P1.34 MULTISEASONALVALIDATION OF GOES-BASED INSOLATION ESTIMATES

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1. INTRODUCTION

Detailed knowledge of the spatial and temporal distribution of incoming solar radiation (insolation) at the earth's surface is important for a wide range of applications including improved agricultural production, water supply management, and estimating evapotranspiration and photosynthesis. During the last several decades, satellite data have been utilized to estimate insolation from hourly to monthly time scales. Though somewhat limited in temporal resolution when compared to surface-based pyranometers, geostationary satellites such as the Geosynchronous Operational Environmental Satellite (GOES) have the distinct advantage of providing continental-scale insolation data with high spatial resolution. Such finely resolved insolation data provide an excellent opportunity to study climate and the surface energy budget.

In this study, hourly and daily GOES-estimated insolation data produced at the University of Wisconsin-Madison will be extensively compared to pyranometer data from six sites in the United States Climate Reference Network (USCRN) over a continuous 15-month period. Such a comprehensive survey will allow us to examine the accuracy of the satellite-based method over a diverse range of seasons and land-surface types.

2. DATA AND METHODOLOGY

2.1 GOES-ESTIMATED INSOLATION DATA

The radiative transfer model used to estimate surface insolation from GOES visible imagery is described in detail by Gautier et al. (1980) and Diak and Gautier (1983). The physical model is based on the conservation of radiant energy in the earth-atmosphere column and contains separate parameterizations for cloudy and clear-sky conditions (Fig. 1). In order to detect the presence of clouds, an instantaneous visible image is compared to a reference clear-sky image of the surface albedo. To construct the reference albedo image, the GOES visible image closest to solar noon for each geographic location is used to calculate the surface albedo for a given day. At the end of that day, the minimum surface albedo at each location during the prior two-week period is assumed to represent the clear-sky surface albedo. Regular updating of the albedo field is necessary in order to capture seasonal changes in vegetation, soil moisture, and snow cover.

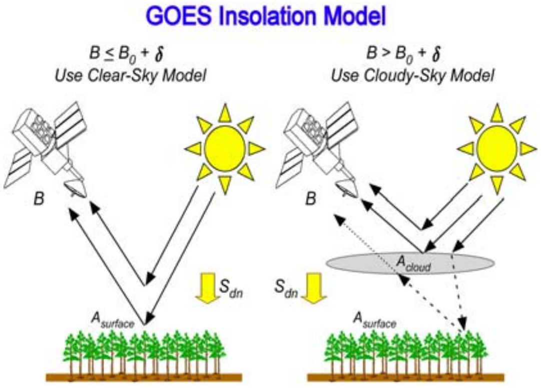

Figure 1. Graphical depiction of the physical model employed for clear-sky conditions (left) and for cloudy-sky conditions (right). B refers to the brightness observed by the satellite, S_{dn} refers to the downward shortwave radiation flux, and $A_{surface}$ and A_{cloud} refer to the surface and cloud albedos, respectively.

The clear-sky albedo is then used along with atmospheric properties and the sun angle at that location to estimate the digital brightness that the satellite would measure under clear-sky conditions. If the actual brightness of the instantaneous data point is at or below the clear-sky threshold, a clear-sky model of the atmosphere that accounts for Rayleigh scattering, water vapor absorption and ozone absorption is employed to estimate the surface insolation. If the measured brightness exceeds the clear-sky threshold, a cloudy model is used to calculate the surface insolation. With the cloudy model, a cloud albedo is computed from the GOES visible imagery, taking into account certain atmospheric effects such as ozone absorption and Rayleigh scattering above the cloud top. Then, a simple parameterization that accounts for Rayleigh scattering, ozone absorption and water vapor absorption above and below the cloud is used to predict insolation at the land surface. The cloudy model assumes plane-parallel clouds and is optimized for low- and mid-level clouds since these clouds most strongly influence the magnitude of the surface insolation.

For this study, satellite data from GOES-8 and GOES-12 (hereafter referred to as GOES-E) were

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used to map surface insolation on a 0.2º latitude-longitude grid (~20 km) across the continental United States. Insolation data is available on our website at http://www.homer.wisc.edu/~insol.

2.2 USCRN DATA

The USCRN is a nationwide network currently being developed to provide continuous, high quality data of key climate-related variables such as near-surface air temperature, precipitation, wind speed, solar radiation, and ground surface temperature. As of early 2004, the network consists of approximately 40 stations across the continental U.S. (Fig. 2). The USCRN sites chosen for this study encompass a wide distribution of land-surface types ranging from heavily forested land (Asheville, NC) to flat agricultural land (Champaign, IL) to complex coastal areas (Lafayette, LA).

Of particular interest for the present study is the availability of high-quality surface insolation measurements. Insolation is measured at each site using a Kipp and Zonen SP Lite photodiode pyranometer. Insolation measurements are taken every 2 seconds and then averaged to obtain 5-minute insolation values. A station's data stream at the top of each hour contains the average and standard deviation of the twelve 5-minute insolation values during the previous hour.

Figure 2. USCRN locations across the continental United States as of early 2004. Stations indicated by red circles were used for this study.

2.3 METHODOLOGY

Insolation data from 6 sites in the USCRN (Fig. 2) will be compared to GOES-E insolation estimates over a continuous 15-month period from 1 December 2002 to 29 February 2004. In order to identify any seasonal variations in the accuracy of the satellite estimates, the 15-month period was divided into 5 standard meteorological seasons (i.e. summer occurs from June to August, etc.).

The timestamps of the hourly-averaged USCRN data have been corrected to represent the midpoint of the averaging interval. The GOES-based insolation estimates were then linearly interpolated to this timestamp, with hourly data from both GOES and the USCRN subsequently integrated to obtain daily values.

Since the current version of the insolation algorithm has a known defect in that it is unable to distinguish between snow cover and clouds, the satellite-based insolation data were first screened for snow cover. Snow-covered days were identified at each station by examining that station's hourly temperature and precipitation records. Future versions of the insolation algorithm will contain a snow albedo module that accounts for this snow cover problem.

3. RESULTS

3.1 SEASONAL INSOLATION COMPARISONS

A seasonal comparison of hourly insolation measurements from six USCRN stations across the eastern U.S. with hourly estimates from GOES-E is presented in Fig. 3. Overall, the highest seasonal correlations (R^2 = .94 to .96) generally occurred within relatively flat agricultural regions characterized by a continental climate (i.e. Lincoln, NE, Stillwater, OK, and Champaign, IL). Coastal areas (Kingston, RI and Lafayette, LA) and mountainous regions (Asheville, NC) tended to be characterized by the lowest correlations each season. Considering the long duration of this study, the average accuracy of the hourly GOES-E insolation data for all seasons and stations was an encouraging 20%, as measured by the RMSE. Given the complex cumulus cloud environment characteristic of warmer seasons, it is not surprising that the largest average seasonal RMSE (~23%) occurred during the summer.

Figure 4 contains a seasonal comparison of daily-integrated USCRN and GOES-E insolation data. Overall, the high linear correlations ($R^2 > .96$) and low RMSEs (< 10%) observed throughout this comparison demonstrate the ability of the satellite-derived insolation method to accurately estimate the surface insolation over daily time scales. The average RMSE (10%) over all stations and seasons compares very favorably to previous satellite-derived insolation studies. The absolute magnitude of the RMSEs varied from 0.9 MJ m^{-2} day^{-1} during the two winter seasons to 2.1 MJ m^{-2} day^{-1} during the summer of 2003. The relative RMSE was lowest during the fall of 2003 (8%) and highest during the winter of 2002-03 (12%). Examination of the individual panels reveals a small positive bias in the daily-integrated GOES-E predictions for some seasons (e.g., the summer of 2003), which serves to increase the magnitude of the RMSE values associated with the GOES-E insolation dataset.

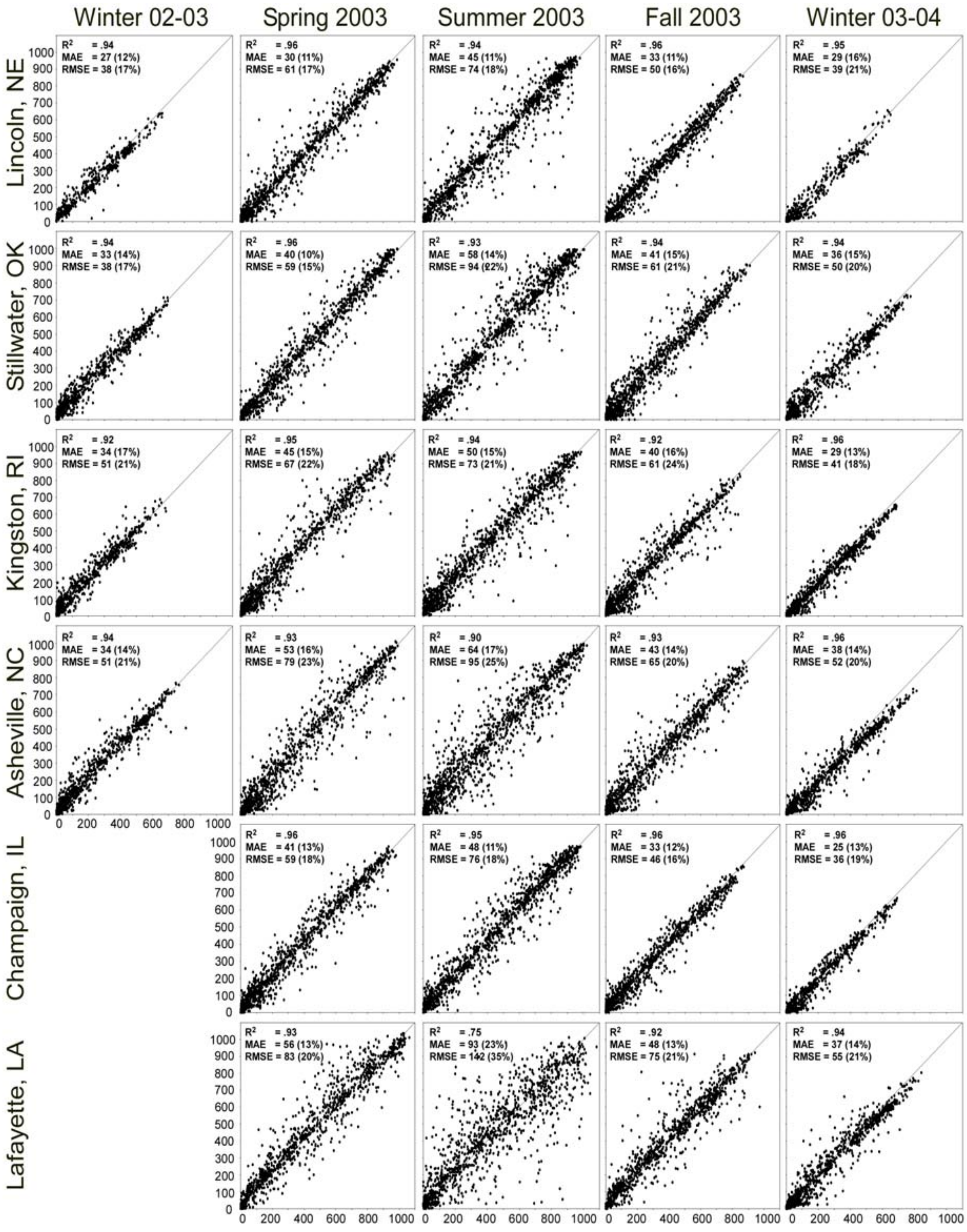

Figure 3. Seasonal comparison of hourly insolation data (W m^{-2}) from GOES-EAST (plotted along the ordinate of each panel) and six USCRN stations (plotted along the absisca of each panel). Station names are indicated along the left-hand side of the figure. Seasons are indicated at the top of the figure. R^2 refers to the coefficient of determination, MAE refers to the mean absolute error, and RMSE refers to the root mean square error. MAE and RMSE percentages are shown in parentheses.

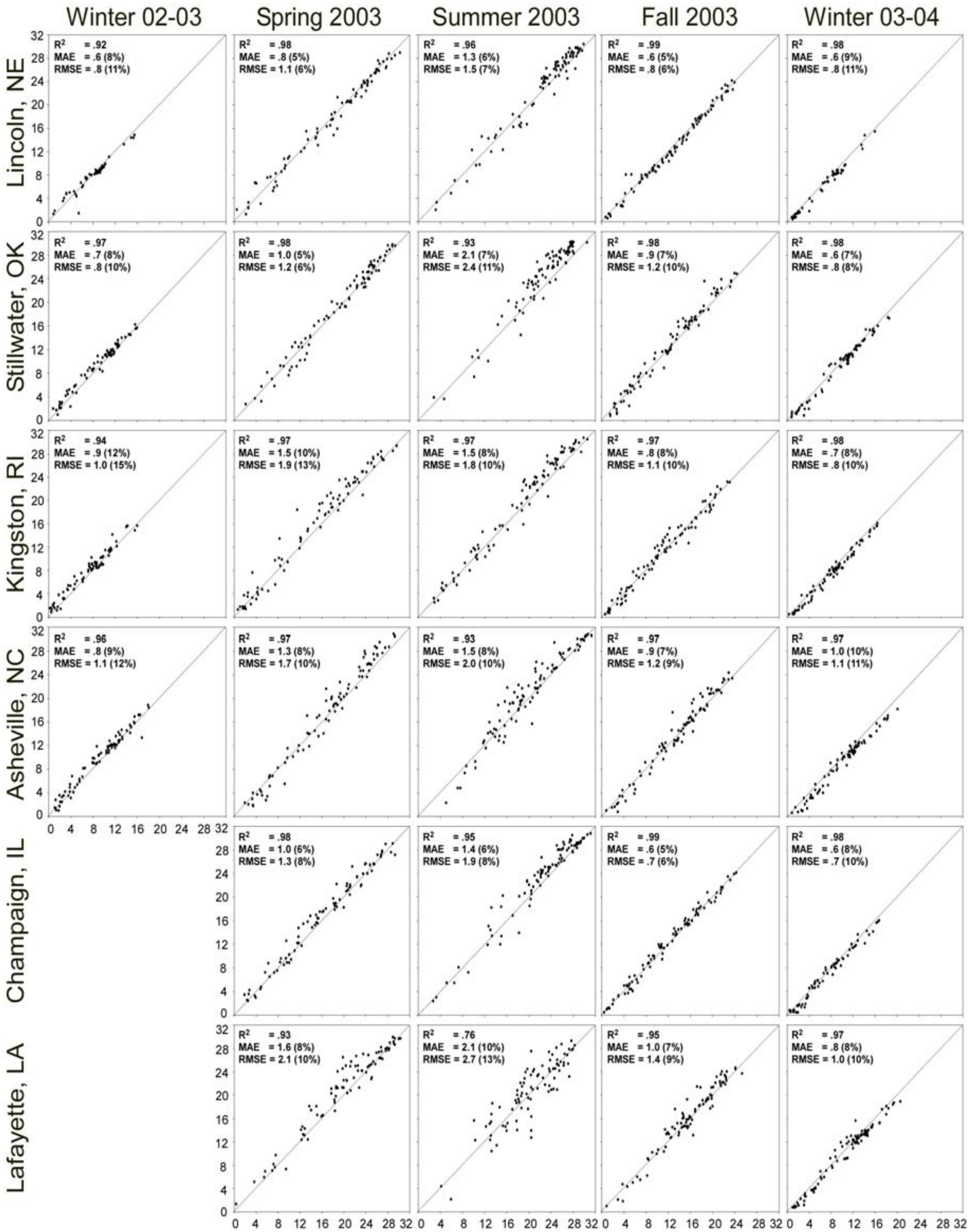

Figure 4. As for Fig. 3, except for daily-integrated GOES-EAST insolation (MJ m^{-2} day^{-1}).

3.2 MEAN DIURNAL CYCLE

Fig. 5 shows the mean diurnal cycle of observed and satellite-estimated insolation at two USCRN locations during June 2003. Although both locations were characterized by complex cloud conditions during this period, it is evident that the satellite-derived insolation algorithm was able to accurately reproduce the diurnal variation of insolation.

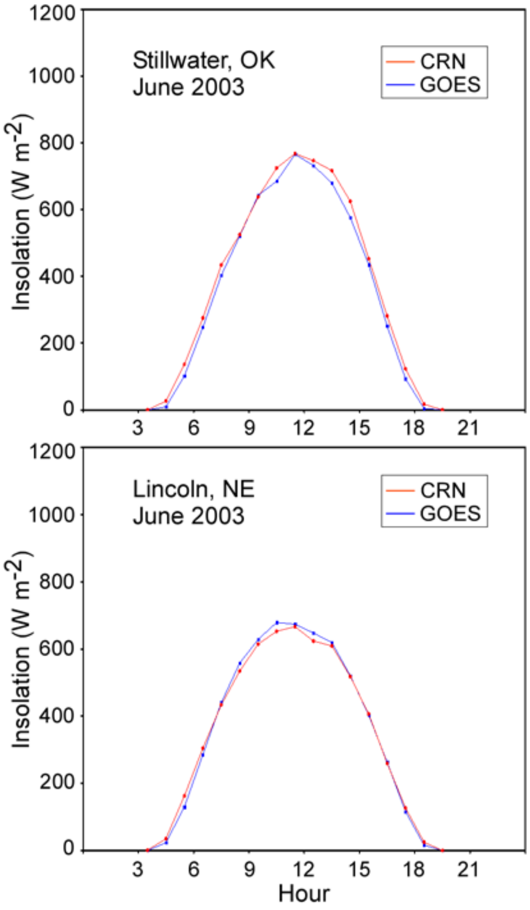

Figure 5. Comparison of monthly mean diurnal cycle for USCRN (red line) and GOES-12 (blue line) insolation at Stillwater, OK (top) and Lincoln, NE (bottom).

3.3 FREQUENCY DISTRIBUTIONS

Fig. 6 shows the frequency distribution of hourly insolation values at Stillwater, OK and Lincoln, NE during the 2003 warm season (May to September). Overall, the relative difference between the ground observations and satellite estimates is very small (less than 1%) with slightly larger differences for extreme insolation values.

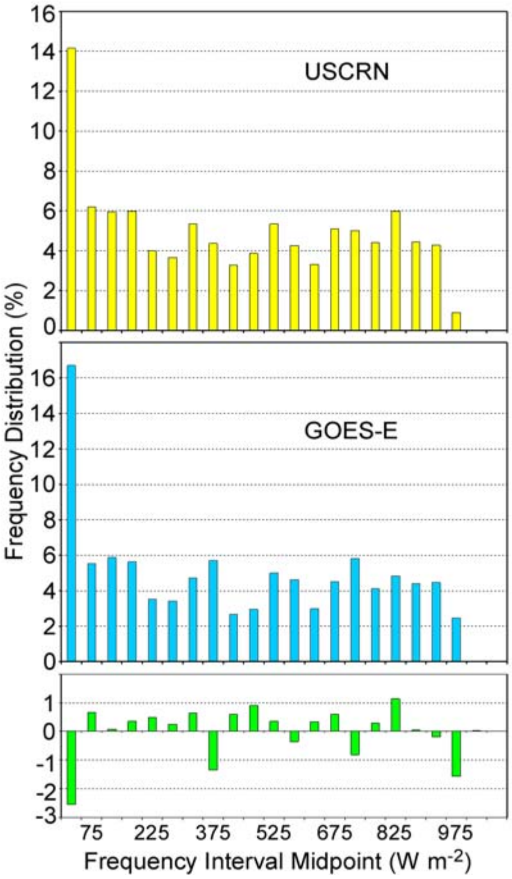

Figure 6. Frequency distribution of hourly insolation values using USCRN data at Stillwater, OK and Lincoln, NE (top panel) and the corresponding satellite estimates (middle panel) for May-September 2003. Each bin is 50 W m^{-2} wide. The difference between the two distributions is shown in the bottom panel.

4. CONCLUSIONS

Hourly and daily-integrated GOES insolation estimates were compared to pyranometer insolation data from the USCRN for a continuous 15-month period from 1 December 2002 to 29 February 2004. The results of this comprehensive survey demonstrated that the satellite-derived insolation method developed by Gautier et al. (1980) and Diak and Gautier (1983) provides accurate hourly and daily-integrated insolation estimates. Given the wide range of seasons and land-surface types included in this study, the average hourly and daily-integrated RMSEs for the GOES-E insolation estimates were an encouraging 20% and 10%, respectively. These results compare very favorably to the results of prior satellite-derived insolation studies.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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