A Study of Skin Temperature/Cloud Shadowing Relationships at the ARM SGP Site

D. P. Duda
Center for Atmospheric Sciences
Hampton University
Hampton, Virginia

P. Minnis
Atmospheric Sciences Division
Langley Research Center
National Aeronautics and Space Administration
Hampton, Virginia

Introduction

Accurate estimates of surface “skin” temperature are necessary inputs for many remote sensing techniques including the split-window retrieval of cirrus microphysical properties and the derivation of cloud temperature in semitransparent clouds. In many satellite retrievals, this surface temperature is derived from nearby clear regions (e.g., Minnis et al. 1995). Unfortunately, these temperatures may be warmer or colder than the surface underneath the cloudy region of interest, leading to retrieval errors. In addition, if the area of interest is overcast, no suitable clear-sky region may be available to determine a surface temperature from satellite measurements. Under these conditions, an alternative measurement of the surface temperature is needed.

The surface air temperature (usually measured at a height near 6 feet above the ground) is one possible alternative to satellite-derived skin temperature measurements. However, solar insolation can heat the surface much more rapidly than the air near the surface and produce large differences between the skin temperature and the surface air temperature during the daytime. The effects of solar insolation, therefore, must be accounted for before the surface air temperature can be used as an alternative to skin temperature. To improve estimates of skin temperature in cloudy conditions, this study examines the relationship between skin temperature, surface air temperature, and cloud shadowing at the Atmospheric Radiation Measurement (ARM) Program’s Southern Great Plains (SGP) site. Time series of infrared (IR, 9.6 μm to 11 μm) pyrometer and shortwave (SW, 0.2 μm to 5 μm) radiometer data at the site under overcast and partly cloudy conditions are compared to determine how much measurements of the nadir-viewing IR instrument changes as the SW insolation changes.

Data and Methods

As a first step towards improving estimates of surface temperature in cloudy conditions, we examined the relationship between skin temperature/surface air temperature differences and cloud shadowing at the ARM SGP central facility site under overcast and partly cloudy skies. The equivalent blackbody temperature (BT) measured by the down-looking infrared thermometer (IRT – a wide field-of-view infrared [9.6 μm to 11.5 μm] pyrometer) was used to simulate the satellite-derived skin temperature, while the uplooking Solar Infrared Radiation Station (SIRS) or Baseline Solar Radiation Network (BSRN) pyranometers measured the total downward shortwave (0.2 μm to 5 μm) hemispheric irradiance. The 30-minute average air temperatures measured from the SGP meteorological tower at a height of 2 m were subtracted from the skin temperatures derived from 1-minute averages of the IR pyrometer data. This temperature difference was then compared to the solar insolation observed by the pyranometers for three common types of cloud conditions.

Overcast Skies –October 30, 1999

Overcast skies were observed over the ARM SGP central facility site throughout the day on October 30, 1999. Figure 1 shows time series of the 2-meter air temperature/IR radiometer skin temperature differences (middle panel) and downward SW hemispheric irradiance (bottom panel) at the SGP central facility site on October 30, 1999. Under overcast conditions at night, the 2-m air temperature and skin temperature were within 1 K of each other. In the daytime, the air/skin temperature differences correlated well with the measured solar insolation. A linear regression between the air/skin temperature difference and the solar insolation during daylight hours (from 1300 Universal Time Coordinates [UTC] to 2330 UTC) showed that the correlation factor squared (R^2) was 0.7948. Similar correlations were found when the sky was overcast for most but not all of the day (not shown). This correlation between the skin/air temperature difference and surface solar insolation suggests that skin temperature could be accurately estimated from surface air temperature during overcast and mostly cloudy conditions. Methods to derive downward solar flux from satellite (similar to Li and Leighton 1993) could be used with surface air temperature measurements to determine the skin temperature.

Partly Cloudy Skies –October 28, 1999

The relationship between skin/air temperature differences and the downward SW irradiance at the surface during partly cloudy days is more complicated than during overcast days. Figure 2 shows time series of the 2-meter air temperature/IR radiometer skin temperature differences (middle panel) and downward SW hemispheric irradiance (bottom panel) at the SGP center facility site on October 28, 1999. We can infer from the bottom panel that the site was covered by intermittent cloudiness between 1330 UTC and 1900 UTC, and was under mostly clear skies until sunset around 0000 UTC on October 29, 1999. A linear regression between the air/skin temperature difference and the solar insolation from 1530 UTC to 1700 UTC (top panel – the time period when the downward hemispheric flux is a fraction of its clear-sky value) shows a good correlation similar to that found in the overcast case. However, this correlation does not continue into the afternoon as the skin/air temperature difference becomes negative after 2200 UTC (two hours before sunset). The correlation between the skin/air temperature difference and solar insolation breaks down under conditions when the downward SW surface irradiance becomes large enough to warm the surface air temperature appreciably (i.e., mostly sunny or clear conditions). The atmosphere near the surface reacts much more slowly to the effects of solar insolation than does the surface, and thus in sunny conditions the skin temperature follows the solar insolation closely while the surface air temperature lags the solar irradiance by 1 or 2 hours.

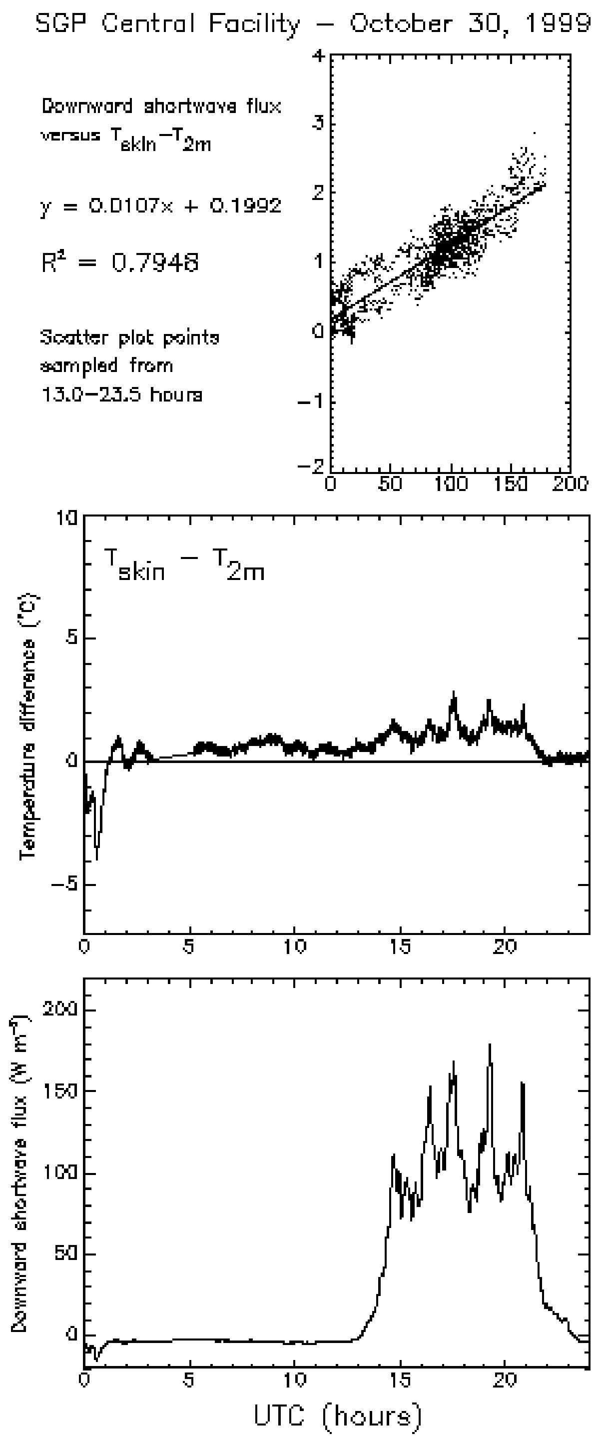

Figure 1. Plot and linear regression of the 2-meter air temperature/IR pyrometer skin temperature difference as a function of downward solar irradiance at the SGP central facility on October 30, 1999 (top panel). Time series of the air/skin temperature difference (middle panel) and of the downward shortwave hemispheric irradiance (bottom panel) measured at the central facility as a function of UTC on October 30, 1999.

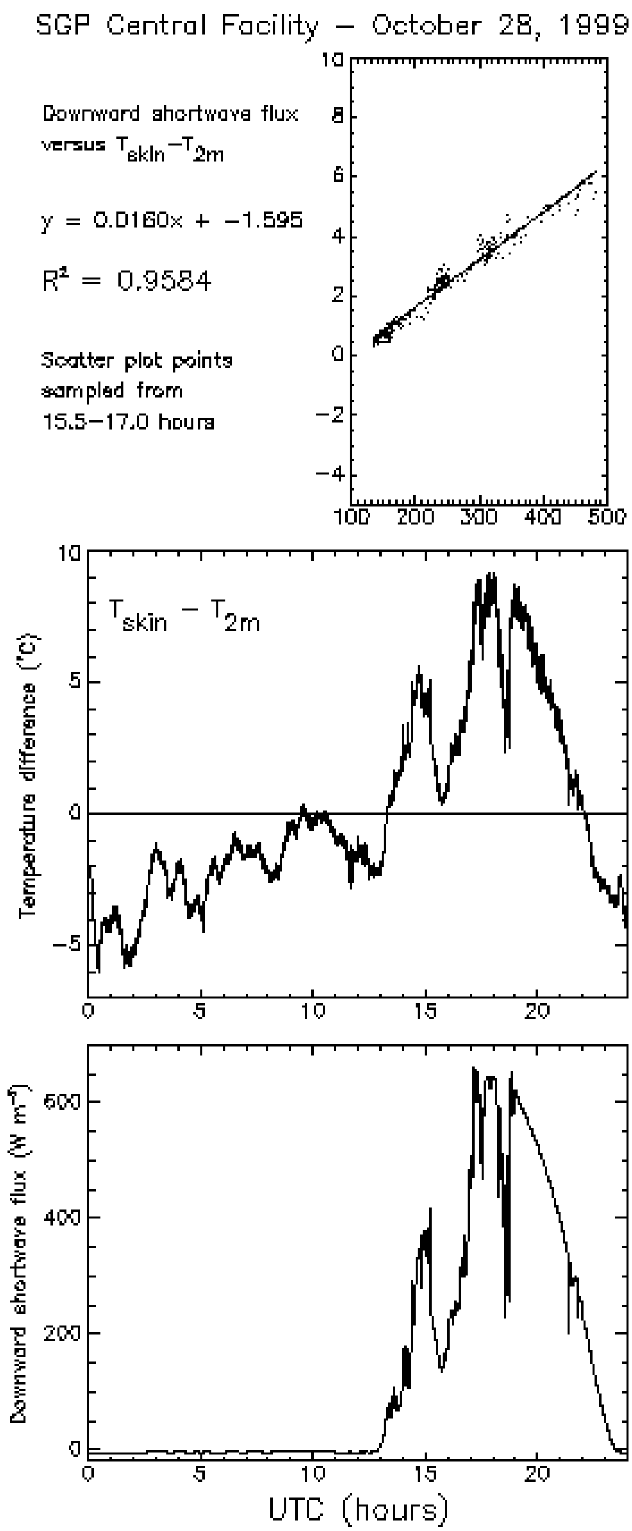

Figure 2. Same as Figure 1, except for October 28, 1999.

Scattered Cumulus Skies –August 19, 1998

Figure 3 shows time series of both the downward shortwave hemispheric irradiance and the IR pyrometer-derived skin temperature measured on August 19, 1998, under skies with scattered cumulus. The skin temperature at the SGP site reacts rapidly to changes in solar insolation. The lag between the SW irradiance and skin/air temperature differences is less than 1 minute. Scattering from cloud sides produced peaks in both the solar insolation and the skin/air temperature differences. Under such cloud conditions, the skin temperature can fluctuate as much as 10 K in 3 minutes.

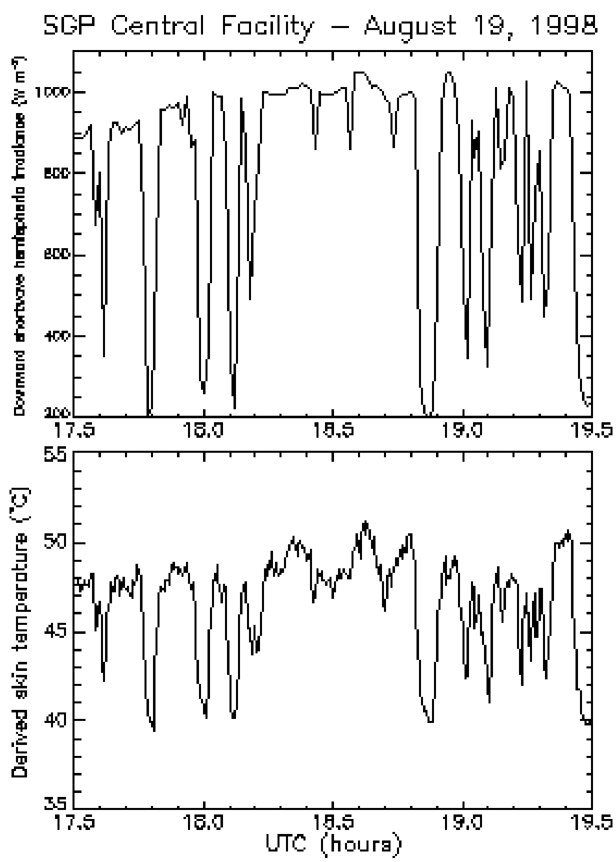

Figure 3. Time series of the downward shortwave hemispheric irradiance (top panel) and the air/skin temperature difference (bottom panel) measured at the central facility as a function of UTC on August 19, 1998.

Figure 4 presents time series of the 2-meter air temperature (dashed line, bottom panel), the IR radiometer skin temperature (solid line, bottom panel), and the skin/air temperature differences (middle panel) at the SGP central facility site on August 19, 1998. A linear regression between the air/skin temperature difference and the solar insolation for the time between 1730 UTC and 1818 UTC and between 1848 UTC and 1942 UTC shows a good correlation. These times were chosen to represent conditions where the solar insolation field was rapidly fluctuating due to shadowing by scattered cumulus clouds, but before the surface air temperature lag became large (note bottom panel).

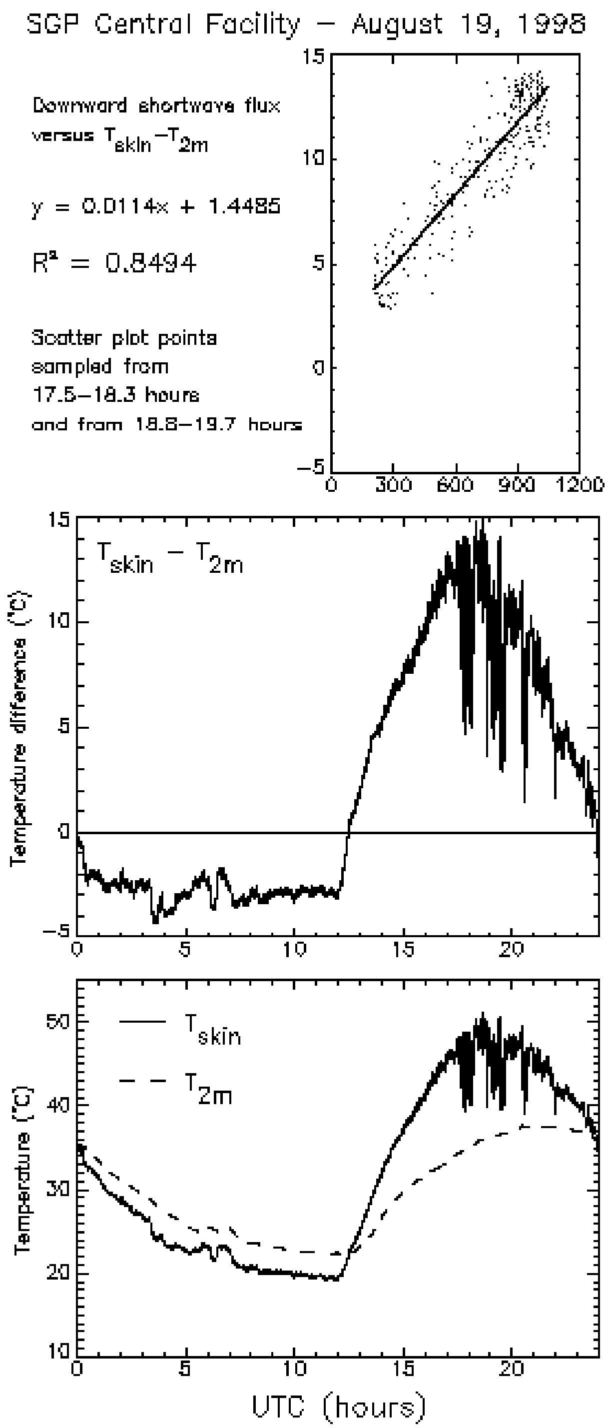

Figure 4. Plot and linear regression of the 2-meter air temperature/IR pyrometer skin temperature difference as a function of downward solar irradiance at the SGP central facility on August 19, 1998 (top panel). Time series of the air/skin temperature difference (middle panel) and of the 2-meter air temperature (dashed line, bottom panel) and the IR pyrometer skin temperature (solid line, bottom panel) measured at the central facility as a function of UTC on August 19, 1998.

Discussion and Future Work

These preliminary results indicate that the skin/air temperature difference remains closely related to solar insolation during overcast conditions, but more study is needed to determine the relationship between skin temperature and air temperature during partly cloudy conditions. We note that errors in skin temperature determination at night also profoundly affect satellite retrievals of cloud properties. At nighttime, the skin temperature remains close to the surface temperature during overcast conditions, but as in the daytime, more study of the relationship between skin and surface air temperature under partly cloudy conditions is needed.

A future goal in determining surface temperatures in cloudy conditions is to use collocated radiometer and satellite data to study how skin temperature relates to the IR brightness temperatures the satellite detects. From the satellite perspective, other factors including variations in surface emissivity obscure the simple relationships between solar insolation and skin temperature presented here.

Acknowledgments

This research was supported by the U.S. Department of Energy (DOE) Interagency Agreement DE-AI02-97ER62341 under the ARM Program. Data were obtained from the ARM Program sponsored by the DOE, Office of Science, Office of Biological and Environmental Research, Environmental Sciences Division.

Corresponding Author

P. Minnis, p.minnis@larc.nasa.gov

References

Li, Z., and H. G. Leighton, 1993: Global climatologies of the solar radiation budgets at the surface and in the atmosphere from 5 years of ERBE data. *J. Geophys. Res.*, **98,** 4919-4930.

Minnis, P., W. L. Smith, Jr., D. P. Garber, J. K. Ayers, and D. R. Doelling, 1995: Cloud properties derived from GOES-7 for the Spring 1994 ARM Intensive Observing Period using Version 1.0.0 of the ARM Satellite Data Analysis Program. *NASA RP 1366*.