Satellite Estimates of Surface Short-Wave Fluxes: Issues of Implementation

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Abstract

Surface solar radiation reaching the Earth's surface is the primary forcing function of the land surface energy and water cycle. Therefore, there is a need for information on this parameter, preferably, at global scale. Satellite based estimates are now available at accuracies that meet the demands of many scientific objectives. Selection of an approach to estimate such fluxes requires consideration of trade-offs between the use of multi-spectral observations of cloud optical properties that are more difficult to implement at large scales, and methods that are simplified but easier to implement. In this study, an evaluation of such trade-offs will be performed. The University of Maryland Surface Radiation Model (UMD/SRB) has been used to reprocess five years of GOES-8 satellite observations over the United States to ensure updated calibration and improved cloud detection over snow. The UMD/SRB model was subsequently modified to allow input of information on aerosol and cloud optical depth with information from independent satellite sources. Specifically, the cloud properties from the Atmospheric Radiation Measurement (ARM) Satellite Data Analysis Program (Minnis et al., 1995) are used to drive the modified version of the model to estimate surface short-wave fluxes over the Southern Great Plain ARM sites for a twelve month period. The auxiliary data needed as model inputs such as aerosol optical depth, spectral surface albedo, water vapor and total column ozone amount were kept the same for both versions of the model. The estimated shortwave fluxes are evaluated against ground observations at the ARM Central Facility and four satellite ARM sites. During summer, the estimated fluxes based on cloud properties derived from the multi-spectral approach were in better agreement with ground measurements than those derived from the UMD/SRB model. However, in winter, the fluxes derived with the UMD/SRB model

were in better agreement with ground observations than those estimated from cloud properties provided by the ARM Satellite Data Analysis Program. During the transition periods, the results were comparable.

1. Introduction

Solar radiation incident at the earth surface determines the surface temperature, sensible and latent heat fluxes which govern most dynamic and hydrologic processes (Stephens and Greenwald, 1991). It plays an essential role in controlling biological processes (Goward, 1989; Running et al., 1999; Platt, 1986) and in validating climate models (Garrat et al., 1993; Wild et al., 1995; Wielicki et al., 2002).

Clouds strongly modulate the energy balance of the earth and the atmosphere through interaction with solar and terrestrial radiation, as demonstrated from both satellite (Ramanathan, 1987; Ramanathan et al., 1989) and from modeling studies (Ramanathan et al., 1983; Cess et al., 1989). The largest uncertainties in surface short-wave fluxes estimated from satellites are due to inadequate information on cloud properties. There have been many attempts at both regional and global scales, to estimate surface radiative fluxes from satellite-observed radiances (Ramanathan, 1986; Pinker and Lazlo, 1992; Li and Leighton, 1993; Stephens et al., 1994; Gupta et al., 1999). Most such models have been designed for a particular satellite, using primarily a single visible channel to derive cloud properties. Cloud optical properties based on multiple-channel information are expected to provide more accurate description of clouds and subsequently, lead to improved estimates of surface solar fluxes. There is a need to find out if independent estimates of cloud optical properties by advanced methods can yield better estimates of surface fluxes than those that use a simplified approach. In this study, the effect of cloud optical properties as derived from the Atmospheric Radiation Measurement (ARM) Satellite Data Analysis Program on the estimates of surface shortwave fluxes from the UMD/SRB model (Pinker et al., 2003) is examined.

To facilitate the use of independently derived optical parameters from multi-spectral satellite observations, the UMD/SRB model, has been modified. The cloud properties provided by the Atmospheric Radiation Measurement (ARM) Satellite Data Analysis Program (Minnis et al., 1995) are chosen to drive the modified mo using information on cloud amount and clear and cloudy radiances derived from the operational cloud detection algorithm as described in Pinker et al., (2003); and from an improved cloud screening approach as described in Li et al. (2006) and Pinker et al. (2006). In section 2 described will be briefly the UMS/SRB model. del. The resulting surface short-wave fluxes are compared with the other satellite products and with ground observation at the Southern Great Plains ARM Central Facility, as well as at four extended ARM sites. The other satellite product is based on the UMD/SRB model. Data used will be described in section 3. Results are presented in section 4 and discussion and conclusions are presented in section 5.

2. Model Description

The UMD/SRB model (model A) is a physical inference scheme based on radiative transfer theory (Pinker et al., 2003). Using forward radiative transfer calculations, relationships are established between the broadband (0.2-4.0 μm) transmissivity and the reflectivity at the top of atmosphere under various conditions pertaining to the surface, atmosphere, and clouds. Then surface albedos are derived from the satellite measured radiances at the TOA representing average clear sky conditions. Once the surface albedo is determined, the atmospheric transmission and reflection (Optical Functions) for instantaneous clear and cloudy conditions are obtained by matching the broadband TOA albedos, derived from the satellite observed clear and cloudy radiances, respectively, with TOA albedos computed by the radiative transfer model. The retrieved optical functions, along with the surface albedo are then used to compute the fluxes for clear and cloudy conditions. Finally, clear and cloudy fluxes weighted by the pixel number of clear and cloudy conditions are summed up to obtain all-sky fluxes.

In the modified version of the UMD/SRB model (model B), the need to estimate aerosol and cloud properties from the clear and cloudy radiances is by-passed. Instead, such information is provided from independent sources. The additional input parameters for driving the model that describe the state of the atmosphere and surface include surface albedo, water vapor and ozone amount.

3. Data

The radiative fluxes used in the comparison were obtained from the "reprocessed product" of the UMD/SRB model (Pinker et al., 2003) (model A); the output of the modified UMD/SRB model (model B) driven with cloud information as obtained from the Atmospheric Radiation Measurement (ARM) Satellite Data Analysis Program (Minnis et al., 1995); and ground observations from the ARM program.

The UMD/SRB model (model A) is run in real time at the National Oceanic and Atmospheric Administration (NOAA)/National Environmental Satellite Data and Information Service (NESDIS) since January 1996, in support of the GEWEX

Continental Scale International Project (GCIP). The primary observing system is the visible channel (0.52-0.72 μm) on the GOES-8 satellite, which is a narrow-band channel. Instantaneous, hourly, daily, and monthly mean information on surface down-welling shortwave (SW), top of the atmosphere downward and upwelling radiative fluxes, are provided for an area bounded by 70^0-125^0 W longitude and 25^0-50^0 N latitude. The "reprocessed" product aims to improve the Surface Radiation Budget (SRB) parameters as currently produced at NOAA/NESDIS operationally by applying updated calibrations; improved cloud detection schemes, in particular, better cloud detection over snow (Li et al., 2006; Pinker et al., 2006), and improved atmospheric input parameters such as ozone (which till now was taken from climatology).

The independent cloud properties used to drive the modified model (model B) have been developed under the Atmospheric Radiation Measurement (ARM) Satellite Data Analysis Program (Minnis et al., 1995). The retrieval of cloud properties is based on an idealized model of clouds, assuming that all clouds are plane parallel, the cloud completely fills the pixel and has a uniform distribution of particle sizes within the pixel. Each cloudy pixel contains a cloud at only one altitude and has a thickness prescribed by empirical formula. The satellite data are calibrated and widely used cloud bi-directional reflectance models describe the anisotropy of the clear-sky conditions. The cloud properties are determined from the satellite data using the VIS-IR parameterization known as the layer bi-spectral threshold method (Minnis et al., 1993). The spatial coverage of the derived cloud properties extends from 32.25^0-41.75^0 N and 91.25^0-104.750 W at a 0.5-degree latitude-longitude grid. These half-hourly cloud properties from January 1 to December 31, 2000 were implemented with model B. To isolate the effect of independently derived cloud properties, all other input parameters were kept the same as those used in the "reprocessed" version of the UMD/SRB model. These include aerosol optical depth, surface spectral albedo, water vapor and ozone amount.

Ground observations are obtained from the Solar and Infrared Radiation Station at the Southern Great Plain of the ARM Central Facility, as well as at four extended sites. To match the estimated surface downward short-wave fluxes at a resolution of half a degree, the point measurements at each minute were averaged over a 30-minute interval.

4. Results

Surface downward short-wave fluxes as estimated from the two model versions, using cloud properties as derived from the "reprocessed" version of the UMD/SRB model (A) and those estimated from the ARM Satellite Data Analysis Program (B) were evaluated against ground observations. **Figure 1** shows the scatter-plot of estimated fluxes against ground observations at the central facility for the entire period of 2000. For most months, surface downward solar fluxes estimated with the ARM Satellite Data Analysis Program cloud properties agree well with ground observations. For instance, for September of 2000, a high correlation coefficient of 0.99, a small rms error of 41.26 W/m^2 and negative bias of 4.72 W/m^2 were achieved. However, for winter months, (e.g., December of 2000), the agreement is not as good, having a correlation coefficient of 0.84 and large negative bias of 40.84 W/m^2 and an rms error of 100.78 W/m^2.

It is of interest to compare the performance of the two products in two winter months. The evaluation of the two data sources for December at the Central Facility and for January at Extended Site 1 are shown in **Figure 2** and **Figure 3**, respectively. UMD/SRB fluxes (A) have a higher correlation coefficient, smaller rms error and bias than fluxes estimated from ARM Satellite Data Analysis Program cloud properties (B). The relatively larger disagreement of estimated fluxes with ground observations is due to the presence of snow at surface. For instance, snow cover from MODIS snow products (MOD10C1) (**Figure 4)** shows that a large area of Southern Great Plains was covered by snow on Dec, 17**.** The comparison indicates that the UMD/SRB model differentiates quite well clouds from snow.

Figure 5 shows the scatter-plot of estimated fluxes against ground observations at the central facility from models A and B for 2000. Twelve months in 2000 were grouped as follows: DJF (December, January and February), MAM (March, April and May), JJA (June, July and August), and SON (September, October and November). For DJF, MAM, AND SON, the two model results compare similarly against ground observations. For the summer months of JJA, UMD/SRB (A) fluxes have a correlation coefficient of 0.93, a positive bias of 15.89 W/m^2 and an rms error of 105.24 W/m^2, while results from model B (ARM Satellite Data Analysis Program cloud properties) have a correlation coefficient of 0.96, a positive bias of 21.48 W/m^2 and an rms error of 86.23 W/m^2.

The evaluation of the satellite estimates over all five ARM sites indicates that in general, model B (ARM Satellite Data Analysis Program cloud properties) yields a better estimate of surface shortwave fluxes than model A during summer, model A performs better in winter and the two are comparable during other time periods.

Since the "reprocessed" data from model A are available only for the period 1996-2000 surface fluxes for three summer months based on the operational product of NOAA/NESDIS are also compared with those estimated from ARM Satellite Data Analysis Program cloud properties. **Figure 6** shows the evaluation of these data against ground observations at Central Facility for JJA. During summer, fluxes from the operational model agree well with ground observations as well as with the fluxes estimated from model B.

5. Discussion and Conclusions

Cloud properties provided by the ARM Satellite Data Analysis Program over the Southern Great Plains are based on a bi-spectral approach while the UMD/SRB model uses single channel retrieval of cloud optical depth. The two-channel approach is labor intensive and more complex to use than the one channel algorithm. It is therefore of interest to evaluate the impact of the two channel approach on estimating surface radiative fluxes. Such an evaluation has been undertaken in this study.

The advanced scheme of the ARM Satellite Data Analysis Program retrievals should in principle lead to more accurate cloud optical properties and a better estimate of surface shortwave fluxes than the simplified inference schemes. Over a one year period, cloud properties derived by this advanced scheme do yield better estimates of surface fluxes during the summer months. During the winter months when snow is on the ground, model A as driven with inputs from the improved cloud detection scheme gave better results. Therefore, ARM Satellite Data Analysis Program cloud properties can be instrumental in cross-validating the UMD/SRB model surface flux retrievals and in identifying error sources in the UMD/SRB model.

This study also demonstrates the ability of the modified version of the UMD/SRB model (B) to estimate surface fluxes with independent satellite based estimates of cloud optical properties. Improvements in estimating surface shortwave fluxes are anticipated from the implementation of this modified version of the UMD/SRB model with cloud and aerosol optical properties from upgraded ARM satellite retrievals (Minnis et al., 2002) that provide better snow detection (Trepte et al., 2002) and from a new generation of satellite instruments of higher spectral and spatial resolution such as MODIS on Terra and Aqua and the Spinning Enhanced Visible and Infrared Imager (SEVIRI) on METEOSAT-8.

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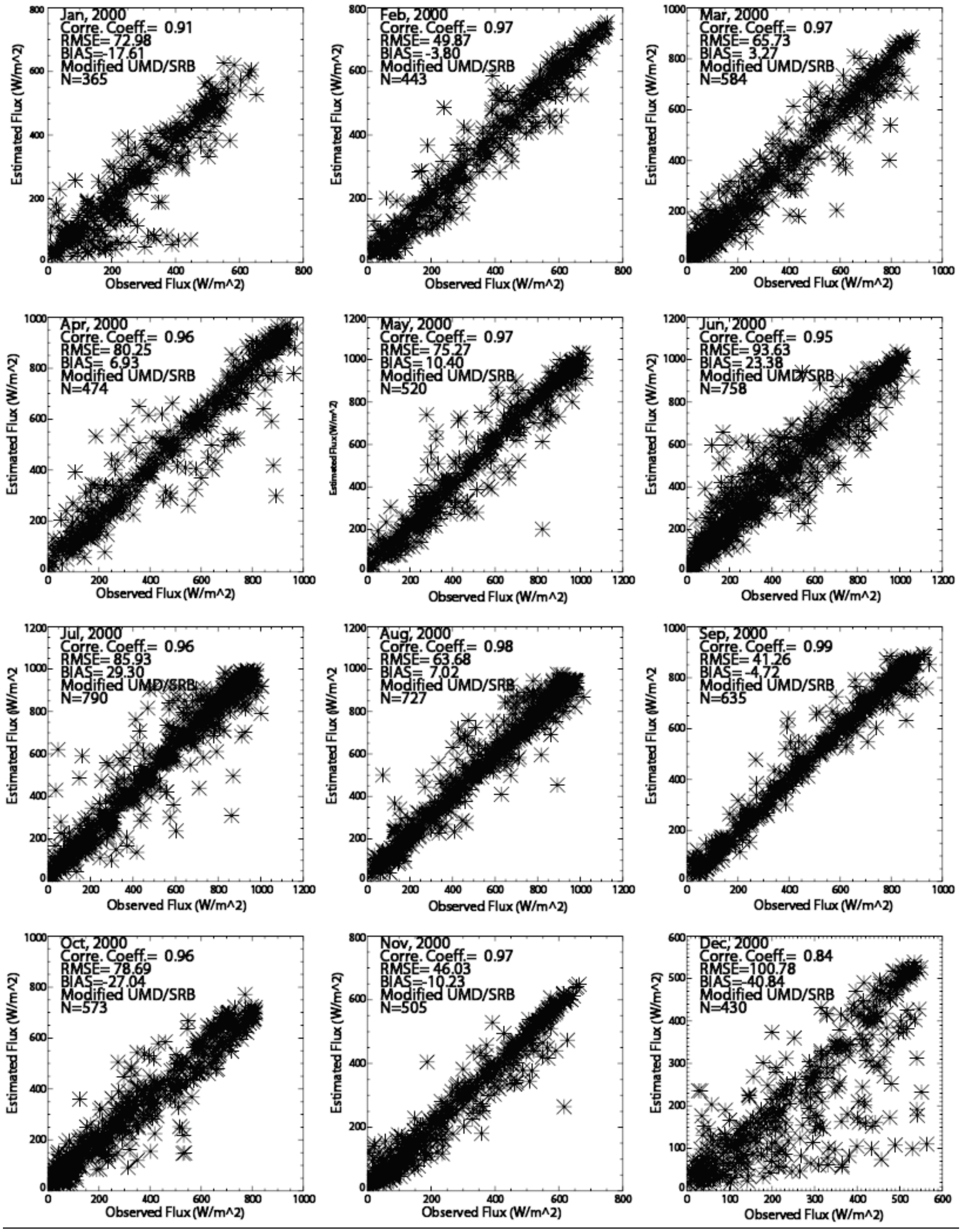
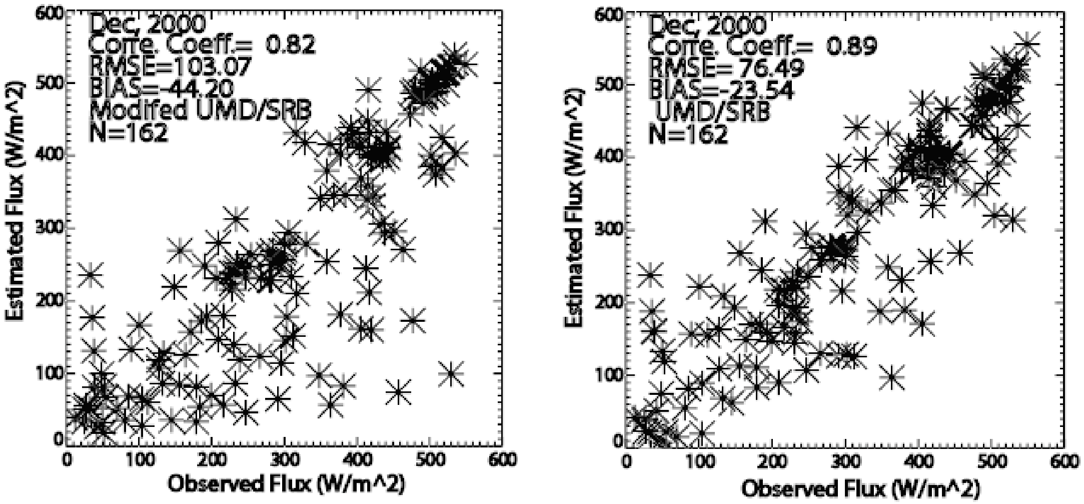


Figure 1. Evaluation of surface downward shortwave fluxes using the UMD/SRB model driven with *ARM Satellite Data Analysis Program* cloud properties. Ground measurement are from the ARM Central Facility, Southern Great Plain, 2000



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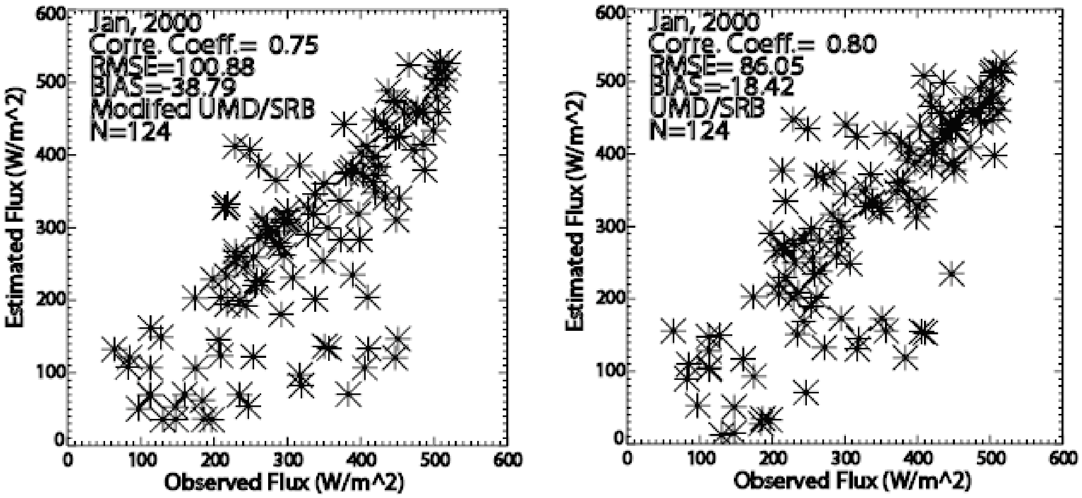

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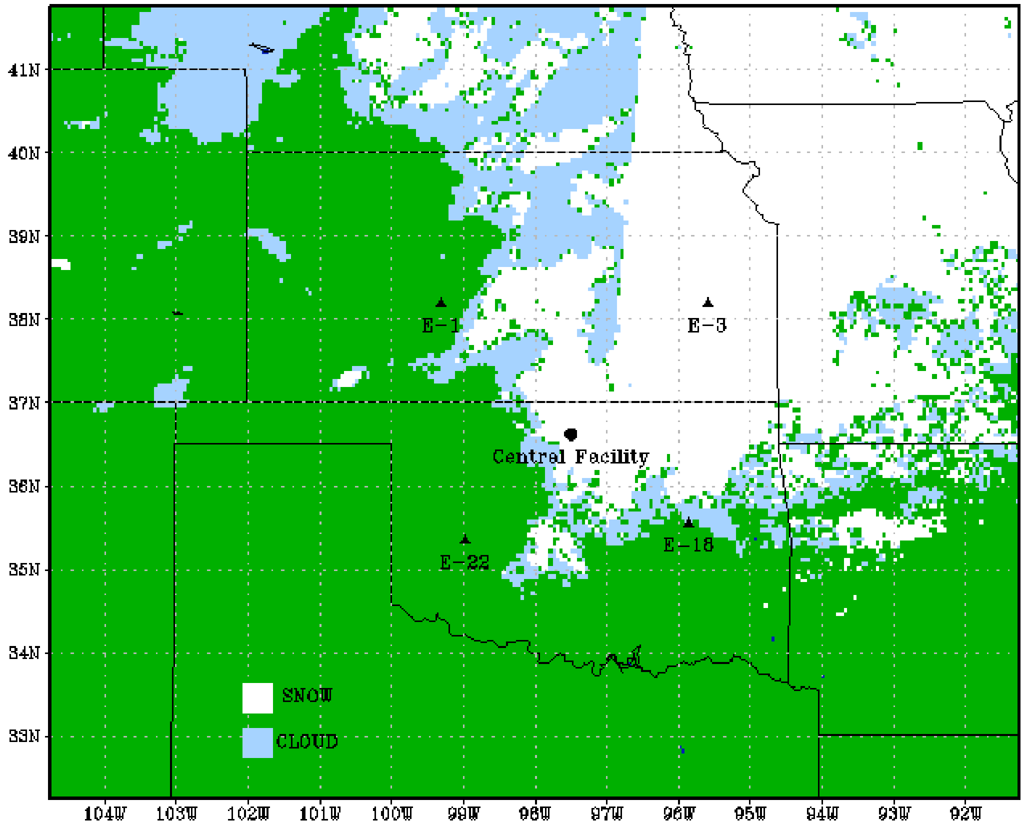

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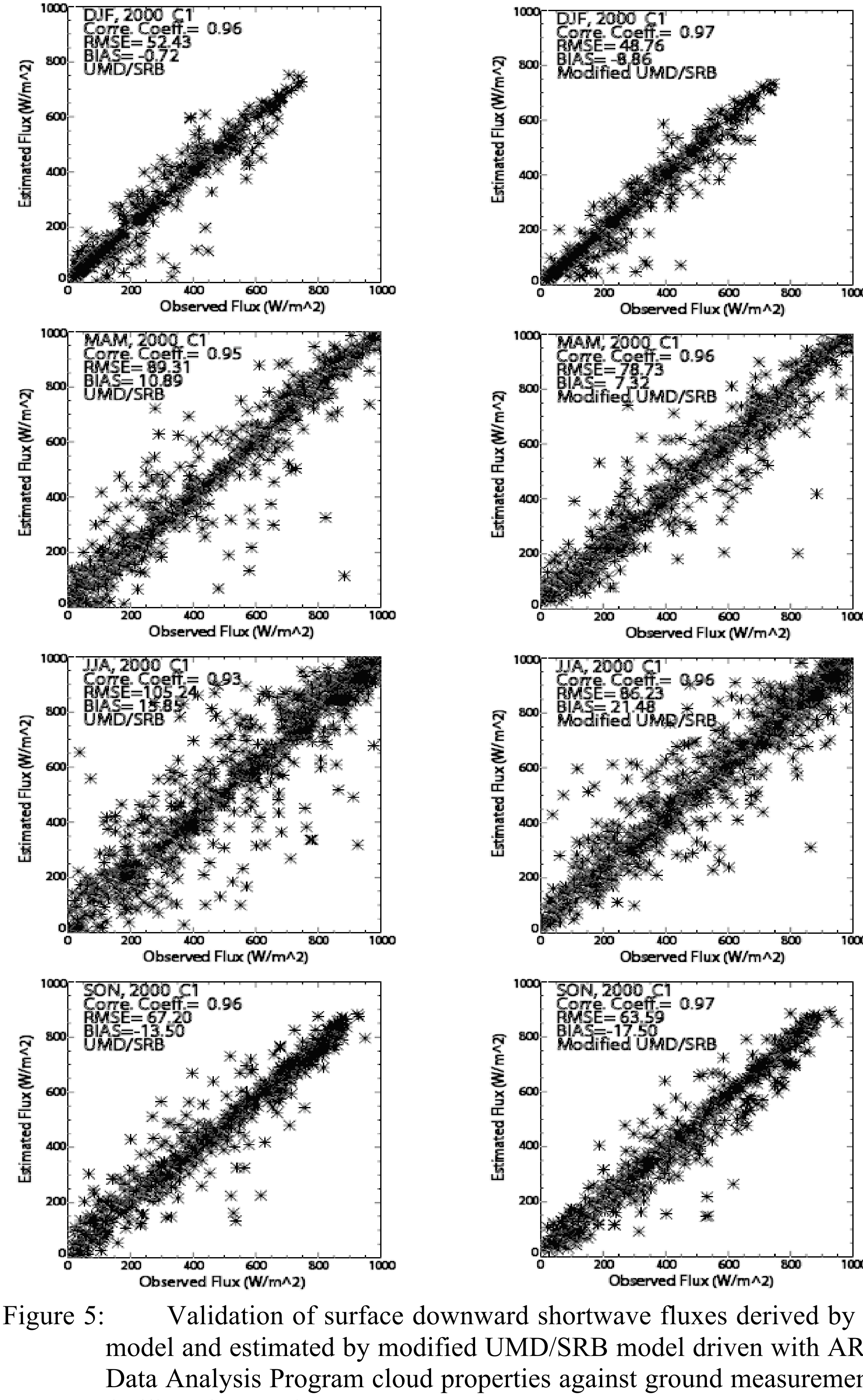

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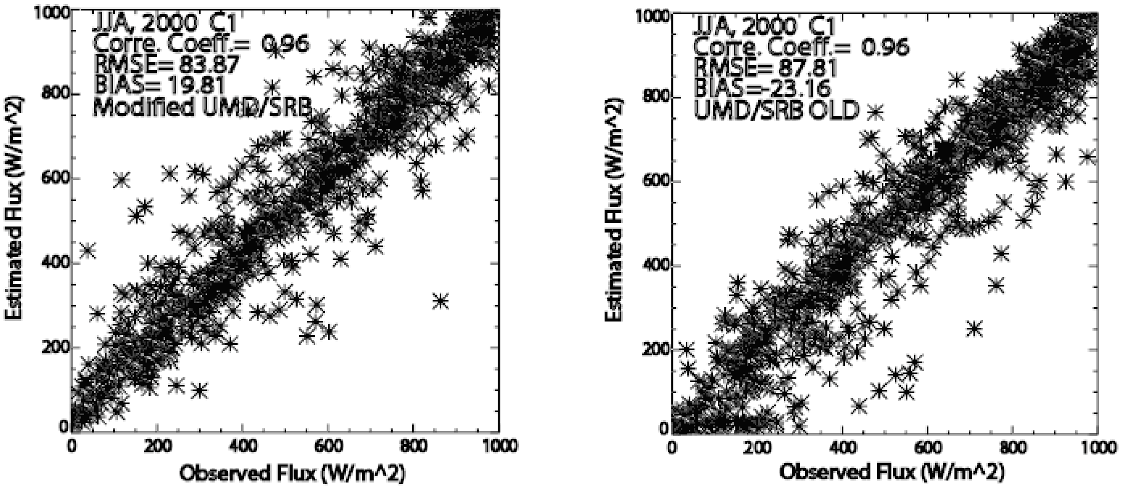

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