Use of AERONET Aerosol Retrievals to Calculate Clear-Sky Irradiance at the Surface

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Motivation

The worldwide aerosol robotic network (AERONET) of ground-based radiometers was developed (in part) as a satellite validation tool (Holben et al. 1998). These sites utilize spectral sky-scanning radiometers, providing more information for aerosol retrievals than conventional sunphotometer measurements. The use of the almucantar sky radiance scans in conjunction with the aerosol optical thicknesses are the basis of the AERONET Dubovik retrievals, which provide the aerosol size distribution and the refractive index at four wavelengths (Dubovik and King 2000). The accuracy of the Dubovik retrieval has been assessed with the retrieval of synthetic data (Dubovik et al. 2000), but an assessment utilizing independent measurements is desirable. Hence, the AERONET retrievals are used here as input to a discrete-ordinates radiative transfer model (DISORT, Stamnes et al. 1988) utilizing 12 computational streams to calculate the solar radiation at the surface, and the results are compared to co-located surface measurements. Included in the comparison are principle plane radiance measurements from the Cimel sunphotometer, irradiance measurements from the Multi-filter Rotating Shadowband Radiometer (MFRSR, Michalsky et al. 2001), and irradiance measurements from the Rotating Shadowband Spectroradiometer (RSS, Harrison et al. 1999).

Method

The aerosol size distributions and refractive index at four wavelengths (0.440, 0.670, 0.870, and 1.020 μm) are provided by the AERONET Dubovik retrievals. The retrievals may be used at these wavelengths to calculate the phase functions, optical depths, and single-scatter albedos required for radiative transfer calculations, but a refractive index extrapolation is necessary for comparisons to radiation measurements at non-AERONET wavelengths. A 3-component χ^2-tuning technique was developed, whereby the composition of retrieved aerosol size distributions are "tuned" by varying the amount of internally-mixed water, soot, and ammonium sulfate until a minimum χ^2-fit of the available refractive index are achieved. (Typically, the volume fraction of soot calculated with this technique is less than 0.01 and of water is 0.6-0.99 at the Atmospheric Radiation Measurement [ARM] Cloud and Radiation Testbed [CART] site). The refractive index obtained in this manner is used in conjunction with the retrieved aerosol size distribution to construct aerosol optical depths, phase functions, and single-scatter albedos throughout the shortwave spectral range via Mie theory (Wiscombe 1980). The atmosphere is modeled with two layers—an ozone layer dictated exclusively by the extinction law (i.e., no scattering) is located above a homogenous molecular-aerosol layer. The surface is assumed to be vegetation with an albedo of 0.03 at wavelengths less than 0.600 μm, 0.08 at wavelengths between 0.600 and 0.700 μm, and 0.28 at wavelengths greater than 0.700 μm. (This assumption was tested at the MFRSR wavelengths by using a dynamic albedo calculated from coincidental Multi-filter Radiometer [MFR] upwelling irradiance. The change in downwelling irradiance associated with the assumed vegetation albedo and the dynamic measured albedo was negligible.) The ozone layer absorption is determined by daily Total Ozone Mapping Spectrometer data, assuming the entire column of ozone is located above the molecular-aerosol layer. Given that typically only about 30 Dobson Units out of 300 Dobson Units of the total column ozone are located in the troposphere (Fishman et al. 1990), this is a reasonable approximation. Molecular extinction in the troposphere is calculated from first principles (Bodhaine et al. 1999). Anisotropy is included in the calculation of the molecular phase function (Chandrasekhar 1950; Bucholz 1999). The optical depth is the sum of the calculated molecular and aerosol optical depths. The phase function and single-scatter albedo of the molecular-aerosol layer is the sum of the individual components fractionally weighted with the corresponding optical depths. We used the spectral solar constant recommended by the World Meteorological Organization for comparisons to the principle plane radiances and MFRSR irradiances, and the RSS-based solar constant of Harrison et al. (2002) for comparisons with the RSS measurements.

Comparison with Independent Measurements

The model was used to calculate radiance and irradiance at the surface, and the results were compared to nearly simultaneous co-located measurements. The solar zenith angle was restricted to angles greater than 45 degrees to assure quality AERONET retrievals. A comparison of the radiance calculated in the solar principle plane to Cimel sunphotometer measurements within 15 minutes of an AERONET retrieval are shown in Figure 1 for the entire year of 2000. The average radiance error is computed over all scan angles greater than 2.8 degrees and viewing zenith angles greater than 74 degrees (denoted by the green symbols) is better than plus or minus 10%. The error bars correspond to 1 standard deviation. The average absolute error was calculated with the same angular restrictions, with typical results in the 6 to 11% range. Comparisons with MFRSR measurements obtained within 1 minute of the AERONET retrieval during the same time period are shown in Figure 2. The error averaged over all wavelengths is generally 10% or better, usually with a positive bias. Comparisons with the RSS using 10-nm wide tophat filter functions every 20 nm are shown in Figure 3. The comparisons are limited to July 2000, and non-window wavelengths between 0.7 and 1.0 μm were not tested because of the lack of water vapor and O_2 in the model. The comparisons at the AERONET wavelengths have discrepancies of 6% or better. The largest uncertainty occurs at 0.400 μm, a wavelength where the solar spectra varies significantly amongst different measurement groups (Thuillier et al. 1998). The negative bias throughout most of the 0.500 to 0.600 μm wavelength range indicates that the modeled irradiance is less than the measured irradiance; hence, an absorbing gas is not the cause of the discrepancy. The real part of the retrieved refractive index often exhibited unrealistic spectral variation during this month,

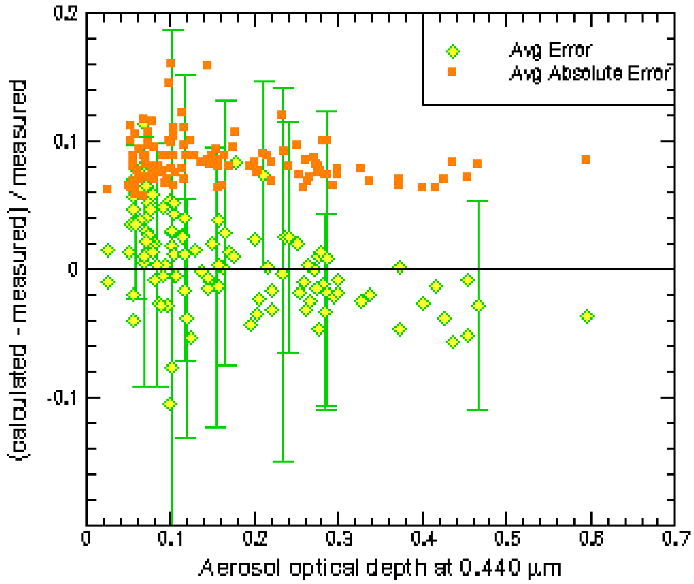

Figure 1. Radiance discrepancy of calculation with respect to nearly simultaneous principle plane measurements (within 15 minutes of the retrieval) at the ARM Central Facility (CF) for the year 2000. Each diamond represents the average for a single retrieval over all wavelengths and angles (scattering angles are restricted to values greater than 2.8 degrees, viewing zenith angles are restricted to values greater than 74 degrees). The error bars correspond to one standard deviation. Squares represent averages of the absolute values over the same angles.

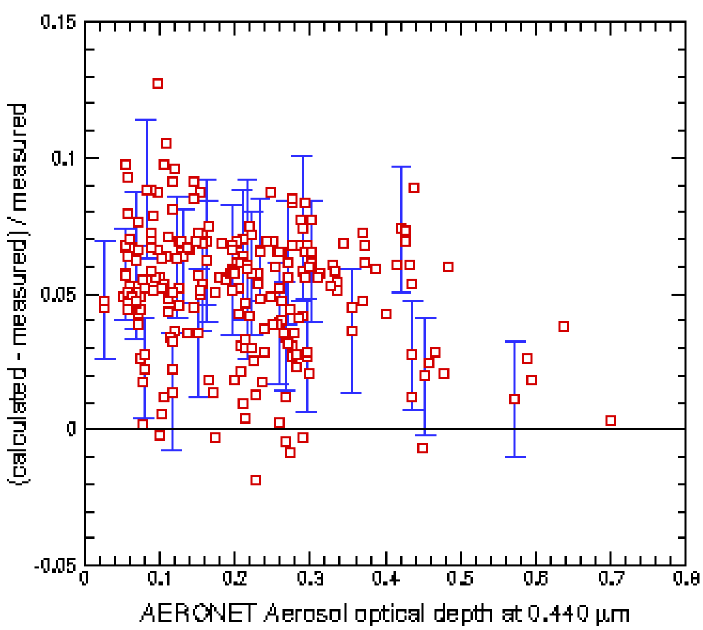

Figure 2. Narrowband irradiance discrepancy of calculation with respect to simultaneous MFRSR measurements at the ARM CF in the year 2000, averaged over all wavelengths. The error bars represent one standard deviation.

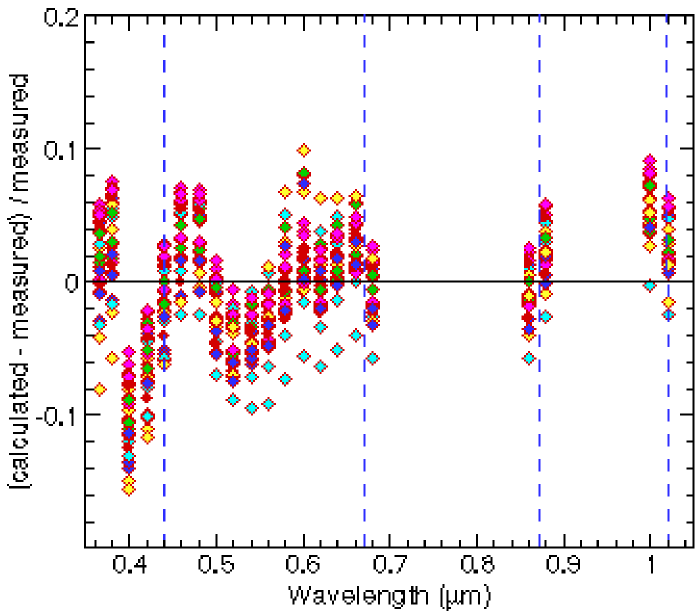

Figure 3. Narrowband irradiance discrepancy (10-nm wide tophat) of calculation with respect to simultaneous RSS measurements at the ARM CF in the year 2000. Dashed blue lines represent the AERONET wavelengths. The model includes aerosols and ozone, but not water vapor or O_2. Hence, comparisons are omitted at wavelengths longer than 0.700 `mm, except at the AERONET (window) wavelengths.

possibly caused by a dust aerosol component (http://aeronet.gsfc.nasa.gov:8080). AERONET recommends only using the 0.870 and 1.020 μm wavelengths in this case. However, repeating the comparison using only the 0.870 and 1.020 μm wavelengths for the 3-component χ^2-tuning of the refractive index did not improve the results

Conclusions

(DISORT, 12 streams) and compared to independent measurements at the ARM CART site for all of the year 2000. The independent measurements used for comparison include principle-plane radiances from sunphotometer data, irradiances from MFRSR data, and irradiances from RSS data. The discrepancy between calculated and measured radiance in the principle plane is generally 11% or less at all optical depths for the year 2000 (absolute error averaged over all angles and all wavelengths). The calculated narrowband irradiances generally agree with simultaneous MFRSR measurements to within a positive bias 10% or less (averaged over all wavelengths). The calculated narrowband irradiances also agreed with the RSS measurements (using a tophat filter at the MFRSR wavelengths) to 10% or better for the one-month period tested (July 2000), but with a negative bias.

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