Are Ground-Based Measurements Sufficient to Quantify Atmospheric Radiative Properties?

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Abstract

Radiation measurements at the surface and simultaneous ground-based measurements of the atmosphere during the FIRE'91[a] cirrus field experiment provided an opportunity to identify essential measurements and deficiencies in parameterizations of current cloud-radiation models. Comparisons between measured and calculated broadband surface fluxes demonstrate the need for 1) accurate humidity and temperature vertical profiles, 2) data that capture the 3-dimensional structure and vertical extinction of clouds, and 3) additional airborne measurements. In-situ cloud microphysical measurements and radiation measurements near the tropopause (taken simultaneously to those at the surface, to define the radiative properties of the troposphere) are vital to improve radiative model parameterizations (and also satellite retrieval algorithms), which are used in the absence of available measurements.

Introduction

To benefit our understanding of radiative transfer processes in the earth's atmosphere, long-term continuous ground-based measurements at a few selected locations all over the world are planned and are already underway at the first Atmospheric Radiation Measurement (ARM) site, in Oklahoma. One of the major difficulties is the definition of the atmospheric radiative properties with measurements from the surface only. Using surface measurements of the atmosphere from the FIRE'91 field experiment and comparing calculated to measured radiative surface fluxes, we seek to identify the most important measurements. This study also points out that many atmospheric properties cannot be measured from the ground and have to rely heavily on model parameterizations, which must be validated and, if necessary, improved.

FIRE'91 measurements, used in this study, are addressed first. Then, the testing procedure is outlined, including a short description of the radiative transfer model. Next, a few selected results are analyzed and, finally, suggestions for future work are given.

Measurements

As a precursor to upcoming measurements at ARM sites, data from the FIRE'91 cirrus field experiment provide a unique opportunity to judge the ability of ground-based measurements to describe the radiative properties of the atmosphere.

This study relies only on a data subset, as most of the measurements were not available at the time this study was conducted (an updated study with more data is underway). Vertical profiles of atmospheric variables (e.g., temperature, humidity) are defined by frequent radiosonde launches by the National Oceanic and Atmospheric Administration (NOAA). Model calculations for times between launches are based on a linear time interpolation of these vertical profiles. Cloud properties and cloud

(a) First ISCCP (International Satellite Cloud Climatology Project) Regional Experiment.

structural data are based on remote sensing data from the ground, including the Pennsylvania State University 94-GHz radar and 10-channel sun-photometer, the latter providing optical depth values for optically thin clouds. Cloud microphysical properties are based on model parameterizations, as in-situ measurements were not processed at the time this work was done. Downward hemispheric broadband solar and infrared fluxes at the ground are provided by Eppley radiometers of the Pennsylvania State University.

Test

The "quality test" involves three stages. First, radiosonde data and measurements from the ground (radar and sun-photometer) are used to define the composition of the atmosphere. Then, a radiative transfer model is applied to derive radiative properties for given atmospheric compositions. Finally, calculated surface fluxes of the model are compared to fluxes actually measured at the surface.

The radiative transfer model is based on a four-stream code at eight solar wavelengths and on a two-stream code at twelve infrared wavelengths. Absorption by atmospheric gases in these bands is expressed via exponential sum-fitting and based on the HITRAN database. Although the selection of radiative method, spectral resolution, and absorption approximation can notably affect calculated fluxes, the chosen model is found to be sufficiently accurate. Deviations of surface broadband fluxes to values based on more accurate models and/or spectral resolution (less than 4%) are found to be small compared with the measurement errors. The model, however, assumes horizontal homogeneity, which is poor for many cloud conditions. To minimize inhomogeneity errors, we use only average flux values for time-periods of at least five minutes.

Results

Comparisons between measured and calculated fluxes carry a combination of errors related to 1) radiative method, 2) model parameterizations, and 3) measurements for model initialization. As errors of the radiative method are small (see above), any significant lack of agreement must be attributed to inaccurate measurements or bad model parameterizations that must be used if important measurements (e.g., cloud micro- and macrophysical properties) are not available.

Broadband surface flux comparison between measured and modeled values for Coffeyville, Kansas, on December 5 and 6, 1991, are given in Figure 1. Daytime surface flux comparisons have been shown separately for the solar and infrared spectral region. In addition, errors for the modeled solar and infrared fluxes are indicated. Clear sky conditions existed in the morning of December 5 and during the afternoon of December 6. Optically thin cirrus, only, was present the afternoon of December 5 and around noon on December 6. Optically thicker mid-level clouds were observed the morning of December 6.

Clear sky comparisons compare moderately well, with errors generally below 10%. Inaccurate humidity and temperature profiles (at best, only radiosonde data every three hours were available) create errors, especially in the infrared spectral region.

Cloudy sky comparisons show larger errors, especially in the presence of optically thicker clouds for the solar region. This is mainly due to the lack of information on cloud optical depth (the radar was not calibrated). However, the radar positioned the cloud base adequately, as infrared errors remain significantly smaller. Some of the large solar error also may be attributed to the horizontal inhomogeneous cloud structure, despite the use of five-minute flux averages in the comparison. The spatial variability of clouds may contribute to the modeling error, as simultaneous cloud radar observations (sunphotometer measurement) and broadband flux measurements were not completely collocated.

Under cirrus cloud conditions, particularly for the afternoon of December 5, calculations systematically overestimate solar downward fluxes. This may indicate a bad model assumption. Model sensitivity studies with a smaller solar asymmetry-factor of less than 0.8 for cirrus clouds result in much better match between model results and actual measurements.

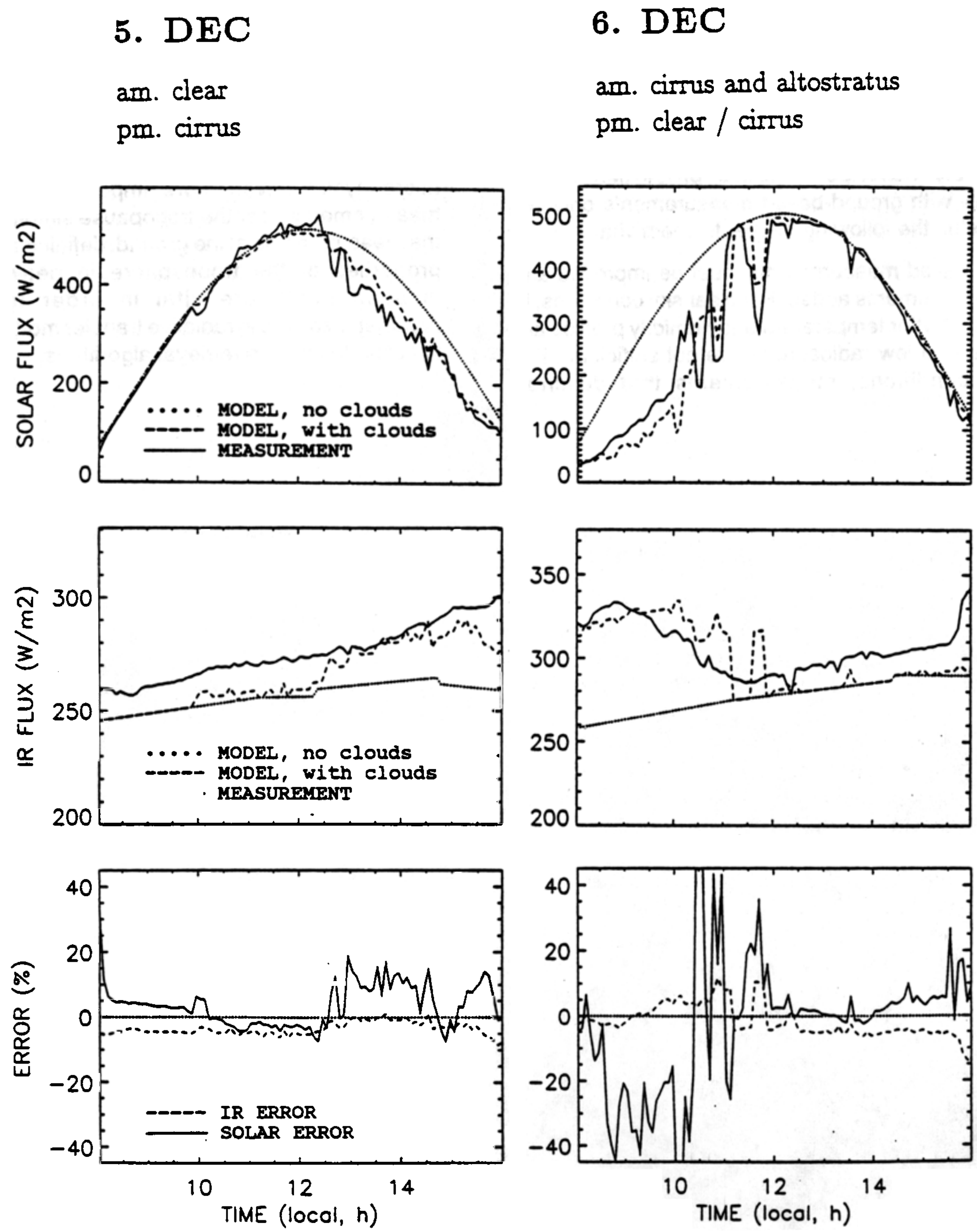

Figure 1. Comparison between measured (solid line) and modeled (dashed line - clouds included; dotted line - clouds omitted) hemispheric downward broadband solar infrared fluxes for December 5 and 6, 1991, at Coffeyville, Kansas. In addition, corresponding errors for calculated solar fluxes (solid line) and calculated infrared fluxes (dashed line) are given.

Conclusion

Our results, which are limited to a few ground-based measurements so far, indicate that a lack of appropriate model parameterizations make it difficult, if not impossible, to accurately describe radiative properties of the atmosphere with ground-based measurements only. To be successful, the following elements seem vital:

- Ground-based measurements must be improved and new measurements added. For clear sky conditions, in particular, better temperature and humidity profiles are necessary (a few radiosondes are not sufficient). For cloudy conditions, measurements that describe horizontal (radiometer-array) and vertical cloud structure as well as cloud extinction (calibrated radar) are needed.

Airborne measurements are highly desirable. Even as short "field experiments," they should provide in-situ cloud measurements that help us understand cloud microphysics. Even more important are radiation measurements near the tropopause simultaneously to the measurements at the ground, defining the radiative properties of the troposphere in between. Such measurements are vital in order to improve parameterizations in radiative transfer models and also to calibrate satellite retrieval algorithms.