Shortwave, Clear-Sky Diffuse Irradiance in the 350 to 1050 nm Range: Comparison of Models with RSS Measurements at the Southern Great Plains ARM Site in September/October 2001

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Abstract

A rotating shadowband spectroradiometer (RSS) operating in the spectral range between 350 to 1050 nm obtained measurements of direct and diffuse components of spectral irradiance during the first diffuse irradiance IOP in the autumn of 2001. Independent measurements of the primary inputs to spectral irradiance models, including aerosol optical depth, water vapor column, and ozone column measurements, were used. A parameterized spectral surface albedo based on filter measurements provided realistic surface reflectance as a further input to the models. Plausible wavelength independent single scattering albedo and asymmetry parameter were assumed for the column based on in situ surface-based measurements typical of early autumn. Spectral irradiance measurements are compared to three models including, MODTRAN, SBDART, and SMARTS2.

Introduction

The current status regarding the clear-sky shortwave irradiance problem is that the differences between broadband measurements and models are narrowing, but the small differences are not yet completely resolved. Kato et al. (1997) pointed out a significant discrepancy between broadband shortwave models of total horizontal irradiance and measurements. When Kato et al. (1997) separated the shortwave into direct and diffuse components they were able to attribute the problem to higher diffuse model results than measurements. Bush et al. (2000) demonstrated that the oft-ignored negative offsets associated with single-black detector thermopile pyranometers are significant. These offsets result because thermopile detectors also respond to thermal imbalances associated with a dome that is cooler than the detector surface. These offsets accounted for about one-half of the difference between diffuse models and measurements according to the careful analysis in the paper by Halthore and Schwartz (2000);

however, a persistent 10-14 W/m^2 remained. By refining the surface spectral albedo input to the model in clear-sky conditions, Michalsky et al. (2003) demonstrated a further reduction of the difference to between 7 and 10 W/m^2.

Mlawer et al. (2000) compared spectral shortwave measurements and models to investigate the spectral signature of the discrepancies. Rotating shadowband spectroradiometer (Harrison et al. 2001) measurements were compared to calculations using the code for high resolution accelerated radiative transfer (CHARTS) (Moncet and Clough 1997) for cloud-free conditions at the Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) site. A significant finding was that there were no missing absorbers in the important spectral range between 350 and 1000 nm. Mlawer et al. (2000) compared three clear-sky cases with small, modest, and high aerosol optical depths. For the modest and high aerosol optical depth cases the differences between direct and diffuse models and measurements were minor if one used moderate absorption for the aerosol. For the small aerosol optical depth case agreement between diffuse measurements and models required a seemingly implausible, large aerosol absorption. The situation remains that the clear-sky cases with aerosol optical depths at 500 nm below about 0.08 are the most difficult to model without invoking large absorption that is currently thought to be unreasonable compared to ground-based in situ data (Sheridan et al. 2001).

This paper takes a different approach to spectral model and measurement comparison than that in the Mlawer et al. (2000) paper. In their approach they forced agreement by modifying the aerosol optical depth and wavelength dependence until the differences in diffuse and direct spectra were minimized. They then compared independent aerosol measurements to those required for the forced model agreement to ascertain reasonableness. In this paper all inputs to the model are independent of the RSS data, to which we make our model comparisons, i.e., we do not use the RSS data to derive any inputs to the model. Aerosol optical depths are taken from the multi-filter rotating shadowband radiometer (MFRSR) at the SGP Central Facility (CF) and checked against the AERONET results. The water vapor is from the microwave radiometer. Ozone is obtained from total ozone mapping experiment spectrometer. Spectral albedos are based on a parameterization using upwelling MFRSRs over a wheat field and over an ungrazed pasture, which are the two predominant surface types in the area, and a downwelling MFRSR at the CF.

Results

The latest versions of three spectral models are used to perform the calculations including SMARTS2 (Gueymard 1995), SBDART (Ricchiazzi 1998), and MODTRAN (Berk et al. 1989). The following table (Table 1) contains the inputs used for the cases studied. In this paper we will show only the comparisons for the italicized cases since they are the extreme cases for aerosol loading in this group.

Table 1.

Day/2001	aot(.5μ)	aot(.55μ)	alpha	H_2O	O3	Day	Time (UT)	T	pres	rh	meanT
Sep 25 (268)	0.045	0.041	0.99	1.16	0.282	268	22:01:47	21.0	984.1	33.6	13.7
Sep 29 (272)	0.102	0.089	1.33	1.38	0.278	272	16:00:37	21.7	986.5	53.3	18.8
Sep 29 (272)	0.084	0.074	1.39	1.21	0.278	272	21:28:22	26.2	984.0	29.6	18.8
Oct 4 (277)	*0.277*	*0.234*	*1.75*	*2.93*	*0.291*	*277*	*15:39:36*	*23.9*	*976.0*	*68.3*	*23.1*
Oct 6 (279)	*0.055*	*0.050*	*1.09*	*0.93*	*0.299*	*279*	*14:05:43*	*7.8*	*988.8*	*88.7*	*11.0*
Oct 6 (279)	0.057	0.053	0.795	1.00	0.299	279	19:39:22	18.7	985.5	31.6	11.0

In each of the models there are several choices for the extraterrestrial solar spectrum. Figure 1 is a plot where all inputs to the total horizontal irradiance model are held fixed, but the extraterrestrial (ET) spectra are different. This is a plot for the SBDART model, but the other models produce similar differences when different ET spectra are selected. The top plot is the irradiance and the bottom plot contains the differences from the default model in LOWTRAN, just to have a point of reference. There is no reason to believe that the LOWTRAN default ET spectrum is more correct than the others listed. Clearly, there are differences that impact the degree of agreement that we can expect between measurements and models caused simply by the uncertainty in the input ET spectrum.

Figure 2 is a plot of the direct irradiance in the top of the figure for a day in early October with a large water vapor column and significant aerosol loading. The difference plot on the bottom is the model minus the RSS measurement. Generally, the direct measurement is slightly higher, however, some parts of the modeled spectra show close agreement with the measurements. In Figure 3 the diffuse irradiance models for this day are higher throughout this spectral region. This is in agreement with the broadband shortwave results.

Figures 4 and 5 are plots of the direct and diffuse modeled and measured irradiance in the tops of the figures for a very clean and low water vapor day in early October. Comparing the differences in the bottoms of the figures with Figures 2 and 3 we see the same general tendencies.

Discussion

A few cases of clear-sky spectral measurements and model comparisons were examined for the diffuse IOP period in the early autumn of 2001. Three models were compared to measurements. Generally, the direct models were slightly low and the diffuse models were high compared to measurements. The direct models agreed with measurements in parts of the spectrum, but were low in others. The diffuse models were high throughout the spectrum. Only two cases are shown here, but the two days compared are very different with one rather hazy and humid and the other clear and dry. The air masses tested were also significantly different.

A better comparison will require a standard, low-uncertainty ET spectrum and a better determination of aerosol properties for the column, specifically, single scattering albedo and asymmetry parameter. Further work on the specification of surface reflectance for clear-sky conditions would also benefit this work.

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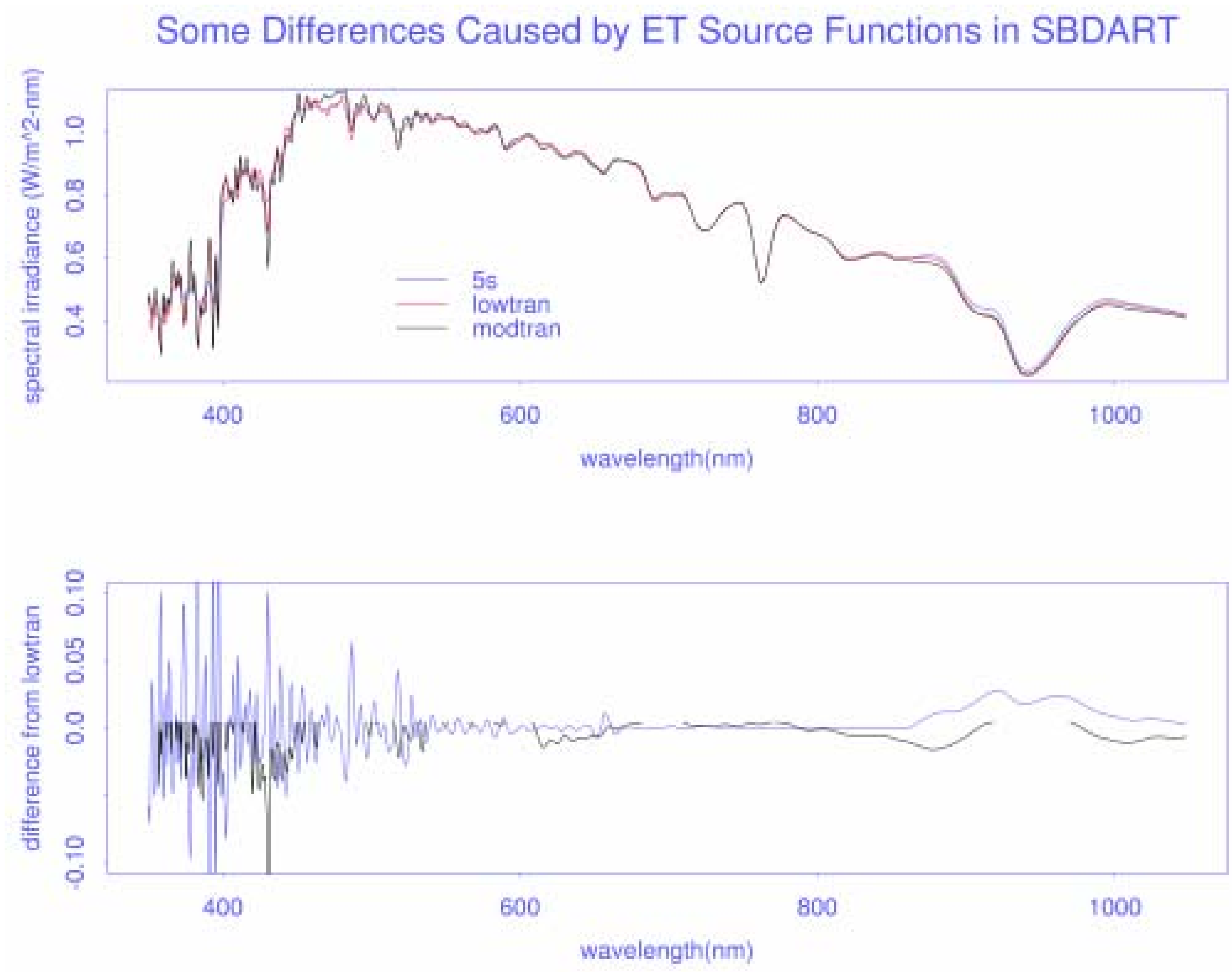

Figure 1. The top figure includes three total horizontal irradiance spectra modeled using the same input parameters except for the ET source function. The bottom figure includes differences caused by using the 5S and MODTRAN default ET spectra as opposed to the LOWTRAN default ET spectrum. This is for SBDART, but other models show similar results.

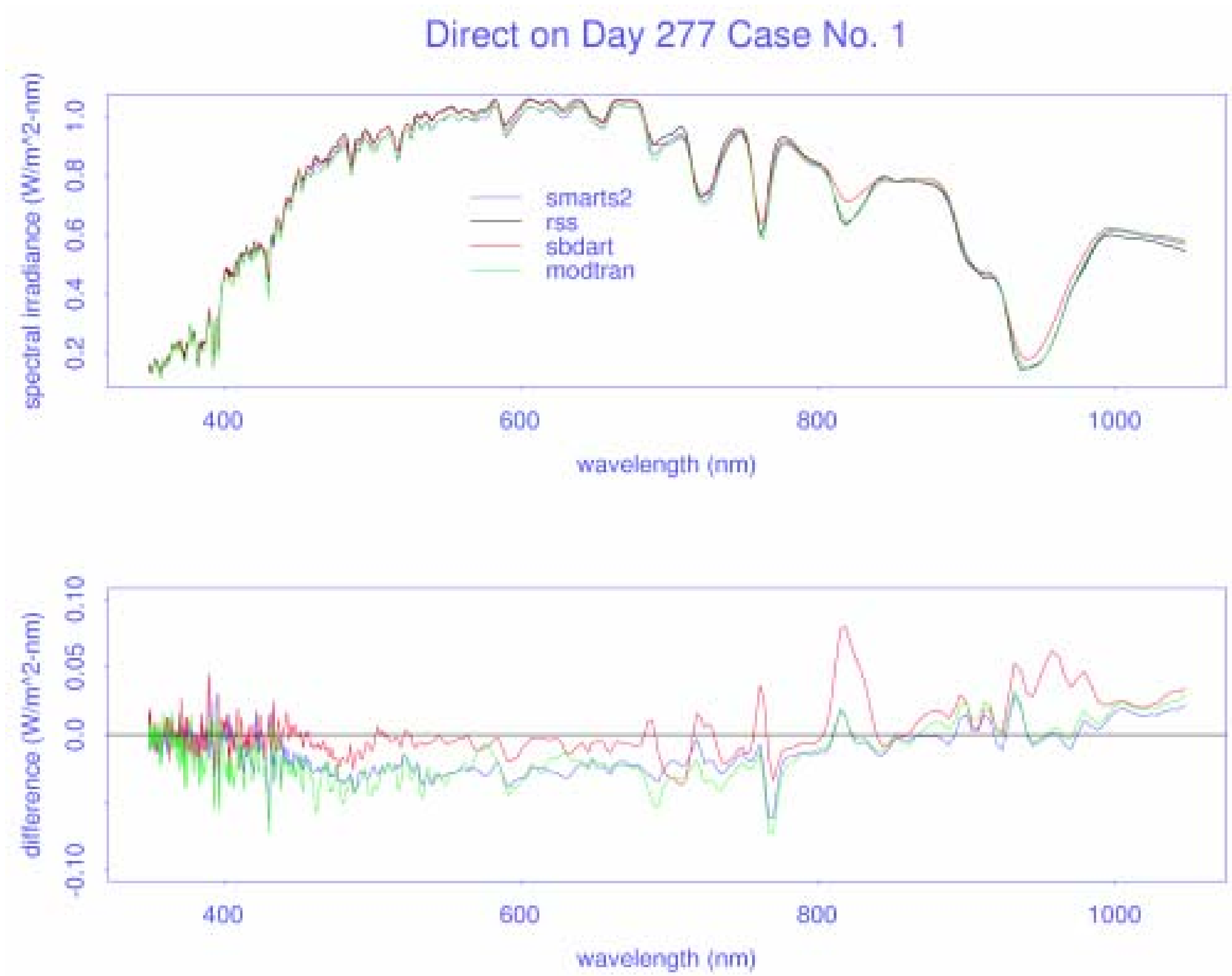

Figure 2. The top figure includes measured and modeled direct irradiance spectra for a humid hazy October day (first italicized case in Table 1). The bottom figure is the modeled – measured differences. There are portions of the spectrum where there is close agreement and others with significant differences that are modeled dependent. SMARTS2 and MODTRAN agree with each other, but not the measurements or SBDART.

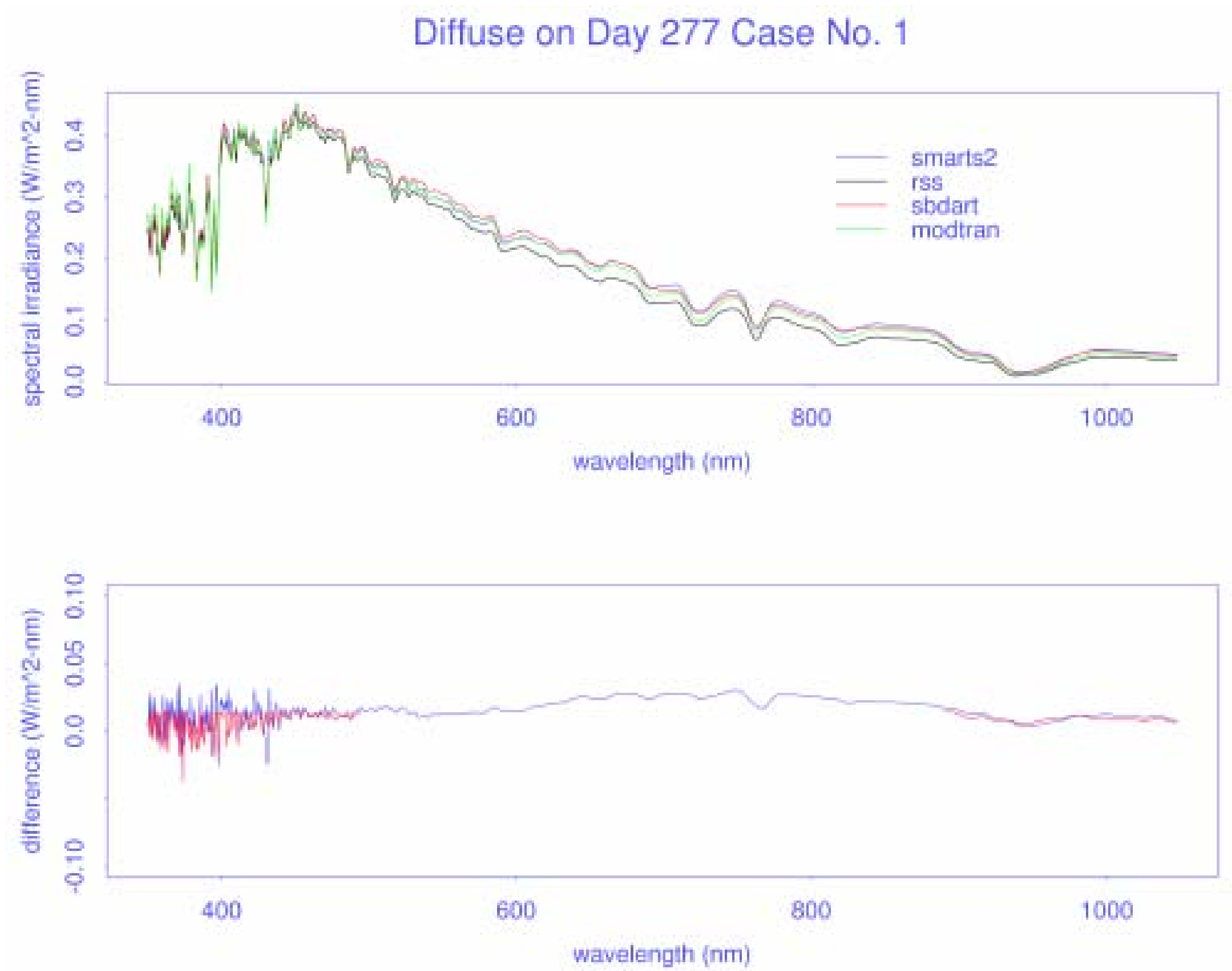

Figure 3. The top figure includes measured and modeled diffuse irradiance spectra for a humid hazy October day (first italicized case in Table 1). The bottom figure is the modeled – measured differences. All parts of the spectrum have modeled differences that are high relative to the measurements.

Figure 4. The top figure includes measured and modeled direct irradiance spectra for a dry clear October day (second italicized case in Table 1). The bottom figure is the modeled – measured differences. The results are very similar to Figure 2 for the hazy humid case.

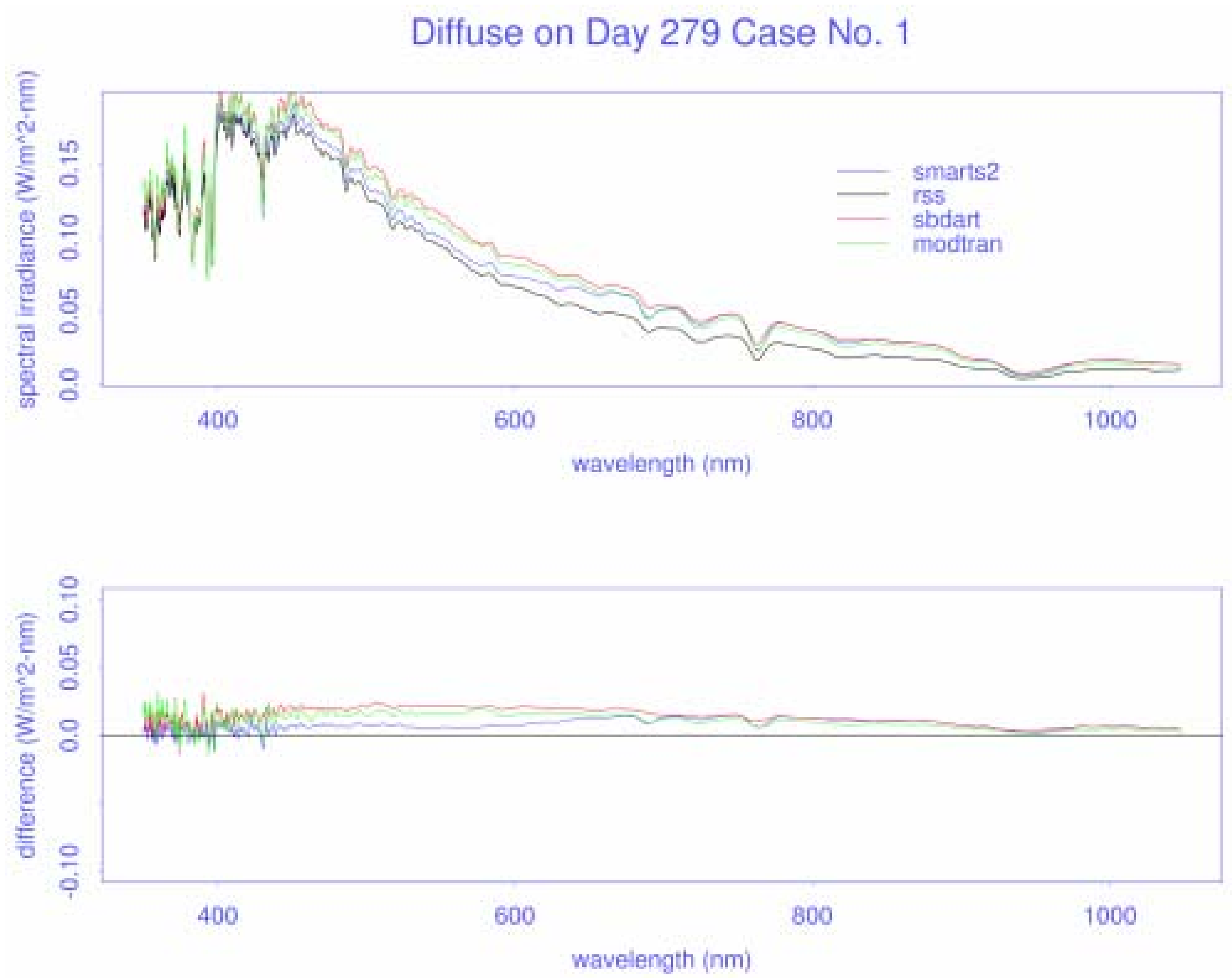

Figure 5. The top figure includes measured and modeled diffuse irradiance spectra for a dry clear October day (second italicized case in Table 1). The bottom figure is the modeled – measured differences. All parts of the spectrum have modeled differences that are high relative to the measurements, which is very similar to Figure 3, the hazy humid case.

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