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Improvement of accuracy and precision of spectral irradiance measurements in annual spectroradiometer intercomparison

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1. Summary

Energy yield measurement and radiation yield determination in the field of photovoltaics (PV) are subject to fast development regarding estimation uncertainties and error in prediction [1]. Both are determined mainly by constraints given by equipment development, calibration schemes and operation routines. Further, an increasing range of PV technologies is available on the market showing rather different spectral responsivities. These require precise PV device calibrations, either outdoor or indoor, with accurate measurement of the light-source. Under these boundary conditions accurate spectrally resolved solar irradiance measurements are gaining higher importance compared to recent years. Finally also PV energy yield estimations (predictions) may benefit from more accurate information on the solar spectrum.

The International Spectroradiometer and Broadband intercomparison (ISRC) is evaluating measurement devices, measurement routine and equivalence in measurement results. Last year edition involved 9 scientific institutions and 5 commercial partners of 8 countries, testingmeasurement capabilities and best practices in spectrally resolved solar irradiance between 300 nm and 1700 nm. This work compares results and best practice approaches during the recent years of intercomparison. Capability of precision improvements in measurement as well as deviation in measurement approaches, instruments and institutes are highlighted. The analysis aims to conclude on effects of harmonization efforts, spreading of best-practice measurement routines and discussions on certain aspects such as temperature control or traceability of calibration.

2. Purpose of the work and approach

The ISRC provides a platform for harmonization of broad band radiometers, solar reference cells and spectroradiometers since its foundation in 2011. With varying participation over the past years the overall number of participants is still increasing. 9 scientific institutions and 5 commercial partners of 8 countries participated at the most recent intercomparison ISRC2017. Among them 10 partners measured with 17 spectrometers of different type and precision. To achieve stable light conditions all partners where measuring in synchronized time (UTC) at Enel GP'site in Catania, Italy from 12th to 16th of June 2017.

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By this wide cross-section of instruments and operating principle, the intercomparison allows to evaluate and compare the entire traceability chain and measurement procedures for each participant. Further the results can be proven against one reference measurement or against the medium value of all instruments. This allows assessing the level of equivalence among laboratories in measuring solar spectral irradiance in a unique way, which would be very difficult, if not impossible, by other round-robin set-ups. Finally, the intercomparison helps to raise the awareness for "good laboratory practices" on solar broadband and spectral measurements.
Although steps forward in the harmonization of good laboratory practices, calibration routines, and results equivalence and reliability have been done [2-4], more efforts are still needed e.g. in instrument characterization like temperature dependence and internal stray light.
In this work we want to analyze the trends of measurements equivalence considering some significant intercomparison editions. An increased measurement accuracy and equivalence has a positive effect not only in primary/secondary PV device calibration but also in energy yield prediction for the qualification of PV plants using different technologies

3. Preliminary results and conclusions

For 2017, the measurement was performed in a range of spectral irradiance wavelength between 300 nm and 1700 nm for nine of the 17 instruments, three had an extended wavelength range of up to 2400 nm and three a reduced one of up to 1100 nm, see table 1. Systems with the full range up to 1700 were composed of two detector types with overlapping spectral ranges from 350 to 400 nm and from 800nm to 1100 nm. From all spectra acquired in each year, spectra measured under weather and irradiance conditions to be reasonable comparable and within a given common time window were analyzed (2017: approximately 170 spectra). This condition was fulfilled when global normal irradiance (GNI) and/or direct normal irradiance (DNI) spectra acquisition were performed at irradiance values stable to +/- 1 % during the measurement cycle. As an example, the comparison of data from different spectrometers is shown in Figure 1 where the mean deviation of the measurements from the reference device is also given.

Figure 2 analyzes the deviation in measurement in the last 3 years of ISRC. The plot shows the average daily differences to the reference instrument (calculated wavelength-by-wavelength) of all participating spectrometers per day. Each boxplot represents the averaged deviation of instruments within one day in the corresponding year. The overall improvement of deviation towards smaller values, accompanies the development of harmonization. In 2015 all instruments deviated systematically to higher values. Whereas in 2016 the over-all deviation band width increased, with mean values closer to the reference instrument. Finally, for 2017 the over-all deviations were smaller than in the two previous years before and the mean values were closer to the reference instrument. This held for all days under investigation, while slight deviations were seen for the days of each year. It has to be noted, that the results could also be an effect of a trend towards instruments with higher accuracies or the use of a main instrument type for the majority of institutes.

Keywords: spectroradiometers, intercomparison, photovoltaics, solar resource assessment, measurements and monitoring

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Supplementary Material

Partner / Instrument group	Spectroradiometers	Measuring Wavelength range nm	DNI/GNI measurement capability	Detector(s) type
#01	3 EKOs	300-1700	Both	Si, Si, InGaAs
#02	2 EKOs	300-1700	Both	Si, InGaAs
#03	2 EKOs	300-1700	GNI	Si, InGaAs
#04	SolarSIM-D2	300-2400	DNI	6 Si filter radiometers plus modelling algoritm
#05	2 EKOs	360-1700	GNI	Si, InGaAs
#06	StellarNet	280-1100	GNI	Si
#07	2 Ocean Optics	280-1700	GNI	Si, InGaAs
#08	Ocean Optics	280-1100	GNI	Si
#09	EKO	300-1100	GNI	Si
#10	2 x SolarSim-D2 SolarSim-G	280-2400	Both (three independent instruments)	6 Si filter radiometers plus modelling algoritm

Table 1: Involved instruments in the ISRC2017.

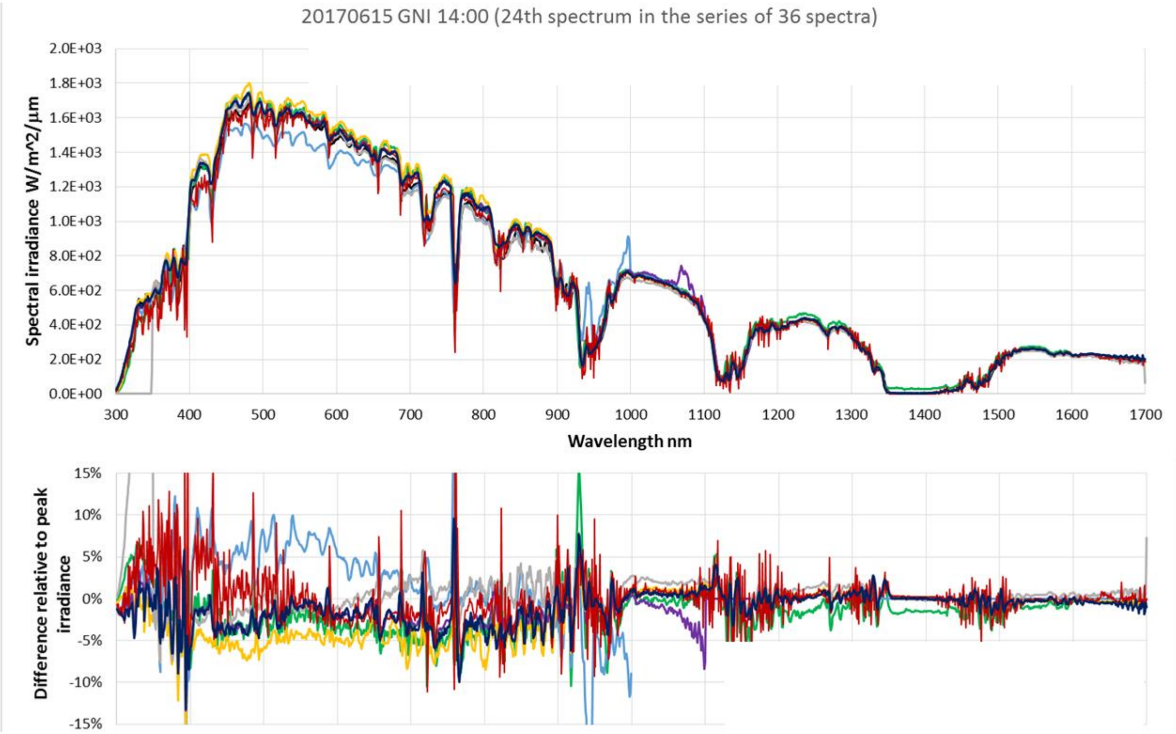

Figure 1: Typical GNI acquisition (upper graph) and wave-by-wave (DNI) 43-spectrum average difference (lower graph) for 8 spectroradiometers at 15th June 2017, respectively.

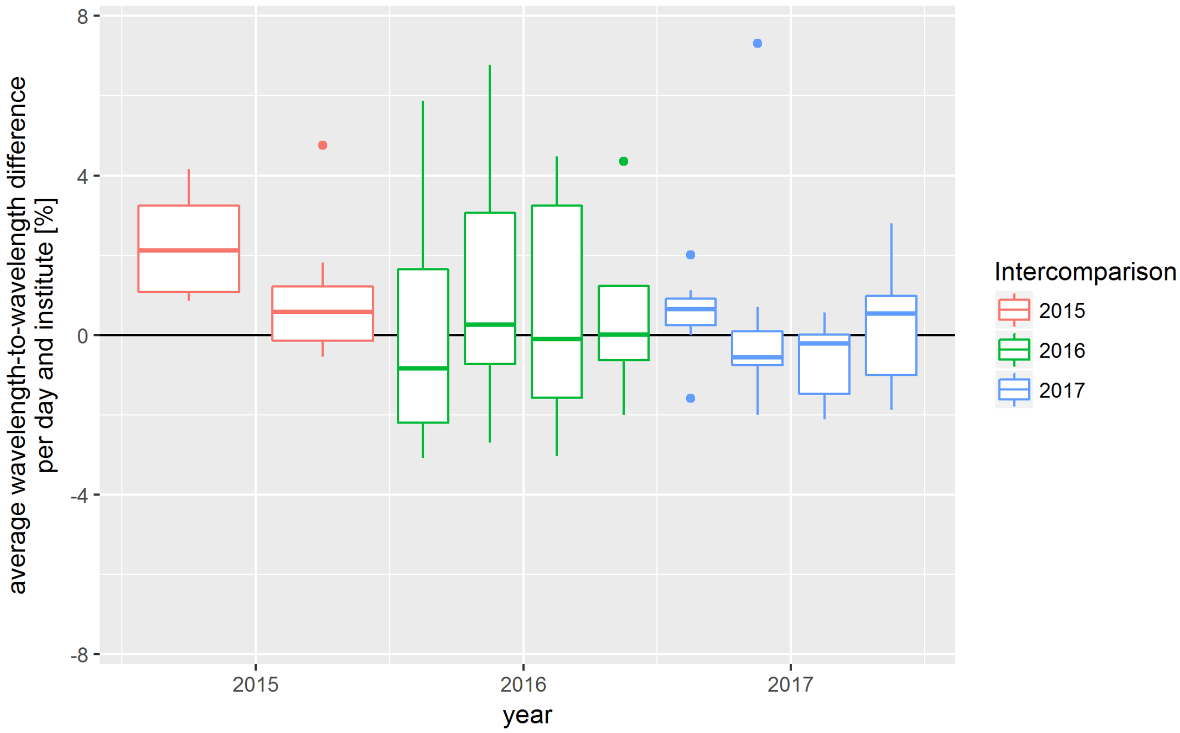

Figure 2: Boxplot of the time evolution of average daily difference to the reference instrument (calculated wavelength-by-wavelength) of all participating spectrometers per day. Each boxplot represents one day in the corresponding year.