

Asymmetry in the Diurnal Variation of Surface Albedo

S. Mayor, W. L. Smith, Jr., L. Nguyen, T. A. Alberta
Analytical Services and Materials, Inc.
One Enterprise Parkway, Suite 300
Hampton, VA 23666

P. Minnis, C. H. Whitlock, G. L. Schuster
MS 420, NASA Langley Research Center
Hampton, VA 23681-0001

S. Mayor: phone, 804-827-4640; fax, 804-827-8659, s.mayor@larc.nasa.gov
P. Minnis: phone, 804-864-5671; fax, 804-864-7996, p.minnis@larc.nasa.gov

Remote sensing of surface properties and estimation of clear-sky and surface albedo generally assumes that the albedo depends only on the solar zenith angle. The effects of dew, frost, and precipitation as well as evaporation and wind can lead to some systematic diurnal variability resulting in an asymmetric diurnal cycle of albedo. This paper examines the symmetry of both surface-observed albedos and top-of-the-atmosphere (TOA) albedos derived from satellite data. Broadband and visible surface albedos were measured at the Department of Energy Atmospheric Radiation Measurement (ARM) Program Southern Great Plains Central Facility, at some fields near the ARM site, and over a coniferous forest in eastern Virginia. Surface and wind conditions are available for most cases. GOES-8 satellite radiance data are converted to broadband albedo using bidirectional reflectance functions and an empirical narrowband-to-broadband relationship. The initial results indicate that surface moisture has a significant effect and can change the albedo in the afternoon by 20% relative to its morning counterpart. Such effects may need to be incorporated in mesoscale and even large-scale models of atmospheric processes.

INTRODUCTION

Remote sensing of surface properties and estimation of clear-sky and surface albedo generally assume that the albedo depends only on the solar zenith angle (SZA). This assumption results in an albedo variation symmetrical about local noon. Both regular and irregular changes in the surface state can negate this assumption. The effects of dew, frost, and precipitation as well as evaporation and wind can lead to some systematic diurnal variability resulting in an asymmetric diurnal cycle of albedo. A combination of satellite and surface albedo measurements are used here to examine asymmetry in the diurnal cycle of clear-sky albedo.

DATA

Geostationary Operational Environmental Satellite (GOES) visible radiance data taken over a 0.3° grid centered on the Atmospheric Radiation Measurement (ARM) Program Southern Great Plains Central Facility (SCF) were converted to visible narrowband and shortwave broadband albedos on a half-hourly basis. GOES-7 and GOES-8 were used for April 1994 and October 1995, respectively. Only data for

completely clear days were considered. Visible albedos were determined by correcting for reflectance anisotropy using the models of Minnis and Harrison [1]. These were converted to broadband albedos using the approach of Minnis et al. [2].

Surface albedos were measured over the SCF using the ARM broadband flux PSP radiometers on a 60-m tower in a wheat field. Other surfaces such as pasture and bare soil are also in the field of view of the downlooking radiometer. During October 1995, albedo measurements were also taken over four different surfaces near the SCF including bare soil, pasture, and newly planted wheat. April 1994 was a relatively wet period, while October 1995 was dry. Vegetation conditions changed between the two seasons. Half-hourly averages were computed from the surface albedo measurements taken over the SCF area. Meteorological conditions were monitored at the ARM SCF. An additional surface albedo data set was taken using a broadband PSP on a 100-m tower over a mixed coniferous-deciduous forest over eastern Virginia during 1995.

RESULTS

Surface albedo data were only available from 2 clear days during April 1994. On April 17, the afternoon albedos were greater than all of the corresponding morning albedos (Fig. 1). A similar variation was observed on April 15, 1994. The average afternoon-morning difference is on the order of 8% for both days. The complete diurnal cycle was not available for these 2 days. However, data were available for April 16 and 26 which were also mostly clear. The mean afternoon-morning difference in clear-sky albedo was slightly less than 2%. The winds were light ($v < 5$ mps) for all of the days. During the month, the ground was often observed to be wet with many puddles after nighttime rains. It did not rain between April 15 and April 17. Dew was noted for the mornings of April 16 and 26.

Many more clear days occurred during October 1995. Clear-sky albedos were observed October 12, 14, 15, 18, 20, 23, and 28. Relative humidity at dawn varied from 88% on October 12 to 46% on October 20. Mean daytime wind speed ranged from 2.5 mps on October 14 to 15 mps on October 23. The half-hourly surface albedos averaged for the SCF and adjacent radiometers are shown in Figs. 2 and 3 for

October 23 and 28, respectively. The mean wind speed varied from

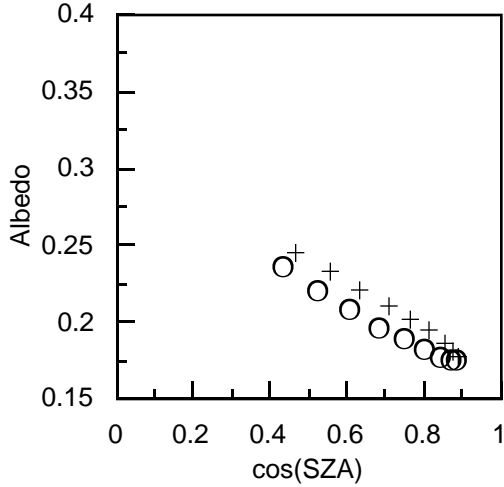


Fig. 1. Comparison of PM (+) and AM (O) broadband surface albedos over the ARM SCF on April 17, 1994.

10-19 mps during the 23rd compared to 1-4 mps on the 28th. The relative humidity (RH) was 48% and 57% at dawn on the 23rd and 28th, respectively. The albedos during the morning and afternoon are almost identical for the same SZA in Fig. 2. On the 28th (Fig. 3), the morning albedos are greater than those observed during the afternoon. The diurnal change in surface albedo during the remaining clear October days was similar to that of the 28th. The SCF radiometers gave results much like the averages for the 5 sites together suggesting that diurnal changes occurred independently of the surface type.

Figs. 4 and 5 show the GOES estimates of top-of-the-atmosphere broadband albedo for the same two days over the SCF area. The diurnal changes in clear-sky albedo during the 23rd and 28th are very similar to their surface-observed counterparts. Diurnal changes in clear-sky albedo during the other days are comparable to those seen on October 28 indicating consistency between the surface and satellite measurements. The GOES narrowband visible albedos revealed even greater morning-afternoon differences.

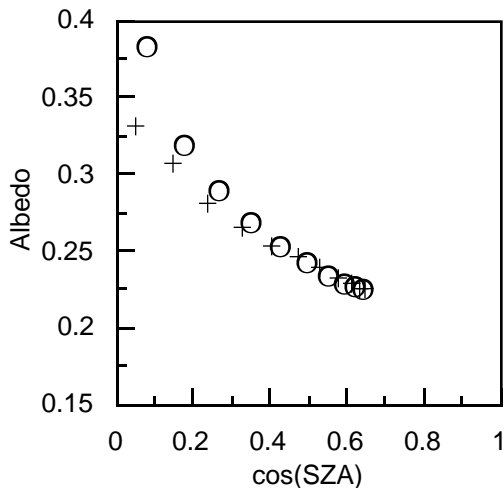


Fig. 3. Comparison of PM (+) and AM (O) broadband surface albedos over the ARM SCF on October 28, 1995.

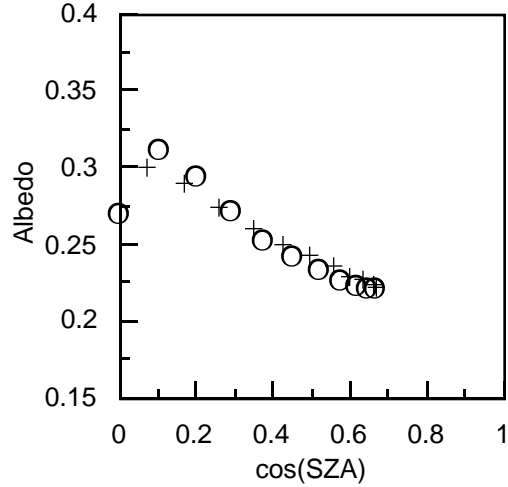


Fig. 2. Comparison of PM (+) and AM (O) broadband surface albedos over the ARM SCF on October 23, 1995.

Together, the satellite and surface measurements provide evidence that the surface albedos are not symmetrical about local noon in many cases over the prairie and pasture of the southern Great Plains.

Data taken over the forest in Virginia also show a morning-to-afternoon asymmetry in surface albedo. The greatest observed change was seen during November 22, 1995 (Fig. 6). In this case, the deciduous trees were leafless, exposing some of the forest floor to direct solar illumination. A similar behavior was seen during other seasons over the forest, but to a lesser degree.

DISCUSSION

Different diurnal changes were observed over the SCF during April 1994 and October 1995. From the present data set, it is difficult to conclude why the afternoon albedos were greater than those in morning during April and less during October. Knowledge of the vegetation state is required.

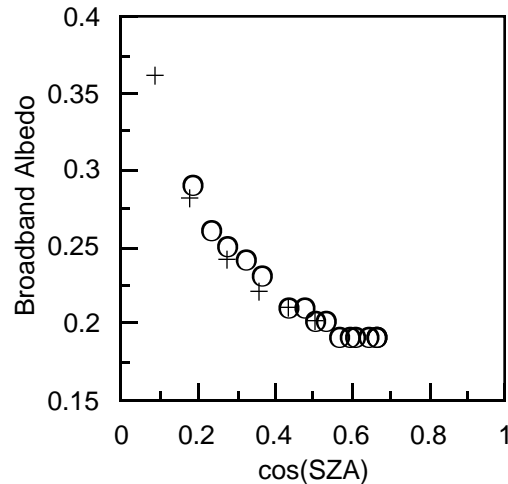


Fig. 4. Comparison of PM (+) and AM (O) broadband TOA albedos over the ARM SCF on October 23, 1995.

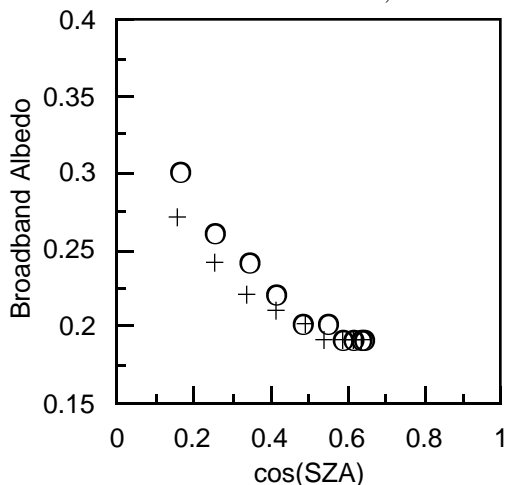


Fig. 5. Comparison of PM (+) and AM (O) broadband TOA albedos over the ARM SCF on October 28, 1995.

There are obvious differences in soil moisture because of the relatively frequent April rains. Perhaps, the ground was moistened by the formation of dew during the night. Solar heating would dry the soil during the day raising the afternoon albedo. This type of effect would require some exposed soil in the surface radiometer field of view. The smaller change observed in the satellite data may indicate that the surface observations may only represent a small portion of the area. More measurements will be required to understand these observations

During October, drying occurred progressively during the month. In light winds, overnight radiative cooling will tend to produce dew on many exposed surfaces depending on the relative humidity and winds. Dew on most vegetation should increase the albedo because of the water droplet scattering. After the dew is evaporated by midmorning, the albedo should be nearly symmetrical for the times remaining around local noon.

To test this hypothesis, a measure of the diurnal change is introduced. The morning albedos are fit with a cubic polynomial. This fit is used to interpolate the morning albedos to the solar zenith angles of the afternoon observations. The average of the differences between the interpolated morning and observed afternoon albedos quantifies the diurnal change. Only data taken for SZA less than 85° are used. For October 28th, this mean difference is 4.2% compared to 0% on the 23rd. The greatest difference was 7.5% on October 15. These seven relative diurnal albedo differences were correlated with the mean daytime wind speed and dawn RH. The squared linear regression coefficients are 0.59 and 0.50, respectively. The correlation with wind speed is negative, indicating less diurnal change with increasing wind speed. Using these quantities as an indication of the probability of dew suggests that the observed changes in albedo over the course of the day are likely to be a result of the occurrence of dew on the vegetation overnight.

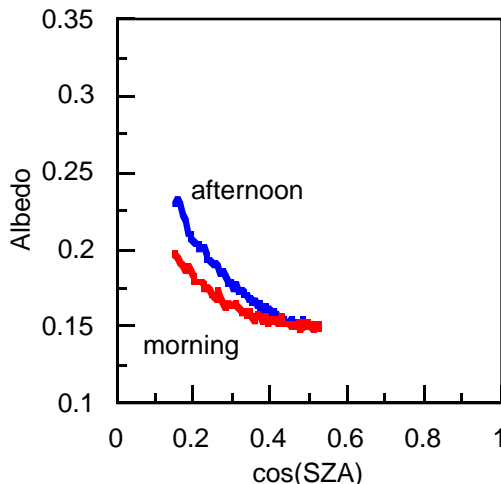


Fig. 6. Comparison of PM and AM broadband surface albedos over eastern Virginia on November 22, 1995.

CONCLUDING REMARKS

These results are limited to a relatively small data set. However, at least during October, they are consistent with intuitive and physical theory about the effects of dew on albedo. During the early morning, the surface albedo can be 20 to 30% greater than the corresponding afternoon albedo. If measurements are taken during the early morning from a satellite such as the NOAA polar orbiter, the clear-sky albedo may be significantly overestimated for the remainder of the day. Thus, effects due to diurnal surface moisture variability should be considered in the remote sensing of clear-sky albedo. Additional measurements should be examined to determine how such changes vary with surface type and season.

ACKNOWLEDGMENTS

Research supported by Department of Energy, Inter Agency Transfer agreement (ITF# 2142216AQ1) through Pacific North-West Labs and by DOE ARM UAV program.

REFERENCES

- [1] P. Minnis and E.F. Harrison, "Diurnal variability of regional cloud and clear-sky radiative parameters derived from GOES data; Part III: November 1978 radiative parameters," *J. Climate and Appl. Meteorol.*, Vol. 23, pp. 1032-1052, July 1984.
- [2] P. Minnis, W.L. Smith, Jr., D.P. Garber, J.K. Ayers, and D.R. Doelling, "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, 59 pp., August 1995.