

Evaluating the World Infrared Standard Group Field Campaign Report

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Evaluating the World Infrared Standard Group Field Campaign Report

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Acronyms and Abbreviations

ACP	absolute cavity pyrgeometer
AERI	atmospheric emitted radiance interferometer
AERIOe	AERI Optimal Estimation
ARM	Atmospheric Radiation Measurement
ASR	absolute sky-scanning radiometer
BBHRP	Broadband Heating Rate Profile
BSRN	baseline surface radiation network
DISORT	Discrete Ordinates Radiative Transfer
IPgC-II	second International Pyrgeometer Comparison
IRIS	infrared integrating sphere
IRSI	infrared sky imager
IWV	integrated water vapor
LBLDIS	LBLRTM with DISORT
LBLRTM	Line-by-Line Radiative Transfer Model
NOAA	National Oceanic and Atmospheric Administration
PIR	precision infrared radiometer
PMOD	Physikalisch-Meteorologisches Observatorium Davos
SGP	Southern Great Plains
VAP	value-added product
WISG	World Infrared Standard Group
WMO	World Meteorological Organization
WRC	World Radiation Center

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1.0 Summary

The standard to which broadband infrared irradiance radiometers (pyrgeometers) are compared is called the World Infrared Standard Group (WISG), maintained in Davos, Switzerland, at the World Radiation Center. WISG consists of four pyrgeometers that were calibrated using the absolute sky-scanning radiometer (ASR; Philipona 2001). The U.S. Department of Energy (DOE)'s Atmospheric Radiation Measurement (ARM) user facility has recently adopted this as its standard and all Eppley precision infrared radiometer (PIR) pyrgeometers in ARM are currently being calibrated by transfer calibrations from WISG.

Subsequently, the ASR has fallen out of operation, Julian Gröbner (2012) developed the infrared integrating sphere (IRIS) radiometer, and Ibrahim Reda (2012) developed the absolute cavity pyrgeometer (ACP). The IRIS and ACP make absolute measurements of broadband downwelling infrared irradiance using different approaches. These two instruments have been compared to each other and to the WISG (Gröbner et al. 2014). The two newer instruments agreed within about 1 Wm^{-2} with each other, but not with the WISG, which was 2-5 Wm^{-2} lower depending on the column water vapor loading. Consequently, a case for changing the current WISG has been made by Gröbner and Reda, basing their suggestion on a total of nine hours of simultaneous IRIS and ACP comparison data as well as data from 177 clear-sky nights between the IRIS and WISG radiometers from October 2009 to December 2013 (Gröbner et al. 2014). These findings were later confirmed during the second International Pyrgeometer Comparison ([IPgC-II](#)) held in September/October 2015 at Physikalisch-Meteorologisches Observatorium Davos (PMOD)/World Radiation Center (WRC), bringing the total to about 20 hours of simultaneous ACP and IRIS measurements spread across two years and five days, in the mountainous environment of Davos.

For this campaign, the WISG evaluation team deployed several instruments for absolute infrared radiation measurements and pyrgeometers that have been tied to the original standard (ASR) to ARM's Southern Great Plains (SGP) atmospheric observatory in the fall of 2017. The experiment was carried out in two phases in order to increase the probability of collecting measurements at a range of water vapor column values, to which the measurements have shown some dependence. Phase 1 of the deployment ran from October 15 to 28, and Phase 2 ran from November 26 to December 9. Four redundant IRIS and two redundant ACP made coincident measurements during this time (the ASR no longer being available for comparison). The link to the WISG was provided by two pyrgeometers calibrated relative to the WISG prior to the campaign at SGP and also measuring coincidentally with the two absolute radiometers. In addition, three of the original pyrgeometers directly tied to the original ASR were deployed. (See Figure 1 for instrument setup.) The experiment took place in the fall when water vapor columns were expected to range below and above the 1-cm level that is crucial for ferreting out the water vapor dependence of these measurements that has been noted in Gröbner et al. 2014 and other measurements.

An additional source of longwave radiation flux observations was provided by the atmospheric emitted radiance interferometer (AERI). The AERI measures downwelling spectral radiance from 3.3 to 19 μm with a calibration that is better than 1% of the ambient radiance (Knuteson et al. 2004), and so serves as a potential source of evaluation for the WISG. The AERI's field of view is 2 degrees, and is directed towards zenith. Earlier ARM projects led by Tony Clough as part of the Broadband Heating Rate Profile (BBHRP) effort demonstrated how to derive longwave flux from these zenith radiance observations.

There, AERIOe (AERI Optimal Estimation) retrievals (Turner and Löhnert 2014) were first performed to derive temperature and humidity profiles from the AERI-observed radiance data. These thermodynamic profiles were used to drive the Line-by-Line Radiative Transfer Model (LBLRTM; Clough et al. 2005) to compute downwelling radiance from 3.3 to 100 μm in wavelength. In particular, the calculation was used to fill in the far-infrared portion of the spectrum from 19 to 100 μm that the AERI does not observe. Then the LBLRTM gaseous optical depths were input into LBLDIS (Line-by-Line DISORT [Discrete Ordinates Radiative Transfer]; Turner et al. 2003), which is a model that combines the LBLRTM with DISORT. The LBLDIS was used to compute the spectral flux from 3.3 to 100 μm . The ratio of the spectral flux to spectral radiance, which is the anisotropy factor, was used to convert the AERI-observed radiance to flux where the AERI makes valid measurements. The spectral flux was then integrated to provide the downwelling longwave flux. The primary assumption in the method is that the sky conditions are uniform and can be assumed to be plane-parallel, which is usually true for the completely cloud-free scenes that were selected for the analysis from this campaign.



Figure 1. Deployment of infrared standard instruments for intercomparisons at the SGP calibration facility in the fall of 2018. Two ACP can be seen in the foreground at left with four IRIS instruments just behind. At right, the PIRs tied to the WISG from Davos are positioned next to the IRIS followed by the three PIRs held by the National Oceanic and Atmospheric Administration (NOAA) that were also tied to the WISG.

The AERI Optimal Estimation value-added data product (AERIOe VAP) provides uncertainty estimates for the retrieved temperature and humidity profiles. These uncertainties were propagated through the method to provide uncertainty estimates on the AERI-derived fluxes. Ongoing research with the AERI to aid in understanding instrument differences among the infrared standards includes a look at radiometer diagnostics (instrument temperatures) as a function of integrated column water vapor and inversion strength as derived from the AERIOe retrieved profiles.

The overall goal of the WISG evaluation experiment is to determine whether the next improvement in infrared radiometry measurement uncertainty can be made with confidence based on comparisons of these

two independently developed absolute instruments—the ACP and the IRIS—a long-term goal of the baseline surface radiation network (BSRN; Driemel et al. 2018) and ARM. In coordination with this campaign, the principal investigators and the larger infrared radiation community has had ongoing discussion on this topic to use the campaign results to address the issue.

2.0 Results

The infrared sky imager (IRSI) at SGP was used to screen the two phases of the deployment for clear-sky periods when the infrared sky emission would be stable and uniform across the hemispheric sky view. Several hours on 12 separate days met the criteria and have been used to produce the preliminary results (a subset of these times) below.

Figure 2 shows the clear-sky measurements from Phase 1 and Phase 2. One PIR (Eppley precision infrared radiometer) and one CG4 (Kipp & Zonen pyrgeometer) were calibrated prior to the campaign with respect to the WISG at PMOD/WRC and are labelled as WISG in the figure. These measurements are on average systematically lower than the measurements of IRIS, ACP, and AERI by 4 Wm^{-2} , while the measurements of ACP and AERI are on average lower than the ones from IRIS by respectively 1.4 Wm^{-2} and 1.7 Wm^{-2} .

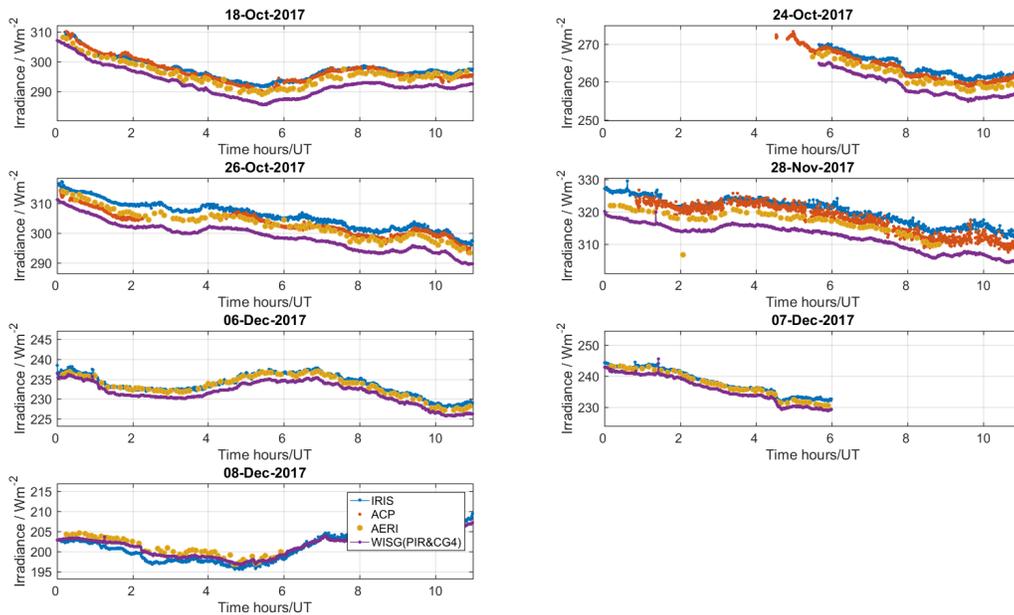


Figure 2. Downwelling longwave irradiance measurements at SGP during clear-sky conditions by IRIS (average of IRIS1, IRIS2, IRIS5), ACP (average of ACP1 and ACP2), AERI, and the average of PIR 30475F3 and CG4 FT005 (calibrated relative to the WISG).

A clear dependence with integrated water vapor (IWV) can be observed in the difference between the longwave measurements of WISG and IRIS, as shown in Figure 3. The largest differences between the WISG and IRIS are seen at IWV around 10 mm, with the WISG traceable pyrgeometers measuring around 6 Wm^{-2} lower irradiances than the IRIS, ACP, and AERI. In contrast, for low IWV content around 2 mm, the WISG measures on average 1 Wm^{-2} higher irradiances than the IRIS and AERI (ACP did not measure during the final days of the Phase 2 campaign).

The group of principal investigators will continue to work with the data and intend to submit a manuscript for peer-reviewed publication in early 2019. Discussions with the larger radiation community will continue as new results come out to determine the preferable path forward for treating the WISG and the implications for reprocessing of infrared radiation data archived using the WISG as a standard from measurements made worldwide.

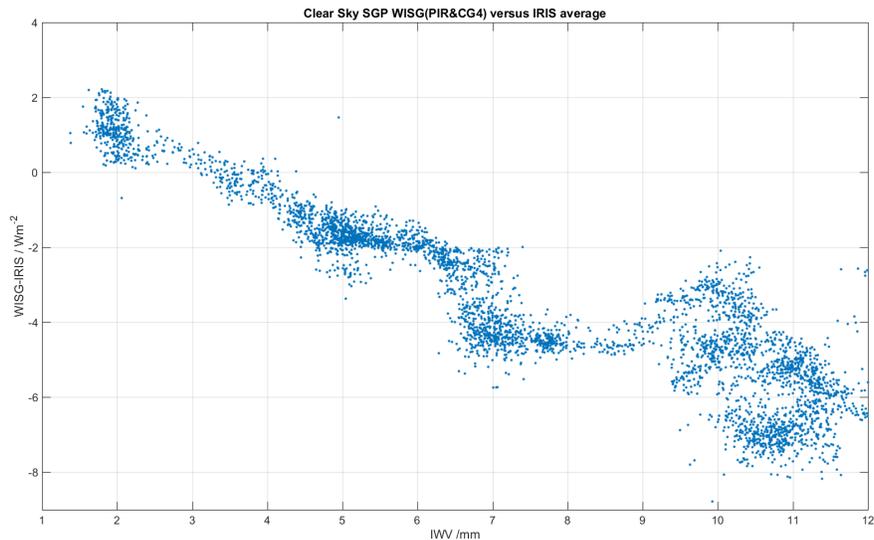


Figure 3. Difference between WISG and IRIS with respect to the integrated water vapor (IWW).

3.0 Conclusion

This issue of standards and calibrations for infrared radiation serving the global radiation measurement community is of importance to the ARM Broadband Radiation Instrument Mentors and Working Group under whose responsibilities and charter fall the calibrations and uncertainties of the ARM broadband measurements. The Working Group has followed the developments with significant interest.

Additionally, a World Meteorological Organization (WMO) Task Team met in the fall of 2017 to assess the status of this topic, the information gained from this field campaign, and path forward for the global community. Several of the principal investigators attended. A discussion was also held at the BSRN Infrared Radiation Working Group Meeting in the summer of 2018 in Boulder, Colorado to determine how results from the above activities can be translated to the larger radiation measurement community. Regular principal investigator team meetings are being held in Boulder and by teleconference.

This campaign was a critical part of an effort to understand IWW dependency of calibrations, understand the offset of the WISG relative to existing/remaining/new longwave radiation standard instruments in a different environment than Davos, and in determining a strategy to recalibrate and reprocess long-term records in light of improved information regarding standards and calibrations. Important preliminary results are that:

- the difference between the irradiance measured by the ACPs, IRISs, and AERI varied from 0.2 W/m² to 2.5 W/m² based on the atmospheric conditions, which is within the stated uncertainties of ± 3 W/m².

- the irradiance measured by the WISG is lower than the average irradiance measured by ACPs and IRISs; the magnitude of the difference varied from +1 W/m² to -7 W/m² depending on the integrated water vapor.

4.0 Publications and References

4.1 Presentation and Discussion of Campaign Results

ASR/ARM PI Meeting, Tysons, Virginia, March 2018.

15th Science and Review Workshop for BSRN, Boulder, Colorado, July, 2018.

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5.0 Lessons Learned

Our experience of running this campaign at SGP with ARM support was excellent. Each stage of the campaign and associated ancillary services and measurements were conducted as expected. Our shipments to the site were made ready when we arrived and onsite assistance in setting up for the campaign made the process progress smoothly and quickly. We appreciate the expertise of the onsite staff and ARM’s willingness to make available the hardware needed, as well as the time of instrument mentors who provided those ancillary data.

There were some serious electromagnetic interferences on the IRIS instruments during certain periods of the Phase 1 and Phase 2 campaign. As illustrated in Figure 4, these interferences occurred periodically and could be reduced by grounding the sensitive equipment.

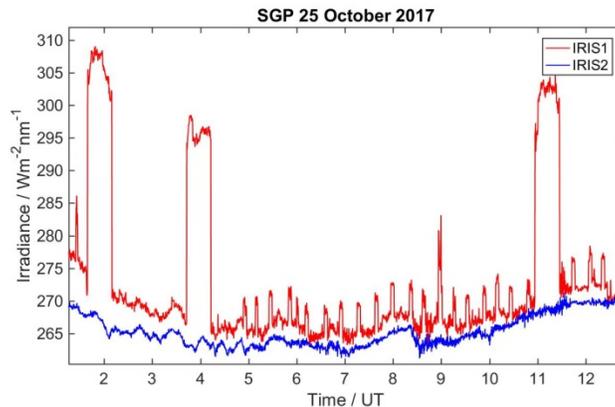


Figure 4. Electromagnetic spikes observed on 25 October on the IRIS1 radiometer (red curve). The spikes could be reduced when the pre-amplifier was grounded.

A lesson learned on our part came out of the fact that we achieved fewer ideal measurement days than desired. While in the planning stages we carefully considered having some ‘dry’ measurement days (< 1 cm), but we actually had fewer moist days (> 1 cm) than hoped for. Planning for a longer measurement period to meet observational criteria and campaign objectives is typically not met with regret.



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