TOWARDS A HIGH RESOLUTION LONG-TERM SOLAR RESOURCE DATABASE: APPLYING THE SUNY MODEL TO ISCCP B1U DATA STREAM

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ABSTRACT

This article presents an operational evaluation of the SUNY satellite irradiance prediction model when using the ISCCP B1U data as an input and compares its performance against the current Unidata-driven operational version of the same underlying the National Solar Resource Data Base (NSRDB). High quality ground truth sites from different US climatic environments are used to benchmark model performance. Results show that the performance of the B1U-driven model is at least as good as the performance of the current US operational model; hence, since the B1U data cover the globe, the model shows potential to be successfully applied to the rest of the planet.

1. INTRODUCTION

The National Aeronautics and Space Administration (NASA), the National Renewable Energy laboratory (NREL), the National Climatic Data Center (NCDC) and the University at Albany (SUNY) are collaborating to develop a long-term high-resolution solar resource archive. The new data set will provide surface irradiances for the entire globe and span nearly 30 years with an expected time resolution of 3 hours and a geographical resolution of approximately 10 km by 10 km.

The new data set is expected to come online in late 2013 when NREL will take the lead on data production and will use it to enhance its solar decision support tools.

The main underlying input of the models that will produce the new irradiances consists of the 3-hourly visible radiance data assembled for the International Satellite Cloud Climatology Project (ISCCP [1]) and referred to as B1U data. The B1U data were extracted from the visible channel of the geostationary weather satellites that have monitored the earth since the early 1980's. Figure 1 provides a space-time view of these satellites and their longitudinal coverage [2].

The SUNY satellite model underlying the US NDRDB [3, 4, and 5] is one of the models considered to produce the new irradiance data. This model is capable of directly processing the B1U data which are essentially recalibrated visible channel data from each geostationary platform.

2. METHODS

2.1 Experimental Data

Surface Measurements: The present evaluation covers three years -- 2005, 2006 and 2007 – and focuses on the B1U pixel locations closest to seven US ground-truth locations from NOAA's SURFRAD network [6]. These sites represent a mix of climatic environments (see Table 1).

Satellite data: Both GOES-East and GOES-West data were analyzed. The western satellite (GOES-10) stayed unchanged throughout the considered period while the eastern satellite switched in mid-2006 from GOES-8 to GOES-12. In addition to the *B1U counts* consisting of the original satellite visible radiances corrected for onboard sensor calibration drifts, we also acquired *scaled reflectivities* from the B1U that were subsetted at NASA Langley Research Center. Scaled reflectivities are analogous to visible counts, but are calibrated on a 0-1 scale so as to be consistent across all satellite platforms and all time frames.

Both B1U counts and scaled reflectivities were tested as a possible operational input to the SUNY model.

Table 1
SURFRAD NETWORK GROUND-TRUTH LOCATIONS

Station	Latitude	Longitude	Elevation	Climate
Goodwin Creek	34.25	89.87	98 m	subtropical
Desert Rock	36.63	116.02	1007 m	Arid
Bondville	40.05	88.37	213 m	Continental
Boulder	40.13	105.24	1689 m	Semi-arid
Penn State	40.72	77.93	376 m	humid continental
Sioux Falls	43.73	96.62	473 m	Continental
Fort Peck	48.31	105.10	634 m	Continental

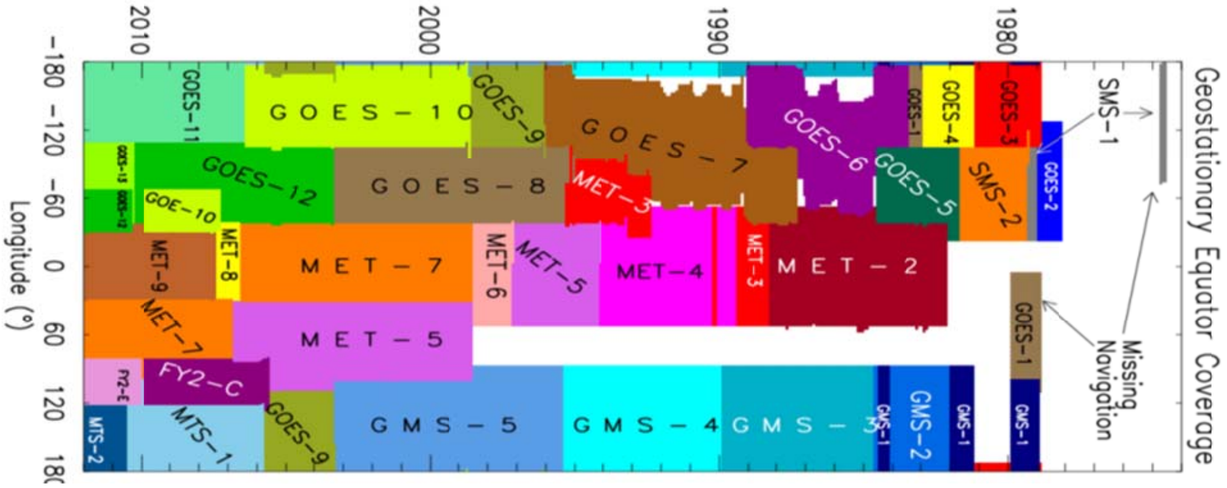


Figure 1: History of geostationary weather satellite coverage of the globe – Source : Knapp, K., NOAA [2]

<u>B1U calibration verification</u>: the SUNY model is a semi-empirical model [7]. One of the advantages of semi-empirical models is that they are essentially self-calibrating; hence they do not require an absolute sensor count-to-radiance calibration. However the SUNY model does require relative calibration information to account for both gradual sensor response decay and more importantly, satellite platform changes.

The SUNY model self-calibrates by determining a dynamic range from lowest to highest cosine-corrected satellite count over a trailing time window. The lowest cosine-corrected counts for a particular location (darkest pixels) correspond to clear sky conditions and the highest counts (brightest pixels) correspond to deep overcast condition. In the SUNY model the location-specific, but well defined, lower edge of the dynamic range is extracted from the count's history at a given location and is location-specific. The higher edge is assumed to be independent of the considered location or time-period because it represents radiance from the top of high clouds. It is assumed to be only dependent upon the relative calibration of the satellite which evolves over time because of sensor decay. This higher edge is determined for the entire viewing area using a few sample locations by fitting an exponential decay upper bound to the sample sites' data (see fig. 1 in [3]).

In principle the B1U counts and scaled reflectivities are corrected for calibration decay. However it is important to verify this assumption so as to ensure adequate model performance.

Figures 2, 3, 4 and 5 illustrate the cosine-corrected B1U count and scaled reflectivity time series for GOES-West and GOES-East, respectively, throughout the selected 3-year period. The considered GOES-East point corresponds to the SURFRAD site of Goodwin Creek, MS and the GOES-West point corresponds to Desert Rock, NV.

The light blue line drawn in each figure represents the upper bound of the SUNY model's dynamic range as estimated from the data. For the scaled reflectivity this upper bound is estimated at 0.76 and appears to be constant and satellite-independent, indicating that the scaled reflectivities analyzed here are properly calibrated. The upper bound also appears to be nearly constant for the B1U counts (as determined by insuring that the count of points above the line remains ~ the same from year to year) but it is not satellite-independent. This operational upper bound was estimated at 155, 135 and 680 for GOES 10, GOES 8 and GOES 12, respectively.

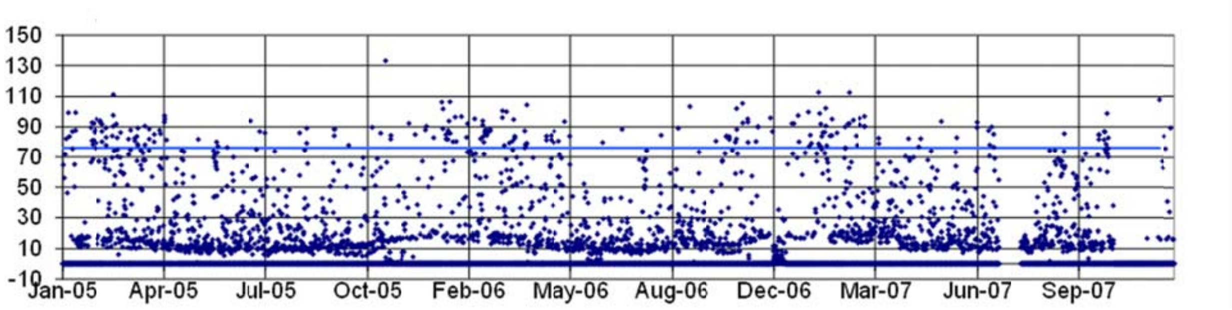


Figure 2: GOES-West cosine-normalized B1U visible count

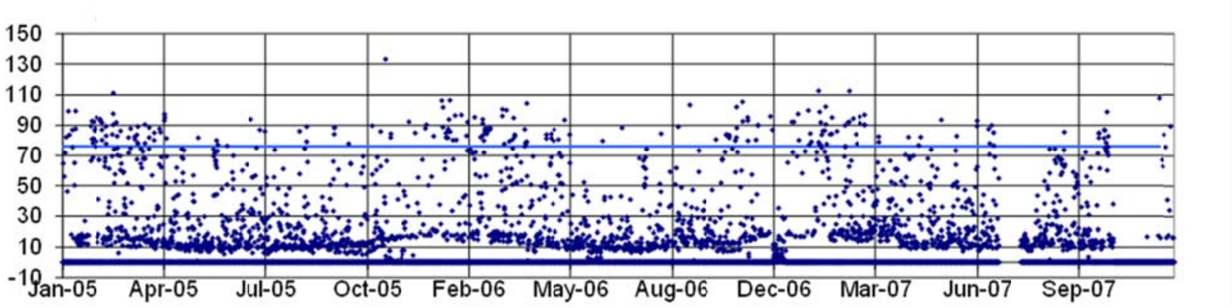


Figure 3: GOES-West cosine normalized B1U scaled reflectivity *100

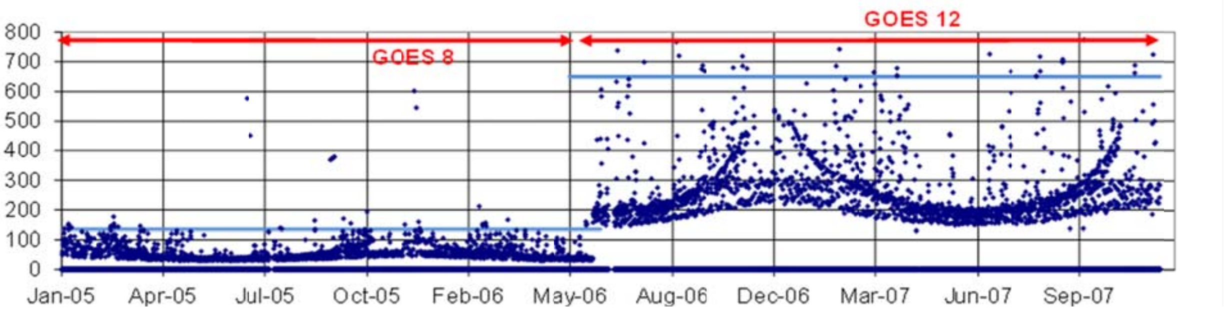


Figure 4: GOES-East cosine normalized B1U visible count

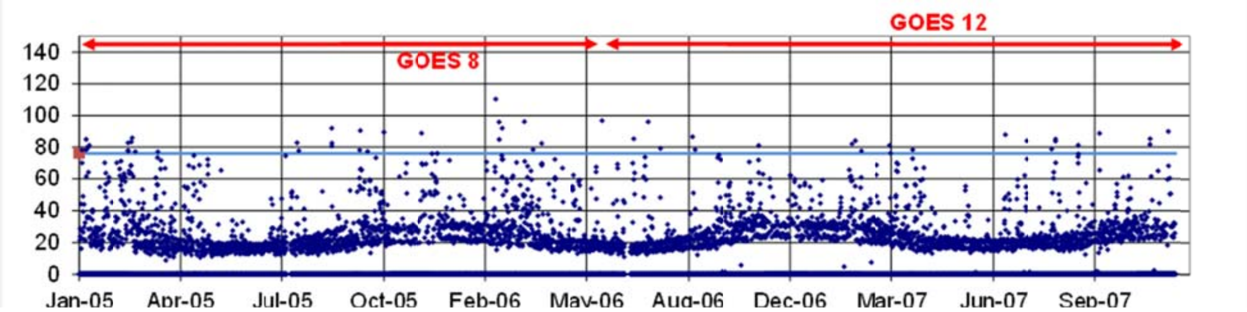


Figure 5: GOES-East cosine-normalized B1U scaled reflectivity * 100

2.2 Model Evaluation Approach

For each test site, we selected the satellite with the best viewing angle. GOES-East, located at 75°W longitude has the best viewing angle for all sites but Desert Rock, NV, where GOES West located at 135°W longitude was selected.

The standard SUNY model hourly input from Unidata [8] was replaced by either the B1U count or the scaled reflectivity for testing. The latter was multiplied by 100 so as to fall in the expected operational range of the model.

The SUNY model is designed to operate nominally with hourly or sub-hourly data. However it is designed to handle missing data and to generate missing points via clear-sky index (Kt*) interpolation. Thus it was straightforward to use the model with the 3-hourly B1U input, treating the intermediate hours as missing, and letting the model interpolate.

Both 3-hourly and interpolated-hourly B1U configurations were compared to the standard hourly SUNY model performance.

Performance evaluation metrics include Mean Bias Errors (MBE), Root Mean Square Errors (RMSE) and Mean Absolute Errors (MAE). The MAE and RMSE are both measures of model dispersion, noting that the MAE has recently been recommended as a preferred measure of dispersion over the RMSE because it is less sensitive to distant outliers and because it is less subject to interpretation when expressed in relative (percent) terms [9].

3. RESULTS

Performance evaluation results quantified by the selected metrics are summarized in Table 2 for each tested model configuration including:

- 3-hourly B1U count input
- Hourly interpolated B1U count input
- 3-hourly B1U scaled reflectivity input
- Hourly B1U scaled reflectivity input
- Standard Unidata hourly input

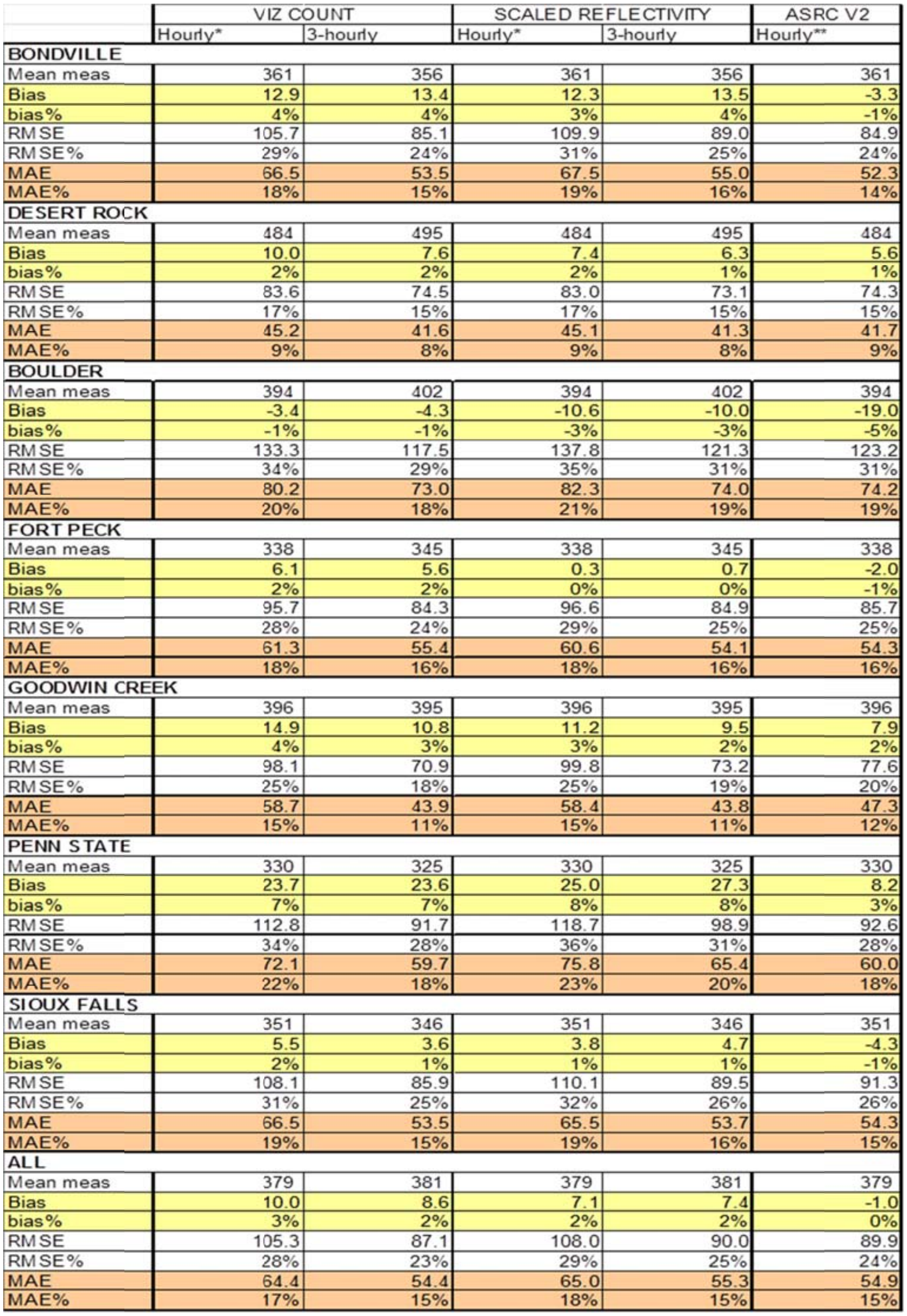
Results are qualitatively illustrated in Fig. 6 for the site of Goodwin Creek.

The following observations are made:

- The performance of both B1U-based models (visible count and scaled reflectivity) is comparable to the Unidata-based model when considering the real (non-interpolated) 3-hourly data points.
- The B1U count model tends to perform slightly better overall than the scaled reflectivity model when considering the RMSE and MBE metrics. Note that the visible count is similar in nature to the Unidata count used operationally by the SUNY model, with two important differences: (1) the B1U data do not include the Unidata Local Data manager (LDM) square root filter and the SUNY quadratic correction applied to remove this filter, and (2) the navigated 10 km B1U data are averaged from higher resolution instead of going through two subsampling processes (the LDM process subsampling down to ~ 3 km and the SUNY process applied downstream down to ~10 km) --which may explain the slight performance edge of the B1U input over the standard operational data stream.
- The small performance difference between count and reflectivity inputs is largely traceable to a few outliers. The scatter plot traces show slightly better linear measure vs. model agreement for the scaled reflectivity.
- Performance degrades substantially, as would be expected, when interpolating the B1U output down to an hourly time step.

TABLE 2

Summary of Model Performance Evaluation



	VIZ COUNT		SCALED REFLECTIVITY		ASRC V2
	Hourly*	3-hourly	Hourly*	3-hourly	Hourly**
BONDVILLE					
Mean meas	361	356	361	356	361
Bias	12.9	13.4	12.3	13.5	-3.3
bias%	4%	4%	3%	4%	-1%
RMSE	105.7	85.1	109.9	89.0	84.9
RMSE%	29%	24%	31%	25%	24%
MAE	66.5	53.5	67.5	55.0	52.3
MAE%	18%	15%	19%	16%	14%
DESERT ROCK					
Mean meas	484	495	484	495	484
Bias	10.0	7.6	7.4	6.3	5.6
bias%	2%	2%	2%	1%	1%
RMSE	83.6	74.5	83.0	73.1	74.3
RMSE%	17%	15%	17%	15%	15%
MAE	45.2	41.6	45.1	41.3	41.7
MAE%	9%	8%	9%	8%	9%
BOULDER					
Mean meas	394	402	394	402	394
Bias	-3.4	-4.3	-10.6	-10.0	-19.0
bias%	-1%	-1%	-3%	-3%	-5%
RMSE	133.3	117.5	137.8	121.3	123.2
RMSE%	34%	29%	35%	31%	31%
MAE	80.2	73.0	82.3	74.0	74.2
MAE%	20%	18%	21%	19%	19%
FORT PECK					
Mean meas	338	345	338	345	338
Bias	6.1	5.6	0.3	0.7	-2.0
bias%	2%	2%	0%	0%	-1%
RMSE	95.7	84.3	96.6	84.9	85.7
RMSE%	28%	24%	29%	25%	25%
MAE	61.3	55.4	60.6	54.1	54.3
MAE%	18%	16%	18%	16%	16%
GOODWIN CREEK					
Mean meas	396	395	396	395	396
Bias	14.9	10.8	11.2	9.5	7.9
bias%	4%	3%	3%	2%	2%
RMSE	98.1	70.9	99.8	73.2	77.6
RMSE%	25%	18%	25%	19%	20%
MAE	58.7	43.9	58.4	43.8	47.3
MAE%	15%	11%	15%	11%	12%
PENN STATE					
Mean meas	330	325	330	325	330
Bias	23.7	23.6	25.0	27.3	8.2
bias%	7%	7%	8%	8%	3%
RMSE	112.8	91.7	118.7	98.9	92.6
RMSE%	34%	28%	36%	31%	28%
MAE	72.1	59.7	75.8	65.4	60.0
MAE%	22%	18%	23%	20%	18%
SIOUX FALLS					
Mean meas	351	346	351	346	351
Bias	5.5	3.6	3.8	4.7	-4.3
bias%	2%	1%	1%	1%	-1%
RMSE	108.1	85.9	110.1	89.5	91.3
RMSE%	31%	25%	32%	26%	26%
MAE	66.5	53.5	65.5	53.7	54.3
MAE%	19%	15%	19%	16%	15%
ALL					
Mean meas	379	381	379	381	379
Bias	10.0	8.6	7.1	7.4	-1.0
bias%	3%	2%	2%	2%	0%
RMSE	105.3	87.1	108.0	90.0	89.9
RMSE%	28%	23%	29%	25%	24%
MAE	64.4	54.4	65.0	55.3	54.9
MAE%	17%	15%	18%	15%	15%

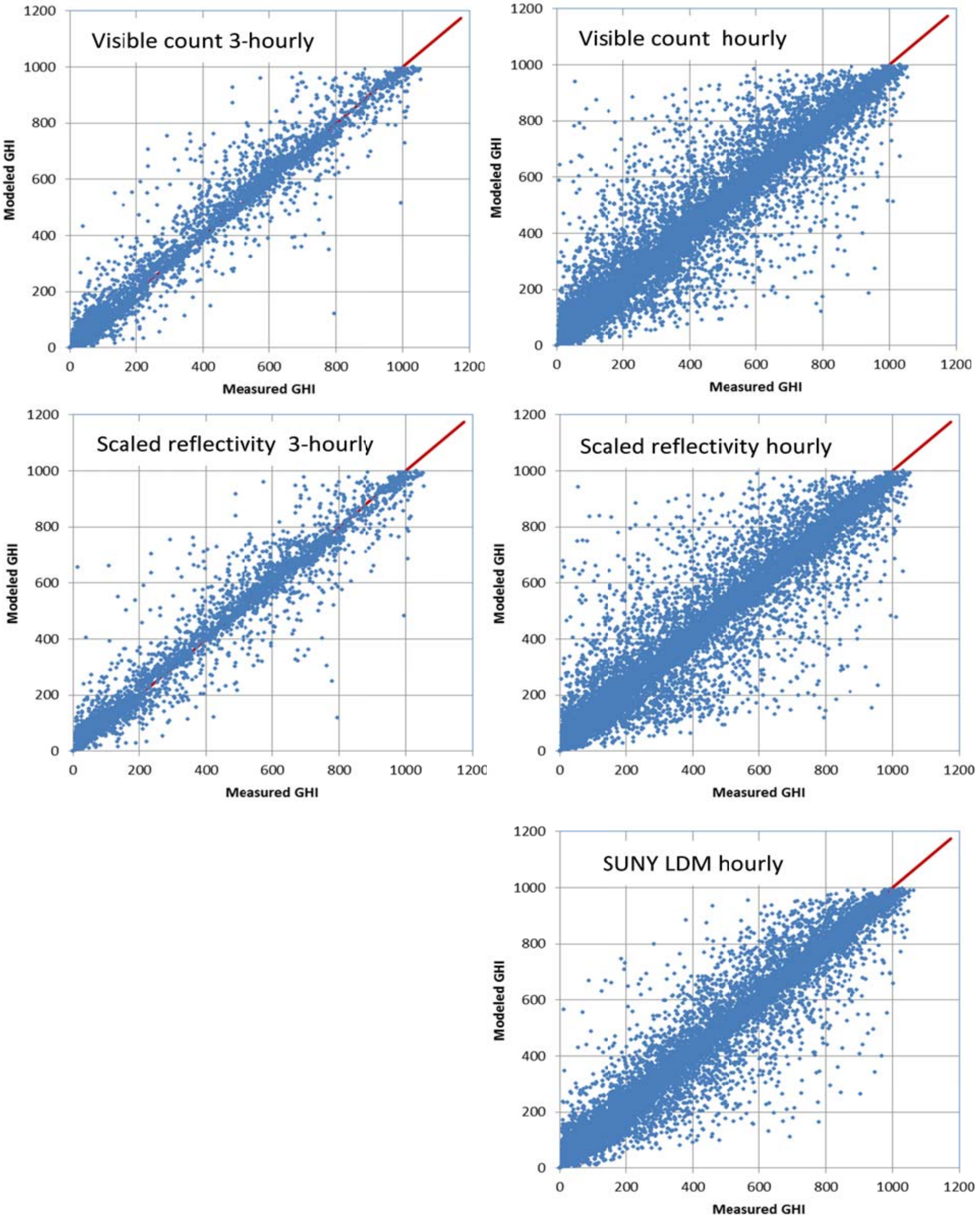


Figure 6: Modeled vs. measured global irradiance (GHI) for the B1U count-based, B1U scaled reflectivity-based and LDM-based SUNY model

TABLE 3

BSRN Station	Time Period	Satellite Platform	Rationale for Test
Lauder, New Zealand	2006	MTS-1	Platform, southern hemisphere
Nauru Island	2002-2003	GMS-5, GMS-9	Equator, platform, platform transition
Fukuoka, Japan	2005-2006	GMS9, MTS-1	Platform & platform transition
Sede Boqer, Israel	2006-2007	MET-5, MET-7	Platform & platform transition
Carpentras, France	2006-2007	MET-7, MET-8, MET-9	Platform & platform transitions
Florianopolis, Brazil	1995-1996	GOES-8	Southern Hemisphere

4. SUMMARY AND FUTURE WORK

The objective of the project described in this article was to undertake an operational evaluation of the SUNY satellite irradiance prediction model when using the 3-hourly ISCCP B1U data as an input instead of its operational Unidata input used to produce the National Solar Resource Data Base (NSRDB

The analysis of model performance, benchmarked against seven climatically distinct US locations, has shown that the B1U data stream can be substituted to the standard Unidata stream without any performance degradation for the real (three hourly) data points.

It is important to note that the other inputs to the SUNY model – the climatological monthly aerosol optical depth (AOD), precipitable water (W) and ozone (O3) defining the model's clear sky's background, and the location-specific ranking process used to correct ground specularity [4] were identical for all tested model versions and consisted of the current operational input to the model. Since these operational ancillary inputs only cover the North American window of the SUNY model, other alternate input will have to be tested in future work.

Another important next step, now ongoing, is to ascertain the performance of the B1U-driven model for other satellites and/or regional environments. Table 3 lists the BSRN sites [10] which have been selected for the next round of testing along with the rationale for their selection

5. ACKNOWLEDGEMENT

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