Simultaneous Spectral Albedo Measurements Near the ARM SGP Central Facility

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Introduction

During ARM Enhanced Shortwave Experiment II (ARESE II) the Twin Otter aircraft made low-altitude (100-300-m) passes over the Central Facility (CF) at the Southern Great Plains (SGP) Clouds and Radiation Testbed (CART) site as part of the flight pattern design for the experiment. The National Aeronautics and Space Administration (NASA) Ames Research Center's Solar Spectral Flux Radiometer (SSFR) (Pilewskie et al. 2002) made frequent zenith-viewing and simultaneous nadir-viewing irradiance measurements on these flight legs with spectral measurements usually covering the 350-1670-nm wavelength range.

The only routine surface albedo measurements at the CF are two sets of Multi-filter Radiometer (MFR) measurements looking down from a 10-meter tower situated above ungrazed pasture and looking down from the 25-m level of the 60-meter tower situated above a wheat field. These two sites were selected because they are the principal surface types in the area surrounding the CF. There are six, 10-nm-wide filters centered near 415, 500, 615, 673, 870, and 940 nm in the MFR heads. There are two Multi-filter Rotating Shadowband Radiometers measuring downwelling spectral irradiance in the central cluster of instruments at the CF using these same wavelengths, thus enabling us to calculate albedo.

On one of the overcast ARESE II measurement days (March 3, 2000) handheld spectral measurements were made over wheat field, pasture, and dry cornfield sites near the CF with an Analytical Spectral Devices (ASD) spectrometer covering the 350-2340-nm wavelength range.

A critical input to downwelling, shortwave irradiance models is the effective surface albedo, especially on overcast days. Clouds more effectively redirect photons to downwelling sensors than do cloudless skies.

This paper examines the level of agreement among these three measurements. A parameterization of the MFR albedo measurements is explained. A comparison of spectral and broadband downwelling irradiance calculations is made using spectrometer-based albedos and the parameterized MFR albedos for optically thin and optically thick clouds.

Some Details

The SSFR measures spectral flux (irradiance) in the nadir and in the zenith between 350 and 1670 nm with 8-12 nm spectral resolution. The spectrometers were mounted on the Twin Otter aircraft during ARESE II and the data were corrected for pitch, roll, and yaw. For the instantaneous comparisons of the SSFR with ground measurements we used the navigation data from the Twin Otter. The latitude and longitude are recorded to the nearest 0.0001 radian. At cruising speed near 60 m/sec the navigation system typically had the same latitude and longitude to this precision for about 12-13 seconds or for about 700-800 meters of travel. We took the mid point as the time when the aircraft was closest to the central radiometer cluster at the CF.

The MFR measurements made on the 10-and 25-meter towers did not receive frequent calibrations because instruments selected showed good filter stability before deployment. The 10-meter tower MFR went two years between calibrations and showed generally less that 10% degradation. We used a linear degradation in time to estimate its calibration during the measurements shown here. The 25-meter tower MFR went three years between calibrations. It showed 12 to 15% degradation in all except one filter that changed by 36% (although this 415 nm wavelength has low reflectivity). These were corrected assuming a linear degradation in time.

The ASD FieldSpec® spectrometer covers the 350-2340-nm spectral range with a spectral resolution between 3 and 10 nm. The unit was used to measure downwelling and upwelling irradiance by hand in the vicinity of the CF. Green wheat with some visible dark brown soil was observed, as was dead pasture grass with no soil visible. Data over a harvested cornfield were also taken, but were not included in the paper, because this is a minor component of the CF albedo.

Results

Figure 1 is intended to orient the reader to the task of measuring surface albedo near the SGP CF. It includes no actual measurements from the sight, but it contains typical albedos (Bowker et al. 1985) that might be found near the CF. All vegetation in this figure indicates fairly low albedo values below about 700 nm that rise sharply to higher values of between 30 and 60% reflectivity in the near infrared and then fall gradually at wavelengths beyond about 1300 nm. Soil reflectivity, on the other hand, rises monotonically from the visible and through a good portion of the near infrared before leveling beyond about 1500 nm. Most of what surrounds the CF is vegetative except during parts of the year when the fields are tilled for planting or when there is snow cover. Therefore, what you might expect for the CF albedo is some composite of albedos similar to these. The amount of radiation reflected depends, of course, on the amount incident. The red curve is a spectrum of total horizontal irradiance for a solar zenith angle (SZA) of the sun at 26°. Note that much of the incident solar radiation is at wavelengths that reflect rather poorly from vegetation.

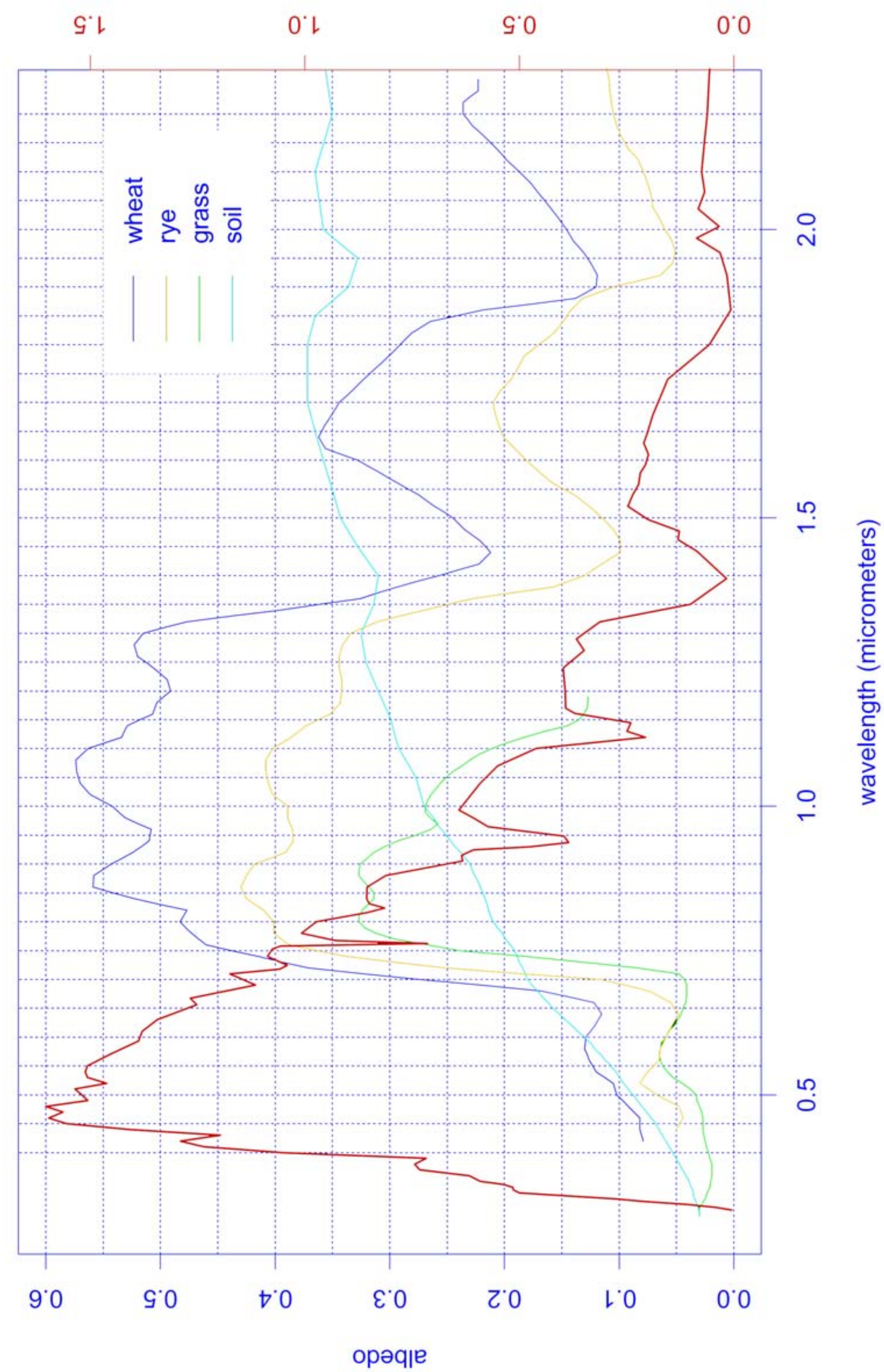

Figure 1. Examples of albedo types that are found around the SGP CART CF. The red plot is a clear-sky irradiance spectrum (ordinate on the right in red). Clearly most of the shortwave irradiance is in the portion of the spectrum that reflects poorly from vegetation.

Figure 2 contains albedo measurements made near the CF on an overcast day (March 3, 2000) during ARESE II. The yellow line is the SSFR measurement at the point when we estimated that the Twin Otter was nearest the central cluster of radiometers as described earlier. The blue line is the average of all measurements for that particular 5-minute leg. SSFR measurements above 900 nm were not available for this leg of the flight. The green and red lines were obtained over grass and wheat, respectively, using the ASD hand-held spectrometer. The grass does not show a sharp near-infrared increase because it is dead pasture grass that has not yet started to grow after the winter kill. The red and light blue points are MFR measurements from the 25- and 10-meter towers over wheat and dead pasture grass, respectively. These three sets of measurements, over similar surfaces in Figure 2, show the same general behavior with wavelength. The SSFR measurements show a sharp increase near 700 nm suggesting a greater influence of greening vegetation, but slightly less so over the CF than over most of the flight leg (compare blue and yellow lines).

Figure 3 is a plot of three spectral albedos, based on the data in Figure 2, that were used to calculate the downwelling spectral irradiances for optical depth 10 and optical depth 20 layer clouds. The light blue line is an average of the ASD wheat and dry pasture albedos. The yellow line is a combination of SSFR measurements and a parameterization for the rest of the near infrared where we did not have measurements. The average of the data between 750 and 900 nm is taken as a constant albedo from 900 to 1300 nm. From 1300 nm it drops linearly to zero at 3000 nm. The green line is a parameterization using a straight line fit to the four shortest wavelength filters from both MFRs. A constant based on the average of the two longest wavelength filters from both MFRs is used between 750 and 1300 nm. A linear interpolation connects 700 and 750 nm, and another linear interpolation is used between 1300 nm and an assumed value of zero albedo at 3000 nm. The 1300- to 3000-nm parameterizations are based on the general tendencies of vegetative surface albedos (see Figure 1).

Figure 4 contains results from the calculations of the downwelling spectral irradiance for the three different albedos in Figure 3. In the left of the figure are the differences for the optical depth 10-cloud layer, and on the right are the differences for the optical depth 20-cloud layer. The differences in downwelling spectral irradiance are relative to the SSFR with the ASD in blue and the MFR in red. The spectral differences are typically less than 5%. Integrated over the shortwave we get broadband irradiance differences of ~0.01% and ~0.02% for the optical depth 10 and 20 clouds, respectively.

Figure 5 contains measurements for another overcast day later in the same month. The blue lines are every measurement in a low-altitude flight leg. One can see the significant variation that occurs over a 16-km leg. The yellow line is the flight-leg average albedo, and the green line is the albedo when the Twin Otter is most nearly over the central cluster of the CF. The MFR measurements for this flight leg are shown as is our parameterization of the six wavelength measurements. In both Figures 2 and 5, which are overcast days, the SSFR measurement closest to the CF and the MFR measurements are consistent although the MFR albedos are, of course, highly parameterized.

On April 5, 2000, multiple low-altitude legs were flown over the CF. It was a clear day. In Figure 6 we plot only the albedos for the measurements that we estimate, using the procedure described earlier, are the closest to the CF on each particular low-altitude leg. This gives us some idea of the uncertainty associated with our assumption that the mid-point of the CF overpass is our best estimate of albedo from the SSFRs as regards comparison to MFR albedos.

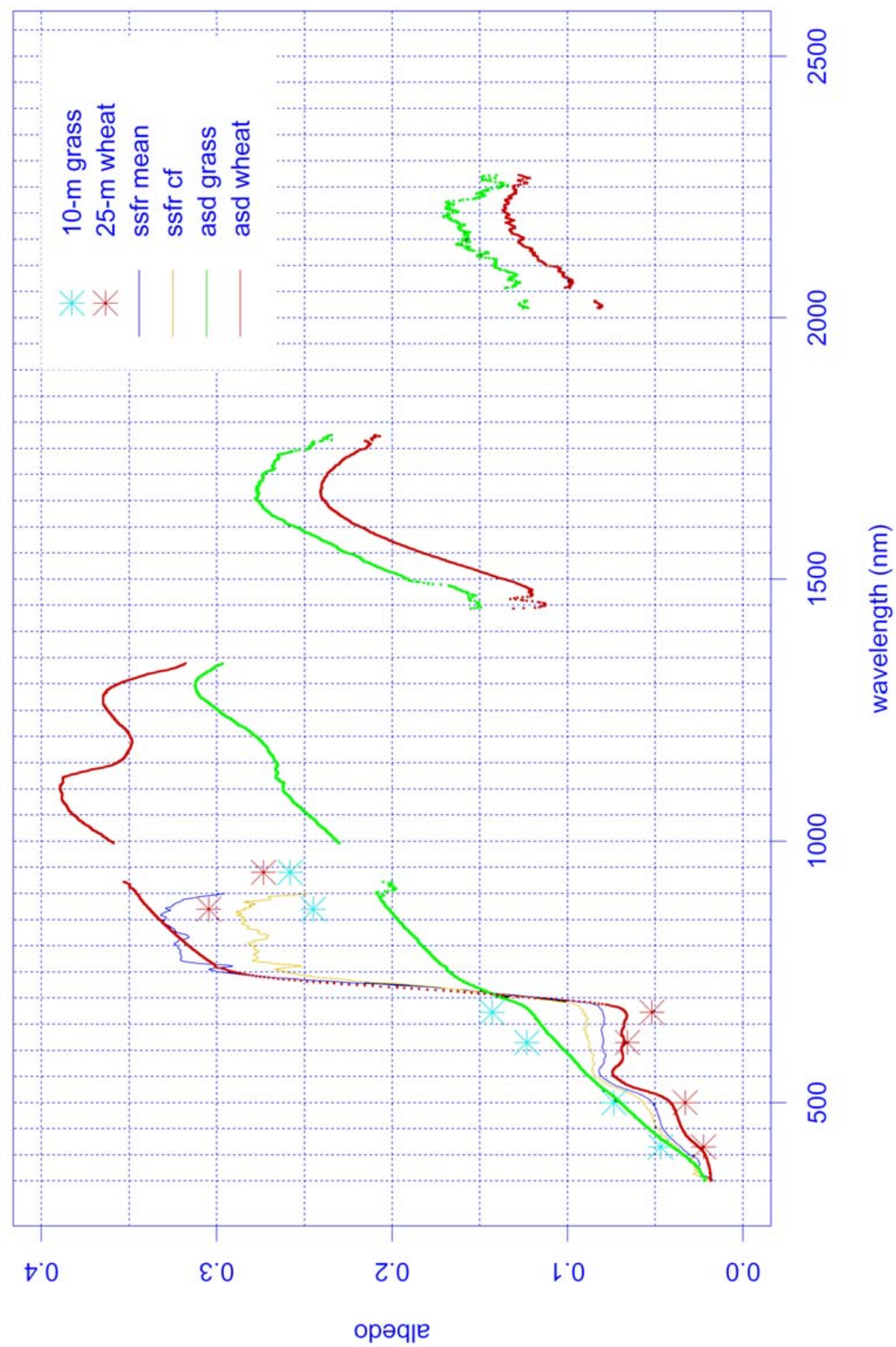

Figure 2. Measured albedos on March 3, 2000. The yellow ssfr data are assumed to represent the albedo directly over the CF. The blue ssfr data are the averaged albedos from all measurements along a single low-level flight leg. Handheld asd measurements are red and green lines and the mfr tower measurements are at six specific wavelengths.

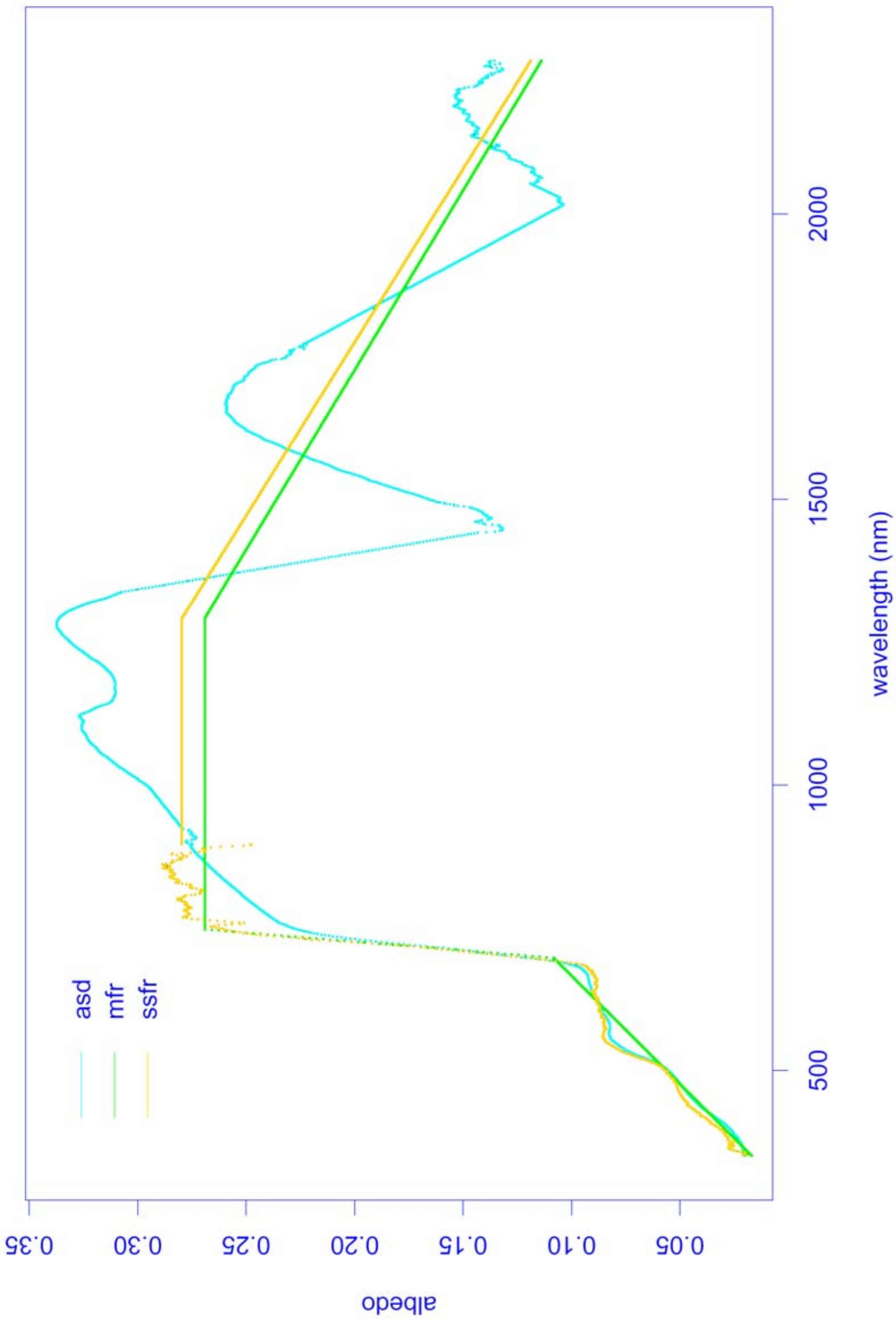

Figure 3. These three curves represent the wavelength dependence of these three albedo measurements from different platforms in Figure 2 for input into models.

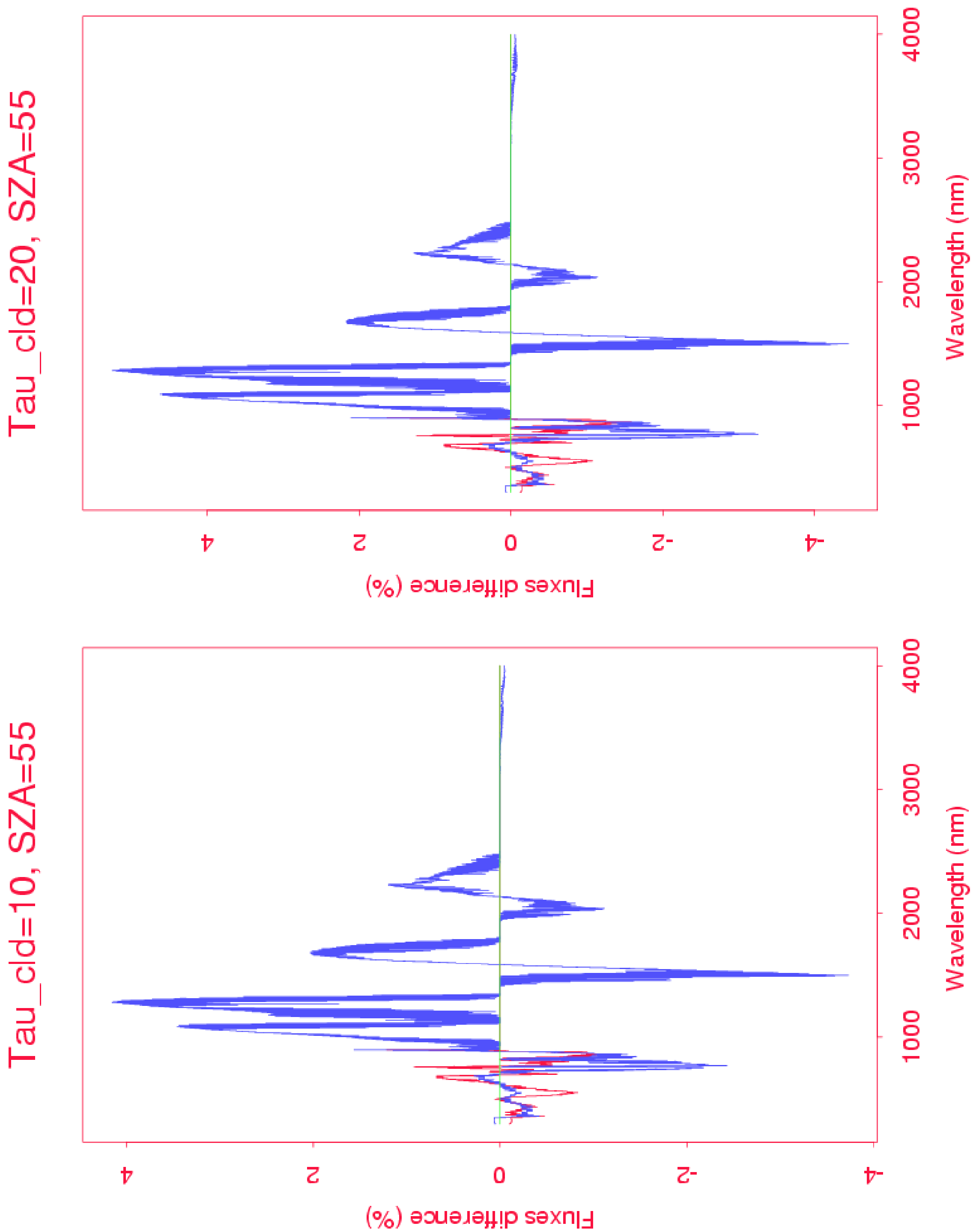

Figure 4. These are the downwelling calculated spectral flux differences using MODTRAN for the ASD albedos (in blue) relative to the SSFR albedos and for the MFR albedos (in red) relative to the SSFR albedos. The integrated differences in downwelling irradiance for the total broadband shortwave indicated differences of only 0.1% and 0.2% for the optical depth 10 and 20 cases, respectively.

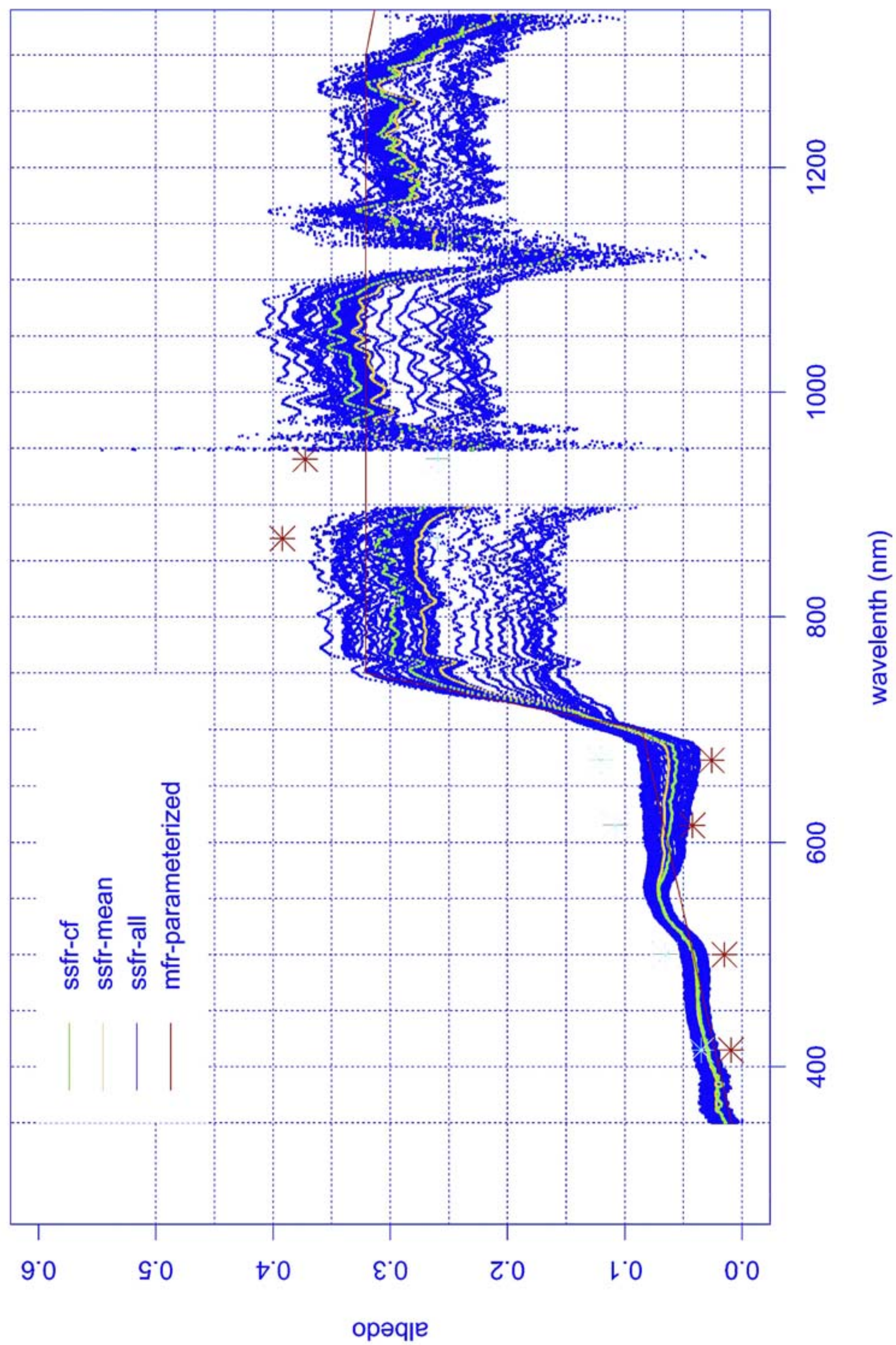

Figure 5. The blue lines are the albedos for each measurement on another overcast day (March 29, 2000) for the low-altitude flight leg. The yellow is the mean and the green is the measurement estimated to be most directly over the CF. Note that the parameterized MFR albedos agree well with the green ssfr measurement for this overcast day as they did for the previous overcast day in Figure 2.

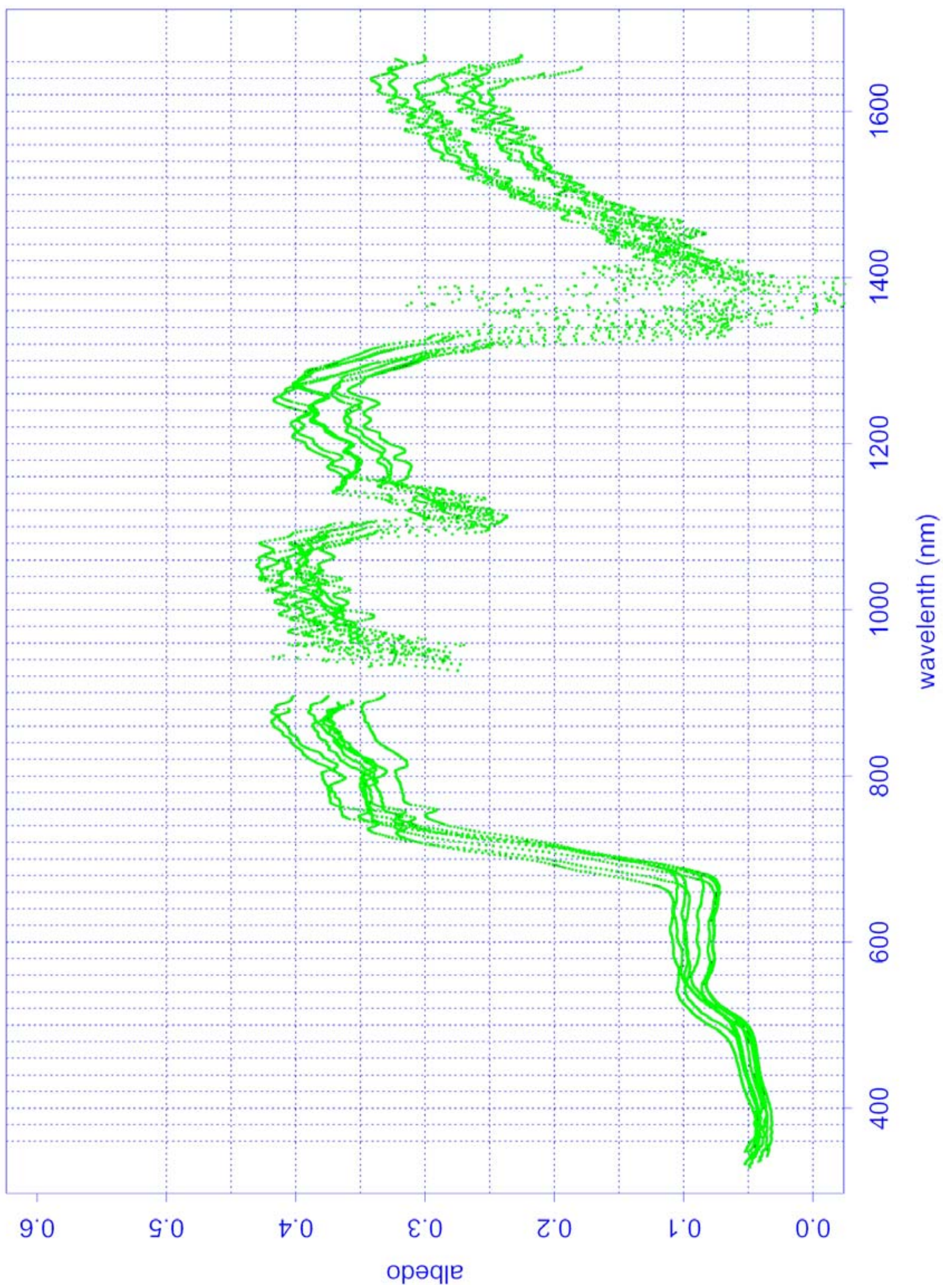

Figure 6. On this clear day (April 5, 2000) multiple low-level flight legs were made. The albedos are SSFR measurements when we judged the aircraft to be most directly over the CF. This gives an indication of the reproducibility of these measurements although the sun's changing angle will also influence the measurements because of bi-directionality effects.

In Figure 7 we plot SSFR and MFR albedo measurements for April 5, 2000. For the cloudy days we had reasonably close correspondence between the SSFR and MFR albedos, but in this case the SSFR is consistently higher at all wavelengths than the MFR estimates. Other clear day data (not shown) indicate agreement similar to the cloudy day data. Still other days, or even in the same day, MFRs may have higher albedos at the shorter wavelengths and lower albedos at the longer wavelengths than the SSFR. We speculate that these differences may be associated with the differences in bi-directional reflectance functions from different surfaces changing in response to different sun angles.

Summary

On the one overcast day where we have three measurements of albedos there are differences in the spectral detail as might be expected since we are comparing spot measurements of the handheld ASD spectrometer with the SSFR integrated view flying 200 m above the CF. These albedos and the parameterized albedo based on the MFR data are used to calculate downwelling spectral irradiance with the result that there are up to 5% differences in spectral detail that average to about 0.2% differences in calculated broadband downwelling irradiances even for the heavy overcast case tested. On the second overcast day we again obtained consistent behavior between the SSFR and MFR. For downwelling shortwave irradiance modeling, especially on overcast days, even some spectral albedo information (e.g., the parameterized MFR albedos) provides needed realistic input to calculations for comparisons to measurements.

On clear days the agreement between these measurements varied noticeably within each day and between days, perhaps, because of bi-directional reflectance effects. Some preliminary calculations indicate that the differences that we see led to downwelling diffuse irradiances that differ at the 2% level for the clear case studied in Figure 7 where the differences were large.

References

Bowker, D. E., R. E. Davis, M. L. Myrick, K. Stacy, and W. T. Jones, 1985: Spectral reflectances of natural targets for use in remote sensing studies, NASA Reference Publication 1139.

Pilewskie, P., M. Rabbette, R. Bergstrom, J. Pommier, and S. Howard, 2002: Cloud solar spectral irradiance during ARESE II. *J. Geophys. Res*., submitted.

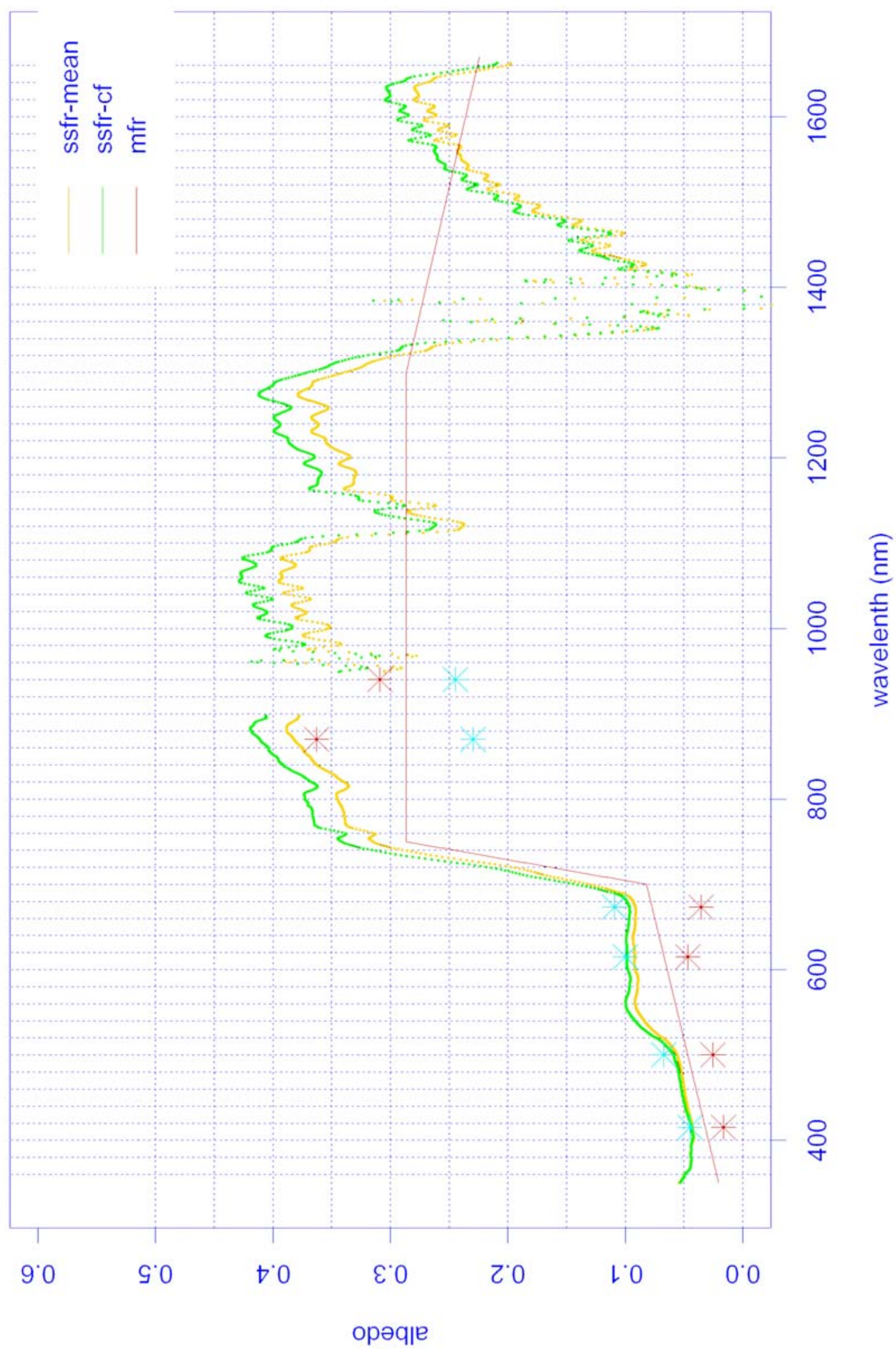

Figure 7. This clear-day measurement of albedo demonstrates that the parameterized mfr measurements and ssfr measurements are not always in agreement, especially on clear days.