Operational Improvements in the Performance of the SUNY Satellite-to-Solar Irradiance Model Using Satellite Infrared Channels

John Dise[1], Adam Kankiewicz[1], Jim Schlemmer[2], Karl Hemker[2], Sergey Kivalov[2], Tom Hoff[1], Richard Perez[2]

[1]Clean Power Research, Napa California 94558, [2]Atmospheric Sciences Research Center at The University of Albany, Albany, NY 12203

***Abstract* — Validation and operational improvements to the existing SUNY satellite-to-solar irradiance model through incorporation of four of the geostationary satellite infrared (IR) channels are presented herein. The SUNY model is the gridded data set used by NREL in the National Solar Radiation Database (NSRDB) and is available commercially through the Clean Power Research software, SolarAnywhere® Data. This improved model addresses the present model's limitations when representing the irradiance conditions in circumstances of snow cover, high ground reflectance and persistent cloud cover. Improvements in the satellite-to-solar irradiance model have been realized using the IR channels to detect snow conditions and modulate the model background to more accurately reflect irradiance conditions.**

***Index Terms* — SUNY satellite irradiance model, GOES, snow conditions, National Solar Radiation Database (NSRDB), SolarAnywhere**

I. Introduction

The SUNY satellite model has been selected by NREL to produce the two most recent (2005, 2010) National Solar Radiation Database releases, and is available throughout North America in the commercial software platform, SolarAnywhere. The model performs appropriately in most climatological conditions, leveraging the visible channel image from the geostationary operational extraterrestrial satellite (GOES) operated by the National Oceanic and Atmospheric Administration (NOAA). However, in conditions of snow cover or when the background visible image is predominantly bright, the model loses ability in reflecting terrestrial irradiance conditions. Improvements to the SUNY model have been developed and proven by Perez et al. [1], and will be made operational through Clean Power Research (CPR) and the software product, SolarAnywhere.

The accuracy of the SUNY model, in practice, relies heavily on the ability to recognize the difference between what is cloudy and what is the clear sky background condition. This ability within the visible model diminishes when certain weather or geological conditions exist:

1) Regions with non-negligible snow cover and minimal forest or building cover.

2) Locations with persistent or long-lasting cloud cover, termed the "Eugene Syndrome" [2]

3) Ground characteristics that include elements of highly reflective or bright material, such as sand.

The work presented summarizes the result of validating the new SUNY model and implementing it operationally to replace the current version used throughout the NSRDB and SolarAnywhere. Incorporating IR sensors from the GOES satellite is possible because of overlapping coverage of capture of both the IR and visible images. Whereas the visible image captured by the satellite represents the solar radiation reflected by the earth's surface and atmosphere, IR radiation is also emitted by both entities, thus making its magnitude a function of the temperature of the emitting source. Combining different IR channels can therefore distinguish between most cloud layers and the ground. This distinction is shown below in Figures 1 & 2, where the former shows no distinction between cloud and snow cover, and the latter only captures clouds.

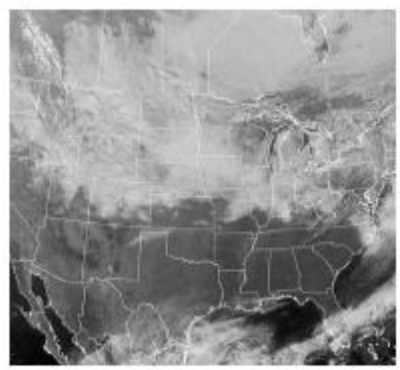

Fig. 1. GOES Visible channel image shows no distinction between cloud and snow cover.

Fig. 2. Combination of GOES IR channel images shows only cloud coverage.

II. Methodology

The current model already accounts for ground snow cover as an input, presenting an effective approach of binary IR channel use. The aim of the improved model is to better represent conditions with snow or high ground reflectance, thus using the model improvements as a secondary approach which will not hinder the overarching accuracy of the present model. There are other known approaches of a single model method that incorporates visible and IR channels at all points of measurement [3].

The updated model version incorporates all four GOES IR channels listed in Table 1, by an empirical approach of least square fitting to a wide range of high quality temperature measurements from distinct climactic environments across North America.

TABLE 1: GOES Satellite IR Channels

IR Channel	Wavelength
2	3.9 µm
3	6.7 µm
4	10.7 µm
5/6*	12 µm/13.3 µm

**** IR Channel 5 used for GOES 8-11 and IR channel 6 used for GOES 12-15 satellite data, respectively.***

The empirical approach is retained because (1) the physical processes linking surface downwelling irradiance and IR channels are not as clear-cut as those linking it with reflected radiances [ref 5 in ASES abstr.]; and (2) it is an effective approach, further noting that existing operational satellite-based snow detection algorithms rely in part on empirical thresholds in their implementation (e.g., [4]).

While the current visible model is self-calibrating and does not depend on evolving satellite calibrations [1], the IR model assumes that the satellite IR channels are properly calibrated and do not drift over time. This is a safe assumption because these channels, which are essentially temperature sensors, are constantly calibrated onboard from an absolute temperature source with an operational accuracy of ± 1K [5].

In addition to the four IR satellite channels, the model also uses operational inputs already available as part of the SolarAnywhere Data production stream, including zenith angle, surface temperature, and ground elevation. Surface temperature is a particularly important input which provides real time ground-truth reference to the remotely sensed brightness temperatures, which are temperatures of the atmospheric layers seen by each IR channel, and that may or may not include the ground temperature, depending on the channel and meteorological conditions.

III. Model Validation

The improved IR+visible SUNY model is validated against a year (2009) of surface-measured irradiance data from fifteen U.S. ISIS and SURFRAD sites. Significant snow cover was present at the Fort Peck, Sioux Falls, Penn State, Bondville and Boulder sites during this validation period, ranging from 12 – 25% of the time. Figures 3 & 4 depict the relative hourly MAE for GHI and DNI, respectively, at the fifteen reference ground sites.

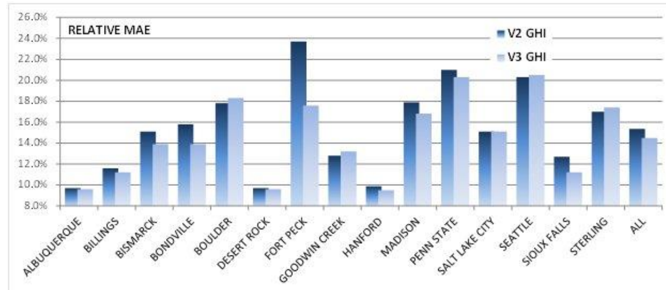

Fig. 3. Hourly averaged MAE for GHI from the visible only (V2) and IR+visible (V3) SUNY models.

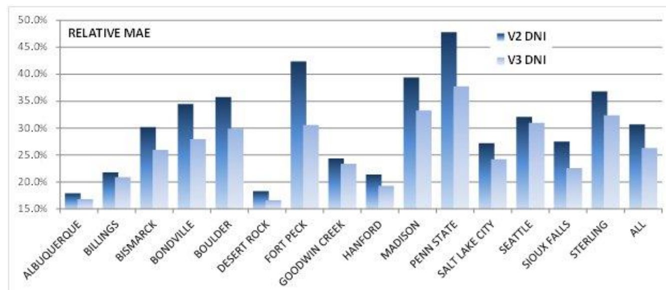

Fig. 4. Hourly averaged MAE for DNI from the visible only (V2) and IR+visible (V3) SUNY models for 2009.

Composite benchmarked RMSE and MBE metrics for the ground vs. satellite-based results are shown in figures 5 & 6.

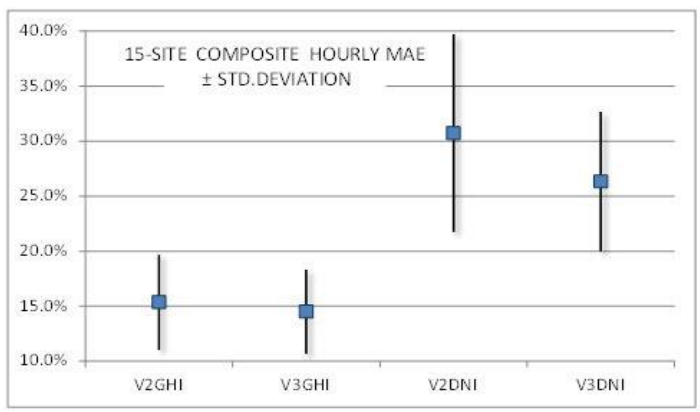

Fig. 5. Composite hourly averaged MAE from the visible only (V2) and IR+visible (V3) SUNY models for 2009.

Additional comparisons can be made showing improvements in snow cover conditions by looking specifically at each site referenced against the ground measurements. For 2009, the Fort Peck site exhibited the highest percentage of snow cover out of the five selected sites. Figure 7 shows the scatter of modeled GHI against ground for the visible-only model. Figure 8 updates this comparison for the new model.

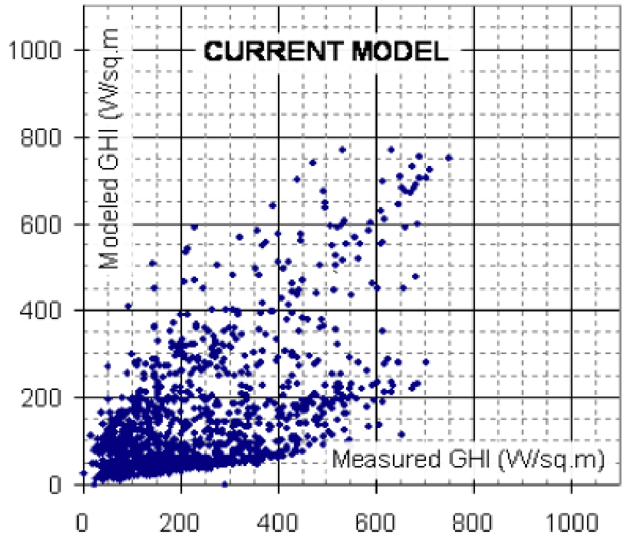

Fig. 7. Comparison of modeled versus measured GHI for Fort Peck, using the visible-only (V2) model for 2009.

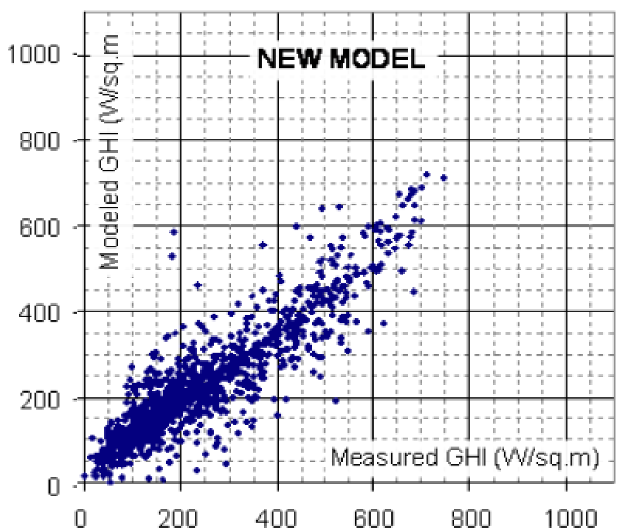

Fig 8. Comparisons of modeled versus measured GHI for Fort Peck, using the IR+visible (V3) SUNY models for 2009.

For the five locations with significant snow cover, the model improvements are shown relative to percentage of time with snow cover for 2009 in figure 9. Comparisons are made for all daylight hours in 2009.

The use of the IR channel model was also effective in addressing conditions with persistent cloud coverage and high ground reflectivity. Seattle was used as an example location with persistent cloud cover. Here, a comparison was made using daylight measurements from 2003. The relative bias over this time period decreases from 1.4% to -0.3% for GHI measurements, whereas the GHI RMSE remained relatively

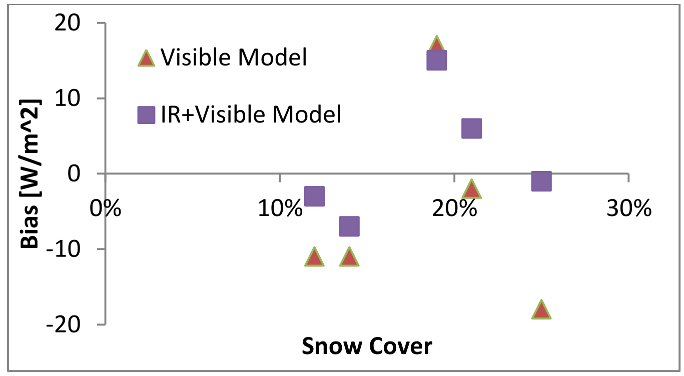

Fig 9. Model bias compared to percentage snow cover for 2009.

consistent from 100.2 to 101.3 W/m^2. Figures 10 and 11 show the scatter comparing the visible-only (V2) and IR+visible (V3) models, respectively, with ground.

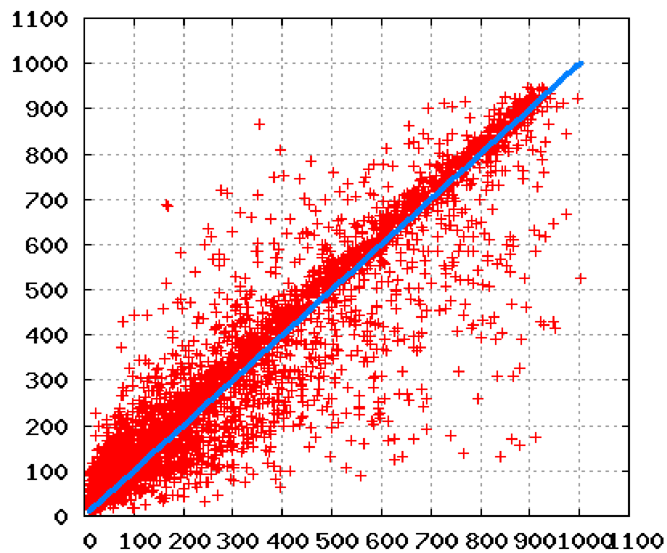

Fig. 10. Comparison of modeled (y-axis) versus measured GHI for Seattle, using the visible-only (V2) model. Model bias for 2003 is 1.4%.

Albuquerque is a location that presents specific challenges in high ground reflectivity due to low vegetation and surface material coverage, such as sand. For comparison at this location, the modeled versus measured direct component is presented. For the existing visible satellite model, direct normal irradiance measurements are particularly challenging in regions of high ground reflectivity. Using all daylight hour data from 2003, a comparison of the existing visible model and the new IR+visible model to ground results in a decreased DNI relative bias from 4.9 to 2.2% and a decrease in RMSE from 169.7 to 156.9 W/m^2.

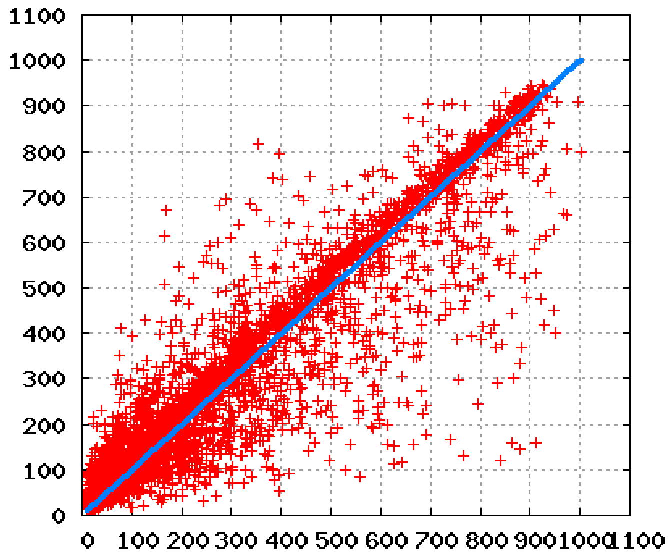

Fig. 11. Comparison of modeled (y-axis) versus measured GHI for Seattle, using the IR+visible (V3) models. Model bias for 2003 is -0.3%.

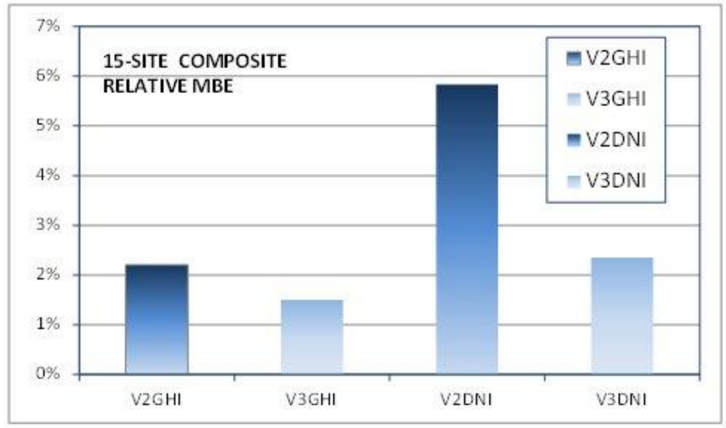

Fig 12. Composite hourly relative MBE from the visible only (V2) and IR+visible (V3) SUNY models for 2009.

IV. Discussion

The results of this study confirm that the new IR-based SUNY model enables considerable operational improvement over the existing model, significantly reducing bias and error in modeled GHI and DNI results. Regions with the most consistent snow cover show the most improvement, while locations with significant ground cover (e.g., vegetation, trees) show modest improvement in the error statistics. Regions with bright surfaces (e.g., deserts) and persistent cloud cover also show modeled irradiance improvement.

The improved IR+visible SUNY model is designed to work with GOES IR channels and is not directly transportable to other geostationary satellites because of differences in the number and the bandwidth of their IR channels; however, a similar approach would be straightforward and could be replicated with similar success.

References

[1] R. Perez, P. Ineichen, K. Moore, M. Kmiecik, C. Chain, R. George and F. Vignola, “A New Operational Satellite-to-Irradiance Model,” *Solar Energy* vol. 73, no. 5, pp. 307-317, 2002.

[2] C. Gueymard, and S. Wilcox, “Spatial and temporal variability in the solar resource: Assessing the value of short-term measurements at potential solar power plant sites,” *in 38th ASES National Solar Conference, Buffalo, New York*, 2009.

[3] T. Cebecauer, M. Suri, and R. Perez, “High performance MSG satellite model for operational solar energy applications,” *in 39th ASES National Solar Conference, Phoenix, Arizona*, 2010.

[4] B. Duerr, and A. Zelenka, “Deriving surface global irradiance over the Alpine region from METEOSAT Second Generation data by supplementing the HELIOSAT method,” *Int. Jour. of Remote Sensing* vol. 30, no. 22, pp. 5821-584, 2009.

[5] NOAA-NESDIS, US Department of commerce, http://www.nesdis.noaa.gov/, 2010.