A Comparison of Observed Clear-Sky Surface Irradiance with Theoretical Computations

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Introduction

The accuracy to which clear sky shortwave fluxes can be computed is not well known. We performed a detailed comparison between the measured and modeled downward shortwave irradiances at the surface, including the total, direct beam, and diffuse field irradiance. We also compared modeled and measured values of the diffuse-total ratio.

Data and Model

We used radiation data taken during the Atmospheric Radiation Measurement (ARM) Enhanced Shortwave Experiment (ARESE). We constructed the total irradiance by adding the average diffuse field irradiance measured by two shaded pyranometers and the direct beam irradiance multiplied by the cosine of the solar zenith angle. We used an empirical formula introduced by Michalsky et al. (1997) to correct the bias error of the direct beam measured by the Solar and Infrared Radiation Observation system (SIROS) pyrheliometer. We used a δ2-stream model to compute irradiances at the surface. A detailed explanation of both the data and the model is found in Kato et al. (1997).

Results and Discussion

The result of the comparison of the total irradiance shows that the model overestimates the irradiance by approximately 5% when a mineral aerosol is used for the computation (Figure 1a). The model simulates the measured direct beam irradiance correctly (Figure 1b). In contrast, a large fractional difference occurs in the diffuse field, where the model overestimates the irradiance significantly (Figure 1c). The overestimate of the total irradiance by the model is entirely due to an overestimate of the diffuse field. Figure 1c also indicates that the measured diffuse field is as low as the diffuse field for the molecular atmosphere. Therefore, to simulate the diffuse field by the model, we have to include a high absorbing aerosol such as soot in the model, of which the single-scattering albedo is less than 0.3. A study of Kuwait oil fires (Weiss and Hobbs 1992) indicates that the single-scattering albedo of particles from black plumes increases quickly with distance. Because there are no major sources of black plumes near the ARM Oklahoma site, the single-scattering albedo of 0.3 is completely unrealistic.

Further, we compared the diffuse-total ratio, which is the diffuse field irradiance divided by the total irradiance, derived from a multifilter rotating shadow-band radiometer (MFRSR) with the model-derived diffuse-total ratio (Figure 2a). The measured diffuse-total ratio is small compared to the modeled ratio. In addition, the difference becomes smaller with increasing wavelength. This result, therefore, also indicates that the measured diffuse field is smaller than the modeled diffuse field. One might argue that this difference is caused by insufficient treatment of the molecular scattering in the model. To check the accuracy of molecular scattering in the model, we compared the modeled diffuse-total ratio with the ratio derived from MFRSR data taken at Mauna Loa. These two diffuse-total ratios agree very well (Figure 2b). Therefore, we conclude that treatment of the molecular scattering in the model is good and the overestimate of the diffuse field by the model is not caused by an inaccurate treatment of the molecular scattering.

We evaluated the uncertainty in the measurement and the amount of error in the model. The uncertainty in the measurement is ±1.5%. The error in the model is mostly due to neglecting the spectral dependency of the surface albedo and adopting the 2-stream approximation. The amount of error due to these two approximations is, however, less than 1%. Therefore, even though we take into account the uncertainty in the measurement and the error in the model, the model overestimates the total irradiance by approximately 2.5%, which corresponds to 15 to 20 Wm^{-2}.

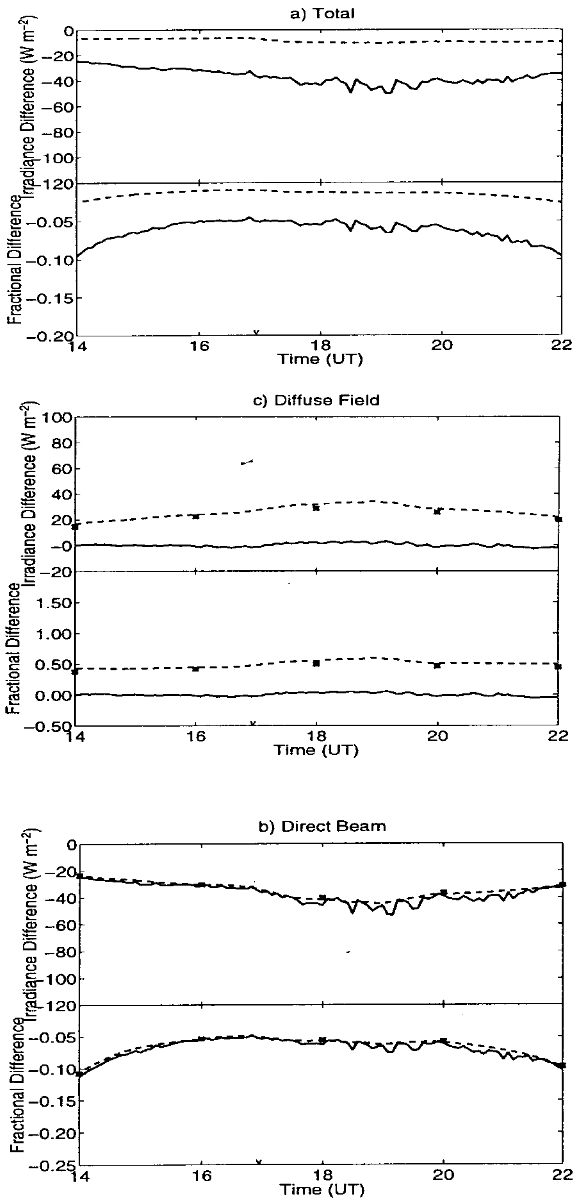

Figure 1. The absolute and fractional differences of the modeled (dashed line) and measured (solid line) downward shortwave total (a), direct beam (b), and diffuse field (c) irradiance at the surface relative to the computed downward shortwave irradiance of the molecular atmosphere for 14 October 1995. The model includes a mineral aerosol. The aerosol optical thickness is determined from sun-photometer measurements. The aerosol size distribution in the model was changed at times that are indicated by a 'v' on the abscissa. Asterisks indicate the direct and diffuse field irradiance computed by a Monte Carlo model.

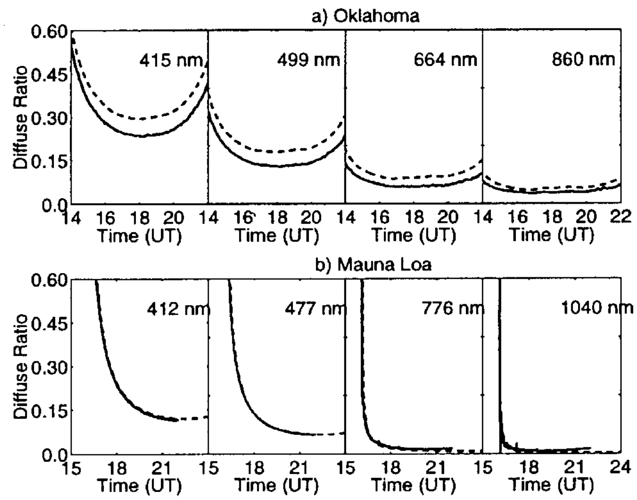

Figure 2. a) Narrow-band diffuse-total ratios on 14 October derived from MFRSR measurements at the Cloud and Radiation Testbed (CART) site (solid line) and δ2-stream model calculations that incorporate a mineral aerosol (dashed line). b) Narrow-band diffuse-total ratios on 6 August 1995 derived from MFRSR measurements at the Mauna Loa Observatory operated by the National Oceanic and Atmospheric Administration (NOAA) Climate Monitoring and Diagnostics Laboratory (solid line) and δ2-stream model calculations for the molecular atmosphere (dashed line).

Summary

A comparison of the measured and modeled downward shortwave irradiance at the surface reveals that the model overestimates the irradiance by 5%. Comparisons of the direct beam and diffuse field irradiances show that the difference is due to an overestimate of the diffuse field irradiance by the model. When uncertainties in the measurements and the model are taken into account, the difference between the measured and modeled total irradiance is reduced, but not eliminated. The model overestimates the total irradiance by approximately 2.5%.

Because, at times, the measured diffuse field is as small as the diffuse field expected from a molecular atmosphere alone, this difference is not caused by the uncertainty in aerosol optical properties. The diffuse-total ratio that is derived from MFRSR measurements also indicates that the measured diffuse irradiance is smaller than the model result. The difference is largest at around 400 nm and becomes smaller with increasing wavelength. Although the difference monotonically decreases with increasing wavelength, it is not caused by the insufficient treatment of the molecular scattering in the model.

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References

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