Professional Grade Validation

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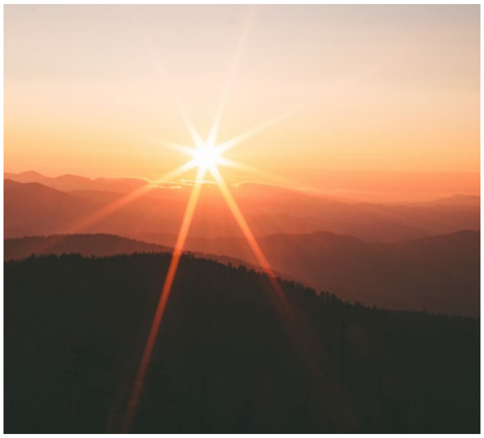

Introduction

One of the most often asked questions about Vaisala's satellite-derived irradiance datasets is simply: "How accurate is it?" Unfortunately, determining accuracy is one of those things that seems so simple in theory but is difficult in practice. The theory says just compare your predictions to high-quality observations at many locations to get a sense for accuracy. The difficulty is that obtaining high-quality observations for a public-facing validation study is easier said than done. Many public stations of high quality were already used to tune the algorithms behind satellite-derived estimates, so therefore they are not truly independent when being used for validation purposes. Public observations of lesser quality are available, but quality control of those data often reveal significant problems and removing those problematic data reduces the length of the comparison period. Obviously, many high-quality observation datasets have been collected by those developing utility scale solar projects — but those data are typically not available for use in public validation studies. The difficulty of obtaining high-quality and independent data for public-facing validation studies has frustrated both the providers and users of solar resource datasets. Those that are familiar with the difficulties of validation ask a follow-on question to the "How accurate?" question. They ask: "What data did you use to determine the accuracy of your data, and are those data truly independent from the observations you used to develop your datasets?"

In this case study we present the results of an independent validation exercise that used data from twelve (12) high-quality solar observation stations in the U.S.A., which were provided to Vaisala by one of our project development clients. Vaisala was given specific approval to disclose the results of this validation exercise publicly at the state level. The data at each station included GHI and DNI and both were extensively quality controlled to a bankable/professional standard before being compared to Vaisala's satellite-derived estimates. These observations are entirely independent of any ground station data that were used to tune the satellite estimates. Each observation location had at least one year of observations after quality control. For the validation study, we compared the hourly mean irradiance estimates from the satellite to the hourly mean observed values. We then calculate differences ("errors") during all coincident hours (n>8760). Furthermore, Vaisala was provided data from 12 additional stations, but these data only had preliminary quality control applied. The data from these stations are used to explore the impact of sample size on the error statistics.

In this case study we refer to three different types of error.

Bias

The Mean Bias Error (or MBE) at an individual station is an estimate for how similar the satellite estimates are to the observed values over the full length of concurrent samples at a single station (in this case at least one year's worth of hourly values). While the term "error" is used, this value is really just a difference between two estimates of the actual irradiance at the site (i.e. neither the satellite nor the ground station is a perfect estimate). MBE is commonly referred to simply as the bias. A high bias means that the satellite estimates were higher than the observations on average at that location. The MBE can vary from location to location and may have as much to do with errors associated with the satellite as errors associated with the observations. Therefore, it is important to not draw too many conclusions from the MBE obtained from just one location.

Mean Bias

The mean (or average) of all the Mean Bias Errors (MBEs as defined above) over a region is an estimate of the typical bias that one would expect when comparing the satellite estimates over a region. Ideally the Mean of the MBE over a large number of stations and over a large region should be close to zero. In theory if the Mean of the MBE is not zero then the satellite derived estimate should be "bias corrected" before being used for decision-making purposes.

Uncertainty — Standard Deviation and Root Mean Square (RMS) of the MBE

A statistic that is commonly used as a first order estimate of the uncertainty is the standard deviation of the individual station's MBEs. An alternative estimate of uncertainty is the Root Mean Squared Error of the individual station MBEs. If the Mean MBE is zero and the number of samples is large, then the two estimates produce exactly the same uncertainty. In our case study, the bias is not zero and the sample size is small — so therefore we report both estimates of uncertainty. This uncertainty, when expressed as a percent, then tells us something very useful as it describes the expected (probability) difference between the satellite estimate and the observations. For example, if the uncertainty is 5%, then we would expect that 66% of the time the actual difference (MBE) between the satellite and the observation would be less than or equal to 5%. If the uncertainty is 2%, then the expected difference (66% of the time) is much smaller.

Results

The results of this case study validation are provided in Table 1, Table 2, and Table 3 below. Table 1 shows the results for Global Horizontal Irradiance (GHI) and Table 3 shows the results for Direct Normal Irradiance (DNI). Table 2 shows results for GHI with a larger sample size (n=24 stations) that included stations with less rigorous quality control. Results are shown indexed by the state in which the observation station was located. Results are also indexed by Vaisala satellite model version (5 models from 1.0 to 2.1).

The overall model bias (Mean MBE) for GHI are similar to those calculated in our global and North America regional validation report. This result is not surprising as we would expect the mean MBE to be fairly small. What is more interesting is the comparison of uncertainty when comparing the results from just these 12 stations that are high quality to the statistics calculated from all global or North America stations. Looking at just these 12 stations, the uncertainty, whether estimated by Standard Deviation or RMS, is in all cases less than 3% for GHI. The average uncertainty is approximately 2.1%. That is much less than the uncertainty of roughly 4.5% from our global validation statistics (Table A-1) and 3.7% from our North American validation (Table A-5). Obviously, there is a significant question of the effect of the small sample size on these estimates. To address that concern, we obtained a second set of 12 stations from the same developer client. On these new 12 stations we did not perform bankable level quality control (QC) and simply accepted the data as they were provided by the developer (with QC having been performed internally by the developer). This difference in QC is why we segregated the dataset. Looking at the summary statistics for all 24 stations (Table 2), the bias is roughly equal to those obtained from the 12 stations, and the uncertainty from both estimates (Standard Deviation and RMS) is still less than 3% in all cases with an average uncertainty of 2.4%. Given the increased uncertainty of the observations themselves — the consistency of the uncertainty estimate across 12 and 24 stations provides confidence in the estimate.

These high-quality observations also allowed us to make an estimate of the uncertainty of Direct Normal Irradiance (DNI). DNI is much more difficult to measure — and requires a much higher level of quality control to be useful. We performed full bankable level quality control on the DNI measurements from these 12 stations (same as Table 1) and those results are shown in Table 3. What is remarkable about the results is that the estimate of the uncertainty is in all cases less than 6.5% and averages 5.2%. Our general guidance regarding uncertainty of DNI from global studies is to use an uncertainty of 9%. This case study suggests that applying such a high uncertainty (9%) to our satellite-derived estimates in North America is likely conservative. This is especially true for Vaisala model 2.1 which has an uncertainty estimate of less than 4%.

Conclusion

Vaisala performed an independent validation of our satellite-derived Global Horizontal Irradiance (GHI) and Direct Normal Irradiance (DNI) against high-quality ground observations provided to us by one of our project developer customers. Results showed that uncertainty obtained from these stations is significantly less than that obtained from using all stations in our global validation studies. GHI uncertainty was estimated to be between 2.1% and 2.4% depending on sample size. DNI uncertainty was estimated to be about 5.2%. This is roughly half the uncertainty, as compared to our previous global validation studies.

Table 1: Global Horizontal Irradiance (GHI) Mean Bias Error (MBE) at each of the 12 stations indexed by state and Vaisala Model version. Summary statistics (Mean MBE, Standard Deviation MBE, and RMS MBE) are in the sub-table below. All values are in percent.

State	Vaisala 1.0	Vaisala 1.1	Vaisala 1.2	Vaisala 2.0	Vaisala 2.1
AL	0.5	1.4	0.9	1.7	2.8
CA	-6.5	-8.1	-7.1	0.1	0.3
CA	-1.4	-1.3	-1.3	4.1	2.2
CA	-0.8	-0.8	-0.9	3.6	3.8
GA	1.2	1.7	0.7	1.7	2.6
GA	0.6	0.8	0.0	1.0	1.9
GA	0.0	0.7	-0.4	1.0	1.9
MD	-3.5	-2.5	-2.6	1.0	1.7
NY	-1.9	-1.0	-1.5	2.6	2.8
TN	-1.9	-1.0	-1.4	0.7	2.1
TX	-2.2	-2.4	-2.1	-1.2	-0.7
TX	0.8	-0.2	-0.1	0.8	1.4
Mean MBE	-1.3	-1.1	-1.3	1.4	1.9
StDev MBE	2.2	2.6	2.1	1.5	1.2
RMS MBE	2.4	2.7	2.4	2.0	2.2

Table 2: Global Horizontal Irradiance (GHI) summary statistics (Mean MBE, Standard Deviation MBE, and RMS MBE) at 24 stations. 12 stations identical as in Table 1 that received full bankable quality control and an additional 12 stations that received first order quality control. All values are in percent.

	Vaisala 1.0	Vaisala 1.1	Vaisala 1.2	Vaisala 2.0	Vaisala 2.1
Mean MBE	-1.0	-1.1	-1.0	1.5	2.1
StDev MBE	2.2	2.6	2.2	2.0	1.8
RMS MBE	2.3	2.6	2.3	2.8	2.9

Table 3: Direct Normal Irradiance (DNI) Mean Bias Error (MBE) at each of the 12 stations indexed by state and Vaisala Model version. Summary statistics (Mean MBE, Standard Deviation MBE, and RMS MBE) are in the sub-table below. All values are in percent.

State	Vaisala 1.0	Vaisala 1.1	Vaisala 1.2	Vaisala 2.0	Vaisala 2.1
AL	-1.0	2.7	1.4	-7.8	-2.7
CA	-13.5	-18.2	-14.8	-3.9	-1.5
CA	-2.9	-2.4	-1.4	3.2	-0.5
CA	2.5	2.7	2.9	3.7	6.4
GA	1.8	3.7	1.9	-7.2	-2.2
GA	3.1	4.5	2.7	-5.9	-1.4
GA	1.7	4.2	2.0	-5.8	-1.0
MD	-3.7	-0.7	0.4	1.1	3.8
NY	3.9	6.4	7.4	5.6	4.7
TN	-5.0	-1.9	-1.6	-9.5	-1.0
TX	-1.1	-1.6	0.3	-9.2	-5.6
TX	6.5	3.4	4.3	-5.6	-0.2
Mean MBE	-0.6	0.2	0.5	-3.4	-0.1
StDev MBE	5.3	6.5	5.4	5.4	3.4
RMS MBE	5.1	6.2	5.2	6.2	3.3

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