International Pyranometer and Pyrheliometer comparison Santiago, Chile. 3 Sep. – 7 Sep.

Training Activity: "Strengthening the capabilities for the calibration of Pyranometers and Pyrheliometers for use in Solar Radiation Measurements"

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Summary

This report presents the final results and calibration factors obtained from the intercomparison and training activity “Strengthening the capabilities for the calibration of Pyranometers and Pyrheliometers for use in Solar Radiation Measurements” performed at Santiago, Chile, between September 3 and September 7, 2018, establishing a metrological traceability for solar radiation measurements. The participating instruments were secondary standard pyranometers for broadband Global Horizontal Irradiance (GHI) and pyrheliometers for broadband Direct Normal Irradiance (DNI). Seven Latin-American institutions (from Chile, Argentina, México, Uruguay, Colombia and Brasil) and the World Radiation Center (WRC/PMOD, Switzerland) participated in this activity, being the first of its kind in Chile.

1. Introduction

An intercomparison and training activity under the project "Strengthening the capabilities for the calibration of Pyranometers and Pyrheliometers for use in Solar Radiation Measurements" was performed at "Universidad de Santiago de Chile" (USACH) (-33.44977, -70.68150) between September 3 and September 7, 2018. This activity, sponsored by the Physikalisch-Technische Bundesanstalt (PTB), sought to develop and strengthen the metrological traceability in solar radiation measurements (pyranometers for broadband "Global Hemispherical Irradiance" (GHI) measurements, and pyrheliometers for broadband "Direct Normal Irradiance" (DNI) measurements) in the Latin American Countries (LAC) region. The activity tests the methods used by the participant institutions to implement the relevant ISO standards (ISO 9847:1992[1] for pyranometers comparison and ISO 9059:1990[2] for pyrheliometers comparison).

This report presents the final results and calibration factors obtained for each of the participant pyranometers and pyrheliometers during this intercomparison campaign. Using the same raw data, each laboratory independently produced calibration factors for several of the participating instruments.

The activity included the participation of eight different institutions, represented by 11 participants from 6 different LAC and Dr. Wolfgang Finsterle from the World Radiation Center (WRC/PMOD, Switzerland) (See **Table 1**), guiding the procedure and establishing the traceability to the World Radiation Reference (WRR).

Figure 1. Pyranometers and pyrheliometers deployment at USACH platform. Santiago Chile, September 5, 2018.

For the pyranometer comparison, two secondary standard instruments from PMOD calibrated with traceability to the World Radiometric Reference (WRR) were used as reference pyranometers: the Hukseflux SR25 2517, and the Kipp & Zonen CM22 990010. For the pyrheliometer comparison, the PMO-6 from USACH, calibrated at PMOD with traceability to the WRR, was used as the reference instrument.

In addition to establish new sensitivities for the participating instruments with metrological traceability to the WRR, this intercomparison serves as a validation of the different procedures and uncertainty estimation methods used by the participant laboratories.

Institution	Country	Representatives	Activity	Instrumentation for comparison	Extra Instrumentation
PMOD/WRC (Physikalisch-Meteorologische Observatorium Davos/World Radiation Center)	Switzerland	Dr. Wolfgang Finsterle	Pyranometer comparison	HukeFlux SR25 2517 **(Reference)**	
				Kipp&Zonen CM22 990010 **(Reference)**	
USACH (Universidad de Santiago de Chile)	Chile	- Dr. Raúl Cordero - Edgardo Sepúlveda - José Jorquera	Pyranometer comparison.	Kipp&Zonen SMP22-V 160026	- Laboratory Transportable Antarctic Research Platform 5 (TARP-05). - 2 Kipp&Zonen SOLYS Trackers
				Kipp&Zonen SMP21-V 170007	
			Pyrheliometer comparison.	PMOD-WRC PMO6-cc 1602 **(Reference)**	
				Kipp&Zonen SHP1-V 175112	
LES (Laboratorio de Energía Solar de la Universidad de la República)	Uruguay	- Dr. Gonzalo Abal - Andrés Monetta	Pyranometer comparison.	Kipp&Zonen CMP22 110282	DataLogger Fischer Scientific DataTaker DT85
				Kipp&Zonen CMP22 120420	
			Pyrheliometer comparison.	Kipp&Zonen CHP1 150261	
				Kipp&Zonen CHP1 120994	
INTI (Instituto Nacional de Tecnología Industrial)	Argentina	Valeria Jesiotr	Pyranometer comparison	Kipp&Zonen CMP11 152963	
CENAM (Centro Nacional de Metrología)	México	Héctor Castillo	Pyranometer comparison	Kipp&Zonen CMP21 140336	
USP (Universidad de Sao Paulo)	Brasil	Gilberto Figueiredo	Pyranometer comparison	EKO Instruments MS80 16002013	DataLogger Agilent 34972A
UNAL (Universidad Nacional de Colombia)	Colombia	- Rafael Ávila - Carlos Perilla	Pyranometer comparison	EKO Instruments MS80 18003080	
				Kipp&Zonen CMP10 141141	
DMC (Dirección Meteorológica de Chile)	Chile	Mauricio Norambuena	Pyranometer comparison	Kipp&Zonen CMP3 164509	DataLogger Campbell Scientific CR6
PTB (Physikalisch-Technische Bundesanstalt)	Germany	María Imilce Zuta Chong	Coordination		

Table 1. Participants institutions

2. Pyranometers comparison

2.1 Procedure

The standard comparison procedure was the Type IA calibration described in the ISO 9847:1992 standard "Calibration of field pyranometers by comparison to a reference pyranometer"[1]. It is based on clear-sky outdoor measurements of solar radiation (using the unobstructed Sun as the radiation source) with the instruments at zero tilt angle. These measurements correspond to Global Horizontal Irradiance (GHI) [W/m^2].

Measurements were taken between September 3 and September 7, 2018 at Santiago, Chile. The instruments were deployed during the morning of September 3 around 10:00 local time (UTC-3). The cleaning of the instrument's domes was the first activity every morning (between 9:00 to 10:00 local time) and the horizontal level alignment of the instruments was checked once per day between September 3 and September 4, and twice per day since September 5 until September 7.

Figure 2. Pyranometers deployment at USACH platform. Santiago Chile, September 5, 2018.

The participant instruments and their respective previous sensitivities are shown at **Table 2**. The pyranometers were distributed in two Data Acquisition Systems (DAQ) (see Table 2), the LXI Data Acquisition 34972A from Agilent Technologies, facilitated by the University of Sao Paulo (USP), and the Fisher Scientific DataTaker DT85, facilitated by the Laboratorio de Energía Solar (LES). The DMC pyranometer was independently connected to a Campbell Scientific CR6 DAQ system from DMC. The USACH pyranometer had its own connection (via RS485 ModBus protocole) to the Kipp & Zonen Smart Explorer Software.

The pyranometers connected to the Agilent DAQ system, the DMC and the USACH's pyranometers were compared against the HukeFlux SR25 reference. The instruments connected to the DT85 DAQ system were compared against the Kipp & Zonen CM22 reference instrument. Both PMOD/WRC reference instruments were recently calibrated (August 28, 2018), at PMOD with traceability to the WRR. In the case of the Kipp & Zonen CM22 reference, only measured values between September 5 and September 7 were used for the final calibration factors.

Every DAQ System recorded simultaneous voltage measurements every 30 seconds, except for the pyranometers's smart sensors from USACH, that recorded irradiance values in the same frequency.

Further details can be found in each of the participating laboratories reports, which complement this document.

Participant Institution	Instrument Manufacturer	Instrument Model	Instrument Serial number	Data Acquisition System	Previous Sensitivity $[\mu V/Wm^{-2}]$	Previous Uncertainty (k=2)
PMOD	HukeFlux	SR25	2517	Agilent	10.93	0.15
PMOD	Kipp&Zonen	CM22	990010	DT85	11.41	0.057
USACH	Kipp&Zonen	SMP22-V	160026	Instrument Smart Sensor	9.91	0.08
USACH	Kipp&Zonen	SMP21-V	170007	Instrument Smart Sensor	10.26	0.14
LES	Kipp&Zonen	CMP22	110282	DT85	8.94	0.06
LES	Kipp&Zonen	CMP22	120420	DT85	8.97	0.19
INTI	Kipp&Zonen	CMP11	152963	DT85	8.45	0.11
CENAM	Kipp&Zonen	CMP21	140336	Agilent	9.22	0.19
USP	EKO Instruments	MS80	16002013	Agilent	11.5	0.078
UNAL	EKO Instruments	MS80	18003080	Agilent	9.7	0.063
UNAL	Kipp&Zonen	CMP10	141141	Agilent	8.81	0.12
DMC	Kipp&Zonen	CMP3	164509	Campbell Scientific	11.79	0.15

Table 2. Participants Institutions and their respective instruments for pyranometers intercomparison activity.

2.2 Results

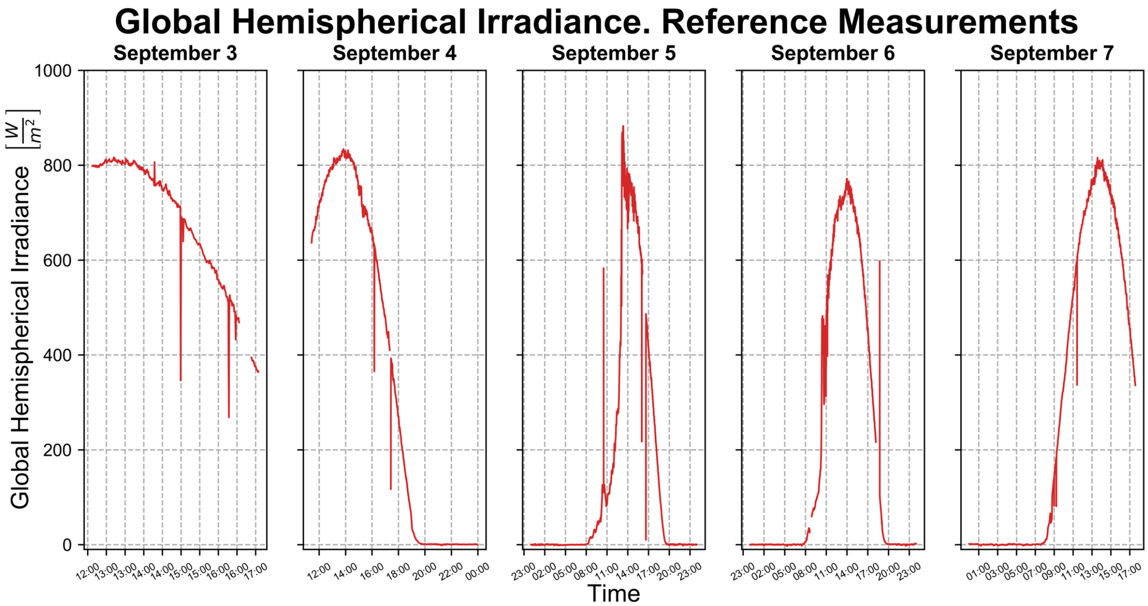

Figure 3. GHI measurements from the HukeFluxe SR25 reference, obtained between September 3 and September 7 at Santiago, Chile.

The GHI measurements acquired during the activity were in the range of 0-883 [W/m^2]. **Figure 3** shows the GHI measured by the HukeFlux SR25 PMOD/WRC reference.

The new sensitivity factors, and their respective combined, expanded uncertainties to 95% confidence level obtained by each participant laboratory, are listed at **Table 3**, expressed according to the GUM guidelines[3]. Every row corresponds to the different pyranometers of the activity, each one with the results from the different institutions (listed at the columns). The difference between the results take into account the different computed methods (e.g. filtering criteria). The results from LES and INTI for their instruments are obtained comparing against the Kipp&Zonen CM22 reference (PMOD/WRC), and the rest, against the HukeFlux SR25 reference (PMOD/WRC). LES presents two results, in this case, for two different methods for obtained the calibration factor. The standard method (referencing the filtering procedure from the ISO9847:1992[1]) is presented here and the second method, based on robust regression techniques is presented in LES Technical Full Report. CENAM presented two calibration factors, both from its measured technique; one factor for irradiance measurements between 500 and 1000 [W/m^2], and a second one, for the range between 150 and 500 [W/m^2]. The first CENAM factor is presented at **Table 3.**

Figure 4 summarized the percentage deviation of the pyranometers comparing its previous sensitivities (old calibration factors) against the new results. For this chart, the PMOD/WRC results were used as reference.

As we can see from the **Figure 4**, INTI and DMC pyranometer presented the highest deviation. INTI's pyranometer was stored previous this activity, and CM3 from DMC is a Second Class instrument (ISO 9060:2018[4]), then the variation is to be expected.

Each deviation will be considered by the participants, to apply for its reference instruments or for measurement purpose, by its own criteria.

Figure 5 shows the comparison between the results obtained by each participant for its instruments, and the deviation against the results obtained by PMOD/WRC. INTI and LES presents results against CM22 reference. In this comparison, the deviations can show difference in the filtering data selection criteria used by each participant against criteria used by the PMOD/WRC.

	USACH	**LES**	**INTI**	**UNAL**	**USP**	**CENAM**	**PMOD**
USACH SMP22-V 160026	9.93±0.14	--	--	--	9.99±0.12	--	9.923±0.169
USACH SMP21-V 170007	10.27±0.15	--	--	--	10.31±0.12	--	10.261±0.161
LES CMP22 110282	8.96±0.14	8.93±0.05	8.93±0.08	8.93±0.22	8.909±0.105	8.926±0.125	8.913±0.121
LES CMP22 120420	8.96±0.14	8.97±0.05	8.98±0.07	8.97±0.22	8.978±0.105	8.984±0.126	8.960±0.116
INTI CMP11 152963	8.27±0.14	8.28±0.05	8.29±0.15	8.28±0.20	8.294±0.098	8.279±0.126	8.259±0.124
USP MS80 16002013	11.54±0.18	11.53±0.16	--	11.52±0.24	11.509±0.181	11.518±0.161	11.549±0.154
CENAM CMP21 140336	9.27±0.15	9.27±0.13	--	9.26±0.20	9.245±0.148	9.250±0.130	9.270±0.099
UNAL CMP10 141141	8.76±0.14	8.73±0.12	--	8.75±0.19	8.754±0.145	8.742±0.122	8.778±0.097
UNAL MS80 18003080	9.78±0.15	9.76±0.14	--	9.77±0.19	9.783±0.152	9.785±0.137	9.784 ±0.121
DMC CMP3 164509	11.62±0.19	--	--	--	--	--	11.569±0.172

Table 3. Pyranometer comparison results. The participant pyranometers are listed in the rows, with the results from the different institutions in every column. Each Sensitivity value in $[\mu V/Wm^{-2}]$.

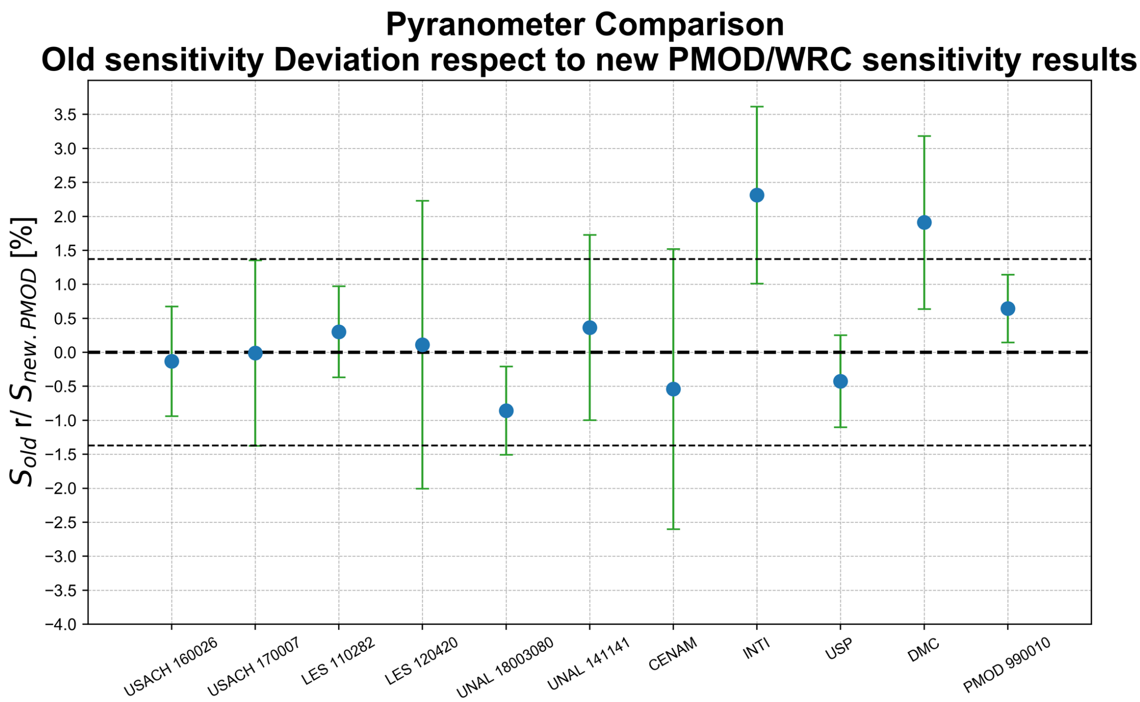

Figure 4. Percentage deviation ((1-S_{old}/S_{new})*100, where S_{new} is the sensitivity result from PMOD-WRC) for each pyranometer respect to PMOD HukeFlux SR25 Reference. Green error bars correspond to the old P95 combined expanded uncertainties of each participants instruments, as is showed at **Table 2.**

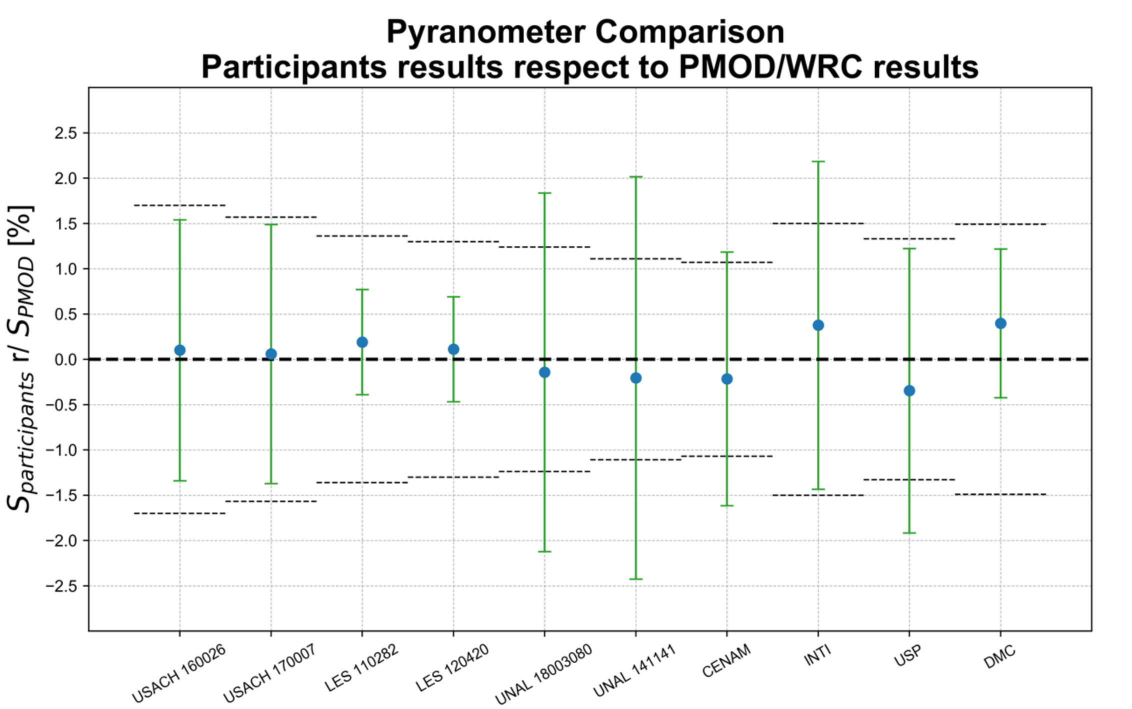

Figure 5. Results comparison from each participant against PMOD-WRC results. The green error bars correspond to the P95 combined expanded relative uncertainties in the new sensitivity from each laboratory. The thin black dashed lines correspond to the P95 combined expanded relative uncertainties computed by PMOD/WRC.

3. Pyrheliometer comparison

3.1 Procedure

The comparison procedure corresponds to the method mentioned at the ISO9059:1992 standard "Calibration of field pyrheliometers by comparison to a reference pyrheliometer"[2], consisting of an outdoor measurement of solar radiation (sun as the radiation source), specifically, Direct Normal Irradiance (DNI) [W/m2] measurements.

The procedure was developed between September 3 and September 7, 2018, and it includes the deployment of the instruments during the morning of September 3 (around 10:00 local time (UTC-3, summer time at Chile)), the cleaning of the instrument's windows as first activity every morning (around 10:00 local time) and the alignment of the pyrheliometers and the sun trackers at the beginning of the activity (September 3) and during the fourth date (September 6).

Figure 6. LES Pyrheliometers deployment at USACH platform. Santiago Chile, September 5, 2018.

The participants institutions for this comparison and their respective previous instrument's sensitivities are shown at **Table 4**. LES's pyrheliometers output voltage signals were acquired by the Fisher Scientific DataTaker DT85. USACH's SHP1-V used its own smart sensor DAQ system. The three pyrheliometers were compared against the USACH's PMO6-cc absolute cavity pyrheliometer as reference (calibrated by the WRC in August 2017, with direct traceability to the WRR).

Figure 7. USACH's PMO6-cc absolute cavity pyrheliometer deployment at USACH platform. Santiago Chile, September 5, 2018.

The PMO6-cc recorded and instant irradiance measurement each three minute (with 90 seconds time lapse for the open phase (shutter open) and 90 seconds time lapse for the close phase (shutter close)). This sampling frequency was then used by the DT85 DAQ system and the USACH's smart sensor (rs485 ModBus protocole connection to Kipp&Zonen Smart Explorer Explorer Software).

Participant Institution	Instrument Manufacturer	Instrument Model	Instrument Serial number	Data Acquisition System	Participant Sensitivity $[\mu V/Wm^{-2}]$	Participant Uncertainty (k=2) $[\mu V/Wm^{-2}]$
USACH	PMOD-WRC	PMO6-cc	1602	PMO6-cc Control Unit	51139.6 m^{-2}	31.5 m^{-2}
USACH	Kipp&Zonen	SHP1-V	175112	Instrument Smart Sensor	8.58	0.09
LES	Kipp&Zonen	CHP1	150261	DT85	8.30	0.12
LES	Kipp&Zonen	CHP1	120994	DT85	7.24	0.08

Table 4. Participants Institutions and their respective instruments for pyrheliometers intercomparison activity.

3.2 Results

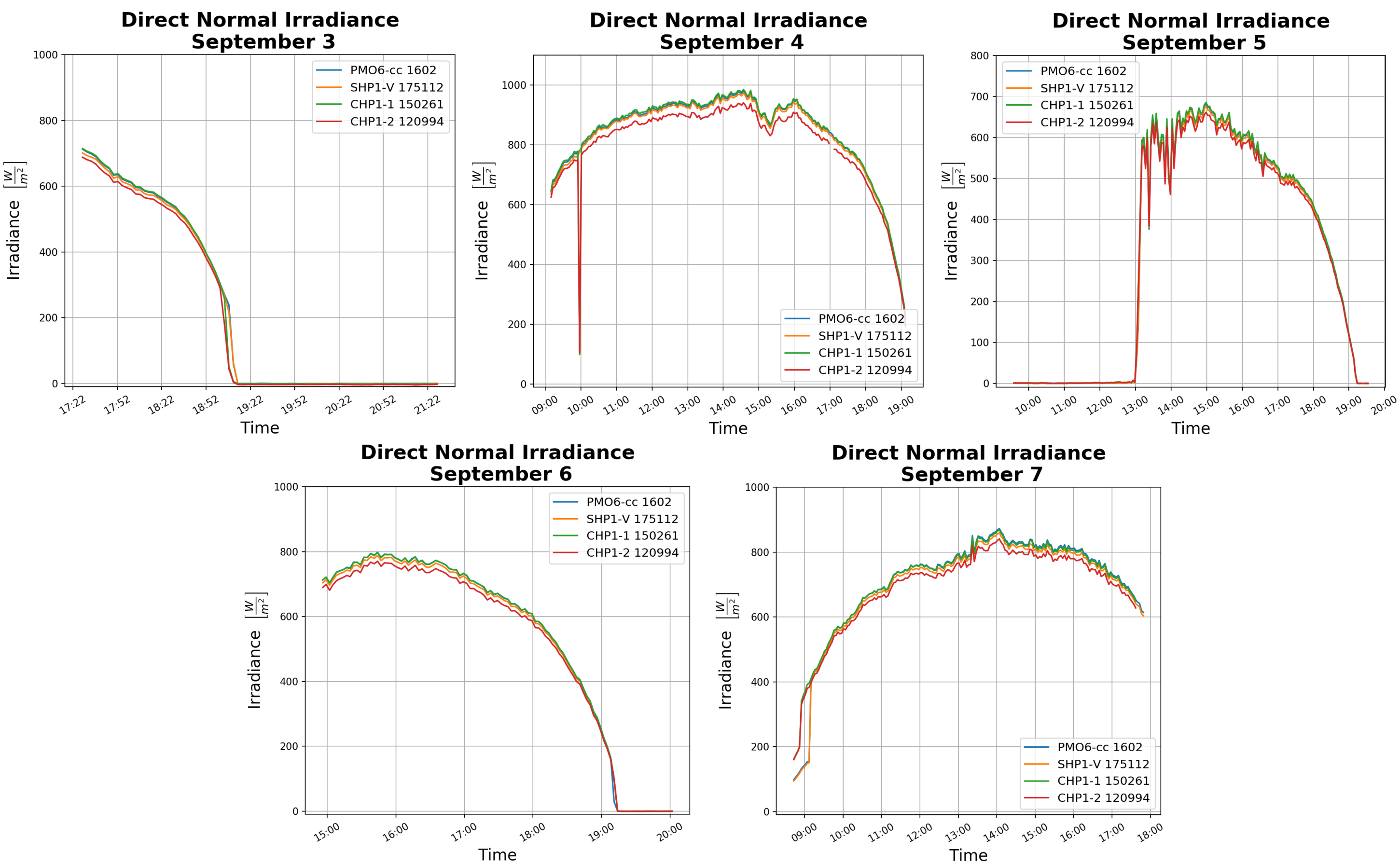

Figure 8. DNI measurements from the participants pyrheliometers, obtained between September 3 and September 7 at Santiago, Chile.

The DNI measurements acquired during the activity were in the range of 0-980 [W/m^2]. **Figure 8** shows the DNI measured by each participant pyrheliometer including the PMO6-CC reference.

The new sensitivities factors $[\mu V/Wm^{-2}]$, that establish the conversion between the output voltage signal from a pyrheliometer to an irradiance measurement, and the respective combined, expanded (k=2) uncertainties obtained from every participant during the comparison are listed at **Table 5.**

	USACH	LES
USACH SHP1-V 175112	8.51±0.09	8.48 ± 0.06
LES CHP1 150261	8.34±0.08	8.29 ± 0.07
LES CHP1 120994	6.98±0.07	6.97 ± 0.06

Table 5. Pyrheliometer comparison results. The participants pyrheliometers are listed in the rows, with the results from USACH and LES in every column. Each Sensitivity value in $[\mu V/W m^{-2}]$.

Uncertainties are expressed following GUM recommendations[3]. Like was presented in **Table 3**, every row corresponds to the different pyrheliometers of the activity, each one with the results from USACH and LES (listed at the columns). The difference between the results take into account the different computed methods (e.g. filtering criteria). USACH used the standard series procedure from the ISO9059:1992, and LES presents their results based on ISO9059:1992 filters criteria and regression techniques, as detailed in LES's technical full report.

Figure 9 summarized the percentage deviation of the pyrheliometers under tests comparing its previous sensitivities (old calibration factors) against the new results, and with PMO6-cc as reference. Comparing both institutions results together works as a comparison from the standard method and the robust regression technique applied for DNI measurements. In this case with 0.4% mean difference between both results.

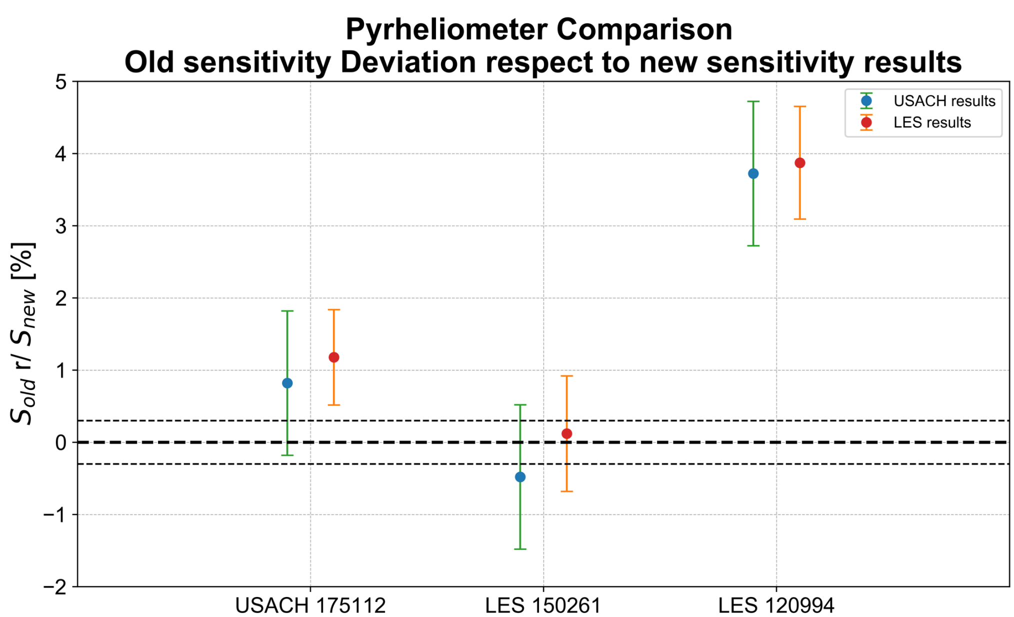

Figure 9. Percentage deviation ($(1-S_{old}/S_{new})*100$, where S_{new} is the sensitivity result from USACH (blue-green) and LES (red-orange)) for each pyrheliometer respect to USACH's PMO6-cc. The error bars correspond to the old P95 combined expanded uncertainties of each participants instruments, as is showed at **Table 4.**

4. Conclusions and Suggestions

Establishing consistent trazable calibration factors for solar resource measurements in LAC is important for applications such as PV or CSP generation plants as well as for assessment of the performance of solar water heating systems. This comparison represented a valuable opportunity for the dissemination and improvement of the quality infrastructure for radiometric measurements in LAC. Furthermore, it gives an opportunity for each laboratory to compare and validate its calibration methods, based on the current international standards. The new calibration factors assigned to the participant instruments by the different laboratories are consistent within the stated uncertainties, with differences of less than 0.5%. Thus, each laboratory can choose its implementation method, taking account the data processing complexity or other factors.

This activity is the first one of this kind in the region and it has established sound foundations for future collaborations between the participating institutions. It is desirable to repeat the intercomparison activities periodically in order to strengthen these links.

Furthermore, several participating laboratories are providing (or are planning to provide) pyranometer calibration services at the national level. For formally trazable calibrations, accreditation under ISO/IEC 17025:2017 standard ("General requirements for the competence of testing and calibration laboratories"[5]) is required. Technical assessment by quality experts to help the participating laboratories to transit the path towards this accreditation could be a natural continuation of this project.

References

[1]Standard ISO 9847:1992(E), Calibration of field pyranometers by comparison to a reference pyranometer. Available at http://www.iso.org/iso.

[2]Standard ISO 9059:1991(en), Calibration of field pyrheliometers by comparison to a reference pyrheliometer. Available at http://www.iso.org/iso.

[3]Joint Committee for Guides in Metrology. JCGM 100: Evaluation of Measurement Data - Guide to the Expression of Uncertainty in Measurement. Technical report, JCGM, 2008.

[4]Standard ISO 9060:2018(en) Solar energy — Specification and classification of instruments for measuring hemispherical solar and direct solar radiation. Available at http://www.iso.org/iso.

[5]Standard ISO/IEC 17025:2017, General requirements for the competence of testing and calibration laboratories. Available at http://www.iso.org/iso.