Progress Towards a Characterization of the Infrared Emissivity of the Land Surface in the Vicinity of the ARM SGP Central Facility: Surface (S-AERI) and Airborne Sensors (NAST-I/S-HIS)

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Introduction

The U.S. Department of Energy (DOE) Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site provides a unique facility for the study of thermal radiation at and above the earth's surface. The site extends across a 250-km-square region in Oklahoma and Kansas dominated by rural agricultural land use. Upwelling thermal infrared (IR) radiation in the SGP CART site region is strongly influenced by surface radiative properties. The surface properties most appropriate for the representation of IR thermal emission are the surface temperature and emissivity. This paper describes the use of ground-based and aircraft-based observations near the SGP CART Central Facility to characterize the surface properties important for IR thermal emission.

Theory

The radiative transfer equation used to model the upwelling IR radiance under cloud-free conditions is

$$N_\nu^{\uparrow} = \int B_\nu(T(P))d\tau_\nu + \tau_\nu^{tot} \cdot e_\nu \cdot B_\nu(T_S) + \tau_\nu^{tot} \cdot (1 - e_\nu) \cdot \overline{N}_\nu^{\downarrow} \qquad (1)$$

where N_ν is the upwelling (or downwelling) radiance spectrum (with units mW/(m^2 sr cm^{-1})) at wavenumber ν, B_ν is the Planck radiation distribution function for temperature profile T(P), τ_ν is the atmospheric transmittance profile, and e_ν is the surface emissivity. The first term of the radiative transfer equation is the contribution of the atmospheric emission to the upwelling radiation. The second term is the contribution of the surface emission transmitted through the total atmospheric column. The third term is the surface reflection term under the approximation of a lambertian surface.

Two limiting cases are useful to consider. When the observer is near the surface, the contribution from the atmospheric upwelling emission can be neglected and the total transmittance can be set to unity for all wavelengths in the long wave window region. In this case, Eq. (1) can be written in the form

$$e_\nu = \frac{N_\nu^{\uparrow} - \overline{N}_\nu^{\downarrow}}{B_\nu(T_S) - \overline{N}_\nu^{\downarrow}} \text{ [near surface only]} \tag{2}$$

When the atmosphere is relatively dry, the atmospheric emission and absorption in the microwindows between absorption lines can be neglected and downwelling radiance at the surface can be set to zero. In this case, Eq. (1) can be written in the form

$$e_\nu \cong \frac{N_\nu^{\uparrow}}{B_\nu(T_S)} \text{ [all altitudes, clean microwindows only]} \tag{3}$$

Observations

Two sets of coincident observations of land-surface emissivity (LSE) were made in the vicinity of the Atmospheric Radiation Measurement (ARM) Program's SGP central facility in late November 2000; the November 2000 ARM LSE Survey and the ARM/FIRE Water Vapor Experiment.

The November 2000 ARM LSE Survey was conducted by personnel from the University of Wisconsin-Madison during the period November 29-30, 2000, to improve our understanding of the variability of surface emissivity in the vicinity of the SGP ARM site central facility. This research was funded by the National Aeronautics and Space Administration (NASA) Atmospheric Infrared Sounder (AIRS) science team project of H. E. Revercomb to support the use of the ARM site data for validation of the AIRS on the Aqua platform. This was the first of several planned surveys designed to capture the seasonal changes of surface emissivity variation on scales appropriate for satellite observations.

The survey approach taken was as follows: (1) spectral data were collected with the University of Wisconsin Scanning-Atmospheric Emitted Radiance Interferometer (S-AERI) positioned on the roadside adjacent to a selection of fields (including bare soil, wheat, sorghum, and pasture land) to form a spectral library, (2) a corresponding cataloging of field types found alongside 22 miles of road near the CART site was undertaken, and (3) the combination of the spectral library and statistical information on the relative proportion of field type in the area gives us the ability to determine an average emissivity over a range of spatial scales.

Figure 1 shows the S-AERI sensor deployed vertically 16 feet above ground level where it is able to make slant view measurements (at 60 degrees) of the surface and the atmosphere. Also shown in Figure 1 is a chart summarizing the results of a survey of the land cover in each quarter-mile section from U.S. 60 north of the ARM central facility south to Billings, Oklahoma. The survey was conducted using a hand-held Global Positioning System (GPS) unit by driving along the road and noting the land cover and position of each field. This 22-mile stretch of unpaved road is about one mile east of the ARM central facility. Table 1 contains the descriptions of the land cover categories used in this survey. The S-AERI measurements of upwelling and downwelling radiance are used in Eq. (2) along with the additional constraint that the emissivity should be smoothly varying across atmospheric emission lines to obtain a skin temperature and surface emissivity at representative locations. Results from the ARM LSE survey and the weighted average emissivity spectrum (39 percent pasture, 55 percent wheat, 6 percent bare soil) are shown in Figure 2.

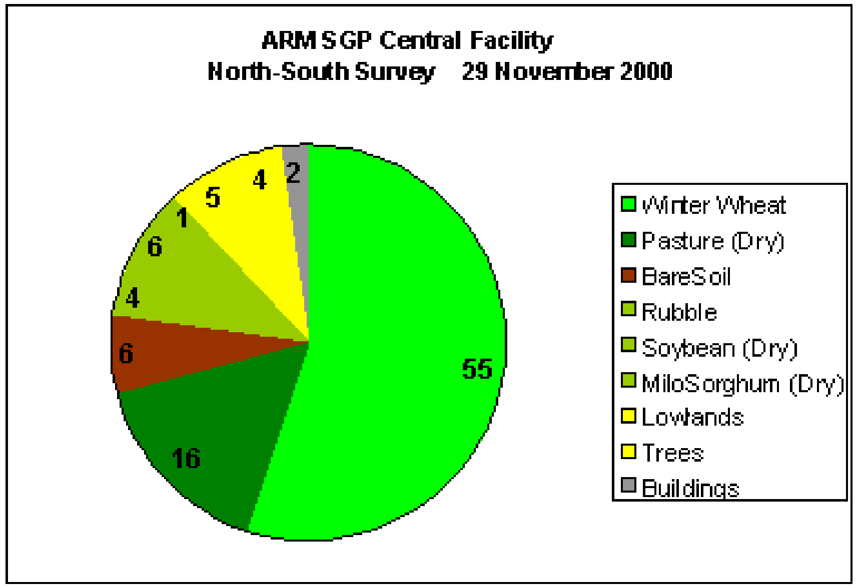

Figure 1. (left) University of Wisconsin-Madison S-AERI instrument deployed along a dirt road near the ARM SGP central facility on November 29, 2000. The instrument is viewing a field of winter wheat. (right) Chart showing the percentage area of each category of land cover over a 22-mile section of road north of Billings, Oklahoma, determined from an on-site survey on the same date.

Table 1. The land use mapping types used in the November 2000 ARM LSE Survey.

Field Type	Comments
Wheat	Winter wheat in early stages of growth. May be sparse (very new growth) or thick. Cattle occasionally present (by Farm Service Bureau guidelines, animals are permitted to graze on the wheat until March). Maximum height seen on this survey, approximately 8 inches (see Figure 2).
Pasture	Dry grasses, fields normally fenced, cattle sometimes present.
Populated	Describes area occupied by settlement, farm buildings, equipment, silos, etc.
Lowlands	Generally pasturelands that are lower lying, often having a creek or other water nearby, topography generally more varied. See, for example, Figure 3. Generally not easily accessible by the AERIBAGO; no measurement site was selected for this land use category.
Milo Sorghum	Primarily used as cattle feed.
Soybean	Soybeans on this trip were seen undersized, dry and left unharvested, most probably an unproductive season.
Rubble	Coarse, straw-like residue remaining after harvesting crops (often Milo Sorghum).
Lake, Water	
Miscellaneous	Land use otherwise not categorized; land type changing too rapidly to record accurately; irregular land plots.

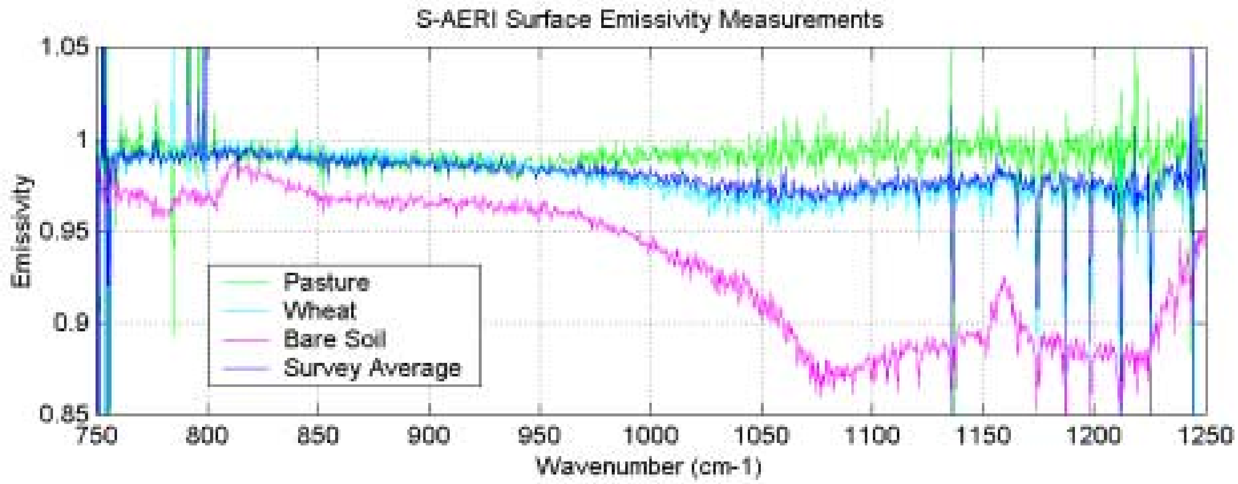

Figure 2. The measured surface emissivities of pasture, wheat, and bare soil overlaid with the weighted average emissivity as determined by the north/south survey results shown in Figure 1 (39 percent pasture; 55 percent wheat; 6 percent bare soil).

The ARM/FIRE Water Vapor Experiment (AFWEX) was an aircraft experiment sponsored jointly by NASA and DOE to provide in situ validation observations for the water vapor sensors permanently installed at the ARM SGP central facility. Two instruments were of particular importance for this study: the NASA Langley NPOESS Atmospheric Sounder Testbed-Interferometer (NAST-I) aboard the high-altitude PROTEUS aircraft and the University of Wisconsin Scanning High-resolution Interferometer Sounder (S-HIS) aboard the NASA DC-8. The DC-8 flew a series of level flight legs at several altitudes while the PROTEUS flew a mapping pattern over the ARM SGP central facility.

Preliminary spectral radiance data from the NAST-I and S-HIS instruments has been analyzed using Eq. (3) with the surface temperature set equal to the maximum brightness temperature in the IR window. The NAST-I and S-HIS data were averaged over a spatial scale similar to that of the ARM LSE Survey. The NAST-I data was taken along a north/south flight track nearly coincident with that survey at an altitude of 55,000 feet, the Scanning-HIS data was collected along a southeast/northwest track at an altitude of 25,000 feet.

Results

The approach taken in this paper to analyze the results of these observations is to find the weights of the three main surface types that provide the best fit to the average aircraft observations. A best-fit weighting of 35 percent pasture, 40 percent wheat, and 25 percent bare soil is shown in Figure 3 compared with the average NAST-I aircraft observations. The NAST-I relative emissivity is given in the lower panel of Figure 3. In precisely the same manner, a weighting of 45 percent pasture, 40 percent wheat, and 15 percent bare soil was found to be a best fit to the S-HIS observations. The comparison of weighted surface emissivity and aircraft S-HIS relative emissivity is shown in Figure 4. The relative emissivity of both the NAST-I and S-HIS has been set equal to 0.99 at 823 cm^{-1} for consistency with the ARM survey measurements.

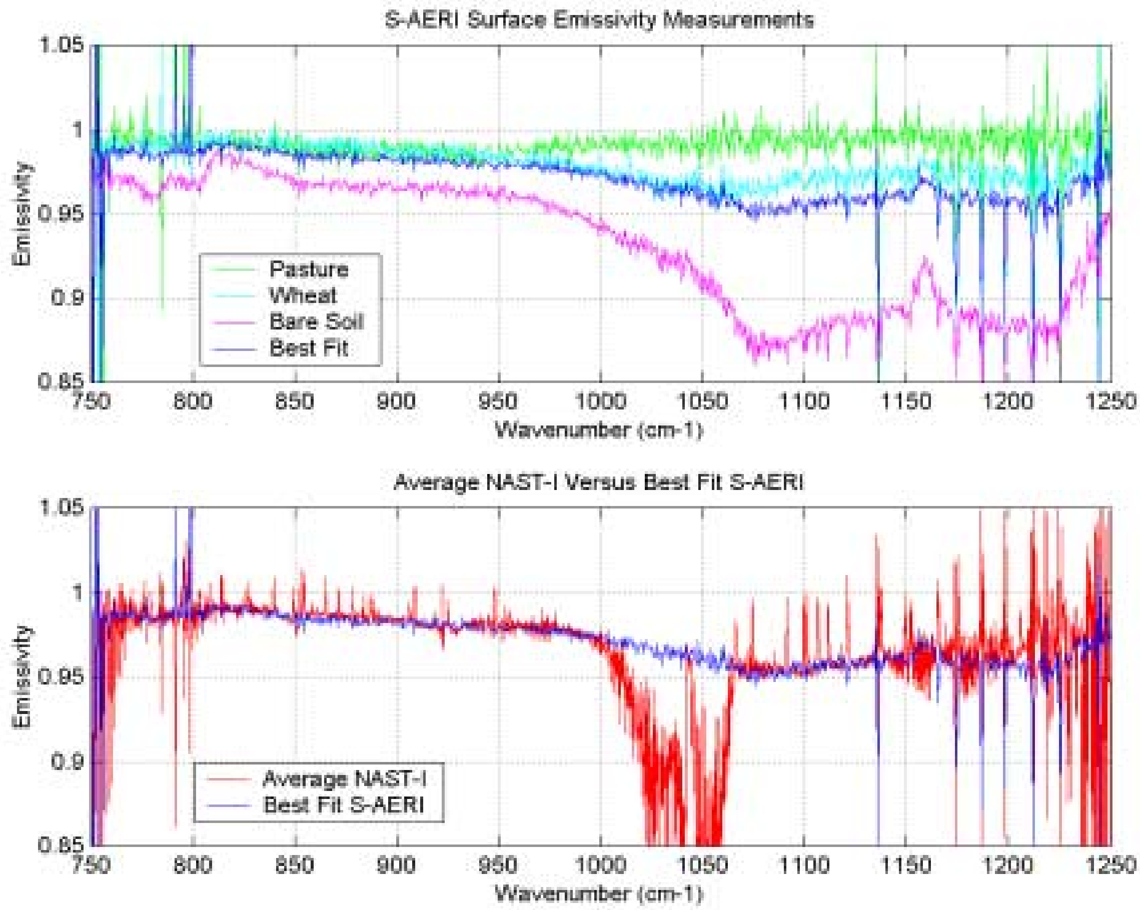

Figure 3. A best-fit weighted average of the ground-based S-AERI measurements (35 percent pasture; 40 percent wheat; 25 percent bare soil) shown in the upper panel is overlaid in the lower panel on the average north/south nadir measurements of the NAST-I at 55,000 feet in the vicinity of the ARM SGP central facility. The feature at 1000 cm^{-1} to 1080 cm^{-1} in the aircraft observations is due to absorption by ozone in the path from the aircraft to the ground. The numerous spikes in the data are due to water vapor and carbon dioxide absorption lines where the approximation leading to Eq. (3) is not valid. The spikes are pointed up because of the presence of a nocturnal surface inversion at the time of the measurements.

Summary

The results show that aircraft observations of relative spectral emissivity in the vicinity of the ARM SGP central facility are generally consistent with a linear combination of the absolute emissivity measured in a ground-based site survey. The comparison of the ARM LSE Survey average emissivity to the average NAST-I and S-HIS emissivities suggests that the aircraft observations have somewhat more spectral contrast than the ground-based S-AERI observations. The differences between the ground-based and aircraft measurements can be explained by several factors: nadir aircraft views are being compared with surface measurements made at a view angle of 60 degrees from nadir (this is especially important for the sparse wheat fields at this time of year), the aircraft fields of view do not exactly overlap with the

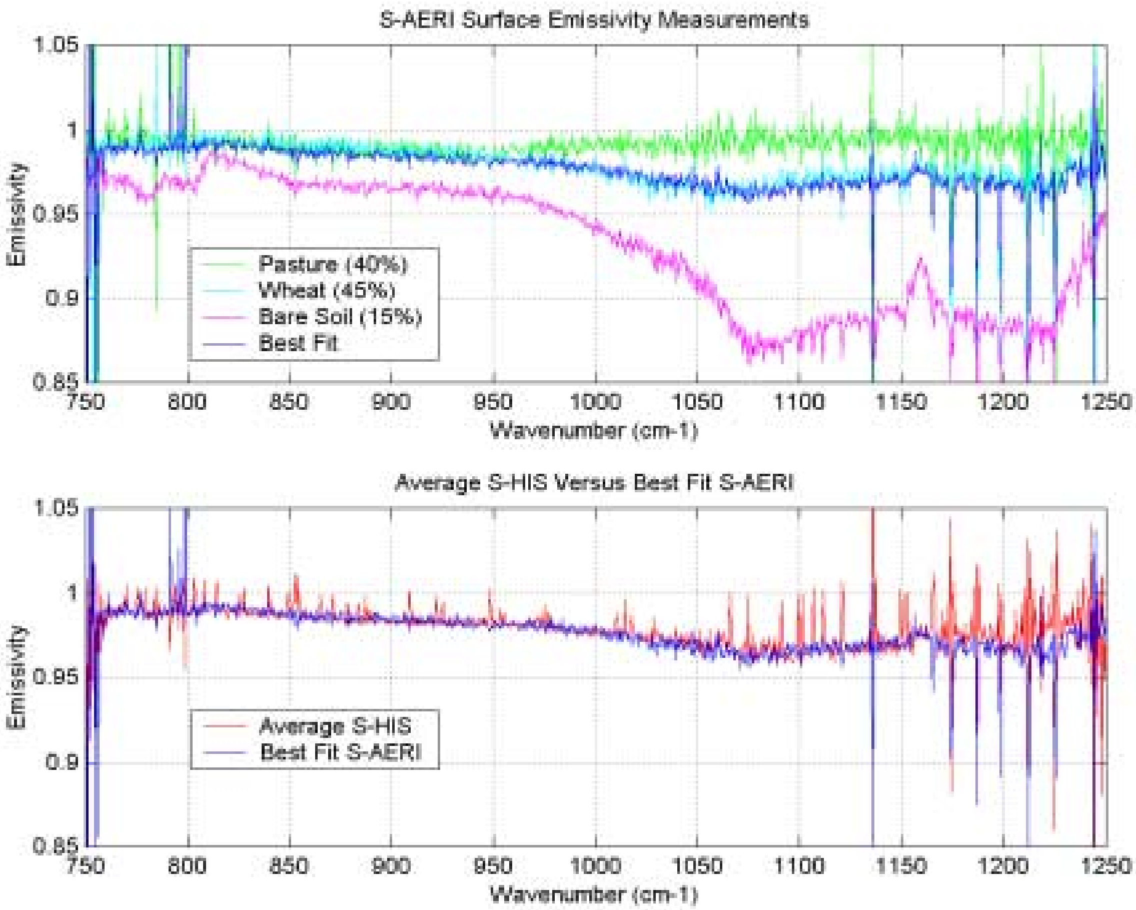

Figure 4. Best fit of a linear combination (40 percent pasture, 45 percent wheat, 15 percent bare soil) of surface emissivity types to the Scanning-HIS aircraft observations made from the NASA DC-8 at 25,000 feet. The flight path of the DC-8 was in the vicinity of the ARM SGP central facility but along a different ground path than the PROTEUS. Notice the lack of ozone absorption at this lower altitude though water vapor absorption lines are still present.

ground survey, and skin temperature differences between bare soil and vegetation are expected to influence the relative weighting of emissivities within an aircraft field of view.

A more comprehensive analysis of the NAST-I and S-HIS data is anticipated to extend the results of the ARM LSE Survey to a larger area of the ARM SGP site. Additional measurements at the ARM site over the next year will help to characterize the seasonal variation of the LSE.

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