SSP Cloud Retrieval Based Shortwave Flux Simulations During ARESE and SUCCESS

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Introduction

During the fall 1995 (ARM Enhanced Shortwave Experiment [ARESE]) and spring 1996 (Subsonic Aircraft Contrail and Cloud Effects Special Study [SUCCESS]) Atmospheric Radiation Measurement (ARM) Program Intensive Operational Periods (IOPs), the Egrett aircraft carried several instruments designed to measure shortwave flux and radiance reflected off clouds and the earth's surface. These instruments included the Scanning Spectral Polarimeter (SSP) measuring spectral radiance and flux between 0.4 μm and 1.1 μm, the Total Direct-Diffuse Radiometer (TDDR) measuring spectral flux at seven wavelengths between 0.5 μm and 1.75 μm, the Total Solar Broadband Radiometer (TSBR) measuring broadband flux between 0.2 μm and 4.0 μm, and the Fractional Solar Broadband Radiometer (FSBR) measuring broadband near-infrared (IR) flux between 0.68 μm and 3.5 μm. Broadband visible flux data are obtained between 0.2 μm and 0.68 μm by subtracting the FSBR data from the TSBR data. The TSBR and FSBR instruments are collectively known as the Radiation Measurement System (RAMS). More information about the SSP can be found in Stephens et al. (1999), TDDR in Valero and Ackerman (1989), and RAMS in Valero et al. (1982). An important use of the data recorded during the Egrett flights has been to test our ability to retrieve and/or parameterize cloud and surface properties.

Along those lines, this study seeks to retrieve cirrus cloud optical properties that can be used as input to a radiative transfer model. The simulated spectral and broadband flux can then be compared to observations, therefore testing model cloud parameterizations and checking the consistency between measured spectral and broadband quantities. The procedure used is as follows. Spectral radiance data measured by the SSP as a function of time are used as input to a retrieval scheme along with cloud height information obtained from a cloud detection lidar (also on-board the Egrett) and water vapor profile information obtained from a radiosonde. The retrieval scheme outputs the cloud optical depth at 0.6 μm as a function of time. This method follows the optimal estimation approach of Rodgers (1976) that attempts to minimize a cost function consisting of measured and simulated radiances and model and observational uncertainty. More information about this retrieval scheme can be found in Miller et al. (1999).

Mie theory is used to obtain other values of spectral cloud optical depth, asymmetry parameter, and single-scattering albedo throughout the shortwave spectrum. These data along with the cloud height, surface albedo, and water vapor profile information are used as input to a 287 spectral band two-stream model. Spectral and broadband flux output from the model are then compared to measured quantities.

Of primary importance to simulations of measured upwelling flux is the accurate specification of the surface albedo. Even under overcast skies, the spectral surface albedo can have a large effect on the upwelling spectral flux above the cloud. Therefore, a spectral surface albedo was derived for each IOP using SSP and TDDR data on clear-sky flights. In particular, October 11, 1995, was used for the ARESE case and April 18, 1996, for the SUCCESS case. The basic procedure consisted of "tuning" the spectral surface albedo in the model until the difference between simulated and observed upwelling spectral fluxes at SSP and TDDR wavelengths averaged to nearly zero for the entire flight. This method of tuning the surface albedo ensures that any spectral differences observed for the cloud cases are due to cloud effects rather than clear-sky issues. Of course, this approach assumes that the flight track for the cloudy case covers the same ground as the clear-sky flight track.

The following sections present the retrieval and spectral and broadband flux comparison results for the cirrus cases of October 26, 1995, during ARESE and April 20, 1996.

ARESE: October 26, 1995

The time series of 0.5 μm optical depth retrieved from SSP radiance measurements on October 26, 1995, are shown in Figure 1. The cloud resided at altitudes between 8 km and 10 km and optical depth values range from 0 to 23. Each time step was considered a column in the plane-parallel model run and only columns that contained cloud were used. Although the cloud field appears to be very inhomogeneous according to Figure 1, it must be remembered that the Egrett flight track covered hundreds of kilometers. All time series plots including Figure 1 are therefore highly compressed.

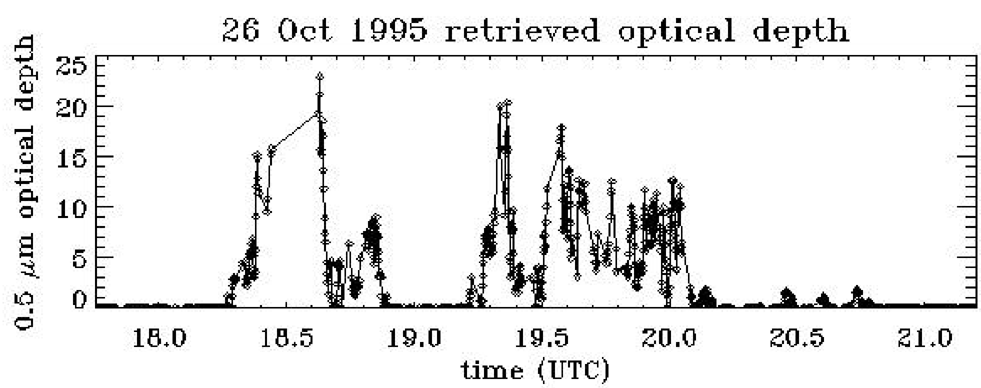

Figure 1. Optical depth retrieved along the Egrett flight track for October 26, 1995.

The flight-averaged spectral flux differences are plotted in Figure 2. The solid line indicates the model - SSP differences between 0.4 μm and 1.1 μm, whereas squares indicate model - TDDR differences. Vertical lines through each wavelength display the standard deviation of the differences throughout the flight. The SSP absolute accuracy of approximately 5% is shown by the shading around the SSP differences. The model and observations match to within SSP accuracy between 0.4 μm and 0.65 μm. Beyond this point, a bias of about 25 W/m^2 is seen where the model overestimates upwelling flux. TDDR measurements show relatively good agreement with the model results beyond 1.2 μm.

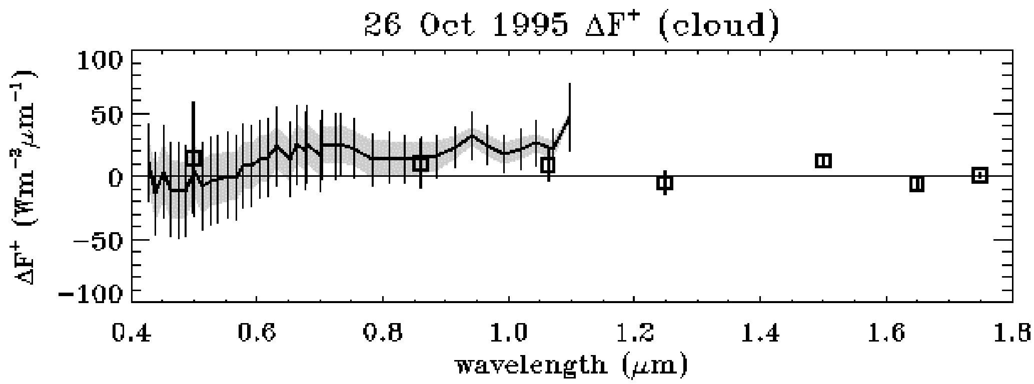

Figure 2. October 26, 1995, flight averaged spectral flux differences for model – SSP (line) and model – TDDR (squares). Vertical lines indicate standard deviation of the differences. Shading represents 5% SSP absolute accuracy.

The model spectral fluxes were then integrated to provide total, visible, and near-IR broadband flux for comparison with the RAMS instruments. The time series results for each spectral range are plotted in Figure 3. The dark points are RAMS data and the light points are model results. Clearly, the model disagrees with the measured total and visible quantities, whereas near-IR results are favorable. Further analysis of the visible flux difference can be performed by integrating the SSP wavelengths that lie within the RAMS visible region (0.4 μm to 0.68 μm). When plotted with the RAMS visible data (0.2 μm to 0.68 μm) in Figure 4, a good agreement is achieved. Because good agreement is shown between two broadband measurements that shouldn't agree, it cannot be concluded that parameterizations or specifications used in the model are the cause of the differences between simulated and observed quantities. Part of the difference may result from an instrument problem.

SUCCESS: April 20, 1999

The same retrieval/analysis procedure was used for the April 20, 1996, cirrus case. For this day, the surface albedo derived from the April 18, 1996, clear-sky day was used. Figure 5 shows the 0.5 μm retrieved optical depth for the cirrus cloud that resided between the altitudes of 7 km and 10 km. Optical depths ranged from 0 to 15.

Flight averaged spectral flux differences at SSP and TDDR wavelengths are shown in Figure 6. Differences for this case are larger than those seen for the ARESE case. Here, however, the model underestimates spectral fluxes for the SSP wavelengths. TDDR comparisons beyond 1.2 μm appear to be in good agreement. The differences between 0.4 μm and 1.1 μm are likely due to the model assumption that the cirrus particles can be approximated as spheres, although this has yet to be proven.

Comparisons with the RAMS broadband fluxes are shown in Figure 7. Here again, there are large differences between modeled and measured total and visible fluxes, whereas near-IR fluxes agree. Plotting the RAMS visible flux with the integration of the SSP data that lie within the RAMS visible spectrum again produces a good match as shown in Figure 8. It is likely that instrument problems occurred during this day as well.

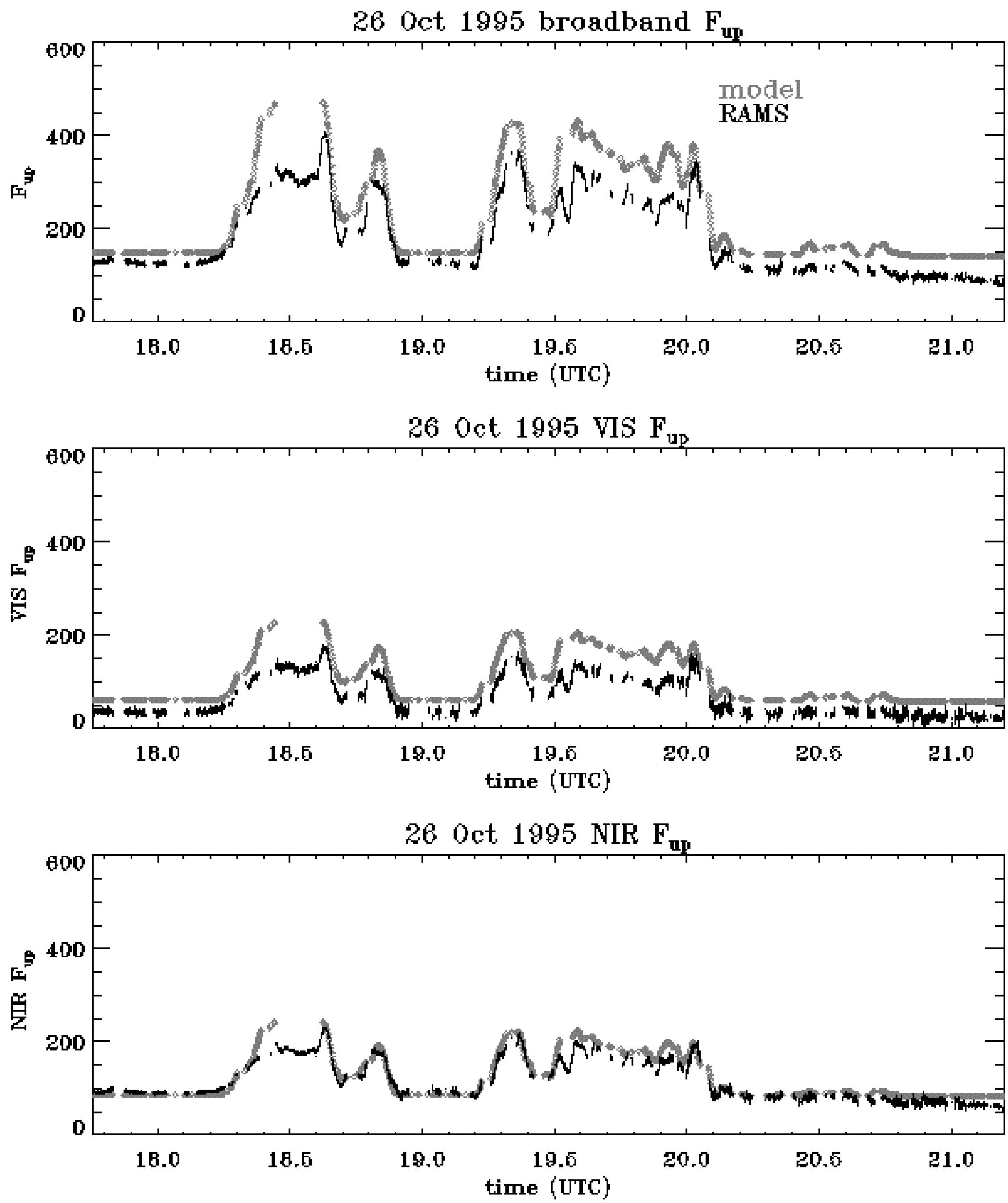

Figure 3. October 26, 1995, broadband flux time series for the model (light) and RAMS (dark). Shown are results for the total (top), visible (middle), and near-IR (bottom) spectral regions.

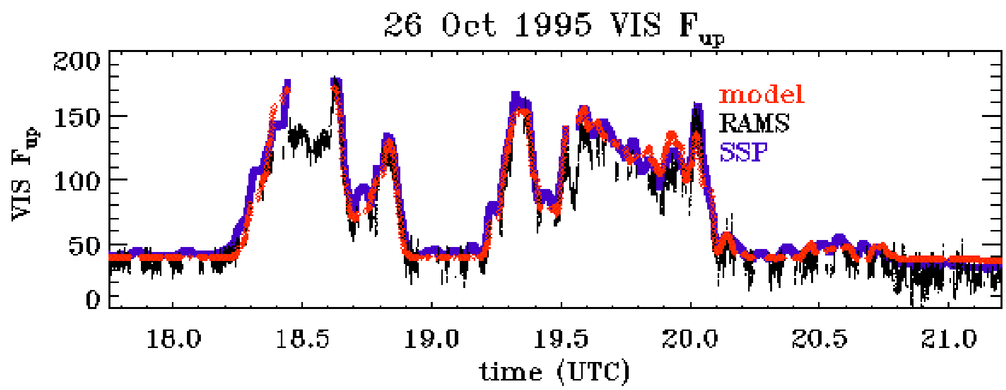

Figure 4. October 26, 1995, visible RAMS measurements (0.2 µm to 0.68 µm) (black) plotted with the integrated SSP spectral measurements that lie within the RAMS visible spectral region (0.4 µm to 0.68 µm) (blue). A good agreement between two measurements with different spectral ranges shows measurement inconsistency. Model broadband flux between 0.4 µm and 0.68 µm is also shown (red).

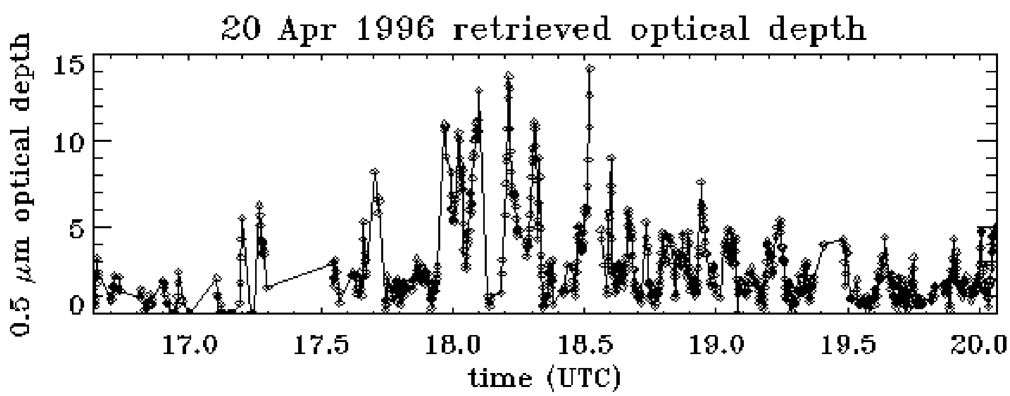

Figure 5. Optical depth retrieved along the Egrett flight track for April 20, 1996.

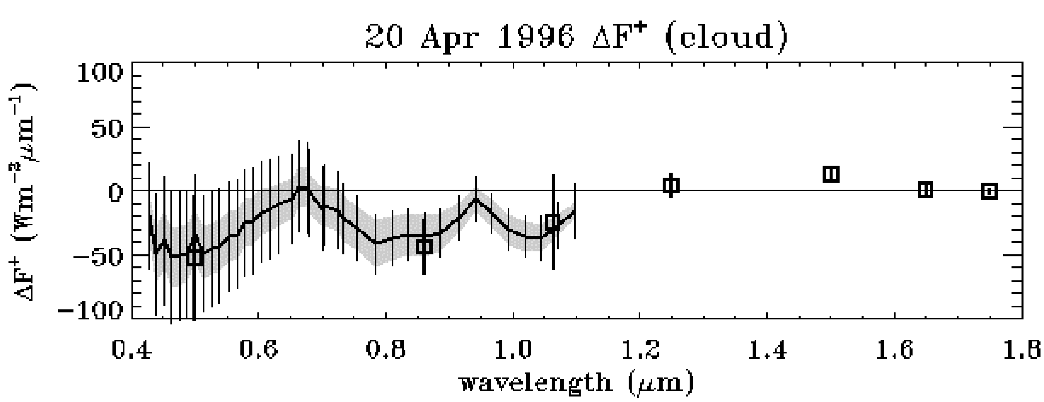

Figure 6. April 20, 1996, flight averaged spectral flux differences for model – SSP (line) and model – TDDR (squares). Vertical lines indicate standard deviation of the differences. Shading represents 5% SSP absolute accuracy.

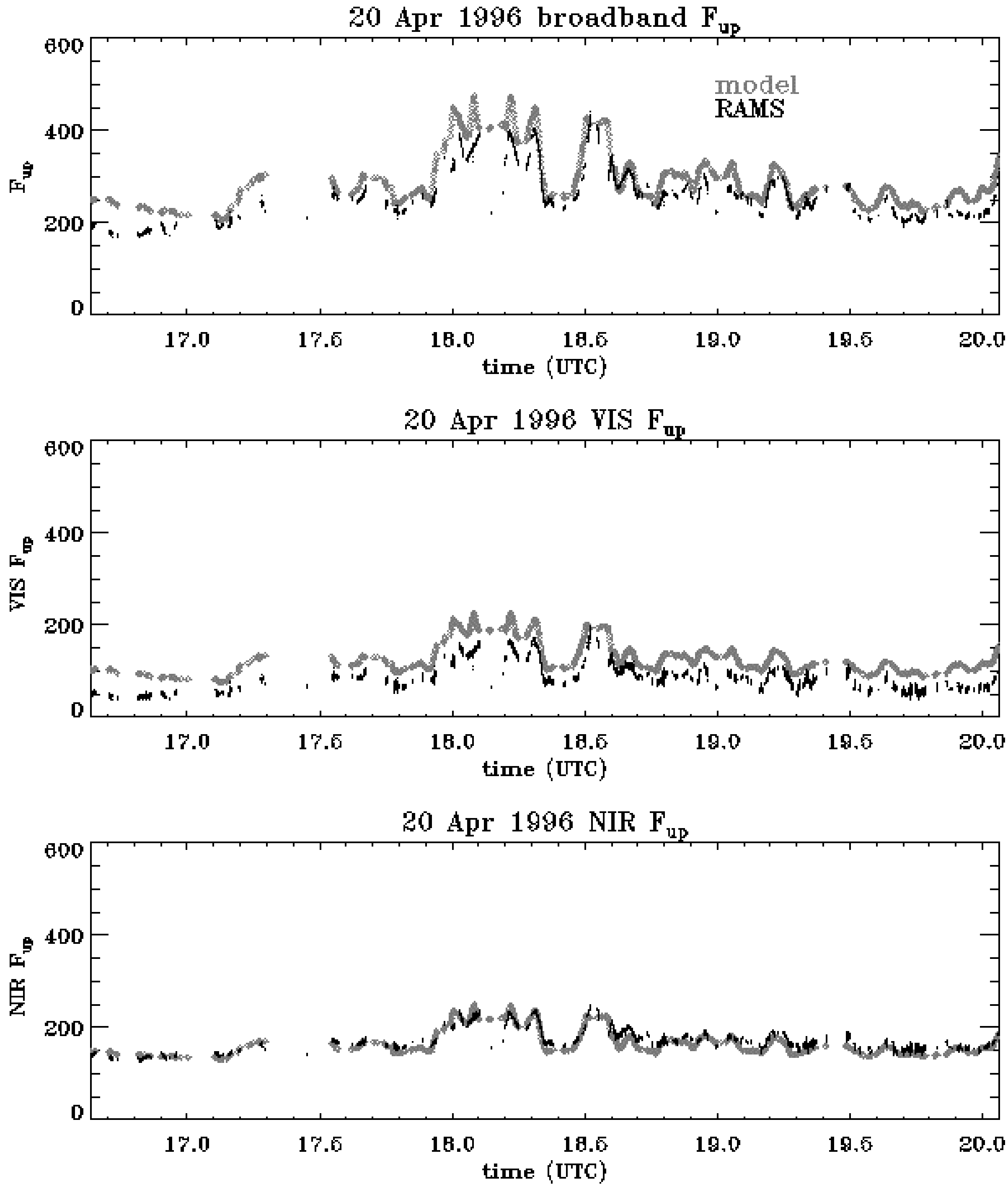

Figure 7. April 20, 1996, broadband flux time series for the model (light) and RAMS (dark). Shown are results for the total (top), visible (middle), and near-IR (bottom) spectral regions.

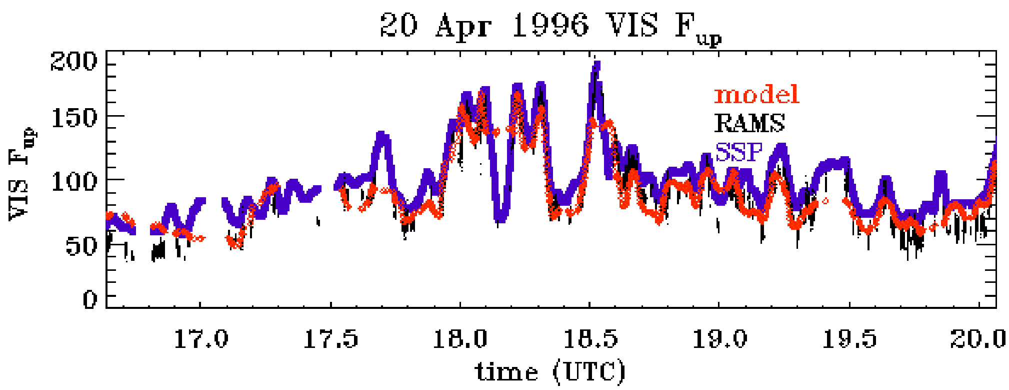

Figure 8. April 20, 1996, visible RAMS measurements (0.2 µm to 0.68 µm) (black) plotted with the integrated SSP spectral measurements that lie within the RAMS visible spectral region (0.4 µm to 0.68 µm) (blue). Model broadband flux between 0.4 µm and 0.68 µm is also shown (red). Again, measurement inconsistency is seen when measurements with different spectral ranges agree.

Conclusions

In order to study differences between simulations and observations of upwelling flux in cloudy atmospheres, potential clear-sky model problems must be overcome. The simplest way of doing so is to incorporate all clear-sky spectral flux differences in the tuned surface albedo. In doing so, differences between simulations and observations in cloudy atmospheres will most likely be due to cloud property specifications. Therefore, spectral differences seen for the ARESE and SUCCESS cirrus cases probably are the result of the insufficient assumption in the retrieval/model that ice crystals can be approximated as spheres. Of course, other uncertainties exist including size distributions of the cirrus particles, changing aerosol properties, and varying aircraft flight tracks, decreasing the validity of the derived surface albedo. However, the differences between modeled and measured spectral fluxes are not large, giving us confidence that our retrievals and parameterizations of cirrus cloud optical properties within the SSP and TDDR wavelengths are valid for use in radiative transfer simulations.

These conclusions speak to the consistency between SSP-measured radiance and SSP- and TDDR-measured spectral flux. Comparisons of simulated to observed broadband flux are not as encouraging. Modeled visible and total broadband flux overestimate measured quantities for both cirrus cases. It was shown that the SSP and RAMS instruments do not agree in the visible part of the spectrum. It is difficult, however, to determine in which instrument the problem lies. Although the model agrees with the SSP measurements, it must be remembered that surface albedo information was only available for the SSP and TDDR wavelengths. All values between and beyond these wavelengths were assumed. Concrete conclusions about model and parameterization accuracy in regions of the spectrum not covered by the spectral flux instruments cannot be made until a spectral flux instrument with high resolution throughout the shortwave spectrum is flown along with the broadband devices.

References

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