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Introducing an Absolute Cavity Pyrgeometer (ACP) for Improving the Atmospheric Longwave Irradiance Measurement

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Abstract: **Advancing climate change research requires accurate and traceable measurement of the atmospheric longwave irradiance. Current measurement capabilities are limited to an estimated uncertainty of larger than ± 4 W/m² using the interim World Infrared Standard Group (WISG). WISG is traceable to the Système international d'unités (SI) through blackbody calibrations. An Absolute Cavity Pyrgeometer (ACP) is being developed to measure absolute outdoor longwave irradiance with traceability to SI using the temperature scale (ITS-90) and the sky as the reference source, instead of a blackbody. The ACP was designed by NREL and optically characterized by the National Institute of Standards and Technology (NIST). Under clear-sky and stable conditions, the responsivity of the ACP is determined by lowering the temperature of the cavity and calculating the rate of change of the thermopile output voltage versus the changing net irradiance. The absolute atmospheric longwave irradiance is then calculated with an uncertainty of ±3.96 W/m² with traceability to SI. The measured irradiance by the ACP was compared with the irradiance measured by two pyrgeometers calibrated by the World Radiation Center with traceability to the WISG. A total of 408 readings was collected over three different clear nights. The calculated irradiance measured by the ACP was 1.5 W/m² lower than that measured by the two pyrgeometers that are traceable to WISG. Further development and characterization of the ACP might contribute to the effort of improving the uncertainty and traceability of WISG to SI.**

Fig. 1. ACP outdoor set-up at NREL/SRRL

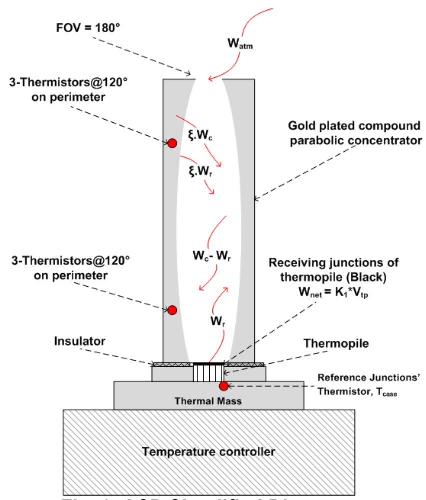

Fig. 2. ACP Simplified Diagram

ACP Measurement Equations

1. ACP Net irradiance (W/m²),

$$K_1 * V_{tp} = \tau * W_{atm} + (1+\varepsilon) * W_c - (2-\varepsilon) * K_2 * W_r$$

where: K_1 = 1/responsivity; V_{tp} = thermopile voltage; τ & ε are ACP throughput and emittance measured at NIST; W_{atm} = atmospheric irradiance; W_c = concentrator irradiance; W_r = receiver irradiance.

2. By cooling the ACP case temperature, with W_{atm} stable (Fig. 3), then K_1 is calculated from the known rate of change of W_c, W_r, and V_{tp} ,

$$K_1 = \frac{(1+\varepsilon) * \Delta W_c - (2-\varepsilon) * K_2 * \Delta W_r}{\Delta V_{tp}}$$

3. Then the atmospheric longwave irradiance is,

$$W_{atm} = \frac{K_1 * V_{tp} + (2-\varepsilon) * K_2 * W_r - (1+\varepsilon) * W_c}{\tau}$$

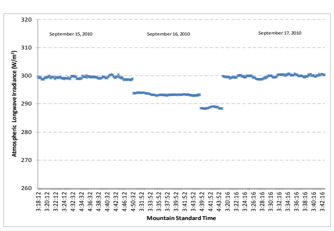

Fig. 3. Atmospheric irradiance during 5 cooling events

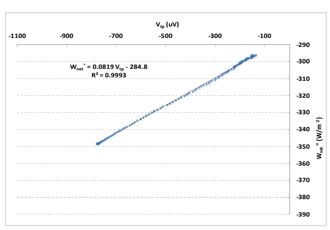

Fig.4. variable irradiance vs thermopile output, 1 of 5 cooling events

Table 1. ACP's Uncertainty

Variable	Value	Standard Uncertainty (u)	Sensitivity Coefficient (c)	c*u	Percentage Contribution
K_1	0.0822	0.00044	-818.24	-0.366	9.4
V_{tp}	-825	-2.38	0.083	-0.198	5.1
ε_g	0.0225	0.00004	-783.23	-0.031	0.8
ε_{cav}	1	.0006	-394.53	-0.228	5.9
W_r	385.5	0.1835	1.994	0.366	9.4
W_c	391.3	0.1061	1.031	0.109	2.8
τ	0.99169	0.00418	-299.32	-1.250	32.2
K_2	1	0.00173	768.65	1.331	34.3
Type-B Combined standard uncertainty = u_B					1.93 ($W.m^{-2}$)
Type-A standard uncertainty from line fit = u_{Af}					0.15 ($W.m^{-2}$)
Type-A standard uncertainty from non-equivalence = u_{Ane}					0.60 ($W.m^{-2}$)
Combined standard uncertainty of W_{atm} = u_{atm}					2.02 ($W.m^{-2}$)
Effective degrees of freedom					290239407
Student's "t" = k					1.96
Expanded Uncertainty = k*u_{atm} = $U_{95, atm}$					3.96 ($W.m^{-2}$)
Percentage Expanded Uncertainty = $U_{95, atm}$					1.3%

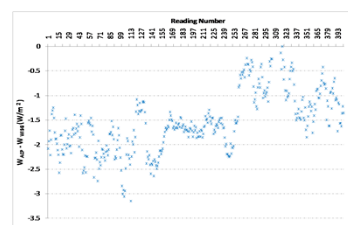

Fig.5. ACP irradiance Minus WISG irradiance for 5 cooling events

Conclusions

- ACP is new, unique, and traceable to SI using the sky as the source rather than a blackbody
- ACP an absolute instrument ; contributes to establishing International reference for measuring the atmospheric longwave irradiance.

Acknowledgements

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Reference: Reda, I.; Zeng, J.; Scheuch, J.; Hanssen, L.; Wilthan, B.; Myers, D.; Stoffel, T. Dec. 2011. "An absolute cavity pyrgeometer to measure the absolute outdoor longwave irradiance with traceability to International System of Units, SI". *Journal of Atmospheric and Solar-Terrestrial Physics.* http://dx.doi.org/10.1016/j.jastp.2011.12.011

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