VAISALA

WHITE PAPER

Professional Grade Validation

updated 2022

This white paper is an update from the Vaisala 2019 "Professional Grade Validation Study" (Vaisala, Oct 2019) and is a companion document to our most recent Global Validation Study (Vaisala, May 2020). The "Professional Grade" study from 2019 looked at the bias of the Vaisala satellite estimate versus high quality observations in the U.S.A. (12 locations for GHI and DNI). The global validation study from 2020 looked at ~200 stations of various quality around the world. This updated "Professional Grade" study increases the sample size of locations in the U.S.A. from 12 to 38. Results show that both "Professional Grade" studies utilizing high quality observations have considerably lower uncertainty than that obtained from the Vaisala global validation, even when just considering those stations in the U.S.A. Furthermore the uncertainty of the previous "Professional Grade" study of approximately 2.2% (at one standard deviation) is essentially unchanged as the sample size of stations in the U.S.A. increases from 12 to 38.

1 Introduction

One of the most often asked questions about Vaisala's satellite derived irradiance datasets is simply, "How accurate is it?". In practice, predictions can be compared to high-quality observations at many locations to get a sense of accuracy. The difficulty is that obtaining high quality observations for a public facing validation study is relatively difficult. Many public stations of very 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 comparison period. Many high quality observation datasets have been collected by those developing utility scale solar projects – but those 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 satellite solar resource datasets. So those that are familiar with the difficulties of validation ask a follow-up question to the "How accurate?" question: "What high-quality data was used to determine the accuracy of the satellite data, and was it truly independent from the observations used to develop the satellite datasets?"

In this white paper we present results of an independent validation exercise that used data from thirty eight (38) high quality solar observations stations in the U.S.A. which were provided to Vaisala by two of our project development clients. This white paper follows up on a previous white paper (Vaisala, Oct 2019) that used only 12 stations. Vaisala was given specific approval to disclose the results of this validation exercise publicly at the state level. All 38 stations included GHI observations and DNI observations were available at 12 stations. All data were extensively quality controlled to

a bankable/professional standard before being compared to the satellite derived estimates. These observations are entirely independent of any ground station data that was used to either explicitly or implicitly tune the satellite. 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).

In this white paper 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 or the ground station is a perfect estimate). MBE is commonly referred to simply as the bias. A high bias, for example, 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 the all the Mean Bias Errors (MBE's 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 MBE's. An alternative estimate of uncertainty is the Root Mean Squared Error of the individual station MBE's. If the Mean MBE is zero and the number of samples is large then the two estimates produce exactly the same uncertainty. In our white paper, the bias is not zero and the sample size is relatively 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.

2 Results

The results of this white paper validation are provided in Table 1 and Table 2. Table 1 shows the results for Global Horizontal Irradiance (GHI) and Table 2 shows the results for Direct Normal Irradiance (DNI). 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). Figure 1 shows a scatter plot of the satellite estimate (y-axis) versus observations (x-axis) for the Vaisala 2.1 model at all 38 sites as well as the line of best fit through these data and the 1:1 line and uncertainty lines at plus or minus one and two standard deviations.

The overall model bias (Mean MBE averaged over all stations) for GHI are similar to those calculated in our global and North America regional validation report (Vaisala, May 2020). This result is not surprising as we would expect the mean MBE to be small. What is more interesting is the comparison of uncertainty when comparing the results from just these 38 stations that are high quality to the statistics calculated from all global or North America stations. Looking at these 38 stations, the uncertainty, whether estimated by Standard Deviation or RMS, is in most cases less than 3% for GHI – and for the Vaisala 2.1 model which is our current benchmark for North America - the uncertainty is between 2.2% and 2.3%. This result is essentially unchanged from our 2019 “professional grade validation” white paper that had a much smaller sample size (N=12) and estimated the uncertainty (RMSE) at 2.2%. The unchanged uncertainty is remarkable with a sample size increase from 12 to 38 stations – more than tripling the number of independent stations. Overall these uncertainties using high quality observations in North America are much less than the uncertainty of roughly 4.5% from our global validation statistics (Vaisala, May 2020: Table A-1) and 3.7% from our North American validation (Vaisala, May 2020: Table A-5).

The scatter plot of Figure 1 shows that the line of best fit through the data (y=0.9958x, R2 0.9995) is nearly identical to the one:one line, with a very slight tendency to underpredict on average (Mean MBE of Vaisala 2.1 is approximately -0.6% in Table 1). Figure 1 shows data pairs with respect to a line on the plot at one and two standard deviations. 100% of the points fall within an uncertainty of two standard deviations. There appears to be equal tendency to over and underpredict for the majority of the values of GHI. However, between satellite predictions of 220 and 240 W/sqm (N=3) the Vaisala 2.1 model has a tendency to overpredict compared to the observations. There also appears to be a tendency to underpredict when the satellite estimate is between 160 and 170 W/sqm (N=7). The highest observed annual average (250 W/sqm) is well predicted by the satellite.

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 2. 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 white paper 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%.

3 Conclusion

Vaisala performed an independent validation of our satellite derived Global Horizontal Irradiance (GHI at 38 stations) and Direct Normal Irradiance (DNI at 12 stations) against high quality ground observations provided to us by two of our project developer customers. Results showed that uncertainty obtained from these stations is significantly less than that obtained from using all stations of various quality in our global validation studies. GHI uncertainty of the Vaisala 2.1 benchmark model for North America was estimated to be between 2.2% and 2.3% depending on method of calculation (RMSE versus St. Dev). This result is essentially unchanged from our previous study published in 2019 with a much smaller number of stations (GHI and DNI at 12 stations). The differences at all (i.e. 100%) of the 38 sites fall within +/- 4.4% (i.e. two standard deviations). DNI uncertainty was estimated to be about 5.2%. For both GHI and DNI, this white paper uncertainty is roughly half the uncertainty when looking at our previous global validation studies.

References

Vaisala, October 2019, Professional Grade Validation. Available at: https://www.vaisala.com/sites/default/files/documents/WEA-DIG-RE-ProfGradeValidation-WP-8.5x11-v1.pdf

Vaisala, May 2020, Vaisala Global Solar Dataset 2019 Release Methodology and Validation. Available at: https://www.vaisala.com/sites/default/files/documents/WEA-DIG-RE-Vaisala-SolarValidation-WP-8.5x11-v1.pdf

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%
AL	-1.6%	-1.8%	-3.5%	-2.6%	-1.2%
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%
FL	-3.7%	-2.9%	-2.8%	-2.8%	-2.3%
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%
GA	-2.8%	-2.9%	-4.3%	-4.1%	-2.5%
IL	-4.3%	-2.7%	-2.0%	-1.9%	-1.7%
IN	-3.6%	-3.4%	-4.6%	0.8%	1.7%
IN	-5.6%	-4.2%	-3.7%	-1.8%	-2.0%
KY	-6.3%	-5.0%	-4.6%	-3.0%	-2.4%
MD	-3.5%	-2.5%	-2.6%	1.0%	1.7%
MI	-4.2%	-2.9%	-2.4%	-1.2%	-1.7%
MI	2.3%	2.3%	-0.2%	1.1%	2.7%
MI	-4.0%	-4.0%	-5.2%	-3.2%	-2.4%
NY	-1.9%	-1.0%	-1.5%	2.6%	2.8%
OH	-5.7%	-4.2%	-3.7%	-2.1%	-2.3%
OH	-4.9%	-3.5%	-2.8%	-0.2%	0.2%
OH	-5.7%	-4.3%	-3.6%	-1.5%	-1.3%
OH	-5.9%	-4.7%	-4.1%	-2.1%	-2.0%
OH	-2.7%	-2.7%	-2.7%	-3.6%	-2.1%
OK	-2.2%	-2.1%	-2.1%	-3.3%	-3.1%
OK	-2.8%	-1.5%	-2.1%	-4.9%	-3.7%
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%
TX	-3.6%	-3.8%	-4.6%	-5.7%	-3.7%
TX	-4.0%	-2.6%	-2.6%	-3.2%	-2.7%
TX	-1.7%	-1.0%	-1.1%	-2.3%	-3.4%
TX	-3.0%	-1.7%	-1.7%	-2.6%	-2.3%
VA	-5.1%	-5.3%	-6.5%	-3.7%	-2.4%
VA	-4.2%	-3.5%	-3.4%	-1.9%	-1.0%
WI	-3.5%	-3.5%	-4.8%	-3.9%	-2.6%
WI	-2.3%	-1.3%	0.9%	-0.9%	-0.6%
WV	-3.1%	-2.0%	-2.0%	-1.7%	-1.0%

Mean MBE	-2.9%	-2.3%	-2.5%	-1.2%	-0.6%
St Dev MBE	2.2%	2.1%	1.9%	2.3%	2.2%
RMS MBE	3.6%	3.1%	3.2%	2.6%	2.3%

Table 1: Global Horizontal Irradiance (GHI) Mean Bias Error (MBE) at each of 38 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.

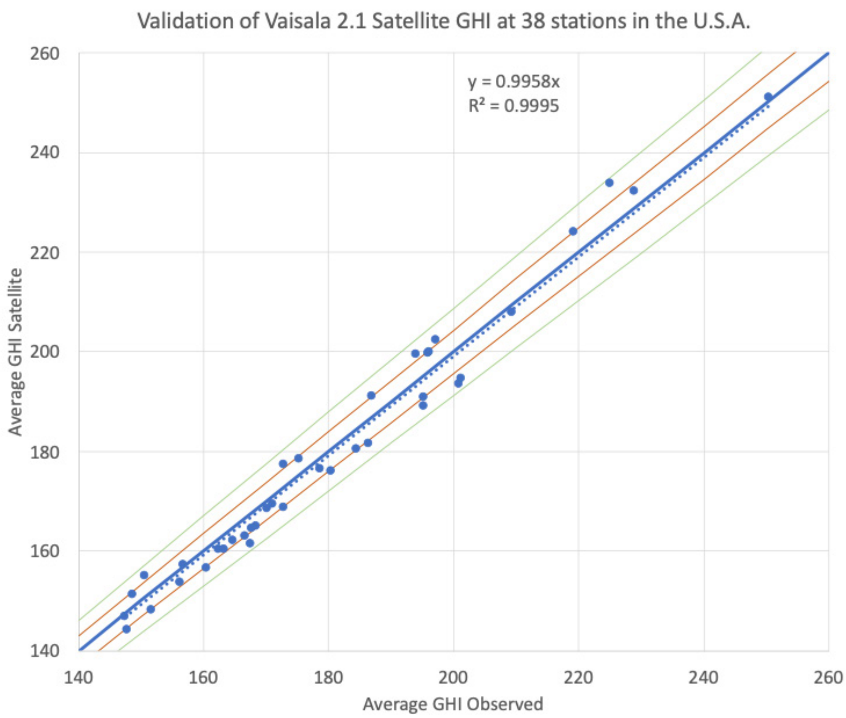

Figure 1. Scatterplot of validation results for Vaisala model 2.1. Only concurrent periods with valid observations are used in the calculation of the average satellite and observed values. The best fit trendline is shown as the dashed blue line along with the equation and R-squared of the fit. The dark blue line is the one:one line. The light orange lines are at +/-2.2% (i.e. the first standard deviation) and the light green lines are at +/-4.4% (i.e. two standard deviations). The differences fall within two standard deviations (+/-4%) at all 38 sites.

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%
St Dev MBE	5.3%	6.5%	5.4%	5.4%	3.4%
RMS MBE	5.1%	6.2%	5.2%	6.2%	3.3%

Table 2: Direct Normal Irradiance (DNI) Mean Bias Error (MBE) at each of 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.

VAISALA

vaisala.com

Scan the code for more information

Ref. B212599EN-A ©Vaisala 2022