Satellite-Derived Surface Characterization and Surface Fluxes Across the Southern Great Plains Cloud and Radiation Testbed Site

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Introduction

Atmospheric processes in the lower boundary layer are strongly modulated by energy and mass fluxes from and to the underlying surface. The atmosphere-surface interactions usually occur at small temporal (seconds to minutes) and spatial (centimeters to meters) scales, which causes difficulties with including surface processes in atmospheric models, which can only handle much larger scales (kilometers). Developing schemes to characterize spatial variabilities in surface fluxes over heterogeneous surfaces for a regionally-representative surface flux that can be correctly used in atmospheric models becomes an important issue. The Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) has an outline area of 350 x 450 km, across which land surface type, topography, vegetation, and soil conditions vary widely (Gao 1994). Surface flux measurements at a limited number of surface stations, including surface latent and sensible heat fluxes, net radiation, and soil heat flux by energy balance Bowen ratio (EBBR) stations, heat and momentum fluxes by eddy correlation stations, and upwelling radiation flux by surface radiation stations, are influenced by local surface conditions surrounding the stations and thus may not be able to provide fluxes representative of the entire CART site. Use of these data to represent the entire CART site in modeling studies and in comparing with large-scale satellite observations could lead to significant uncertainties. This study uses high-resolution (~1 km) remote sensing by National Oceanic and Atmospheric Administration (NOAA) polar-orbiting environmental satellites to characterize spatial and temporal variations in land surface conditions and then to develop methods for estimating spatial variations and CART-representative values of surface fluxes.

AVHRR-Derived Surface Variabilities Across the CART Site

The daily data of five channels of the advanced very high resolution radiometers (AVHRR) of NOAA-12 and NOAA-14 satellites have been captured for the SGP CART site since April 1994. The calibrated spectral reflectances in channel 1(ρ_r) (0.580.68 µm) and channel 2 (0.725-1.10 µm) (ρ_n) were combined to compute the normalized difference vegetation index (NDVI) (which is defined as $[\rho_n-\rho_r]/[\rho_n+\rho_r]$). The NDVI is a good indicator of the density of green vegetation elements because leaf pigments absorb most incident radiation in the red band and reflect and transmit most incident radiation in the near-infrared band. Channels 4 and 5 in the thermal infrared bands were used to compute surface temperature (Ts) with the splitwindow method. All AVHRR imageries were registered to 1-km spatial resolution for the CART area within 34.88º to 38.88º N and 95.50º to 99.55º W, which corresponds to an area of 314 x 344 km. Figure 1 shows the spatial distribution of AVHRR-derived NDVI values across the CART site for clear days selected during different seasons. Most of the imageries chosen were captured under clear sky conditions (when no cloud was visible in channel 1 imagery) except for August 11, 1995, when some scattered clouds appeared in the southeast corner. The data from NOAA-14, which passed over the site in the early afternoon near 1400 local standard time (LST) were used for most selected days except for April 13, 1995 (representing spring season), when clear-sky NOAA-14 imagery was not available, and clear-sky NOAA-12 imagery was used.

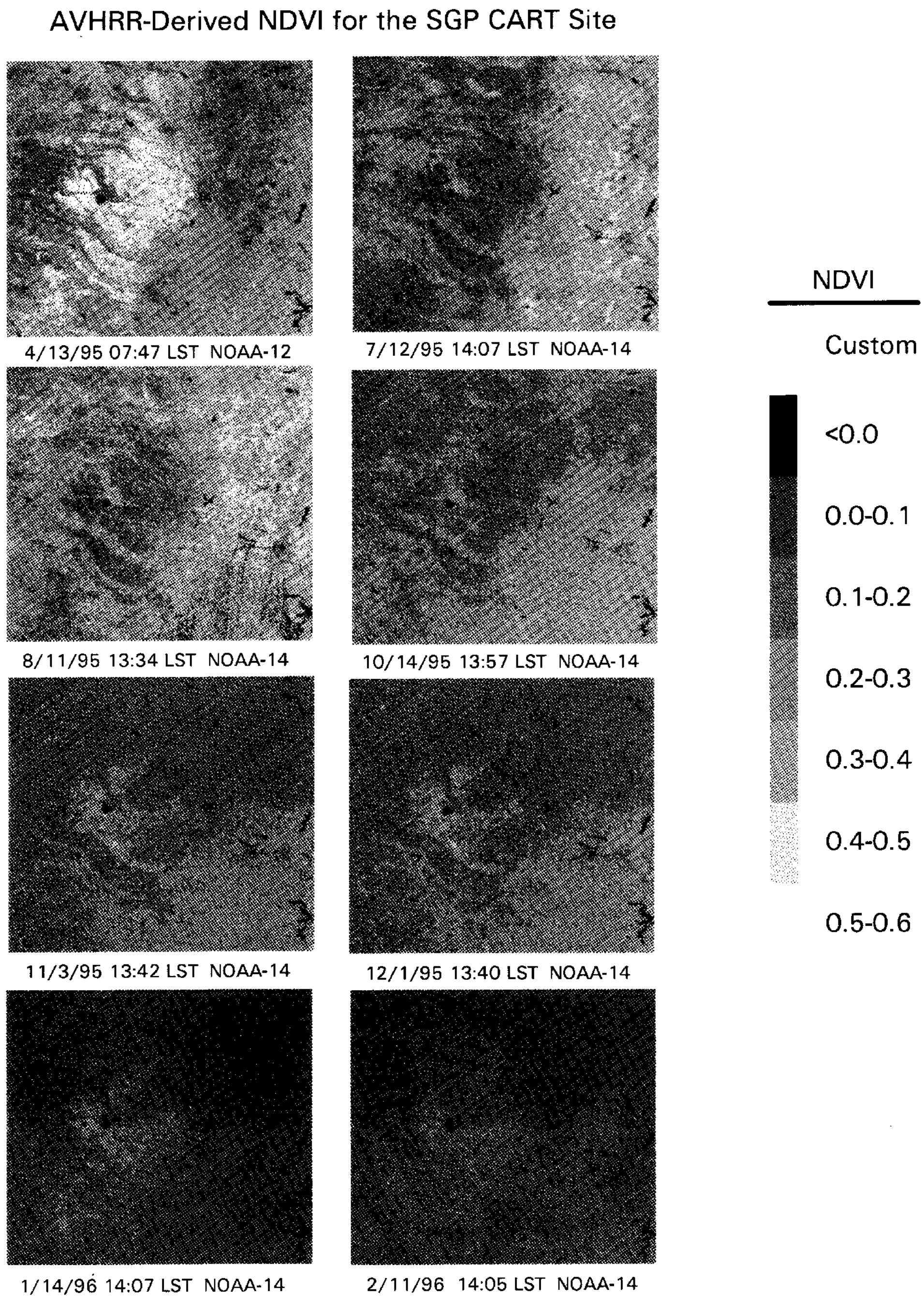

Figure 1. Normalized difference vegetation index (NDVI) derived at 1 km spatial resolution for the SGP CART site within an area of 314 x 344 km.

In the NDVI imageries of Figure 1, the pixels with an NDVI less than zero should represent water bodies (which have higher channel 1 reflectance than channel 2 reflectance), the pixels with an NDVI between 0 and 0.1 probably represented bare soil or nonvegetated surfaces, and the vegetation density should increase with increasing NDVI. On April 13, 1995, the wheat area along the crop belt near the middle of the site had a high NDVI, while the northeast quarter, where the land types primarily were pasture and rangeland, had relatively smaller NDVI. As the season progressed, by July 12, 1995, the wheat area had a small NDVI after harvesting, and the eastern part of the site had a higher vegetation density, which may also be due to spatial variations in rainfall amount. The vegetation density or NDVI value gradually declined during the fall and became very small in the winter.

The spatial variabilities in vegetative conditions or NDVI can lead to spatial variations in various surface fluxes across the CART site. A spatial variability function can be derived from the high-resolution satellite data to facilitate the estimation of spatial distribution and areal average of surface fluxes. The variability function is defined here as a probability function calculated with all land pixels. Figure 2a shows that the probability function is fairly flat in growth seasons, indicating a large spatial variability, and becomes narrower in fall and winter, indicating a more uniform distribution. The AVHRR-derived T_s (Figure 2b) shows a similar change in the probability distribution or spatial variability from summer to winter.

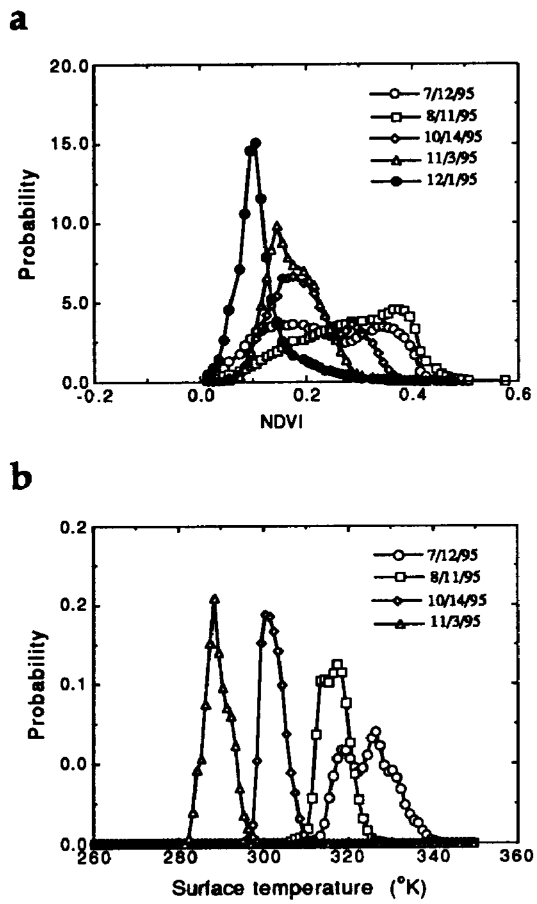

Figure 2. Statistical distribution of (a) remotely sensed optical vegetation index, NDVI and (b) surface temperature across the SGP CART site during different seasons.

Methods for Deriving Surface Fluxes

Several methods may be attempted to estimate spatial variations in surface fluxes. The previously defined distribution functions can be used to weight the relative contribution to total fluxes from different surfaces if the relationship between a given flux and NDVI or T_s is known. Such a relationship may be derived from measurements at EBBR stations or from a modeling study. Here we demonstrate a coupled method developed for combining remote sensing data with limited surface observations to estimate spatial and temporal variations in various surface fluxes. The method is based on a land surface model (PASS model) (Gao 1995) that is designed to effectively use satellite-measured surface spectral radiances in the solution of the surface energy budget. The PASS model adopts empirical functions to describe variations in surface parameters, including surface conductance, surface albedo, surface roughness length, and soil heat flux ratio, with satellite-derived spectral vegetation indices. The surface energy balance and surface temperature are then calculated for individual pixels with derived pixel-specific surface parameters and with a rapid computation algorithm that is included in the model to appropriately distribute mean meteorological parameters (including wind speed, air temperature, and humidity) to individual pixels according to satellite-described local surface conditions and boundary-layer mixing as characterized by wind speed and local surface roughness.

In the present model calculation, the surface albedo was derived from the NDVI with the PASS model. The net radiation was estimated with derived surface albedo, AVHRR T_s, air temperature, and relative humidity at 2 m. Because the 2-m air temperature and humidity can be influenced by local surface conditions, functions describing their relationships with local NDVI were obtained from the regression of the temperature and humidity data taken at the 10 EBBR stations and the site-specific NDVI. The sensible heat flux was calculated with AVHRR T_s, distributed 2-m air temperature, and wind speed. The ratio of soil heat flux to net radiation was estimated as a function of vegetation density or NDVI as described in the PASS model. The latent heat flux then was calculated as a residual term in the energy budget for net radiation, sensible heat flux, and soil heat flux. This approach, slightly different from that used in the original PASS model, can be used to calculate the surface energy budget at the time of satellite overpass because the approach uses direct T_s measurements from satellite remote sensing. Also, because of use of AVHRR T_s data, the influence of soil moisture may have been included in the resulting surface fluxes. Under this assumption, the latent heat flux estimated with this approach can further be used to estimate surface conductance under different water stress conditions and to estimate the relative soil moisture, which can be used to estimate the surface energy balance at other times during the same day.

Figure 3 shows the spatial distributions of resulting surface albedo, net radiation, surface temperature, sensible heat flux, and latent heat flux across the CART site at 1400 LST when the NOAA-14 satellite passed the site.

Large spatial variations are evident in surface albedo and various surface energy components across the CART site. On July 12, 1995, the western portion of the site had less vegetation (thus higher albedo and lower net radiation) and a relatively drier surface (thus higher T_s and sensible heat flux and lower latent heat flux) than the eastern part of the site. Also, some detailed terrain features are evident in the derived surface albedo and fluxes.

Figure 4 compares the calculated latent heat (LE) fluxes for each satellite pixels with measurements taken by the ten EBBR stations. For a given NDVI or vegetation density, there is a range of LE values, largely because of the difference in AVHRR-derived T_s, which may be indicative of variations in soil moisture. Three unusually high EBBR-derived LE values for NDVI less than about 0.4 may be associated with large latent heat fluxes from a local small scale that cannot be identified by 1-km-resolution AVHRR pixels that were extracted for the stations.

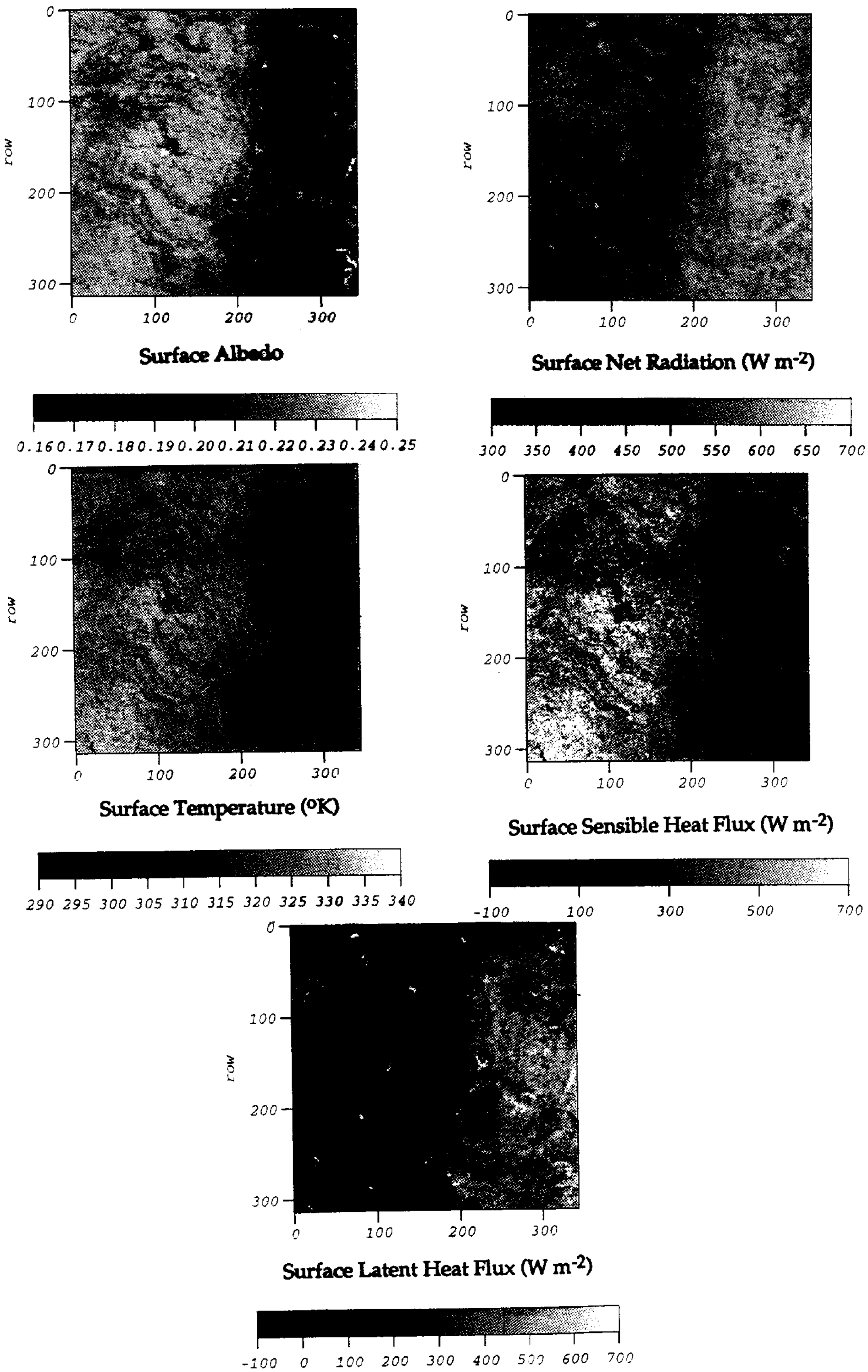

Figure 3. Derived surface albedo and fluxes across the SGP CART site for 1400 LST July 12, 1995

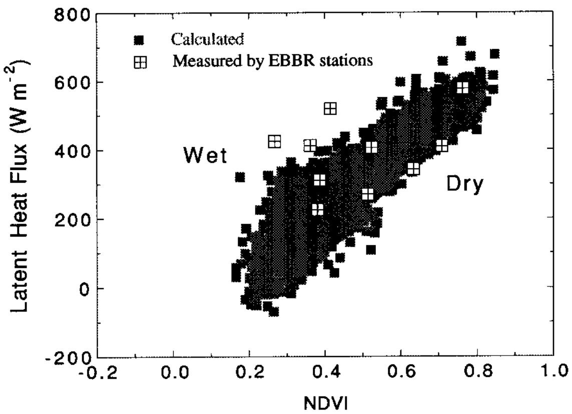

Figure 4. Comparison between latent heat fluxes calculated for satellite pixels and measured by ground EBBR stations at ten locations across the SGP CART site on July 12, 1995.

References

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