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Efforts to reduce errors in infrared radiation observations at the Earth's surface

Nozomu Ohkawara Meteorological Research Institute (MRI), Japan Meteorological Agency (JMA) Nagamine 1-1, Tsukuba, Ibaraki 305-0052, JAPAN

Background

In the study of the global energy balance, radiation observation in ground-based radiometric networks, such as the Baseline Surface Radiation Network (BSRN), are essential for the estimation of the surface component, and contributing to recent climate research advances such as the estimation of the global energy balance under cloud-free conditions in addition to all-sky conditions (Wild et al., 2019). To contribute further progress in climate research, the World Meteorological Organization (WMO) has established the Expert Team on Radiation Observation Standards (ET-RR) in cooperation with experts in the meteorological and metrological fields to establish new solar and infrared radiation reference scales traceable to SI units to improve the accuracy of surface radiation observations.

In this effort, it is found that the current infrared radiation reference has an offset mainly depending on the amount of integrated water vapor (IWV) to the IRIS (Gröbner, 2012) and ACP (Reda et al., 2012), windowless radiometers expected to be adopted as the standard instruments for the new radiation reference, due to the non-flat spectral characteristics of the outer dome (silicon dome) of the pyrgeometers making up the World Infrared Standard Group (WISG)(Gröbner et al., 2014, Fig.1). The adoption of the new radiation reference would be expected to reduce the offset error by about 3 to 5 Wm-2 under all-sky conditions and clear-sky conditions (Nyeki et al., 2017).

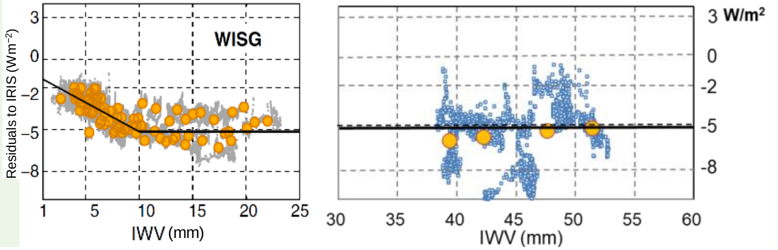

Fig.1 Residuals between the current infrared radiation reference and the windowless radiometer (IRIS) under clear-sky condition in nighttime

The thick black lines are the average offset at IWV larger than 10 mm, and a linear fit between the residuals and IWV below 10 mm.

Left) Intercomparisons at Physikalisch Meteorologisches Observatorium Davos (PMOD), in Davos, Switzerland (Gröbner et al., 2014).

Right) Bureau of Meteorology (BoM) and JMA pyrgeometer intercomparison in Darwin, Australia, 2017.

Possible errors after the radiation reference change

However, since surface infrared irradiance observation are conducted under various weather conditions, the pyrgeometer with silicon dome will continue to be used in surface observation networks after the adoption of the new radiation reference. Before the pyrgeometer is operationally used in the network, it must be calibrated in order to transfer the new radiation reference scale to the pyrgeometer. The infrared irradiance spectrum varies during the calibration period, and that can cause errors due to the non-flat spectral characteristics of the silicon dome. In addition, during operational observations, IWV in the atmosphere as well as the air temperature vary largely depending on the geolocation and the observation time, and the observed infrared irradiance spectrum may differ significantly from that at the time of calibration, which may result in errors in the measured infrared irradiance (Fig. 2).

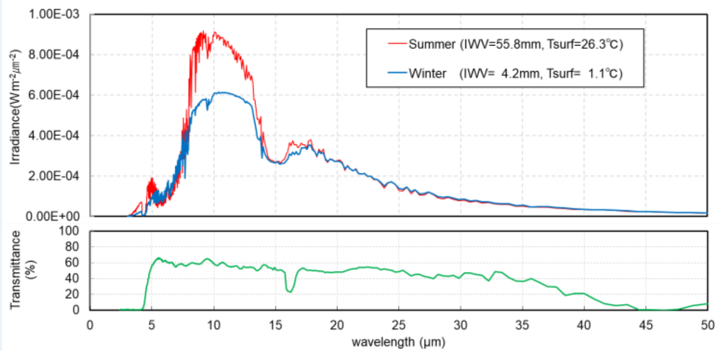

Fig.2 Examples of the measured infrared irradiance spectrum at the surface under clear-sky in nighttime and the pyrgeometer silicon dome spectral transmittance

Top) Infrared irradiance spectrums at BSRN Tateno station calculated by MODTRAN radiative transfer model using aerological data. Red line: summer (2005/8/5 12UTC), Blue line: winter (2005/12/27 12UTC).

Bottom) An example of silicon dome spectral transmittance of Kipp&Zonen CG4 pyrgeometer.

An example of errors in the pyrgeometer calibration

The infrared irradiance measured by the pyrgeometer is calculated by the following radiometric equation (Philipona et al., 1995):

$$E = \frac{U}{C}(1 + k_1\sigma T_B^3) + k_2\sigma T_B^4 - k_3\sigma(T_D^4 - T_B^4)$$

E: the infrared irradiance in Wm^{-2}, C: the pyrgeometer sensitivity in V/Wm^{-2},
U: the output voltage of the pyrgeometer thermopile in volts,
σ: the Stefan-Boltzmann constant (5.6704×10^{-8} $Wm^{-2}K^{-4}$),
k_1, k_2, k_3: the instrument constants,
T_B and T_D: the measured body and dome temperatures of the pyrgeometer in Kelvin.

In the actual pyrgeometer calibration, the sensitivity of the test pyrgeometer is decided by outdoor intercomparisons with the reference radiometer. The table below shows differences in test pyrgeometer sensitivity between winter and summer, and Fig.3 shows infrared irradiance residuals between the test pyrgeometer and the reference radiometer with respect to the reference infrared irradiance in winter and summer. These results imply that the equation does not adequately account for the effects of non-flat spectral characteristics of the silicon dome into the irradiance spectrum incident on the sensing elements of the pyrgeometer under various atmospheric conditions, and that finally leads to errors in the pyrgeometer sensitivity in calibration and measured infrared irradiances.

Table Differences in the test pyrgeometer sensitivity (C) between winter and summer

The nighttime measurement data from December to February are used for winter and those from June to August are used for summer, respectively.

Instrument ID	C for Winter ($\mu V/Wm^{-2}$)	C for Summer ($\mu V/Wm^{-2}$)	Difference (%)
CG4#010567	11.69	11.82	1.1
CG4#050798	11.04	10.92	-1.1
CGR4#120502	11.66	11.39	-2.3
CGR4#180302	13.35	13.10	-1.9
CGR4#190313	12.63	12.39	-1.9

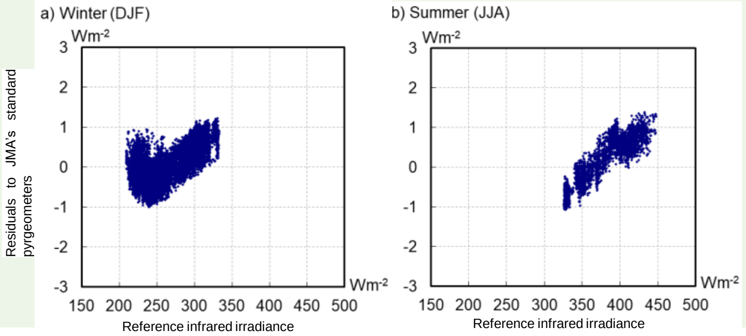

Fig.3 Residuals between the Infrared irradiance by a test pyrgeometer (CGR4#180302) and the reference radiometers (JMA's standard pyrgeometers)

a) winter and b) summer.

How to reduce errors?

The following efforts are considered to be necessary to reduce the errors in infrared irradiance measurements through collaboration of metrology and meteorology communities

1) Improvement of pyrgeometer calculation equation

It is necessary to study a new pyrgeometer calculation equation to reduce the influence of the non-flat spectral characteristics of silicon domes. For this purpose, intercomparisons of pyrgeometers and windowless radiometers should be conducted under various atmospheric conditions to accumulate data such as the reference irradiance by the windowless radiometer, the thermopile output voltage and body/dome temperatures of the pyrgeometer, and related atmospheric data. Spectral characteristics of individual or representative pyrgeometer silicon domes are also helpful to correctly estimate the radiation spectrum incident on the sensing element of the pyrgeometer.

2) Development of new operational pyrgeometers

In the future, it is desirable to develop an pyrgeometer with a window that has flat spectral characteristics in the infrared wavelength region and cuts off incident solar radiation on the sensing element for operational infrared radiation measurements in the surface observation network.

References

Gröbner, J. (2012), A transfer standard radiometer for atmospheric longwave irradiance measurements, Metrologia, 49, S105–S111, doi:10.1088/0026-1394/49/2/S105.

Gröbner, J ., et al.. (2014), A new absolute reference for atmospheric longwave irradiance measurements with traceability to SI units, J. Geophys. Res.-Atmos., 119, https://doi.org/10.1002/2014JD021630.

Nyeki, S., Wacker, S., Gröbner, J., Finsterle, W., and Wild, M. (2017), Revising shortwave and longwave radiation archives in view of possible revisions of the WSG and WISG reference scales: methods and implications, Atmos. Meas. Tech., 10, 3057–3071, https://doi.org/10.5194/amt-10-3057-2017.

Philipona,R ., C. Fröhlich, and C. Betz (1995), Characterization of pyrgeometers and the accuracy of atmospheric long-wave radiation measurements, Appl. Opt., 34(9), 1598-1605

Reda, I., et al. (2012), An absolute cavity pyrgeometer to measure the absolute outdoor longwave irradiance with traceability to International System of Units, SI, J. Atmos. Sol. Terr. Phys., 77, 132–143, doi:10.1016/j.jastp.2011.12.011.

Wild M., et al. (2019), The cloud-free global energy balance and inferred cloud radiative effects: an assessment based on direct observations and climate models. Clim Dyn 52:4787–4812. https ://doi.org/10.1007/s0038 2-018-4413-y.