Detecting Calibration Drift at Ground Truth Stations A Demonstration of Satellite Irradiance Models' Accuracy

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***Abstract* — In this article we show how a state-of-the-art satellite irradiance model – SolarAnywhere – is capable of identifying undetected calibration issues at a trusted reference ground truth irradiance measurement station. This evidence suggests that the best satellite models have now achieved a degree of accuracy and versatility that makes them an acceptable, if not a preferred choice, for solar energy engineering applications ranging from long-term site characterization and system monitoring.**

***Index Terms* —solar resource, satellite, modeling, irradiance, benchmarking.**

I. Introduction

Satellite-derived irradiances have several operational advantages over ground measurements. These advantages include a global reach, a geographical resolution ranging from sub-kilometer scale to entire continents, a long-term time reference spanning decades, and a real-time accessibility that can drive operational forecasts. The long-term reference capability, in particular, is widely applied for site characterization and project financing, especially when this is ascertained by short-term measurements tuning.

The known advantage of measurements over satellite data is localized accuracy, but only if instruments are properly calibrated and maintained.

In this article we suggest that state-of-the art satellite models have now achieved such degree of accuracy that they can spot undetected calibration errors in trusted reference stations.

This assertion is based on the comparative analysis of the SolarAnywhere V3 [1] satellite model and the SurfRad station of Fort Peck, Montana. The SurfRad stations are part of WMO's BSRN network [2]. They are considered to be of unquestionable quality, with calibrations traceable to primary standards. These reference stations are frequently used to both validate and tune satellite models.

A SolarAnywhere user triggered the present investigation. The user was comparing SolarAnywhere global irradiance (GHI) data against Fort Peck ground-truth station data. The SolarAnywhere user noticed unexplained discrepancies between the two data sets. The user reported that the year-to-year variability was not always well-matched to Fort Peck ground observations. Figure 1 compares the annual, measured GHI to Solar Anywhere GHI. In particular, SolarAnywhere data are significantly higher than ground measurements in 2015, a difference that slightly exceeds the model's published margin of error.

Our first assumption was that this was an acceptable level of uncertainty. A strength of satellite data, however, is the ability to provide a long-term evaluation resource that accurately accounts for year-to-year variability. This is beneficial to developers and planners. We decided to investigate this issue further.

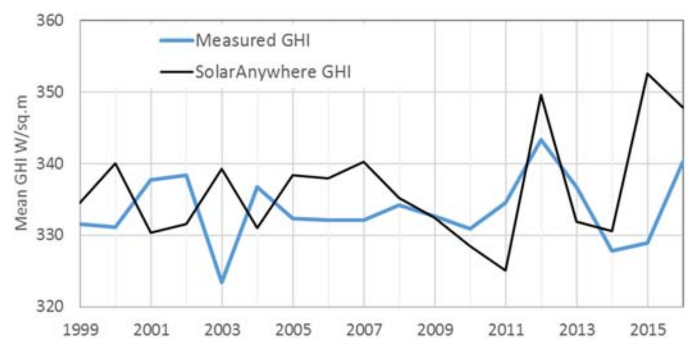

Fig. 1. Annual GHI long-term trends for Fort Peck SURFRAD and SolarAnywhere

II. Data Analysis

Large 2015 Discrepancy: In Figure 2 we compare SolarAnywhere GHI against Fort Peck GHI measurements in 2013 (when the satellite model slightly underestimated ground measurements) and 2015 (when the model significantly overestimated measurements.)

The 2015 positive bias is visible through clear sky condition events – i.e., the points densely concentrated near the 1-1 line during higher irradiance conditions. There is a close alignment between clear sky points detected by the ground and

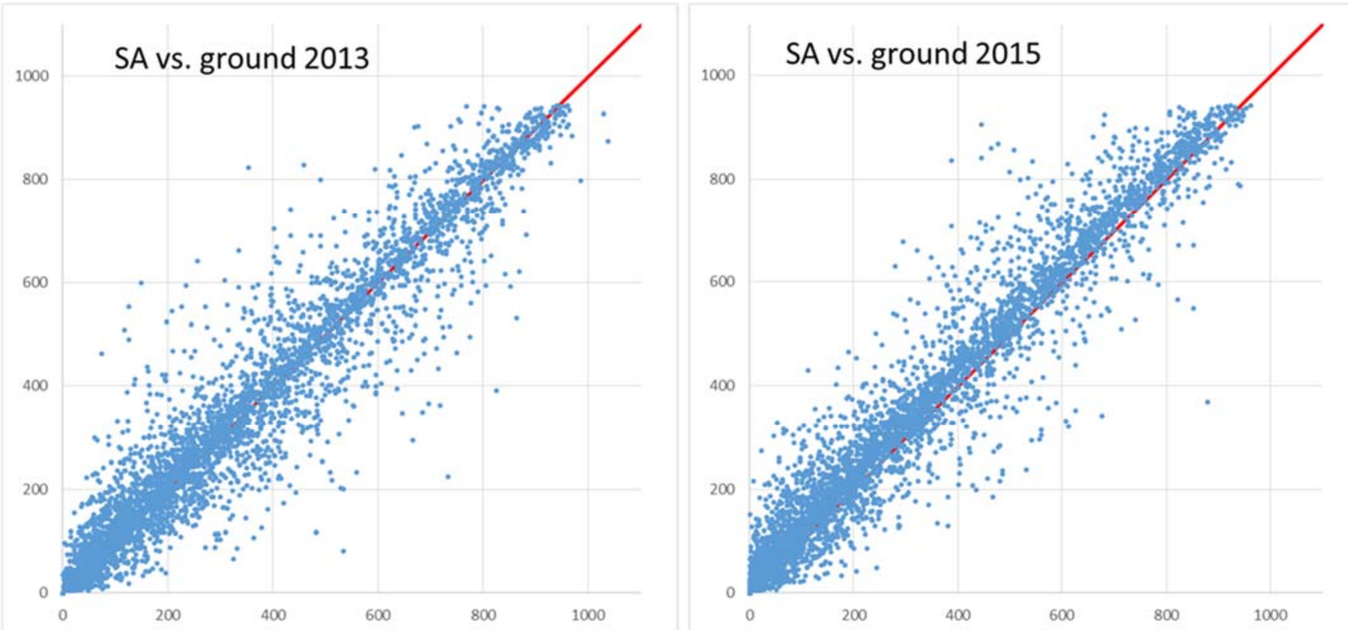

Fig. 2. SolarAnywhere GHI (y axis) vs. SURFRAD GHI (x axis) in 2013 and 2015.

SolarAnywhere in 2013. SolarAnywhere clear sky points are systematically higher than ground measurements in 2015.

There are no significant differences in the satellite model's turbidity inputs (i.e., AOD and precipitable water) underlying the satellite model's clear sky calculations between the two years. Therefore, the difference in Figure 2 must originate from ground observations.

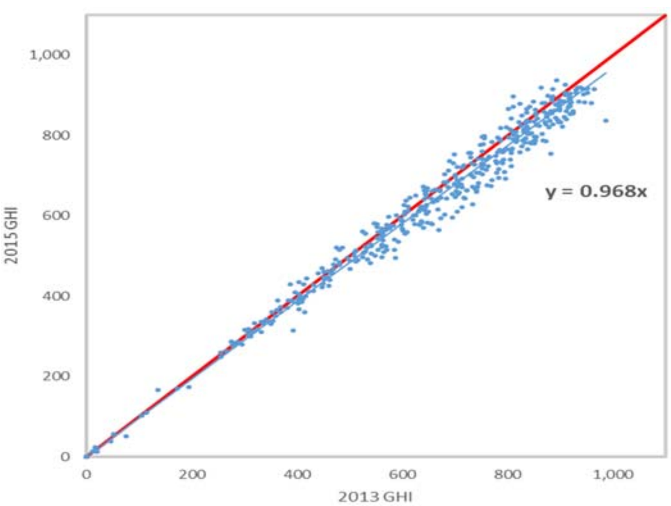

Fig. 3. Date/time coincident clear sky GHI observations in 2015 and 2013.

Focusing on ground measurements alone, Figure 3 compares measured GHI clear sky events in 2013 and 2015. Each point of the scatter plot corresponds to conditions when GHI was above 92 percent of clear sky conditions (i.e., Kt*> 0.92) in both years for the same calendar day and same time. The sample of coincident points indicates a mean ~ 3.4% decrease of observed clear sky conditions GHI from 2013 to 2015.

What is the reason for this decrease in ground data in 2015? Was it due to higher turbidity in 2015 resulting from an intense fire season in the Western US? Or was it due to instrument calibration change? The former would show that the satellite model has limitations because it is not precise enough to adapt to changing turbidity conditions. The latter would suggest that SolarAnywhere can identify calibration issues.

To answer this question, we examined independently measured DNI. A decrease in clear sky DNI between the two years should be amplified relative to GHI clear sky decrease if the cause is higher turbidity. We repeated the procedure of Figure 3 for DNI, selecting calendar/time of day-coincident points above a clear sky threshold in both years. Figure 4 presents the results.

Figure 4 shows that there is no appreciable change in clear sky DNI events in Fort Peck between 2013 and 2015. It is physically impossible to have a clear sky GHI reduction without a concurrent and larger clear sky DNI reduction. Therefore, we can only conclude that the 2015 calibration of the SurfRad GHI instrument was lower in 2015 than in 2013.

The example shown in Figure 5 both illustrates and ascertains this conclusion. Figure 5 presents measured DNI and GHI and

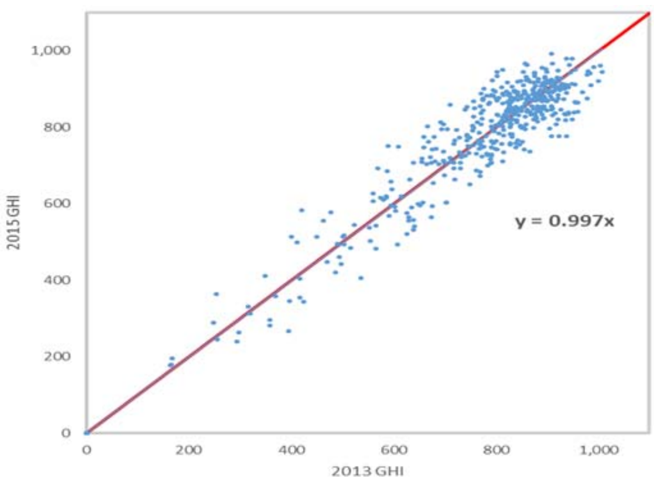

Fig. 4. Date/time coincident clear sky DNI observations in 2015 and 2013

identified it. NOAA has since posted a Data Problem Report following our inquiry [3].

Long Term Reliability of Solaranywhere: Figure 1 shows that, in addition to the large 2015 difference analyzed above there are other noticeable year-to-year differences between the two data streams. In Figure 6, we added indirectly measured GHI to the long term annual trends. Indirectly measured GHI is obtained by summing measured direct horizontal irradiance and measured diffuse irradiance. This indirect GHI measurement is considered to be more accurate than pyranometer measurements because it eliminates issues associated with sensors' cosine response [4]. However it does not eliminate possible calibration issues.

The mean yearly absolute value difference between SolarAnywhere and measured GHI is 2% over the considered 18-year time span. Interestingly, the mean absolute value difference between directly and indirectly measured GHI at

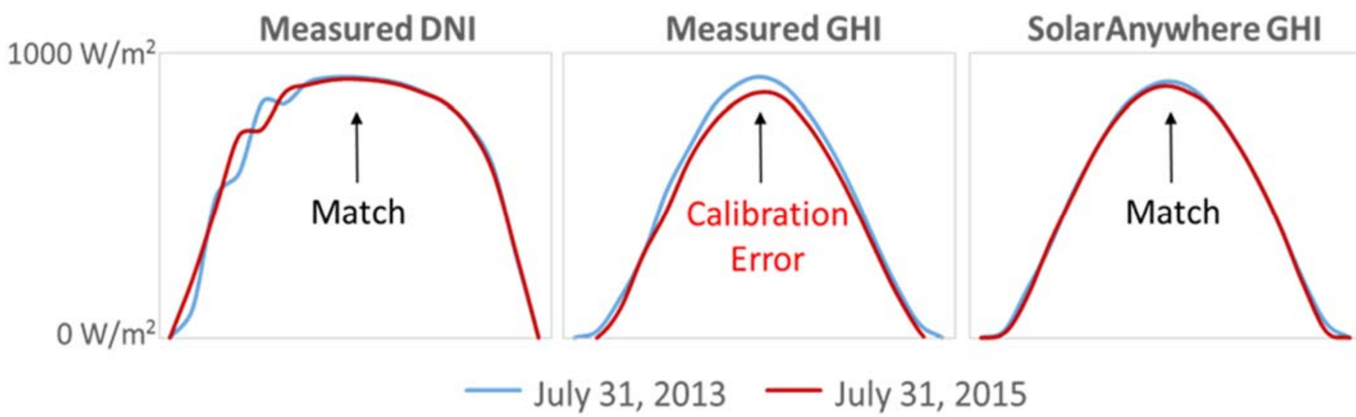

Fig. 5. Comparing measured DNI, GHI and SolarAnywhere GHI on July 31, 2013 and 2015

satellite-based SolarAnywhere GHI on comparable clear days in 2013 and 2015 (July 31, 2013 and July 31, 2015).

Measured DNI (left graph) is nearly identical for both years. SolarAnywhere GHI (right graph) is nearly identical for both years. Measured GHI (middle graph), however, is not. The measured 2015 GHI is substantially lower than the measured 2013 GHI.

Further, we used independently measured diffuse irradiance (DIF) and DNI to calculate GHI. We found that indirectly measured GHI via diffuse and DNI was nearly identical in both years. This confirms the thesis of a GHI calibration error.

The station operator (NOAA) confirmed that there was indeed a calibration mismatch issue with the GHI sensor that covered much of 2015 and that had not been noted until we

Fort Peck is also 2%. In Figure 7 we plotted the ranked yearly absolute value differences between any two of the three GHI sources. This plot shows that SolarAnywhere's year-to-year uncertainty is equivalent to the uncertainty that exists between two side-by-side GHI measurements obtained with first class instrumentation at a carefully maintained reference station.

Another way to assess SolarAnywhere long-term reliability is presented in Figure 8. This figure respectively plots annual GHI from each of the three considered sources against the two others. SolarAnywhere RMSE vs any of the two measured sources is marginally higher than when comparing one measured source against the other. However, the RMBE is

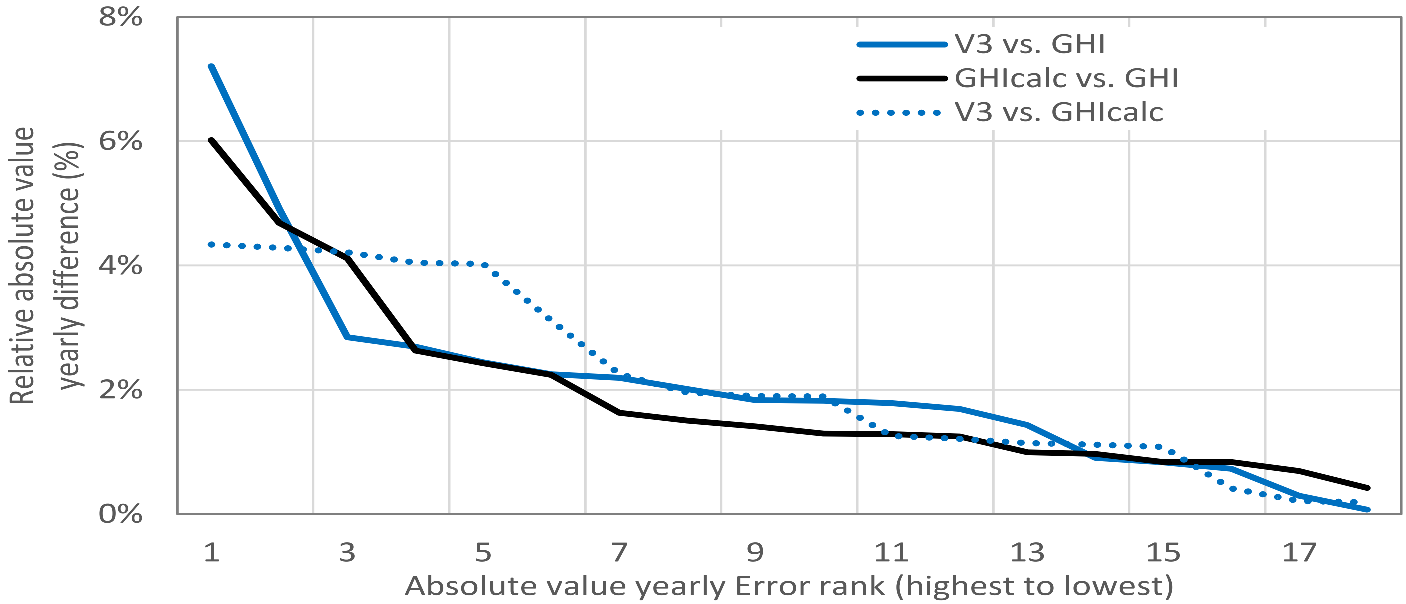

Fig. 7. Ranked absolute value yearly differences between the three sources of GHI

noticeably smaller, positioning this resource as a middle common ground between the two measurement sources.

Taking a detailed look at two one-year periods in addition to the 2015 problem discussed above sheds some light on these differences. Figure 8 contains two sets of scatterplots. The first set (left) includes data spanning October 2007 to September 2008. The second set (right) includes data from October 2008 to September 2009 (Note that we used September as a cutoff date because SURFRAD irradiance sensors are generally switched in September.)

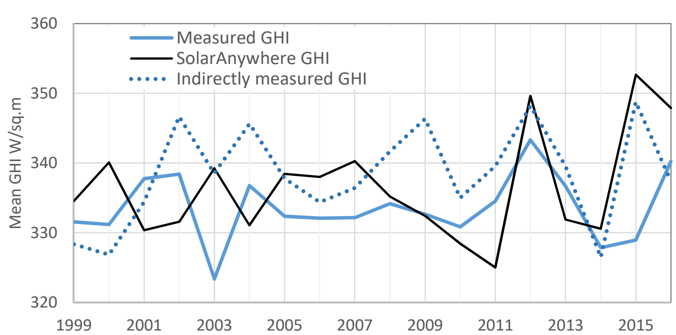

Fig. 6. Comparing annual GHI long-term trends in Fort Peck from SolarAnywhere, direct and indirect ground measurements

The top scatterplots show SolarAnywhere GHI vs. directly measured GHI. The middle plots show SolarAnywhere GHI vs. indirectly measured GHI and the bottom plots compare the direct and indirect GHI measurements.

The bottom plots show the tell-tale sign of pyranometer cosine response. This is apparent through the curvature between the two GHI measurements. In addition, there is substantial calibration difference between two periods for the two sources of GHI amounting to about 2%.

In the middle plots, the behavior of SolarAnywhere is reminiscent of measured GHI in the first period when compared to calculated GHI, while in the second period, the agreement between SolarAnywhere and calculated GHI is excellent.

The top plots show a similar agreement between SolarAnywhere and measured GHI in both periods.

These observations lead to conjecture that, in this case, the source of GHI that is out of pattern is the first period's calculated GHI – the DNI sensor was possibly slightly off calibration that year. This example shows that accurate satellite data such as SolarAnywhere may be a safe common denominator source of quality control between the two measurement methods.

IV. Conclusions

We draw four conclusions from this investigation.

First, SolarAnywhere is a reliable source of long-term solar resource data. It is precise enough to identify small calibration issues at one of the nation's most trusted irradiance reference data sets. Its year-to-year uncertainty is comparable to the uncertainty between two collocated measurements at a well-maintained station

Second, while it is widely accepted that indirect GHI measurement obtained from DNI and diffuse is preferable to pyranometric GHI measurement for ground truth validations and climate studies [ref] when both sources are available, it does not preclude that, even at the best reference stations, a pyranometric measurement may sometimes be more accurate because of operational calibration uncertainty.

Third, quality remote sensing measurement of irradiance such as SolarAnywhere can be an effective common denominator reference to check the field calibrations and identify/resolve issues between direct and indirect GHI measurements.

Finally, satellite data tuning using ground sensors – a common practice in the industry, e.g., [5], is only as good as the instruments used for tuning. A user must confirm proper calibration and maintenance before proceeding with data tuning.

REFERENCES

[1] Perez, R., J. Schlemmer, K. Hemker, Jr., S. Kivalov, A. Kankiewicz, and C. Gueymard, (2015): Satellite-to-Irradiance Modeling – A New Version of the SUNY Model. in 42nd IEEE PV Specialists Conference, 2014

[2] Ohmura, A., E. Dutton, B. Forgan, C. Fröhlich, H. Gilgen, H. Hegner, A. Heimo, G. König-Langlo, B. McArthur, G. Müller, G. Philipona, R. Pinker, C. Whitlock, K. Dehne, and M. Wild, (1998): Baseline Surface Radiation Network (BSRN/WCRP): New Precision Radiometry for Climate Research. Bulletin of the American Meteorological Society, Vol. 79, No. 10, pp. 2215-22136.

[3] NOAA Earth System Research Laboratory, Global Monitoring Division, (2016): Notice of SURFRAD Network Data Problem Reports. https://www.esrl.noaa.gov/gmd/grad/surfrad/problems.html

[4] Michalsky, J., E. Dutton, M. Rubes, D. Nelson, T. Stoffel, M. Wesley, M. Splitt, and J. Deluisi, (1999): Optimal Measurement of Surface Shortwave Irradiance Using Current Instrumentation. Journal of Atmospheric & Oceanic Technology, 16, pp. 55-69.

[5] Kankiewicz, A., J. Dise, E. Wu and R. Perez, (2014): Reducing Solar Project Uncertainty with an Optimized Resource Assessment Tuning Methodology. Proc. ASES Annual Conference, San Francisco, CA.

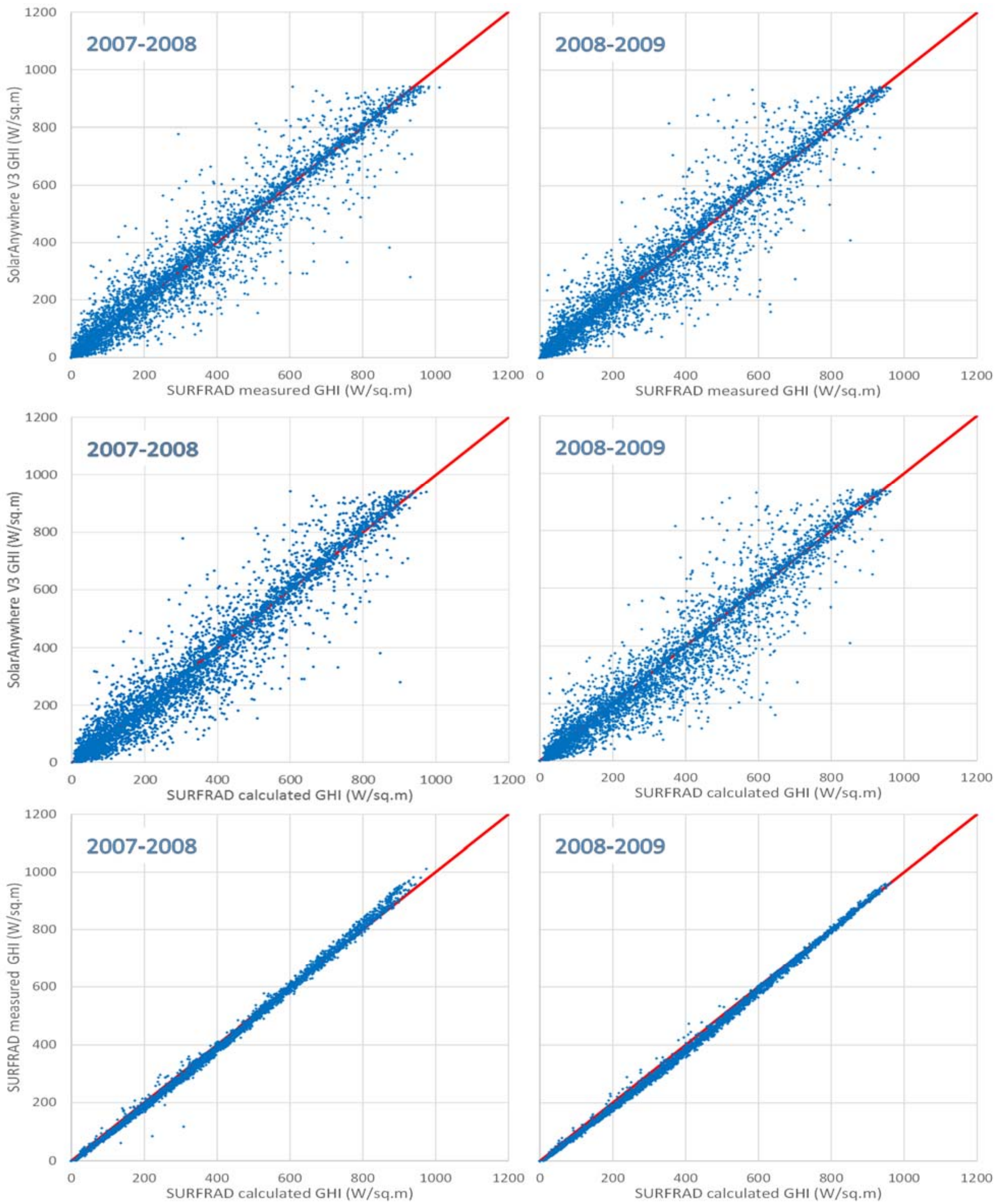

Fig. 8. Hourly SolarAnywhere GHI vs. pyranometer GHI (top), SolarAnywhere GHI vs. indirectly measured GHI (middle), and pyranometer GHI vs. indirectly measured GHI (bottom) for two consecutive one year periods.