A Comparison Between Clear Sky Shortwave Flux Calculations and Observations During ARESE

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Introduction

The accuracy to which clear sky shortwave fluxes can be computed is not well known. Measurements of the downwelling short wave flux on clear days as well as measurements of the atmospheric quantities that affect the flux during the Atmospheric Radiation Measurement Program (ARM) Enhanced Shortwave Experiment (ARESE) allow us to evaluate our current understanding of computing clear sky flux. Three independent measurements of the downwelling flux are available. These observations are compared with fluxes computed by a theoretical model.

Data

Three sets of data were taken at and near the ARM Southern Great Plains (SGP) central facility (latitude: 36.605N, longitude: 97.485W). The Baseline Surface Radiation Network (BSRN) uses a pyranometer which is installed 1.5 m from the ground to measure the total downward shortwave hemispheric radiation. The flux is a 60-second average of 1-second measurement. The Solar and Infrared Observing System (SIROS) uses a ventilated pyranometer which is installed 1.5 m from the ground. The flux is an instantaneous value acquired every 20 seconds. The third data set was supplied by C. Whitlock. We used his measurements taken at latitude: 36.686N; Longitude: 97.482W over new wheat covered ground. His data set was taken by an Eppley PSP installed 2 m above the ground.

Model and Computation

We used a two-stream radiative transfer model (Toon et al. 1989). Gaseous absorption by H_2O, CO_2, O_3, and O_2 is included in the model. The absorption cross-sections of these species are obtained from a look-up table, which is built based on the results of a line-by-line code. The correlated-k assumption was used to compute the transmission through the atmosphere. The atmosphere was divided into 250-m-thick layers up to 15.75 km above the ground. We computed instantaneous downward fluxes at the ground every five minutes.

Water vapor profiles were obtained by interpolating every three hour soundings (Mace 1994). Surface observations were used for the ground level pressure, temperature, and water vapor concentration. The aerosol optical thickness was measured by a 10-channel sun-photometer. Values were averaged over one- to two-hour periods during which the optical thickness was relatively constant. This leads to two or three sets of averaged aerosol optical thickness per day. Mineral aerosol with uni-modal log-normal distribution was assumed. We used refractive indices of mineral reported by d'Almeida et al. (1991). The aerosol optical thickness was evenly distributed throughout the planetary boundary layer, which was assumed to have a depth of 1 km.

Since the surface albedo changes during the day depend on the solar zenith angle, the observed surface albedo measured by the upward looking pyranometer at the surface and a downward looking pyranometer at 10 m above the surface was used. A standard mid-latitude summer ozone profile was used for all calculations.

Results and Discussion

We chose seven days of clear sky data from the ARESE period. There were visually no clouds in the entire sky on these seven days for the entire day. The aerosol optical thickness at 519 nm for these seven days varies from 0.04 to 0.14. Figure 1 shows the result of comparison between computed downward flux at the ground and observed flux on October 14, 1995. The flux difference is defined by:

$$\text{(Computation, SIROS, or, WL)} - \text{BSRN},$$

and the error is defined by:

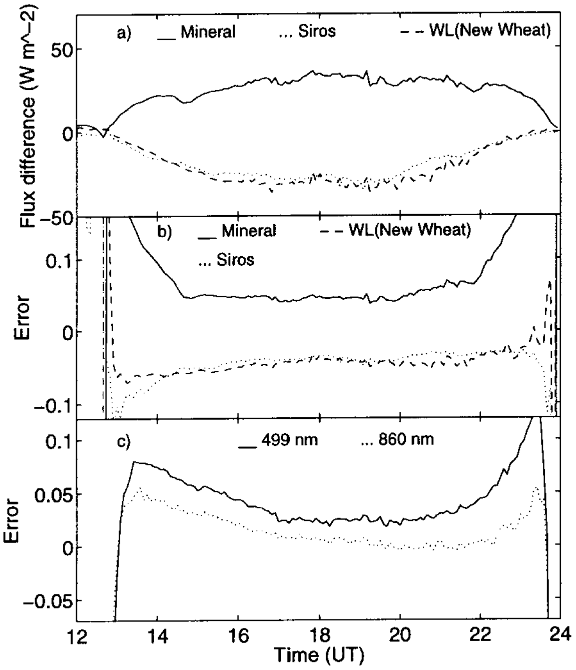

Figure 1. a) The absolute downward flux difference, b) the fractional error, c) the fractional error of the flux in 10 nm bands on Oct. 14, 1995.

$$\frac{(\text{Computation, SIROS, or, WL}) - \text{BSRN}}{\text{BSRN}},$$

where WL indicates Whitlock's data.

Our computations are a 5 to 10 over-estimate of the downward flux at the ground. This over-estimation by the model is consistent for all seven days. The large fractional error at high solar zenith angle is caused by dividing by the small measured flux to compute the fractional error. When the solar zenith angle is not large, the error is nearly constant with time. We increased the aerosol optical thickness and the column water vapor in order to simulate downward flux measured by BSRN. At local solar noon, the aerosol optical thickness has to be increased nearly five times to reduce the downward flux at the ground by 5. Similarly, the column water vapor amount has to be increased three times, from 0.97 to 2.91, to obtain the measured downward flux.

We also altered the solar constant to simulate the downward flux measured by the BSRN. The reduced solar constant was obtained by multiplying by a constant number independent of wavelength. To simulate BSRN downward flux, the solar constant has to be reduced by approximately 5. Since a solar constant of 1366Wm^{-2} (Thekaekara 1970) was used, this corresponds to a reduction of the solar constant, which is not plausible. On the other hand, this also implies that if the calibration constant for the Eppley precision spectral pyranometer (PSP) radiometer used in the BSRN is increased by 5, the computed flux agrees with the measurements.

Further, we doubled the water vapor continuum cross-sections to obtain a rough estimate of the sensitivity to the flux computation. This was done by treating continuum absorption as an independent species. Doubling the continuum cross-sections reduced the downward flux at the ground by approximately 5 on the October 14 case. However, the fractional error does not correlate with an increase in the column water vapor. The fractional error in a tropical case we have analyzed is not as great as it would be if the error were caused by the water vapor continuum.

Figure 1c shows the fractional error of two 10-nm band flux computations compared with observed flux from the multifilter rotating shadow-band radiometer (MFRSR) (Harrison et al. 1994) at wavelengths of 499 and 860 nm. The gaseous absorption in these bands is set to zero for the computation, but the observed aerosol optical thickness from the sun-photometer was used. Two minutes were added to the data clock to obtain approximate symmetry about the local solar noon. The reason for this is that the recorded time may be slightly offset, or there may be an error in the longitude measurement of the site. One might argue that this process of computing fluxes in a 10-nm band is slightly circular, because the fluxes measured by MFRSR at zero airmass in 10-nm bands (calibration constants) are obtained by the Langley technique. Then, the measured aerosol optical thickness by sun-photometer, which is very close to the values from the MFRSR, and those calibration constants were used for the computation. Theoretically the calibration constants obtained by the Langley technique, however, are independent of the aerosol optical thickness. The assumption made by using the Langley technique is that the aerosol optical thickness is constant with time. Moreover, since the sun-photometer, as well as MFRSR, measure the extinction optical thickness; the single scattering albedo, which is the ratio of the scattering optical thickness to the extinction optical thickness, is still unknown. Consequently the relatively good agreement of computed and measured flux in the 10-nm bands implies that our assumption of the single scattering albedo for these bands is correct.

Summary

The downward flux at the ground measured by BSRN and SIROS differ by about 5. The theoretical computation overestimates the BSRN flux by 5, and SIROS flux by 10. These difference between observations and between observations and computed fluxes are much greater than we can accept. Moreover, the overestimation is greater than that caused by measurement error in the column water vapor or the aerosol optical thickness. To match the computed flux to the observed flux, the water vapor continuum cross-sections have to be doubled or PSP calibration constants have to be increased by 5. We, however, did not find a correlation between the fractional error and the column water vapor amount. On the other hand, the theoretical computation can predict the flux in a 10-nm band relatively well when gaseous absorption is negligible. Further work such as spectral flux measurements or evaluation of radiometer calibration process is necessary to clarify these discrepancies.

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