National Renewable Energy Laboratory Pyrheliometer Comparisons: 24 September–5 October 2012 (NPC 2012)

T. Stoffel and I. Reda

National Renewable Energy Laboratory

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Technical Report

NREL/TP-5500-58430

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Figure i. National Renewable Energy Laboratory (NREL) Pyrheliometer Comparisons 2012 (NPC-2012) participants: (left to right, standing) Don Nelson, Jim Wendell, Mark Kutchenreiter, Mike Dooraghi, Erik Naranen, Craig Carmignani, Fred Denn, Steve Wilcox, Tom Stoffel, Joop Mes, Afshin Andreas, Ibrahim Reda, Preston Morse, and (between equipment) Aron Habte; (kneeling): Craig Webb, Mary Watkins, Bill Boyson, Wim Zaaiman, Tom Kirk, Christian Thomann, and Victor Cassella. (Not pictured: Akihito Akiyama, Robert Dolce, Bill Dokos, Keith Emery, Tsukasa Kobashi, and Kees Van Den Bos.)
Photo by Dennis Schroeder, NREL

Figure ii. NPC-2012. Radiometer deployment near sunrise. *Photo by Dennis Schroeder, NREL*

Figure iii. Ibrahim Reda operated 10 NREL absolute cavity radiometers on solar trackers. (These include four DOE/NREL reference standards used to determine WRR transfer factors [WRR-TFs] for participating radiometers.) *Photo by Dennis Schroeder, NREL*

List of Acronyms

BMS	Baseline Measurement System
DOE	United States Department of Energy
IPC	International Pyrheliometer Comparison
IPC-XI	Eleventh International Pyrheliometer Comparisons
MST	Mountain Standard Time
NOAA	National Oceanic and Atmospheric Administration
NPC	National Renewable Energy Laboratory Pyrheliometer Comparisons
NREL	National Renewable Energy Laboratory
PMOD/WRC	Physikalisch-Meteorologisches Observatorium Davos World Radiation Center
SDp	pooled standard deviation
SI	International System of Units
SRRL	Solar Radiation Research Laboratory
TSG	transfer standard group
WMO	World Meteorological Organization
WRR	World Radiometric Reference
WRR-TF	World Radiometric Reference transfer factor
WSG	World Standard Group

Executive Summary

Accurate measurements of direct normal (beam) solar irradiance from pyrheliometers[1] are important for the development and deployment of solar energy conversion systems, improving our understanding of the Earth's energy budget for climate change studies, and for other science and technology applications involving solar flux. Providing these measurements places many demands on the quality system used by the operator of commercially available radiometers. Maintaining accurate radiometer calibrations traceable to an international standard is the first step in producing research-quality solar irradiance measurements.

In 1977, the World Meteorological Organization (WMO) established the WRR as the international standard for the measurement of direct normal solar irradiance (Fröhlich 1991). The WRR is an internationally recognized, detector-based measurement standard determined by the collective performance of seven electrically self-calibrated absolute cavity radiometers comprising the World Standard Group (WSG). Various countries, including the United States,[2] have contributed these specialized radiometers to the PMOD/WRC to establish the WSG.

As with all measurement systems, absolute cavity radiometers and other types of pyrheliometers are subject to performance changes over time. Therefore, every five years, the PMOD/WRC in Davos, Switzerland, hosts an International Pyrheliometer Comparison (IPC) for transferring the WRR to participating radiometers. Representing the DOE, NREL has participated in each of the IPCs since 1980. As a result, NREL has developed and maintained a select group of absolute cavity radiometers with direct calibration traceability to the WRR. These reference instruments are used by NREL to calibrate pyrheliometers and pyranometers using the ISO 17025 accredited Broadband Outdoor Radiometer Calibration (BORCAL) process (Reda et al. 2008).

NPCs are held annually at the Solar Radiation Research Laboratory (SRRL) in Golden, Colorado. Open to all pyrheliometer owners/operators, each NPC provides an opportunity to determine the unique WRR transfer factor for each participating pyrheliometer. By adjusting all subsequent pyrheliometer measurements by the appropriate WRR-TF, the solar irradiance data are traceable to the WRR.

NPC-2012 was scheduled from September 24 through October 5, 2012. Twenty participants operated 32 absolute cavity radiometers and 18 conventional thermopile-based pyrheliometers to simultaneously measure clear-sky direct normal solar irradiance during this period. The transfer standard group (TSG) of reference radiometers for NPC-2012 consisted of four NREL radiometers with direct traceability to the WRR, having participated in the Eleventh International Pyrheliometer Comparisons (IPC-XI) in the fall of 2010. As the result of NPC-2012, each participating absolute cavity radiometer was assigned a new WRR-TF, computed as the reference irradiance determined by the TSG divided by the observed irradiance from the participating radiometer. The performance of the TSG during NPC-2012 was consistent with previous comparisons, including IPC-XI. The measurement performance of the TSG allowed the transfer of the WRR to each participating radiometer with an estimated uncertainty of ± 0.33% with respect to the International System of Units.

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[1] Pyrheliometers are a type of radiometer used to measure solar irradiance (i.e., radiant flux in Watts per square meter) on a surface normal to the apparent solar disk within a 5.0º or 5.7º field of view, depending on the optical design of the instrument. A solar tracker is used to maintain proper alignment of the pyrheliometer with the sun during daylight periods.

[2] The WSG includes radiometers on permanent loan from the Eppley Laboratory, Inc., and NREL.

The comparison protocol is based on data collection periods called *runs*. Each measurement run consists of an electrical self-calibration requiring 6 minutes, a series of 37 solar irradiance measurements at 20-second intervals, and a post calibration. More than 2,900 reference irradiance measurements were collected by the TSG during NPC-2012. Clear-sky daily maximum direct normal irradiance levels ranged from 987 Wm^{-2} to 1019 Wm^{-2}.

Ancillary environmental parameters (e.g., broadband irradiance, spectral irradiance, and other surface meteorological data) collected at SRRL during the comparison are presented in Appendix B to document the environmental test conditions.

Future NPCs are planned annually at SRRL to ensure worldwide homogeneity of solar radiation measurements traceable to the WRR.

Table of Contents

List of Figures

List of Tables

1 Introduction

Accurate measurements of broadband solar irradiance require radiometers with proper design and performance characteristics, correct installation, and documented operation and maintenance procedures, including regular calibration. Calibrations of any measuring device must be traceable to a recognized reference standard. The World Radiometric Reference (WRR) is the internationally recognized measurement standard for direct normal irradiance measurements of broadband solar radiation (Fröhlich 1991).

The WRR was established by the WMO in 1977 and has been maintained by the Physikalisch-Meteorologisches Observatorium Davos—World Radiation Center (PMOD/WRC) in Switzerland (www.pmodwrc.ch). This reference is maintained for broadband solar irradiance with an absolute uncertainty of better than ± 0.3% with respect to the International System of Units (SI) (Romero et al. 1996). This standard is widely used for the calibration of pyrheliometers and pyranometers with a wavelength response range compatible with the solar spectrum wavelengths from 280 nm to 3,000 nm. Every five years, the WRR is transferred to WMO regional centers and other participants at International Pyrheliometer Comparisons (IPC) held at the PMOD/WRC. The eleventh IPC (IPC-XI) was completed in 2010 (Finsterle 2011). At each IPC, instantaneous measurements from the World Standard Group (WSG) are compared at 90-second intervals with the data from participating radiometers recorded under clear-sky conditions. A new WRR transfer factor (WRR-TF) is calculated for each of the participating radiometers based on the mean WRR of the WSG radiometers for each IPC. Multiplying the irradiance reading of each radiometer by its assigned WRR-TF will result in measurements that are traceable to WRR and therefore consistent with the international reference of solar radiation measurement.

In compliance with ISO 17025 accreditation requirements for demonstrating inter-laboratory proficiency, the National Renewable Energy Laboratory (NREL) hosts annual pyrheliometer comparisons at the Solar Radiation Research Laboratory (SRRL) in Golden, Colorado, for non-IPC years. The sixteenth National Renewable Energy Laboratory Pyrheliometer Comparisons (NPC-2012) were held from September 24 to October 5, 2012, at the SRRL. Twenty participants operated 32 absolute cavity radiometers and 18 conventional thermopile-based pyrheliometers during the comparisons. (See Appendix A for the list of participants.) The following organizations were represented at NPC-2012:

- Atlas Material Testing Technology, DSET Laboratories, Inc.
- U.S. Department of Energy/Office of Science/Atmospheric Radiation Measurement Program
- EKO Instruments Co. Ltd.
- The Eppley Laboratory, Inc.
- European Commission/Directorate General/Joint Research Centre/Institute for Energy and Transport
- Florida Solar Energy Center
- HuksefluxUSA, Inc.

- Kipp & Zonen USA, Inc.
- National Aeronautics and Space Administration Langley Research Center, Atmospheric Sciences Division
- The National Oceanic and Atmospheric Administration's (NOAA's) Earth System Research Laboratory
- NREL
    - Electricity, Resources, and Building Systems Integration Center
    - Quality Management Systems and Assurance—Metrology Laboratory
    - Solar Energy Technologies Program
- PMOD/WRC
- Sandia National Laboratories, Photovoltaic Systems Evaluation Laboratory

The results presented in this report are based on clear-sky direct normal solar irradiance data collected during the NPC. (See Appendix B for more specific meteorological information.)

2 Reference Instruments

NREL developed the transfer standard group (TSG) of four absolute cavity radiometers to serve as the measurement reference for each NPC. The radiometers comprising the TSG participated in the most recent IPC and maintain the WRR for NREL. (See Table 1.) Using the method described by Reda (1996), the mean of the TSG measurements was maintained for establishing the reference irradiance data for NPC-2012 data reduction. Table 1 provides a list of the TSG absolute cavity radiometers with their WRR-TFs and pooled standard deviations as determined from the latest IPCs, in 2010 (Finsterle 2011).

Table 1. IPC-XI Results Summary for the NPC-2012 TSG

Serial Number	WRR Factor (IPC-XI)	Standard Deviation (%)	Number of Readings
AHF 28968	0.99773	0.0656	420
AHF 29220	0.99769	0.0669	418
AHF 30713	0.99755	0.0679	421
TMI 68018	0.99680	0.0642	415
Mean WRR for the TSG	0.99744	**SDp for the TSG** 0.07%	

The pooled standard deviation (SD_p) for the TSG was computed from the following equation:

$$SD_p = \sqrt{\frac{\sum_{i=1}^{m} n_i * S_i^2}{\sum_{i=1}^{m} n_i}}$$

where,

- i = i^{th} cavity
- m = number of reference cavities
- S_i = standard deviation of the i^{th} cavity, from IPC-XI
- n_i = number of readings of the i^{th} cavity, from IPC-XI

3 Measurement Protocol

The decision to deploy instruments for a comparison was made daily. Data were collected only during clear-sky conditions, which were determined visually and from the stability of pyrheliometer readings. Simultaneous direct normal solar irradiance measurements were taken by most cavity radiometers in groups of 37 observations at 20-second intervals (PMO6 used a 40-second open-/closed-shutter cycle). Each group of observations is called a run. An electrical self-calibration of each absolute cavity, requiring up to six minutes, was performed prior to each run. Previous WRR-TFs determined from results of IPCs or NPCs were *not* applied to the observations. The original manufacturer calibration factor was used according to the standard operating procedure provided by the manufacturer for each radiometer. A timekeeper announced the beginning of each calibration period and gave a 6-minute countdown prior to the start of each run to facilitate cavity calibrations and the simultaneous start for each participant. (See Appendix C for more details.)

By consensus, at least 300 observations from each radiometer were required to determine the WRR-TF for an NPC. Participants also agreed that a minimum of ten runs should be made during a period of at least three days to provide a variety of temperature and spectral irradiance conditions when computing the WRR-TF. A statistically significant data set was required to derive the WRR-TF for each pyrheliometer.

Data from each pyrheliometer/operator system were collected at the end of the day using USB flash memory. (Additional operational notes can be found in Appendix C.)

4 Transferring WRR

The primary purpose of an NREL pyrheliometer comparison is to transfer the current WRR from the NPC TSG to each of the participating pyrheliometers. This requires the collection of simultaneous measurements of clear-sky direct normal (beam) solar irradiance by the participating pyrheliometers and the TSG.

4.1 Calibration Requirements

Using WMO guidelines (Romero 1995), the following conditions were required before data collection was accomplished during NPC-2012:

- The radiation source was the sun, with irradiance levels greater than 700 Wm^{-2}.
- Digital multimeters with accuracy better than 0.05% reading were used to measure the thermopile signals from each radiometer.
- Solar trackers were aligned within ± 0.25˚ slope angle.
- Wind speed was low (< 5 m/s) from the direction of the solar azimuth ± 30˚.
- Cloud cover was less than 1/8 of the sky dome, with an angular distance larger than 15˚ from the sun.

4.2 Determining the Reference Irradiance

Four absolute cavity radiometers that are maintained by NREL and that participated in IPC-XI were used as the TSG to transfer the WRR in the comparison. The WRR-TF for each TSG is presented in Table 1 above. The reference irradiance at each reading was calculated using the following steps, as described by Reda (1996):

a. Each irradiance reading of the TSG is divided by the irradiance measured by AHF28968.
b. By maintaining the mean of WRR for the TSG, a new WRR-TF for NPC-2012 is recalculated for each of the TSG cavities. (See Figure 1.)
c. The reference irradiance for each 20-second observation in a run is computed as the mean of the simultaneous reference irradiances measured by the TSG. The reference irradiance reading for each cavity in the TSG is the irradiance reading of the cavity multiplied by its new WRR-TF calculated in Step B.

4.3 Data Analysis Criteria

AHF28968 was used to check irradiance stability at the time of each comparison reading during a run. Stable irradiance readings are defined to within 1.0 Wm^{-2} during an interval of two seconds centered on the comparison reading—i.e., one second before and one second after the recorded reading. Unstable irradiance readings are marked in the data record and automatically rejected from the data analysis. Historically, this has affected less than 10% of the data collected during an NPC.

Additionally, all calculated ratios of the test instrument irradiance divided by AHF28968 irradiance that deviated from their mean by 0.3% were rejected (Reda 1996). Typically, data rejected from the analysis in this manner were the result of failed tracker alignment, problems with the pre-calibration, or similar cause for a bias greater than expected from a properly functioning absolute cavity radiometer.

Note that the ratios of windowed pyrheliometers do not have a normal distribution (see histograms in the data figures), yet their uncertainty is calculated using a normal distribution for consistency with the NPC protocol for un-windowed pyrheliometers. Users must recalculate the uncertainty of their windowed pyrheliometers based on the actual distribution and their knowledge about the spectral effect due to the specifications of their respective window.

4.4 Measurements

NPC-2012 was held from September 24 to October 5, 2012. The comparisons were completed on October 2, after more than 2,800 data points were collected by the reference cavities during the requisite clear-sky conditions. The actual number of readings for each participating radiometer compared with the reference irradiance varied according to the data analysis selection criteria described above. Additionally, some instruments experienced minor data loss due to a variety of problems with the measurement systems and operating difficulties.

4.5 Results

The results for the TSG are presented in Table 2. To evaluate the performance of these instruments, the standard deviations of each radiometer were monitored during the comparisons. The results suggest successful performance of the TSG during this NPC:

- For the TSG, the NPC-2012 WRR-TF did not change by more than a fraction of the standard deviation derived during IPC-XI in 2010. (See Figure 1.)
- For the control standards—i.e., cavities that participated in IPC-XI and NPC-2012—their new WRR-TF, from NPC-2012, were consistent with their IPC-XI results. (See Table 2.)

Results for each radiometer participating in NPC-2012 are presented in Table 3.

Table 2. Summary Results for the Control Standards for NPC-2012

Pyrheliometer Serial Number	WRR (IPC-XI)	WRR (NPC-2012)	SD% (NPC-2012)	WRR_{IPC} - WRR_{NPC} %
AHF14915	0.999682	1.00010	0.14	-0.04
AHF17142	0.998281	0.99811	0.05	0.02
AHF23734	0.998281	0.99820	0.03	0.01
AHF28553	0.996842	0.99721	0.06	-0.04
AHF31041	0.996286	0.99647	0.06	-0.02
AHF31105	0.999964	0.99954	0.05	0.04
AHF31114AWX	1.001244	1.00154	0.06	-0.03
AHF32448AWX	0.999939	1.00035	0.07	-0.04
AHF32455	1.000276	1.00054	0.06	-0.03
PMO6 81109	0.998577	0.99816	0.06	0.04
PMO6 911204	0.999711	0.99942	0.08	0.03
PMO6cc 0103*	0.999424	0.99865	0.06	0.08
PMO6cc 0401	1.020979	1.02107	0.05	-0.01
PMO6cc 0803	1.000364	1.00032	0.07	0.00
TMI67502	0.999294	0.99984	0.07	-0.06
TMI68835	1.00098	1.00095	0.08	0.00

* From IPC-X

Table 3. Results for Radiometers Participating in NPC-2012

Pyrheliometer Serial Number	WRR-Reduction Factor	Type A Standard Uncertainty ±%uA	Number of Readings	Combined Standard Uncertainty ±%u	Effective Degrees of Freedom	Expanded Uncertainty ±%U95
CH1 040370	0.99387	0.16	2826	0.24	15690	0.48
CH1 060460	0.99914	0.13	2864	0.23	23929	0.45
CH1 930018	0.99965	0.28	2899	0.34	5904	0.66
CH1P 110533	0.99814	0.18	2828	0.26	12086	0.51
DR01-8174	1.00467	0.15	2880	0.24	17485	0.47
PMO6 81109	0.99816	0.06	761	0.19	86214	0.38
PMO6 911204	0.99942	0.08	767	0.20	37407	0.39
AHF14915	1.00010	0.14	487	0.23	3785	0.45
AHF17142	0.99811	0.05	1719	0.19	348380	0.38
AHF21182	1.00190	0.14	2712	0.23	22111	0.45
AHF23734	0.99820	0.03	2873	0.19	4785205	0.37
AHF28553	0.99721	0.06	2645	0.20	250097	0.38
AHF28556	0.99535	0.05	1628	0.19	305727	0.38
AHF29219-WIndow	1.06145	0.06	2874	0.20	241834	0.39
AHF29222-WIndow	1.05881	0.06	2871	0.19	347123	0.38
AHF30494	0.99791	0.11	2825	0.21	46994	0.42
AHF30495	0.99833	0.05	2822	0.19	487701	0.38
AHF31041	0.99647	0.06	1737	0.20	160112	0.38
AHF31104	0.99915	0.04	2884	0.19	1182200	0.37
AHF31105	0.99954	0.05	1721	0.19	364371	0.38
AHF31108	0.99713	0.06	2747	0.20	270052	0.38
AHF31114AWX	1.00154	0.06	2600	0.19	319874	0.38
AHF32448AWX	1.00035	0.07	2489	0.20	170576	0.39
AHF32452AWX-Window	1.03130	0.08	2823	0.20	101251	0.40
AHF32455	1.00054	0.06	2715	0.19	400711	0.38
CH1-070541	0.99859	0.14	2902	0.23	22756	0.45
CHP1-090127	1.00125	0.11	2900	0.21	47971	0.42
CHP1-REF1	0.99711	0.11	2898	0.22	43593	0.42
CP01P-002	0.99598	0.16	800	0.24	4509	0.48
CP01T-002	0.99573	0.13	799	0.23	6679	0.45
CP01U-002	0.99238	0.28	821	0.34	1703	0.66

Pyrheliometer Serial Number	WRR-Reduction Factor	Type A Standard Uncertainty ±%uA	Number of Readings	Combined Standard Uncertainty ±%u	Effective Degrees of Freedom	Expanded Uncertainty ±%U95
DR03-T2-10008 Corrected	1.00911	0.24	2901	0.31	7256	0.60
DR03-T2-10008 Non-Corrected	1.00964	0.35	2903	0.40	4721	0.78
PMO6cc 0103	0.99865	0.06	350	0.19	38896	0.38
PMO6cc 0401	1.02107	0.05	351	0.19	65760	0.38
PMO6-cc 0803	1.00032	0.07	352	0.20	21545	0.39
REF.02	0.99991	0.29	1668	0.35	3291	0.68
REF.03	0.99821	0.31	1665	0.36	3121	0.70
REF-001	1.00070	0.26	1667	0.32	3724	0.63
SHP1-110003	0.99991	0.15	2884	0.24	19505	0.46
SNIP 36476	0.99809	0.08	533	0.20	18691	0.40
SNIP 36477	1.00295	0.16	546	0.25	2800	0.49
TMI 68835	1.00095	0.08	2890	0.20	113924	0.40
TMI67502	0.99984	0.07	2654	0.20	165516	0.39
TMI67603	0.99995	0.06	2873	0.19	327538	0.38
TMI68017	0.99957	0.09	1825	0.21	47582	0.41
TMI69036	1.00021	0.06	1056	0.19	139304	0.38

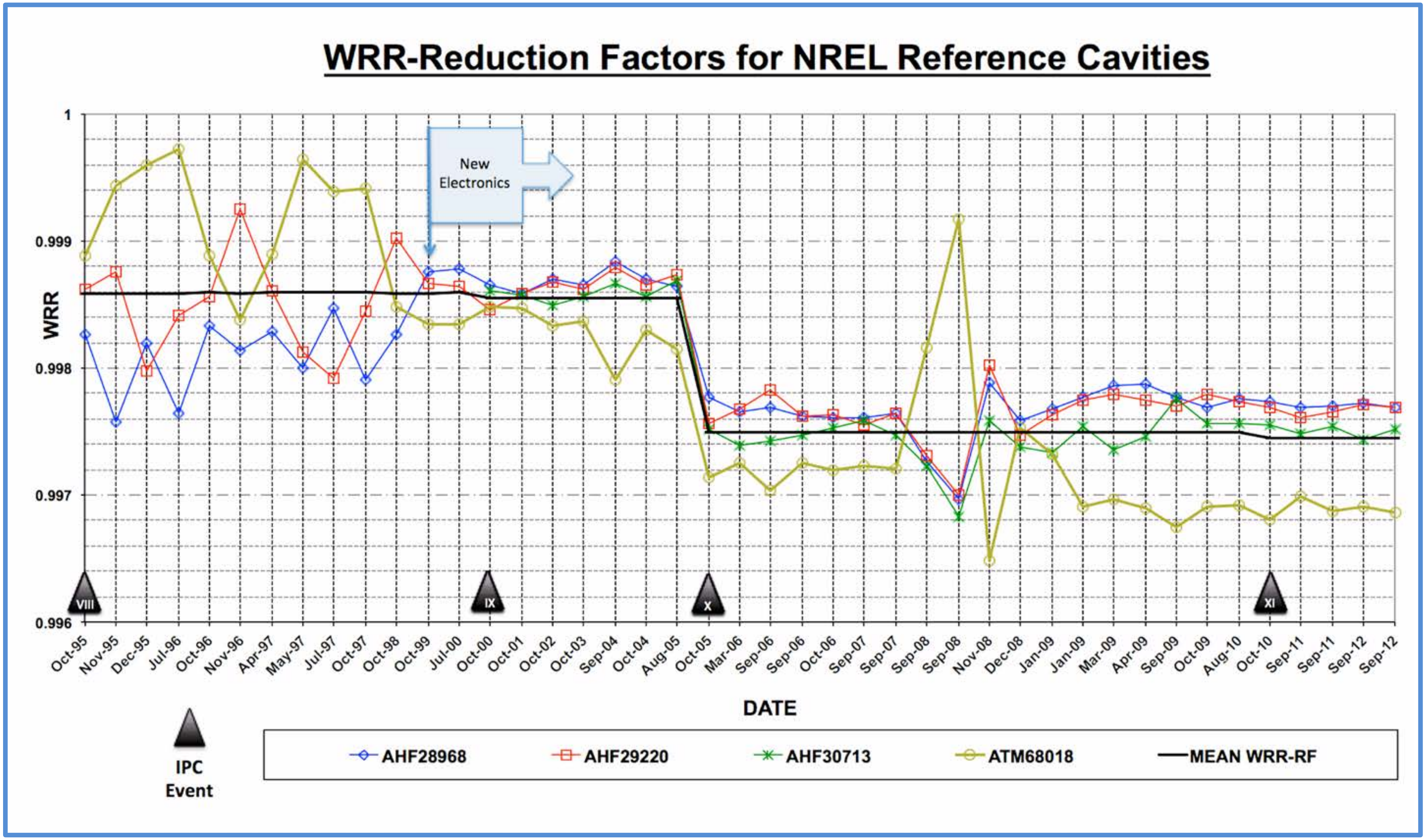

Figure 1. History of WRR reduction factors for NREL reference cavities

The uncertainty of the WRR-TF associated with each participating radiometer with respect to SI was calculated using the following formula:

$$U_{95} = \pm 1.96 * \sqrt{u_A^2 + u_B^2}$$

where,

- U_{95} = Uncertainty of the WRR-TF (in percent) determined at NPC-2012 with 95% confidence level
- 1.96 = Coverage factor
- u_A = Type A standard uncertainty = standard deviation of each participating (in percent) determined at NPC-2012
- u_B = Type B standard uncertainty
- $u_B = \pm \sqrt{(\frac{0.3}{\sqrt{3}})^2 + 0.7^2}$

where:

- 0.3 = Estimated expanded uncertainty (±%) of the WRR scale with respect to SI
- $\sqrt{3}$ = Coverage factor for rectangular distribution
- 0.07 = Pooled standard deviation of the four reference radiometers (TSG) that participated in IPC-XI (September/October 2010).

The statistical analyses of WRR-TF for 46 participating pyrheliometers are presented in Figures 2 through Figure 48. These graphical summaries indicate the mean, standard deviation, and histograms of the WRR-TF determined during NPC-2012.

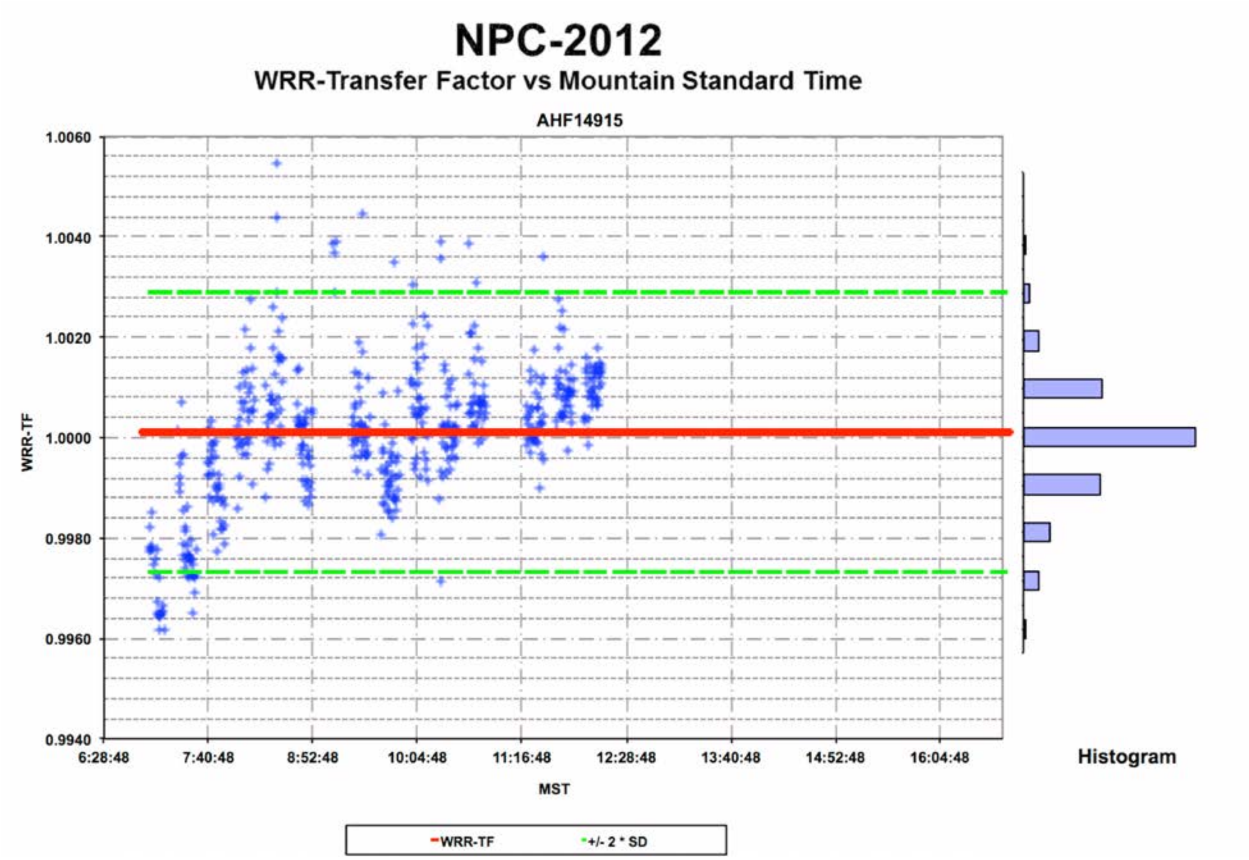

Figure 2. WRR-TF versus Mountain Standard Time (MST) for AHF14915 during NPC-2012

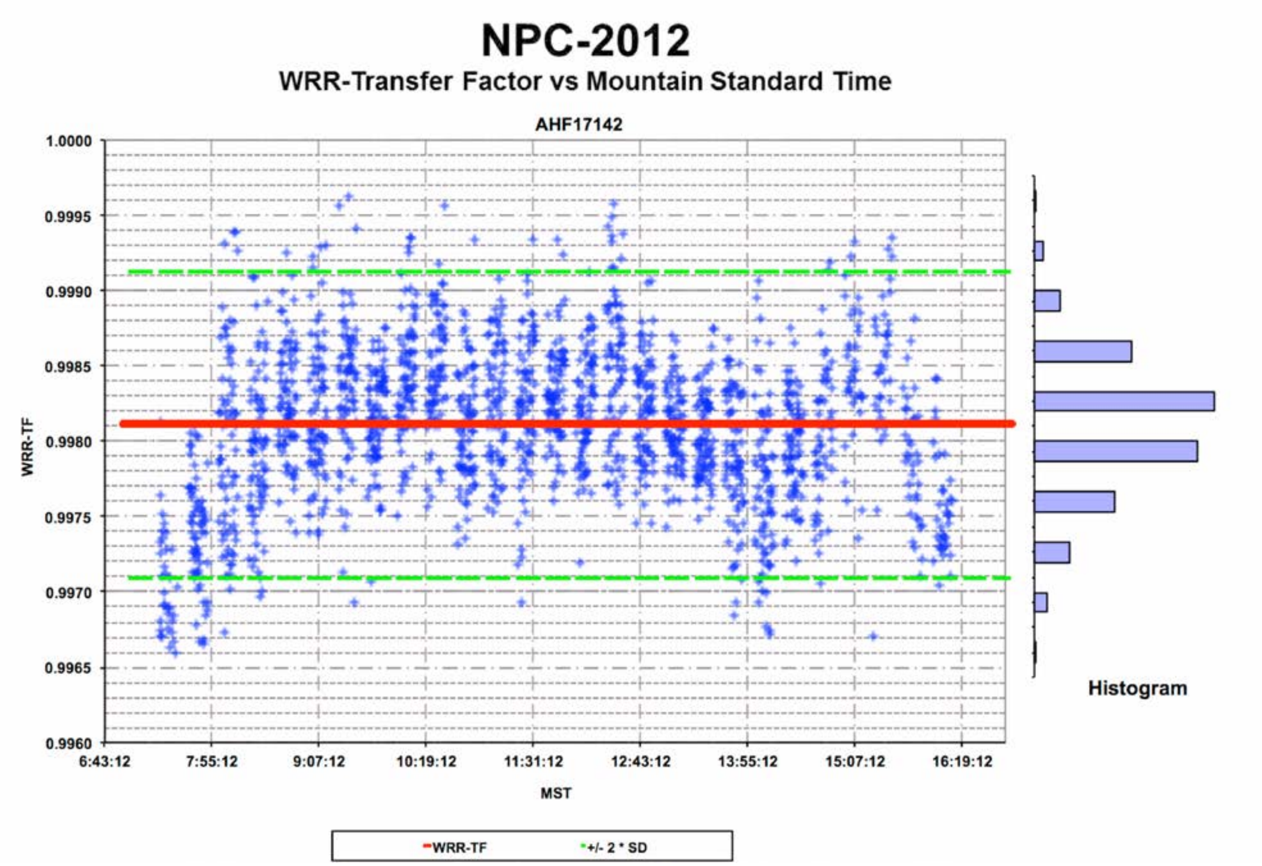

Figure 3. WRR-TF versus MST for AHF 17142 during NPC-2012

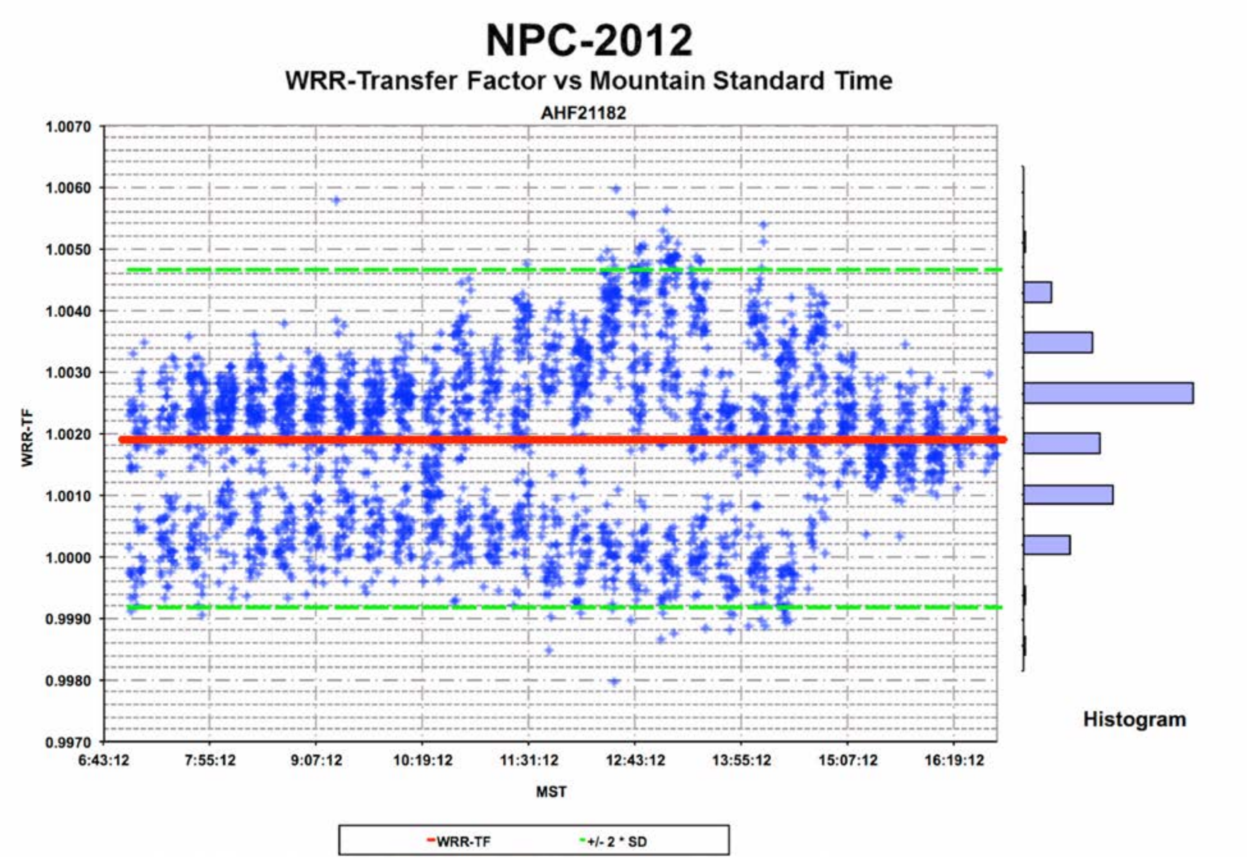

Figure 4. WRR-TF versus MST for AHF 21182 during NPC-2012

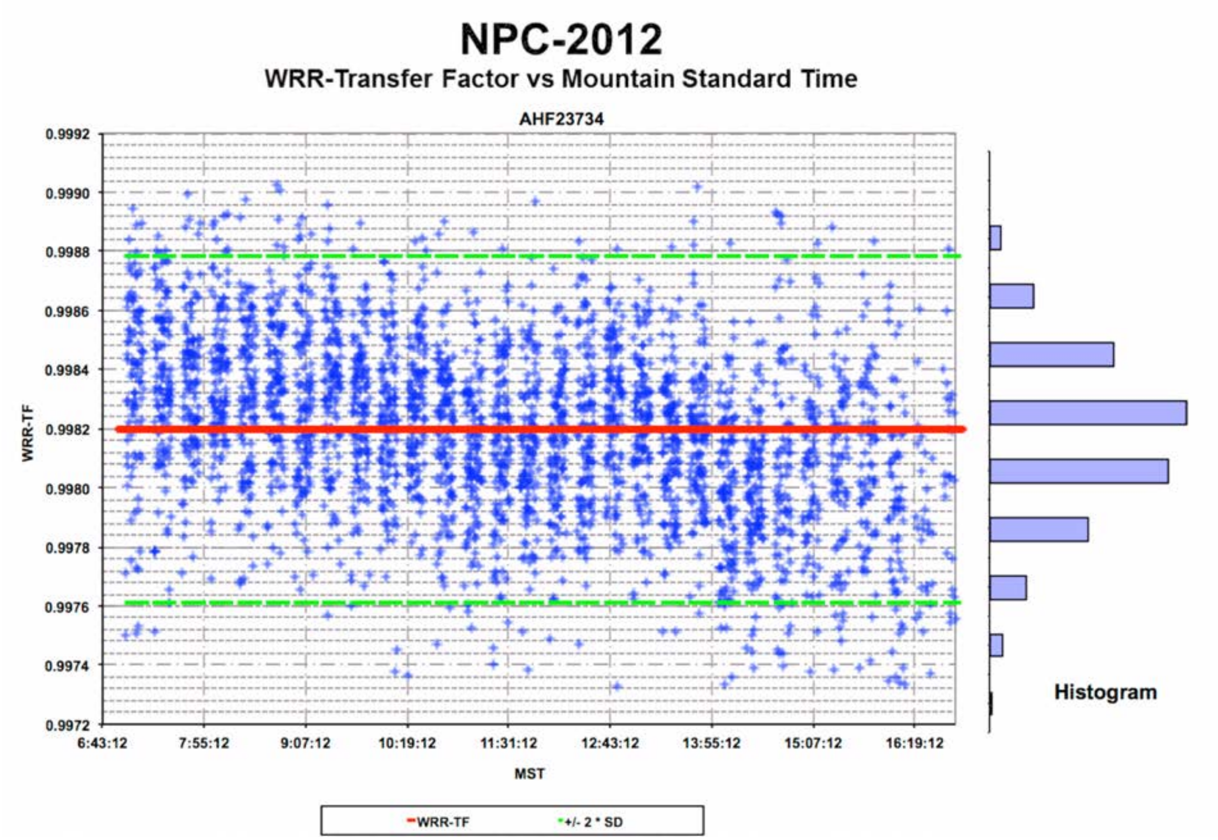

Figure 5. WRR-TF versus MST for AHF 23734 during NPC-2012

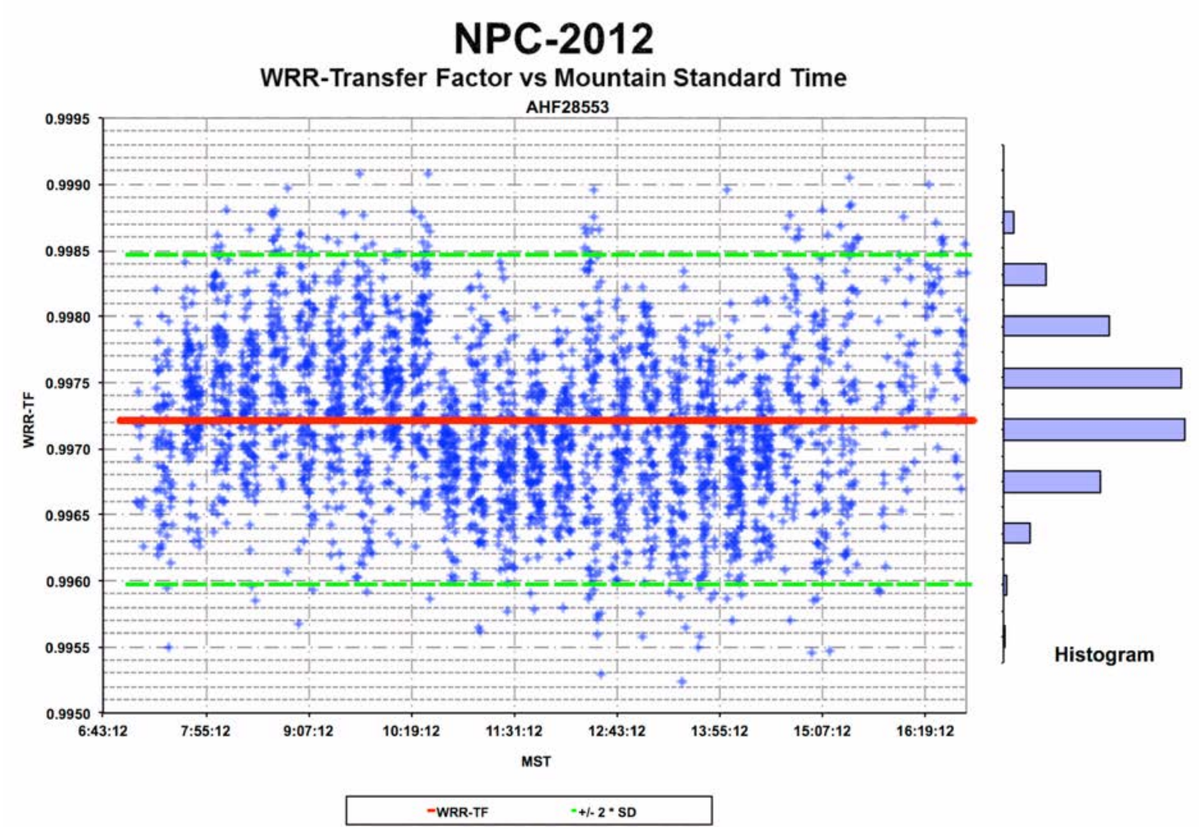

Figure 6. WRR-TF versus MST for AHF 28553 during NPC-2012

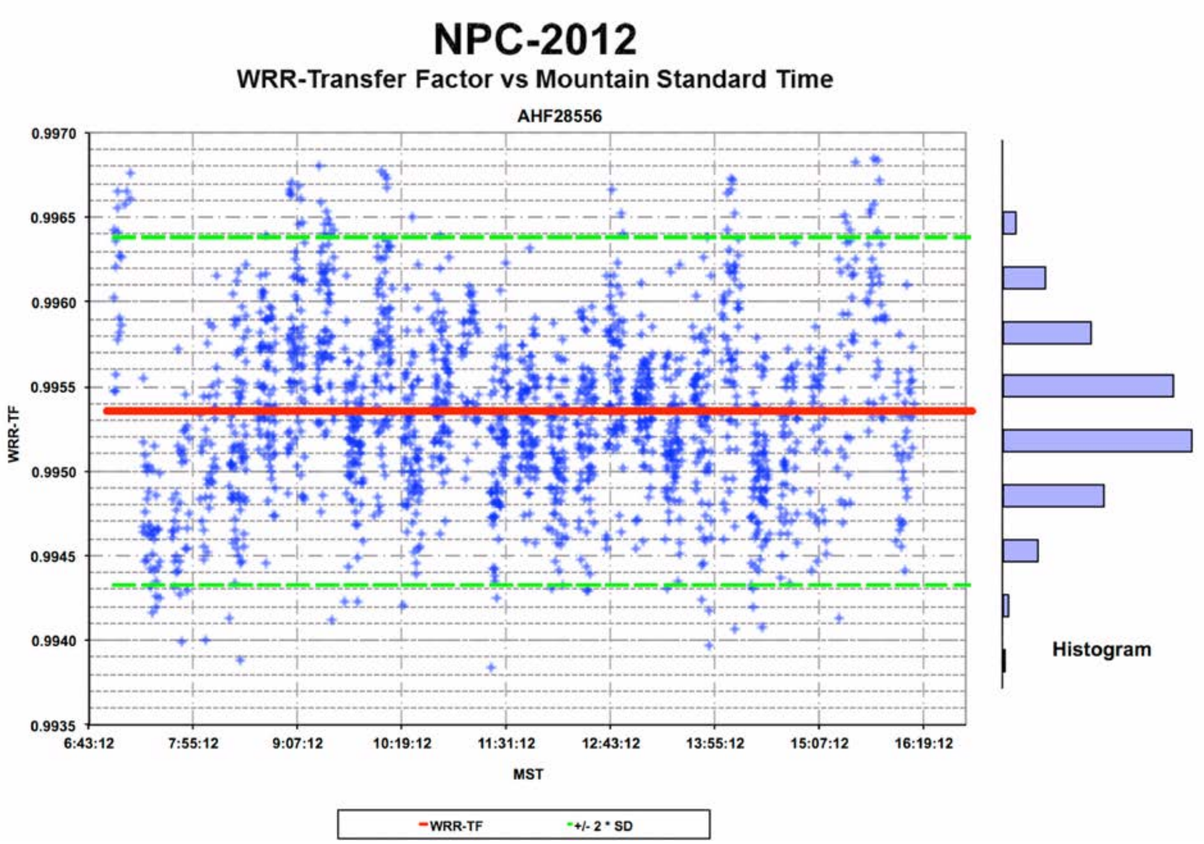

Figure 7. WRR-TF versus MST for AHF 28556 during NPC-2012

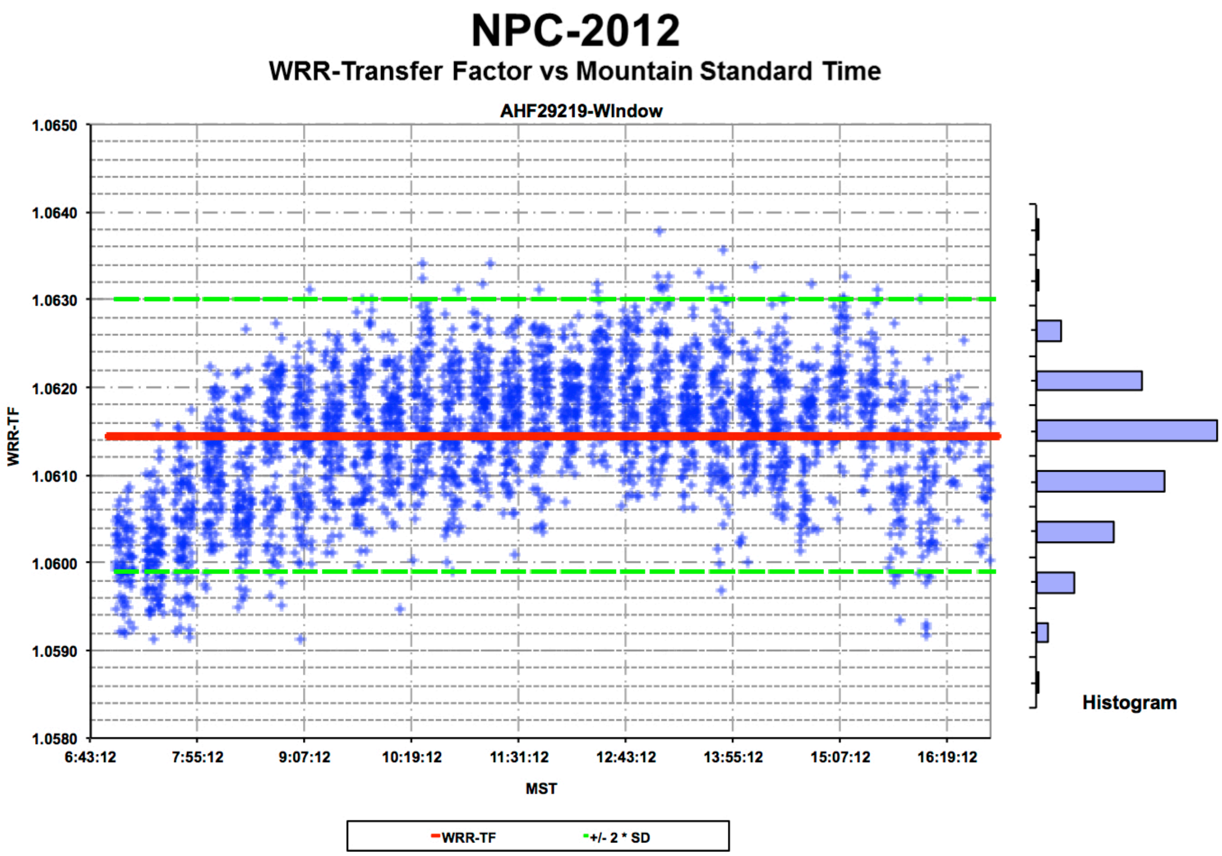

Figure 8. WRR-TF versus MST for AHF 29219 during NPC-2012

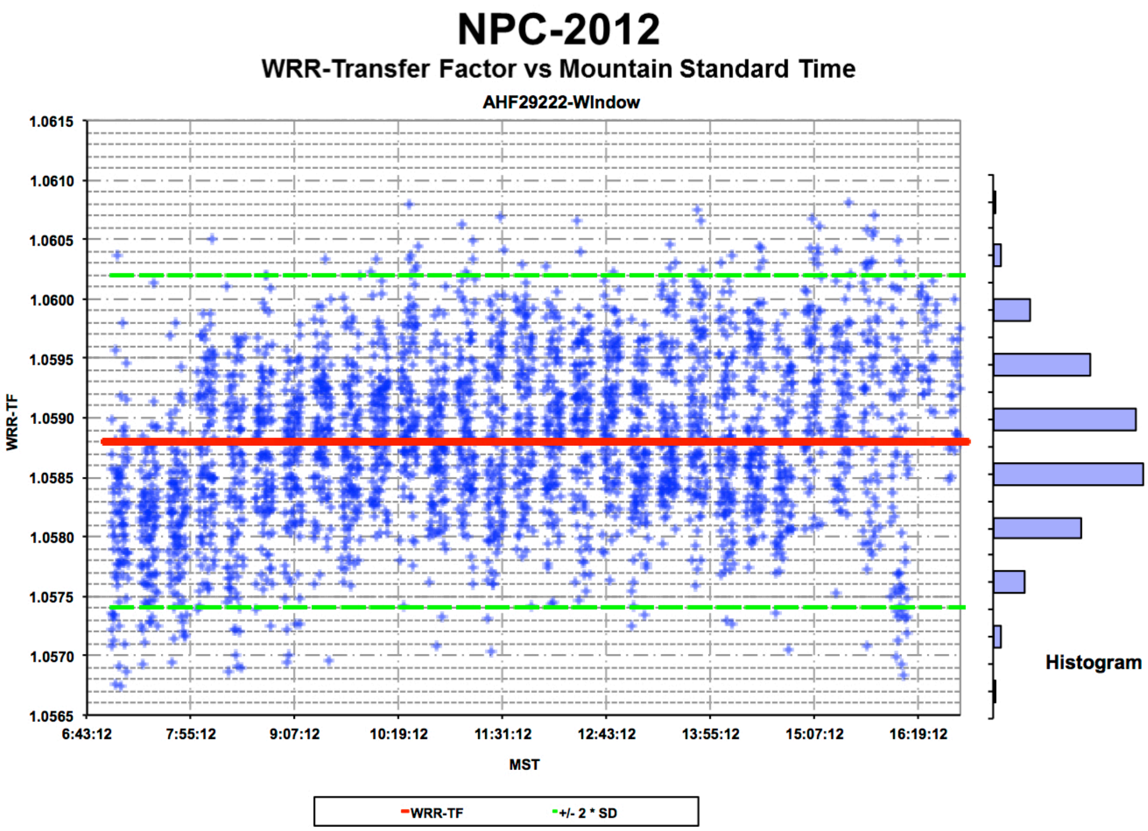

Figure 9. WRR-TF versus MST for AHF 29222 during NPC-2012

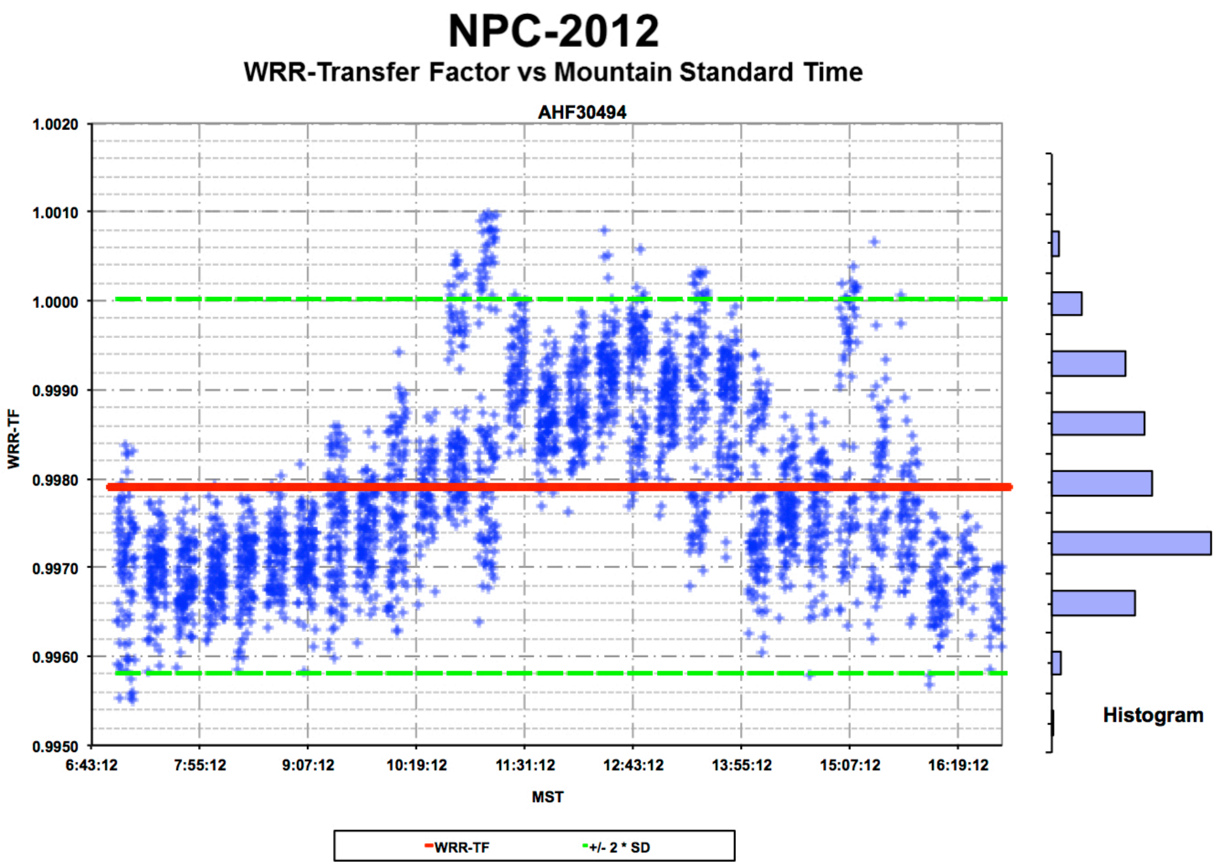

Figure 10. WRR-TF versus MST for AHF 30494 during NPC-2012

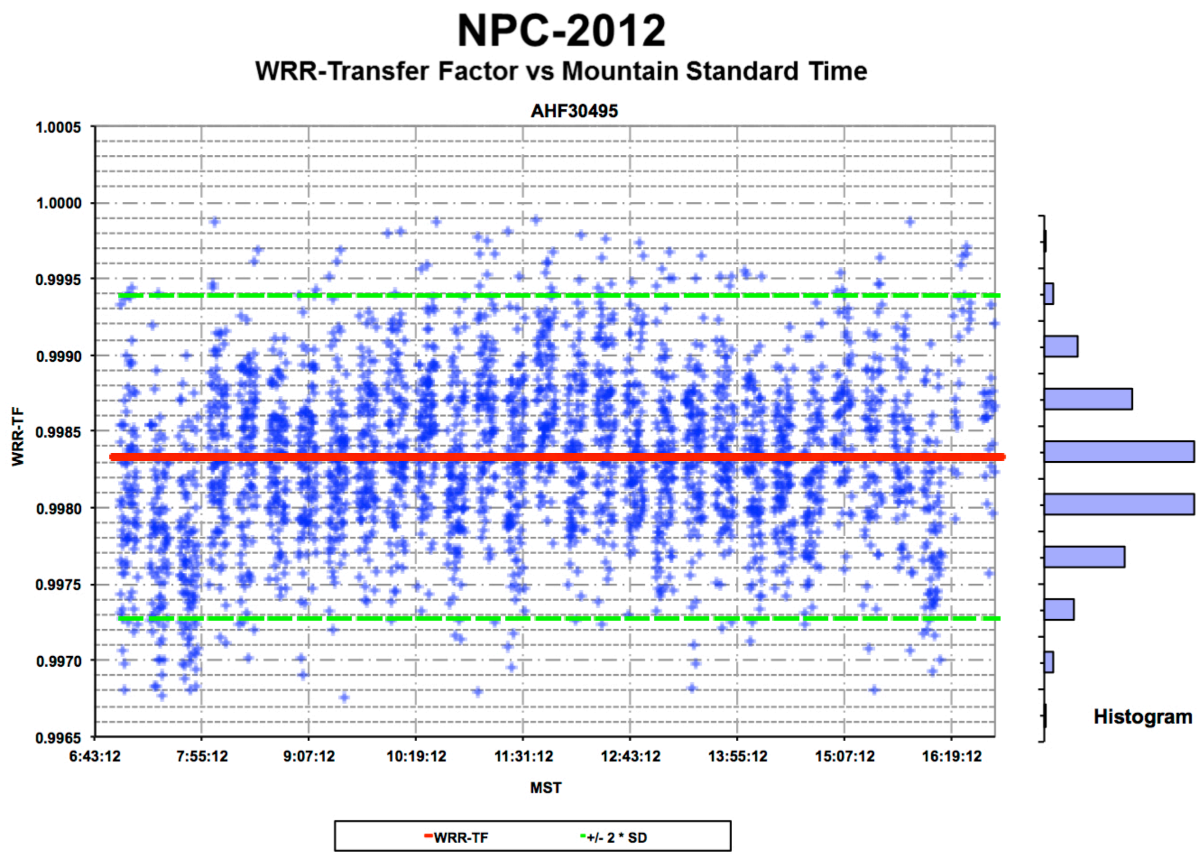

Figure 11. WRR-TF versus MST for AHF 30495 during NPC-2012

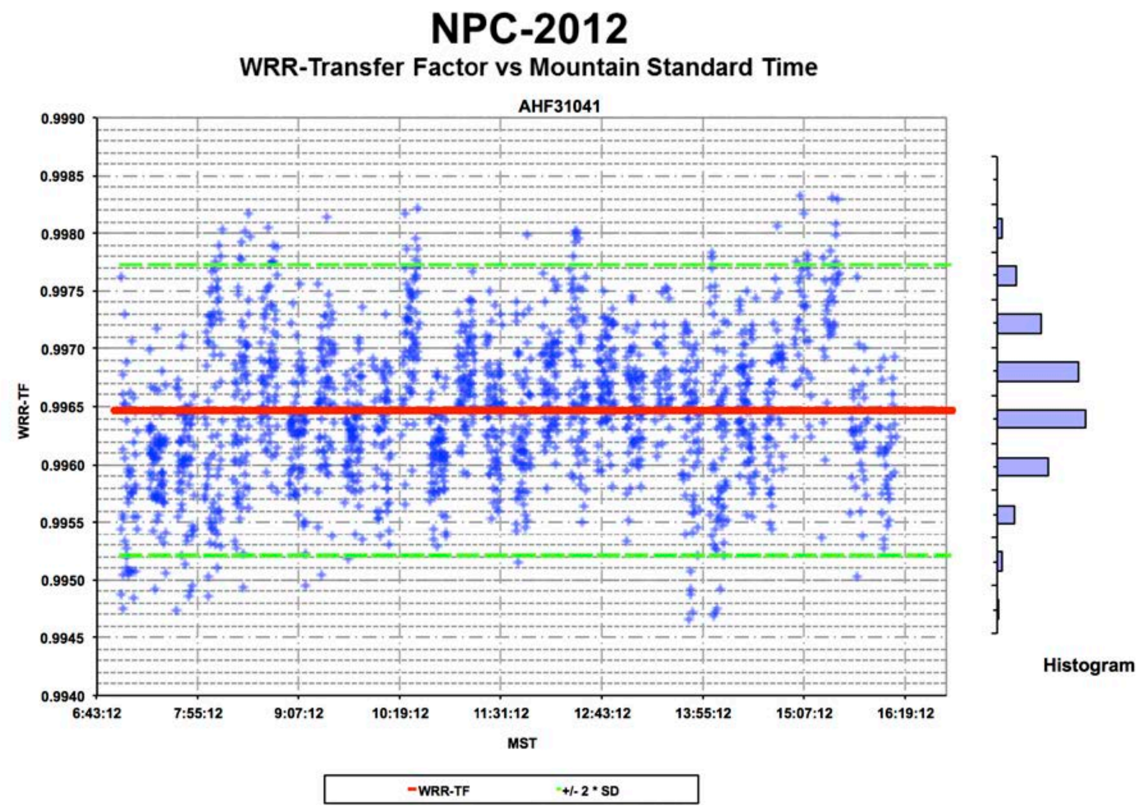

Figure 12. WRR-TF versus MST for AHF 31041 during NPC-2012

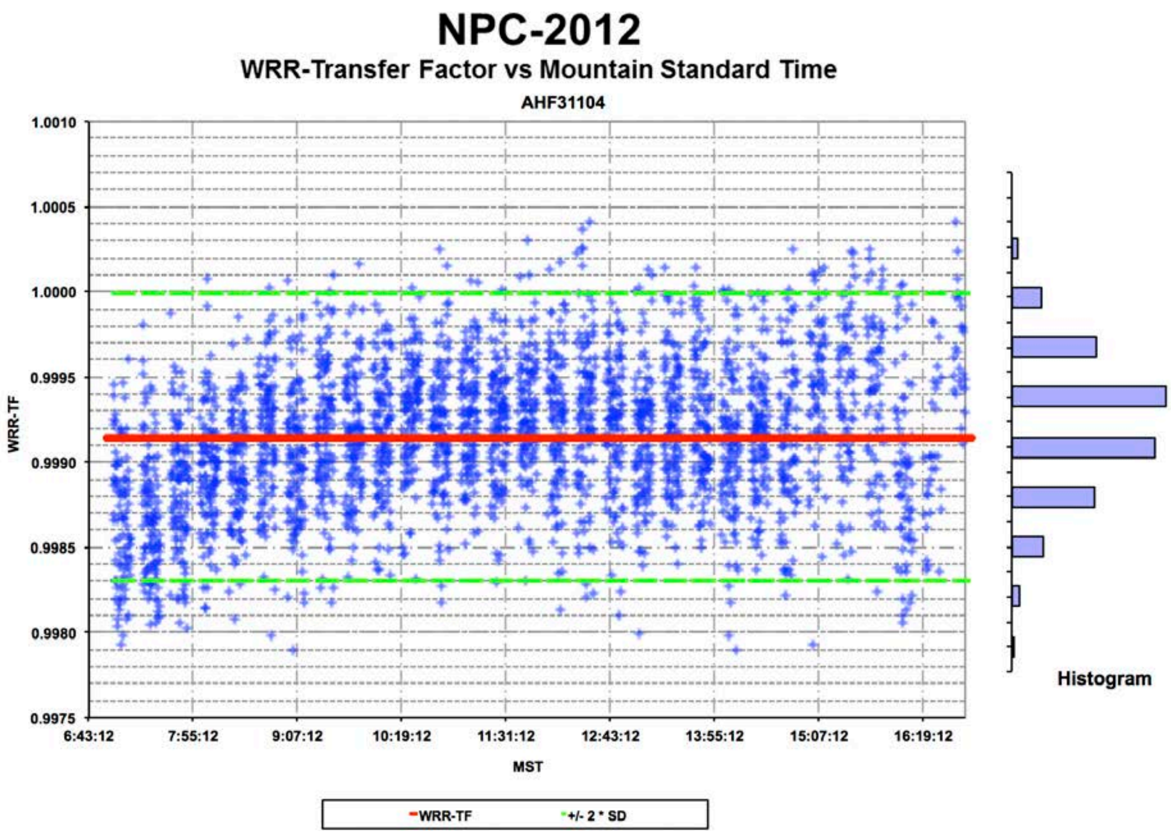

Figure 13. WRR-TF versus MST for AHF 31104 during NPC-2012

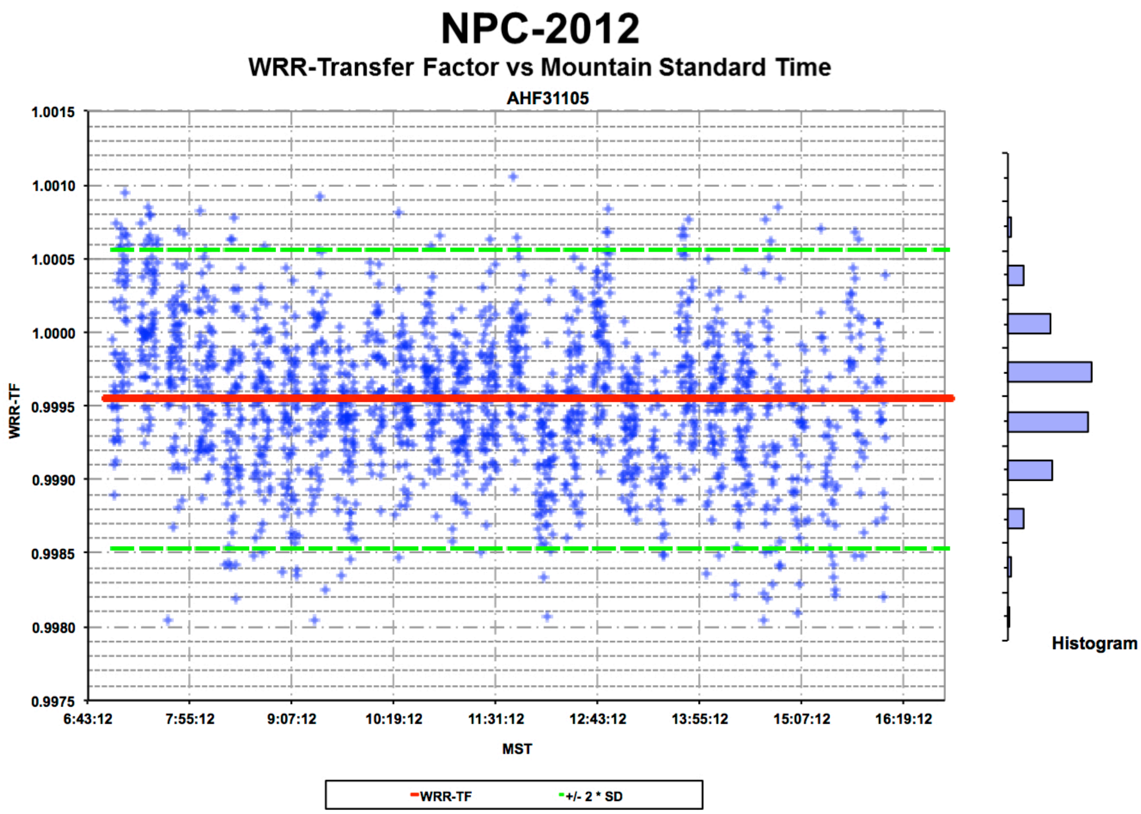

Figure 14. WRR-TF versus MST for AHF 31105 during NPC-2012

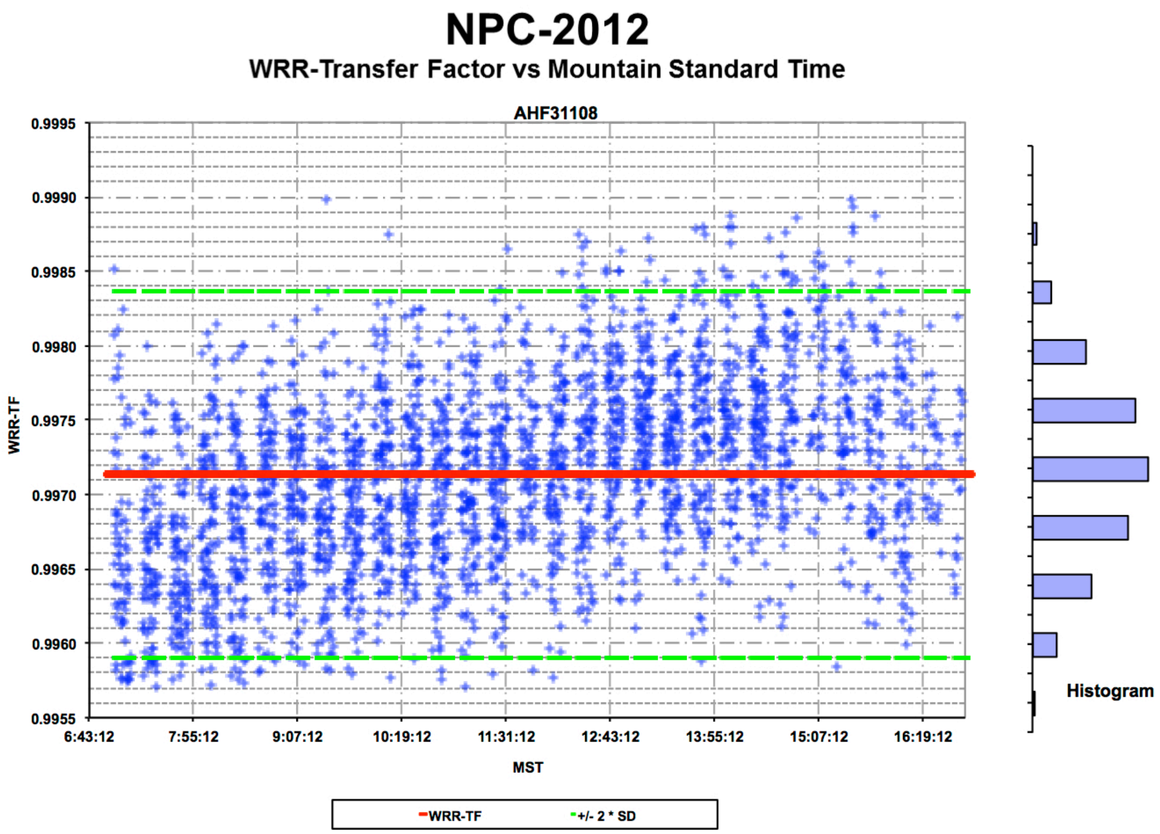

Figure 15. WRR-TF versus MST for AHF 31108 during NPC-2012

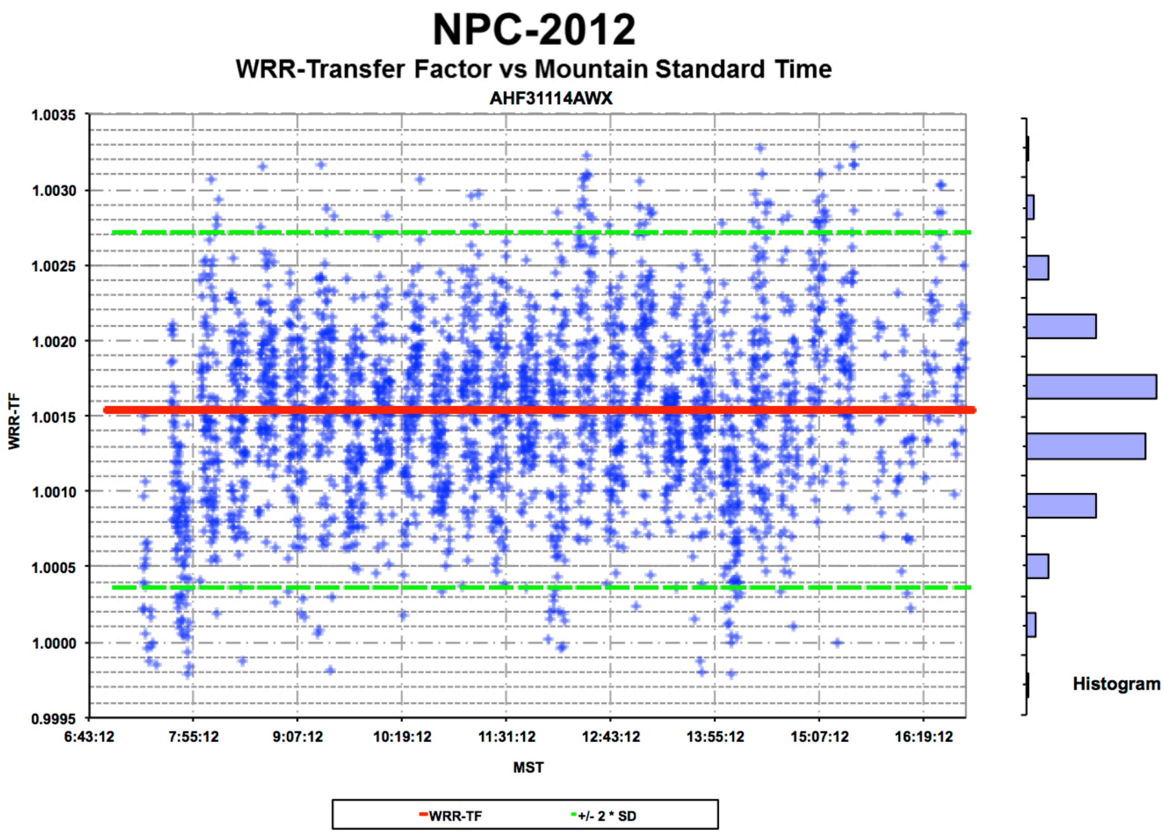

Figure 16. WRR-TF versus MST for AHF 31114AWX during NPC-2012

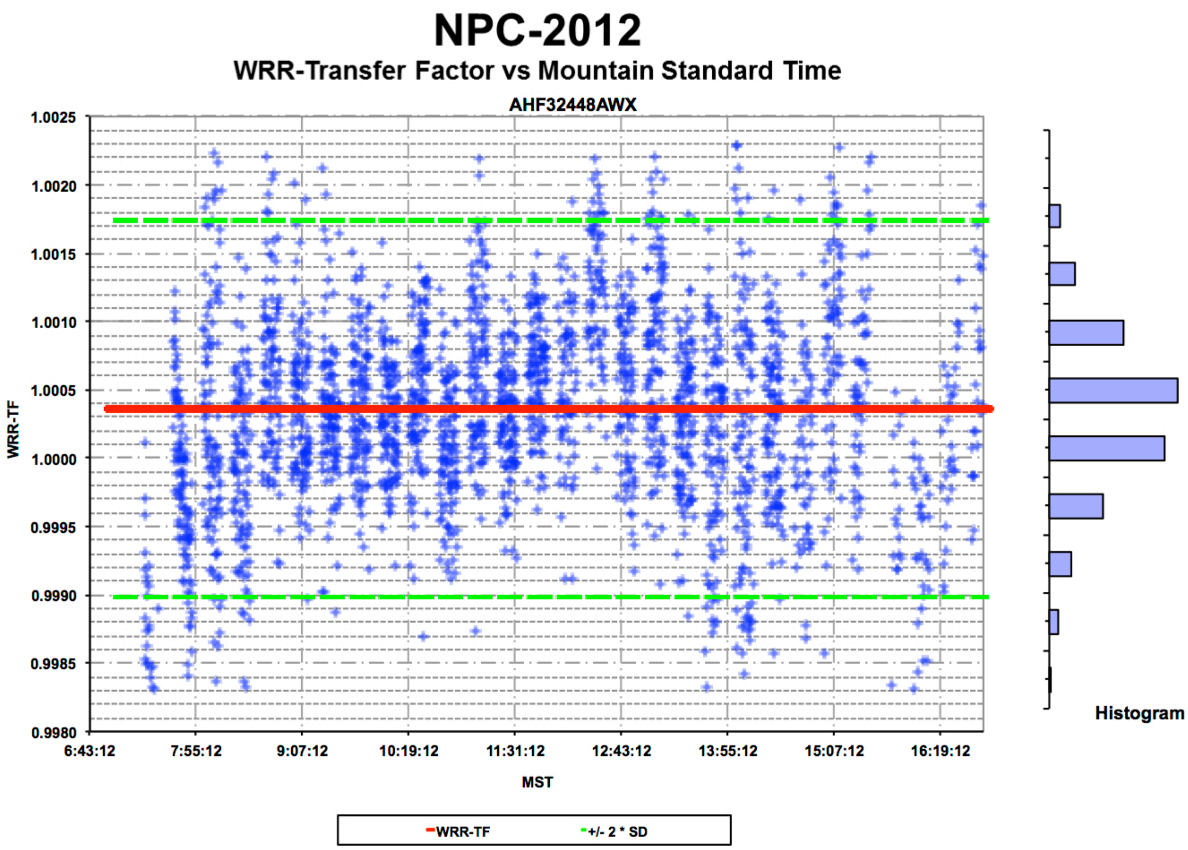

Figure 17. WRR-TF versus MST for AHF 32448AWX during NPC-2012

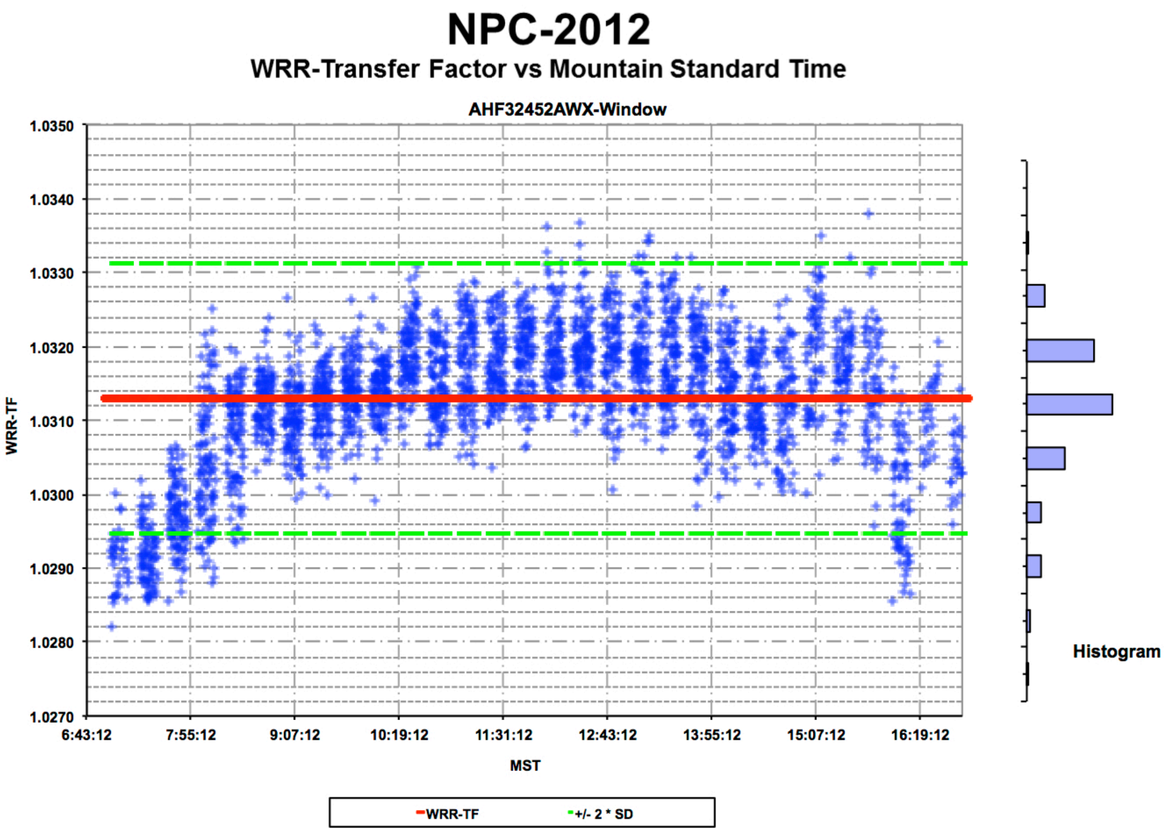

Figure 18. WRR-TF versus MST for AHF 32452AWX during NPC-2012

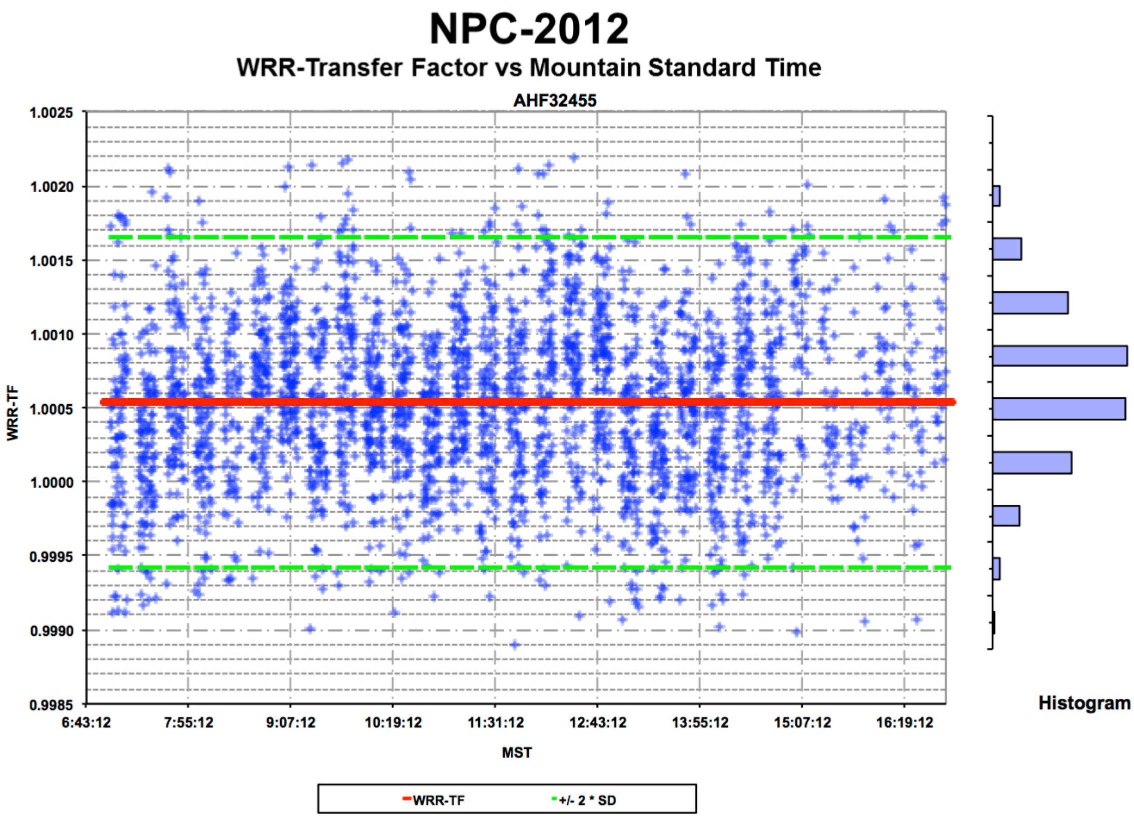

Figure 19. WRR-TF versus MST for AHF 32455 during NPC-2012

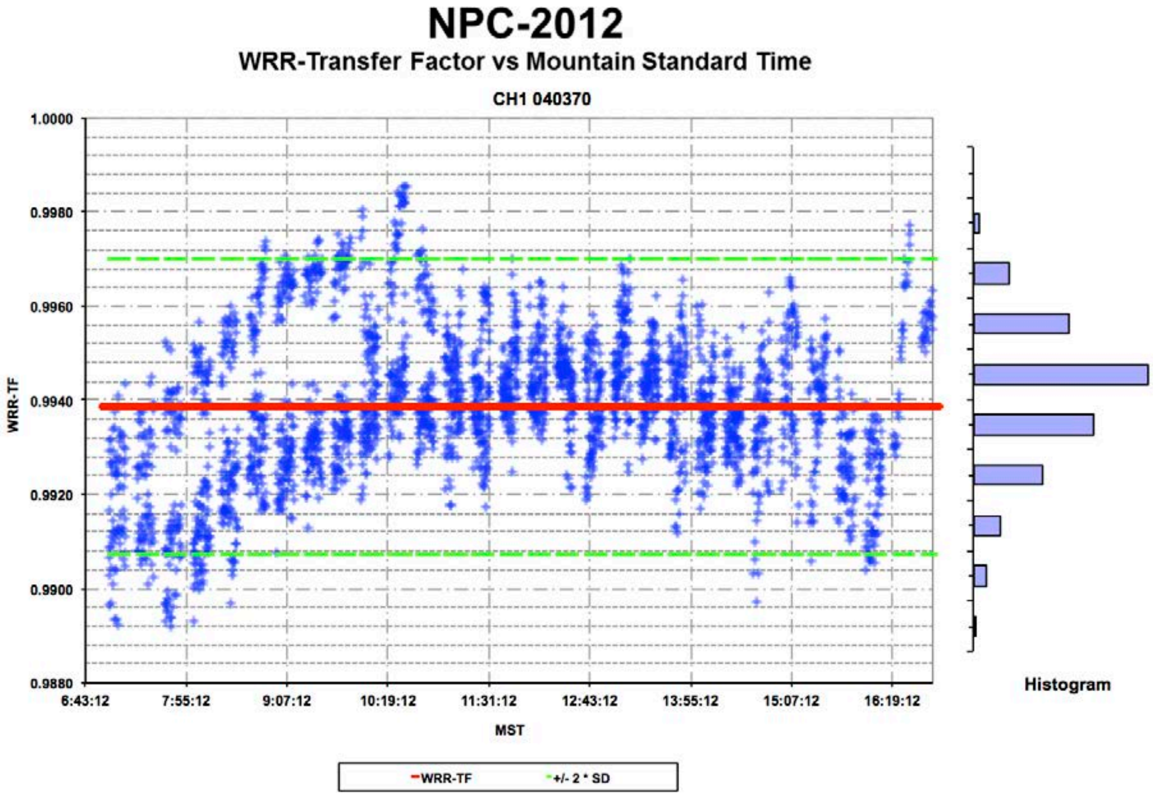

Figure 20. WRR-TF versus MST for CH1 040370 during NPC-2012

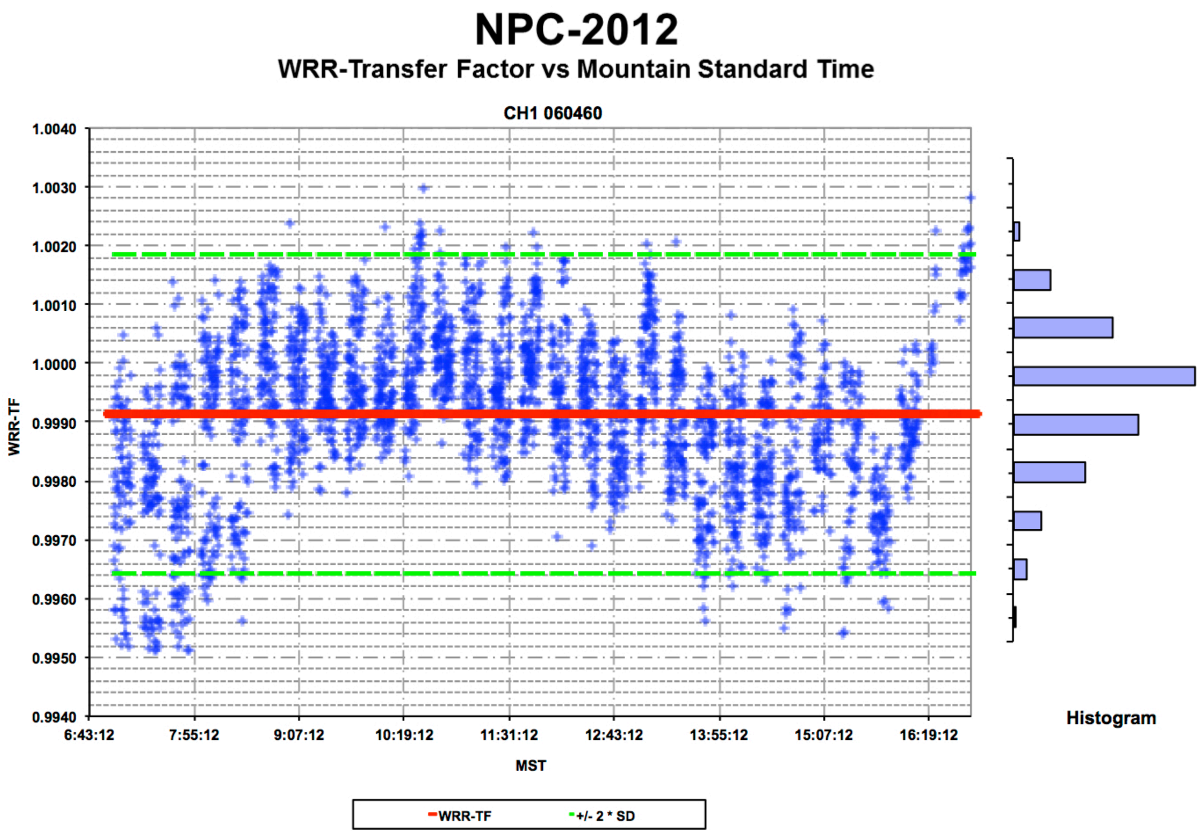

Figure 21. WRR-TF versus MST for CH1 060460 during NPC-2012

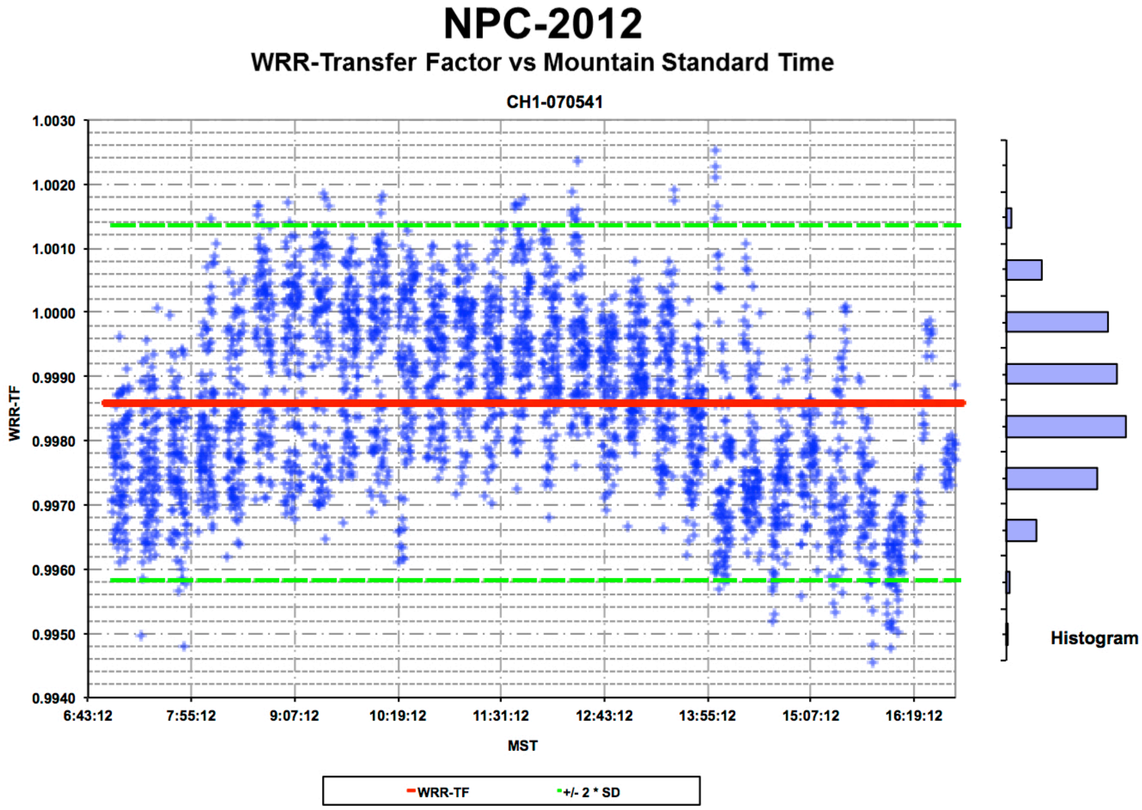

Figure 22. WRR-TF versus MST for CH1 070541 during NPC-2012

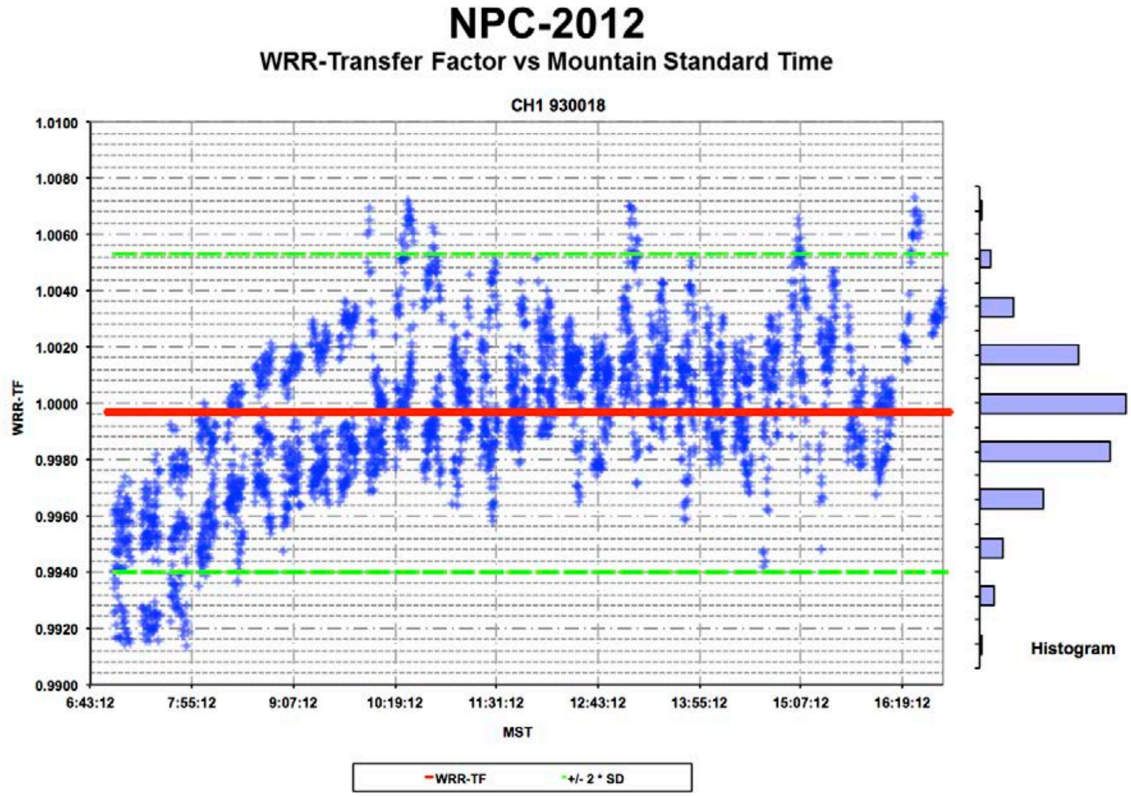

Figure 23. WRR-TF versus MST for CH1 930018 during NPC-2012

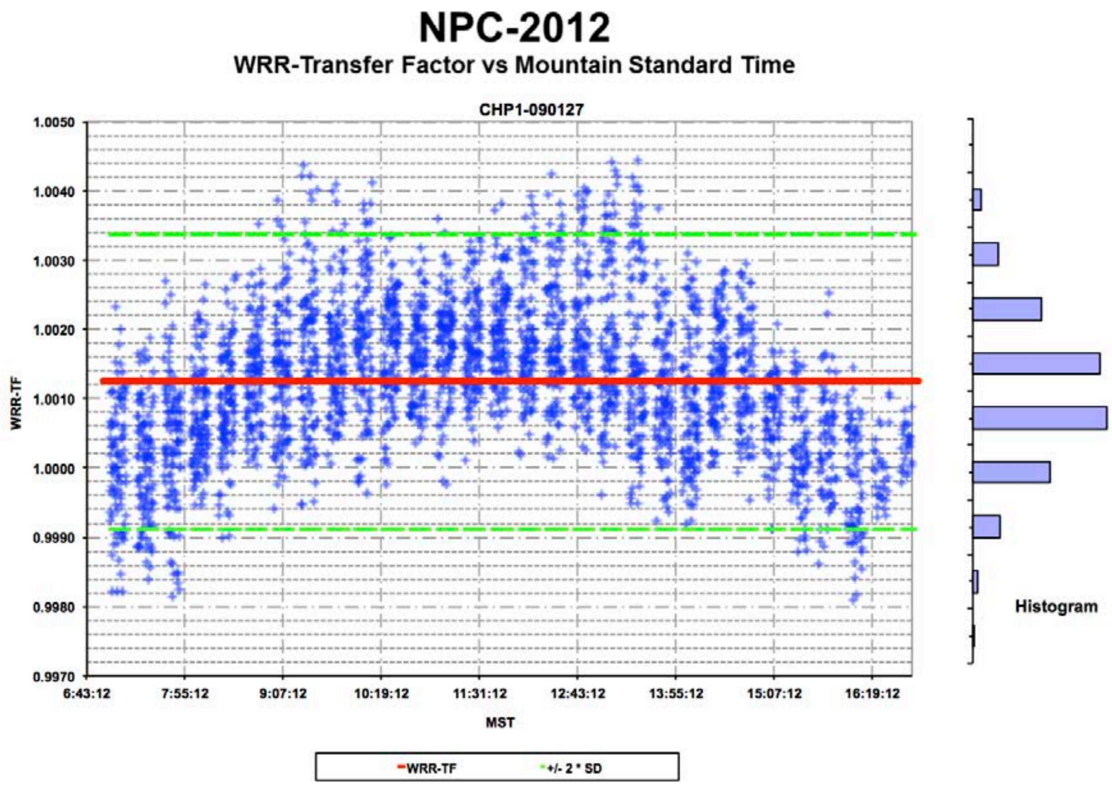

Figure 24. WRR-TF versus MST for CHP1 090127 during NPC-2012

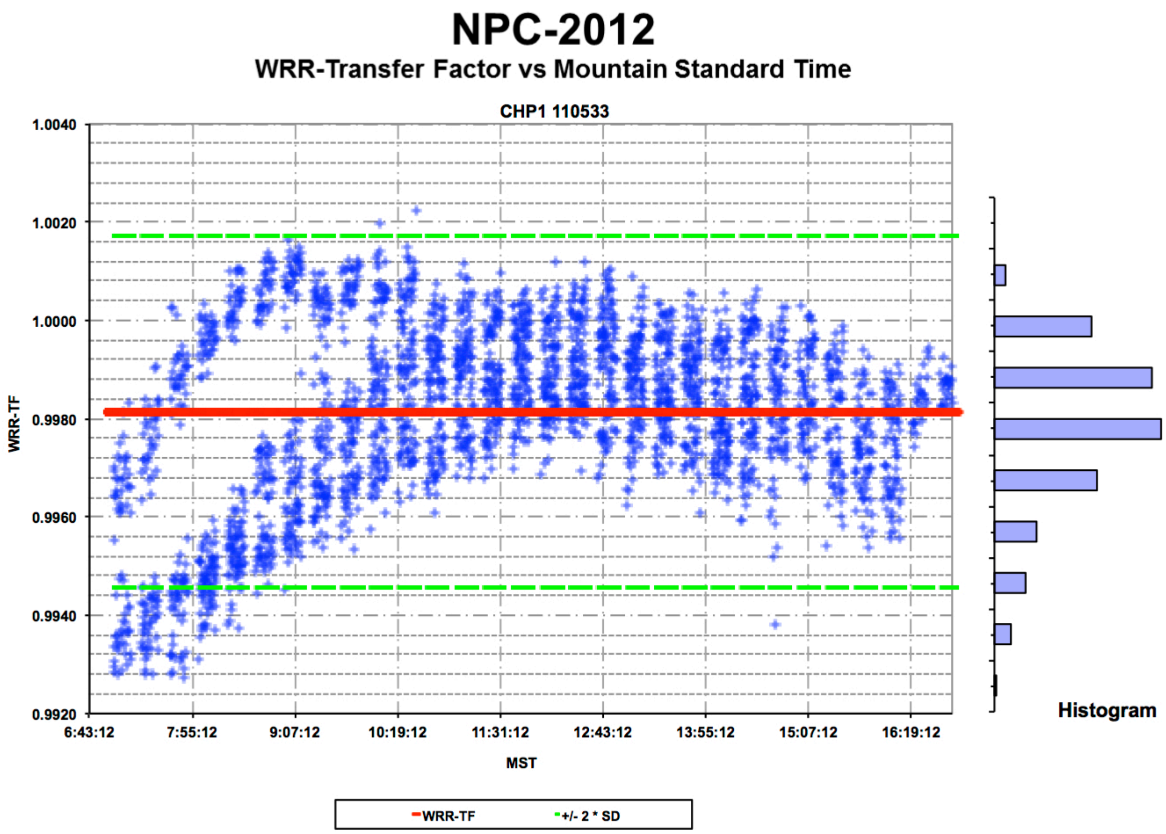

Figure 25. WRR-TF versus MST for CHP1 110533 during NPC-2012

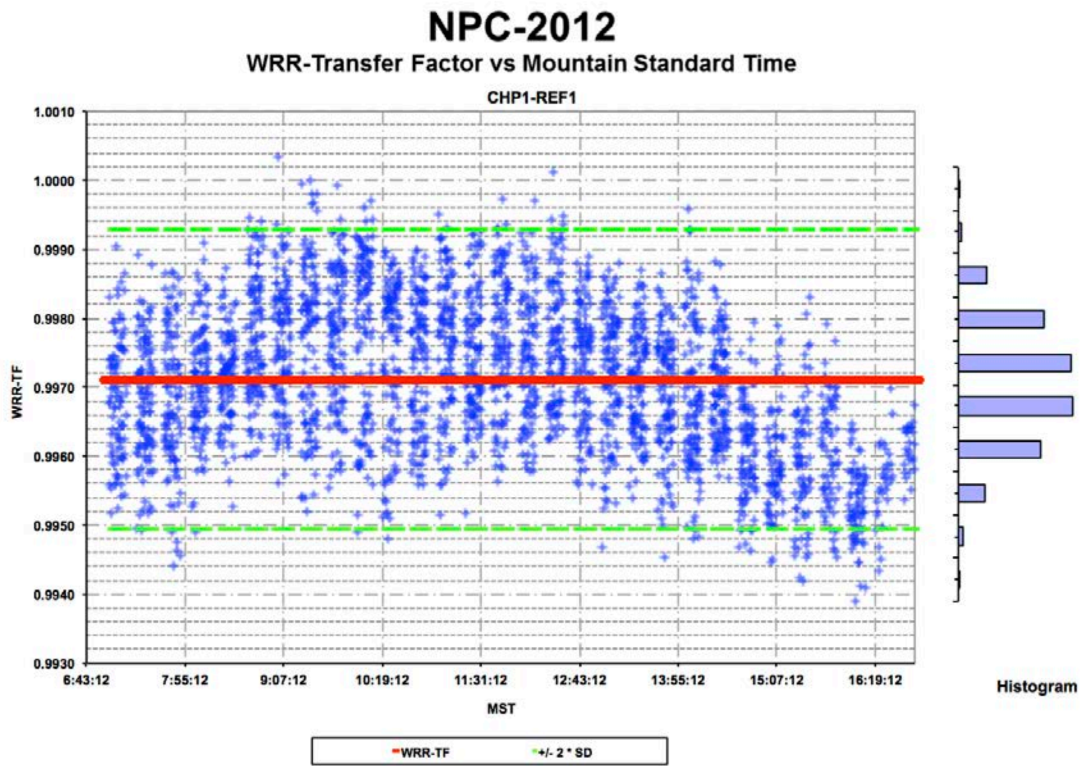

Figure 26. WRR-TF versus MST for CHP1 REF1 during NPC-2012

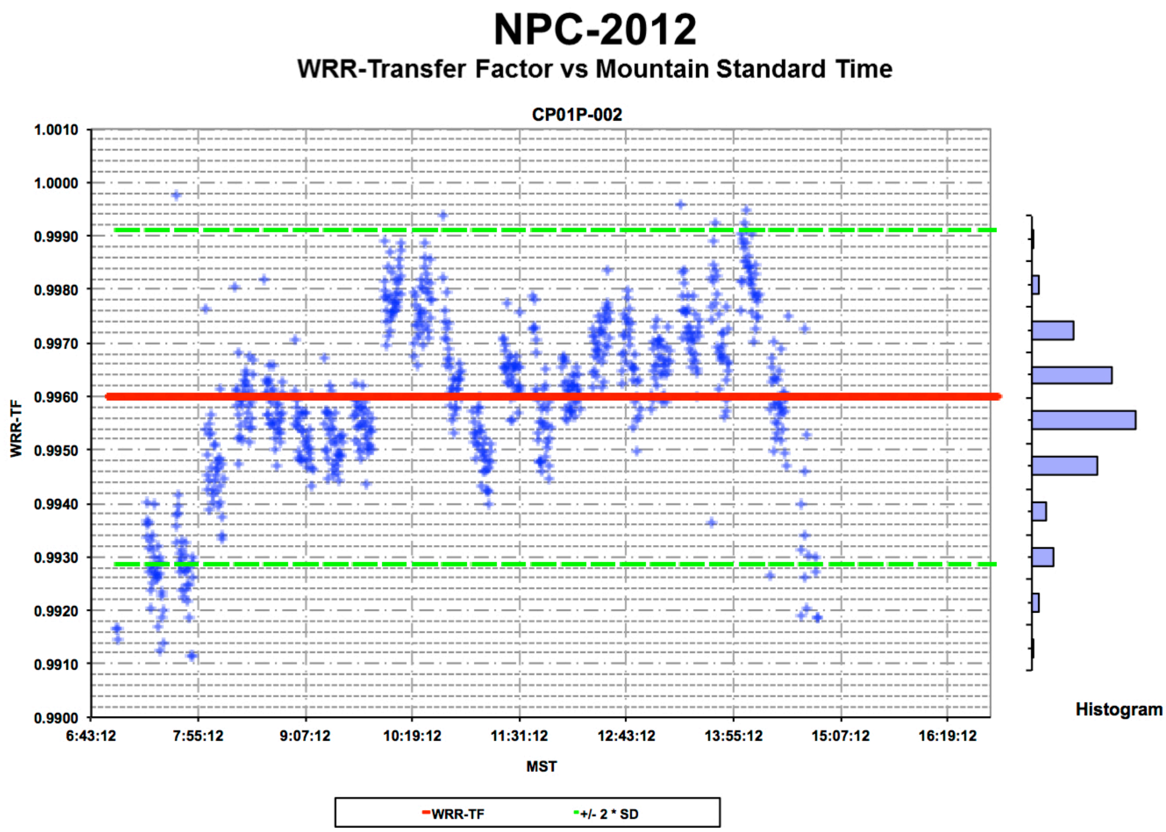

Figure 27. WRR-TF versus MST for CP01P 002 during NPC-2012

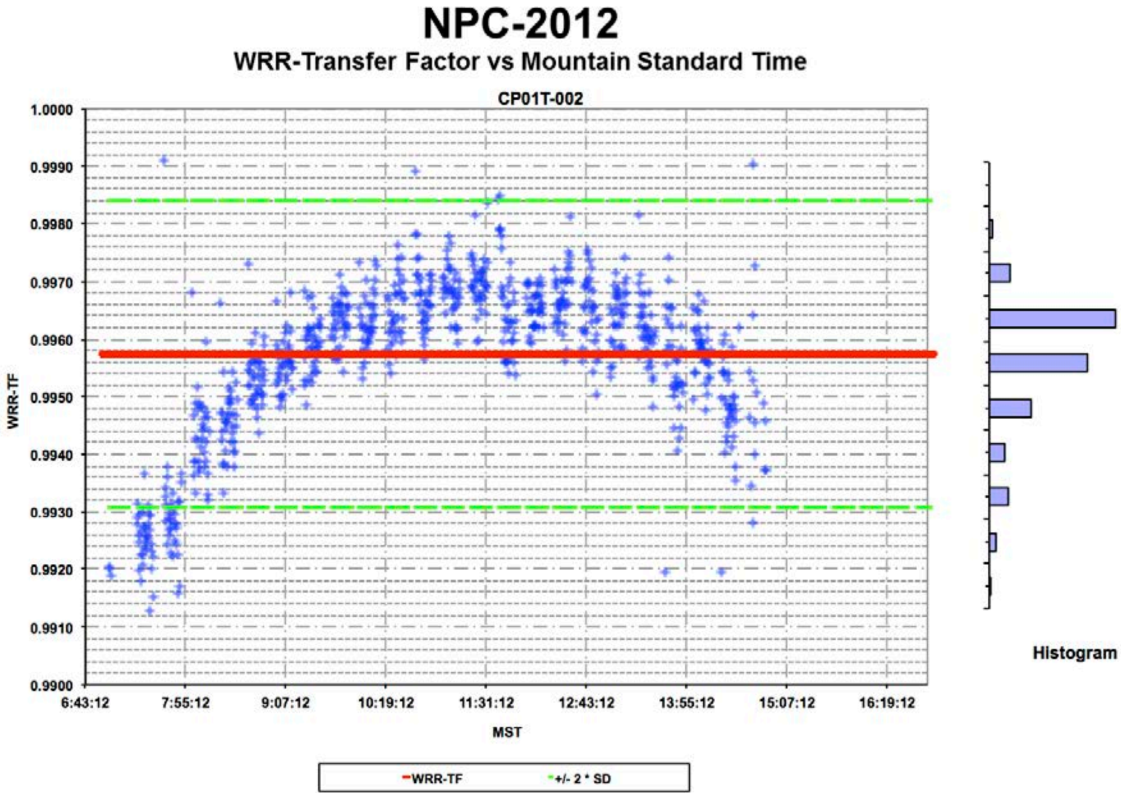

Figure 28. WRR-TF versus MST for CP01T 002 during NPC-2012

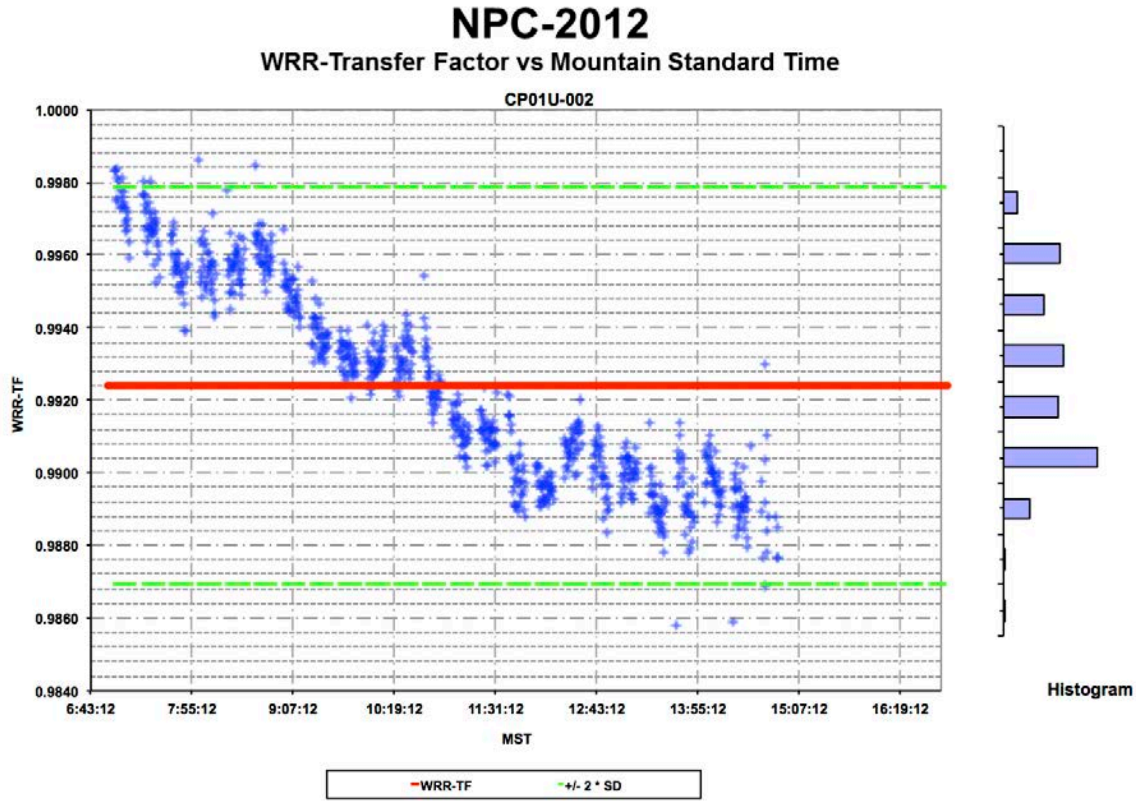

Figure 29. WRR-TF versus MST for CP01U 002 during NPC-2012

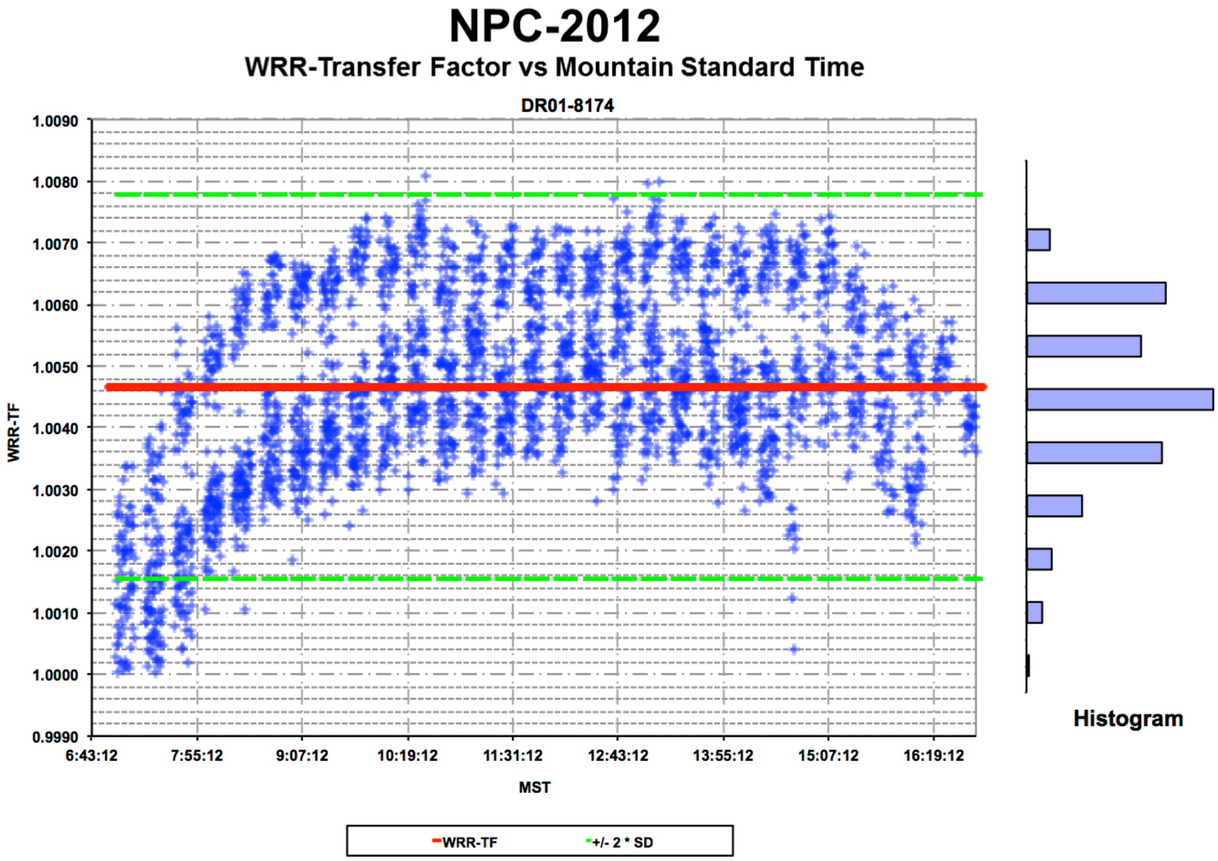

Figure 30. WRR-TF versus MST for DR01 8174 during NPC-2012

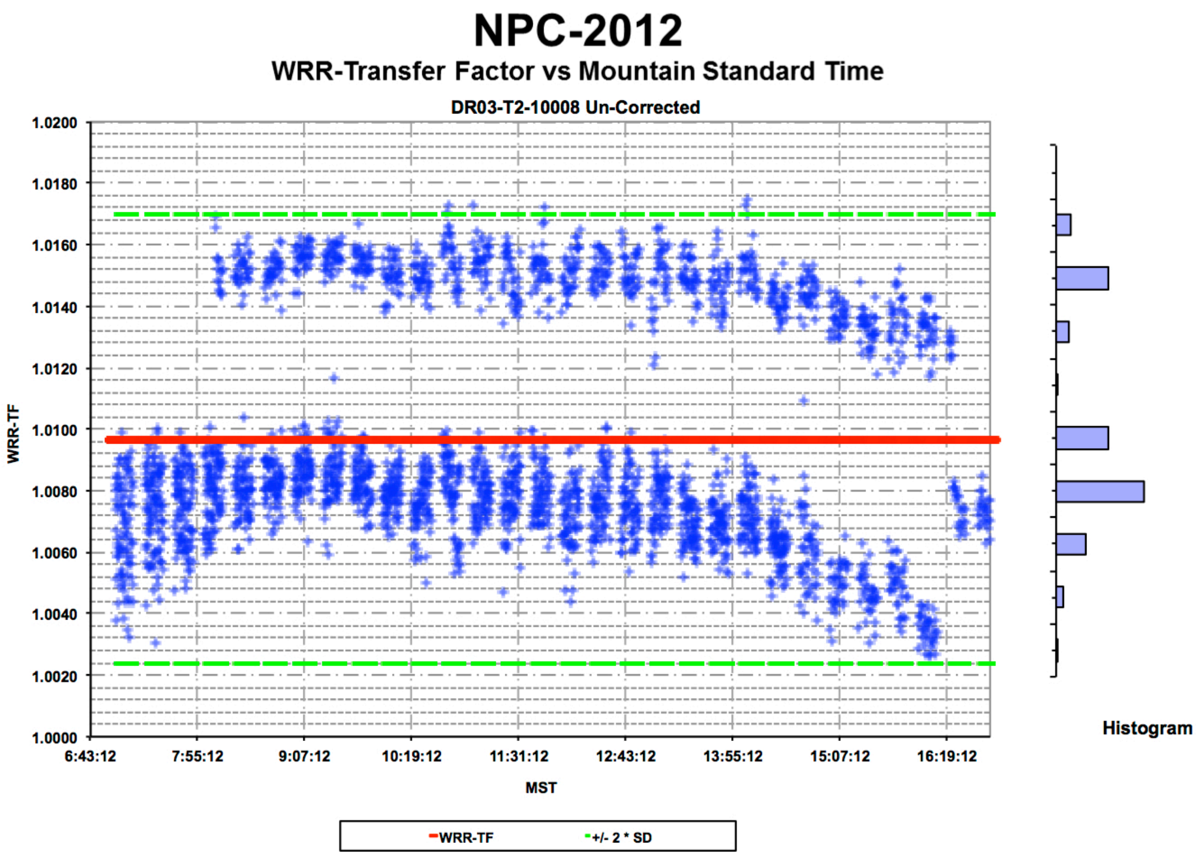

Figure 31. WRR-TF versus MST for DR03 T2-10008 during NPC-2012

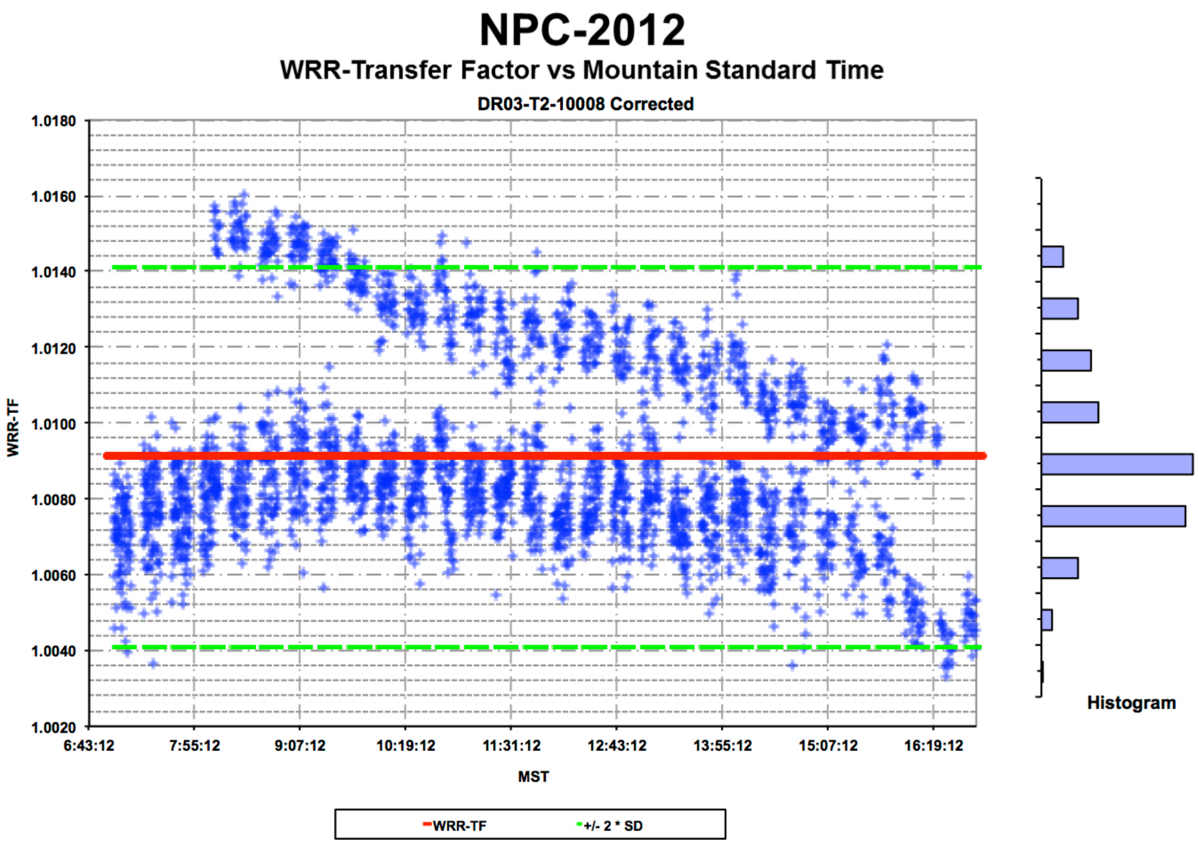

Figure 32. WRR-TF versus MST for DR03 T2-10008 Corrected during NPC-2012

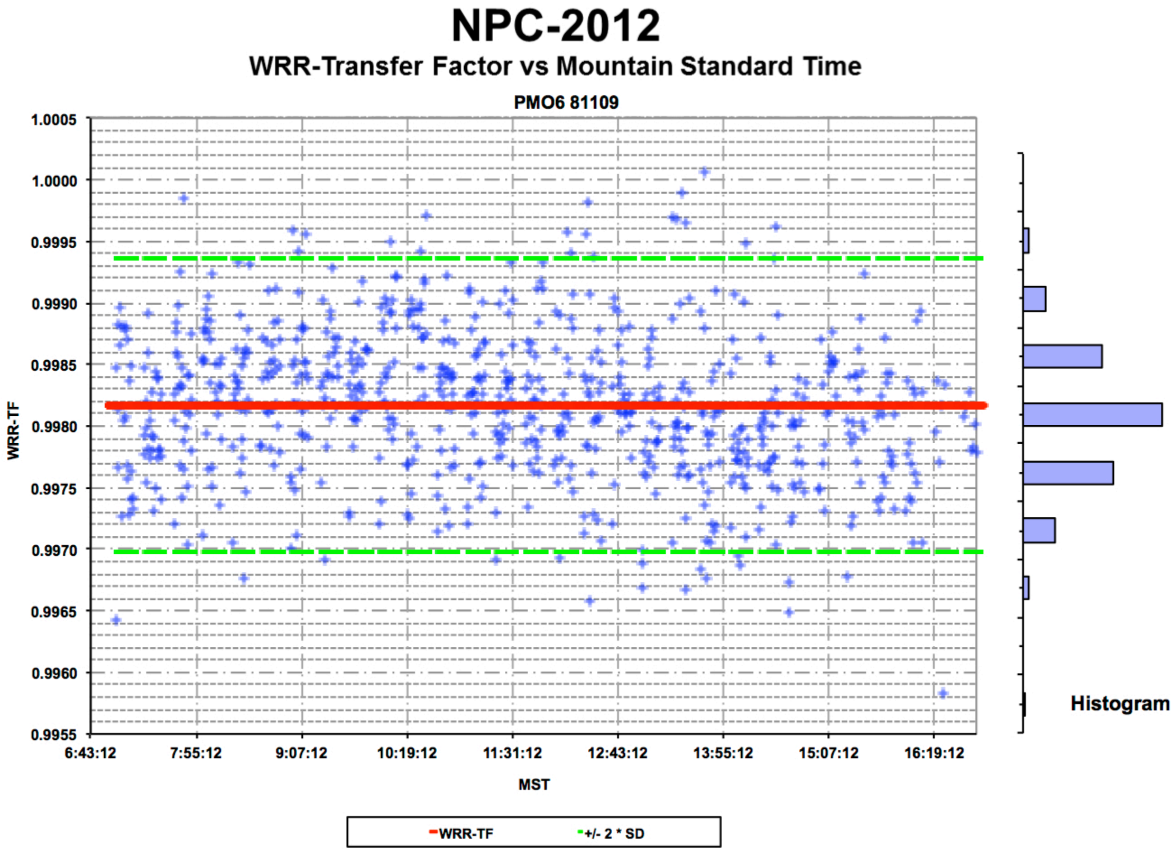

Figure 33. WRR-TF versus MST for PMO6 81109 during NPC-2012

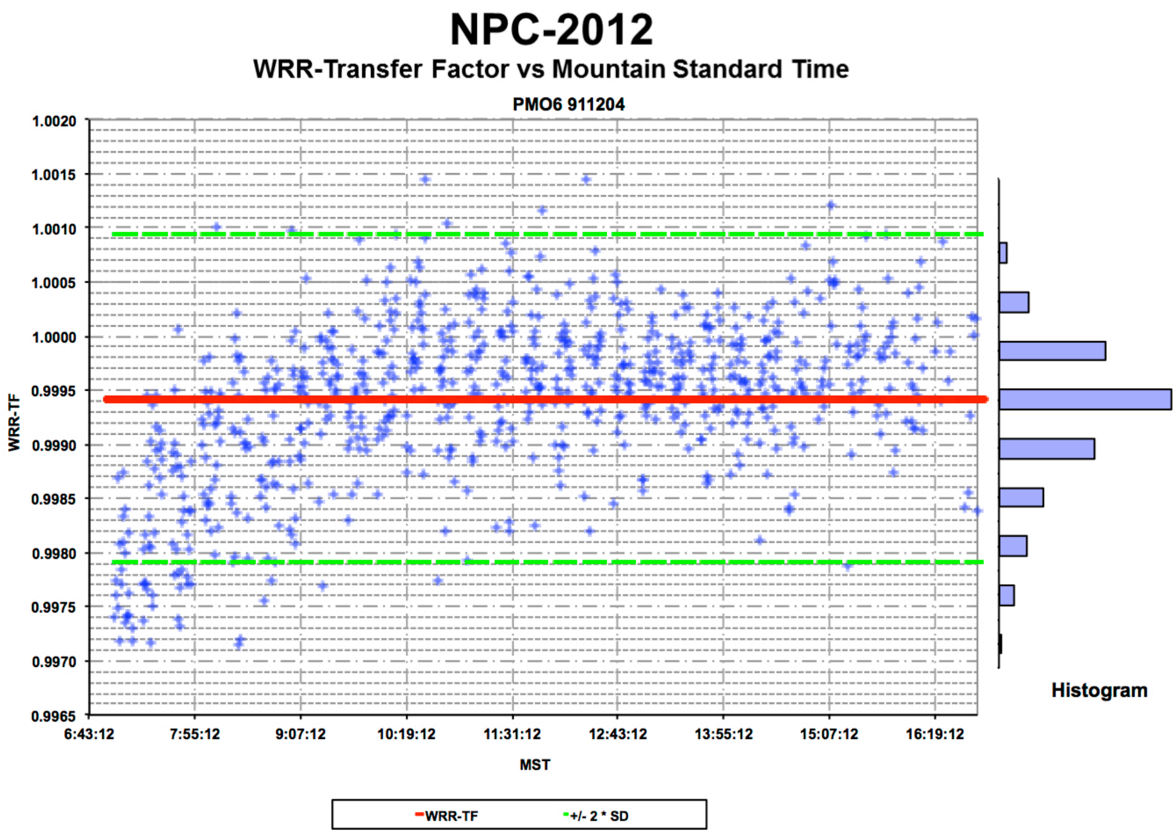

Figure 34. WRR-TF versus MST for PMO6 911204 during NPC-2012

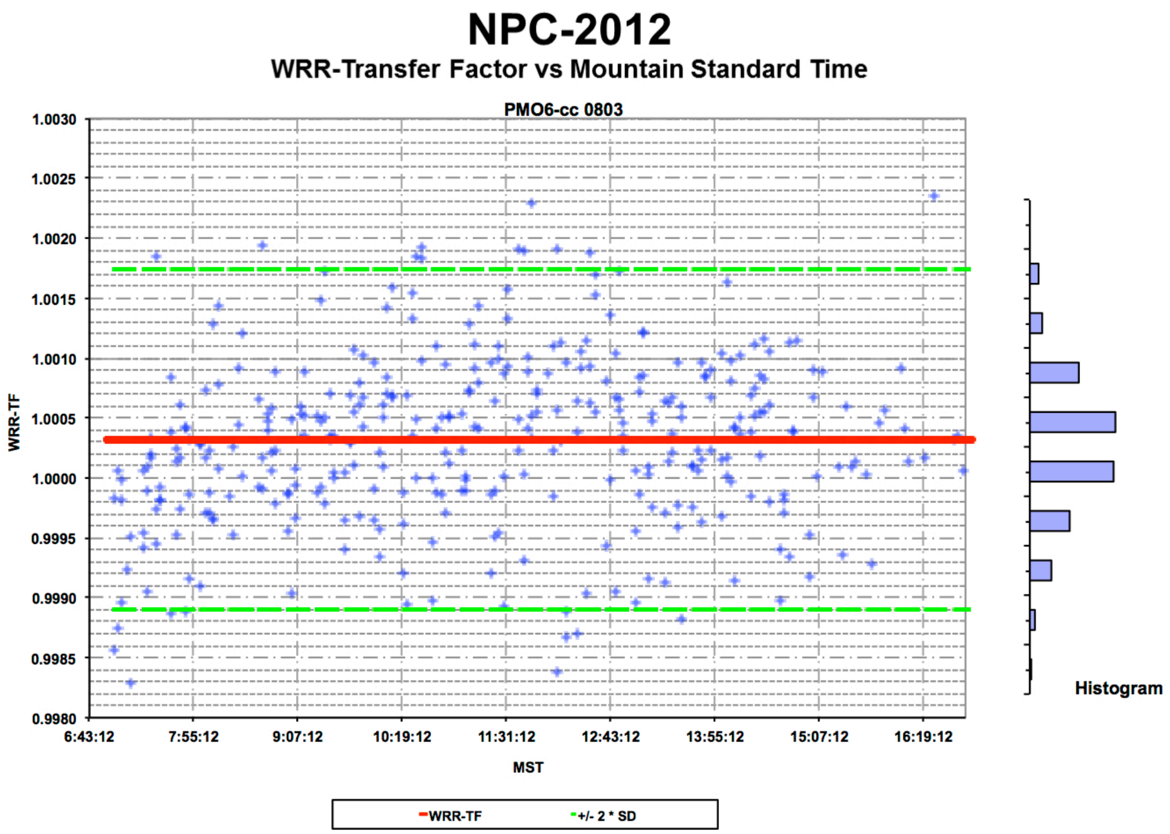

Figure 35. WRR-TF versus MST for PMO6cc 0803 during NPC-2012

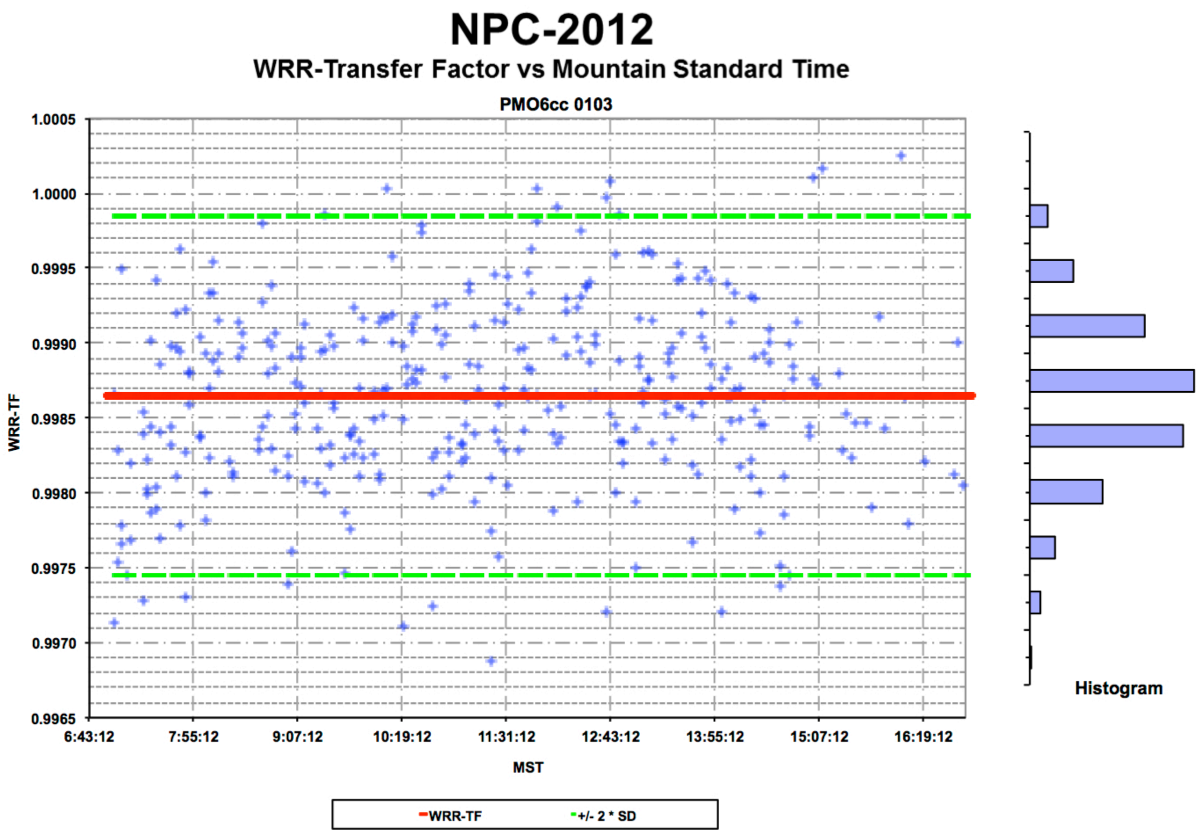

Figure 36. WRR-TF versus MST for PMO6cc 0103 during NPC-2012

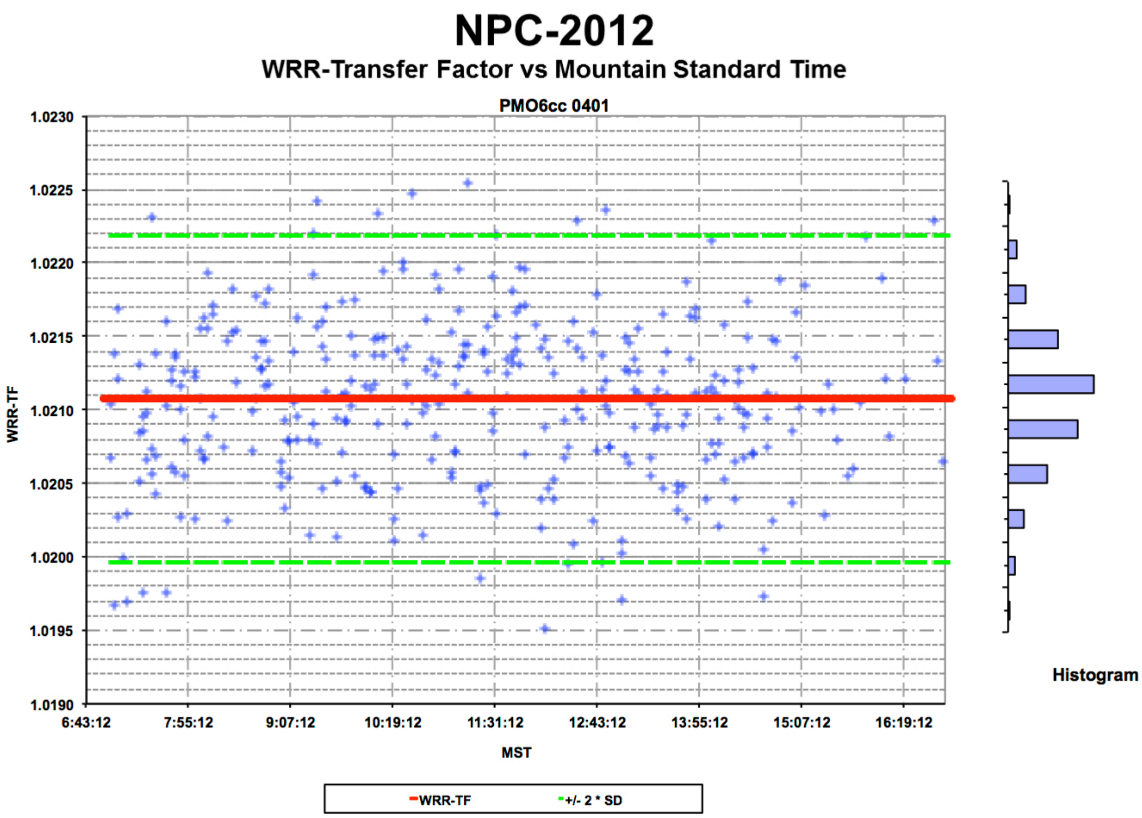

Figure 37. WRR-TF versus MST for PMO6cc 0401 during NPC-2012

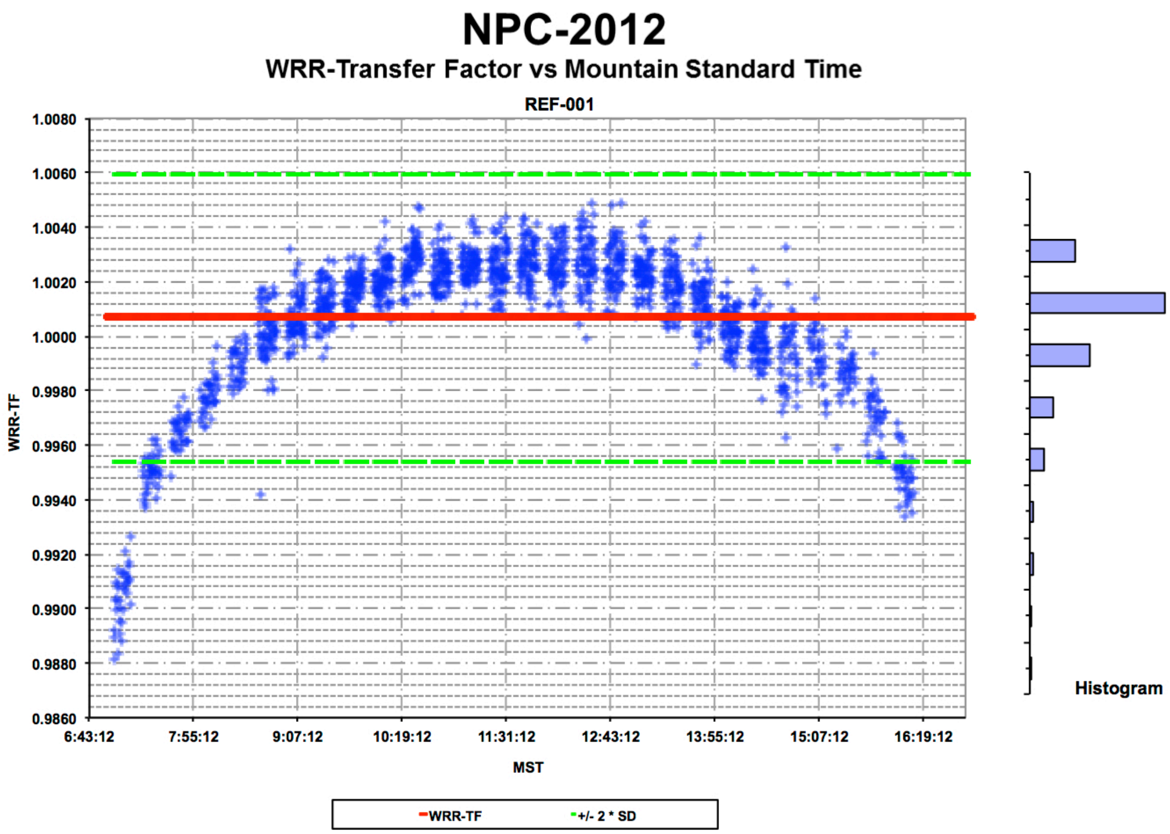

Figure 38. WRR-TF versus MST for REF-001 during NPC-2012

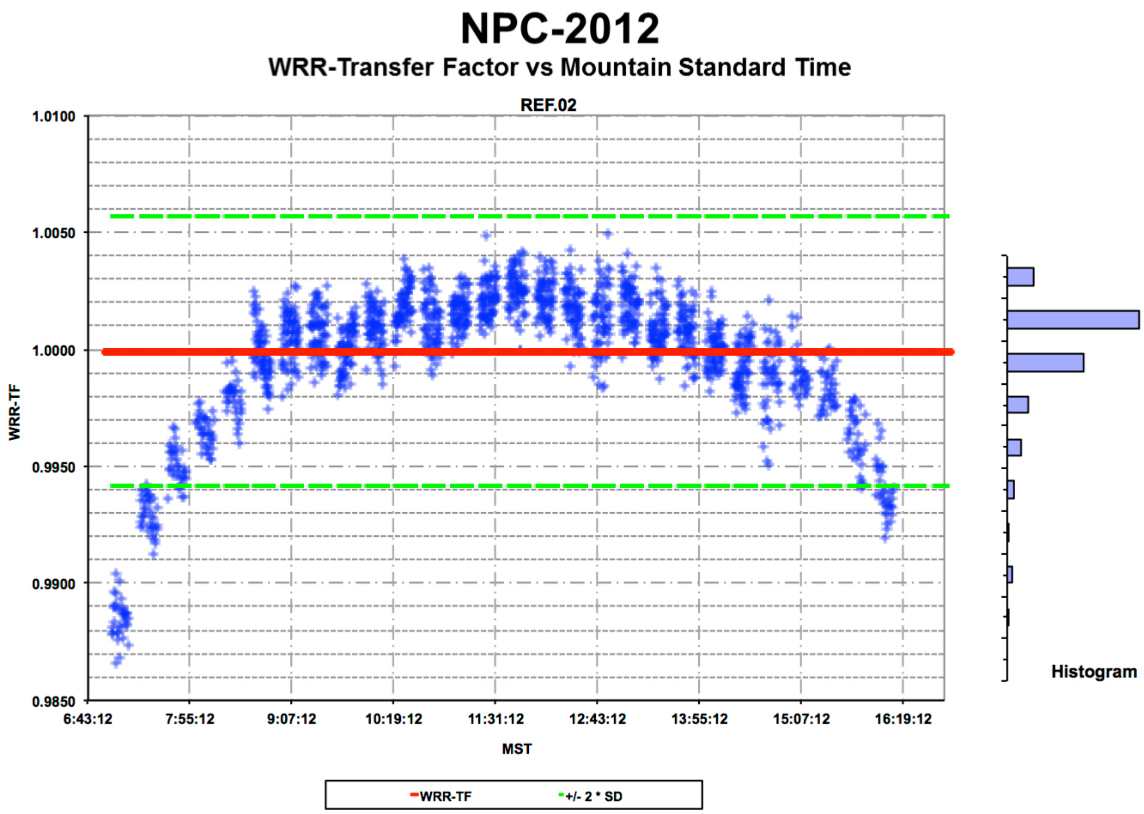

Figure 39. WRR-TF versus MST for REF-002 during NPC-2012

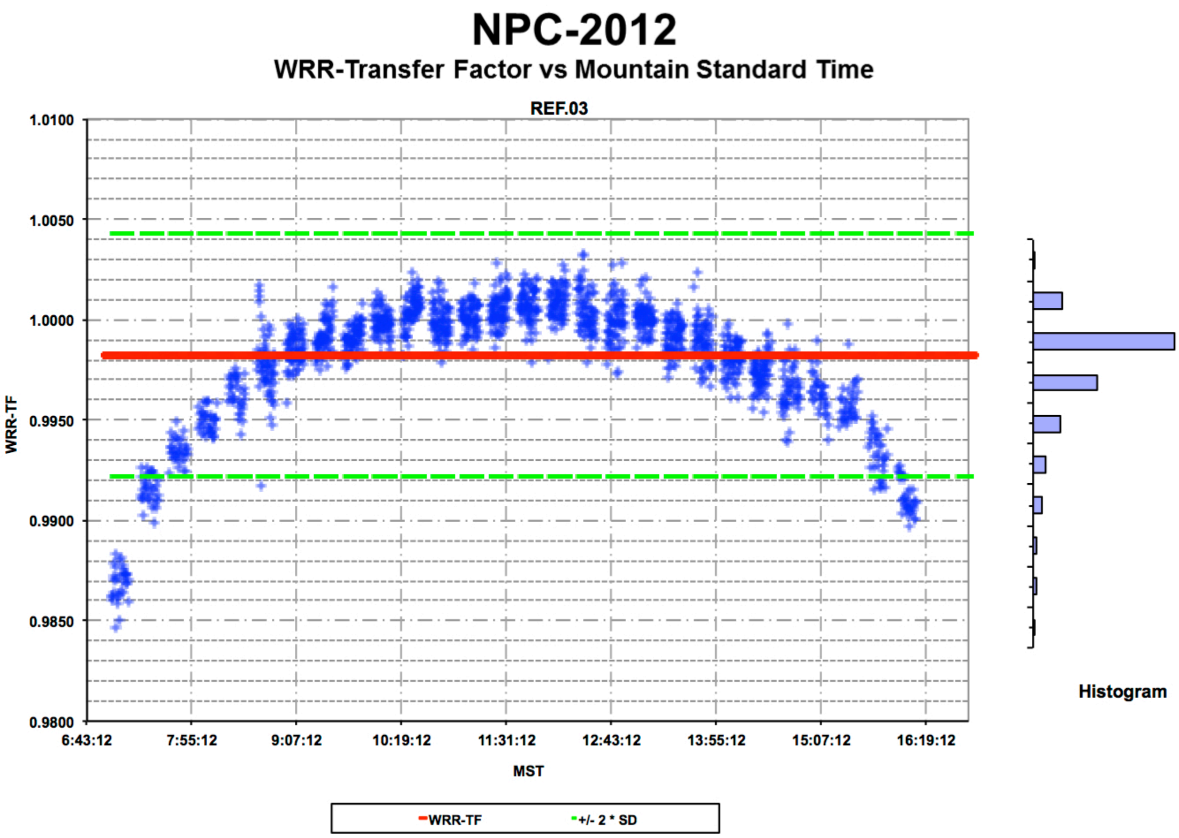

Figure 40. WRR-TF versus MST for REF-03 during NPC-2012

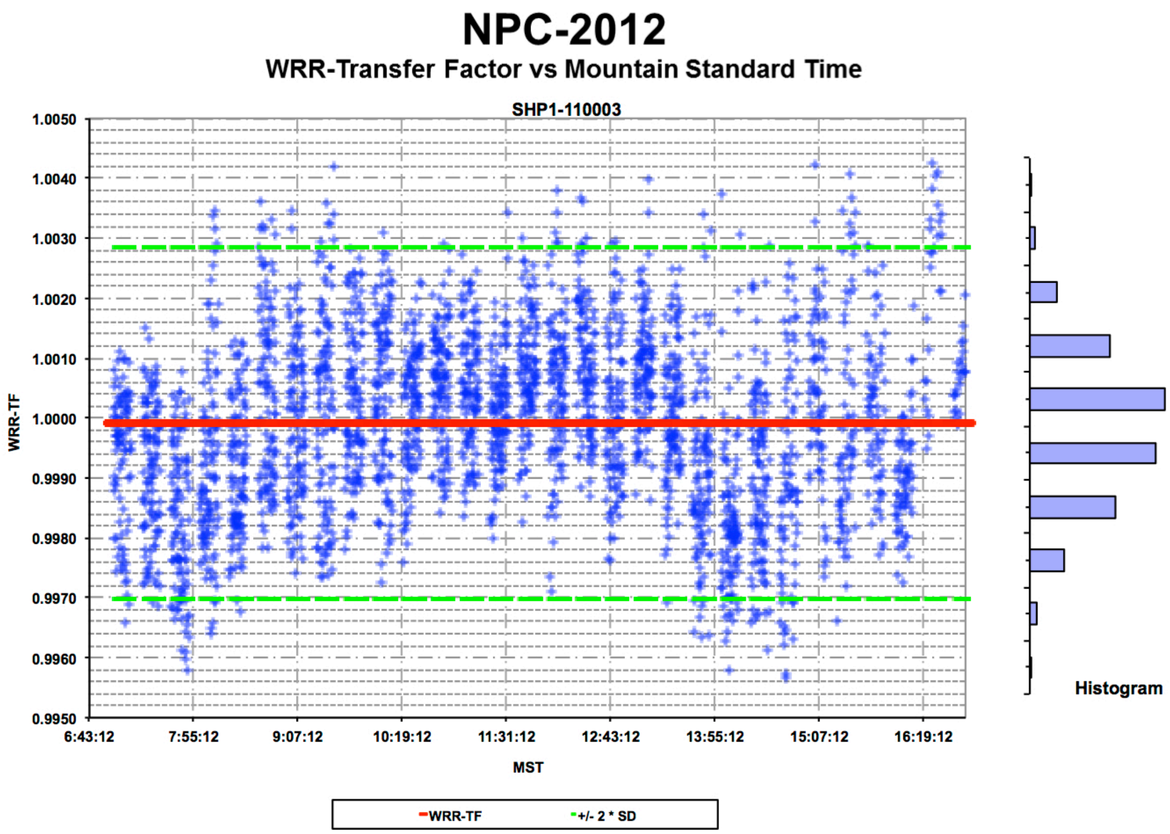

Figure 41. WRR-TF versus MST for SHP1-110003 during NPC-2012

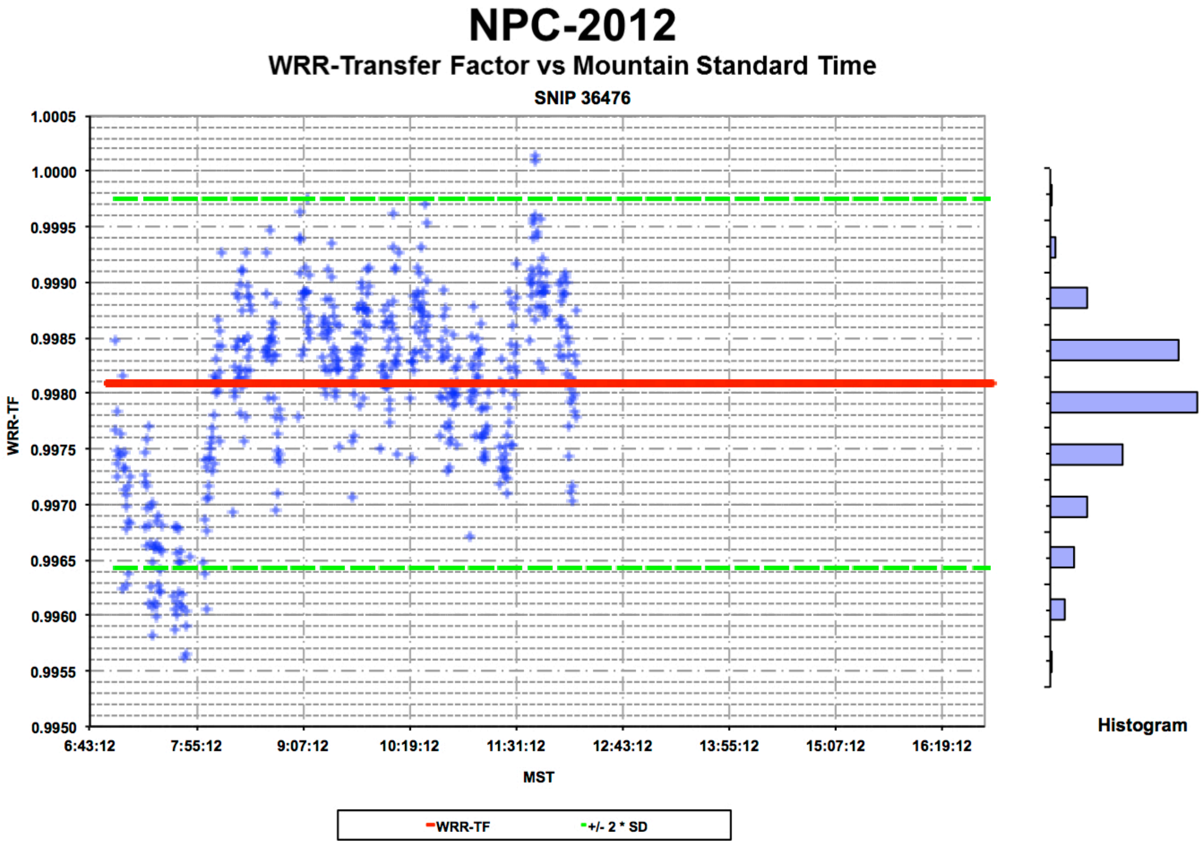

Figure 42. WRR-TF versus MST for SNIP 36476 during NPC-2012

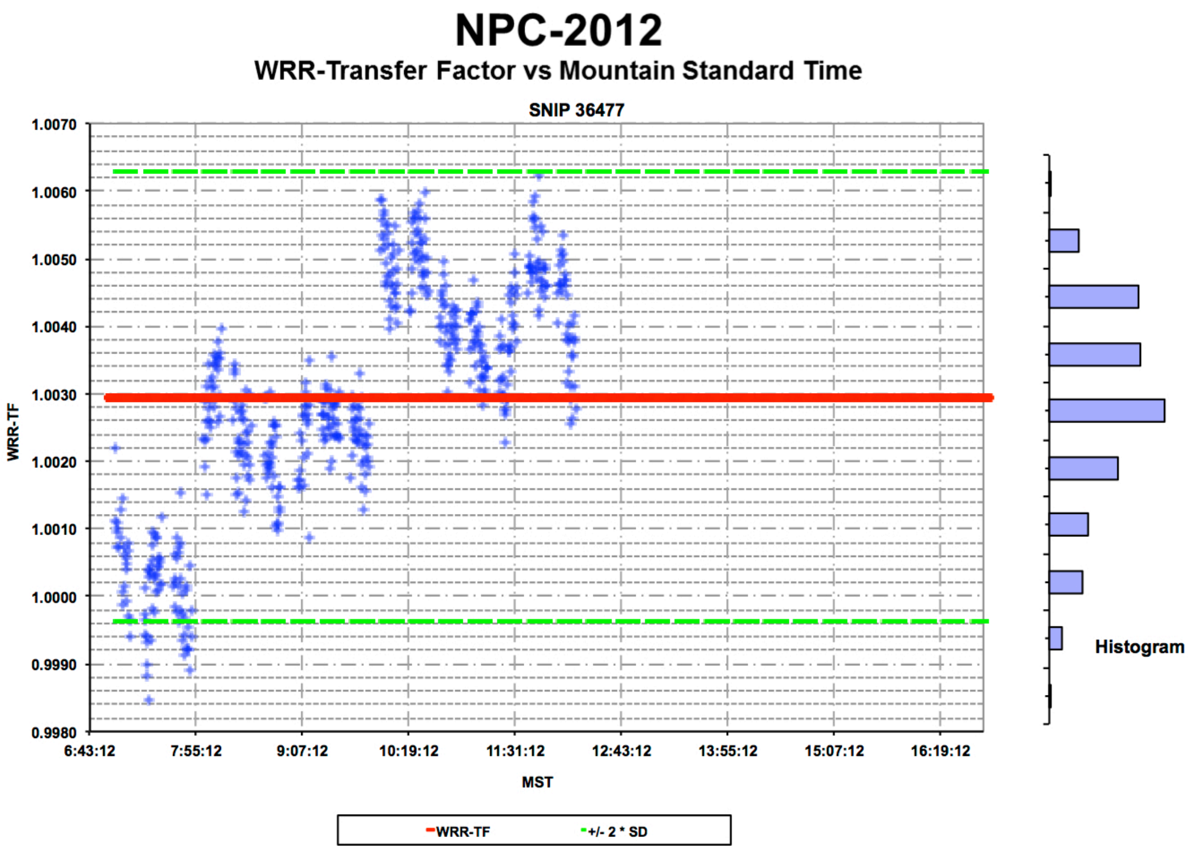

Figure 43. WRR-TF versus MST for SNIP 36477 during NPC-2012

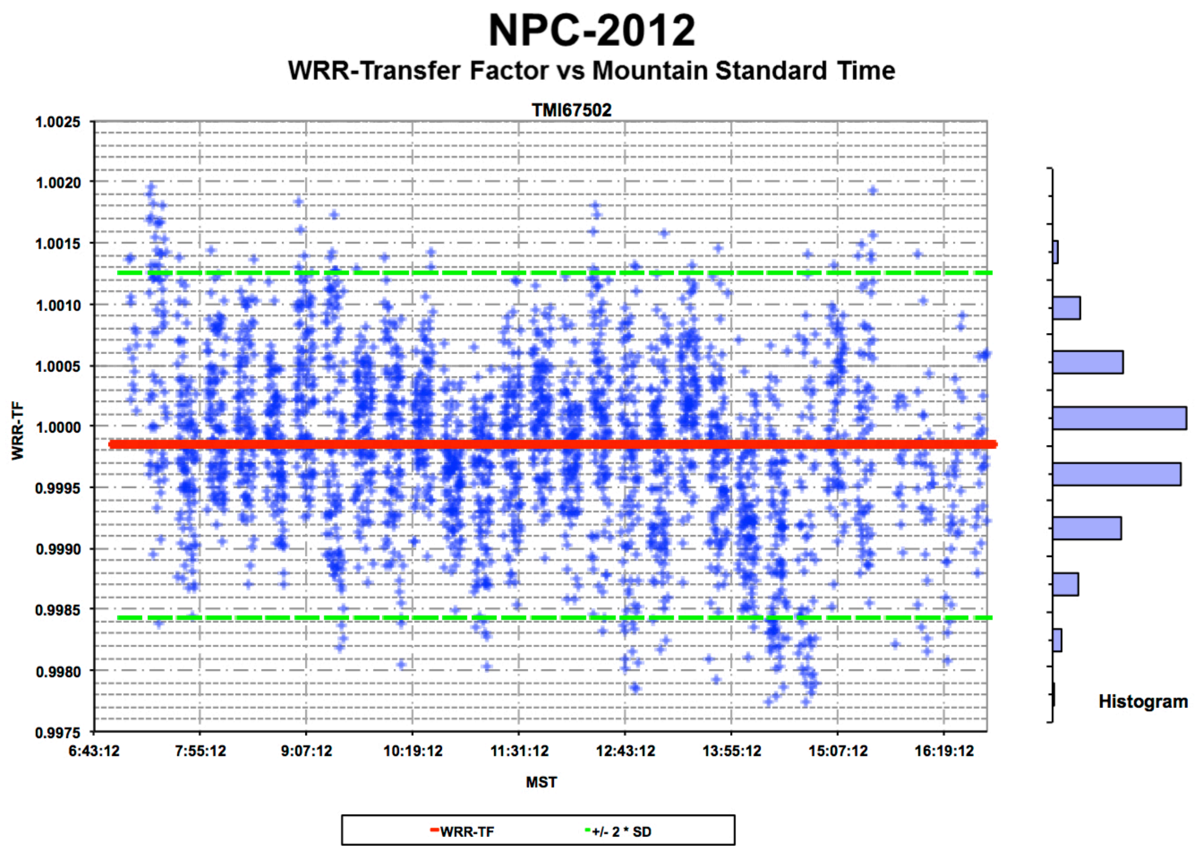

Figure 44. WRR-TF versus MST for TMI 67502 during NPC-2012

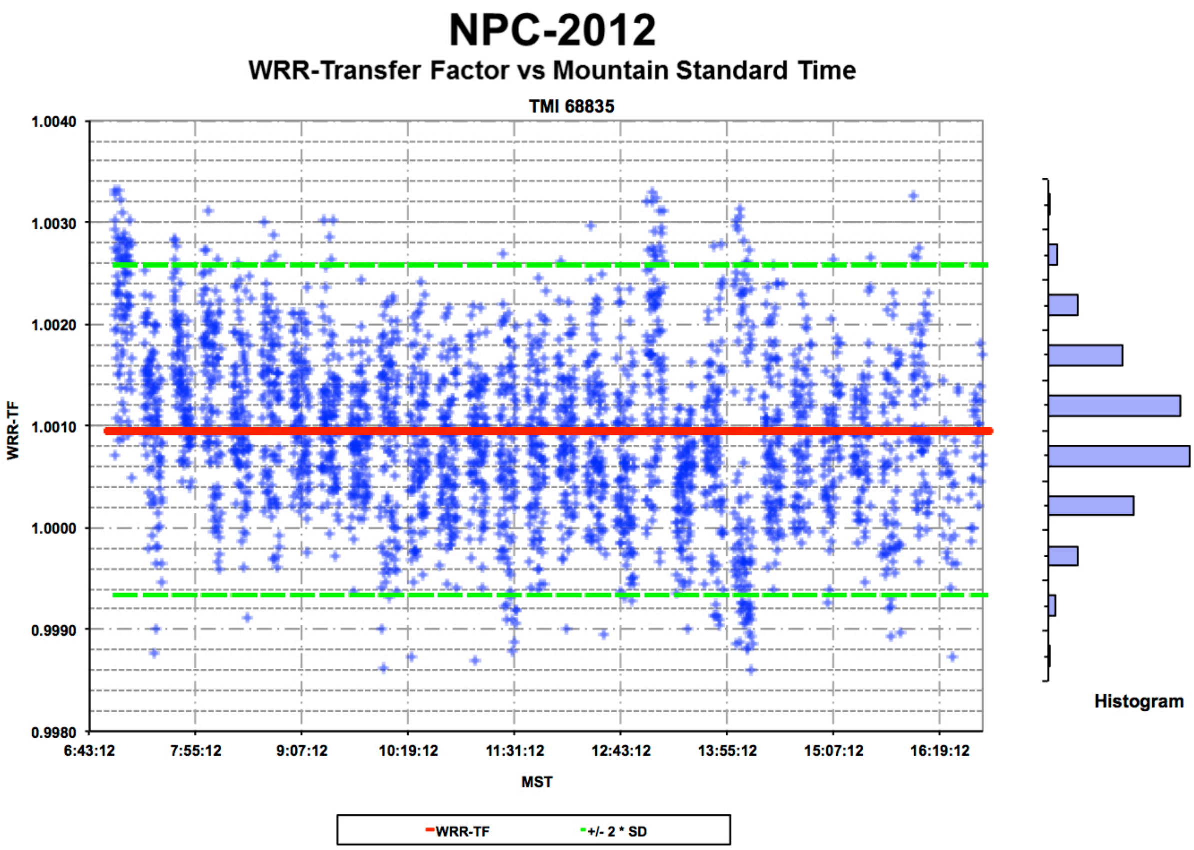

Figure 45. WRR-TF versus MST for TMI 68835 during NPC-2012

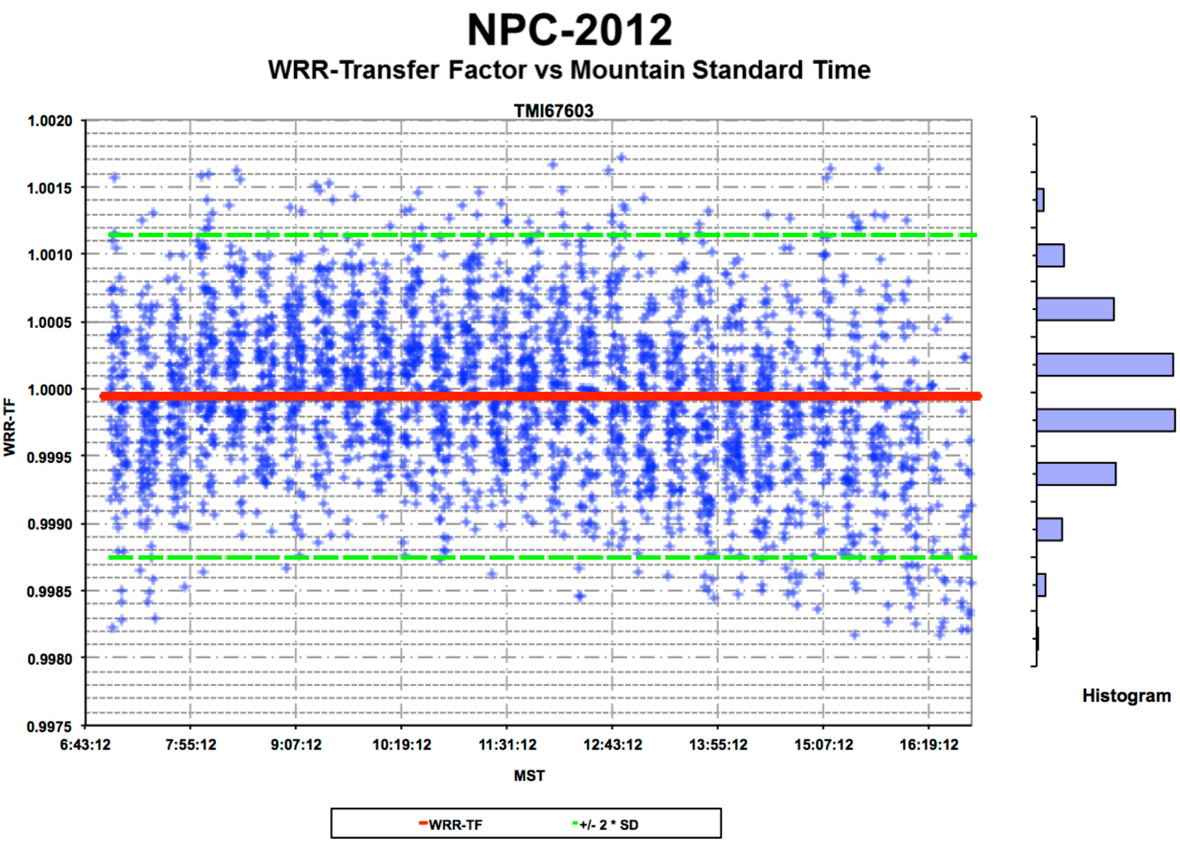

Figure 46. WRR-TF versus MST for TMI 67603 during NPC-2012

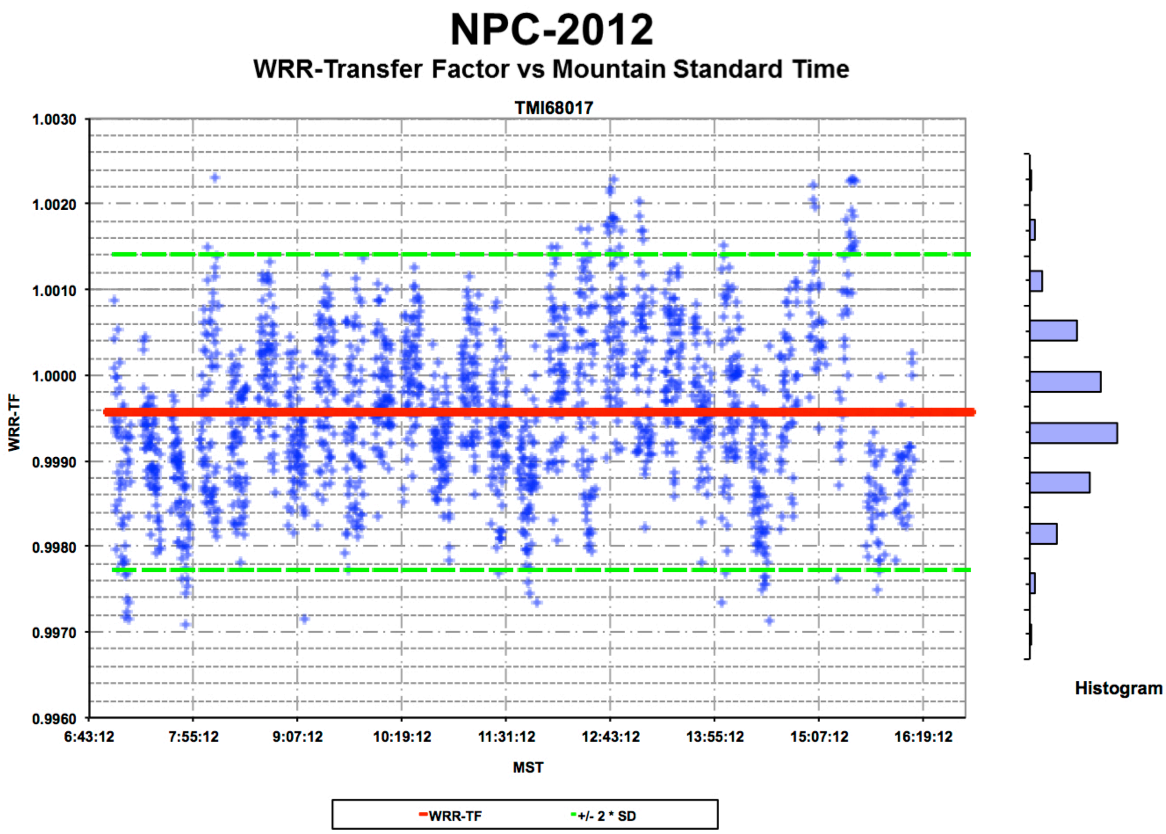

Figure 47. WRR-TF versus MST for TMI 68017 during NPC-2012

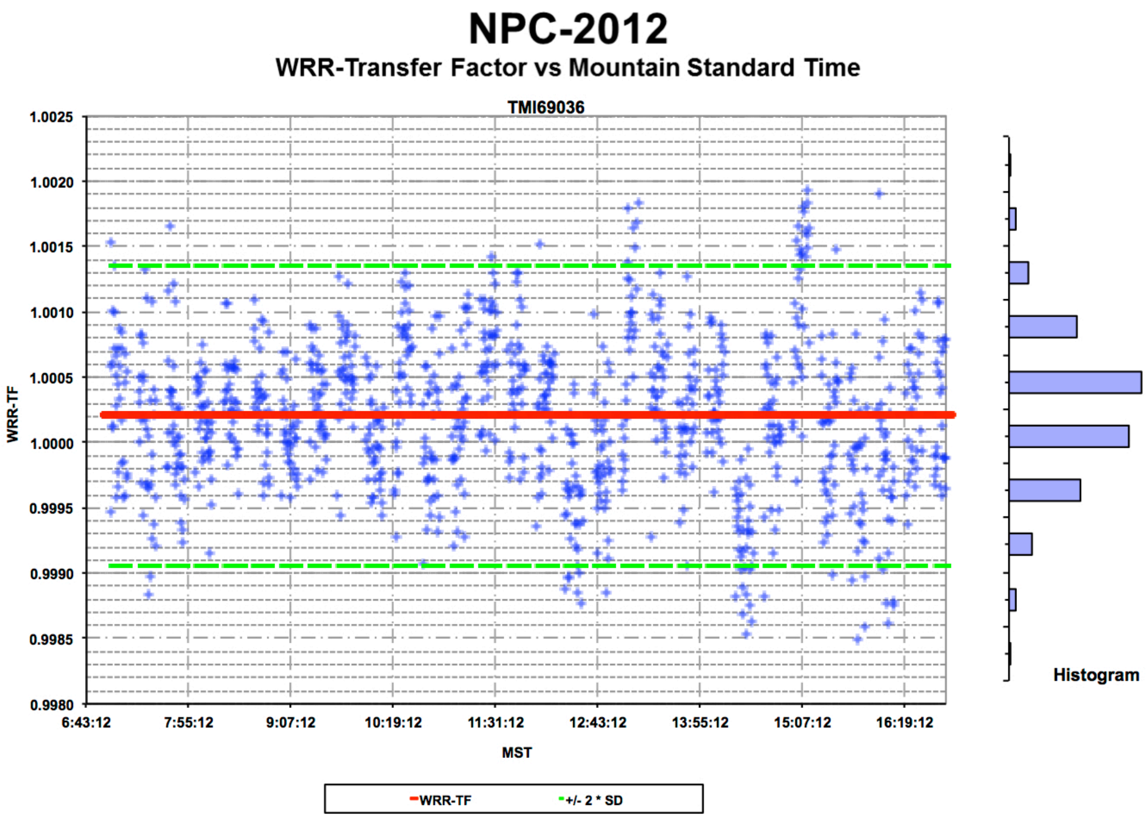

Figure 48. WRR-TF versus MST for TMI 69036 during NPC-2012

4.6 Recommendations

As a result of these comparisons, we suggest that participants observe the following measurement practices:

- For the purpose of pyrheliometer comparisons, such as NPC-2012, we recommend that the user apply only the manufacturer's calibration factor, not the WRR-TF or the new calibration factor, to report his/her absolute cavity radiometer's irradiance readings. This eliminates the possibility of compounding WRR factors from previous comparisons.
- For data collection in the field, the manufacturer's calibration factor should be used to calculate the cavity responsivity. Each irradiance reading should then be *multiplied* by the appropriate WRR-TF to provide homogeneity of solar radiation measurements traceable to the WRR. We recommend this approach to realize the benefits of participating in the NPC.
- For future pyrheliometer comparisons, we strongly urge participants to provide their irradiance readings in the following format:

  Serial number

  ##, HH:MM:SS, IRR

where,

- Serial number = Instrument serial number (first line only)
- ## = Reading number (1 to 37) within the run
- HH:MM:SS = Hour, minute, and second of the reading (local standard time, 24-hour clock)
- IRR = Computed irradiance (Wm-2) with resolution of XXXX.X

The file naming convention is suggested to include the radiometer serial number and date of observations (e.g., AHF30713092212 would correspond to data from AHF30713 on 22 September 12).

5 Ancillary Data

The meteorological data—i.e. temperature, relative humidity, and barometric pressure—were measured during the comparisons using the meteorological station at SRRL. A NIP, PSP, and Model 8-48 were also used to measure direct, global, and diffuse irradiances respectively. These radiometers are used in SRRL's Baseline Measurement System (BMS). The BMS provides one-minute averages of three-second samples. Additional information, including data and graphical summaries, can be found at the Measurements and Instrumentation Data Center: www.nrel.gov/midc/srrl_bms.

Time-series plots and other graphical presentations of these data collected during the pyrheliometer comparisons are presented in Appendix B.

6 References

Finsterle, W. (2011). *WMO International Pyrheliometer Comparison, IPC-XI, 27 September – 15 October 2010: Final Report.* WMO IOM Report No. 108. Davos, Switzerland. 86 pp.

Fröhlich, C. (1991). “History of Solar Radiometry and the World Radiometric Reference.” *Metrologia*, (28:3); pp. 111–115.

Reda, I. (1996). *Calibration of a Solar Absolute Cavity Radiometer With Traceability to the World Radiometric Reference.* NREL/TP-463-20619. Golden, CO: The National Renewable Energy Laboratory. Accessed April 9, 2013: www.nrel.gov/docs/legosti/fy96/20619.pdf.

Reda, I.; Myers, D.; Stoffel, T. (2008). “Uncertainty Estimate for the Outdoor Calibration of Solar Pyranometers: A Metrologist Perspective.” *Measure* (NCSLI Journal of Measurement Science) (3:4), December 2008; pp. 58–66. NREL/JA-581-41370.

Romero, J. (1995). *Direct Solar Irradiance Measurements with Pyrheliometers: Instruments and Calibrations. IPC-VIII.* Davos, Switzerland. 16p.

Romero, J.; Fox, N.P.; Fröhlich, C. (1996). “Improved Comparison of the World Radiometric Reference and the SI Radiometric Scale.” *Metrologia* (32:6) May; pp. 523–524.

WRC/PMOD. (1996). *International Pyrheliometer Comparison, IPC VIII, 25 September – 13 October 1995, Results and Symposium.* Working Report No. 188. Davos Dorf, Switzerland: Swiss Meteorological Institute, Dorfstrasse 33, CH-7260; 115 pp.

Note: Digital images taken during NPC-2012 are available from www.flickr.com/photos/85746078@N06/sets/72157631228235838/. Images from previous NPC’s are available from the U.S. Department of Energy/Office of Science/Atmospheric Radiation Measurement Program/Instrument Management website: www.nrel.gov/aim/npc

7 Appendix A: List of Participants and Pyrheliometers

NPC-2012 Participants

Participant	Affiliation	Address
Akihito Akiyama	EKO Instruments Co. Ltd.	1-21-8 Hatagaya Shibuya-ku, Tokyo 151-0072 Japan
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Fred Denn	Science Systems and Applications, Inc.	Atmospheric Sciences Group 1 Enterprise Parkway, Suite 200 Hampton, VA 23666
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Joop Mes	Kipp & Zonen	Delftechpark 36 Delft The Netherlands
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Participant	Affiliation	Address
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Kees Van Den Bos	Hukseflux Thermal Sensors BV	Elektronicaweg 25 Delft The Netherlands
Mary Watkins	Florida Solar Energy Center	Central Florida University 1679 Clearlake Road Cocoa, FL 32922-5703
Craig Webb	U.S. Department of Energy/Office of Science/Atmospheric Radiation Measurement Program	109596 Coal Rd Billings, OK 74630
Jim Wendell	NOAA	Earth System Research Laboratory Global Monitoring Division Mail Code R/Global Monitoring Division 1 325 Broadway Boulder, CO 80305
Wim Zaaiman	European Commission/Directorate General/Joint Research Centre	Institute for Energy and Transport Building 45, TP450 Via Fermi, 2479 I-21020 Ispra (Va), Italy

List of Pyrheliometers Sorted by Serial Number

No.	Serial No.	Owner/Application
1	AHF 14915	The Eppley Laboratory, Inc., Primary Reference Standard
2	AHF 17142	Atlas Material Testing Technology, DSET Laboratories, Inc., Primary Reference Standard
3	AHF 21182	Florida Solar Energy Center, University of Central Florida, Primary Reference Standard
4	AHF 23734	NREL/National Center for Photovoltaics Program Reference
5	AHF 28553	NOAA Global Monitoring Division Reference
6	AHF 28556	Atlas Material Testing Technology, DSET Laboratories, Inc., Secondary Reference
7	AHF 28968*	U.S. Department of Energy/Office of Science/Atmospheric Radiation Measurement Program Reference
8	AHF 29219	NREL/Metrology Lab Working Standard (Broadband Outdoor Radiometer Calibration-Windowed)
9	AHF 29220*	NREL/Metrology Lab Reference Standard #2
10	AHF 29222	U.S. Department of Energy/Office of Science/Atmospheric Radiation Measurement Program (Broadband Outdoor Radiometer Calibration-Windowed)
11	AHF 30494	U.S. Department of Energy/Office of Science/Atmospheric Radiation Measurement Program Reference
12	AHF 30495	U.S. Department of Energy/Office of Science/Atmospheric Radiation Measurement Program Broadband Outdoor Radiometer Calibration Reference
13	AHF 30713*	NREL/Metrology Lab Reference
14	AHF 31041	National Aeronautics and Space Administration/Langley Research Center/Science Systems and Applications, Inc. Reference
15	AHF 31104	NREL/Metrology Lab Broadband Outdoor Radiometer Calibration Transfer Standard
16	AHF 31105	National Aeronautics and Space Administration/Langley Research Center/Science Systems and Applications, Inc. Reference 2
17	AHF 31108	Sandia National Laboratories Photovoltaic Reference Standard
18	AHF 31114AWX	NOAA/Global Monitoring Division Baseline Surface Radiation Network Reference
19	AHF32448AWX	NOAA/Global Monitoring Division All Weather Cavity
20	AHF32452AWX	NREL/Metrology Lab All-Weather Transfer Standard
21	AHF 32455	PMOD Reference
22	CH1 040370	European Commission/Directorate General/Joint Research Centre/Institute for Energy and Transport—Renewable Energy Unit
23	CH1 060460	European Commission/Directorate General/Joint Research Centre/Institute for Energy and Transport—Renewable Energy Unit
24	CH1 070541	Kipp & Zonen Reference
25	CH1 930018	European Commission/Directorate General/Joint Research Centre/Institute for Energy and Transport—Renewable Energy Unit
26	CHP1 090127	Kipp & Zonen Reference

27	CP01P 002	Hukseflux Thermal Sensors
28	CP01T 002	Hukseflux Thermal Sensors
29	CP01U 002	Hukseflux Thermal Sensors
30	DR01 8174	European Commission/Directorate General/Joint Research Centre/Institute for Energy and Transport—Renewable Energy Unit
31	DR03 T2-10008 U	Hukseflux Thermal Sensors (uncorrected)
31	DR03 T2-10008 C	Hukseflux Thermal Sensors (corrected)
32	MS-56 REF-001	EKO Instruments Reference
33	MS-56 REF-02	EKO Instruments Reference
34	MS-56 REF-03	EKO Instruments Reference
35	PMO6 81109	European Commission/Directorate General/Joint Research Centre/Institute for Energy and Transport—Renewable Energy Unit
36	PMO6 911204	European Commission/Directorate General/Joint Research Centre/Institute for Energy and Transport—Renewable Energy Unit
37	PMO6-cc0401	PMOD Reference
38	PM06 0103	Kipp & Zonen Reference
39	PMO6-cc0803	PMOD Reference
40	SHP1-110003	Kipp & Zonen (experimental)
41	SNIP 36476	The Eppley Laboratory, Inc.
42	SNIP 36477	The Eppley Laboratory, Inc.
43	TMI 67502	NOAA/Global Monitoring Division Primary Reference Standard
44	TMI 67603	Sandia National Laboratories Primary Reference Standard
45	TMI 68017	NREL/Metrology Lab Control Instrument #1
46	TMI 68018*	NREL/Metrology Lab Reference Standard #1
47	TMI 68835	European Commission/Directorate General/Joint Research Centre/Institute for Energy & Transport—Renewable Energy Unit
48	TMI 69036	NREL/Metrology Lab Control Instrument #2

* Instrument assigned to the NPC TSG

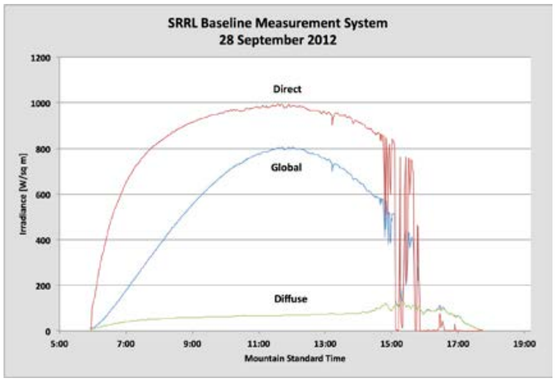
Summary

- Absolute cavity radiometers: 32
- Thermopile pyrheliometers: 16

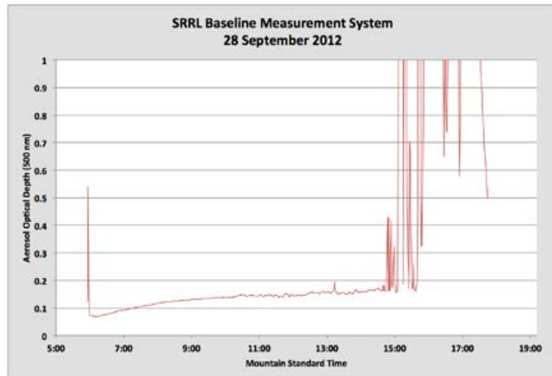
8 Appendix B: Ancillary Data Summaries

The measurement performance of an absolute cavity can be affected by several environmental parameters. Potentially relevant meteorological data collected during the NPC are presented in this appendix. The BMS has been in continuous operation at the SRRL since 1985. BMS data are recorded as one-minute averages of three-second samples for each instrument. (Additional information about SRRL and the BMS can be found at the Measurement and Instrumentation Data Center: www.nrel.gov/midc/srrl_bms.)

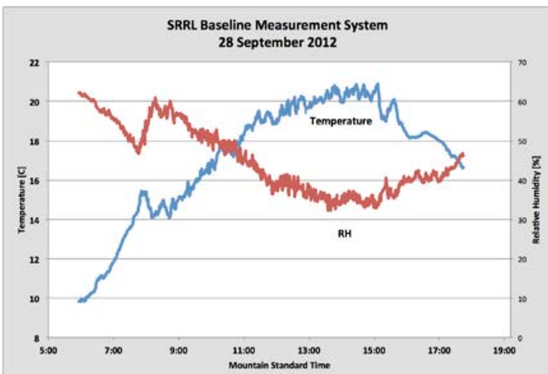
Time-series plots and other graphical presentations of these data acquired during the NPC-2012 measurements are presented here.



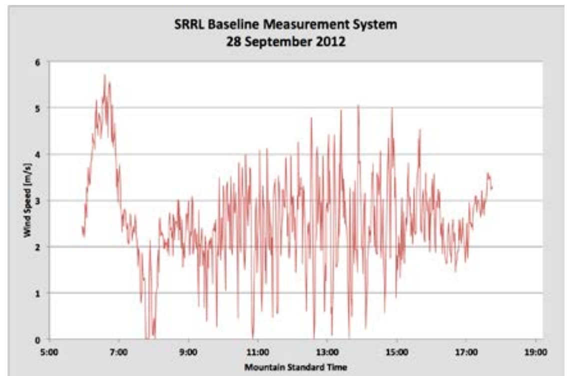
Broadband irradiances



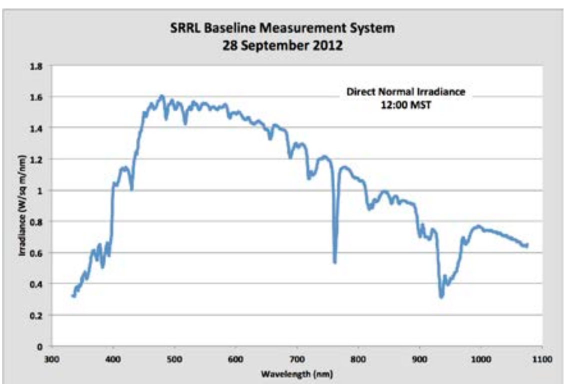
Aerosol optical depth



Temperature and relative humidity

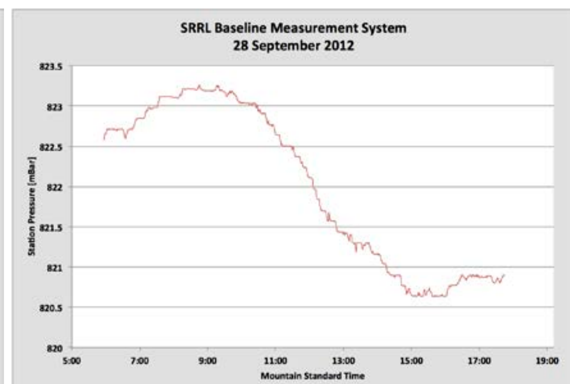


Wind speed



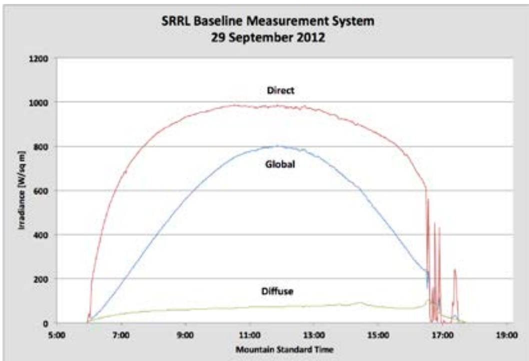
Direct normal solar spectrum

(12:00 MST)

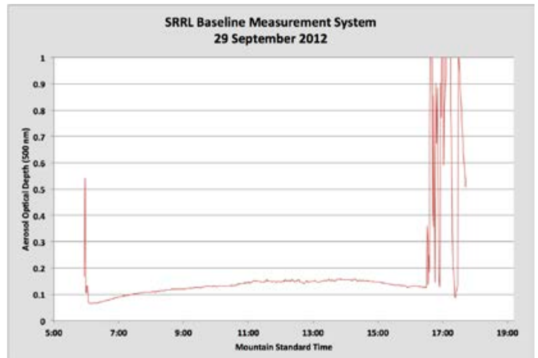


Barometric pressure

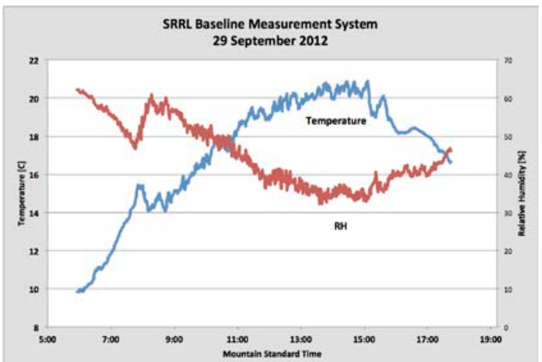
Figure 49. BMS data for September 28, 2012



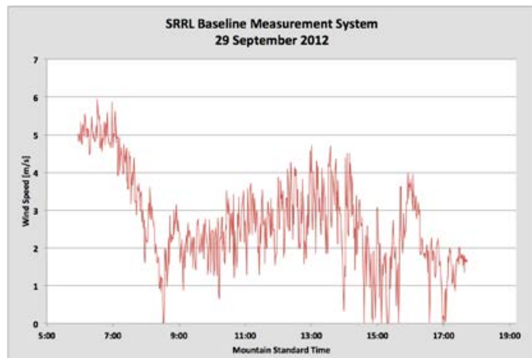
Broadband irradiances



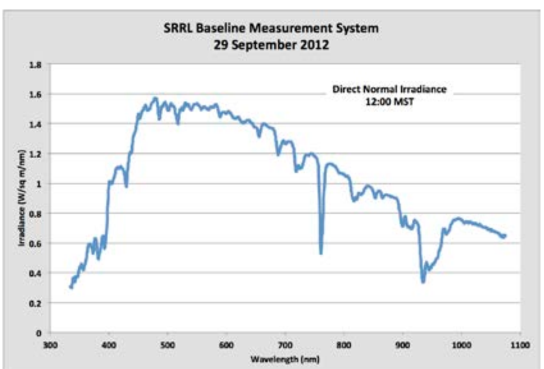
Aerosol optical depth



Temperature and relative humidity

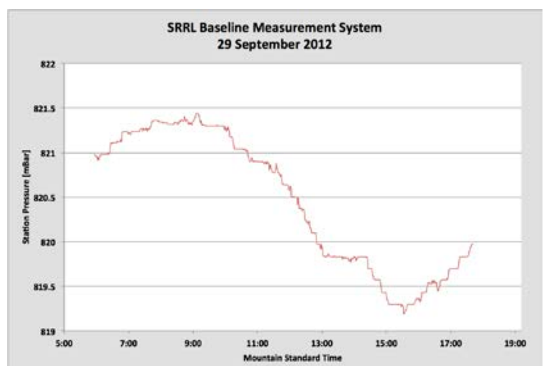


Wind speed



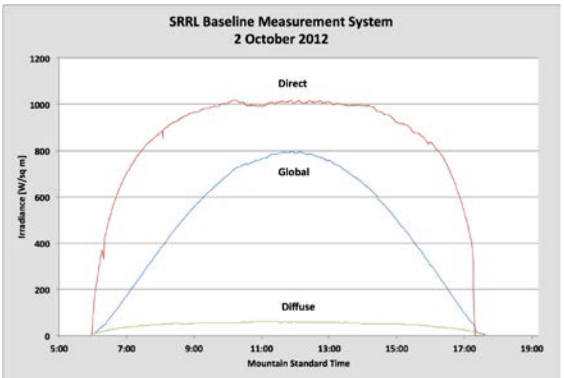
Direct normal solar spectrum

(11:00 MST)

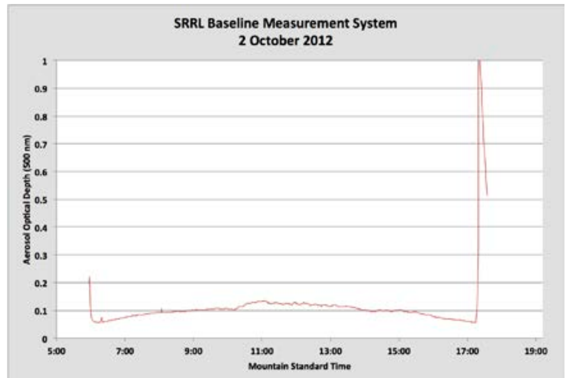


Barometric pressure

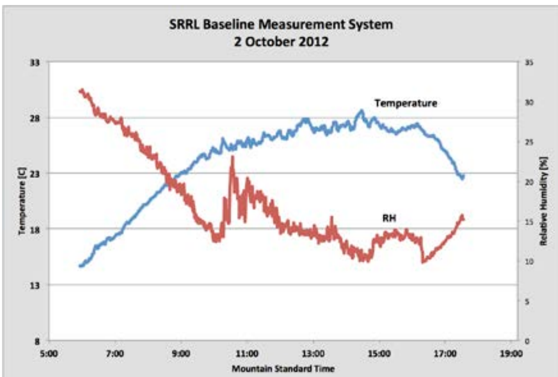
Figure 50. BMS data for September 29, 2012



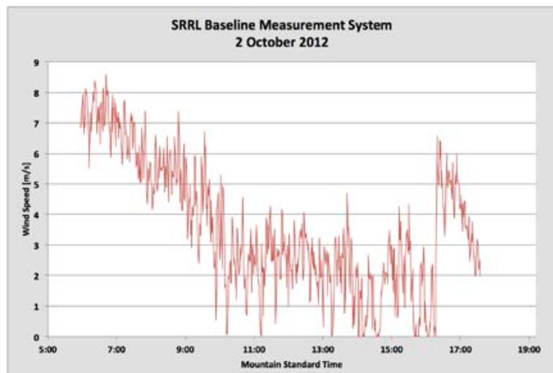
Broadband irradiances



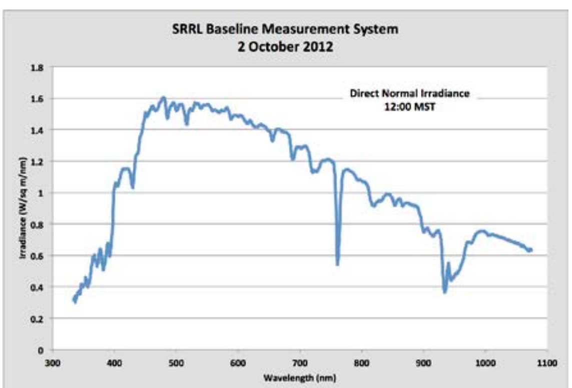
Aerosol optical depth



Temperature and relative humidity

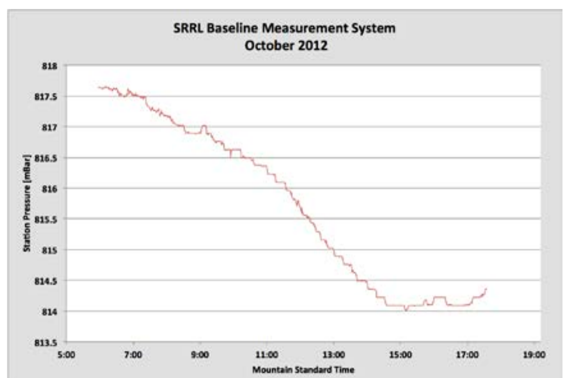


Wind speed



Direct normal solar spectrum

(12:00 MST)



Barometric pressure

Figure 51. BMS data for October 2, 2012

9 Appendix C: Operational Notes

The following information was distributed to the participants at the opening of the NPC.

Welcome!

NREL Pyrheliometer Comparisons 2012

24 September–5 October, 2012

Figure 52. NPC-2011 Participants. *Photo by Dennis Schroeder, NREL*

- Atlas Material Testing Technology
- U.S. Department of Energy/Office of Science/Atmospheric Radiation Measurement Program
- The Eppley Laboratory, Inc.
- European Commission/Directorate General/Joint Research Centre/Institute for Energy and Transport
- Florida Solar Energy Center
- Hukseflux USA, Inc.
- Kipp & Zonen
- Lockheed Martin Denver Metrology Services
- NOAA
- NREL
- PMOD/WRC
- Sandia National Laboratories
- Science Systems and Applications, Inc.
- Stasiun Pemantau Atmosfer Global (Indonesia)
- Sustainable Energy Technologies, LLC
- University of Oregon

Figure 53. Radiometers at the SRRL. *Photo by Tom Stoffel, NREL*

Welcome to the 17th Annual
NREL Pyrheliometer Comparisons (NPC-2012)
24 September–5 October 2012
Solar Radiation Research Laboratory
Golden, Colorado

The purpose of this NPC is to provide participants with current WRR reduction factors for their absolute cavity radiometers and other reference pyrheliometers based on results from the IPC-XI, conducted 27 September–15 October 2010,at the PMOD/WRC. Information about IPC-XI is available from www.pmodwrc.ch/pmod.php?topic=ipcxi.

Contents

SRRL Staff
Electricity, Resources, and Building Systems Integration Center
Resource Information and Forecasting Group

Mary Anderberg	Co-host (food)
Afshin Andreas	Computer issues (Measurements and Instrumentation Data Center)
Mike Dooraghi	Tools, parts (electronics and hardware), trackers
Aron Habte	General assistance
Mark Kutchenreiter	Electric power, tools, parts, trackers
Preston Morse	Reference cavity setup and operations
Ibrahim Reda	NPC data collection and processing, reference cavity operations
Manajit Sengupta	General assistance
Tom Stoffel	Host (security, safety, logistics, food)
Steve Wilcox	Computer issues, trackers, cavity operation

SRRL Coordinates for Solar Tracker Programs

Latitude:	39.742 N
Longitude:	105.18 W
Elevation:	1828.8 m AMSL
Mean Station Pressure:	820 mBar
Time Zone:	(GMT – 7.0)

Telephone Numbers:

EMERGENCY	**1 2 3 4** (From ***any*** NREL Phone)
SRRL	303-384-6326
Daily Schedule	720-219-7999 (Tom)

NREL Pyrheliometer Comparisons
NPC-2012

Safety

- Emergency Phone: RED BOX UNDER INSTRUMENT DECK
- OR dial 1 2 3 4 from any NREL extension
- Evacuation assembly area: North Parking Lot (near signage on fence)

Security

- Phone: 303-384-6811
- OR dial 6811 from any NREL extension

NREL visitor badges will be issued on the first day of the NPC at the Visitor Center. If you are *not* a U.S. citizen, please present the same documentation (passport, visa, etc.) you used on the NREL Foreign National Data Card (FNDC). Please wear your badge at all times at SRRL. Badges will be renewed as needed, according to expiration date.

Communications

Check your text messages after 06:30. Tom will issue the Daily Plan based on the weather forecast for sky conditions.

- SRRL Phone: 303-384-6326 (also rings outside)
- Local (long distance): Press 9 + (1) Area Code + Number
- Wireless available at SRRL—please see Preston for details

Food and Beverages

- The lunch menu will be circulated daily by 10:30 MDT
- Non-alcoholic beverages and snacks provided

Equipment Storage

- Please use designated areas in SRRL staging areas.

2012 NREL Pyrheliometer Comparisons
Solar Radiation Research Laboratory
NPC-2012 Protocol Summary
Tom Stoffel and Ibrahim Reda

1. Schedule

DAY #1, Sept. 24

a. Visitor check-in at NREL Visitor Center, 15013 Denver West Parkway, Golden, CO 80401
   Please plan on arriving at NREL between 07:30 and 08:30 MDT.
b. Transport equipment to SRRL (dry weather) or to indoor lab (precipitation)
c. 09:00 MDT - Safety and SRRL orientation briefing for all participants
d. 09:20 MDT - Equipment installation and tests
   - See the ***seating diagram*** on Page 9 for your workstation.
e. 12:00 MDT - Conclude equipment tests as needed
f. Review measurement protocol and procedures
g. 13:00 to Sunset - Dry run(s) and/or NPC measurements (weather permitting)

DAILY Please check your text messages for Tom's announcement based on the weather forecast.

DAYS #2 – #14, Sept. 25th – Oct 5th (daily, including the weekend):

a. Clear sky = take measurements!
   - Arrive at SRRL by 08:00 MDT
   - Equipment warm-up for at least 30 minutes
      - First cavity calibration at 08:55 MDT
   - Begin comparison "runs" by 09:00 MDT (08:00 MST)
   - Continue measurements until sundown or clouds interfere

b. Cloudy sky = no Measurements, but optionally...
   - Review previous day's data analyses
   - Technical briefings on radiometry, measurement network operations, etc.
   - Equipment tests
   - NREL tours
   - Office time (wireless available)

c. We will determine the need for more measurements at the end of each day.

2. SRRL Coordinates

Program your solar tracker using:

LAT = 39.7425º North
LON = 105.1778º West
ELEV = 1828.8 m above mean sea level (6,000 ft)
BARO = 820 mBar (average station pressure)

3. Time Keeping

- Wim Zaaiman will be our time keeper again (as long as his voice holds out!)
- ***All time records will be MST***
- Outdoor time display
   - The NIST atomic clock is a local call: 9-303-499-7111

-We need to keep all PC clocks in agreement to better than 2 sec.

-***Set your system clock at the daily start-up*** or as often as needed to keep 2-second accuracy. Check personal computer clocks during the day.

4. Minimum Data Set

Our goal for a minimum data set for these comparisons is to measure irradiance during three different days (all day or portion). Historically, we have acquired more 3,000 data values for each participating cavity radiometer. At least 300 data values are needed to provide a valid transfer of the WRR to the participating radiometers.

5. Measurements

- Do *not* apply any previous WRR correction factors to your measurements.
- Use *only* the factory calibration factor to adjust your data beyond any other adjustments you feel are needed to correct your data (e.g., pre- and post-calibration drifts in sensitivity are okay). As in the past, we will use the following terms:

- Calibrate: Perform electrical calibration and wait for next measurement period to begin
- Reading: A measurement of direct irradiance within 1 second of announcement at 20-second intervals.
- Run: Collection of 37 readings taken in sequence (also called a *series*)

The time keeper will make the following announcements for each run:

- Next run begins at HH:MM (MST) [HH:MM (MDT)]
- T minus 6 minutes. BEGIN CALIBRATION
- T minus 3 minutes
- T minus 2 minutes
- T minus 1 minute
- T minus 30 sec
- T minus 10 sec
- T minus 5 - 4 - 3 - 2 - 1 - READ!

Continued countdowns at 20-second intervals until 37 readings have completed a run

6. Data Transfer

The following *standard data format* will be used by each participant to improve our data processing efficiency.

a. Single instrument per file:

YYYYMMDD,HH:MM:SS,NNNNN,XXXX.XX

b. Multiple instrument per file:

YYYYMMDD,HH:MM:SS,NNNNN,XXXX.XX,NNNNN,XXXX.XX,...

Where, for each run of 37 measurements:

- YYYY = Year
- MM = Month
- DD = Day of month
- HH = Hour (MST) of run start
- MM = Minute " " " “
- SS = Second " " " “
- NNNNN = Radiometer serial number (not limited to 5 figures)
- XXXX.XX = Irradiance (watts per square meter)

After the last daily run, and *before* equipment teardown, place your *USB flash drive* in the “IN BOX” or send an e-mail message with your corrected irradiance data. Cavity calibration files are not needed.

7. Data Processing

-Reda has developed an Excel spreadsheet system for reducing the data.

8. Data Reporting

-Our goal is to provide each participant with next-day analyses.
-NPC WRR reduction factors will be sent to the participants within one month of the comparisons.
-A final report will be published by NREL within six months of the comparisons.

9. Equipment Storage

-Each participant will be given space to store systems at SRRL.
-Please let us know if you wish to have any electronics connected to AC power while in storage.

10. Courtesies

-Please obtain permission before touching someone else’s equipment (turning off power strips, adjusting trackers, etc.) to prevent inadvertent data loss.
-Please return borrowed tools to owner.

11. Dinner on Wednesday (September 26)

Please join us for an Italian dinner at the Wilcox residence! (Directions to be provided)

Schedule of Events (Overview)

Monday, 24 Sept 2012

- Obtain your NREL ***Site-Access Badge*** at the Site Entrance Building
- Call SRRL ext. 6326 for your escort to the Mesa Top Facilities
- Participants unpack and install equipment for testing. (Please use ***Seating Chart*** on next page.)
- Tom will review ***important safety, security, and logistics*** information.
    - Clear sky? Take solar irradiance measurements!
    - Cloudy, but no precipitation? Take practice data

25 September – 5 October:

- After 06:30 MDT—Check Tom's voicemail announcement (303-384-6395)
- SRRL will be OPEN DAILY from 07:00 MDT to at least 17:00 MDT
- Clear sky?
    - Arrive at SRRL by 08:00 MDT
    - Install equipment and allow electronics to warm up
    - Prepare to TAKE DATA by 09:00 MDT!
- Cloudy sky?
    - Arrive at SRRL by 09:00 MDT
    - Technical presentations in SRRL conference room

Table 4. NREL Pyrheliometer Comparisons 2012
Seating Diagram

South

NREL Pyrheliometer Comparisons 2012
Seating Diagram

KEY
Tracker Info
Organizational Name
Participant Names

	Providing own tracker
	Sandia National Laboratories
	Bill Boyson
	Craig Camianani

Bench # 1: Breaker # 2S

Providing own tracker	NREL- Brusag
Kipp & Zonen	Physkalisch Meteorologisches Observatorium Davos
Joop Mes	Christian Thomann
Victor Casella	

Bench # 2: Breaker # 4N

Providing own tracker	Providing own tracker
DOE Atmospheric Radiation Measurement Program	European Commission/Joint Research Center
Craig Webb	Wim Zaaiman

Bench # 3: Breaker # 6S

Providing own tracker	NREL-SMT-3
NOAA/GMD	The Eppley Laboratory, Inc.
Don Nelson	Tom Kirk
Jim Wendell	

Bench # 4: Breaker # 10

Providing own traacker	Providing own tracker
Atmospheric Sciences Group - NASA	Atlas Material Testing Solutions-DSET
Fred Denn	Eric Naranen
	Akihito Akiyama / Bill Dokos
	Tsukasa Kobashi

Bench # 5: Breaker # 8

	NREL-2AP
	Florida Solar Energy Center
	Mary Watkins

Bench # 6: Breaker # 7

NREL-2AP
HukseffluxUSA, Inc.
Robert Dolce
Kees Van Den Bos
On SRRL BMS Platform

NREL Brusag & Celestron
NREL-Metrology
Ibrahim Reda
Keith Emery
Breaker # 1

Table 1	Table 2	Table 3

NPC-2012 Technical Discussions: Candidate Topics

The following are simply suggestions for possible presentations and discussions. Please let Tom know if you would like to add a topic!

- NPC TSG, Data Analyses, and Trends (Reda)
- Angular Dependencies of Two Pyrheliometer Types (Wim)
- Absolute Cavity Pyrgeometer and World Infrared Standard Group (Reda)
- ASTM Standards (Aron/Daryl)
- SRRL Overview (Tom)
- Resource Information and Forecasting Group Overview (Tom)
- RCC/BORCAL Overview and Long-term Trends (Steve)
- DQMS-3 Overview (Mary)
- ARM/NREL Overview (Tom)
- Historical Trends in Solar Data for SRRL (Tom)
- MIDC Overview (Afshin)
- RReDC Overview (Mary)
- SOLRMAP Overview (Steve)
- Demonstration of K&Z Indoor Calibrator (Steve & Victor/Joop)