NREL Comparison of Absolute Cavity Pyrgeometers, InfraRed Integrating Sphere, and Pyrgeometers Traceable to World Infrared Standard Group: September 23-October 4, 2024

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Technical Report
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National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

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1 Introduction

The comparison of the absolute cavity pyrgeometers (ACPs) with the CG4 FT005 pyrgeometer traceable to the InfraRed Integrating Sphere (IRIS) referred to by FT005(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 23 to October 4, 2024. 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. Two methods described in [1] and [2] were used for the comparison based on original Reda et. al and proposed Forgan et. al. For ACP20F3, ACP21F3, and ACP95F3 the original method is only used; for ACP10F3, ACP57F3, and ACP96F3 both methods are used.

Using the original method the average (av) irradiance difference measured by ACPs and FT005 (IRIS) varied from -1.27 W/m^2 to 0.99 W/m^2, standard deviation (sd) from 0.50 W/m^2 to 1.26 W/m^2, and uncertainty U_{95} from 1.61 W/m^2 to 2.51 W/m^2. Using the proposed method the average (av) irradiance difference measured by ACPs varied from -0.15 W/m^2 to 1.32 W/m^2, standard deviation (sd) from 0.51 W/m^2 to 2.74 W/m^2, and uncertainty U_{95} from 1.30 W/m^2 to 5.49 W/m^2. The average irradiance difference measured by ACP95F3 minus the average irradiance measured by all pyrgeometers equal 3.16 W/m^2, sd 2.05 W/m^2, and uncertainty U_{95} 5.18 W/m^2.

Instrument List

- Absolute Cavity Pyrgeometer:
  - ACP20F3: DOE-Atmospheric Radiation program (ARM)
  - ACD21F3: NREL
  - ACP95F3: NREL
  - ACP10F3: Japan Meteorological Agency (JMA)
  - ACP57F3: Deutscher Wetterdienst (German Meteorological Service, DWD)
  - ACP96F3: Physikalisch-Meteorologisches Observatorium Davos—World Radiation Center (PMOD/WRC)

- InfraRed Integrating Sphere:
  - FT005 (IRIS): PMOD
- KZ pyrgeometer CGR4: 060881 (NREL), 010567 (JMA, Japan), FT005 (PMOD/WRC)
- PIR pyrgeometer: 31197F3 (NREL)

2 Measurement Equations

ACP

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

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 ($W.m^{-2}$) = $\sigma * (T_{case} + 0.0007074 * V_{tp})^4$, where T_{case} is the pyrgeometer case temperature in Kelvin, and σ is the Stefan-Boltzmann constant ($W.m^{-2}$).
- W_c is the concentrator irradiance ($W.m^{-2}$).
- τ is the ACP's throughput.

FT005 (IRIS)

$$W_{atm} = \frac{V}{C}(1 + K_1 \sigma T_b^3) + K_2 W_b + K_3(W_d - W_b)$$

Where C, K_1, K_2, K_3 are the calibration coefficients with traceability to IRIS, W_d and W_c are the dome and case irradiance.

PIR&KZ (NREL)

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

Where,

- 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, FT005 (IRIS). Figure 2 shows ACP95F3 irradiance and irradiance measured by pyrgeometers. Figure 3 shows ACPs irradiance using proposed method. Figure 4 shows ACP95F3 thermopile output voltage. Figure 5 shows the water vapor content. Table 1 shows that U_{95} from 1.61 W/m^2 to 2.51 W/m^2 for all ACPs and FT005 (IRIS), and U_{95} 5.18 W/m^2 for ACP95F3 minus the average irradiance measured by all pyrgeometers. Table 2 shows the proposed method U_{95} from 1.30 W/m^2 to 5.49 W/m^2.

References:

1. Reda, I., Zeng, J., Scheuch, J., Hanssen, L., Wilthan, B., Myers, D., and T. Stoffel (2011), J. Atm. and Sol.-Terr. Phys. 77, 132-143, doi:10.1016/j.jastp.2011.12.011.
2. Forgan, B. W., Gröbner, J., and Reda, I.: New Absolute Cavity Pyrgeometer equation by application of Kirchhoff's law and adding a convection term, Atmos. Meas. Tech., 16, 727–743, https://doi.org/10.5194/amt , 16-727-2023, 2023

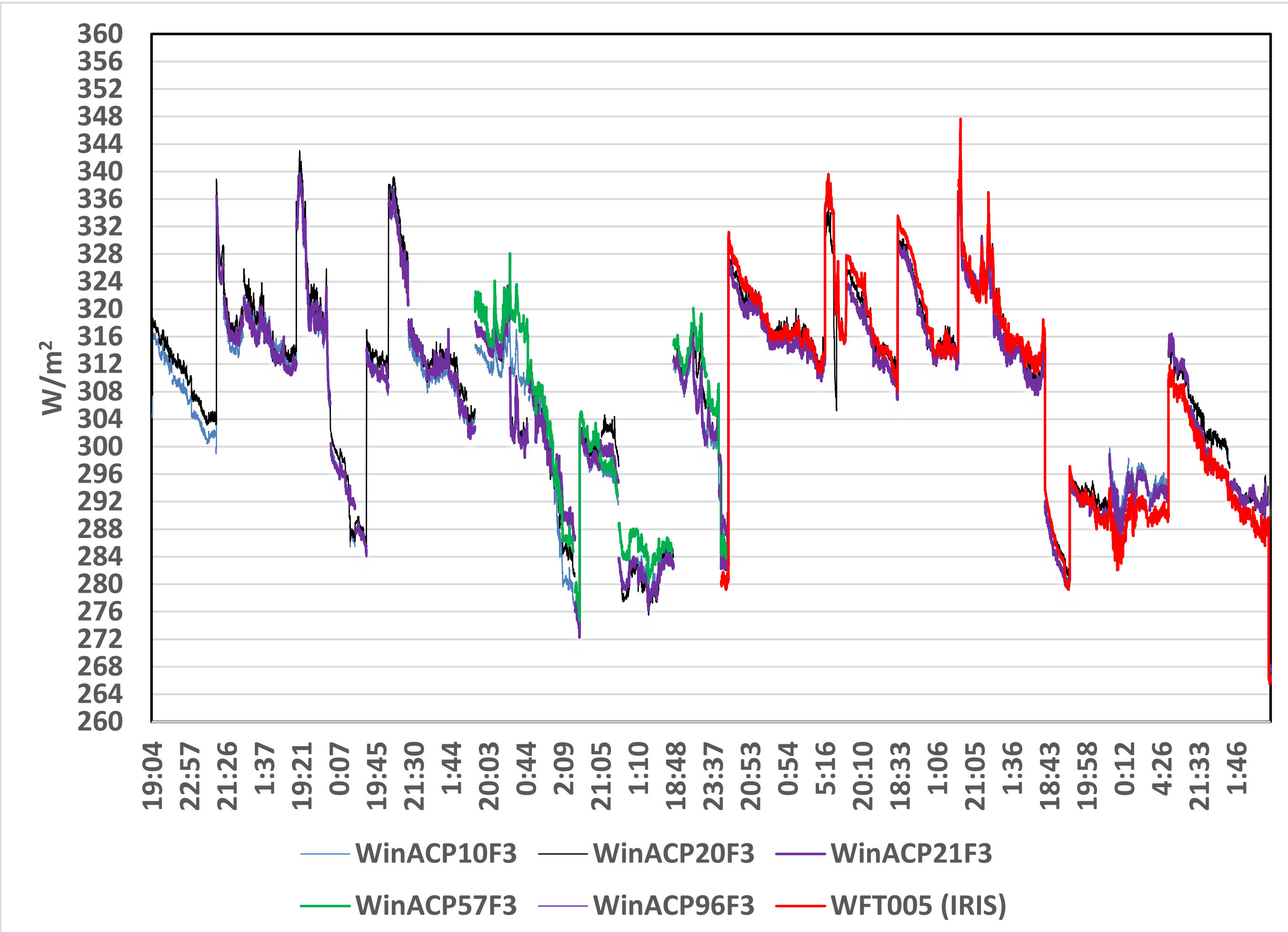

Figure 1. ACPs and FT005 (IRIS) irradiance

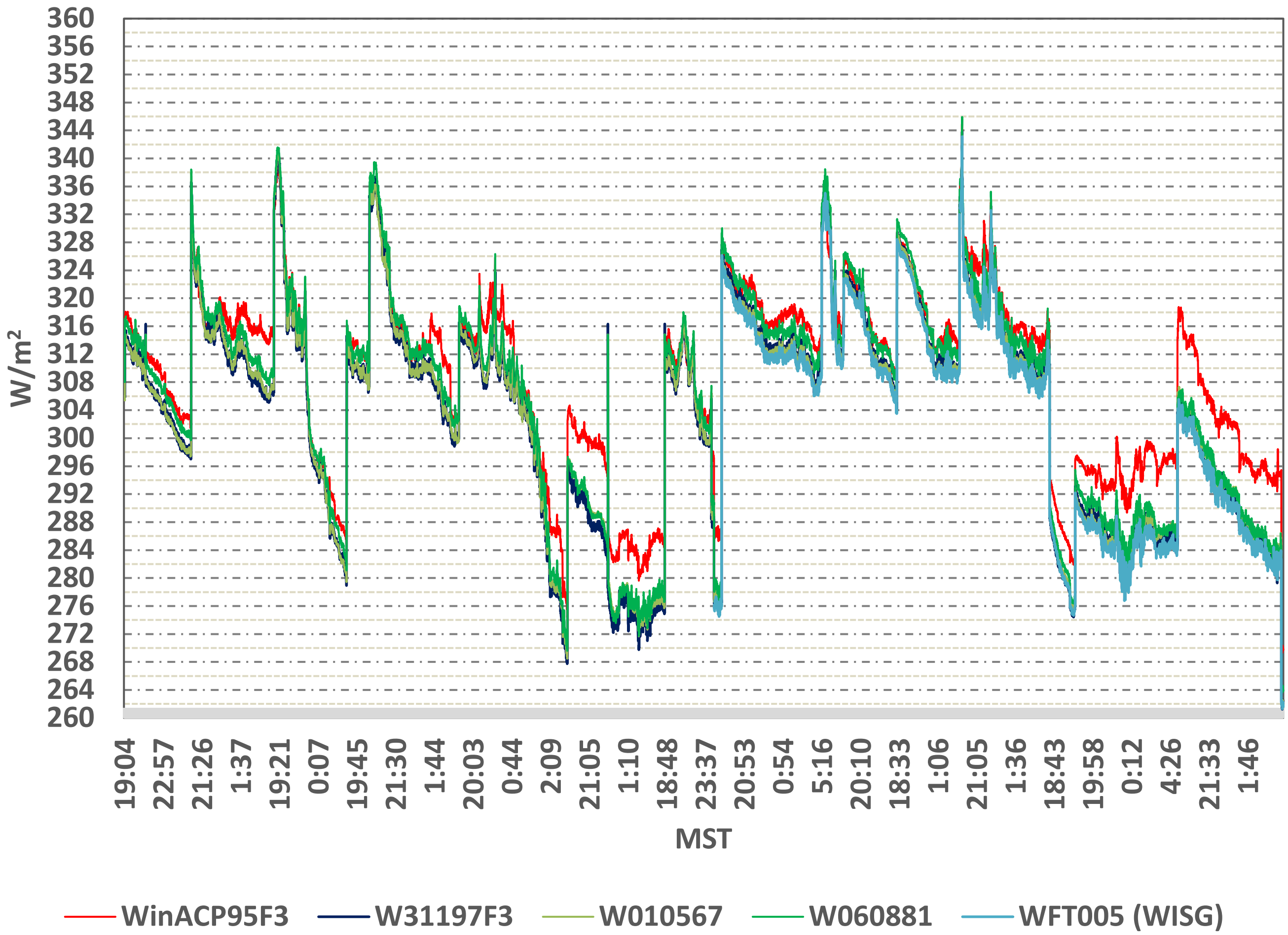

Figure 2. ACP95F3 irradiance and irradiance measured by pyrgeometers

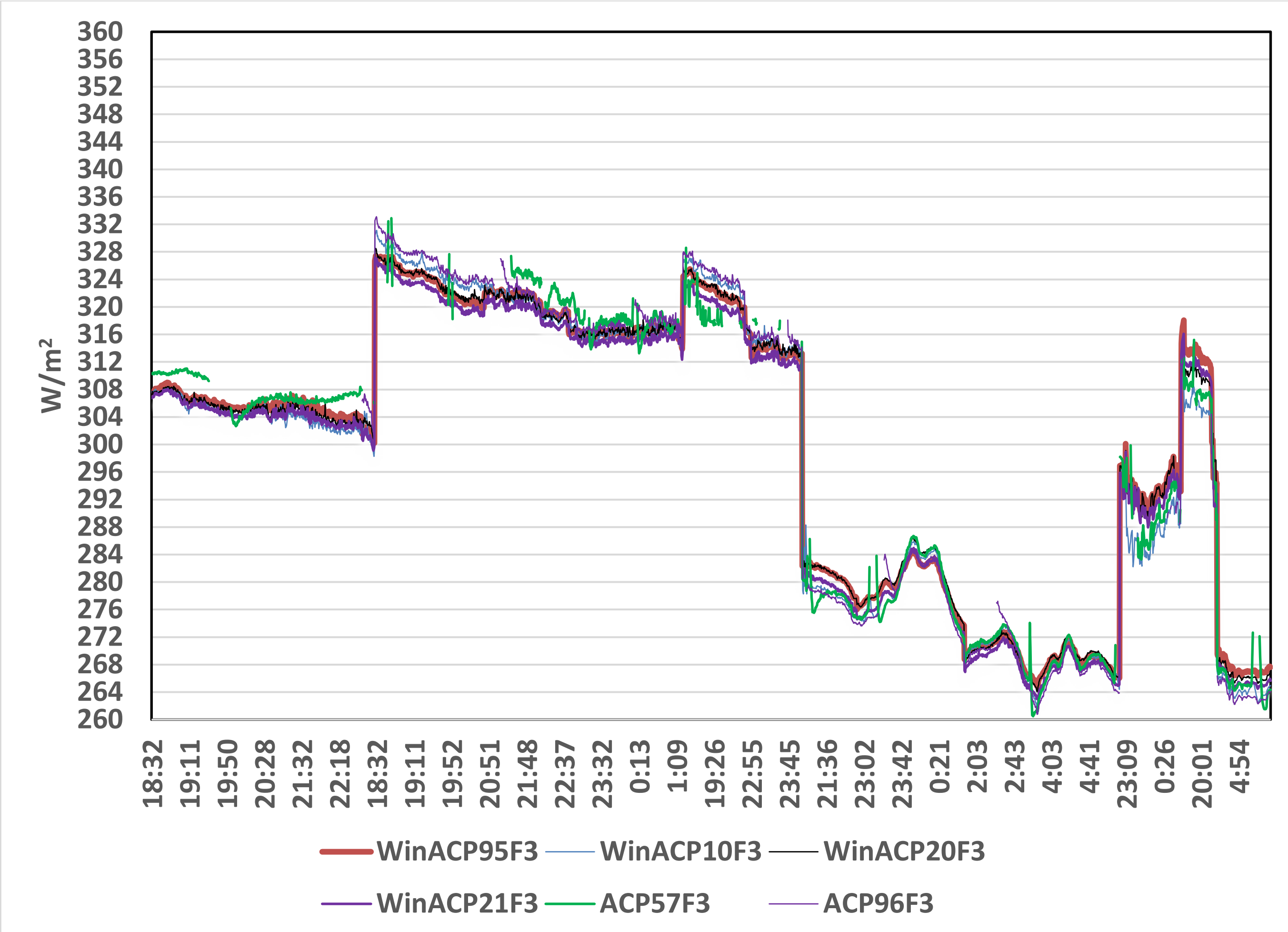

Figure 3. ACPs irradiance using proposed method

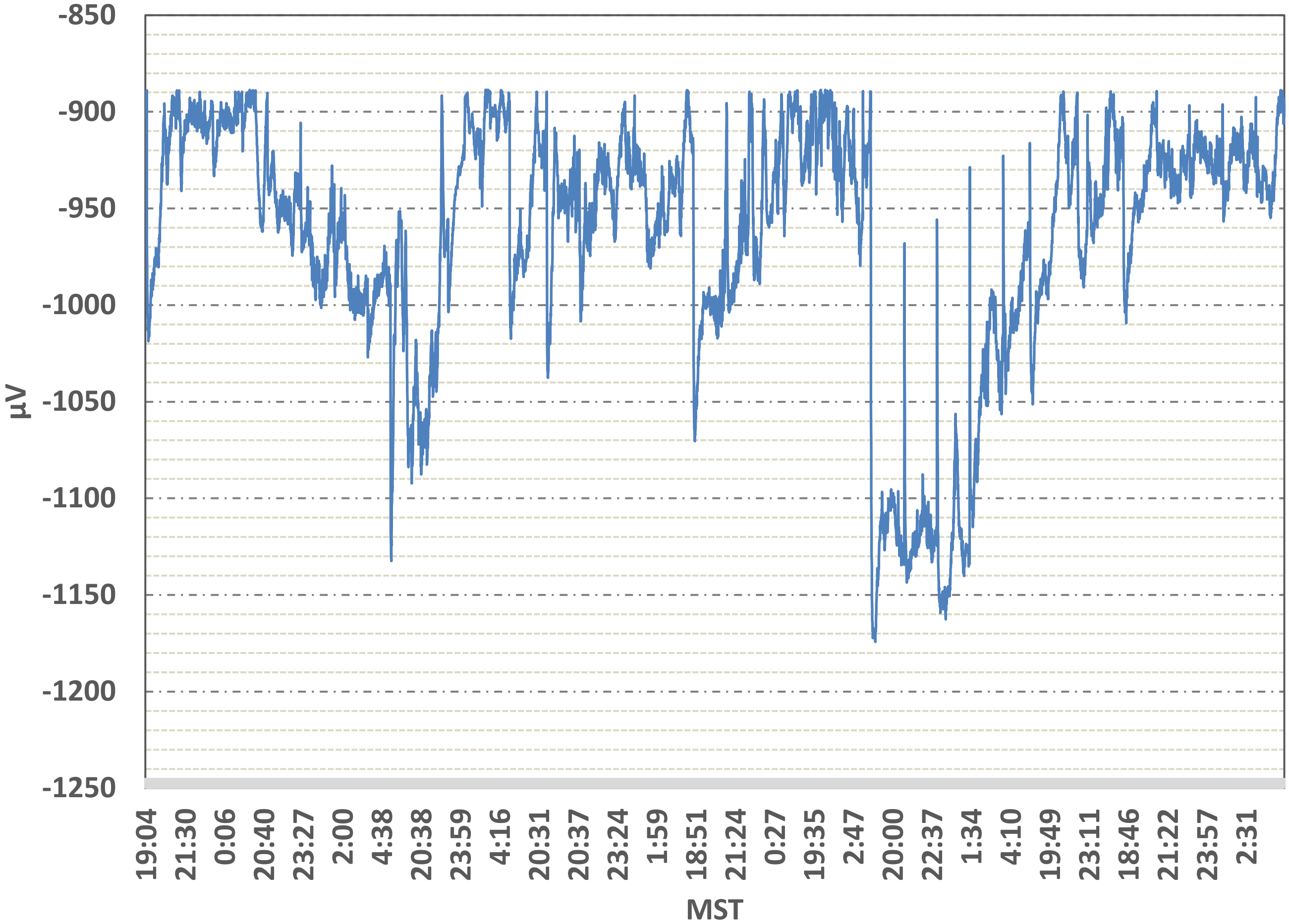

Figure 4. ACP95F3 thermopile output voltage*

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

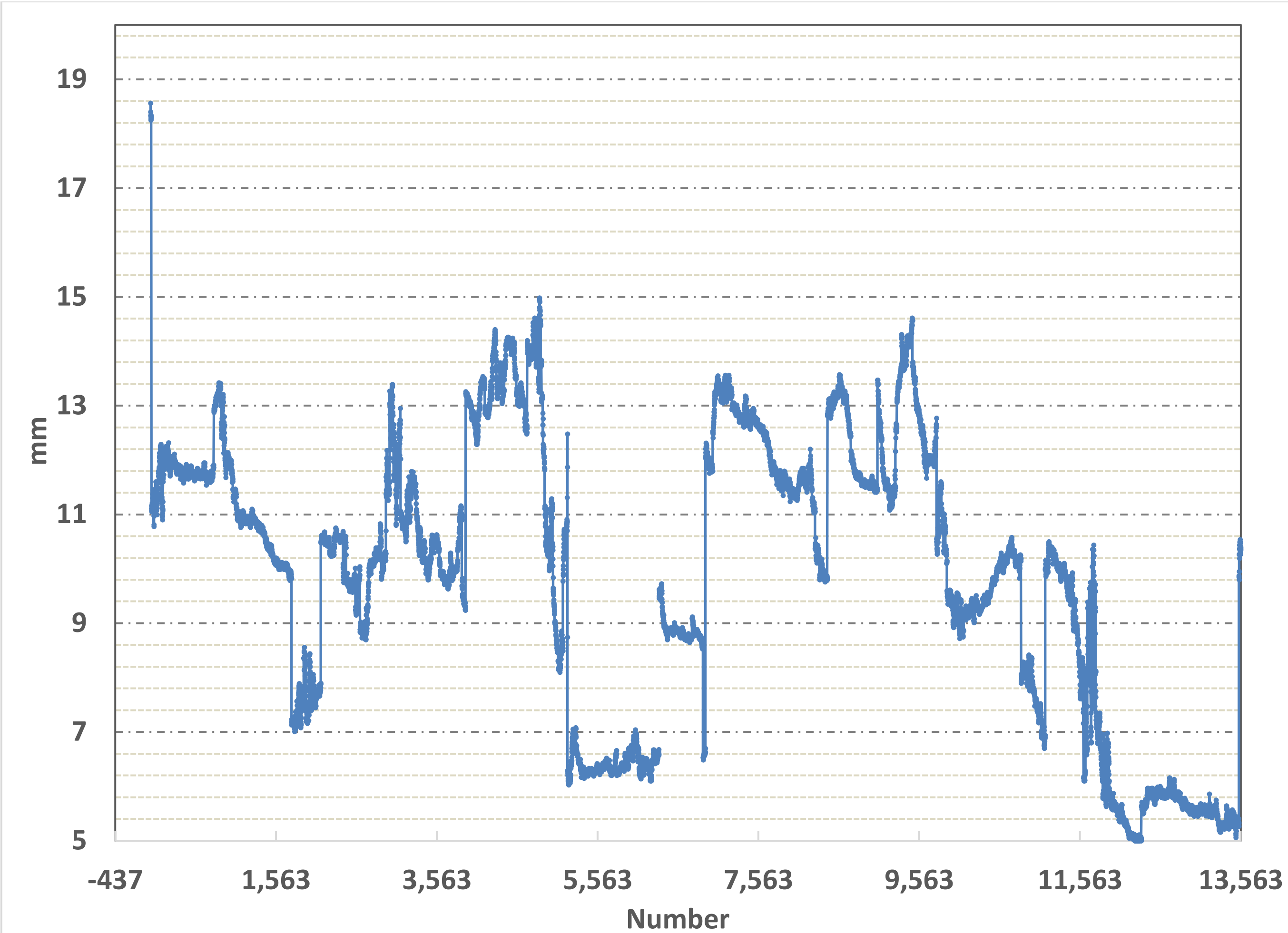

Figure 5. Water vapor content

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

W/m^2	ACP95F3-ACP10F3	ACP95F3-ACP20F3	ACP95F3-ACP21F3	ACP95F3-ACP57F3	ACP95F3-ACP96F3	ACP95F3-WFT005 (IRIS)	ACP95F3-Av(WISGpyrg)
av	0.99	-0.04	0.68	-0.48	-1.27	0.08	3.16
sd	0.90	1.04	0.95	0.89	0.50	1.26	2.05
U_{95}	2.06	2.09	2.01	1.84	1.61	2.51	5.18
nrdg	4492	8426	5932	2099	88	3484	9415

Table 2. ACP95F3 Irradiance Minus All Radiometers using Proposed Method

W/m^2	ACP95F3-ACP10F3	ACP95F3-ACP20F3	ACP95F3-ACP21F3	ACP95F3-ACP57F3	ACP95F3-ACP96F3
av	0.88	0.03	1.32	0.07	-0.15
sd	2.32	0.65	0.51	2.74	2.52
U95	4.72	1.30	1.68	5.49	5.05
nrd	2298	2217	2298	1734	1632