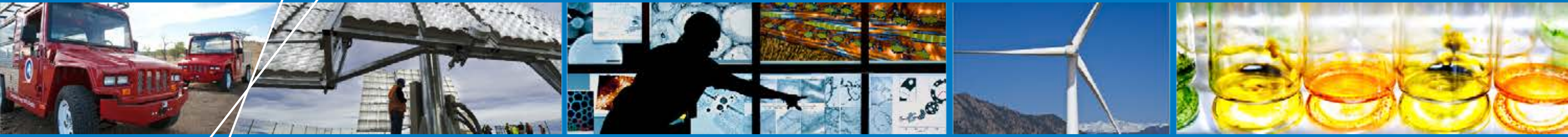
Introducing an Absolute Cavity Pyrgeometer for Improving the Atmospheric Longwave Irradiance Measurement



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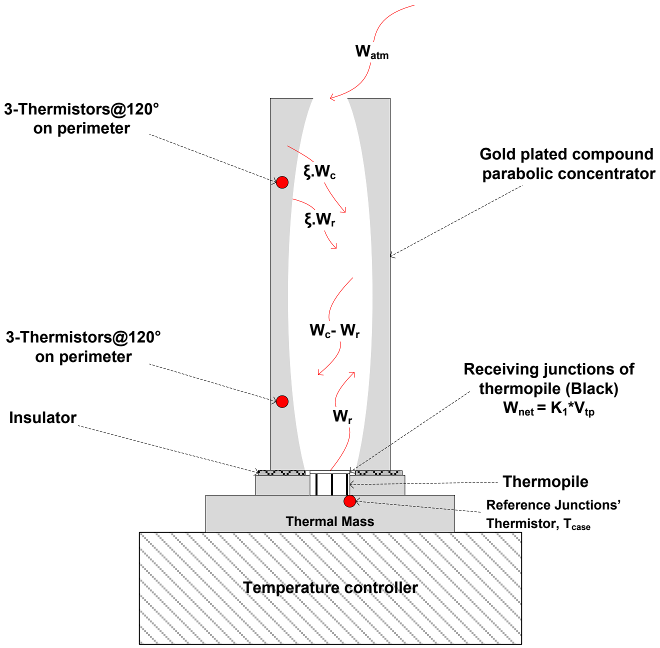
Abstract

The Absolute Cavity Pyrgeometer (ACP), U.S. Patent application No. 13/049,275 is being developed to measure the absolute outdoor longwave irradiance with traceability to the Système international d'unités (SI). ACP consists of domeless thermopile, gold-plated dual compound parabolic concentrator (CPC), temperature controller. The incoming irradiance is reflected from the specular gold surface of the CPC and concentrated on the thermopile’s blackened surface. The CPC’s interior surface design result in an ACP throughput value, characterized by the National Institute of Standards and Technology (NIST). The responsivity of the thermopile is determined by lowering the temperature of reference junctions of the thermopile, then 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/m^2 with traceability to SI. The measured irradiance was compared with the irradiance measured by two pyrgeometers calibrated by the World Radiation Center with traceability to the Interim World Infrared Standard Group, WISG. A total of 408 readings were collected over three different nights. The calculated irradiance measured by the ACP was 1.5 W/m^2 lower than that measured by the two pyrgeometers that are traceable to WISG. The WISG is claimed to be traceable to SI to within ±4 W/m^2. Therefore, further development /characterization of the ACP might contribute to the effort of establishing an improved absolute world reference with traceability to SI.



Reference: Reda, I.; Zeng, J.; Schulch, J.; Hanssen, L.; Wilthen, 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, 77 (2012) 132-143.* http://dx.doi.org/10.1016/j.jastp.2011.12.011

Overview

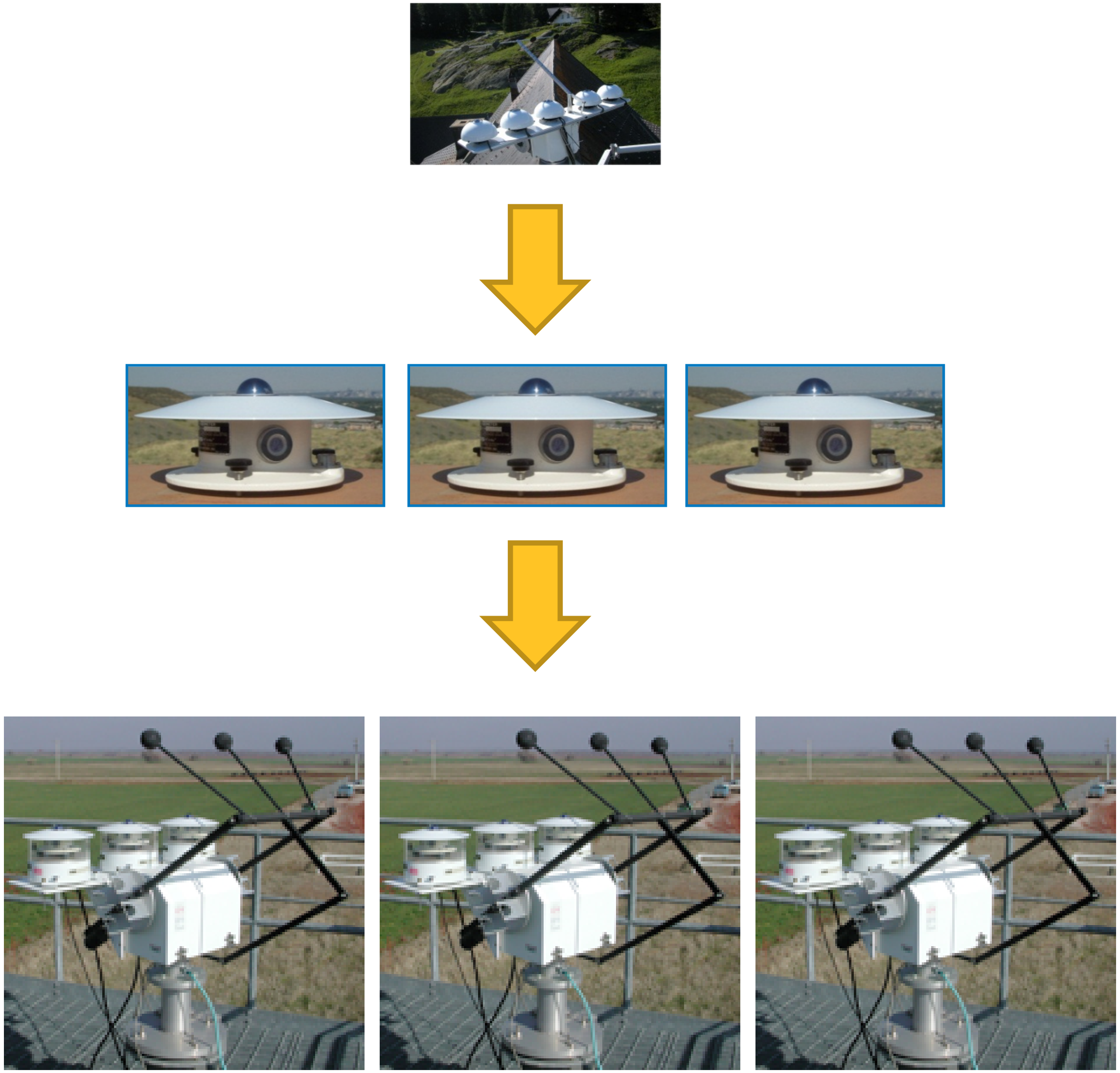
- Purpose
- Interim World Infrared Standard Group (WISG) & calibration traceability
- Measurement Equation
- Outdoor measurement and uncertainty estimate
- Comparison to WISG
- Application and why unique?
- Conclusion and future work.

Purpose

- Measure outdoor absolute longwave irradiance
- Absolute measurement traceable to International System of Units, SI
- To date: Interim world reference traceable to blackbody (not sky/atmosphere) = World Infrared Standard Group, WISG. Traceable to blackbody irradiance, not SI
- ACP is a contribution to develop the world reference with traceability to SI, using the outdoor irradiance as the source, instead of blackbody.

WISG at the Physikalisch-Meteorologisches Observatorium Davos (PMOD)

Traceability of Pyrgeometer Calibration



WISG: Established using an absolute scanner with a blackbody

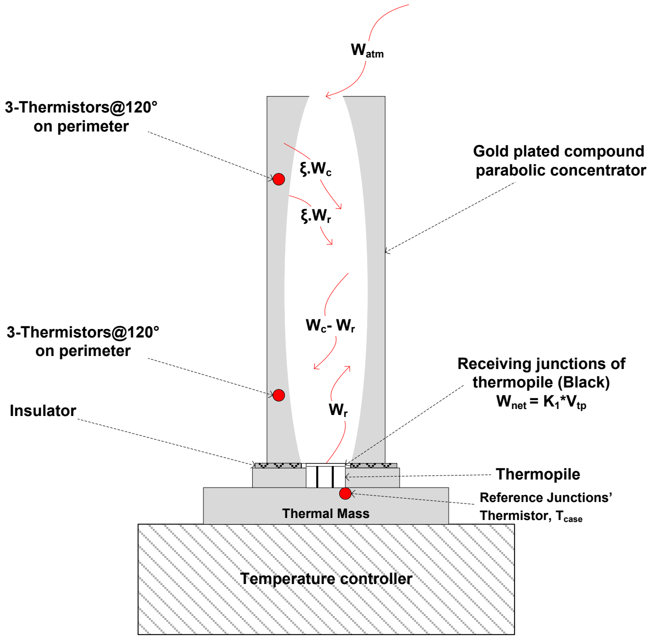
Transfer pyrgeometers

Field pyrgeometers to Measure atmospheric Longwave irradiance

Measurement Equation

- ACP Net irradiance:

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



- By cooling the ACP case temperature, and since W_{atm} is stable, then,

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

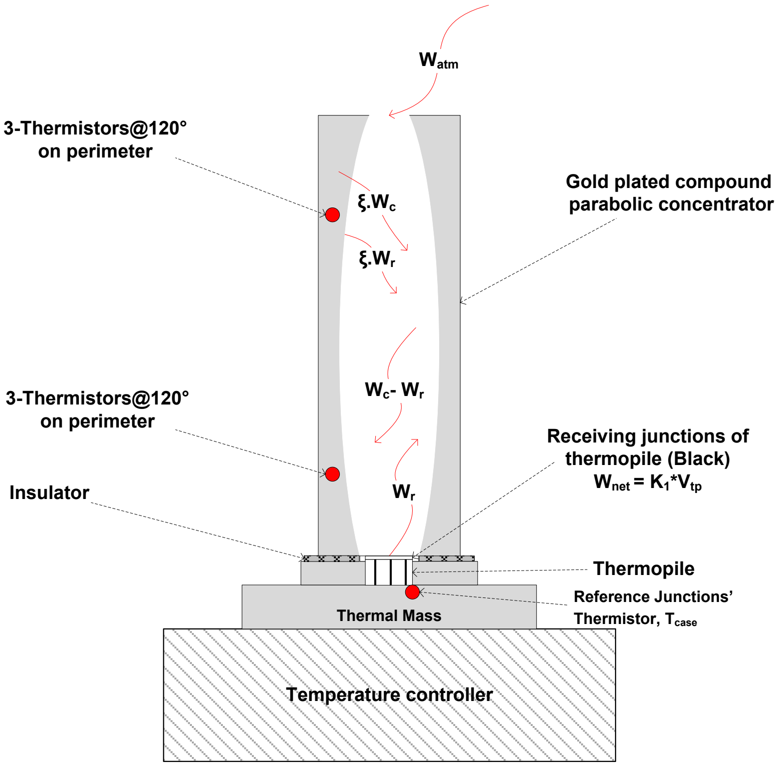
- Then the atmospheric longwave irradiance is,

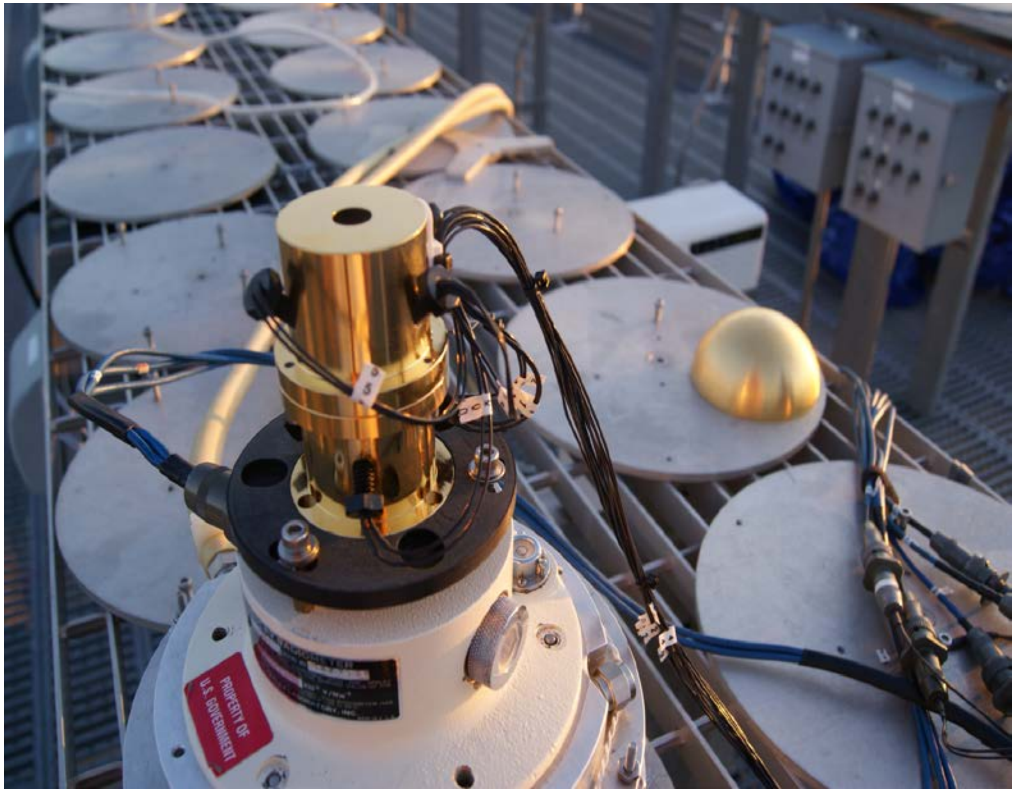
$$W_{atm} = \frac{K_1 * V_{tp} + (2-\varepsilon) * K_2 * W_r - (1+\varepsilon) * W_c}{\tau}$$

Where,

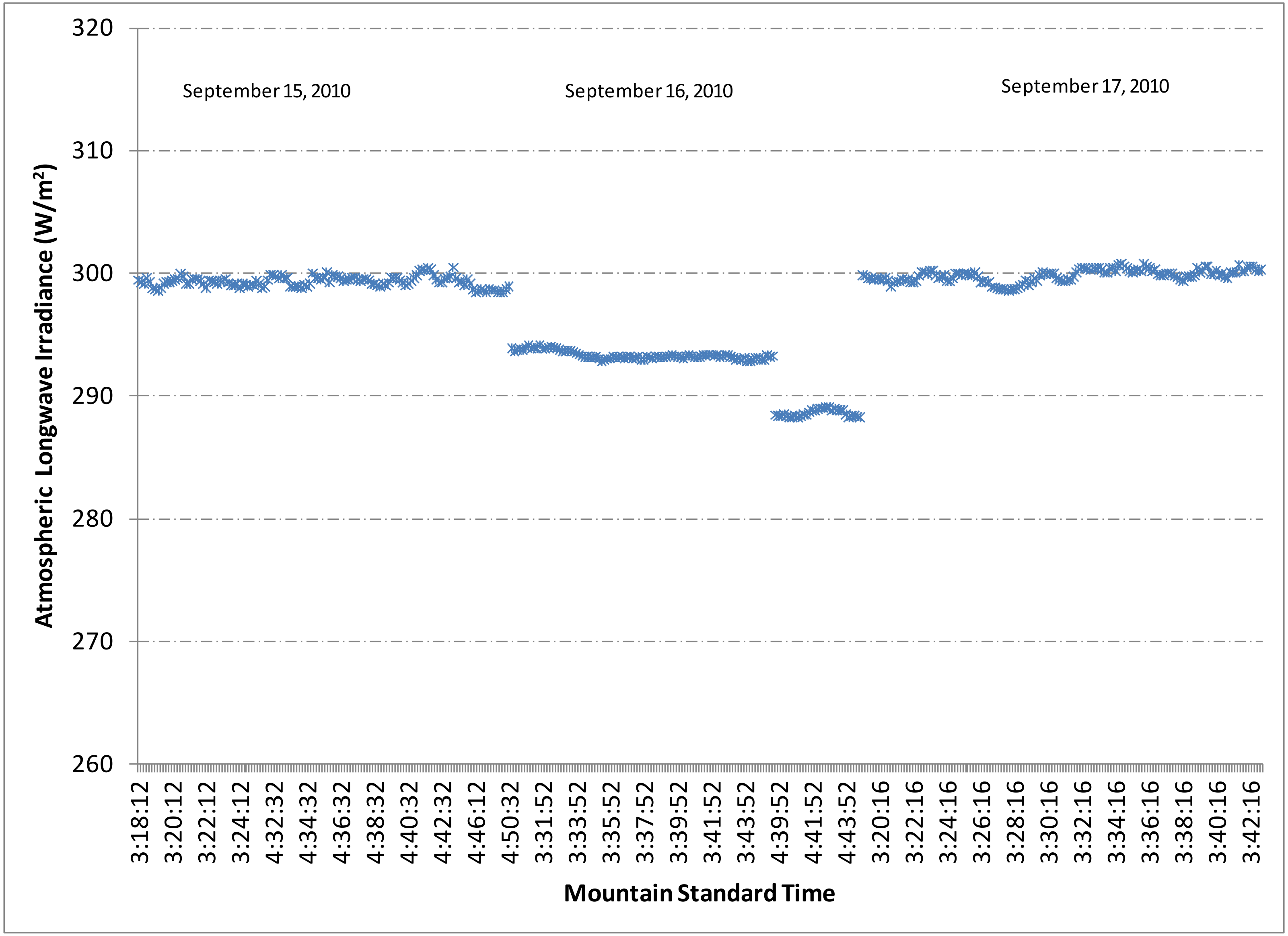
K_1, V_{tp}, ϵ , K_2, W_r , W_c and τ are the reciprocal of ACP's responsivity, thermopile voltage, gold emittance, detector's emittance, receiver irradiance, CPC irradiance, and throughput (NIST characterization), consecutively.

Outdoor Set-Up at NREL-SRRL

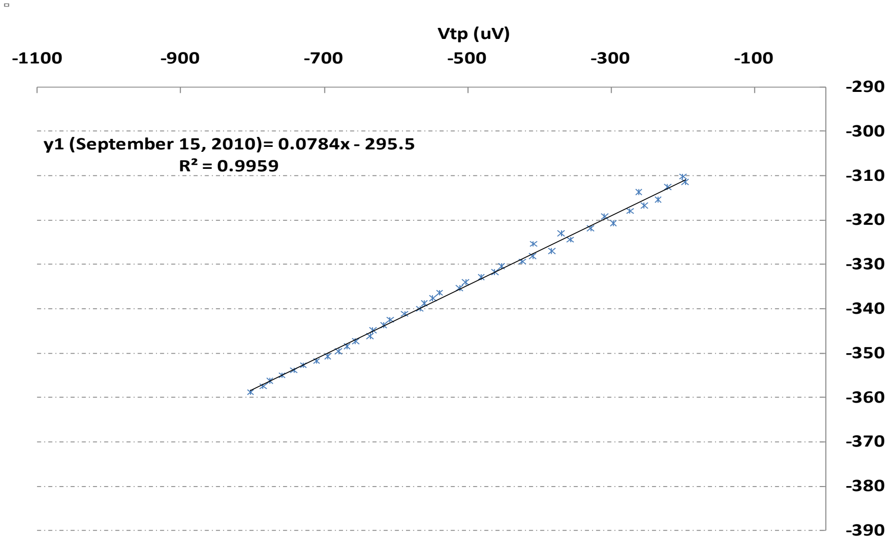


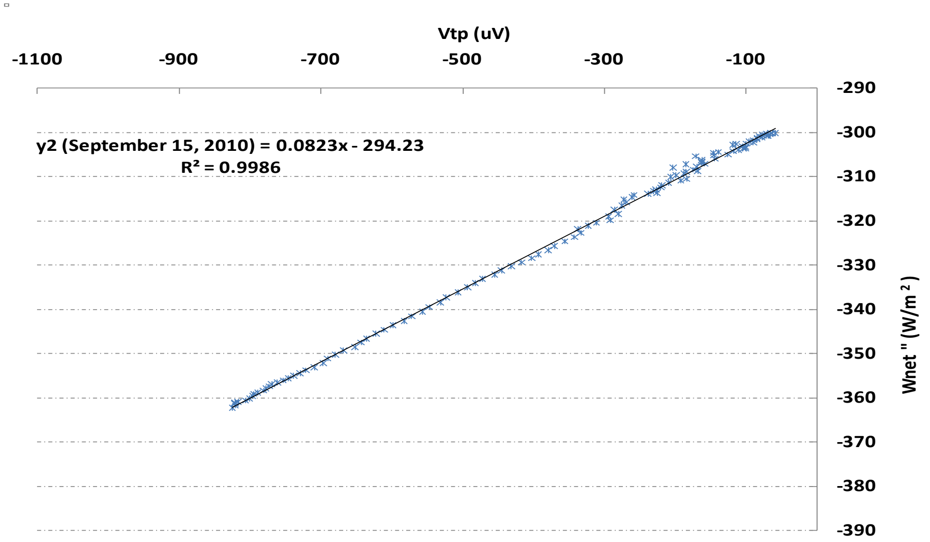


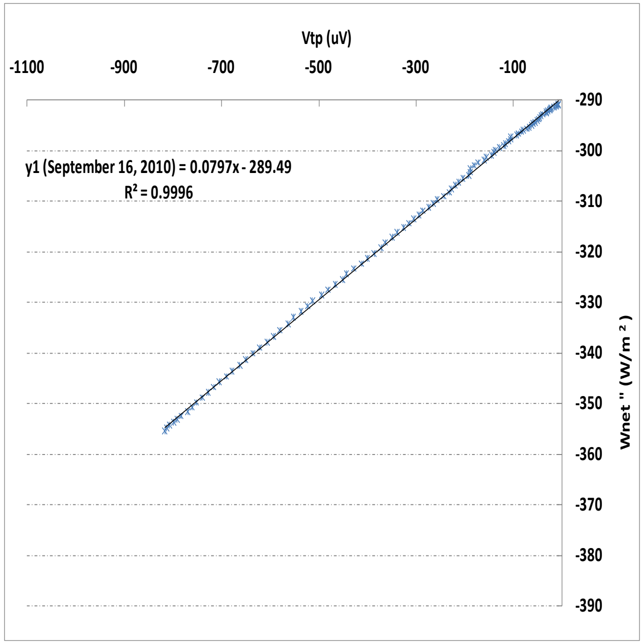
Atmospheric Longwave Irradiance

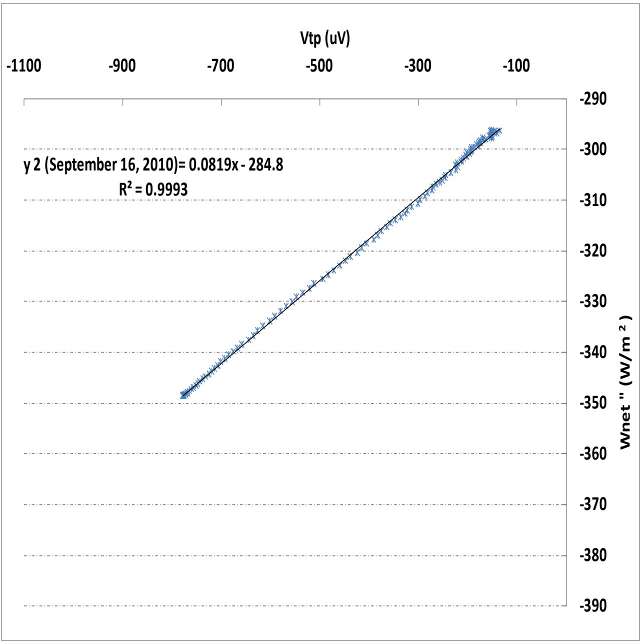


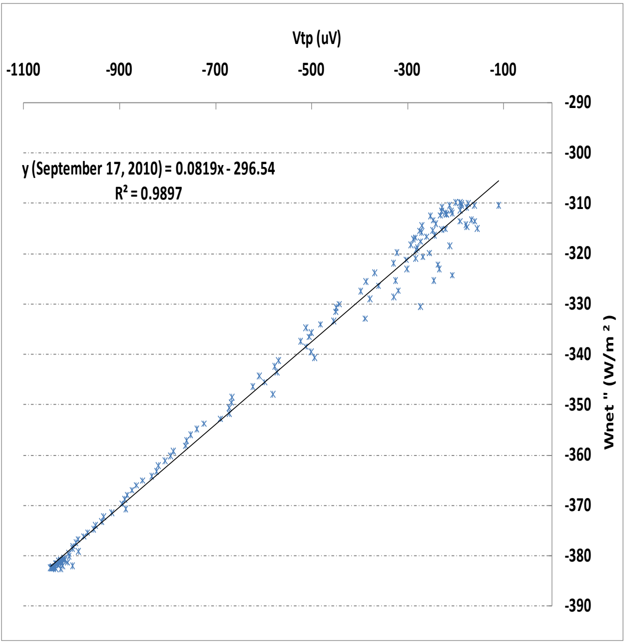
Variable Net Irradiance vs Thermopile Output











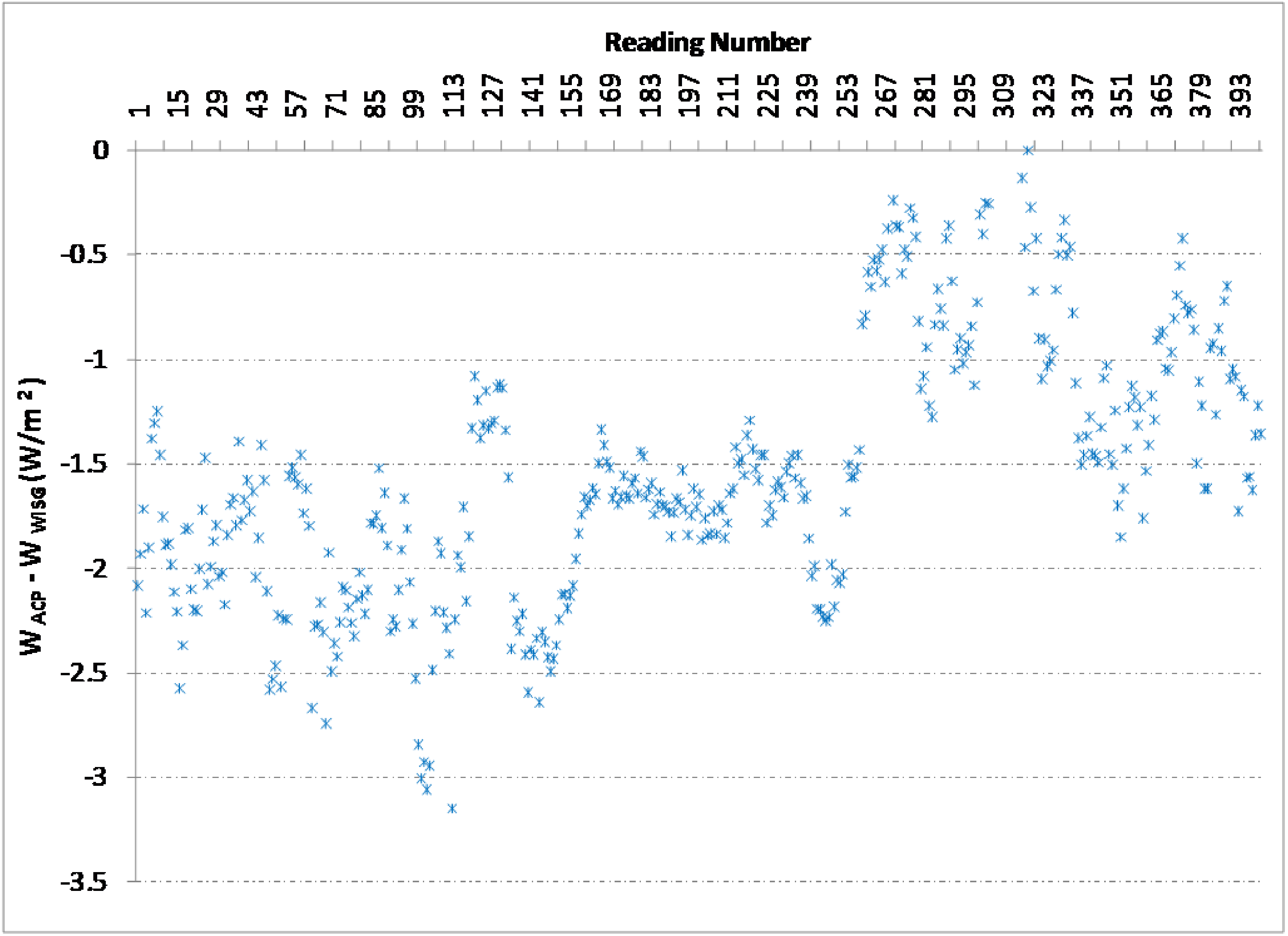
Uncertainty Estimate

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

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%

Measured Irradiance difference



Applications

ACP is a reference instrument traceable SI, and might be used to calibrate instruments for the following applications:

1. **Renewable-Energy: Thermal systems, window efficiency, resource assessment/maps, PV efficiency, solar and wind energy**
2. **Atmospheric science: Cloud cover, meteorology, earth energy budget/profile, climate study**
3. **Agriculture**
4. **Military**
5. **IR thermometry**

Why Unique?

- Uses the irradiance (intended to be measured) as the source to avoid spectral mismatch
- Independent from the irradiance value and spectral distribution
- Traceable to SI
- All other systems are traceable to blackbody irradiance, i.e. blackbody/indoor/outdoor spectral mismatch.

Conclusion and Future Work

- ACP is New, unique, and traceable to SI rather than a blackbody
- ACP might contribute to establishing an Internationally recognized reference for measuring the atmospheric longwave irradiance
- Future ACP comparison with PMOD's absolute reference (under development) and other absolute references if available.