Surface Albedo at the Atmospheric Radiation Measurement Southern Great Plains Site from Helicopter Observations

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Introduction

In August 1998, scientists from the National Aeronautics and Space Administration (NASA) Langley Research Center conducted a series of helicopter flights to determine spectral bidirectional reflectance distribution functions (BRDFs) using a scanning field spectrometer mounted below the aircraft. The experiment named CERES (Clouds and Earth's Radiant Energy System) ARM (Atmospheric Radiation Measurement) Radiation Experiment (CARE) also carried a precision spectral pyranometer (PSP). Beyond BRDF patterns, several flights sampled upwelling flux in an area the approximate size of a footprint from the CERES instrument (Wielicki et al. 1996), which was on board the Tropical Rainfall Measuring Mission (TRMM) satellite. These were flights of opportunity with six completed at different solar zenith angles (SZAs). The CERES Surface and Atmospheric Radiation Budget (SARB) group models heating and cooling rates beneath each CERES footprint (~20km), requiring an estimate of surface albedo for its lower boundary condition. In global production runs, surface albedo is estimated with a top of atmosphere to surface parameterization (Rutan and Charlock 1999). CARE flights were meant to validate the surface albedo parameterization used in SARB production runs. Comparisons of CERES-derived surface albedo and albedos derived from 10m-tower observation are of limited use due to spatial mismatch of the two observations. To make this helicopter-CERES comparison, it is necessary to "remove" the atmosphere between the helicopter and surface. Atmospheric modeling is done using the Fu and Liou radiation transfer model (Fu and Liou 1993), ARM profile information and aerosols, and albedo spectral shape from the CARE experiment. Surface albedo is then adjusted such that model fluxes approximate those observed by the PSP at helicopter altitude. These "tuned" albedos are averaged over the entire flight path and compared with those determined via the CERES/SARB algorithm. It is found that surface albedos derived in this way match well with SARB albedos when SZAs are small but they do not show a change with SZA. Comparing estimates of broadband albedo, via integration of spectral radiometer data, indicates a possible calibration problem with the PSP on the helicopter.

Helicopter Observations

Data for CERES footprint flights were taken August 18, 19, and 20. Figure 1 shows (inset) the mirror image "S" shape pattern flown with the ARM Central Facility (CF) at the center of each flight. With all flights flown at 1 km altitude and a nominal PSP half power at 45deg, this implies a footprint size of 2km diameter. The instrument sampling rate was 3 Hz and measurements were subject to high frequency instrument noise as well as noise due to aircraft pitch/yaw/roll (fugoid motions). Figure 1 shows flight observations, times, and locations on August 18 (Julian day 230). This day had complete flights at three different SZAs with flight paths indicating the flight crew did an excellent job of keeping the helicopter within plan designs for each run.

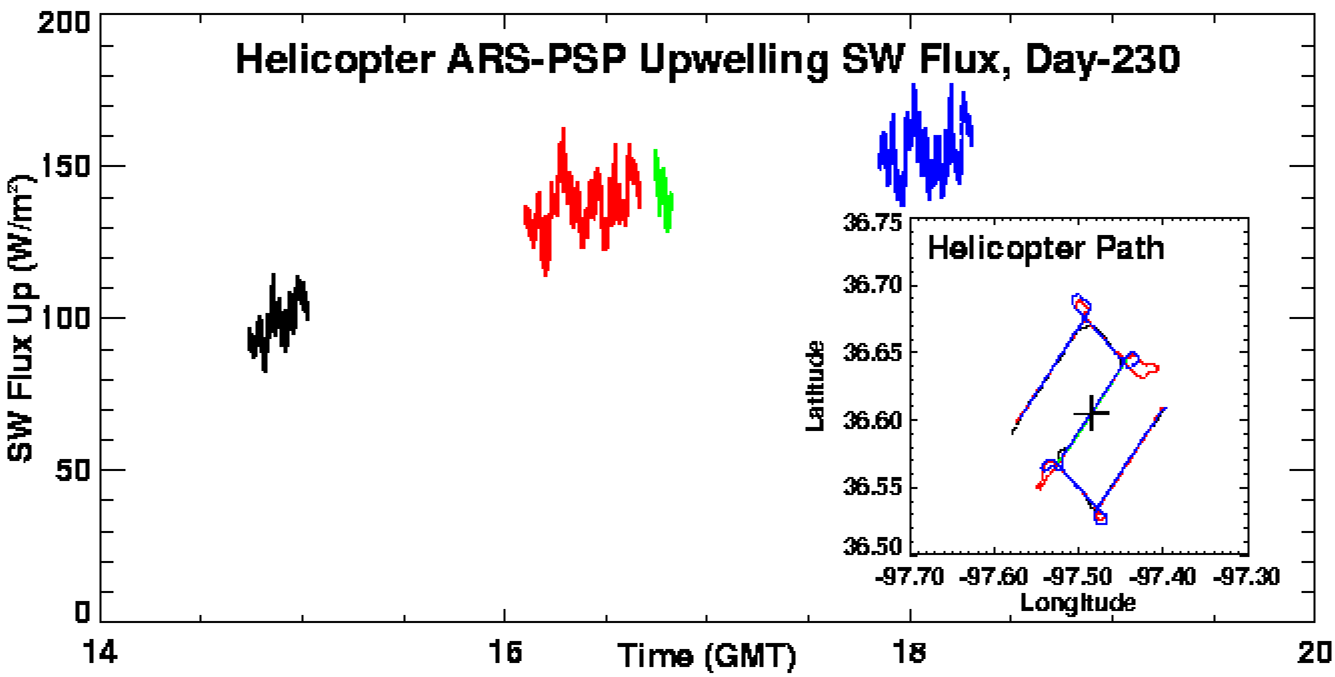

Figure 1. Helicopter PSP flux observations on August 18, 1998. Inset shows helicopter flight path with the ARM CF centered on the third leg of each flight.

Two numerical filters were applied to remove noise within the flux observations. A "Lee" filter (Lee 1986), with a neighborhood of 12 points (4 seconds) was used to remove high frequency electronic noise. Because fugoid motion frequency was on the order of 5 to 10 seconds depending on ambient conditions, a moving average filter of 30 points, 10 seconds was used to remove this portion of the signal. The effect of filtering is seen in Figure 2. All data was processed in a like manner. The top two plots show original data, with high frequency, noise and its spectra. Bottom left shows the first few hundred points with first electronic noise removed by the Lee filter (red line), then fugoid motion removed by the moving average filter.

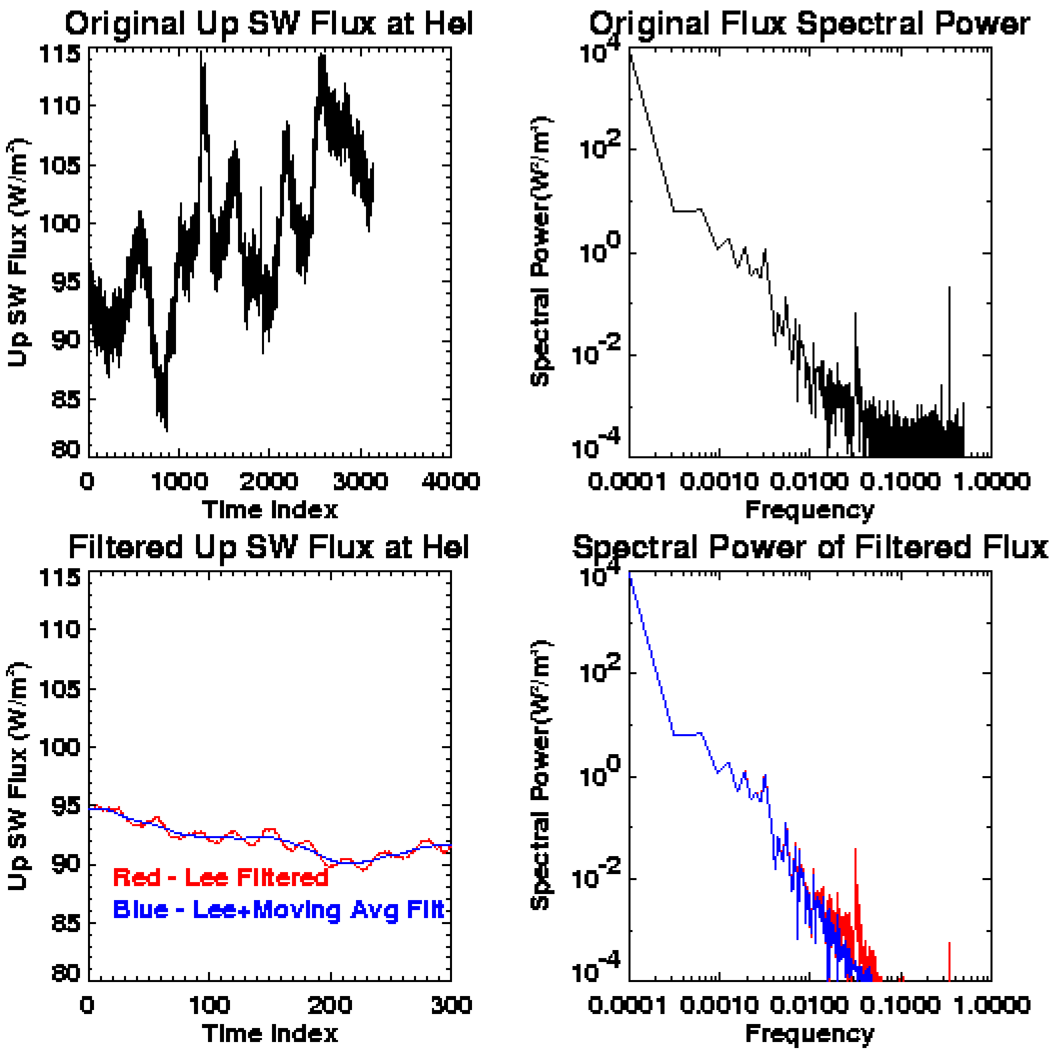

Figure 2. Original PSP observations and spectra (black lines) and filtered data and spectra (red/blue lines.)

Radiation Transfer Model/Inputs

The radiation transfer model used to remove the atmosphere between helicopter and surface was a modified version of that developed by Fu and Liou. It is a delta-two stream (2 for SW, 2/4 for LW) with 15 spectral bands from 0.2 to 5.0 µm in SW and twelve spectral bands between 2850 and 0 cm^{-1} in LW. ARM Geostationary Operational Environmental Satellite (GOES)/Atmospheric Emitted Radiance Interferometer (AERI) value-added product supplied meteorological profile data (Feltz et al. 1998).

Figure 3 shows a variety of crops seen by the PSP as it flew. Since it was not practical to determine the percentage of each crop type within the field of view, an average of four CARE spectral albedos were used to supply spectral albedo shape for each model run.

Figure 3. Video image of CF during CARE flight on August 18, 1998.

CARE spent most of its effort measuring spectral BRDFs over specific scene types (Zhou et al. 2001). Once BRDF flights were complete spectral albedos of the four crop types were measured in a separate series of flights at lower altitude where downwelling spectral flux was measured by an up looking field spectrometer with a diffuser. These spectral albedos are plotted in Figure 4. The spectral albedos were integrated in wavelength to match the Fu and Liou SW band limits (black lines in Figure 4) then spectral shape was adjusted to match broadband albedo observed by ARM E13 radiometers for initial model runs.

Aerosol profile information was taken from aerosol extinction profiles observed real time by the Raman lidar at 355nm at the ARM CF. Extinction profiles were normalized such that, if integrated vertically, the integral equaled 1.0. These profiles of "weights" were then used to distribute the vertically integrated spectral aerosol optical thickness (AOT) at other wavelengths observed by the multi-filter rotating shadow-band radiometer (MFRSR), supplied by the Atmospheric Sciences Research Center (ASRC) Solar Group of the State University of New York (SUNY) at Albany (http://hog.asrc.cestm.albany.edu). A spline fit provides spectral AOT at wavelengths not covered by the MFRSR. During August 18 through 20 there was a significant aerosol layer above 850hPa (above the helicopter) carried in on south to southwest flow from fires in Mexico. A global scale run of the Model for Atmospheric Transport and Chemistry (MATCH) (Collins et al. 2001), a complex chemical transport model that assimilates both AOT (from AVHRR over the ocean and meteorological parameters (from 12 hourly National Centers for Environmental Prediction [NCEP] analyses) was used to designate the aerosol constituents for each day. MATCH provides the optical depth of respective aerosol types. Using spectral AOT based on MFRSR, we further assigned asymmetry parameters and single-scattering albedos according to the fraction of dust, soot, etc., produced by MATCH. Asymmetry parameters and single-scattering albedos tabulated by OPAC (Hess et al. 1998) and Tegen and Lacis (1996) were used for each aerosol type. The MATCH constituents used, shown in Table 1, are consistent with aerosols associated with significant burning.

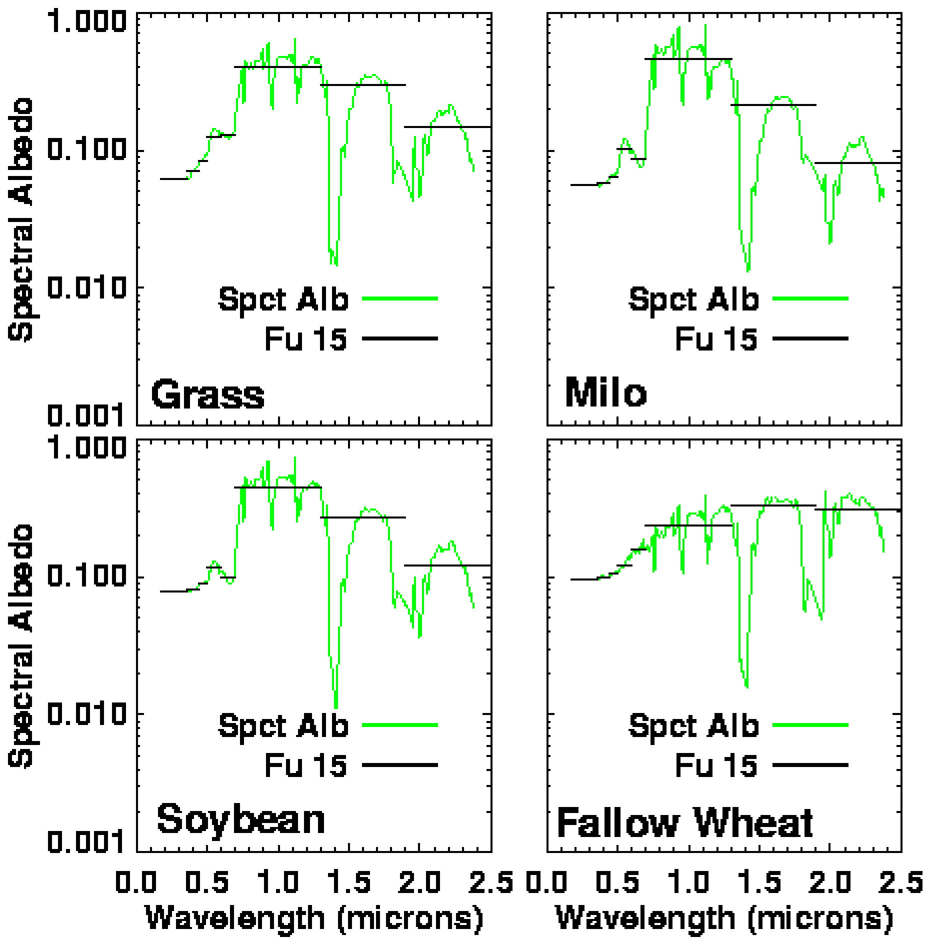

Figure 4. Spectral albedos derived from spectral radiometer BRDF flights for various scene types. (Data is available from http://www-svg.larc.nasa.gov/).

Table 1. Aerosol constituents used in model calculations from MATCH

Aerosol Type	18-Aug	%Aerosol Each Day 19-Aug	20-Aug
0.5um dust	49%	47%	36%
Sulfates	35%	36%	46%
Continental	11%	12%	12%
Soot	4%	4%	4%
Insoluble Carbon	1%	1%	2%

A check of model inputs is accomplished by comparing untuned model downwelling shortwave (SW) flux against observations by the E13 up looking PSP. Results in Figure 4 show that model insolation matches well with observations. In each case the difference is less than 3% (15W/m^2.)

Comparison with SARB Surface Albedo Retreivals

For final analysis, the Fu and Liou code is run once every 40 seconds along the flight path and surface albedo is adjusted (tuned) such that SW model flux up at helicopter altitude matches that observed by the helicopter borne PSP. These tuned surface albedos are then integrated along the flight path for comparison with those derived during global processing of SARB for CERES footprints near the ARM CF during the month of August 1998. Black dots in Figure 5 show all clear-sky CERES/SARB-derived surface albedos within 30 km of the CF during August 1998. The black line is a second order fit to those data. Large blue dots show the problem of trying to match E13 (10m tower) albedos against those derived from a much larger CERES footprint. In almost all cases, the SARB-derived albedo is darker than those calculated from tower observations. The large red dots are average albedos for CARE flights derived as specified above. Vertical bars indicate 1-sigma variability along the flight path. It is clear that the surface albedos derived from helicopter observations match better with CERES/SARB surface albedos at high sun angles.

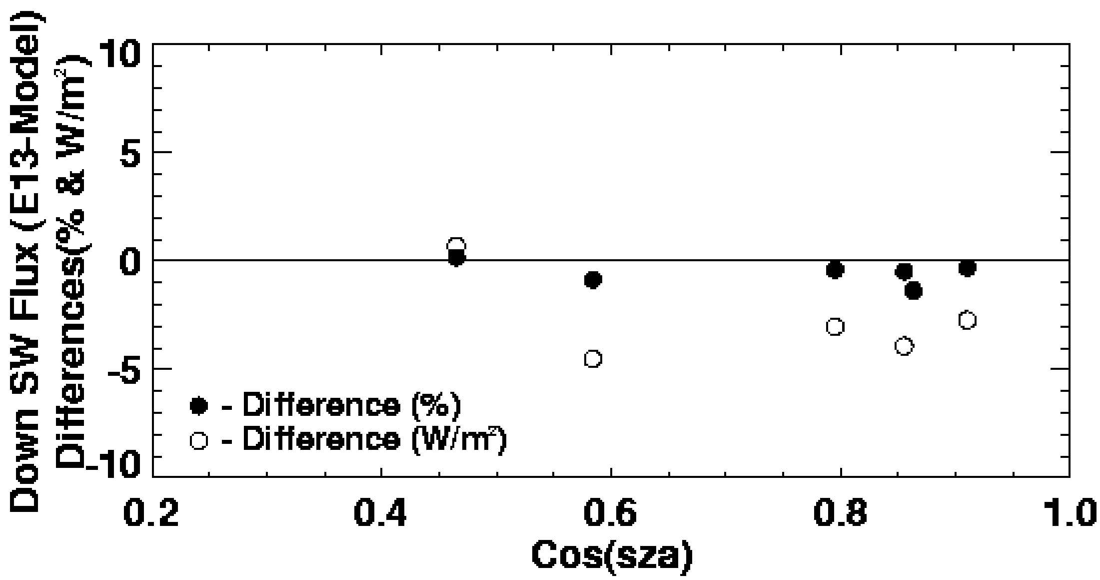

Figure 5. Comparison of model SW insolation with E13 PSP observations.

The lack of change in helicopter based surface albedo (red circles in Figure 6) with respect to SZA was at first attributed to the complicated nature of aerosols during this time period. However, a comparison of the helicopter borne PSP and spectral radiometer indicate it is more likely due to the PSP observations. Figure 7 shows albedo at helicopter altitude for both instruments as the helicopter passed above the CF during CERES footprint flights. In these results flux up is observed by the field spectrometer (integrated in wavelength) and the PSP. The online (http://www-cave.larc.nasa.gov/jin/rtest) radiation transfer model of Jin et al. (2002), provided short wave flux down at helicopter altitude. Here we find the broadband albedo inferred from the PSP does not trace the change, with respect to SZA, of broadband albedo inferred by integrating the spectral radiometer. Experiments flown

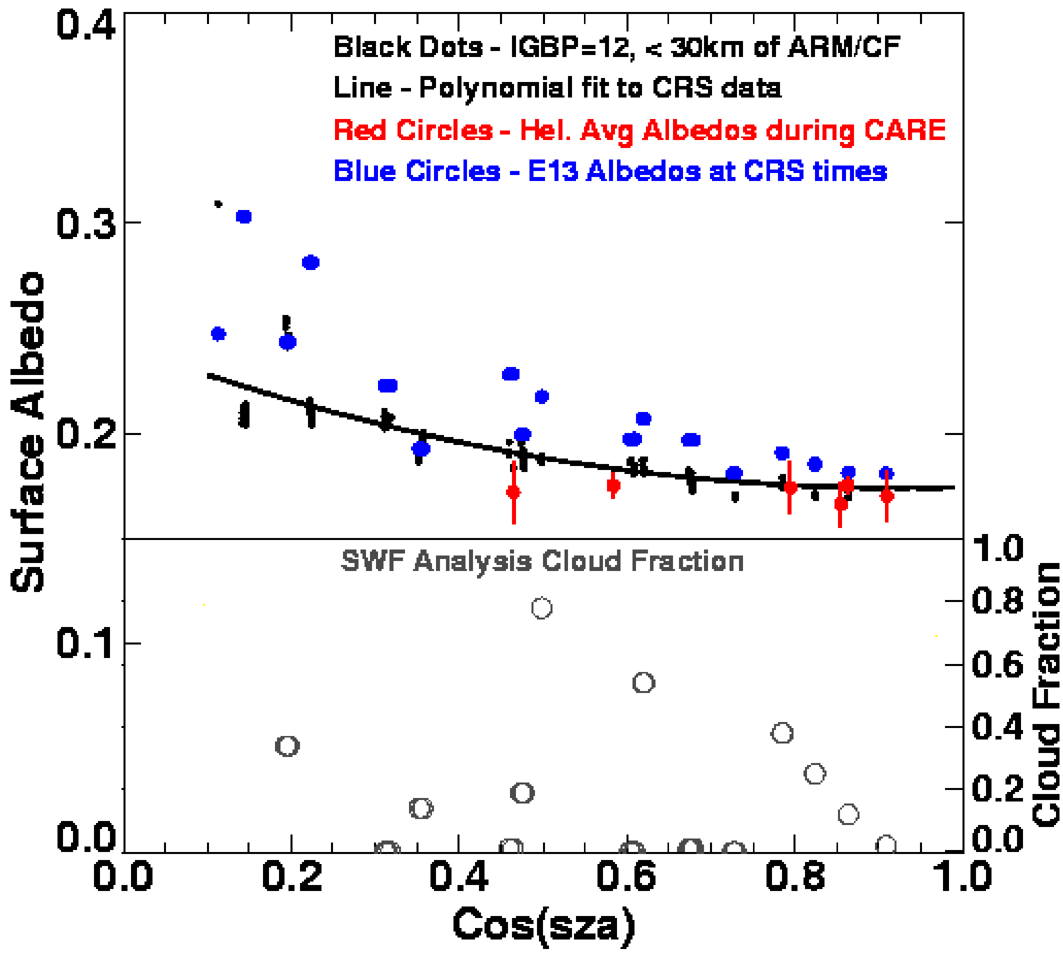

Figure 6. Comparison of final tuned albedos, integrated over the helicopter flight path, with CERES/SARB surface albedo derived from CERES top of the atmosphere (TOA) fluxes.

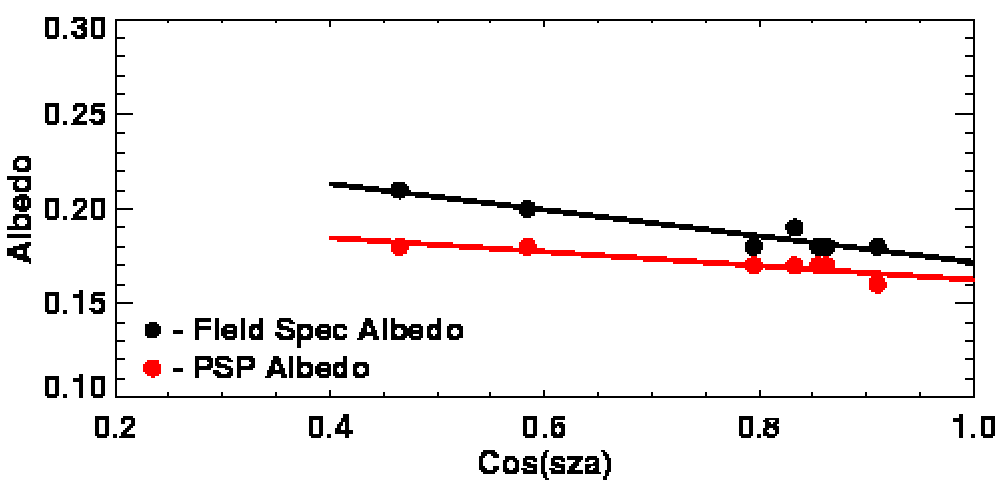

Figure 7. Comparison of albedos at helicopter altitude (downwelling SW flux from the COART model http://www-cave.larc.nasa.gov/jin/rtest) showing spectral radiometer and PSP albedos do not track one another.

on NASA Langley's OV-10 aircraft, where similarly both a PSP and spectral radiometer are mounted, show when each is properly calibrated observations of albedo track each other with respect to sun angle over the course of a day. (Personal communication, Bill Smith.)

Acknowledgement

Atmospheric Radiation Measurement data is made available through the U.S. Department of Energy as part of the Atmospheric Radiation Measurement Program.

CARE data is made available through NASA Langley Research Center's, Atmospheric Sciences Competency, CERES Surface and Airborne Radiometry Calibration group and was downloaded from their Website: http://www-svg.larc.nasa.gov/.

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