VALIDATION OF THE SUNY SATELLITE MODEL IN A METEOSAT ENVIRONMENT

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ABSTRACT

The paper presents a validation of the SUNY satellite-to-irradiance model against four ground-truth stations from the Indian solar radiation network located in and around the province of Rajasthan, India. The SUNY model had initially been developed and tested to process US weather satellite data from the GOES series and has been used as part of the production of the US National Solar Resource Data Base (NSRDB). Here the model is applied to processes data from the European weather satellites Meteosat 5 and 7.

1. INTODUCTION

The SUNY satellite model [1, 2] was developed to produce surface irradiances from the visible channel of the GOES weather satellites series -- the GOES satellites include two operational units located respectively at the longitudes of the American East Coast (75^o West) and West Coast (135^o West)

The model has been extensively validated for the western hemisphere [e.g., 3] and was recently used to produce the 1998-2005 high resolution data distributed as part of the National Solar Radiation Data Base [3].

In this paper we evaluate the model's performance with another set of satellites: the European Meteosat 5 and 7 satellites which are positioned at the longitude of central Asia (57.5^o East). This evaluation was undertaken as part of the production of high resolution irradiance maps for Northwestern India as an activity of the New Technology and Renewable Energy Working Group under the US—India Energy Dialogue [4].

In addition to markedly different climatic conditions, there are small but significant differences between the treatment of GOES and Meteosat images which can impact the accuracy of the model. The GOES visible channel data used in the US model are pre-processed for better visual appearance by application of a square-root filter to image pixel counts. The treatment of the Meteosat archives was not known and had to be inferred from the data signature with respect to solar geometry; the analysis revealed that, in all likelihood, no filter had been applied. Another pertinent difference between the two sets of satellites is a wider visible channel spectral range for the European satellite (0.45-0.95 μ, against 0.5-0.75 μ for GOES).

2. EXPERIMENTAL DATA

2.1 Satellite Data

Hourly visible channel frames covering western India from December 2002 through January 31, 2007 were subsampled onto a 0.1^o x 0.1^o latitude-longitude grid analogous to the

US operational grid. Data are from Meteosat 5 up to January 25, 2007, and from Meteosat 7 thereafter.

2.2 Ancillary Model Input Data

The gridded ancillary data used by the SUNY model include:

- Monthly climatological broad-band Aerosol optical Depth (AOD)
- Monthly climatological precipitable water
- Monthly climatological ozone
- Terrain elevation
- Daily Snow Cover

The first two inputs, AOD and precipitable water, are used to parameterize turbidity (AOD being the more influential of the two). AOD was obtained from the Aqua satellite's MODIS [5] sensor modeled via GOCART [6].

2.3 Ground Truth Data

Hourly solar radiation measurements from the Indian Meteorological Department network [7] were received for the year 2006 for four western India stations: Bhopal, Jaipur, Delhi and Jaisalmer (see locations in Fig. 5 and 6). GHI is measured at all stations, but DNI was only recorded in Jaipur and Bhopal during the considered period. Data availability was quasi complete (>85%) for all sites, except Delhi where over 70% of the GHI data were missing. Instrumentation consists of thermopile pyranometers and pyrheliometers.

3. VALIDATION

Model performance is summarized in Table 1 where overall Root Mean Square and Mean Bias Errors (RMSE and MBE) are presented. The results indicate that the model works well for GHI prediction. The GHI scatter plots shown in Fig.1 visually confirm that performance is on par with the North American sites previously used for model evaluation [2]. The model tends to overestimate slightly (2-3%) -- this slight overestimation could be remedied by moderately increasing turbidity. The positive MBE is larger in Delhi, but evidence indicates that this may be traceable to instrument calibration: see for instance the comparison between Jaipur and Delhi for time coincident GHI data in Figure 2 (left). The clean, systematic departure from the one-to-one line expected between the two sites is more symptomatic of a calibration difference than weather differences; in fact a simple linear adjustment suffices to bring the satellite model to agreement with the Delhi data (see Figure 2, right).

For DNI, both the results in table 1 and the scatter plots in Figure 3 show a strong model overestimation: +100% in Bhopal, and +80% in Jaipur.

Is this overestimation real and reflective of a massively underestimated turbidity, or simply reflective of measurement uncertainty?

The turbidity argument is difficult to defend, because increasing AOD so as to eliminate the DNI bias results in a considerable underestimation of GHI; indeed the GHI-DNI relationship observed from measurements in both Jaipur and Bhopal is markedly different from that observed, understood and validated in the western hemisphere and Europe,). This unknown difference between the Indian sites and the U.S. site is illustrated Figure 4 where the Kb-Kt relationship for Jaipur and a US site (Penn State) are intercompared . At this time, given the data available to us, it is not possible to put this question to rest. Its answer will first require a controlled in-situ experiment comparing ongoing ground measurements with referenced standards to first ascertain the quality of the measured data, and then as appropriate, refine the GHI-DNI relationships to reflect a different type of environment.

TABLE 1
Model Validation Summary

	BHOPAL		JAIPUR		DHELI		JAISALMER	
	GHI	DNI	GHI	DNI	GHI	DNI	GHI	DNI
MEAN	225	108	206	116	187	na	246	na
yearly data recovery	91%	91%	99%	99%	28%	na	86%	na
MBE	8	115	7	94	17	na	6	na
RMSE	55	213	55	201	47	na	46	na
MBE%	3.5%	107.2%	3.3%	81.1%	10.7%	na	2.5%	na
RMSE%	24%	198%	27%	173%	30%	na	19%	na

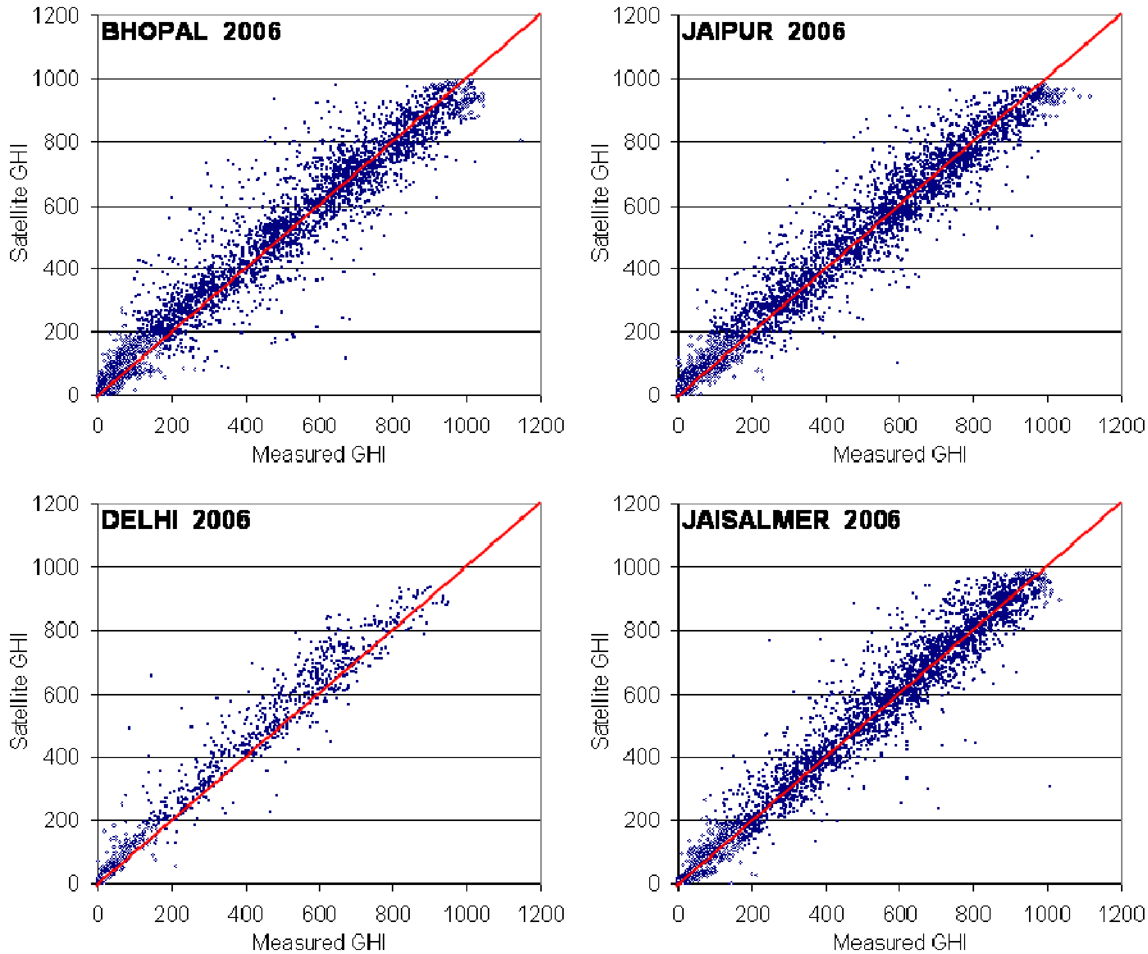

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Figure 1: Satellite vs. measured GHI

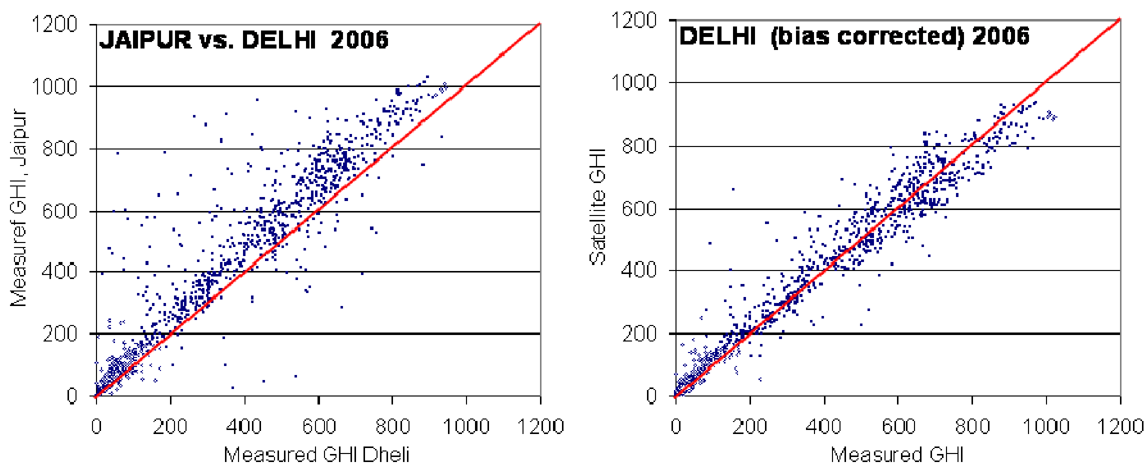

Figure 2: Comparing Delhi and Jaipur GHI (left), and satellite vs. ground data in Delhi using a single calibration correction factor (right)

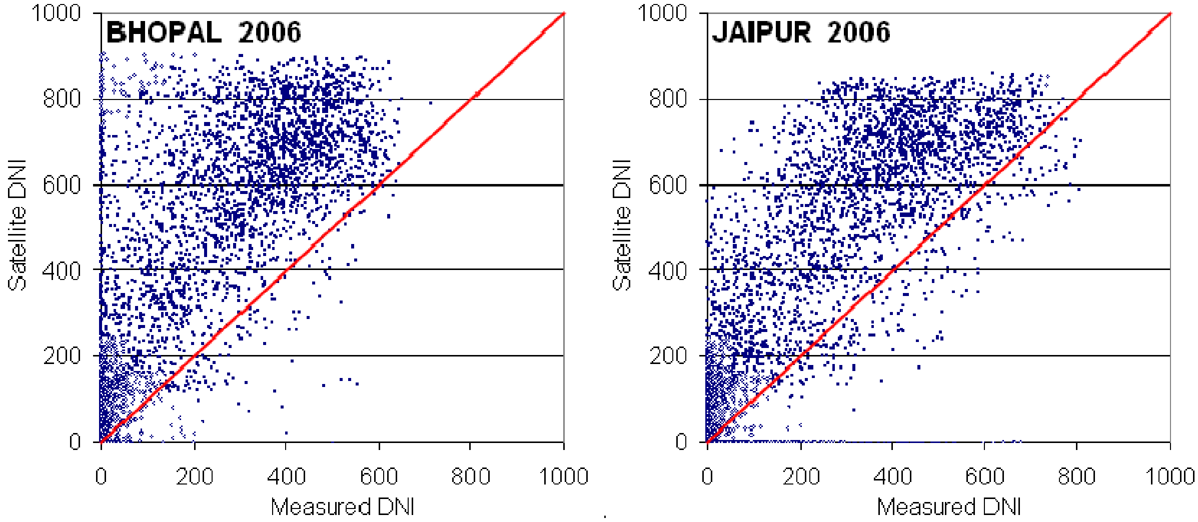

Figure 3: Satellite-derived vs. measured DNI

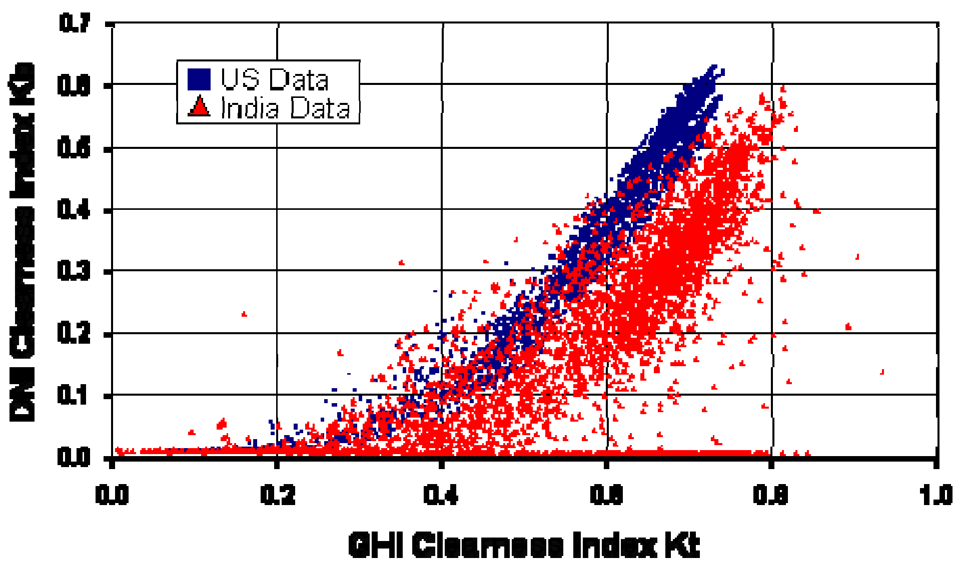

Figure 4: Comparing Kb-Kt relationship observed from the Indian network to a typical relationship in the US

4. <u>RAJAHSTAN SOLAR RESOURCE</u>

With the DNI caveat discussed above, and the confidence acquired in GHI modeling, we were able to produce six years of high resolution irradiances for the Rajasthan. Examples of this effort are shown in Figs. 5 and 6 where the mean daily GHI for August and February are compared, showing a very intense monsoon effect and a complete reversal of the province's north-south gradient in summer.

The solar resource data from this project are available through NREL [8].

5. <u>CONCLUSION</u>

This study indicates that SUNY model works adequately with Meteosat data. The performance of the GHI model is comparable to that observed in the western hemisphere.

A big unknown remains with DNI modeling which will require further investigation. Is this a measurement issue? or does the radiative environment of Western India – characterized by high turbidity from high dust content -- warrant a revision of well known GHI-to-DNI models?

6. ACKNOWLEDGEMENT

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7. REFERENCE

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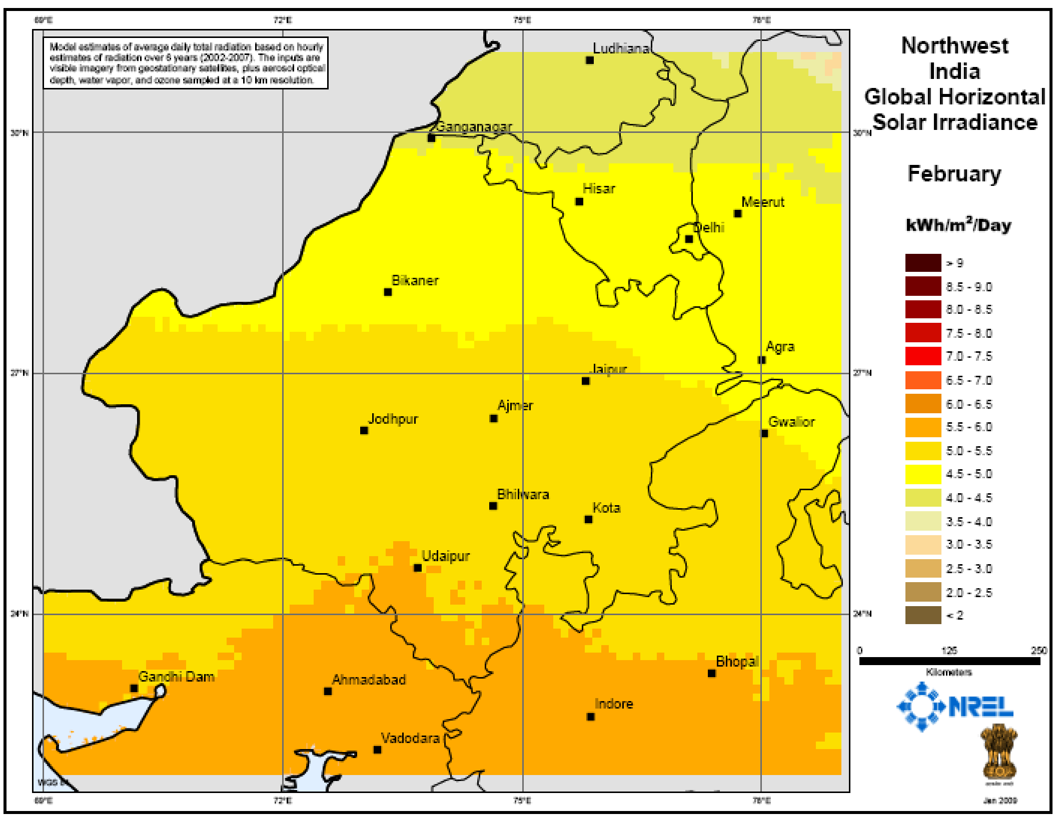
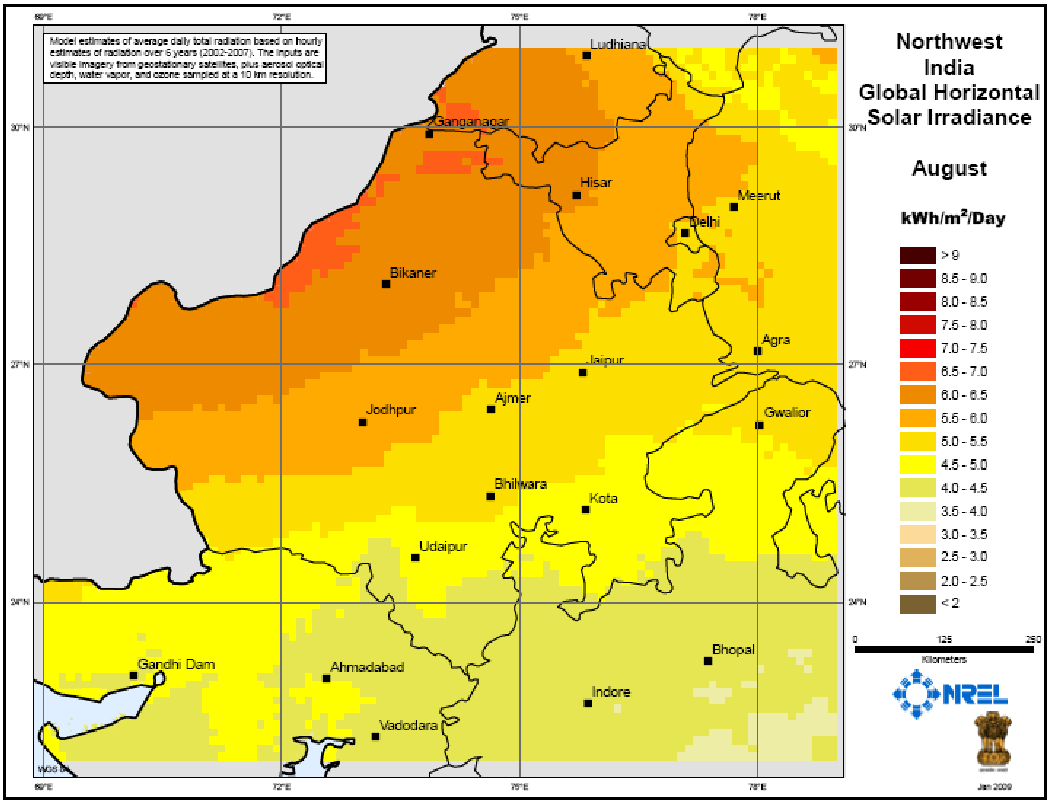


Figure 5



Model estimates of average daily total radiation based on hourly estimates of radiation over 6 years (2002-2007). The inputs are visible imagery from geostationary satellites, plus aerosol optical depth, water vapor, and ozone sampled at a 10 km resolution.
Northwest India Global Horizontal Solar Irradiance
August
kWh/m²/Day
> 9
8.5 - 9.0
8.0 - 8.5
7.5 - 8.0
7.0 - 7.5
6.5 - 7.0
6.0 - 6.5
5.5 - 6.0
5.0 - 5.5
4.5 - 5.0
4.0 - 4.5
3.5 - 4.0
3.0 - 3.5
2.5 - 3.0
2.0 - 2.5
< 2
0 125 250
Kilometers
NREL
Jan 2009
Ludhiana
Ganganagar
Hisar
Meerut
Delhi
Bikaner
Agra
Jaipur
Ajmer
Jodhpur
Gwalior
Bhilwara
Kota
Udaipur
Bhopal
Gandhi Dam
Ahmadabad
Indore
Vadodara

Figure 6