coverage of the surface variability across the SGP CART site.

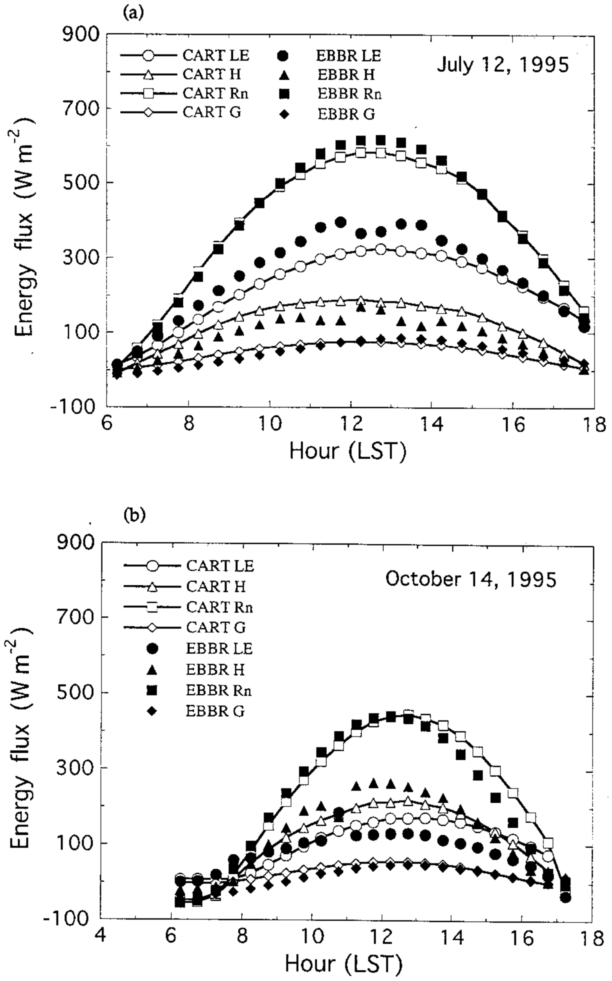

Figure 4. Comparison of CART average values of surface energy budget components derived from pixel-specific calculations with average values from the ten EBBR stations for (a) July 12, 1995, and (b) October 14, 1995.

Acknowledgments

This work was supported by the U.S. Department of Energy, Office of Energy Research, Office of Health and Environmental Research, Environmental Sciences Division, under contract W-31-109-Eng-38 through the Atmospheric Radiation Measurement (ARM) Program, and by the U.S. Department of Defense, Strategic Environmental Research and Development Program (SERDP), through the ARM Unmanned Aerospace Vehicle Program.

References

Gao, W., 1993: A simple bidirectional reflectance model applied to a tallgrass canopy. *Remote Sens. Environ.*, **45**, 209-224.

Gao, W., 1995: Parameterization of subgrid-scale land surface fluxes with emphasis on distributing mean atmospheric forcing and using satellite-derived vegetation index. *J. Geophys. Res.*, **100**, 14,305-14,317.

Gao, W., and B. M. Lesht, 1997: Model inversion of satellite-measured reflectances for obtaining biophysical and bidirectional reflectance characteristics of grassland. *Remote Sens. Environ.* (in press)

Qiu, J., and W. Gao, 1997: Surface albedo at SGP CART site retrieved from AVHRR Satellites and observed by UAV flights. (this proceedings).