NREL Comparison of Absolute Cavity Pyrgeometers, InfraRed Integrating Sphere, and Pyrgeometers Traceable to World Infrared Standard Group: September 26–October 7, 2022

Ibrahim Reda, Afshin Andreas, Mark Kutchenreiter, Martina Stoddard, and Aron Habte

National Renewable Energy Laboratory

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Technical Report
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1 Introduction

The comparison of the absolute cavity pyrgeometers (ACPs) with the InfraRed Integrating Sphere (IRIS), Eppley Precision Infrared Radiometer (PIR) pyrgeometers, and Kipp & Zonen (KZ) pyrgeometers traceable to the World Infrared Standard Group (WISG) was held during NREL ACP and IRIS Comparisons (NAIC) from September 26 to October 7, 2022. Data from all instruments was collected during nighttime clear sky conditions only. The irradiance measured by the ACPs is collected in 30 seconds intervals during the measurement period of two hours, and 10 seconds intervals during the calibration period of 6 minutes.

During the comparison, the average (av) irradiance difference measured by ACPs and IRIS varied from -0.80 W/m^2 to 0.29 W/m^2 and standard deviation (sd) from 0.98 W/m^2 to 1.78 W/m^2. The average irradiance difference measured by ACP95F3 minus the irradiance measured by all pyrgeometers varied from 2.07 to 5.03 W/m^2 with sd from 2.64 W/m^2 to 2.67 W/m^2.

Instrument List

- Absolute Cavity Pyrgeometer:
  - ACP20F3: DOE-Atmospheric atmospheric Radiation program (ARM)
  - ACP21F3: NREL
  - ACP57F3: German Weather Service (DWD)
  - ACP95F3: NREL
  - ACP96F3: Physikalisch-Meteorologisches Observatorium Davos—World Radiation Center (PMOD/WRC)
- InfraRed Integrating Sphere:
  - IRIS5: DWD
- PIR pyrgeometer: 31205F3, 31197F3, 36362F3 (NREL)
- KZ pyrgeometer CGR4: 060881(NREL), FT005(PMOD/WRC)

2 Measurement Equations

ACP

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

Where,

- W is the atmospheric longwave irradiance (W.m^{-2}).
- K_1 is the reciprocal of the ACP's responsivity (W.m^{-2}.uV^{-1}).
- V_{tp} is the thermopile output voltage (uV).
- ϵ is the gold emittance.
- K_2 is the emittance of the black receiver surface.
- W_r is the receiver irradiance (W.m^{-2}).
- W_c is the concentrator irradiance (W.m^{-2}).
- τ is the ACP's throughput.

IRIS

$$W = \frac{\mathrm{U} * \mathrm{Cos}\,(\theta)}{C(1 + dt(T - 293.15))} + k\sigma T^4$$

Where,

- U is the signal (V).
- Θ is the signal phase measure by the lock-in amplifier (°).
- C is the responsivity ($VW^{-1}m^2$).
- T is the IRIS temperature (K).
- k is the emissivity correction factor.
- dt is the temperature coefficient of the pyroelectric detector ($W.m^{-2}$).
- σ is the Stefan-Poltzmann constant ($W.m^{-2}$).

PIR&KZ (NREL)

$$W = K_1 * V_{tp} + K_2 * W_r + K_3 * (W_d - W_r)$$

Where,

- K_0, K_1 , K_2 , and K_3 are the calibration coefficients.
- W_d is the dome irradiance, in W/m^2.

KZ (PMOD)

$$W = \frac{V_{tp}}{C}(1 + K_1 * \sigma T_c^3) + K_2 * W_c - K_3 * (W_d - W_c)$$

Where C, K_1, and K_2 are the calibration coefficients, W_d and W_c are the dome and case irradiance.

3 Results

Figure 1 shows the irradiance of ACPs and IRIS5. Figure 2 shows ACP95F3 irradiance and irradiance measured by pyrgeometers. Figure 3 shows ACP95F3 thermopile output voltage. Figure 4 shows the water vapor content. Figure 5 is the water vapor content during the comparison. Table 1 shows that the difference between ACP95F3 and ACP20F3, ACP21F3, ACP57F3, ACP96F3 and IRIS5 varied from -0.2 W/m^2 to 0.8 W/m^2 , and uncertainty from 1.36 W/m^2 to 3.56 W/m^2 with 95% confidence level (U_{95}). As is shown in Table 1, U_{95} of the difference between ACP95F3 and all pyrgeometers varied from 5.68 W/m^2 to 7.3 W/m^2.

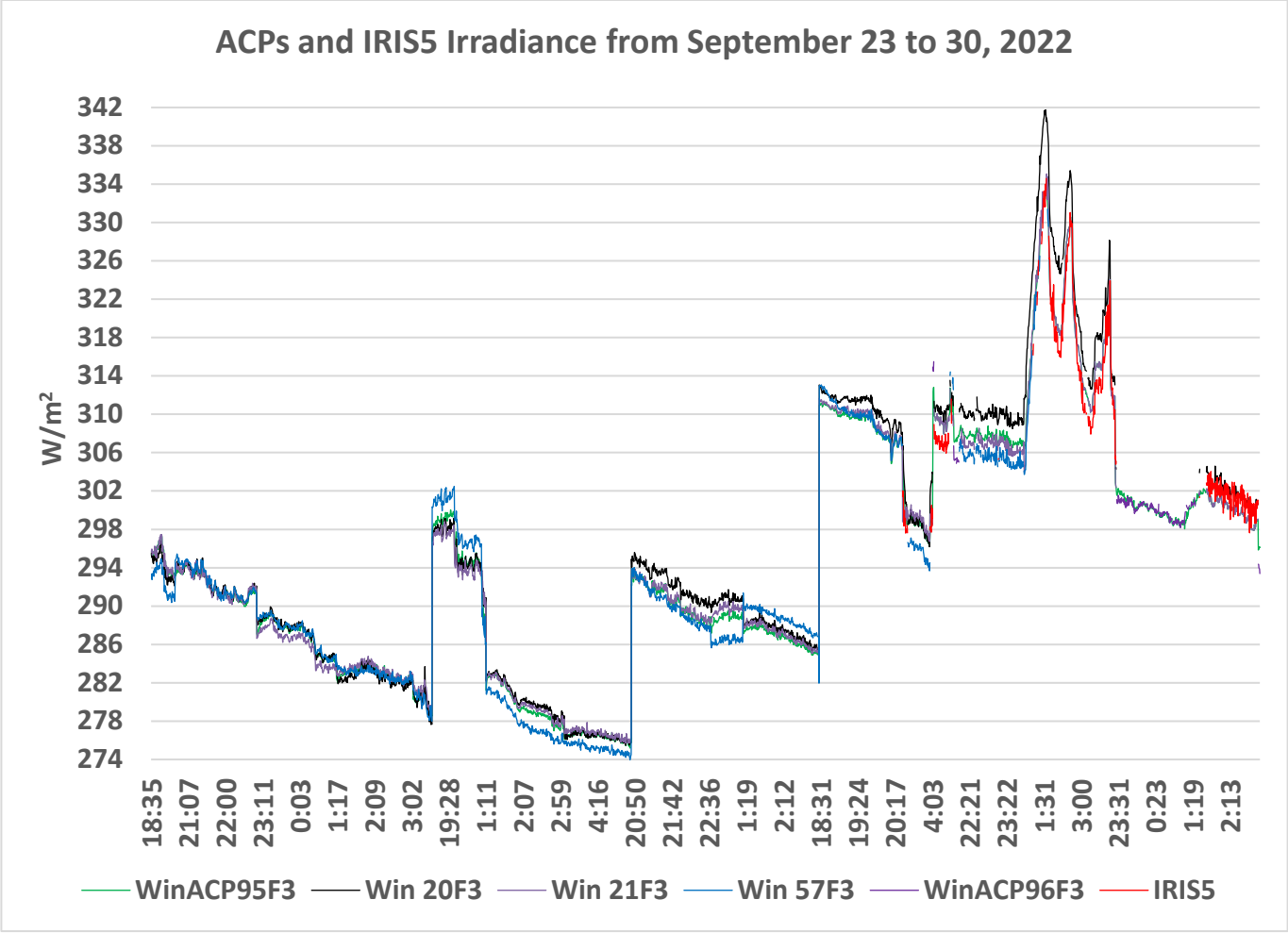

Figure 1. ACPs and IRIS5 irradiance

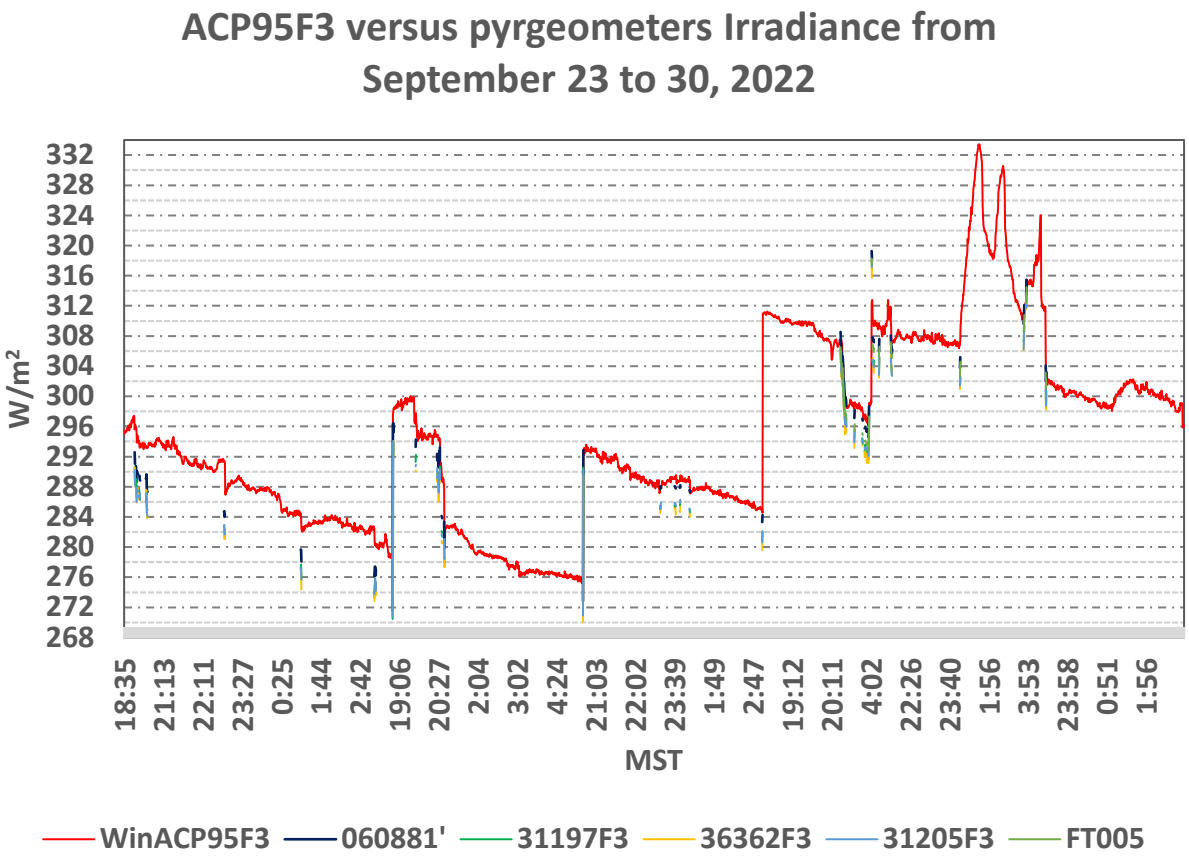

Figure 2. ACP95F3 irradiance and irradiance measured by pyrgeometers

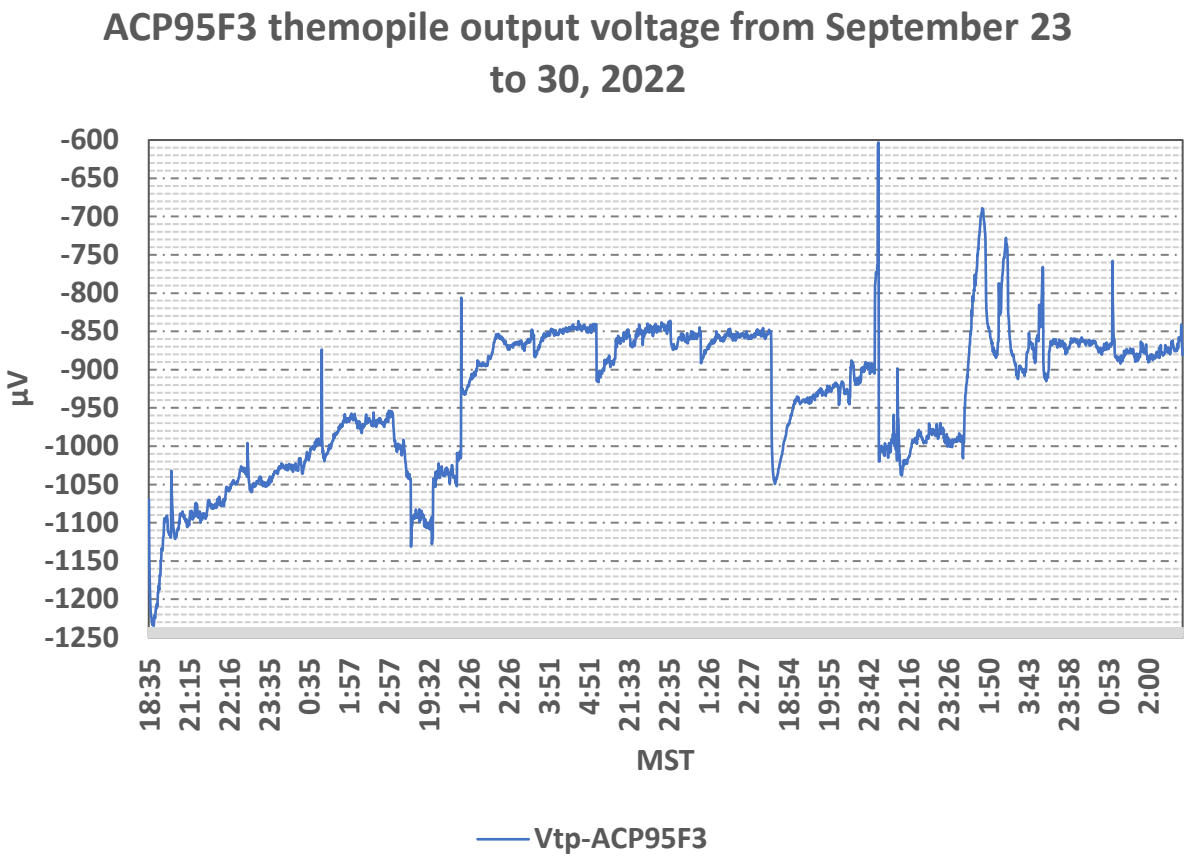

Figure 3. ACP95F3 thermopile output voltage*

** ACP thermopile output voltage is a good indication of how clear the sky is.*

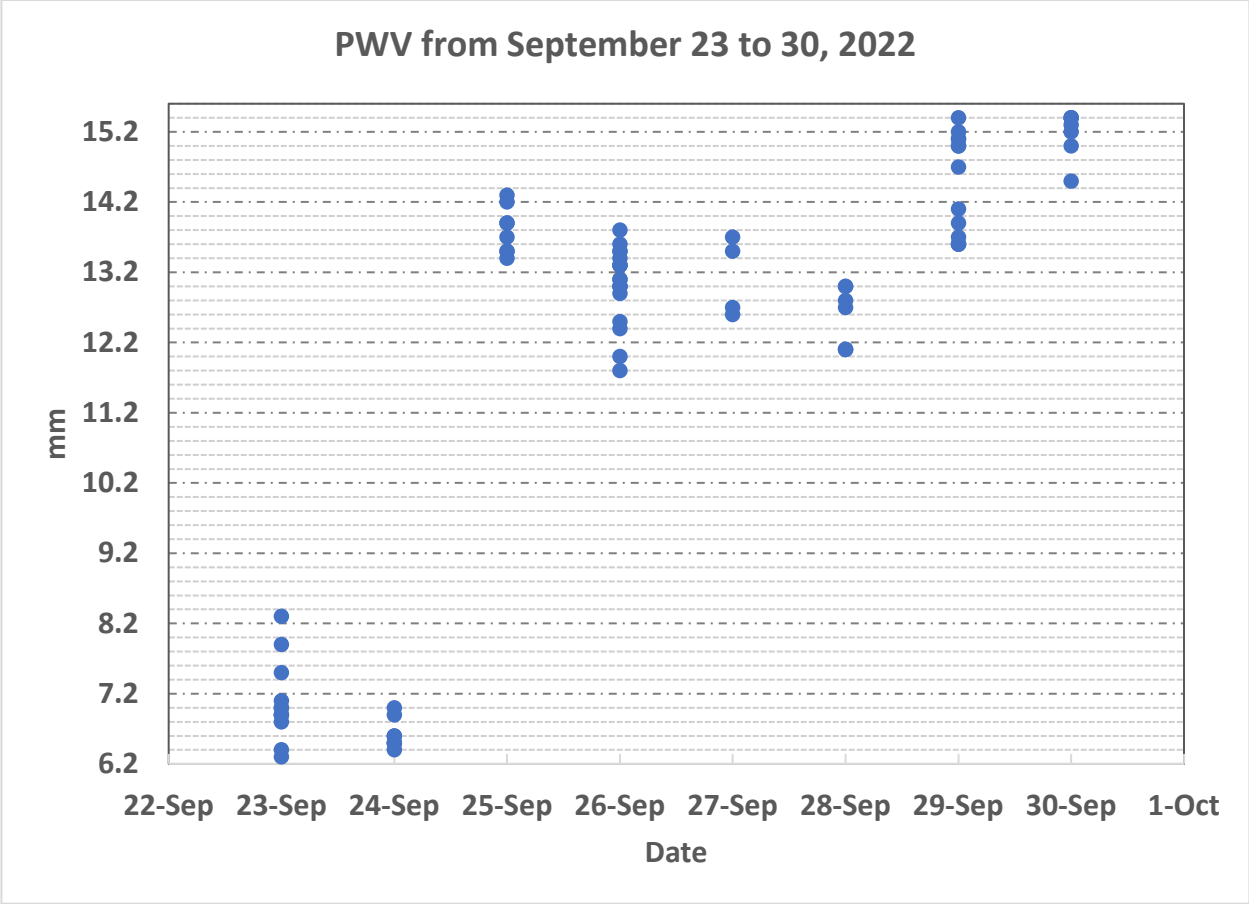

Figure 4. Water vapor content

Table 1. ACP95F3 Irradiance Minus the Irradiance Measured by all radiometers

W/m^2	ACP95F3-ACP20F3	ACP95F3-ACP21F3	ACP95F3-ACP57F3	ACP95F3-ACP96F3	ACP95F3-IRIS5	ACP95F3-06881	ACP95F3-FT005	ACP95F3-31197F3	ACP95F3-36362F3	ACP95F3-31205F3
av	-0.80	-0.05	0.29	0.23	0.20	2.07	1.49	4.54	5.03	4.57
sd	0.98	0.68	1.42	0.88	1.78	2.64	2.12	2.64	2.67	2.63
U_{95}	2.11	1.36	2.86	1.78	3.56	5.68	4.50	6.96	7.34	6.97
nrdg	2647	2421	2401	251	476	467	207	467	467	467