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Global Validation of REST2 Incorporated Into an Operational DNI and GHI Irradiance Model

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Abstract

Two categories of models can be used to predict direct normal irradiance (DNI) for solar concentration or tracking photovoltaic applications. The first type are broadband radiative models that predict DNI under clear skies from atmospheric data. The second are methods used to extract DNI from global horizontal irradiance (GHI). While many validation studies have been done on the latter the former have only been evaluated in localized studies of a dozen or fewer sites and those mostly in the USA [1,2]. We propose to do a global validation of the REST2 direct irradiance model at 100+ locations world wide against both GHI and DNI.

Keywords: *satellite dataset, irradiance modeling, REST2, Perez SUNY, GHI, DNI*

1. Introduction

We incorporated the REST2 clear sky model into our existing operational system for producing hourly time series of GHI, DNI and diffuse at a resolution of 2 arc minutes globally. This process also required incorporating the MERRA2 (Modern Era-retrospective Analysis for Research and Appliations) datasets for turbidity and aerosol modeling. At independent ground stations with GHI and/or DNI measurements for a concurrent period of time we compared the REST2 derived irradiances to the measured irradiances to determine the bias, RMSE and MAE statistics between the two.

Further, at the same sites we compared GHI and/or DNI modeled on the SUNY Perez clear sky methodology[3], which derives DNI from clear sky GHI estimates. This process derives the turbidity and aerosol modeling from the MODIS dataset. Stations are as globally distributed as possible in order to represent a variety of climates, elevations, etc. The ground measurement data has been lightly quality controlled to ensure only high quality data is included.

Results are presented in tables and in maps such as in Fig. 3 below so readers can easily see the spatial differences. Due to file size limitations, only a sample of the maps we created are included in this manuscript.

2. Methods

2.1. Current processing methodology

We are following the basic methodology laid out by Richard Perez in his paper[3] modified with certain proprietary algorithms and various publicly available source data. We use a 2 arc-minute base resolution, processing various broad-band visible data from geosynchronous weather satellites to create cloud indexes (estimates of cloud cover and optical thickness). Currently GOES-13, GOES-15, Meteosat 7, Meteosat 10, and Himawari are processed daily, with historical data back to 1997-1999, depending on the region. Snow

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cover data derived from National Ice Center dataset[4] is also used in the cloud index calculation. These cloud indexes are calculated using a proprietary algorithm.

Clear Sky Irradiance is calculated from Linke values using Perez methodology. Linke values are calculated using methodology from Ineichen's paper[5] with data MODIS daily Aerosol Optical Depth (AOD) and water vapor datasets, shown in Table I.

Cloud indexes calculated from raw weather satellite data and snow cover are used to modulate Clear Sky GHI to calculate GHI values. DNI values are calculated from GHI using Perez's modified DIRINT method[3]. Diffuse is calculated from GHI and DNI and the solar zenith angle. after. This process is illustrated in Fig.1.

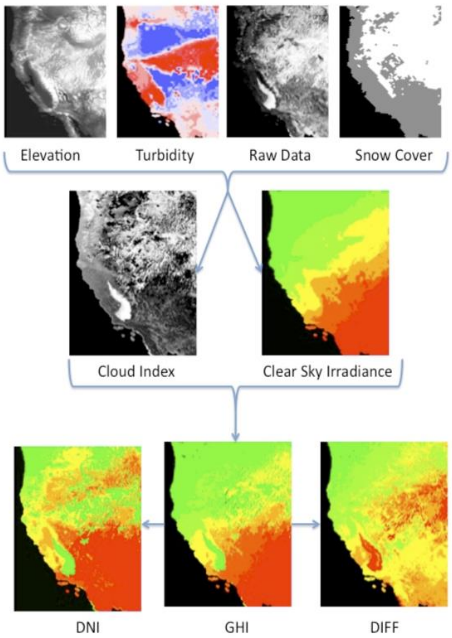

Fig. 1: Current processing methodology

2.2 Replacement of Perez Clear Sky Model with REST2 Clear Sky Model

The REST2 model is a parameterized version of Dr. Gueymard's SMARTS radiative transfer model. We are using a version of the code which uses the inputs listed in Table 1. Defaults are currently used for ozone, albedo, single scattering albedo and asymmetry parameter.

Tab. 1: INPUTS TO PEREZ-INEICHEN CLEAR SKY MODEL

Quantities	Source	Notes
AOD at 550 nm	MODIS	Spatial Res: 1.0 degree Temporal Res: daily
Precipitable Water (cm)	MODIS	Spatial Res: 1.0 degree Temporal Res: monthly

Tab. 2: INPUTS TO REST2 CLEAR SKY MODEL

Quantities	Source	Notes
Alpha (Angstrom Exponent),	MERRA2	Spatial Res: 0.5-0625 degree Temporal Res: 1 hours
AOD at 550 nm	MERRA2	Spatial Res: 0.5-0625 degree Temporal Res: 1 hours
Precipitable Water (cm)	MERRA2	Spatial Res: 0.5-0625 degree Temporal Res: 1 hours
Surface Pressure (pa)	MERRA2	Spatial Res: 0.5-0625 degree Temporal Res: 1 hours

MERRA2 inputs replace MODIS inputs, and directly feed REST2. Linke turbidity is not calculated. The REST2 calculation replaces Perez-Ineichen clear sky calculation.

In both models, GHI is calculated by modulating the cloud index values with the clear sky GHI values to calculate the GHI value. In the Perez model DNI is calculated from GHI using Dr Perez's DIRINT methodology. In the REST2 model a second modulation function is used to calculate DNI from the cloud index and the clear sky DNI value. Diffuse is then calculated from the GHI, DNI values and solar zenith angle.

These modulation functions vary regionally (and in some cases temporally) as the cloud index values have a dependence on the satellites being used to calculate them. These modulation functions are calculated for each region from a selected set of high-temporal resolution observations.

The fit is based on ground-observed GHI and calculated GHC, with kt = GHI(obs) / GHC(calc). These kt values are then related to the satellite-based CI values. Once this relationship is established (kt = f(CI)), it is used to calculate GHI from satellite-based CI and calculated GHC. An example modulation function is shown in Fig. 2.

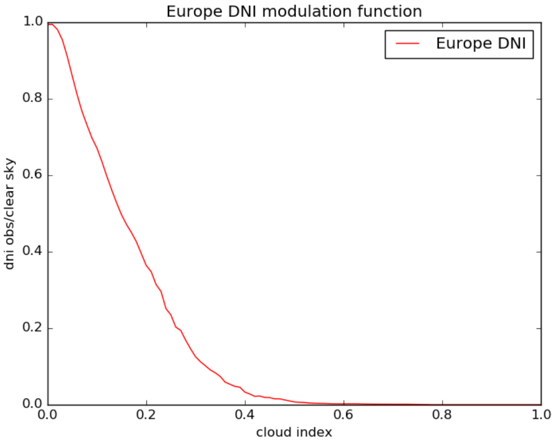

Fig. 2: DNI Modulation function for Europe

3. Observations From Ground Stations

For validation purposes we gathered GHI data from 186 publicly available ground stations plus 59 from clients who have authorized the release of their data. This covers 1689 station-years of observations. For DNI we have 158 public, and 2 private sites, covering 1165 station-years. The stations are independent of one another, and independent of the modeled output. Beyond the handful of stations used to create the modulation functions Vaisala does not allow local observations to affect our model, so that comparisons can be made site to site.

4. Validation

Overall Mean Bias Error (MBE), Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) both absolute and as a percentage of Observed Mean are calculated. Our clients are typically most interested in low MBE to ensure that our resource estimates will be accurate, RMSE tests that residuals are not too large and looking at MAE ensures that we do not have bias errors that are canceling each other.

Figure 3 shows Perez based GHI percent bias error, while Figure 4 shows the same information for REST2 based GHI percent bias error. The more pastel the points are the closer they to zero biased. Generally, REST2 data is closer to unbiased (e.g. Australia, South Africa) although there are exceptions (Saudi Arabia). Figure 5 shows Perez based DNI percent bias error, while Figure 6 shows the same information for REST2 based DNI percent bias error.

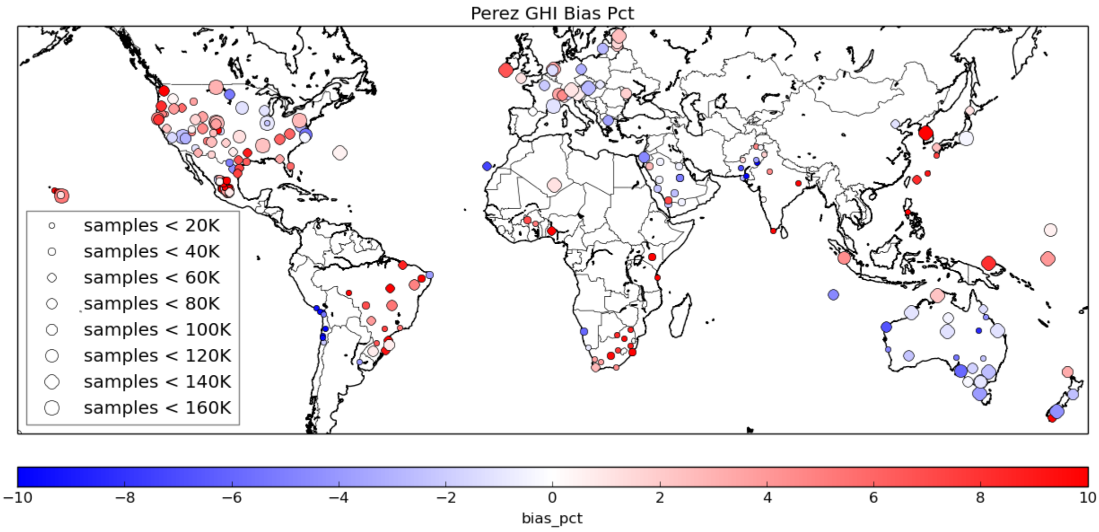

Fig. 3: GHI bias as percentage for Perez

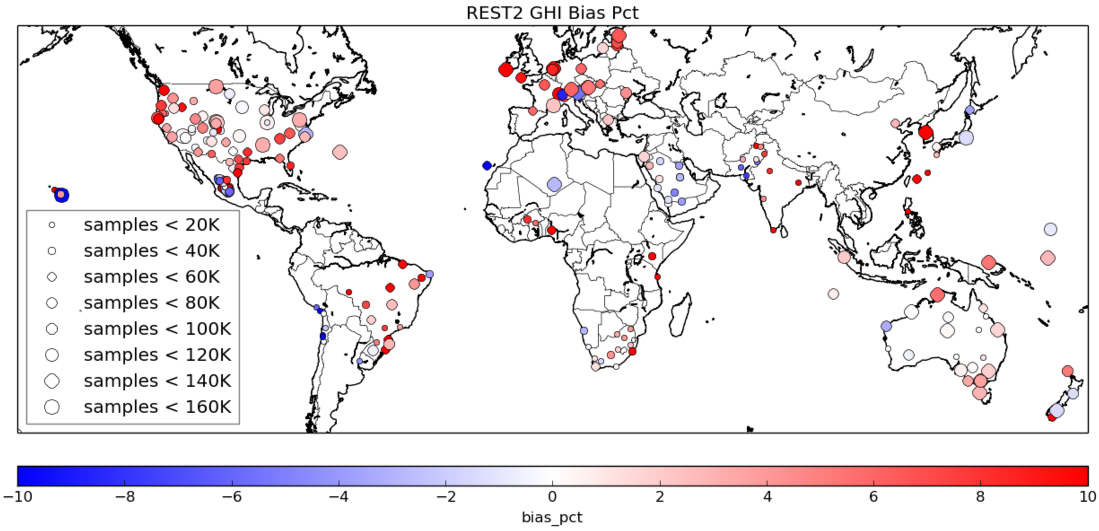

Fig. 4: GHI bias as percentage for REST2

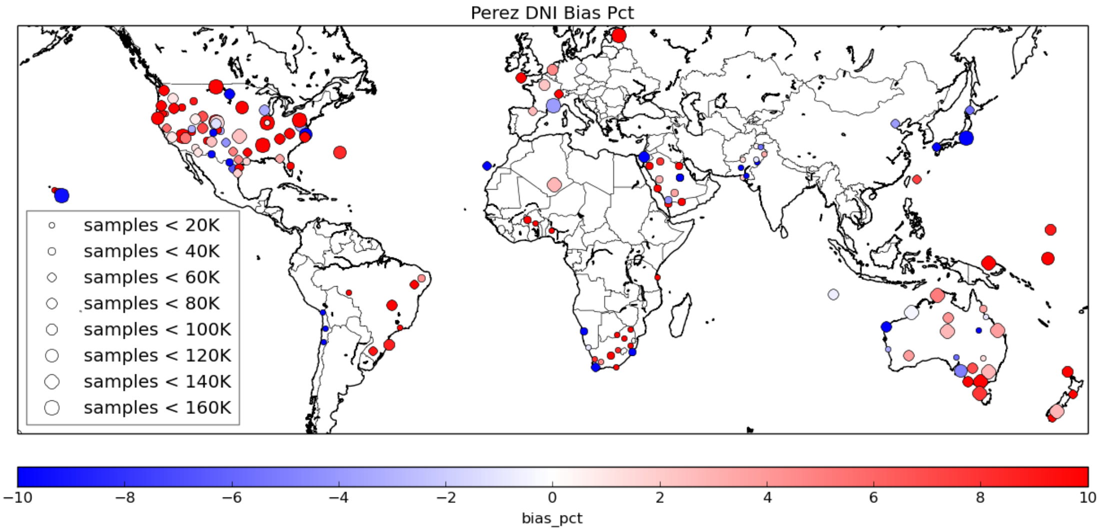

Fig. 5: DNI bias as percentage for Perez

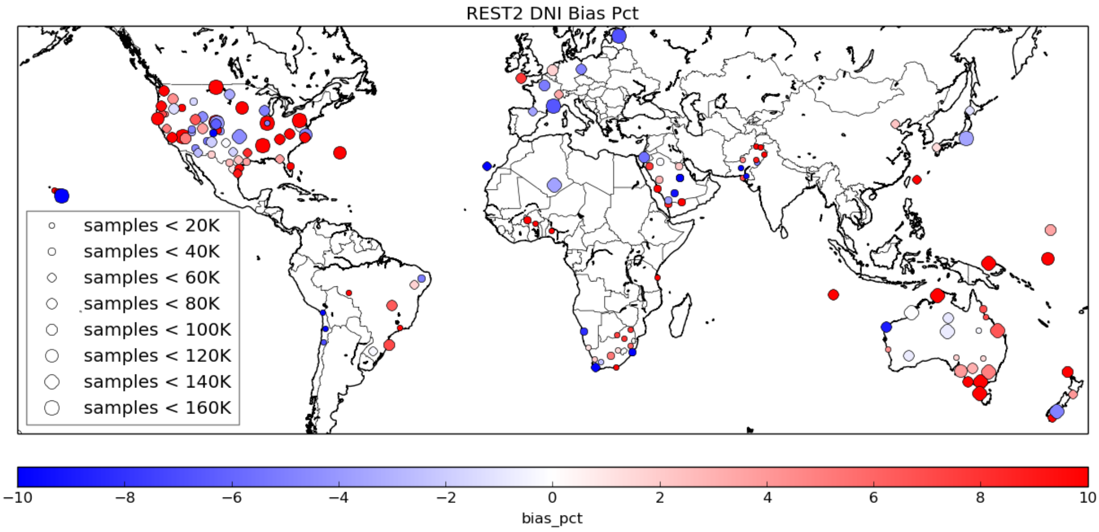

Fig. 6: DNI bias as percentage for REST2

Tables 3-6 show aggregate statistics of MBE, percent MBE, RMS, percent RMS, and MAE, percent MAE for REST2 and Perez GHI, and REST2 and Perez DNI respectively. The median values and 75th percentile values for all parameters show significant improvement from Perez to REST2.

Tab. 3: REST2 GHI AGGREGATE STATISTICS

REST2 GHI aggregate statistics (N=245)				
parameter	25%	mean	median	75%
MBE	0.99-	5.97	4.28	11.72
MBE Pct	0.46-	3.21	2.28	6.51
RMS	52.73	78.70	61.10	80.33
RMS Pct	23.77	38.14	31.17	44.31
MAE	22.67	38.08	28.42	39.62
MAE Pct	10.70	18.46	14.16	20.53

Tab. 4: PEREZ GHI AGGREGATE STATISTICS

Perez GHI aggregate statistics (N=245)				
parameter	25%	mean	median	75%
MBE	-2.76	6.53	3.60	12.77
MBE Pct	-1.31	2.97	1.83	5.92
RMS	54.78	80.00	64.46	80.80
RMS Pct	24.55	38.06	31.62	40.26
MAE	24.35	39.11	29.56	40.17
MAE Pct	11.36	18.60	14.58	20.11

Tab. 5: REST2 DNI AGGREGATE STATISTICS

REST2 DNI aggregate statistics (N=160)				
parameter	25%	mean	median	75%
MBE	7.23-	2.64	6.28	22.45
MBE Pct	3.59-	11.11	3.58	11.48
RMS	100.84	188.56	120.98	173.35
RMS Pct	47.65	86.56	63.89	88.65
MAE	43.14	79.49	51.02	68.80
MAE Pct	20.66	38.06	26.97	37.62

Tab. 6: PEREZ DNI AGGREGATE STATISTICS

Perez DNI aggregate statistics (N=160)				
parameter	25%	mean	median	75%
MBE	-8.16	4.56	8.21	29.63
MBE Pct	-3.34	11.33	3.66	13.67
RMS	107.59	197.25	132.18	176.88
RMS Pct	50.83	85.73	66.14	90.49
MAE	49.55	88.63	61.96	85.85
MAE Pct	23.70	40.69	30.98	41.33

Tables 7 and 8 show direct comparison statistics between Perez and REST2 for GHI and DNI. The tables show how many stations have better statistics for each parameter, and which ones tie within 1%. REST2 wins in every category.

Tab. 7: DIRECT GHI COMPARISON STATISTICS

GHI (N=245)			
parameter	REST2	Tie (1%)	Perez
MBE	144	16	92
MBE Pct	144	25	83
RMS	147	48	57
RMS Pct	149	61	42
MAE	162	40	50
MAE Pct	161	60	31

Tab. 8: DIRECT DNI COMPARISON STATISTICS

DNI (N=160)			
parameter	REST2	Tie (1%)	Perez
MBE	96	7	53
MBE Pct	93	17	46
RMS	115	10	31
RMS Pct	93	29	34
MAE	135	6	15
MAE Pct	130	17	9

5. Summary

This validation process will allow us to see how different methods of deriving GHI and DNI fare against independent ground station measurements. Our validation results may suggest that model performance varies regionally, or indeed, that one model is superior to the other across all regions included in the global validation study. This will provide the industry with information it can use to improve the accuracy of resource assessments, and therefore decrease the risk and uncertainty associated with large project developments.

6. References

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