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NREL Pyrheliometer Comparisons

22 September – 3 October 2008 (NPC-2008)

T. Stoffel and I. Reda

Technical Report
NREL/TP-550-45016
February 2009

NREL is operated for DOE by the Alliance for Sustainable Energy, LLC

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We are also grateful for the support from Bobi Garrett and Daryl Myers who authorized funds from the NREL Metrology Laboratory Technical Overhead and the U.S. Department of Energy (DOE)/National Renewable Energy Laboratory (NREL) Photovoltaics Research Program. The DOE Atmospheric Radiation Measurement (ARM) Program, funded through Argonne National Laboratory and Pacific Northwest National Laboratory, provided additional support.

The Physikalisch-Meteorologisches Observatorium Davos World Radiation Center (PMOD/WRC); The Eppley Laboratory, Inc.; NOAA's Earth System Research Laboratory/Global Monitoring Division; ATLAS Material Testing Technologies LLC/DSET Laboratories, Inc.; and the DOE Office of Science ARM Program provided solar irradiance measurements from reference radiometers with direct traceability to the World Radiometric Reference (WRR). These radiometers greatly strengthened our ability to transfer the WRR to the participating radiometers.

Thanks to each NPC-2008 participant for their patience and cooperation during this weather-dependent exercise.

NPC-2008 Participants. From left (standing): Tom Stoffel, Wim Zaaiman, Don Nelson, Fred Denn, Tom Kirk, David Halliwell, Ibrahim Reda, Mike Edgar, Ed Smith, Mary Watkins, Erik Naranen, Christian Thomann. From left (kneeling): Dan Riley, Bill Boyson, Craig Webb, Anthony Bucholtz, Cary Thompson. Not shown: Jim Goza and Phil Thacher.

List of Acronyms

BMS	Baseline Measurement System
CF	calibration factor
DOE	U.S. Department of Energy
IPC	International Pyrheliometer Comparison
IPC-X	Tenth International Pyrheliometer Comparisons
NOAA	National Oceanic and Atmospheric Administration
NPC	NREL Pyrheliometer Comparisons
NPC-2008	NREL 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	WRR transfer factor
WSG	World Standard Group

Executive Summary

Accurate and continuous long-term measurements of direct-normal (beam) solar irradiance from pyrheliometers[1] are important for the development and deployment of renewable energy conversion systems and other science and technology applications involving solar radiation flux, and ultimately, improving our understanding of the earth's energy budget for climate change studies. Providing these data places many demands on the quality of the 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 *World Radiometric Reference* (WRR) as the international standard for the measurement of direct-normal solar irradiance. 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 Physikalisch-Meteorologisches Observatorium Davos World Radiation Center (PMOD/WRC) to help establish the WSG.

Like any measurement system, 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 U.S. Department of Energy (DOE), the National Renewable Energy Laboratory (NREL) has participated in all 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 instruments are used by NREL to transfer WRR calibration to other radiometers.

NREL Pyrheliometer Comparisons (NPCs) are held annually at the Solar Radiation Research Laboratory (SRRL) in Golden, Colorado. Open to all pyrheliometer owner/operators, the NPC provides an opportunity to determine the unique WRR transfer factor (WRR-TF) for each participating pyrheliometer. By adjusting all subsequent solar irradiance measurements by the appropriate WRR transfer factor, the operator can establish calibration traceability to the WRR.

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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.

Figure ES-1. NPC-2008 Radiometer Deployment at NREL's Solar Radiation Research Laboratory (SRRL)

NPC-2008 was scheduled from September 22 through October 3, 2008. Twenty-three participants operated 37 absolute cavity radiometers and two 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-2008 consisted of three[3] out of the four NREL radiometers with direct traceability to the WRR having participated in the Tenth International Pyrheliometer Comparisons (IPC-X) in the fall of 2005. As the result of NPC-2008, 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-2008 was consistent with previous comparisons, including IPC-X. 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 Systems of Units.

Figure ES-2. Ibrahim Reda operates NREL's absolute cavity radiometers on solar trackers. Four DOE/NREL reference standards were used to determine WRR-TFs for participating radiometers.

The comparison protocol is based on data collection periods called *runs*. Each run consists of a six-minute electrical self-calibration, a series of 37 solar irradiance measurements at 20-second intervals, and a post-calibration. More than 1,000 reference irradiance measurements for each

[3] Historically, there have been four cavity radiometers in the TSG: AHF 28968, AHF 29220, AHF 30713, and TMI 68018. Due to optical contamination discovered during NPC-2008, TMI 68018 was removed from the TSG.

participating radiometer were collected during NPC-2008. Clear-sky daily maximum direct-normal irradiance levels ranged from 941 Wm^{-2} to 1002 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 this report 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.

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1. Introduction

Collecting solar irradiance data for applications in renewable energy technology research, global climate change studies, satellite remote sensing validations, general atmospheric science research, or a myriad of other applications involving the knowledge of solar flux, requires measurements traceable to a recognized calibration reference. The World Radiometric Reference (WRR) is the internationally recognized reference for direct-normal solar irradiance measurements (Fröhlich 1991).

The WRR was established by the World Meteorological Organization (WMO) in 1977 and has been maintained by the Physikalisch-Meteorologisches Observatorium Davos World Radiation Center (PMOD/WRC) in Switzerland (http://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 shortwave radiometers (pyranometers and pyrheliometers) with a wavelength response range of 280 nm to 3000 nm. Every five years, the WRR is transferred to WMO Regional Centers and other participants in the International Pyrheliometer Comparisons (IPC) held at the PMOD/WRC. The tenth IPC was completed in 2005 (Finsterle 2006). 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.

The 2008 NREL Pyrheliometer Comparisons (NPC-2008) was scheduled from September 22 to October 3, 2008 at the Solar Radiation Research Laboratory (SRRL) in Golden, Colorado. Twenty-three participants operated 36 absolute cavity radiometers during the comparisons (see Appendix A for a list of participants). The following organizations were represented at NPC-2008:

- Atlas Weathering Services, Inc. - DSET Laboratories
- Atmospheric Radiation Measurement Program of the U.S. Department of Energy
- The Eppley Laboratory, Inc.
- Florida Solar Energy Center
- NASA Langley Research Center, Atmospheric Sciences Division
- Naval Research Laboratory
- National Oceanic and Atmospheric Administration (NOAA), Earth System Research Laboratory
- National Renewable Energy Laboratory
    - Electricity, Resources, and Building Systems Integration Center
    - Metrology Laboratory
    - Solar Energy Technologies Program

Weather conditions during the period September 22 to September 27, 2008 were adequate for this year's NPC data collection (see Appendix B for more specific meteorological information). The results presented in this report are based on clear-sky direct-normal solar irradiance data collected on these six days.

2. Reference Instruments

Historically, four absolute cavity radiometers maintained by NREL that participated in the most recent IPC are used as the Transfer Standard Group (TSG) to maintain the WRR for the NPC. During the measurement periods of NPC-2008, TMI 68018 was discovered to be consistently measuring low irradiances, about 2% less than the other TSG radiometers. Equipment inspections during the comparisons yielded no apparent cause for the discrepancies. During subsequent investigations, which included the disassembly and visual inspection of the radiometer components, a spider and its web were removed from the precision aperture (see Figure 2.1). This optical obstruction was determined to be the cause of the measurement differences. *Therefore, data from TMI 68108 were not used to determine the WRR for NPC-2008*. Using the method described by Reda (1996), the mean of the remaining TSG measurements was maintained for establishing the reference irradiance data for NPC-2008 data reduction[4]. Table 2.1 provides a list of the TSG absolute cavity radiometers with their WRR reduction factors and pooled standard deviations as determined from the latest International Pyrheliometer Comparisons in 2005 (Finsterle 2006).

Table 2.1 IPC-X Results Summary for the NPC-2008 TSG

Serial Number	WRR Reduction Factor (from IPC-X)	Standard Deviation (%)	Number of Readings
AHF 28968	0.99777	0.0753	911
AHF 29220	0.99756	0.0737	922
AHF 30713	0.99751	0.0668	911
Mean WRR for the TSG	0.99761	**Pooled Std Deviation for the TSG** 0.07%	

The pooled standard deviation (SDp) for the TSG is computed from the following equation:

$$SD_p = \left[\sum_{i=0}^{m} (n_i * S_i^2) / \sum_{i=0}^{m} n_i \right]^{1/2}$$

where,

i = i^{th} cavity

m = number of reference cavities

S_i = standard deviation of the i^{th} cavity, from IPC-X

n_i = number of readings of the i^{th} cavity, from IPC-X

[4] After the instrument was cleaned and reassembled, comparisons of TMI 68018 with the other TSG radiometers confirmed the measurement performance was restored to historical levels. The storage of all TSG instruments has been improved to prevent future insect intrusion.

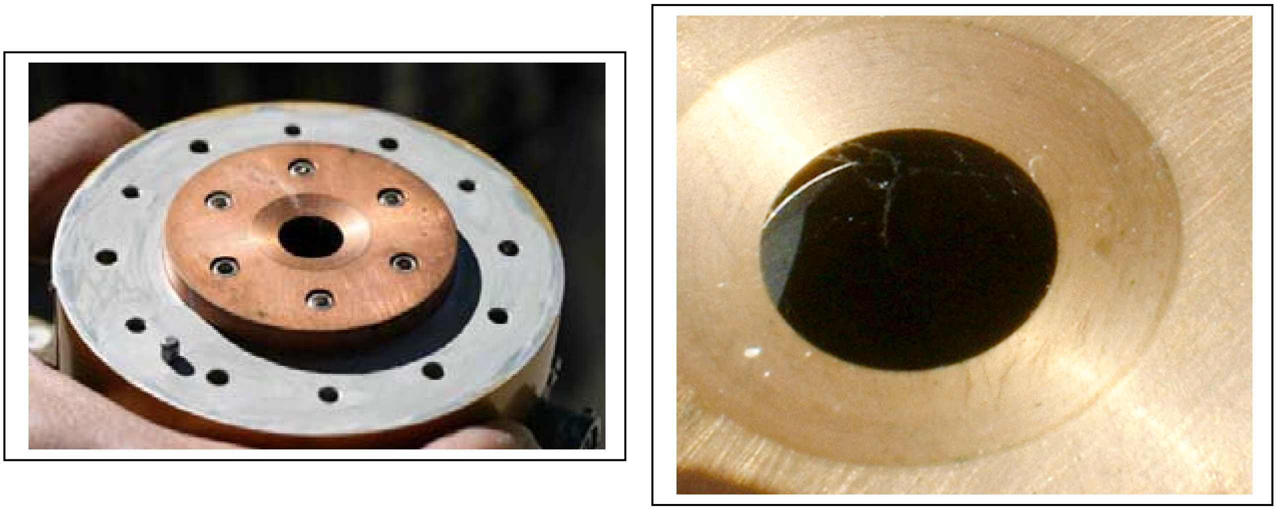

Figure 2.1 Inspection of TMI 68018 (left) revealed a spider and its web obstructed the precision aperture (right) resulting in 1.5% to 2.5% lower irradiance measurements when compared to other TSG radiometers.

3. Measurement Protocol

The decision to deploy instruments for a comparison is made daily. Data are collected only during clear-sky conditions determined visually and from 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 40-second open/closed shutter cycle). Each group of observations is called a *run*. An electrical self-calibration of each absolute cavity is performed just prior to each run. Previous WRR-TFs were <u>not</u> 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 calibration periods and gave a 6-minute countdown prior to the start of each run to facilitate a simultaneous start for each participant (see Appendix C for details).

By consensus, the goal was set to acquire at least 300 observations from each radiometer to determine the WRR-TF. Participants also agreed that a minimum ten runs should be performed over a period of at least three days to provide a variety of temperature and spectral irradiance conditions. The goal was to build a statistically significant data set from which to derive individual WRR-TF.

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

4. Transferring World Radiometric Reference

The primary purpose of these absolute cavity comparisons is to transfer the WRR from the NPC TSG to each of the participating radiometers. This requires the collection of simultaneous measurements of clear-sky direct-normal (or beam) solar irradiance by the participating radiometers and the TSG.

4.1 Calibration Requirements

Using WMO guidelines (Romero 1995), the following conditions were required before data collection was accomplished during NPC-2008:

- Radiation source was the sun, with irradiance levels greater than 700 Wm-2
- Digital multimeters with accuracy better than 0.05% of 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 with an angular distance larger than 15˚ from the sun.

4.2 Determining the Reference Irradiance

Three absolute cavity radiometers maintained by NREL and that participated in IPC-X, were used as the TSG to transfer the WRR in the comparison. The WRR-TF for each of the TSG is presented in Table 2.1. The reference irradiance at each reading is calculated using the following summarized steps (Reda 1996):

a. Each irradiance reading of the TSG is divided by the irradiance measured by AHF 28968.
b. By maintaining the mean of WRR for the TSG, a new WRR-TF for NPC-2008 is recalculated for each of the TSG cavities (Reda 1996).
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

AHF 28968 was used to check irradiance stability at the time of each comparison reading. Stable irradiance readings are defined to be within 1.0 Wm^{-2} during an interval of three seconds centered about 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 reference irradiance divided by the test instrument irradiance that deviated from their mean by more than 1.0% were rejected (PMOD/WRC 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.

4.4 Measurements

NPC-2008 took place on September 22 to October 3, 2008. The comparisons were completed on September 27, after more than 3,400 data points were collected by the reference cavities from 63 runs completed during six days with the requisite clear-sky conditions. The actual number of readings for each participating radiometer compared with the reference irradiance varies 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 4.5.1. To evaluate the performance of these instruments, the standard deviations of each radiometer are monitored during the comparisons. The results suggest successful performance of the TSG during this NPC:

- For the TSG, the NPC-2008 WRR-TFs did not change by more than a fraction of the standard deviation derived during IPC-X in 2005 (see Figure 4.5.1).
- For the control standards, i.e., cavities that participated in IPC-X and NPC-2008, their new WRR-TFs, from NPC-2008, are consistent with their IPC-X results (see Table 4.5.1).

Results for each radiometer participating in NPC-2008 are presented in Table 4.5.2.

Table 4.5.1 Summary Results for the Control Standards for NPC-2008

Serial Number	WRR (IPC-X)	WRR (NPC-2008)	SD (%)	Number of Readings	U_{95} (%)
AHF 31041	0.99629	0.99641	0.05	2865	0.35
AHF 31105	1.00165	1.00127	0.05	1369	0.35
AHF 32455	0.99909	1.00068	0.06	1719	0.35
AHF32448AWX	0.99987	1.00030	0.09	675	0.38
PMO6cc 0401	1.02153	1.02019	0.05	224	0.35
PMO6 81109	0.99841	0.99798	0.07	944	0.36
PMO6 911204	0.99901	0.99973	0.08	955	0.37
AHF 14915	0.99964	0.99954	0.05	3688	0.35
AHF 17142	0.99915	0.99817	0.05	2451	0.35
AHF 18747	1.00268	1.00042	0.09	2849	0.38
AHF 20406	1.00407	1.00198	0.06	2904	0.35
TMI 67502	0.99948	0.99992	0.06	3304	0.35

Table 4.5.2 Results for Radiometers Participating in NPC-2008

NO.	Serial Number	WRR-TF (NPC-2008)	Std Deviation	%SD	# of Readings	Uncertainty (% w.r.t. SI)
1	AHF 14915	0.99954	0.000530844	0.05	3688	0.35
2	AHF17142	0.99817	0.000460714	0.05	2451	0.35
3	AHF18747	1.00042	0.000948785	0.09	2849	0.38
4	AHF20406	1.00198	0.000601874	0.06	2904	0.35
5	AHF 21182	0.99944	0.000565848	0.06	2640	0.35
6	AHF 23734	0.99761	0.000313995	0.03	3271	0.34
7	AHF 28553	0.99709	0.000454355	0.05	3430	0.35
8	AHF 28964	1.00074	0.000673196	0.07	3444	0.36
9	AHF 29219	1.06316	0.001003922	0.09	3273	0.38
10	AHF 29222	1.05854	0.000805821	0.08	3544	0.37
11	AHF 30494	0.99759	0.000944403	0.09	3196	0.38
12	AHF 30495	0.99730	0.00051585	0.05	3521	0.35
13	AHF 31041	0.99641	0.000471782	0.05	2865	0.35
14	AHF 31104	0.99900	0.000432813	0.04	3259	0.34
15	AHF 31105	1.00127	0.000522191	0.05	1369	0.35
16	AHF 31108	0.99704	0.000554171	0.06	3226	0.35
17	AHF 32452	1.03201	0.00110431	0.11	3255	0.40
18	AHF 32455	1.00068	0.00059834	0.06	1719	0.35
19	AHF 33392	0.99857	0.000551443	0.06	1990	0.35
20	AHF 32448AWX	1.00030	0.000947899	0.09	675	0.38
21	AHF 34320AWX	0.99294	0.000540878	0.05	2894	0.35
22	AHF 34321AWX	0.99457	0.000560289	0.06	2886	0.35
23	CH1 060460	1.00150	0.001553733	0.16	1831	0.45
24	CH1 930018	0.99994	0.002838122	0.28	1844	0.66
25	PMO6 81109	0.99798	0.000715043	0.07	944	0.36
26	PMO6 911204	0.99973	0.000769796	0.08	955	0.37
27	PMO6-cc 0103	0.99842	0.000646085	0.06	501	0.36
28	PMO6-cc 0401	1.02019	0.000534765	0.05	224	0.35
29	PMO6-cc 0803	1.00016	0.000546063	0.05	506	0.35
30	TMI 67502	0.99992	0.000594285	0.06	3304	0.35
31	TMI 67603	0.99977	0.000540898	0.05	3162	0.35
32	TMI 67811	0.99948	0.000783858	0.08	2979	0.37
33	TMI 68017	0.99907	0.001225733	0.12	2767	0.41
34	TMI 68020	1.00026	0.000809904	0.08	3241	0.37
35	TMI 68022	1.00034	0.001171687	0.12	3023	0.41
36	TMI 68835	1.00393	0.00080238	0.08	2474	0.37
37	TMI 69036	1.00042	0.000477065	0.05	487	0.35

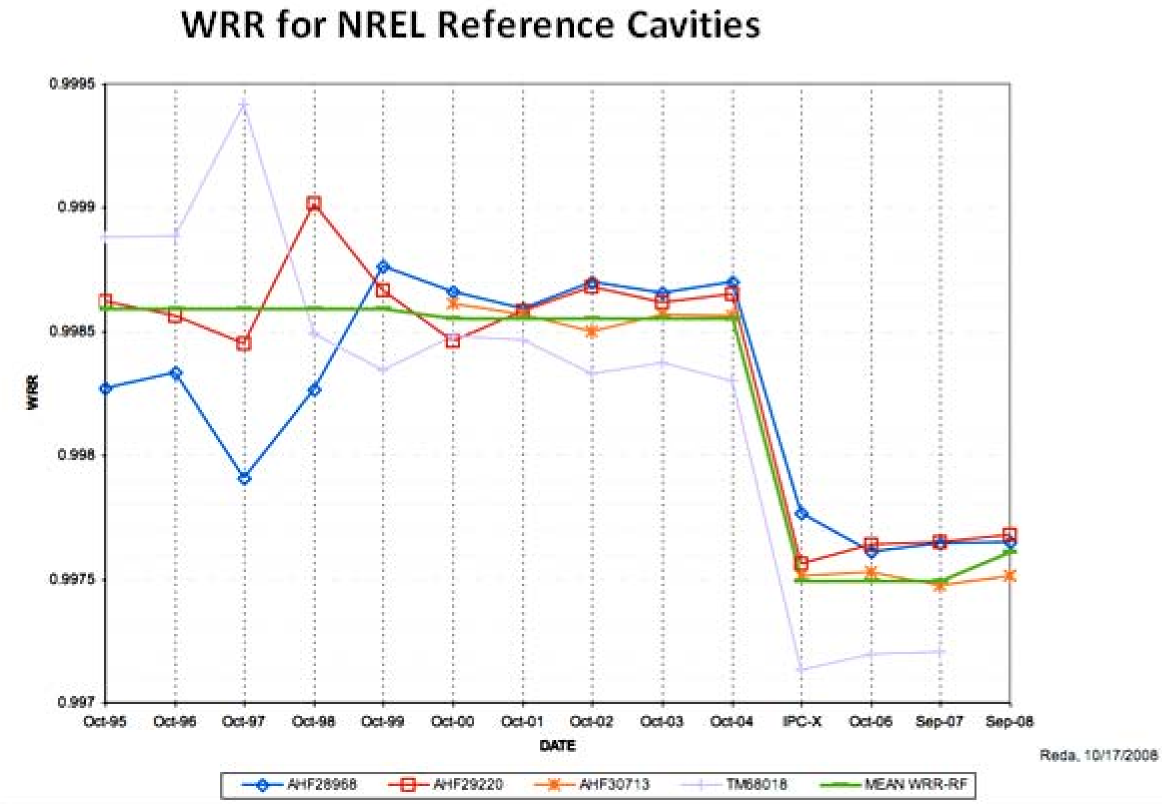

Figure 4.5.1 – History of WRR Factors for NREL Reference Cavities

The uncertainty of the WRR-TFs associated with each participating radiometer with respect to the WRR is calculated using the following formula:

$$U_{95} = \pm [(2 * 0.07)^2 + (2 * SD)^2]^{1/2}$$

where,

U_{95} = Uncertainty of the WRR-TF (in percent) determined at NPC-2008 with 95% confidence level

0.07 = Pooled standard deviation of the three reference radiometers (TSG) that participated in IPC-X (September/October 2005).

SD = One standard deviation of the WRR-TF (in percent) determined at NPC-2008 for each participating cavity.

The uncertainty of the WRR transfer factors associated with each participating radiometer with respect to International System of Units (SI) was calculated using the following formula:

$$U_{95} = \pm [(0.3)^2 + (2 * 0.07)^2 + (2 * SD)^2]^{1/2}$$

where,

0.3 is the uncertainty (±%) of the WRR scale with respect to SI units.

The statistical analyses of WRR-TFs for 37 participating radiometers are presented in Figures 4.5.2 through

4.5.38. These graphical summaries indicate the mean, standard deviation, and frequency of occurrence of the WRR-TFs determined during NPC-2008.

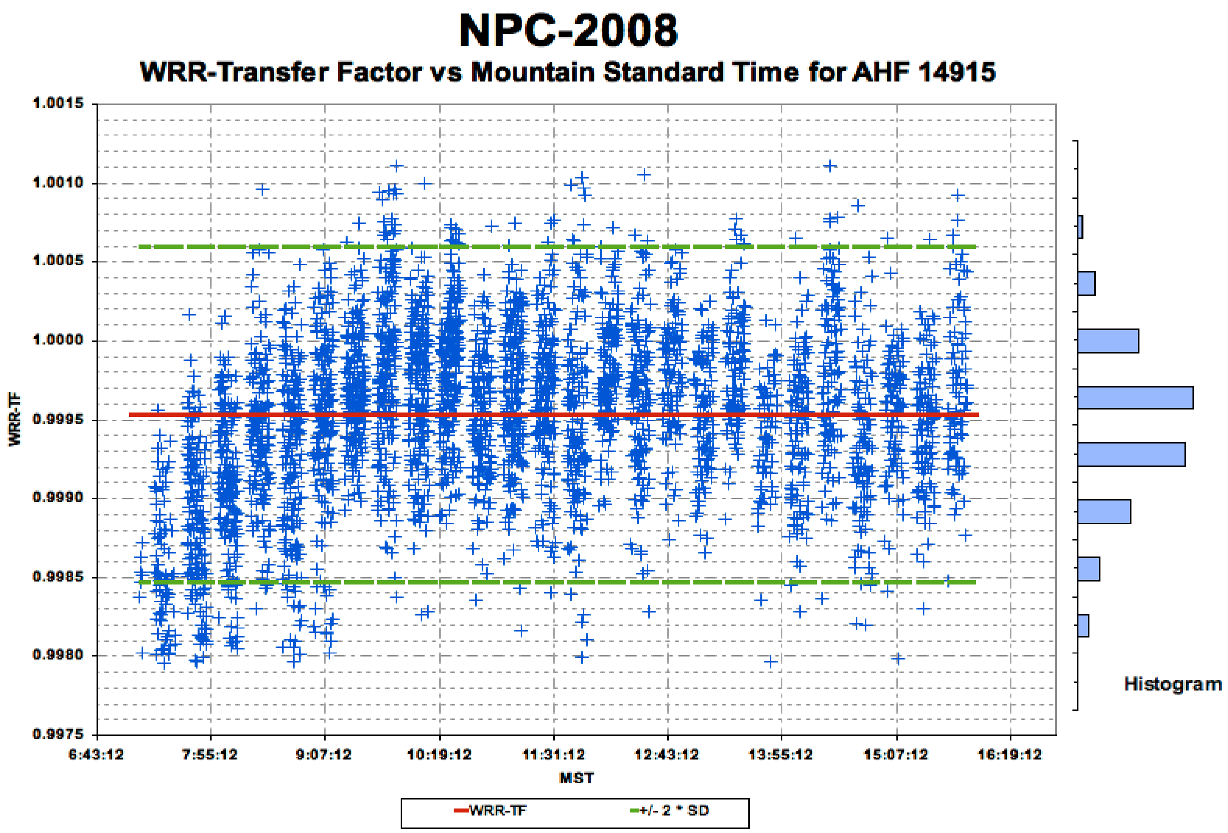

Figure 4.5.2 WRR-TF vs. Mountain Standard Time for AHF 14915 at NPC-2008

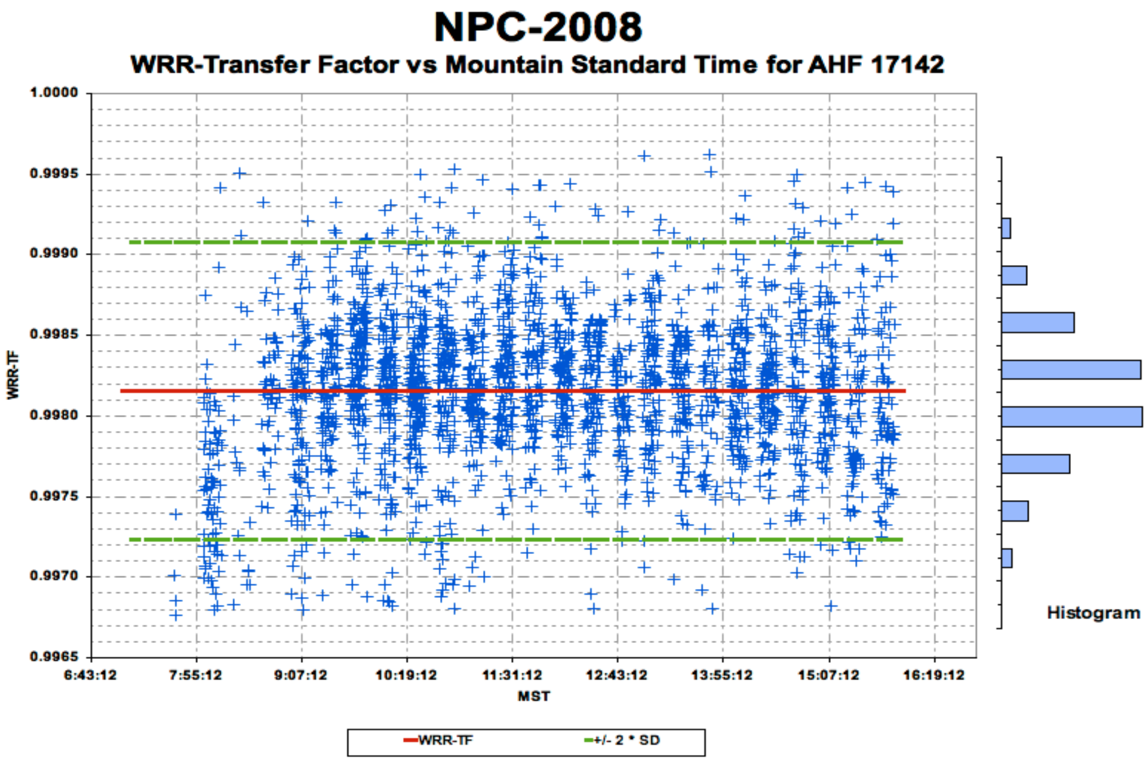

Figure 4.5.3 WRR-TF vs. Mountain Standard Time for AHF 17142 at NPC-2008

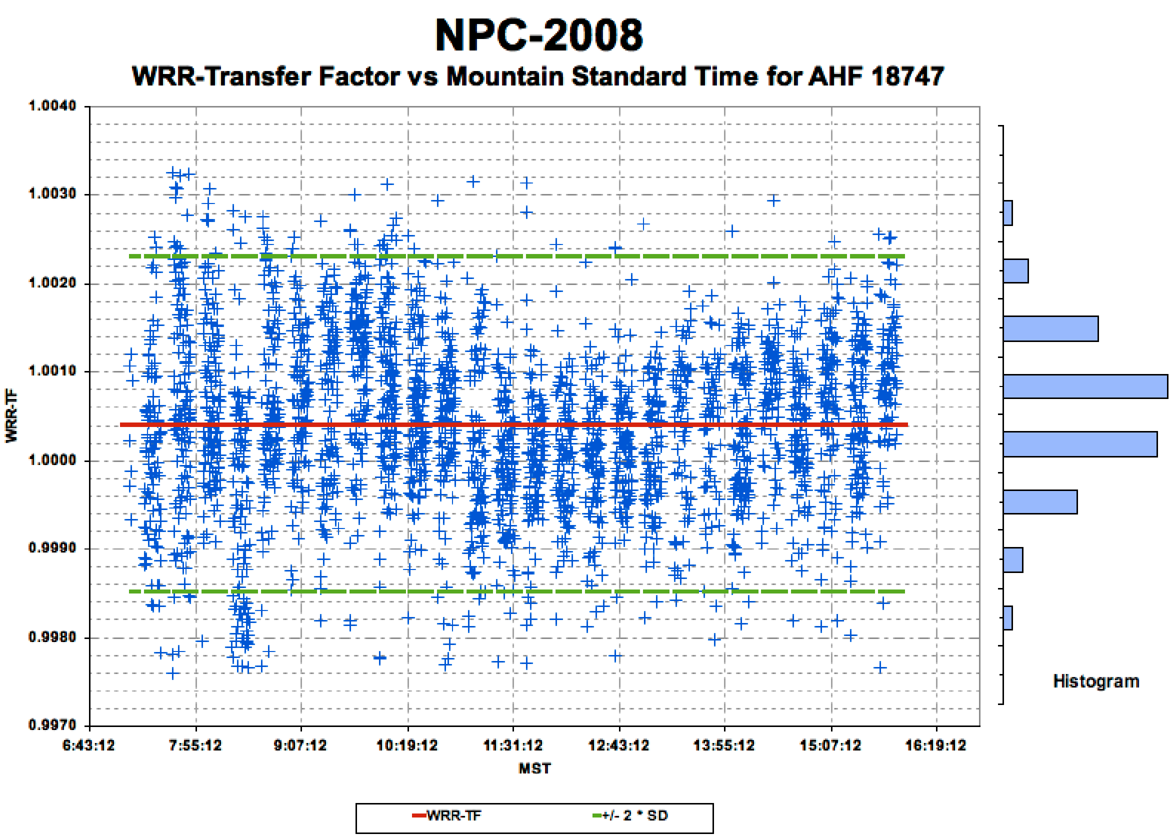

Figure 4.5.4 WRR-TF vs. Mountain Standard Time for AHF 18747 at NPC-2008

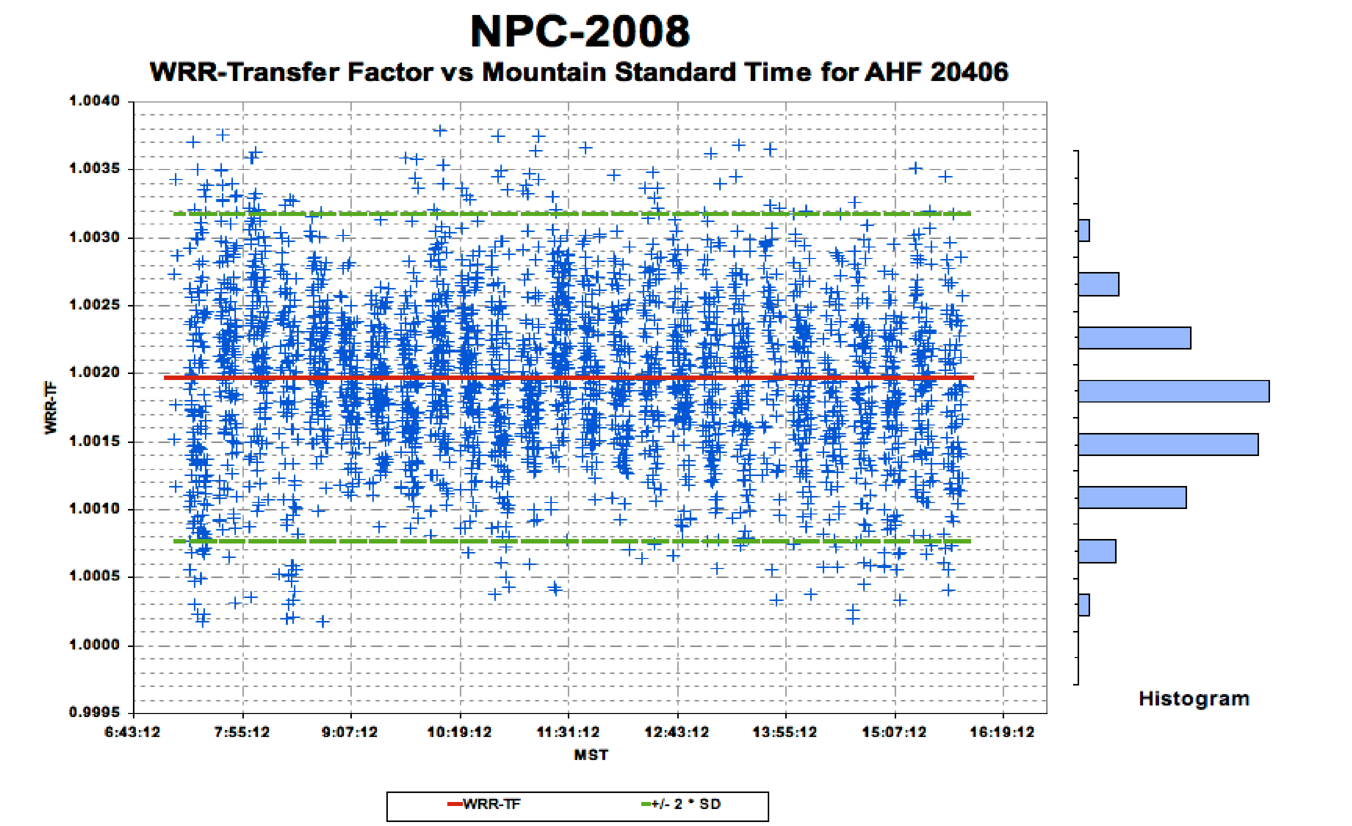

Figure 4.5.5 WRR-TF vs. Mountain Std Time for AHF 20406 at NPC-2008

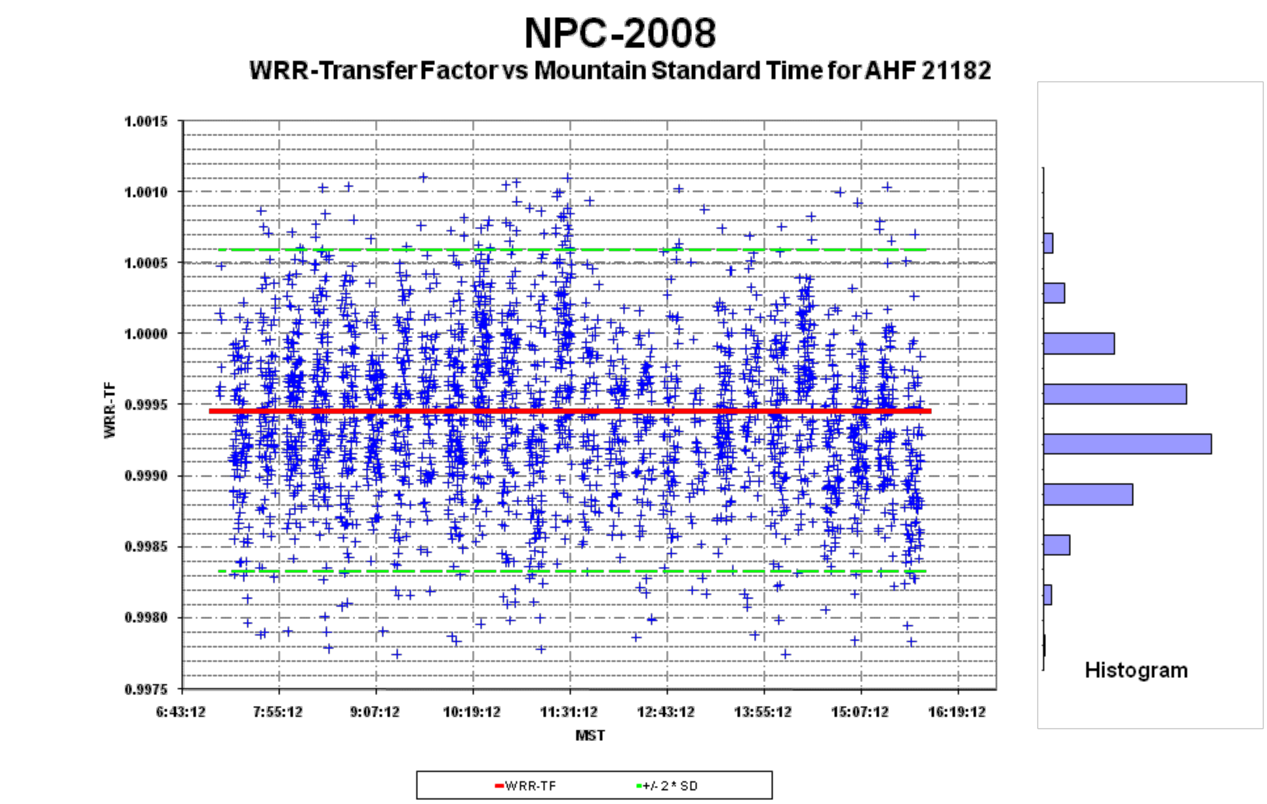

Figure 4.5.6 WRR-TF vs. Mountain Standard Time for AHF 21182 at NPC-2008

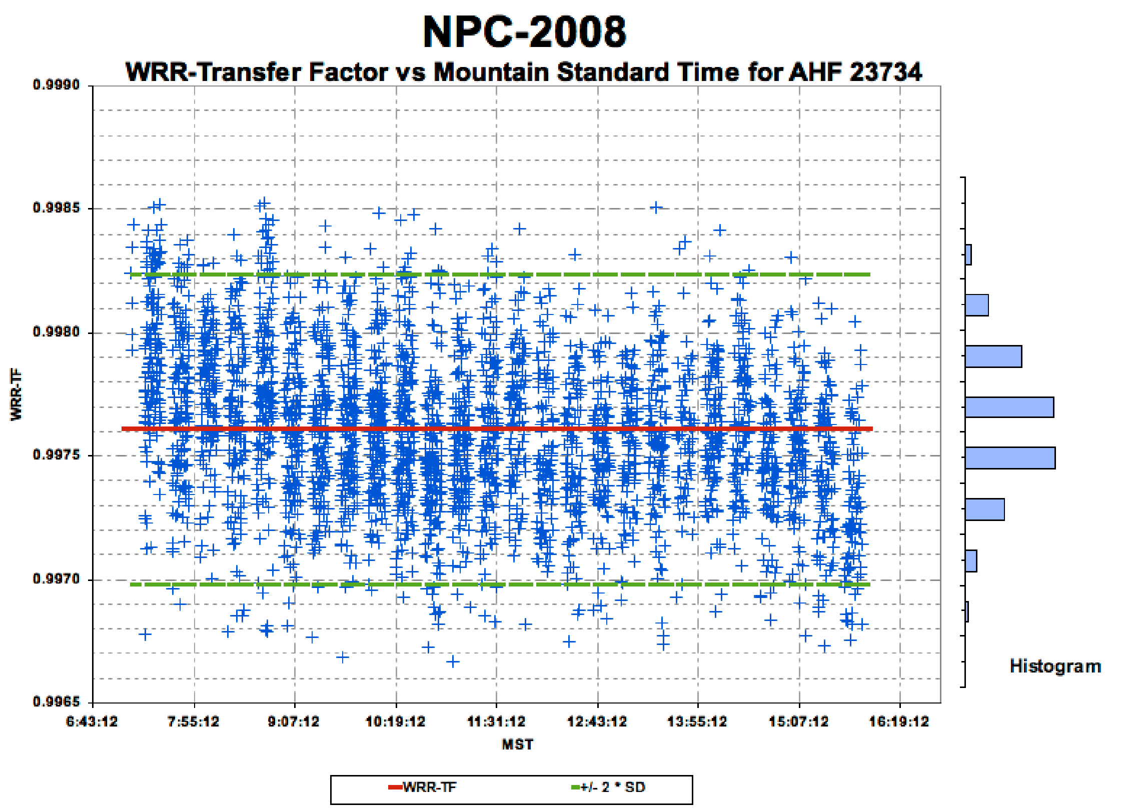

Figure 4.5.7 WRR-TF vs. Mountain Standard Time for AHF 23734 at NPC-2008

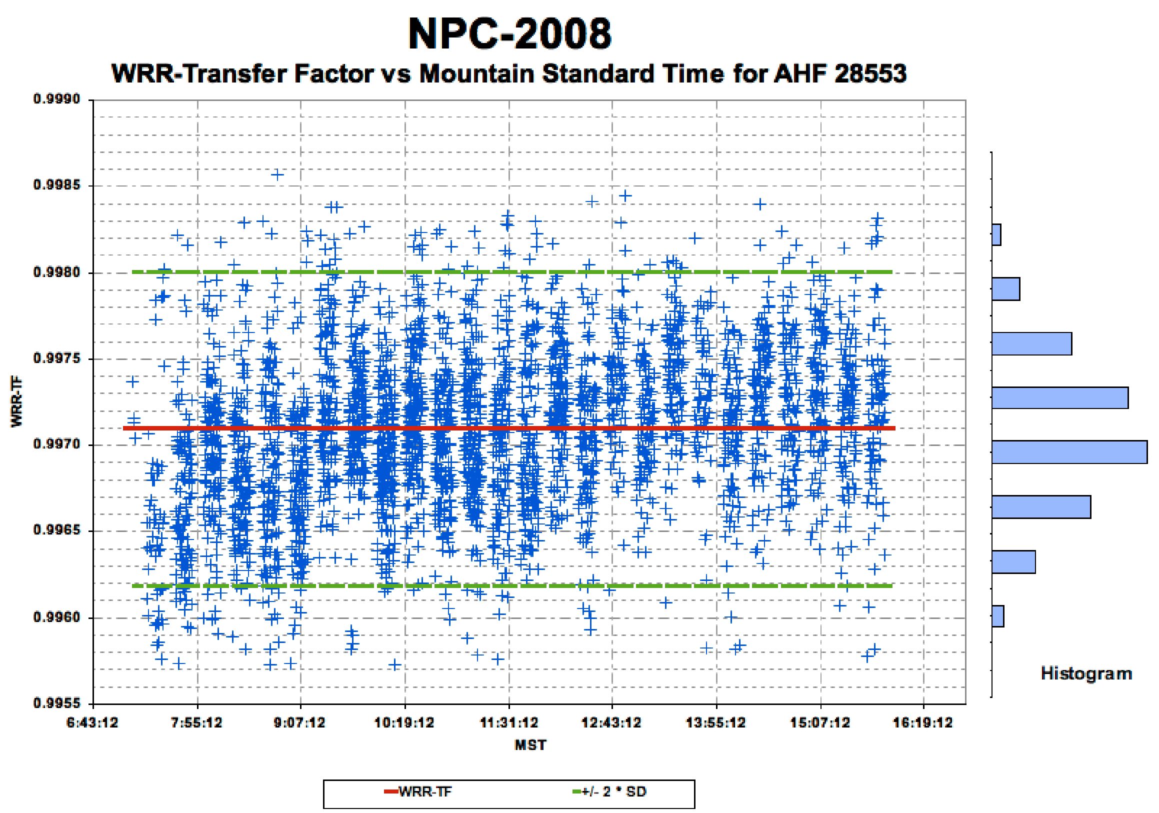

Figure 4.5.8 WRR-TF vs. Mountain Standard Time for AHF 28553 at NPC-2008

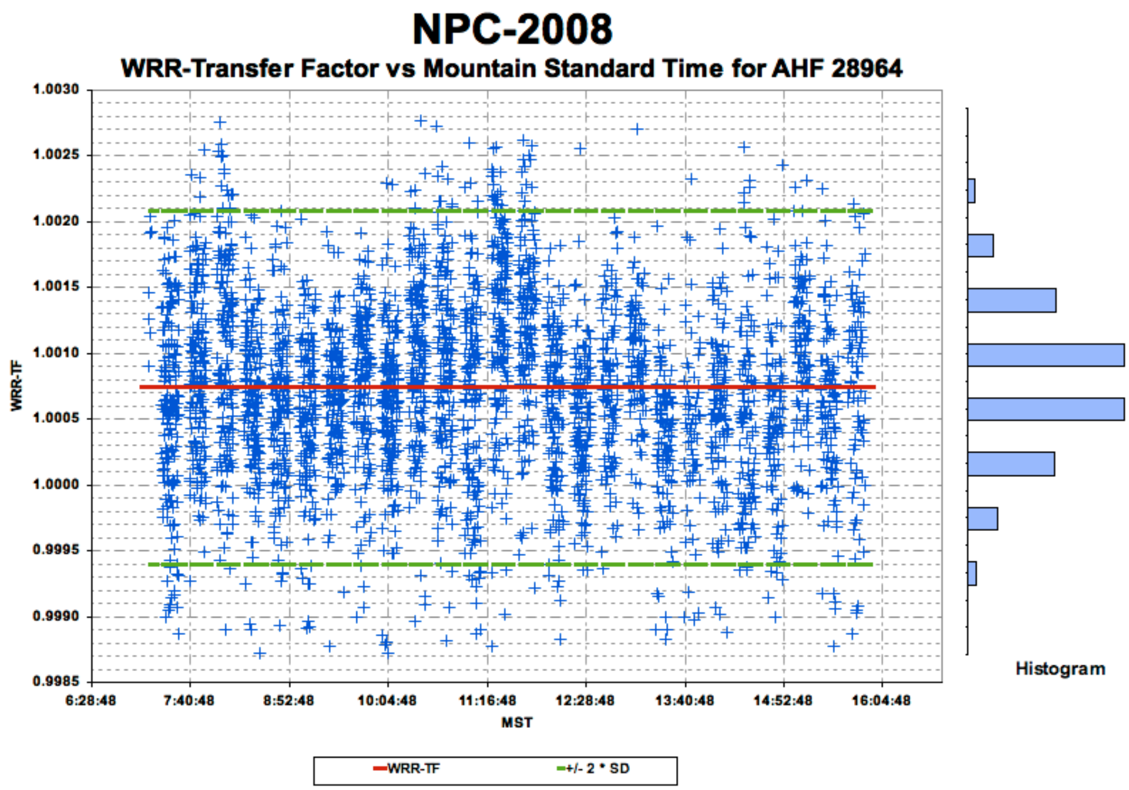

Figure 4.5.9 WRR-TF vs. Mountain Standard Time for AHF 28964 at NPC-2008

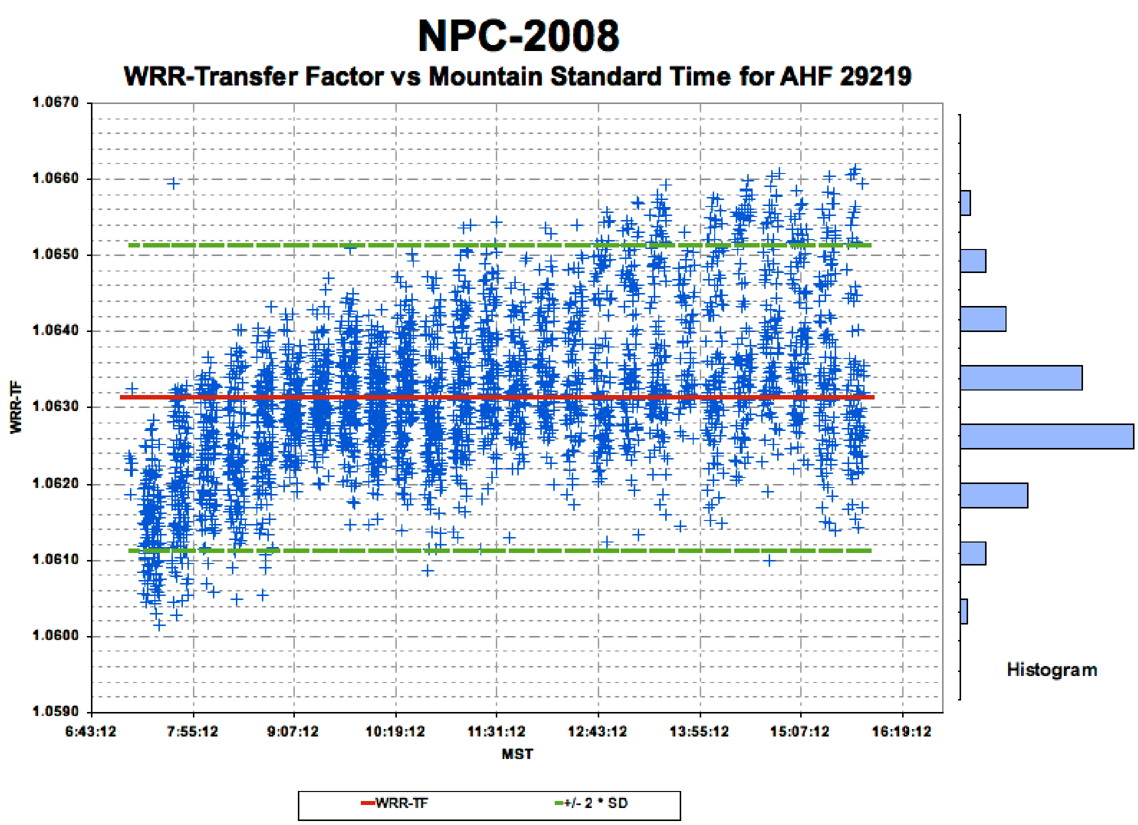

Figure 4.5.10 WRR-TF vs. Mountain Standard Time for AHF 29219 at NPC-2008

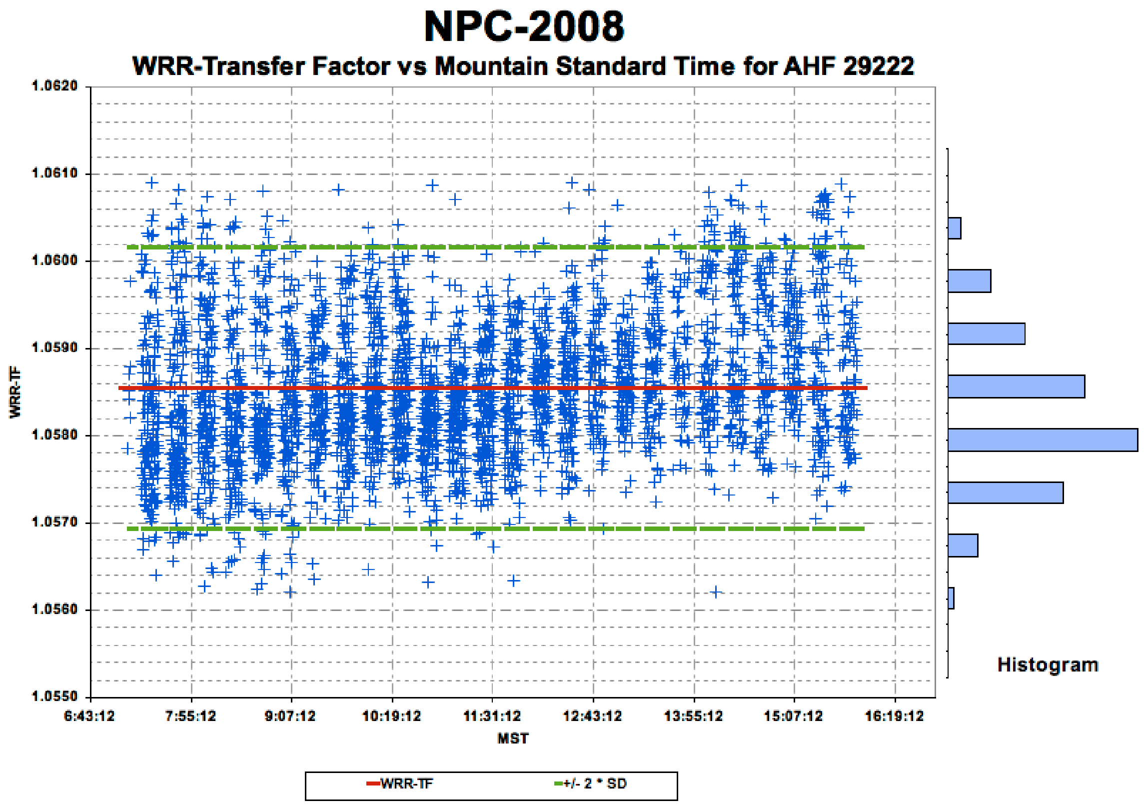

Figure 4.5.11 WRR-TF vs. Mountain Standard Time for AHF 29222 at NPC-2008

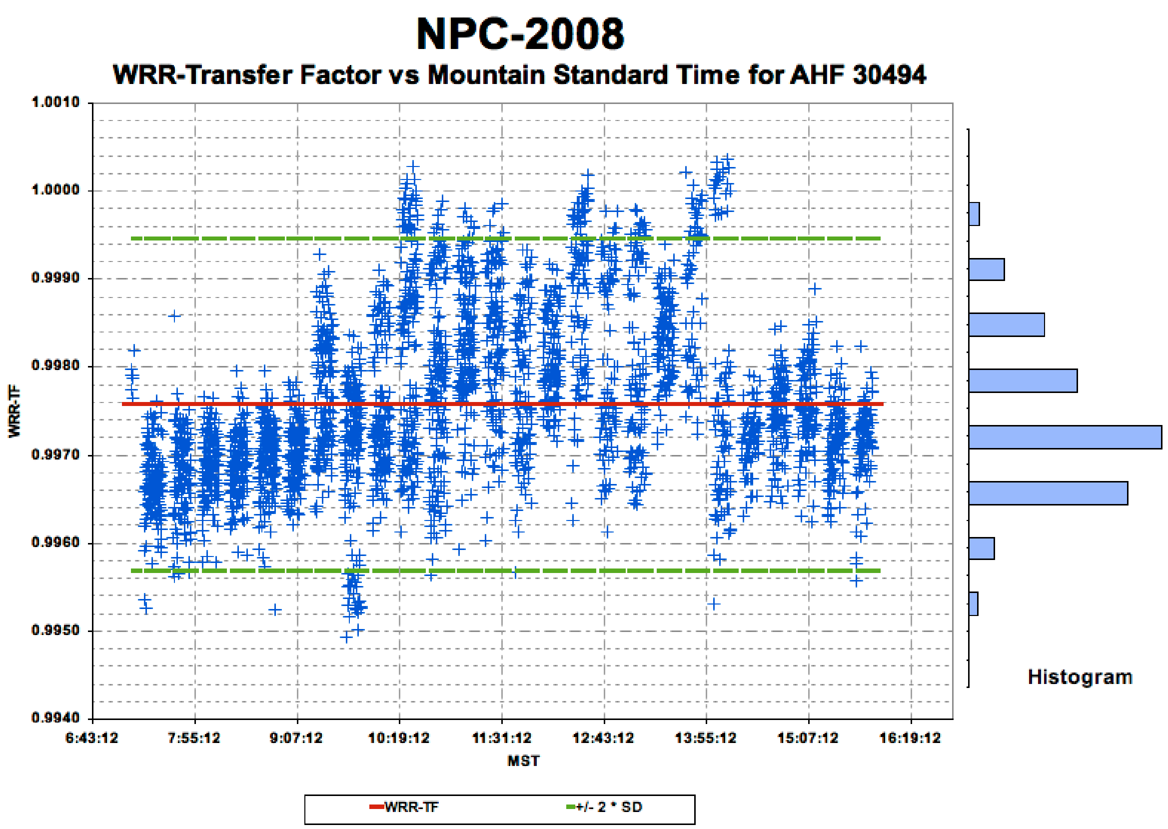

Figure 4.5.12 WRR-TF vs. Mountain Standard Time for AHF 30494 at NPC-2008

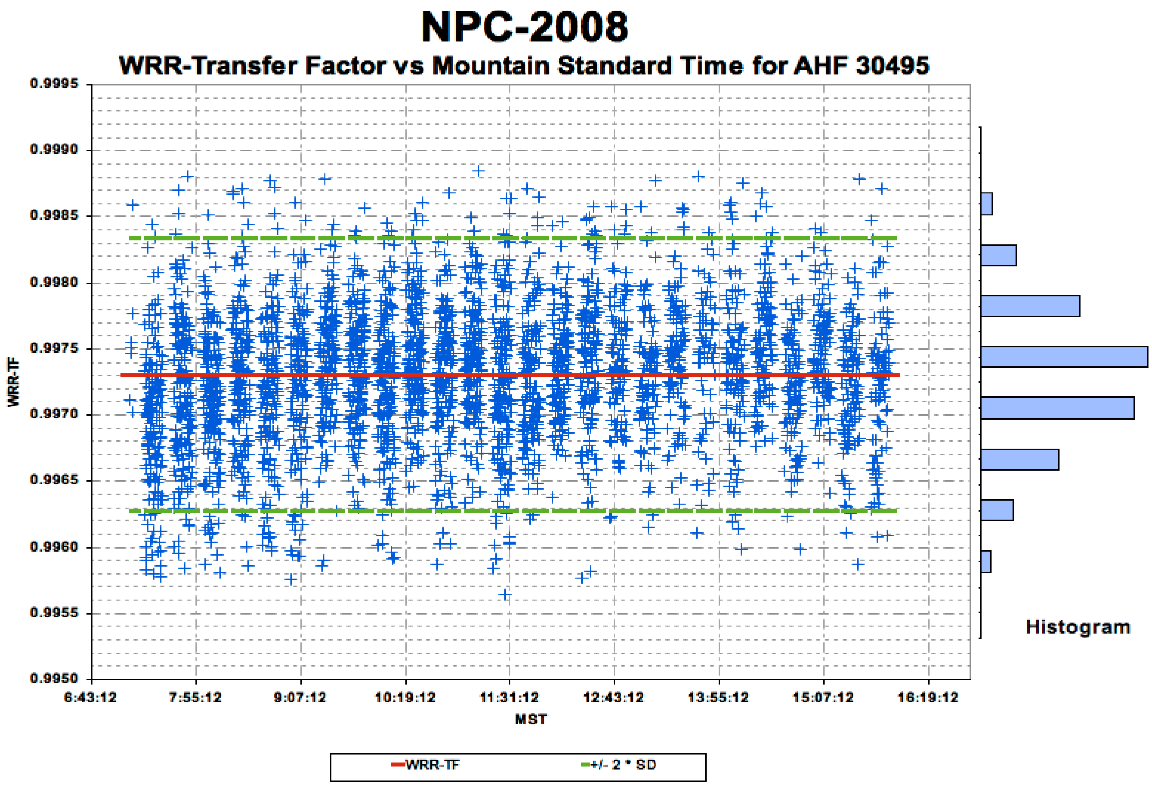

Figure 4.5.13 WRR-TF vs. Mountain Standard Time for AHF 30495 at NPC-2008

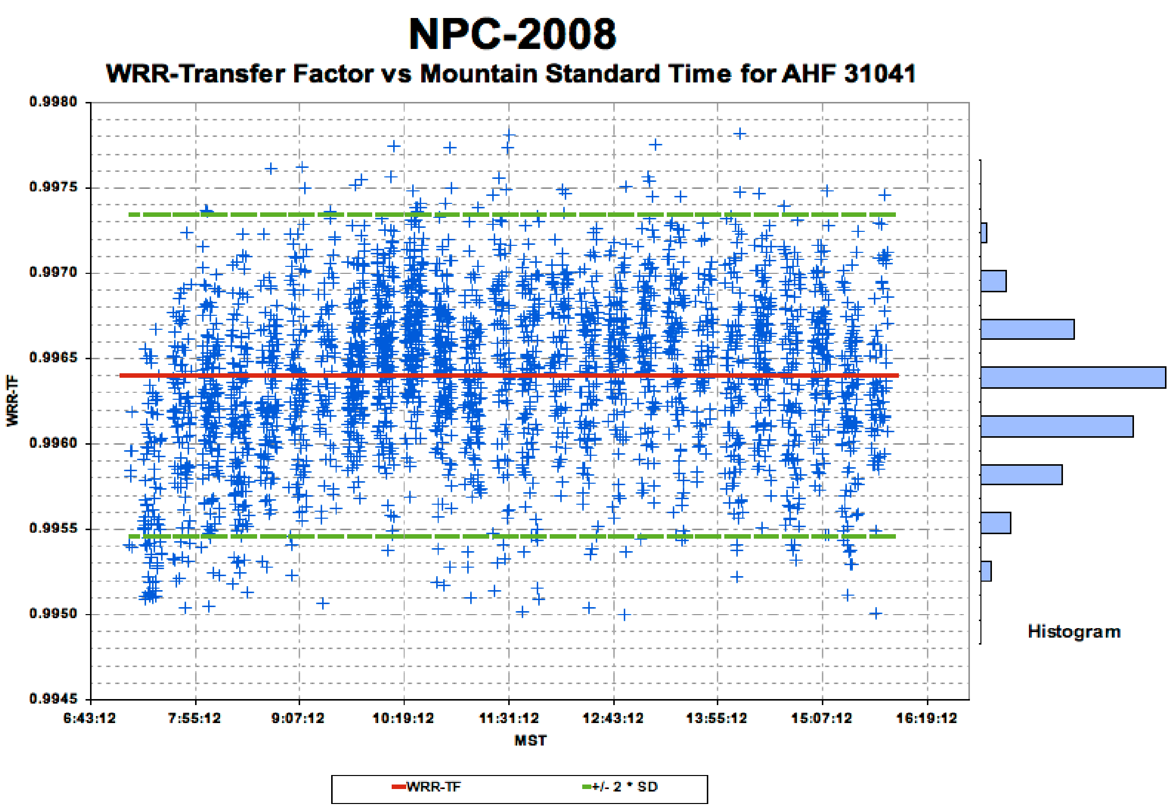

Figure 4.5.14 WRR-TF vs. Mountain Standard Time for AHF 31041 at NPC-2008

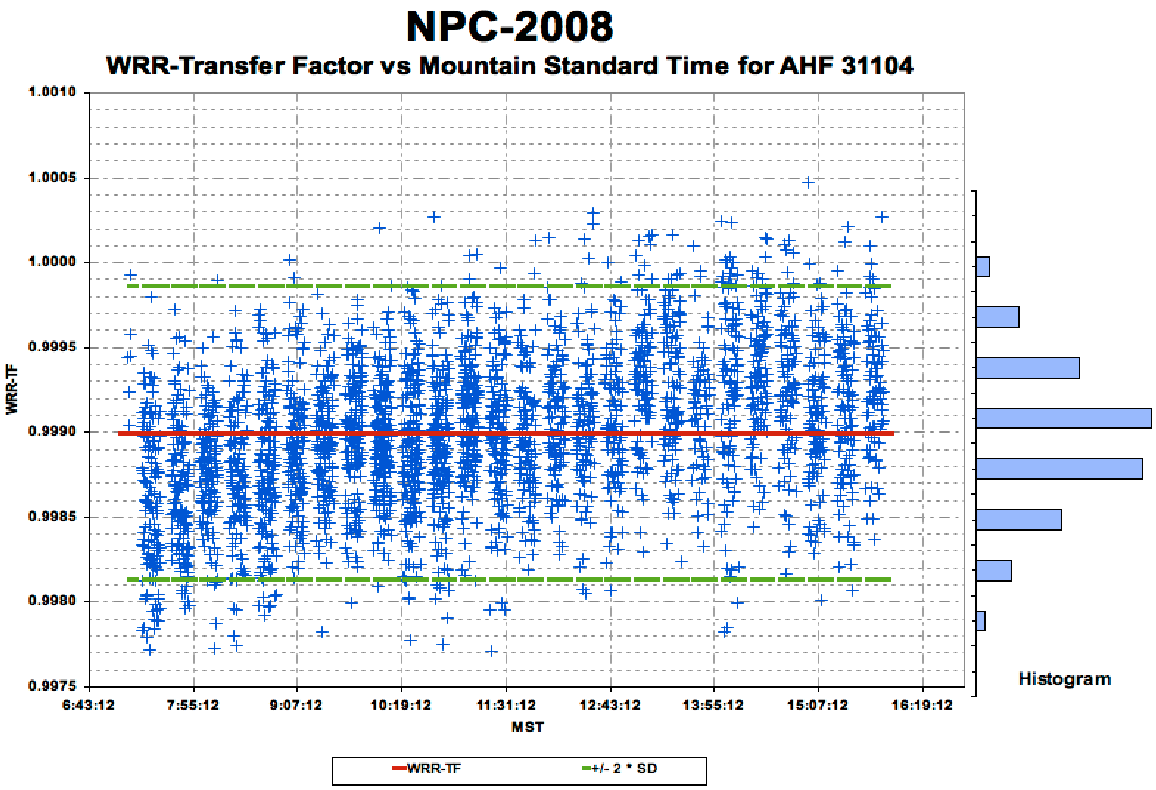

Figure 4.5.15 WRR-TF vs. Mountain Standard Time for AHF 31104 at NPC-2008

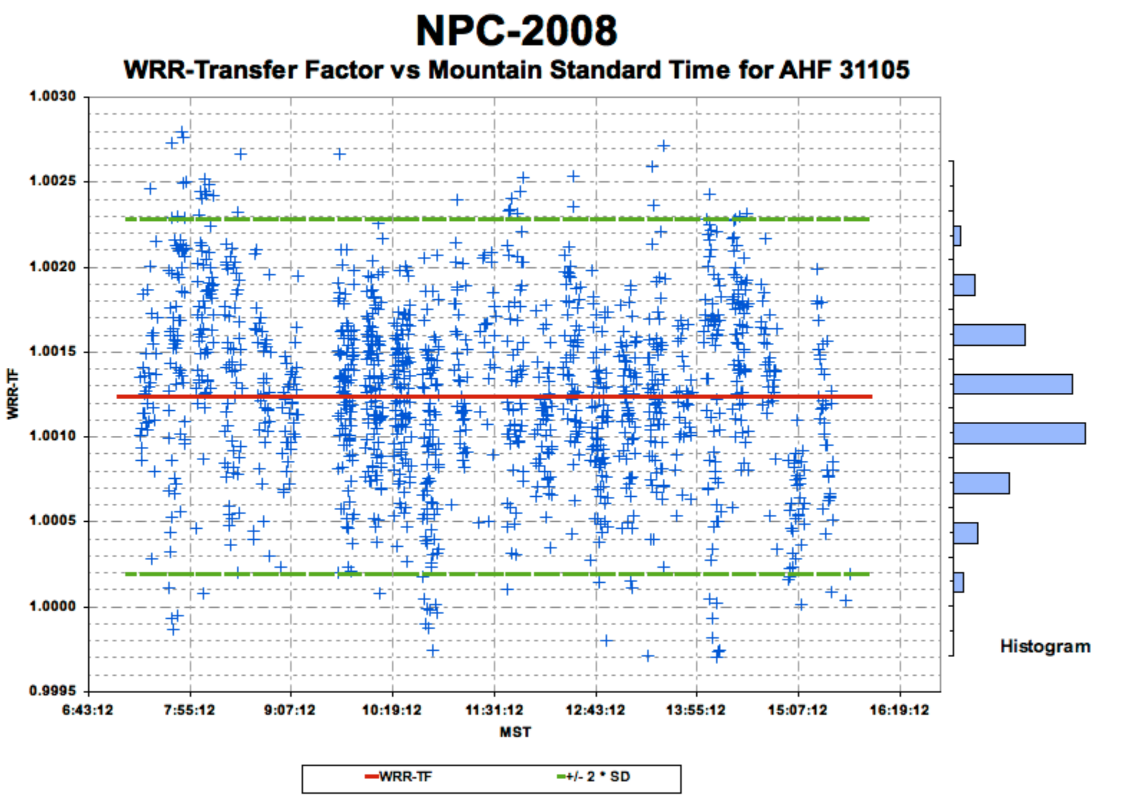

Figure 4.5.16 WRR-TF vs. Mountain Standard Time for AHF 31105 at NPC-2008

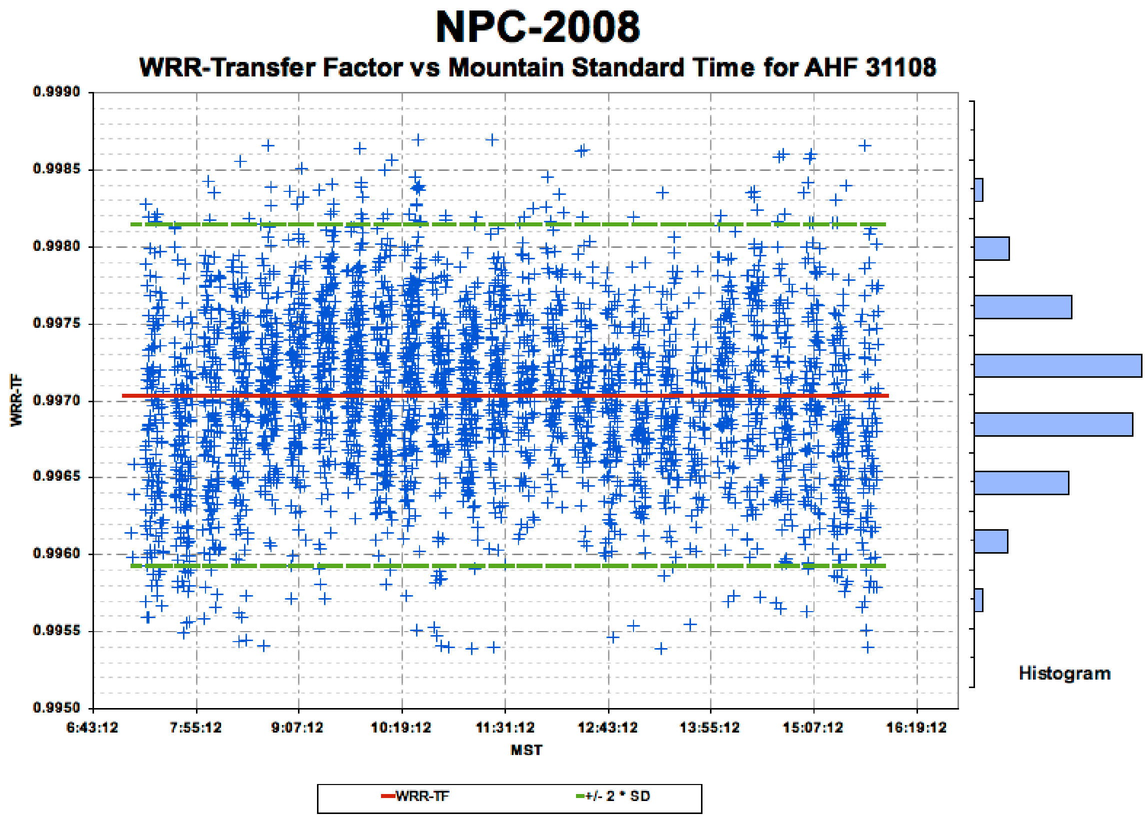

Figure 4.5.17 WRR-TF vs. Mountain Standard Time for AHF 31108 at NPC-2008

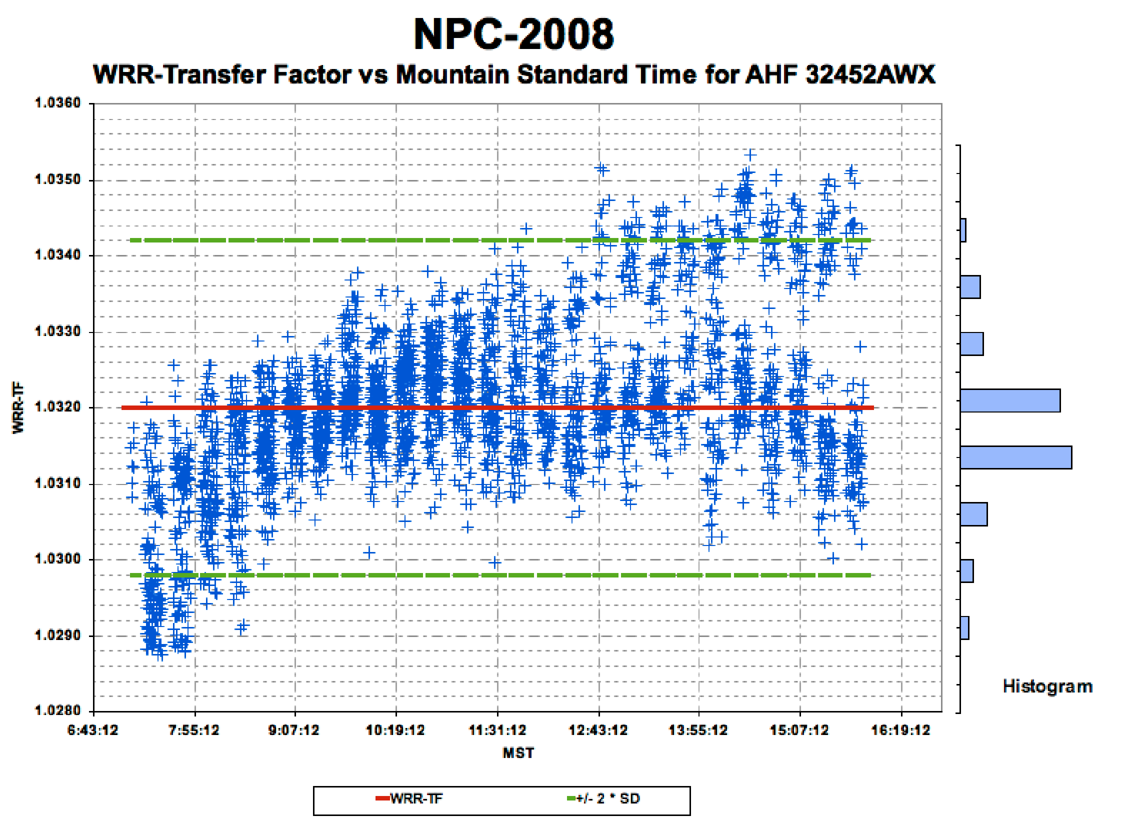

Figure 4.5.18 WRR-TF vs. Mountain Standard Time for AHF 32452AWX at NPC-2008

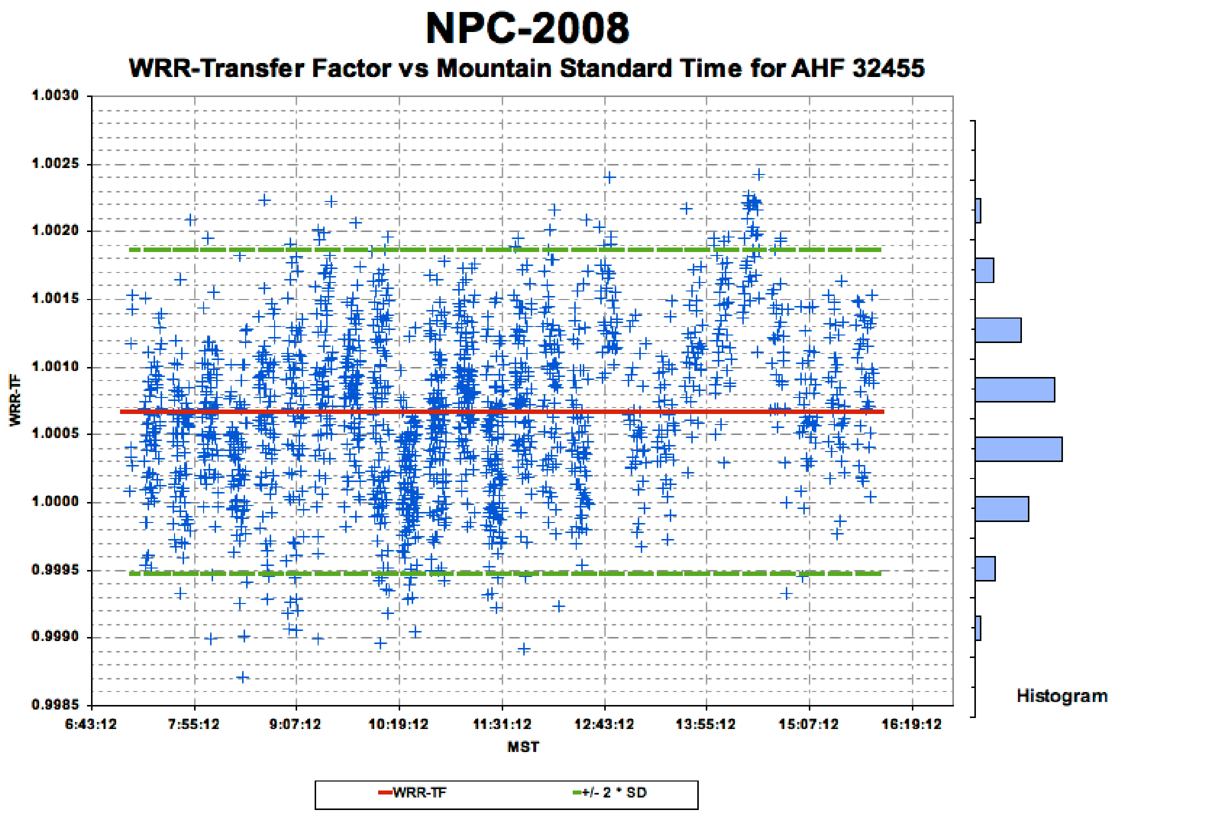

Figure 4.5.19 WRR-TF vs. Mountain Standard Time for AHF 32455 at NPC-2008

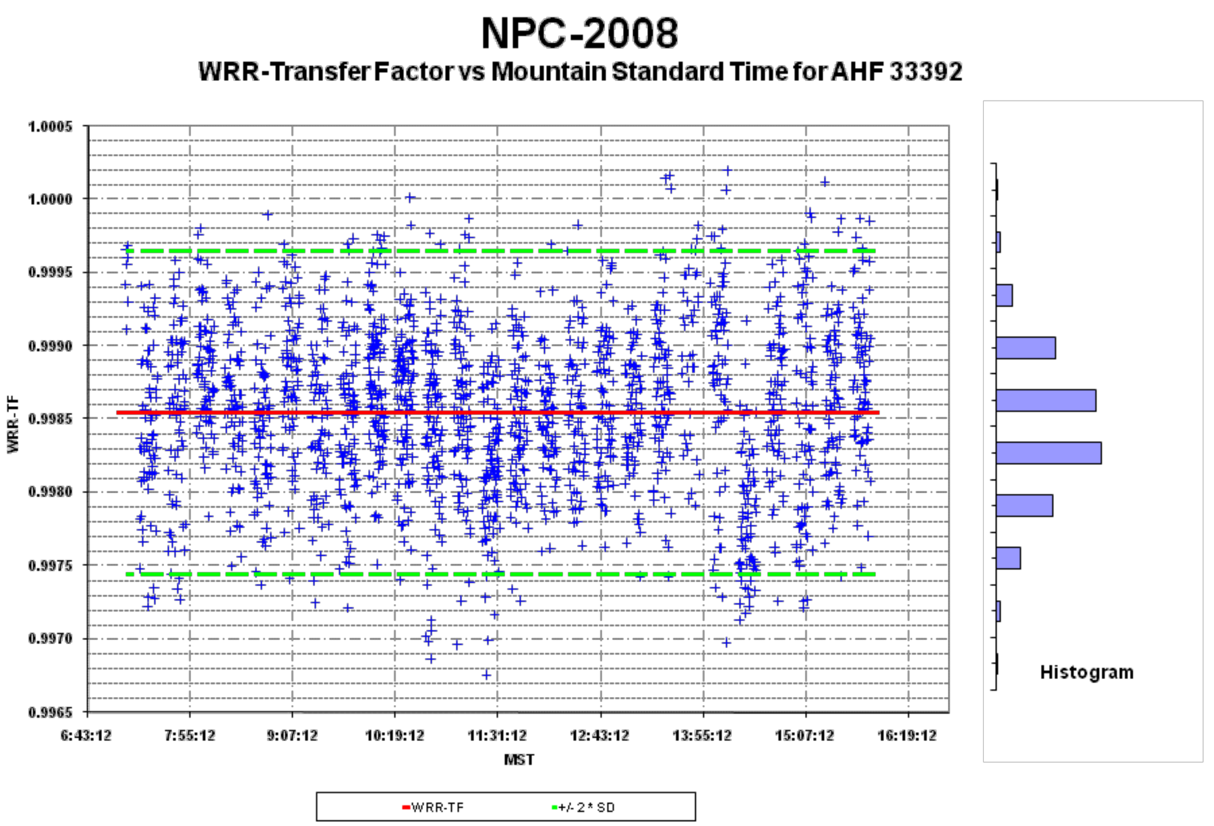

Figure 4.5.20 WRR-TF vs. Mountain Standard Time for AHF 33392 at NPC-2008

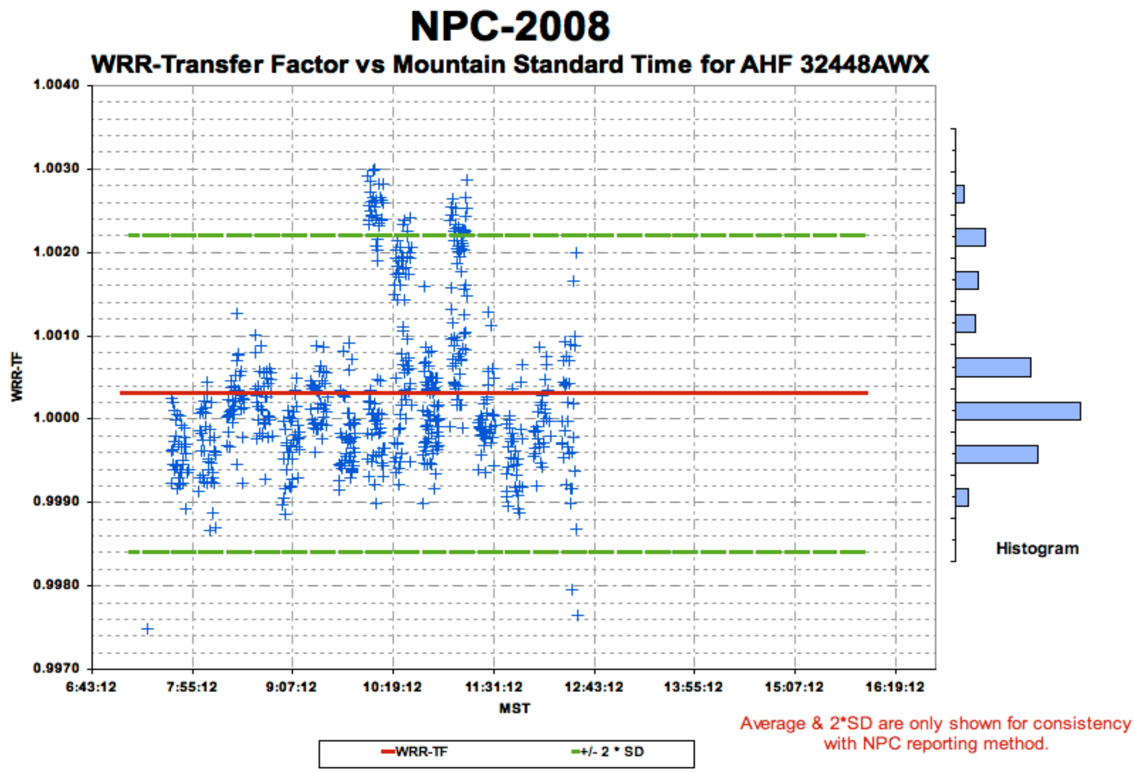

Figure 4.5.21 WRR-TF vs. Mountain Standard Time for AHF 32448AWX at NPC-2008

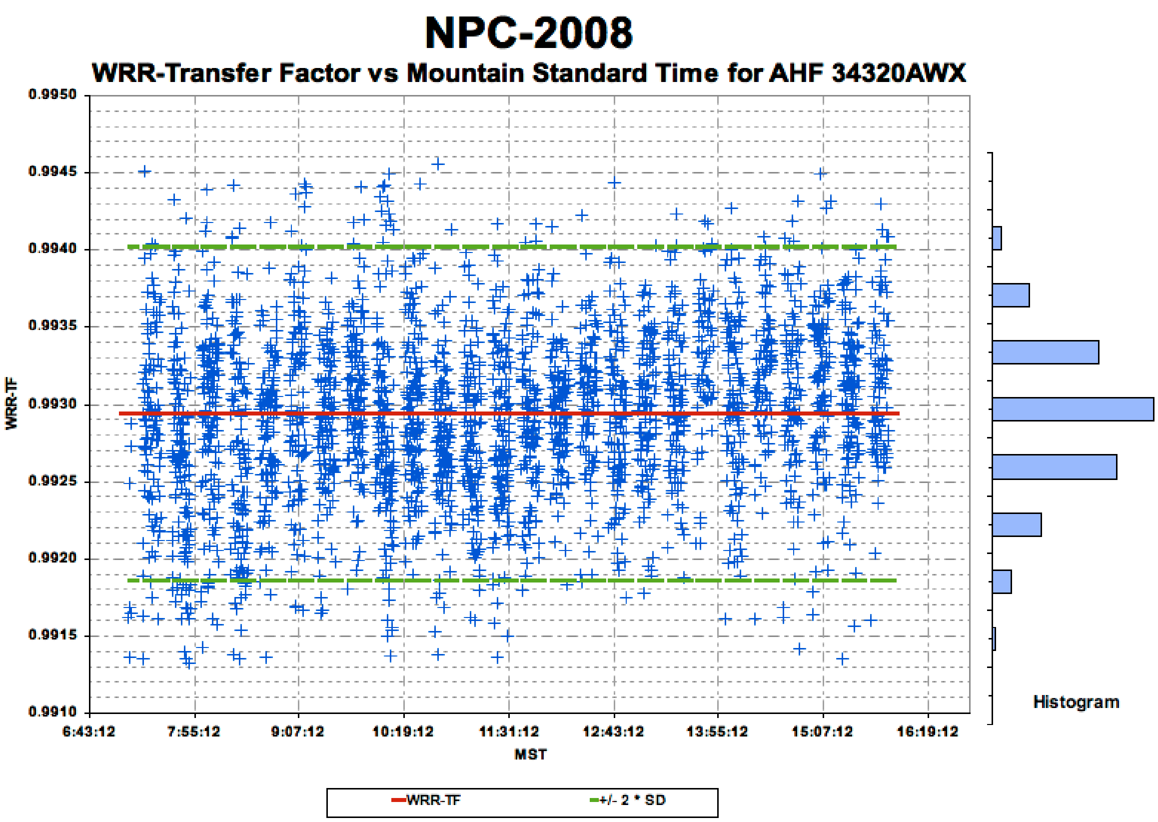

Figure 4.5.22 WRR-TF vs. Mountain Standard Time for AHF 34320AWX at NPC-2008

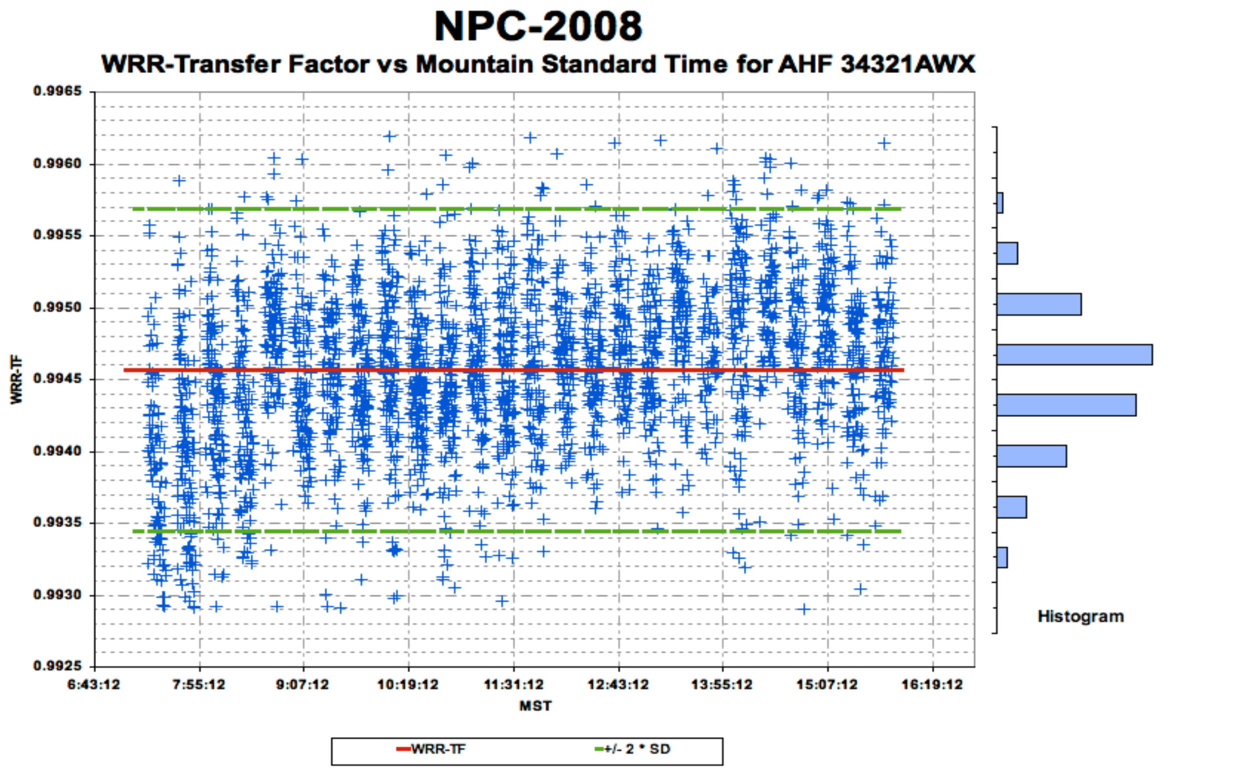

Figure 4.5.23 WRR-TF vs. Mountain Standard Time for AHF 34321AWX at NPC-2008

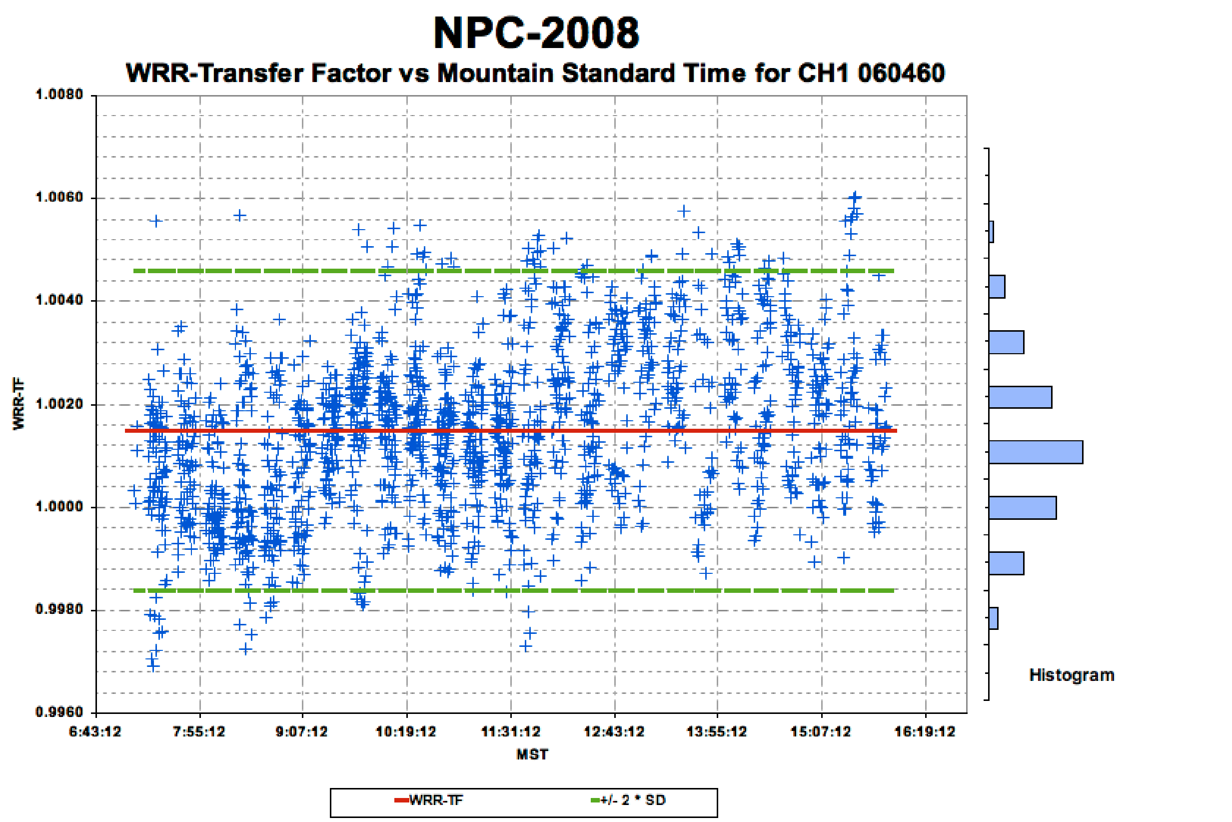

Figure 4.5.24 WRR-TF vs. Mountain Standard Time for CH1 060460 at NPC-2008

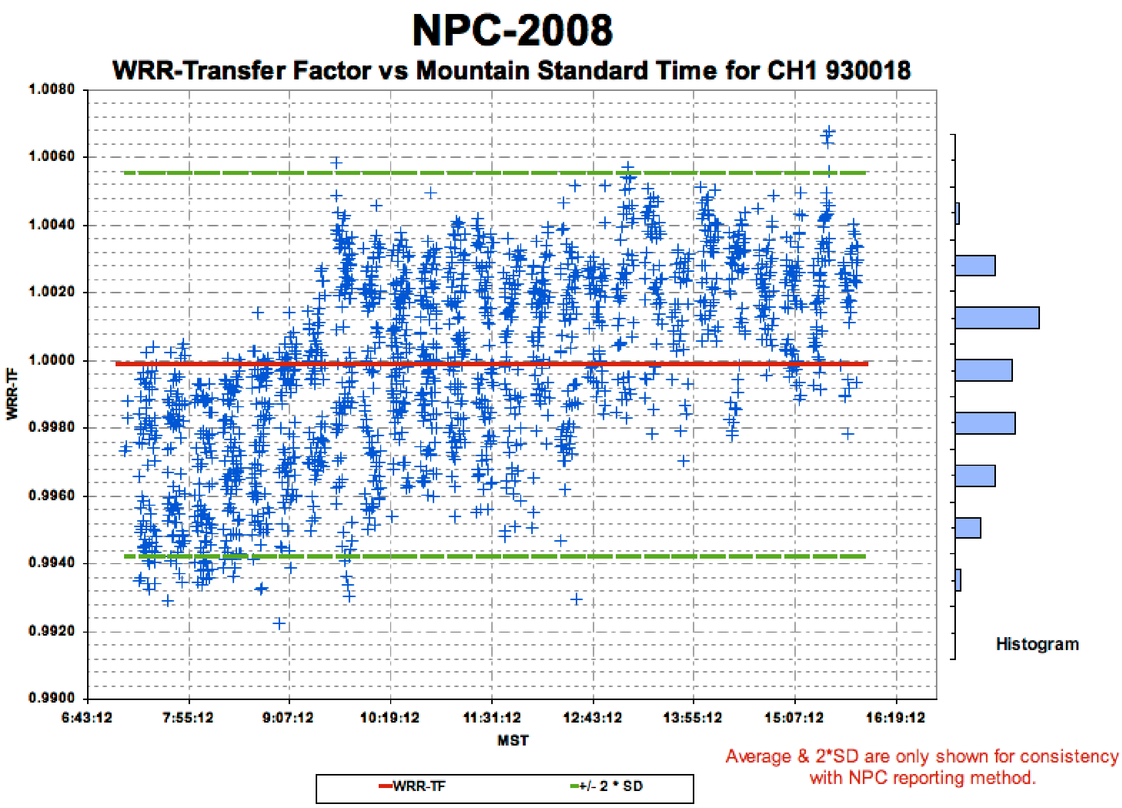

Figure 4.5.25 WRR-TF vs. Mountain Standard Time for CH1 930018 at NPC-2008

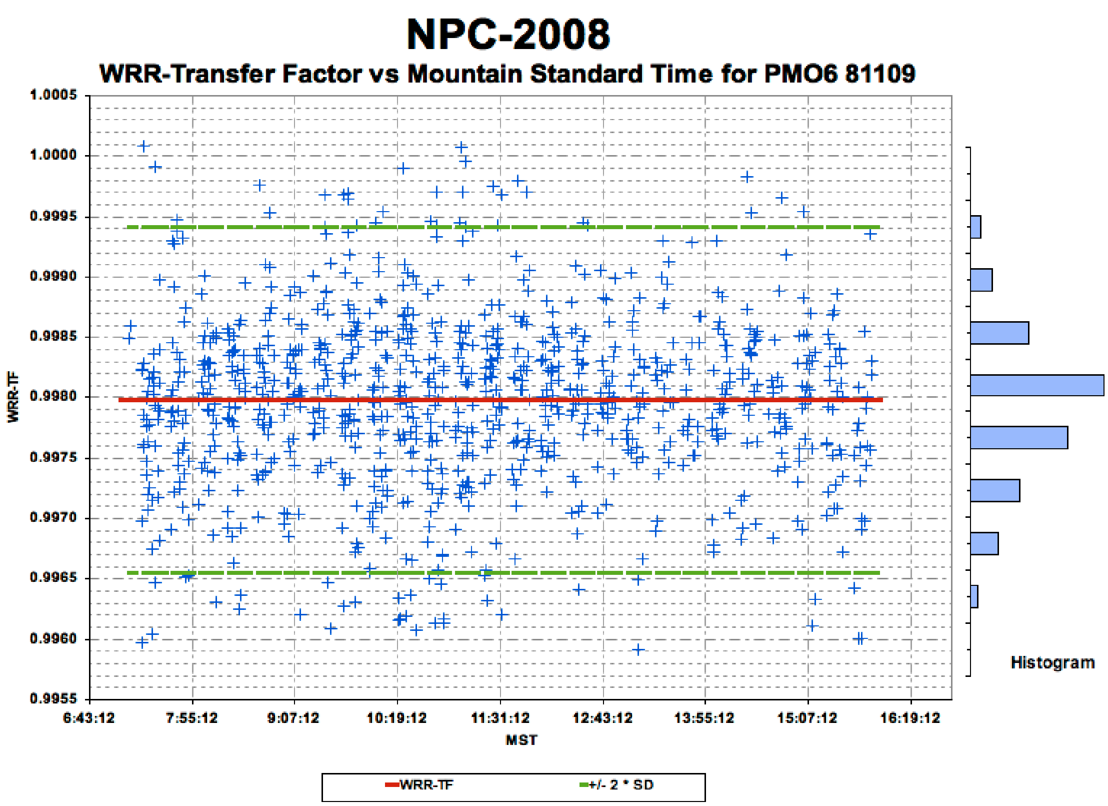

Figure 4.5.26 WRR-TF vs. Mountain Standard Time for PMO6 81109 at NPC-2008

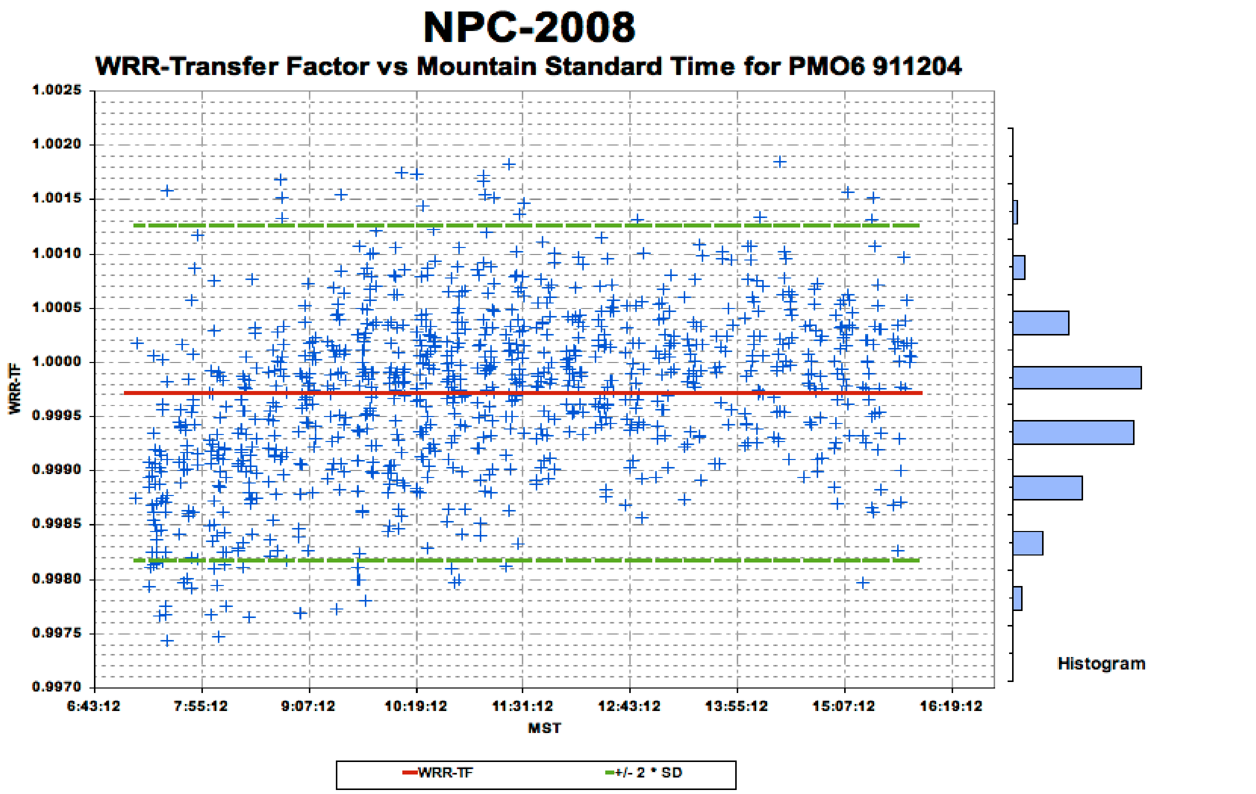

Figure 4.5.27 WRR-TF vs. Mountain Standard Time for PMO6 911204 at NPC-2008

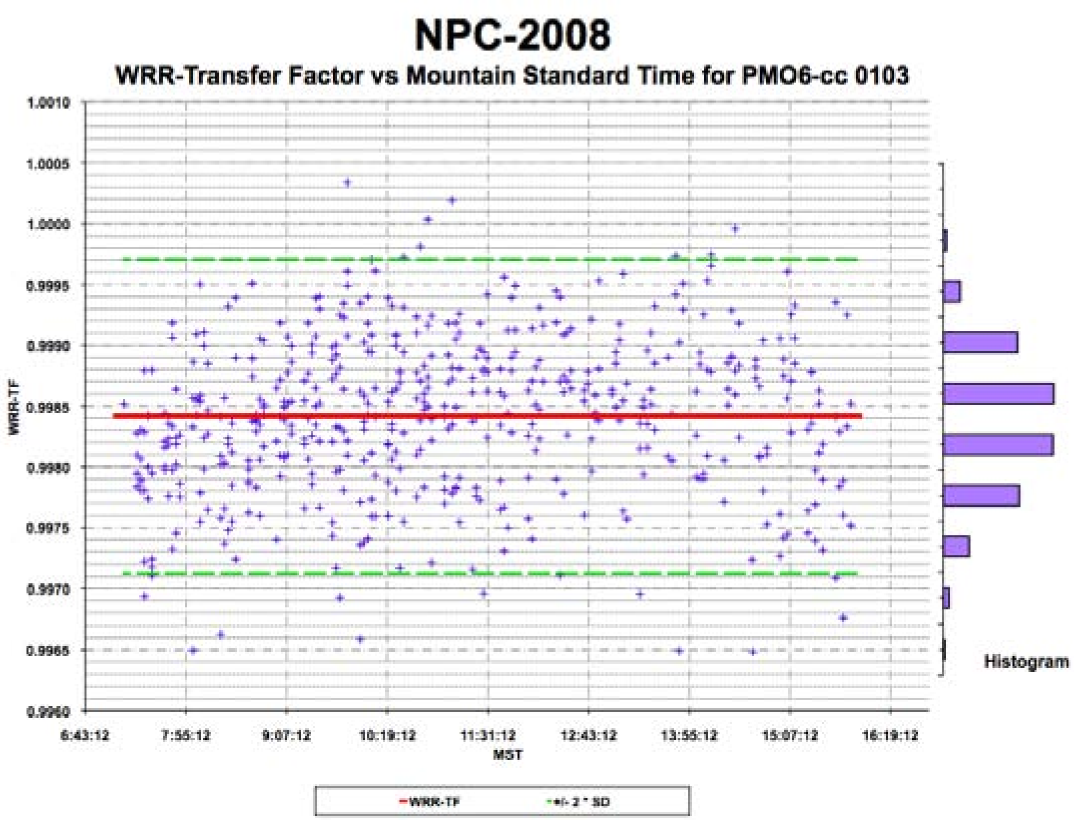

Figure 4.5.28 WRR-TF vs. Mountain Standard Time for PMO6-cc 0103 at NPC-2008

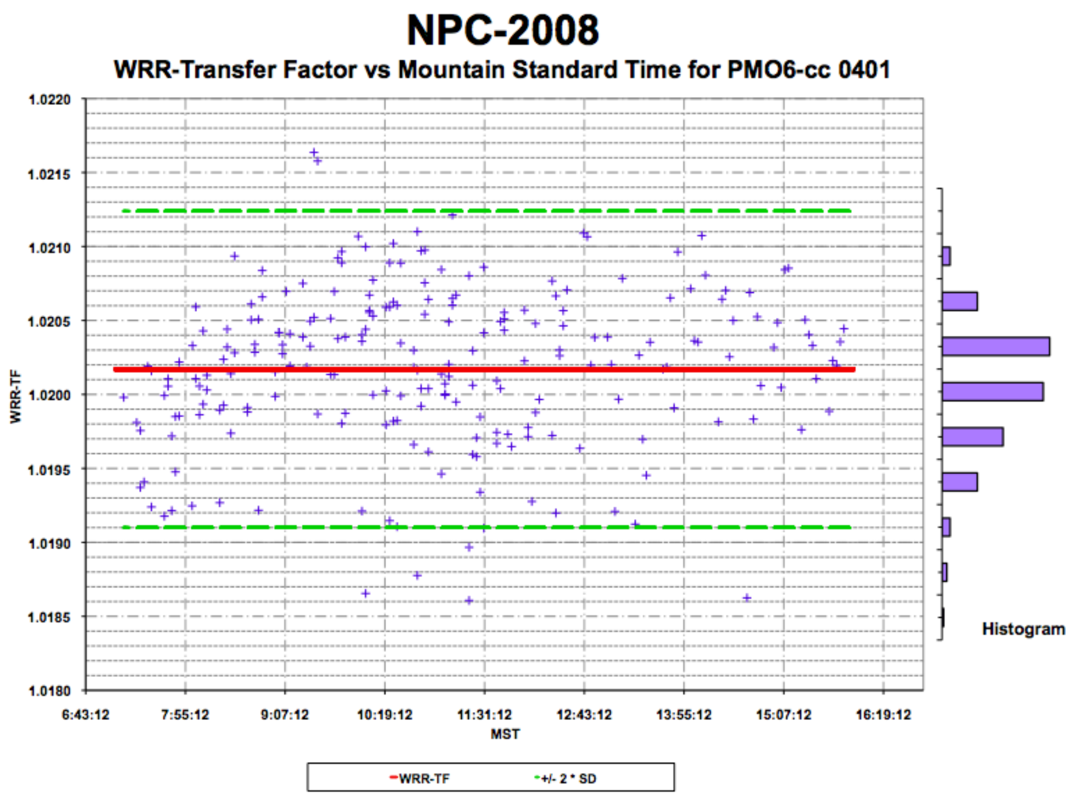

Figure 4.5.29 WRR-TF vs. Mountain Standard Time for PMO6–cc 0401 at NPC-2008

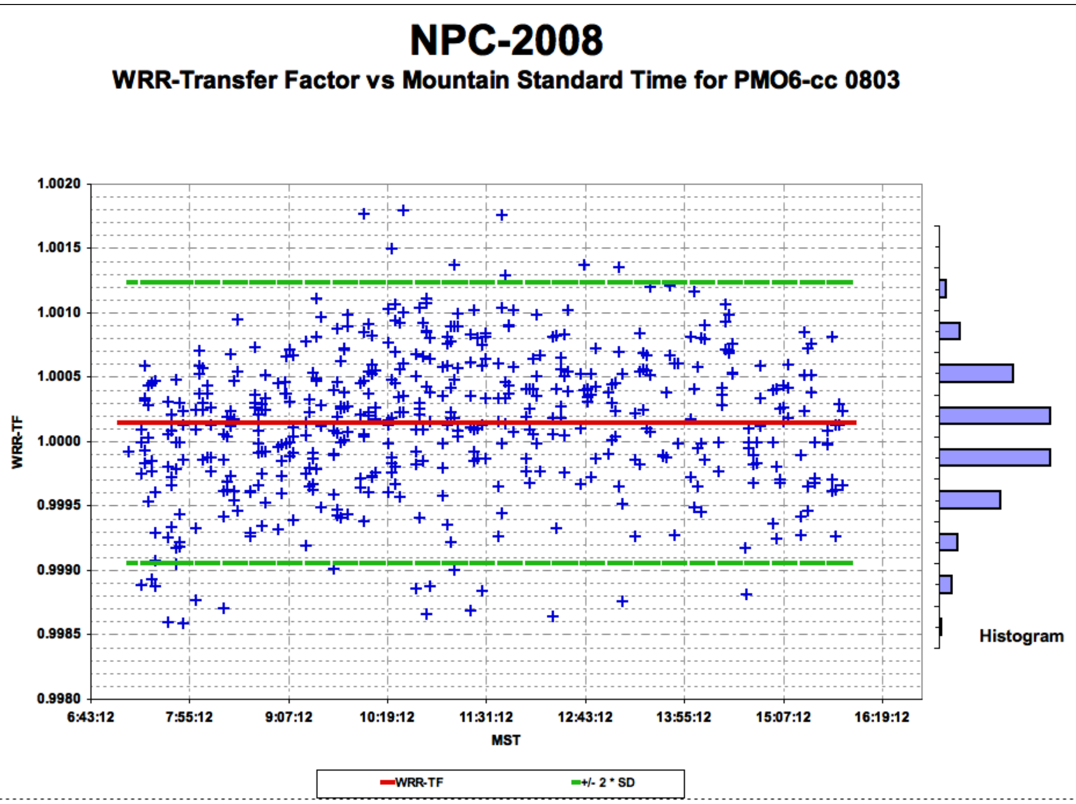

Figure 4.5.30 WRR-TF vs. Mountain Standard Time for PMO6–cc 0803 at NPC-2008

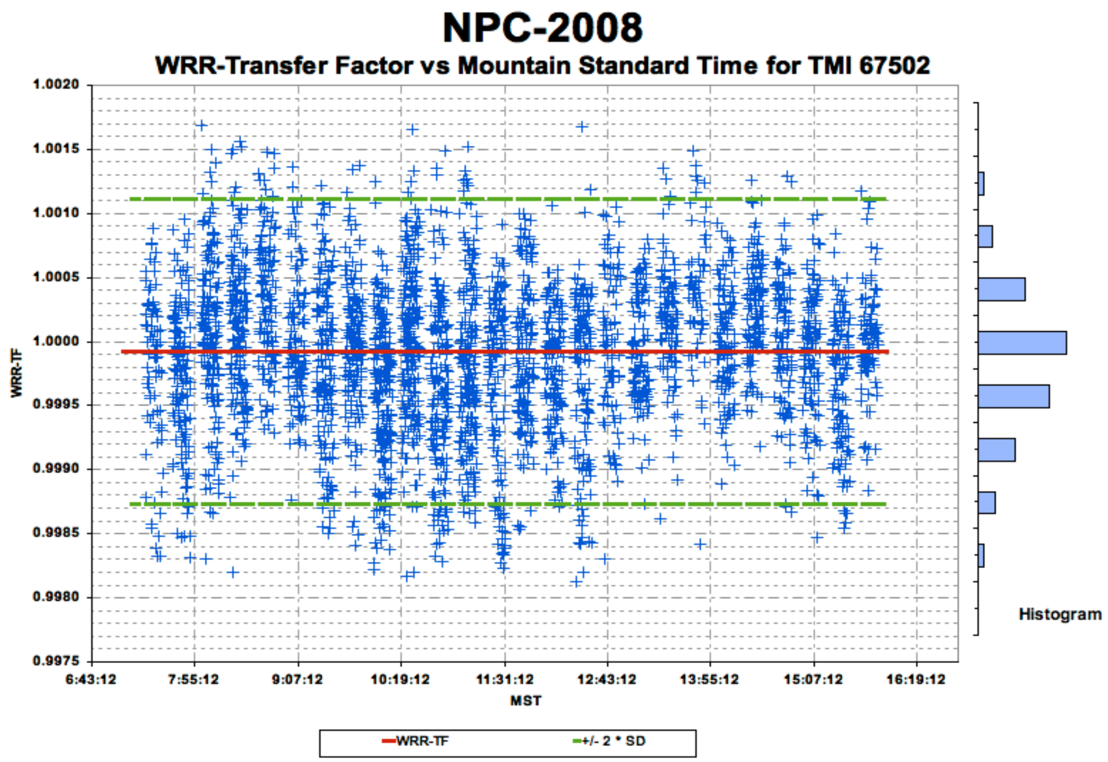

Figure 4.5.31 WRR-TF vs. Mountain Standard Time for TMI 67502 at NPC-2008

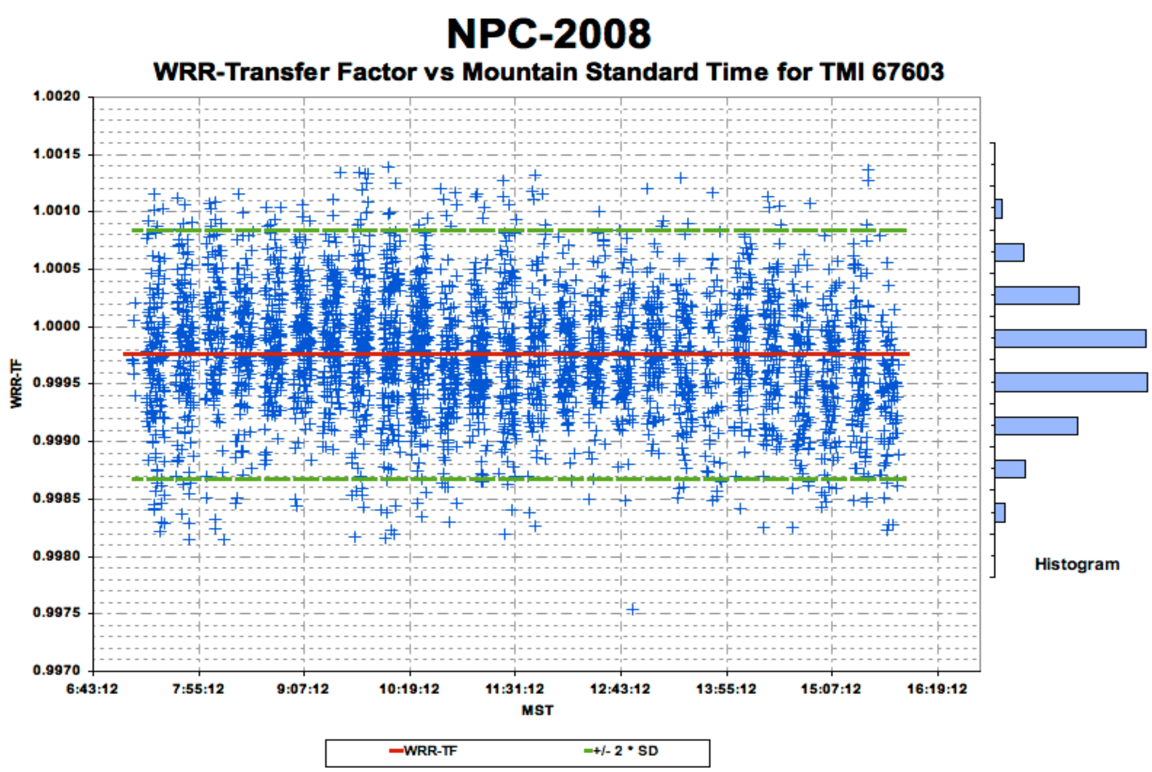

Figure 4.5.32 WRR-TF vs. Mountain Standard Time for TMI 67603 at NPC-2008

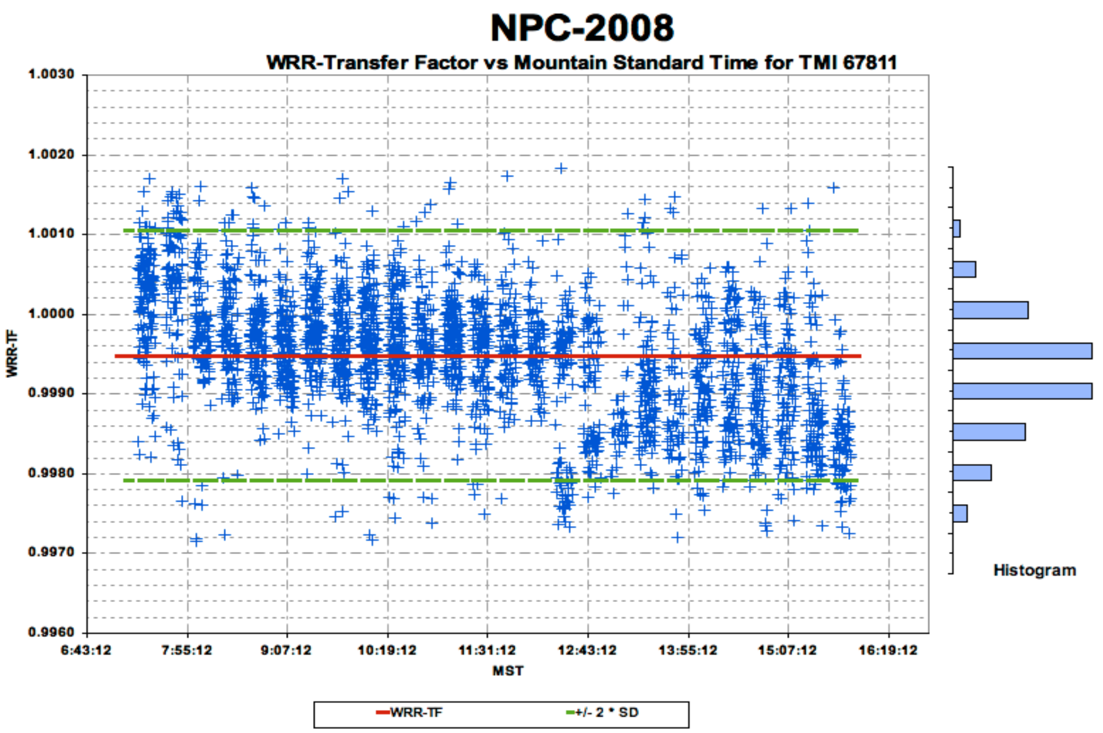

Figure 4.5.33 WRR-TF vs. Mountain Standard Time for TMI 67811 at NPC-2008

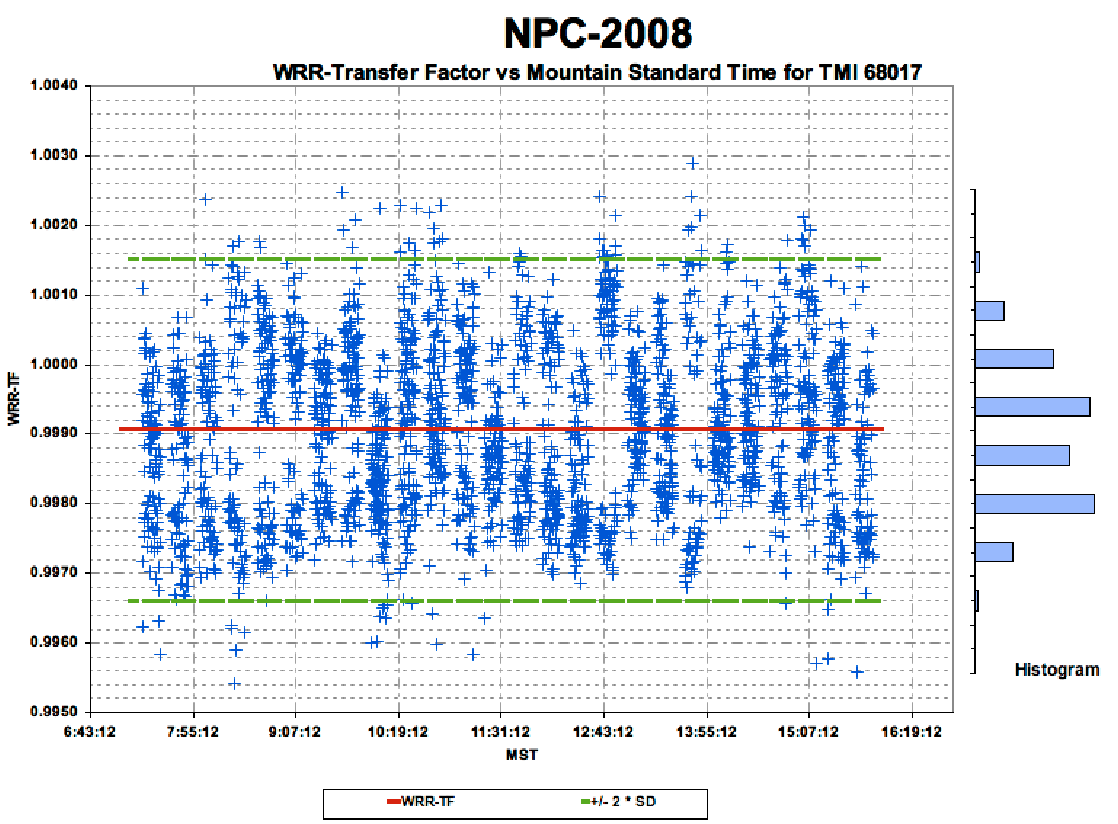

Figure 4.5.34 WRR-TF vs. Mountain Standard Time for AHF TMI 68017 at NPC-2008

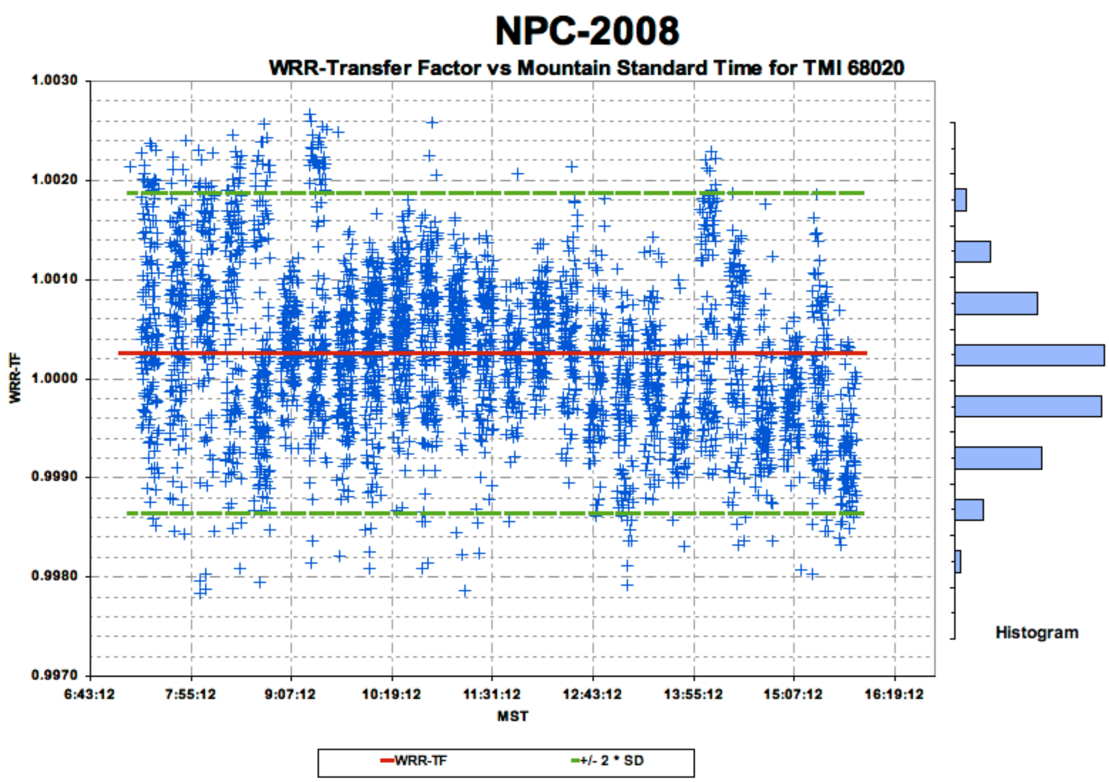

Figure 4.5.35 WRR-TF vs. Mountain Standard Time for TMI 68020 at NPC-2008

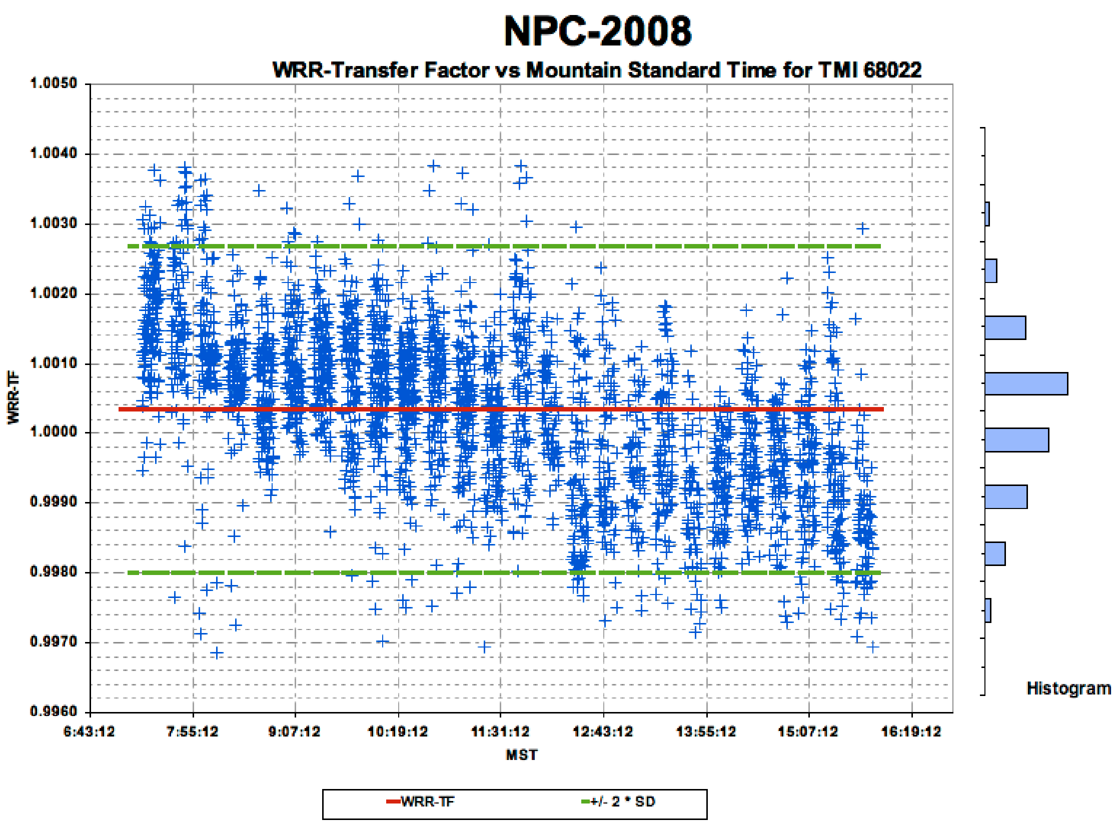

Figure 4.5.36 WRR-TF vs. Mountain Standard Time for TMI 68022 at NPC-2008

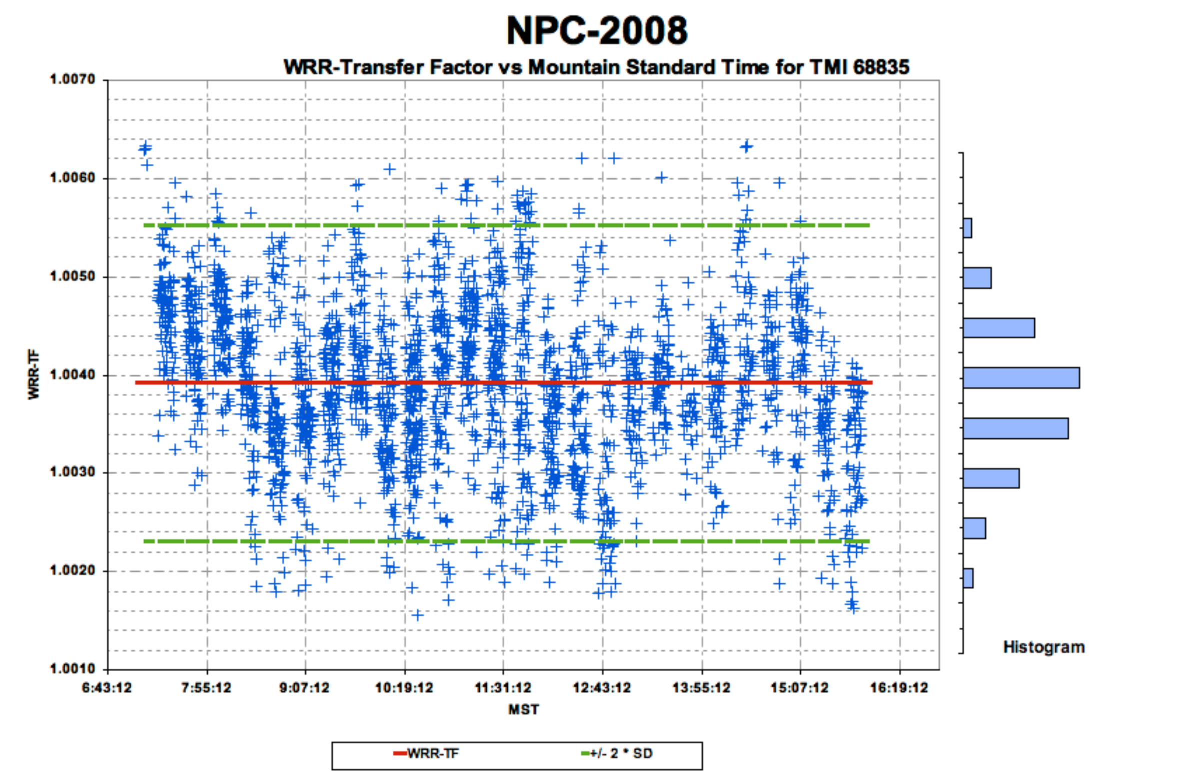

Figure 4.5.37 WRR-TF vs. Mountain Standard Time for TMI 68835 at NPC-2008

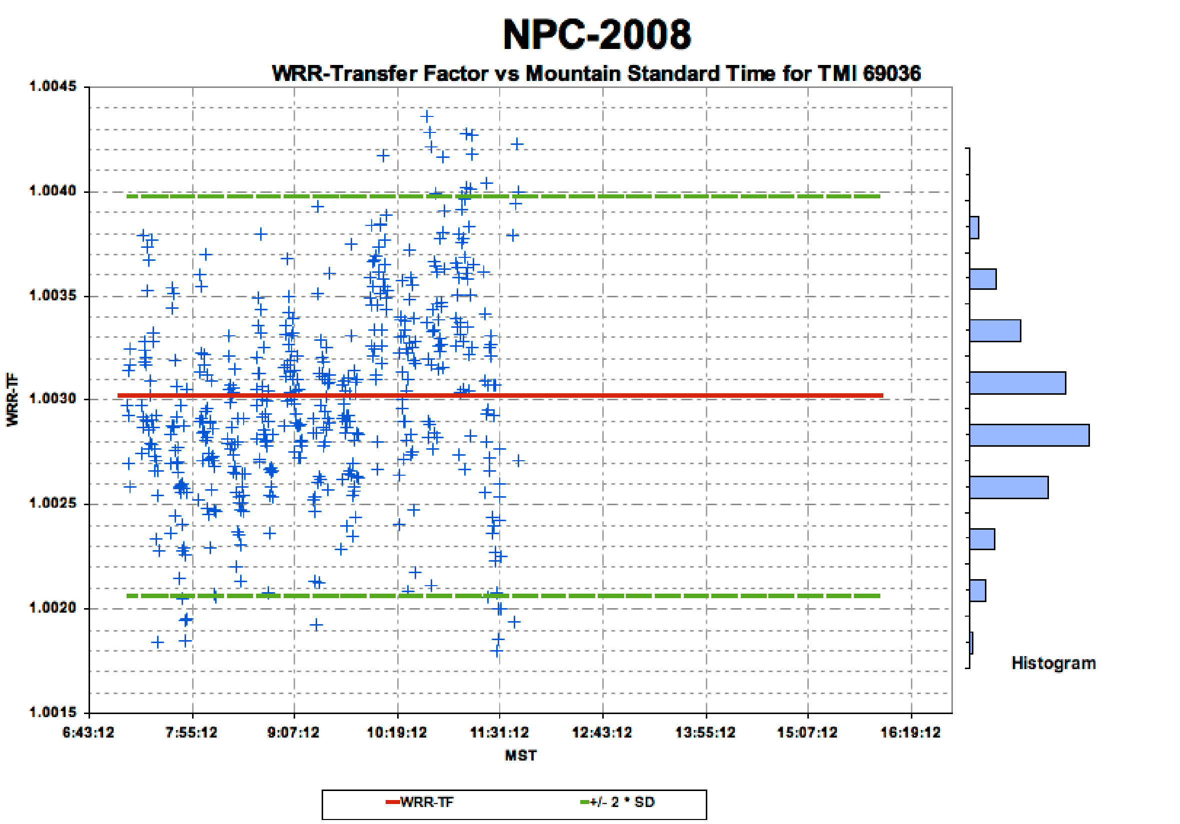

Figure 4.5.38 WRR-TF vs. Mountain Standard Time for TMI 69036 at NPC-2008

4.6 Recommendations

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

- For the purpose of pyrheliometer comparisons, such as NPC-2008, we recommend the user apply only the manufacturer's calibration factor (CF), 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 CF is used to calculate the cavity responsivity. Each irradiance reading is then ***multiplied*** by the appropriate WRR-TF.

For future comparisons, we strongly urge the 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., *AHF307130922.08* would correspond to data from AHF30713 on 9/22/08).

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 at http://www.nrel.gov/midc/srrl_bms.

Time-series plots and other graphical presentations of these data are presented in Appendix B.

References

Finsterle, W. (2006). “WMO International Pyrheliometer Comparison, IPC-X, 26 September – 14 October 2005, Davos, Switzerland, Final Report.” IOM Report No. 91, WMO/TD No. 1320, 65 pp.

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

Reda, I. (1996). “Calibration of a Solar Absolute Cavity Radiometer with Traceability to the World Radiometric Reference.” NREL/TP-463-20619. Golden, Co: National Renewable Energy Laboratory.

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

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

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

Note: Digital images taken during NPC-2008 are available from the ARM Instrument Management (AIM) Web site at http://www.nrel.gov/aim/npc.

Appendices

Appendix A: List of Participants and Pyrheliometers

NREL Pyrheliometer Comparisons (NPC-2008)
22 September - 3 October 2008

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List of Pyrheliometers

No.	Serial No.	Owner / Application
1	AHF 14915	The Eppley Laboratory, Inc. / Primary Reference Standard
2	AHF 17142	Atlas Weathering Services-DSET / Primary Reference Standard
3	AHF 18747	Environment Canada / Primary Reference Standard
4	AHF 20406	Environment Canada / Primary Reference Standard
5	AHF 21182	FSEC / Primary Reference Standard
6	AHF 23734	NREL / Photovoltaics Program Reference
7	AHF 28553	NOAA Global Monitoring Division (GMD) / Reference
8	AHF 28964	DOE ARM / Southern Great Plains Site Reference
9	AHF 29219	NREL/Metrology Lab windowed cavity
10	AHF 29222	DOE ARM-Southern Great Plains / All-Weather
11	AHF 30494	NREL/Metrology Lab
12	AHF 30495	DOE ARM-Southern Great Plains Working Standard
13	AHF 31041	NASA Clouds and the Earth's Radiant Energy System (CERES) / Reference
14	AHF 31104	NREL / Metrology Lab BORCAL Transfer Standard
15	AHF 31105	NASA / CERES Reference 2
16	AHF 31108	Sandia National Laboratories / PV Reference Standard
17	AHF 32455	PMOD/WRC / Transfer Standard
18	AHF 34320AWX	Environment Canada / All-Weather Reference
19	AHF 34321AWX	Environment Canada / All-Weather Reference
20	AHF 32448AWX	NOAA/GMD / All Weather
21	AHF 32452AWX	NREL / All-Weather Transfer Standard
22	AHF 33392	Naval Research Laboratory / Primary Reference Standard
23	CH1 930018	European Commission Directorate General / Control Standard
24	CH1 060460	European Commission Directorate General / Control Standard
25	PMO6-cc 0103	Kipp & Zonen
26	PMO6-cc 0401	PMOD/WRC / Transfer Standard
27	PMO6 81109	European Commission Directorate General / Reference Standard
28	PMO6 911204	European Commission Directorate General / Reference Standard
29	PMO6-cc 0803	PMOD
30	TMI 67502	NOAA GMD / Reference Standard
31	TMI 67603	Sandia National Laboratories / Primary Reference Standard
32	TMI 67811	Sandia National Laboratories / Central Receiver Test Facility (CRTF)
33	TMI 68017	NREL / SRRL All-Weather BORCAL Working Standard #2
34	TMI 68020	Lockheed Martin Mission Services /Primary Reference Standard
35	TMI 68022	Sandia National Laboratories / CRTF
36	TMI 68835	European Commission Directorate General / Control Standard
37	TMI 69036	NREL Metrology Lab / BORCAL Working Standard #3

Summary:

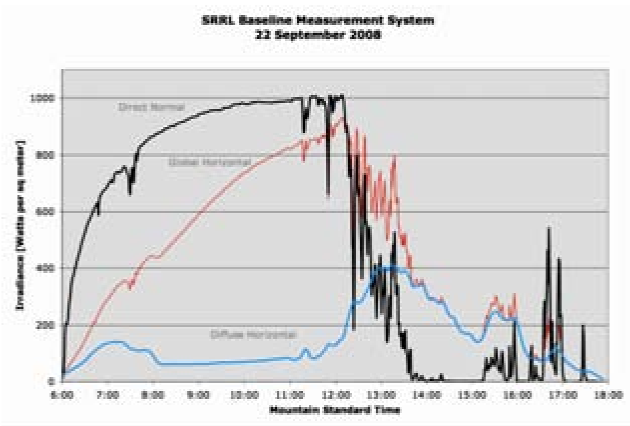
Absolute Cavity Radiometers 35
Thermopile Pyrheliometers 2

Appendix B: Ancillary Data Summaries

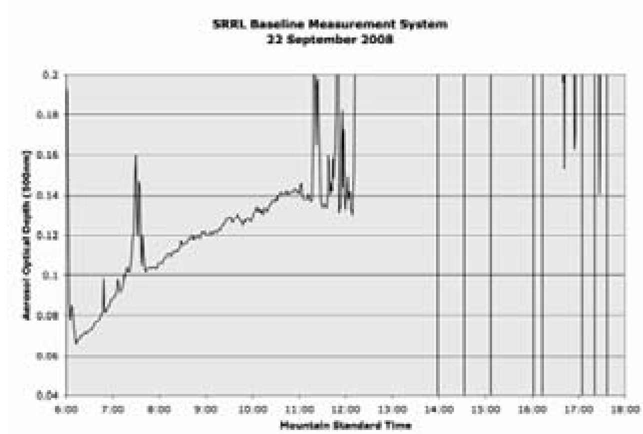
The measurement performance of an absolute cavity can be affected by several environmental parameters. Potentially relevant meteorological data collected during the NPC are presented in this appendix. The Baseline Measurement System (BMS) has been in continuous operation at the Solar Radiation Research Lab (SRRL) since 1985. BMS data are recorded as 1-minute averages of 3-second samples for each instrument. Additional information about SRRL and the BMS can be found at our Measurement & Instrumentation Data Center at http://www.nrel.gov/midc/srrl_bms.

Time-series plots and other graphical presentations of these data acquired during the NPC-2008 measurements are presented here.

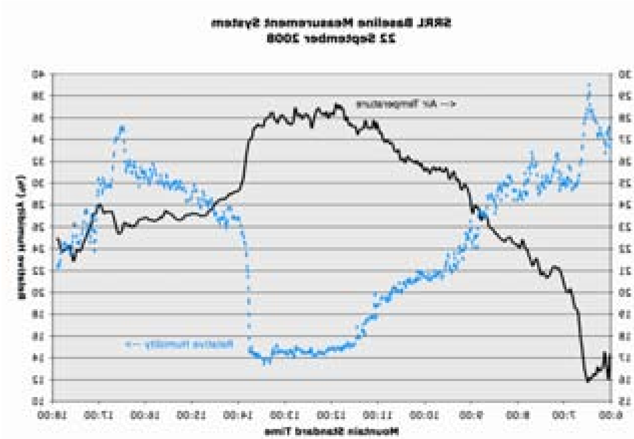
Baseline Measurement System Data for September 22, 2008



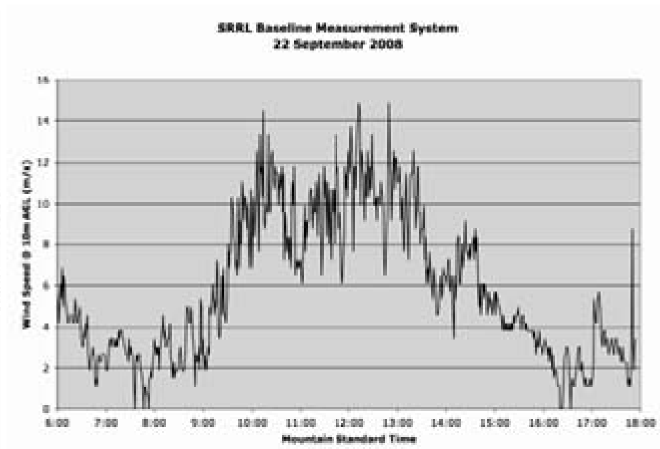
Broadband Irradiances



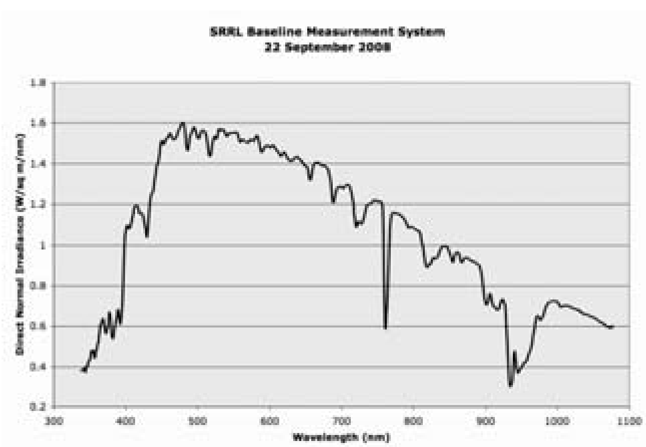
Aerosol Optical Depth



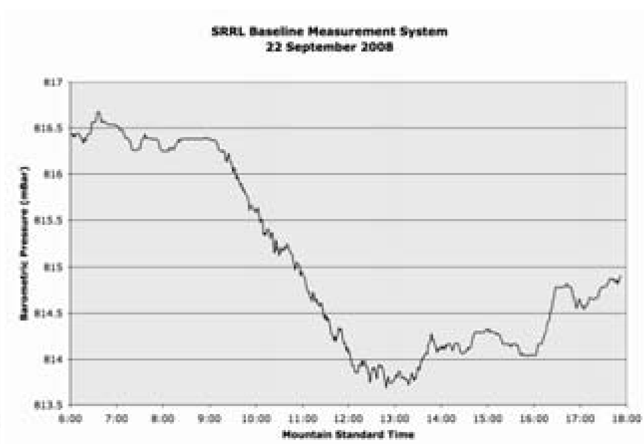
Temperature & Relative Humidity



Wind Speed

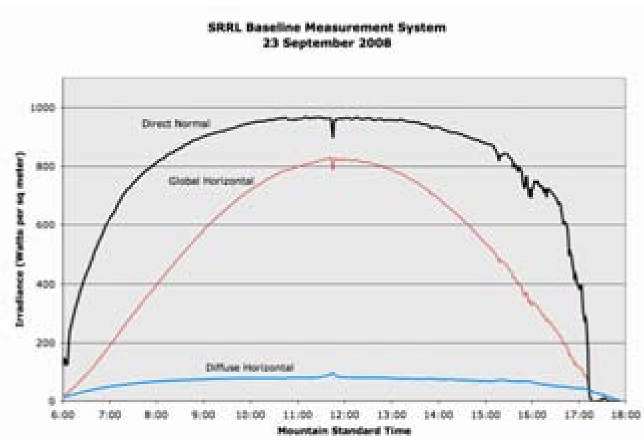


Direct-Normal Solar Spectrum (11:00 MST)

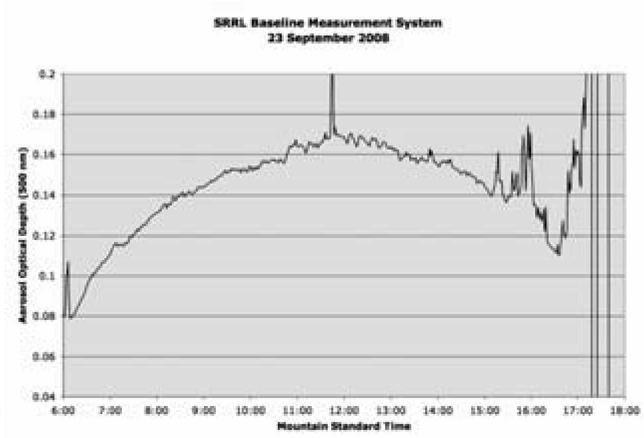


Barometric Pressure

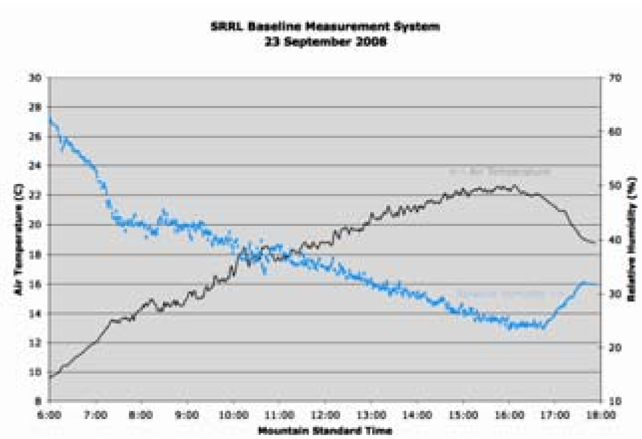
Baseline Measurement System Data for September 23, 2008



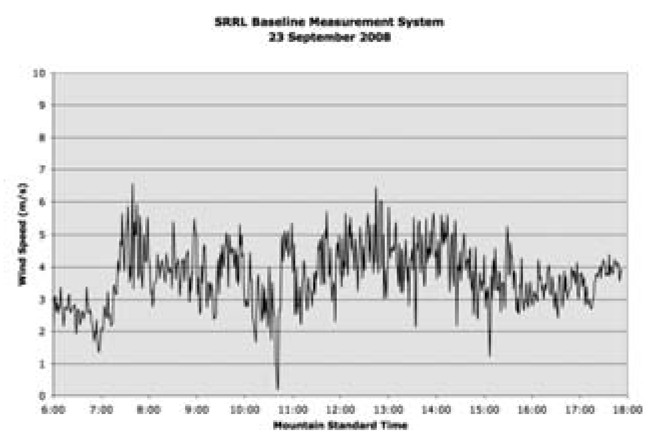
Broadband Irradiances



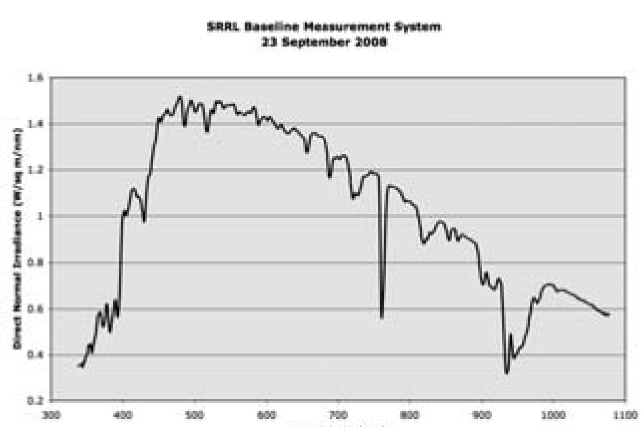
Aerosol Optical Depth



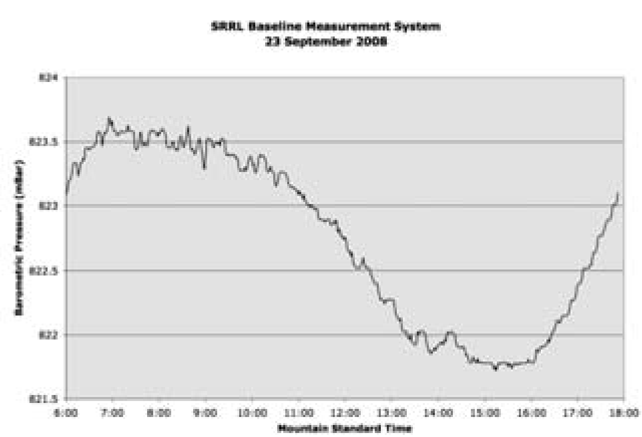
Temperature & Relative Humidity



Wind Speed

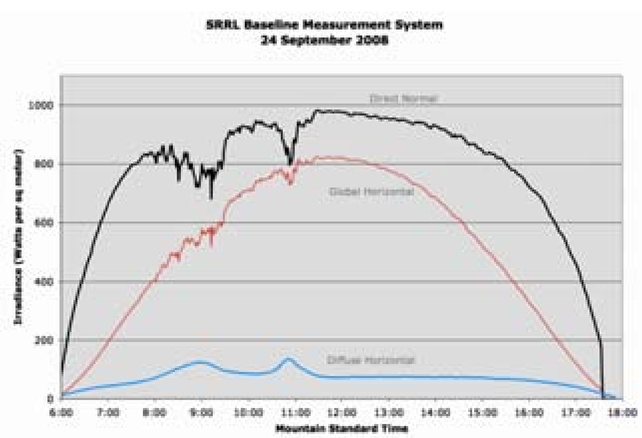


Direct-Normal Solar Spectrum (11:00 MST)

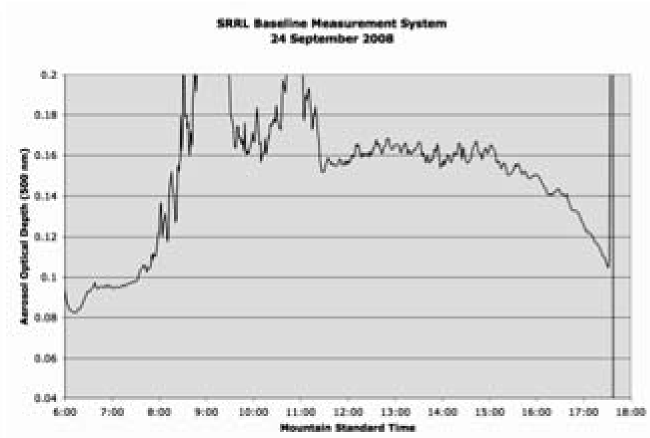


Barometric Pressure

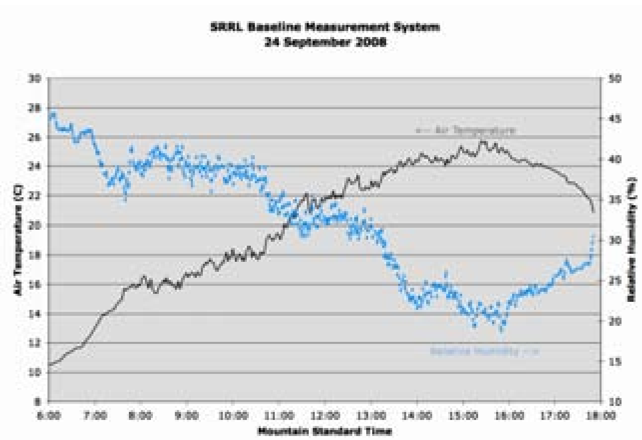
Baseline Measurement System Data for September 24, 2008



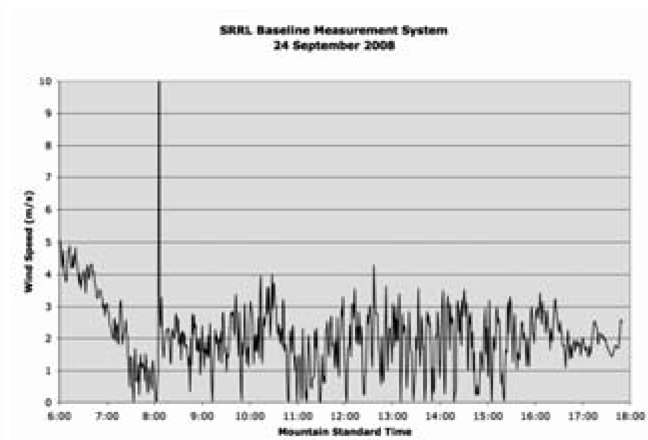
Broadband Irradiances



Aerosol Optical Depth

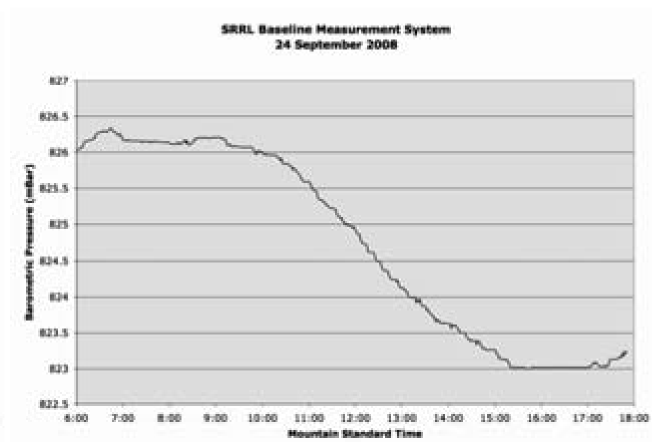


Temperature & Relative Humidity



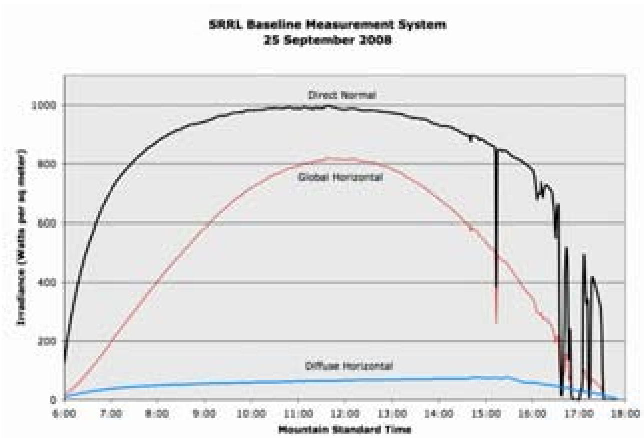
Wind Speed

Direct-Normal Solar Spectrum (12:00 MST)

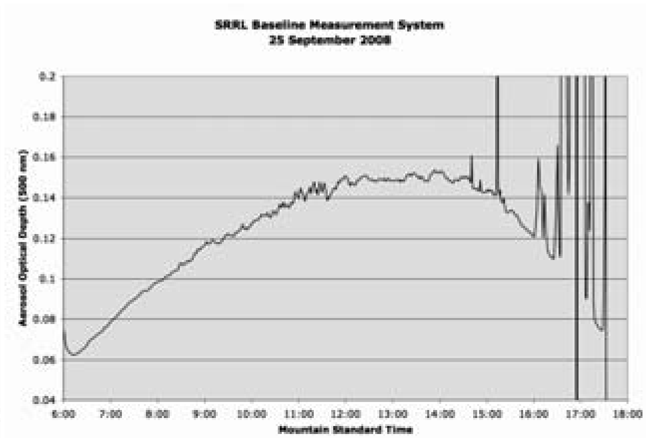


Barometric Pressure

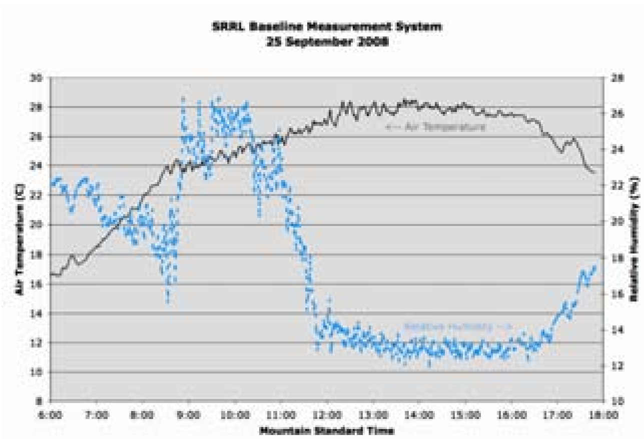
Baseline Measurement System Data for September 25, 2008



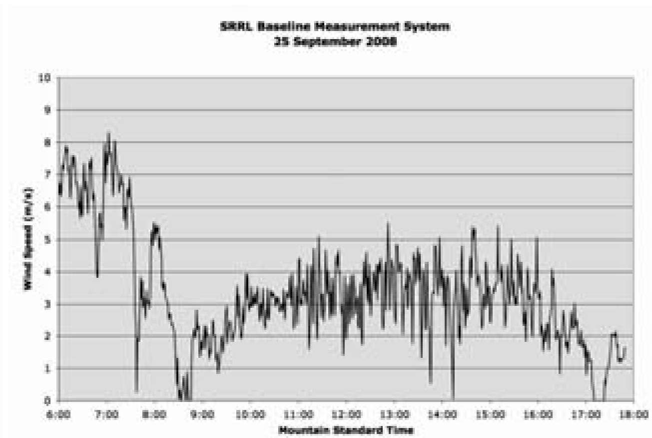
Broadband Irradiances



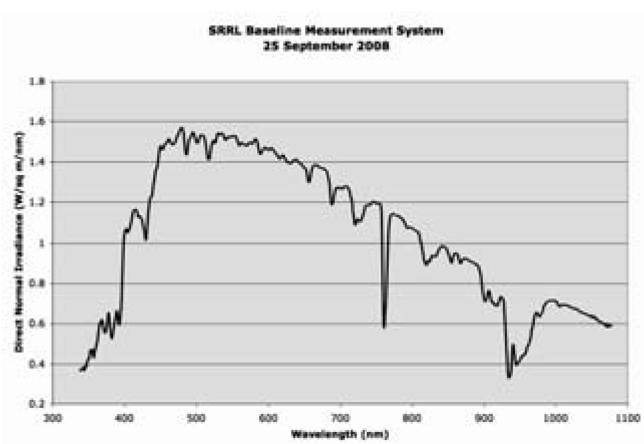
Aerosol Optical Depth



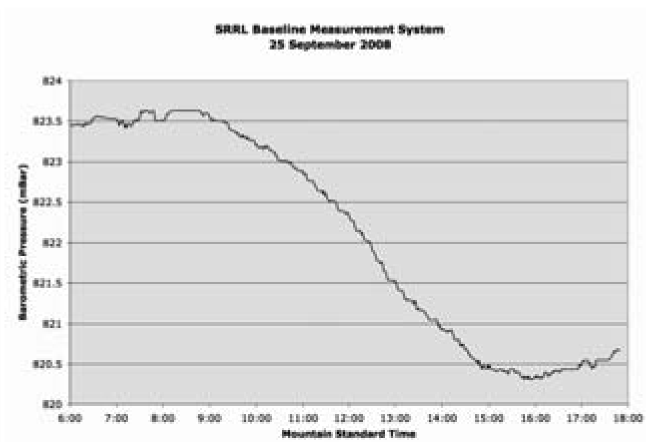
Temperature & Relative Humidity



Wind Speed

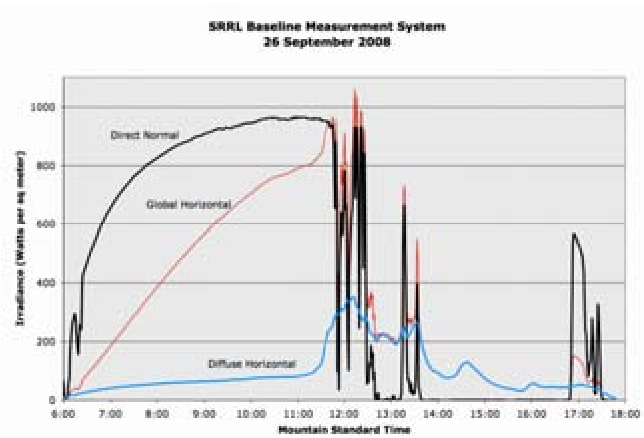


Direct-Normal Solar Spectrum (12:00 MST)

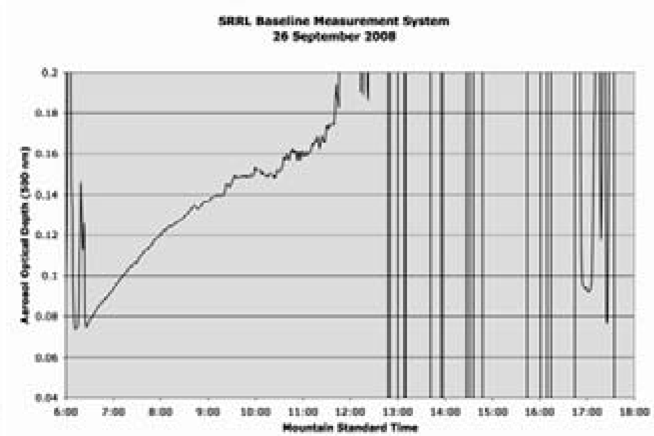


Barometric Pressure

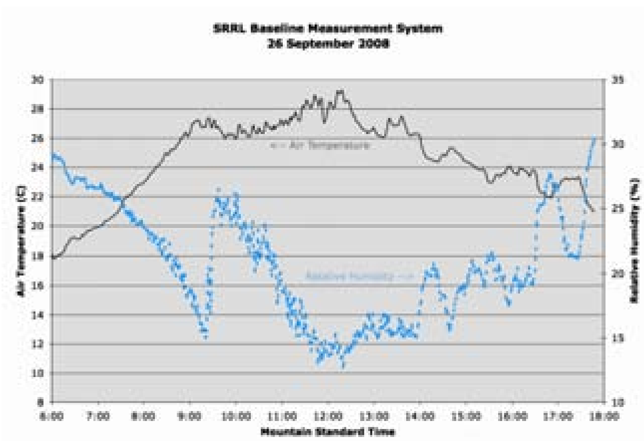
Baseline Measurement System Data for September 26, 2008



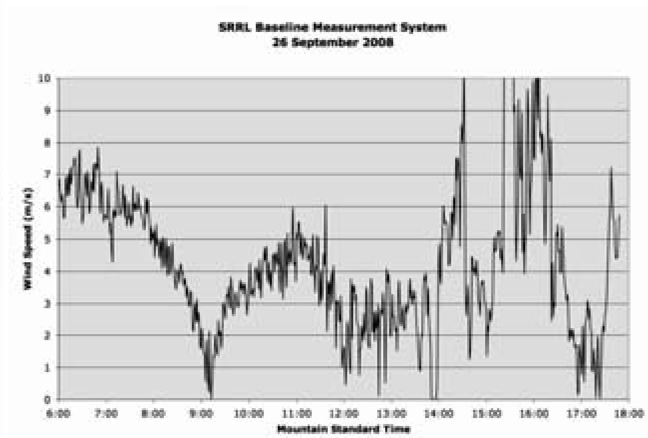
Broadband Irradiances



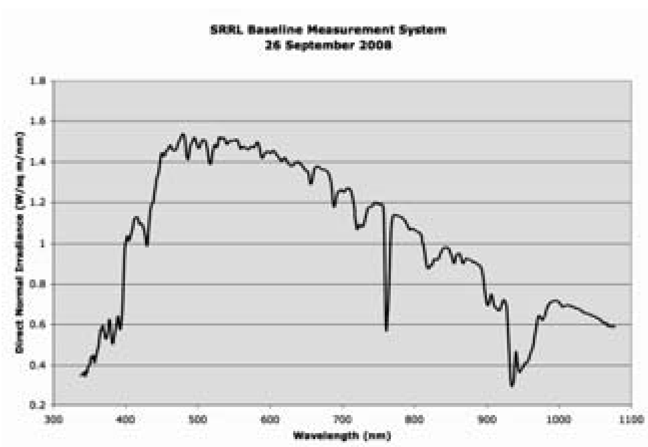
Aerosol Optical Depth



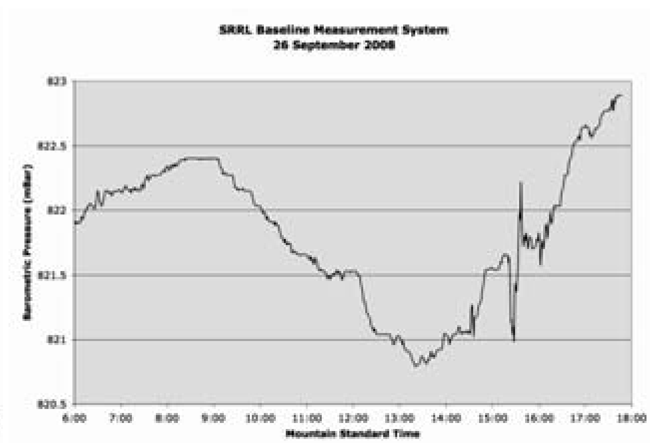
Temperature & Relative Humidity



Wind Speed

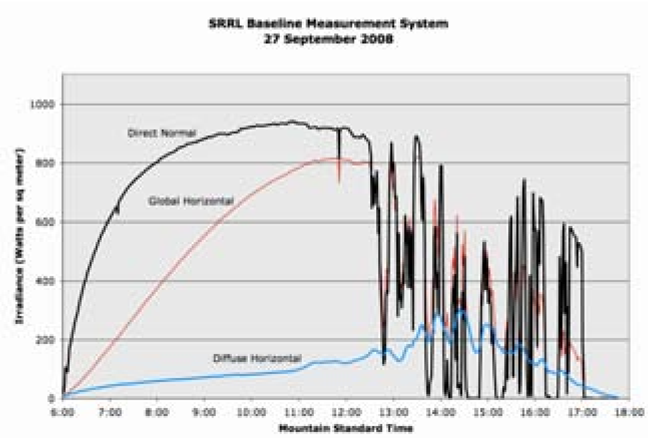


Direct-Normal Solar Spectrum (11:00 MST)

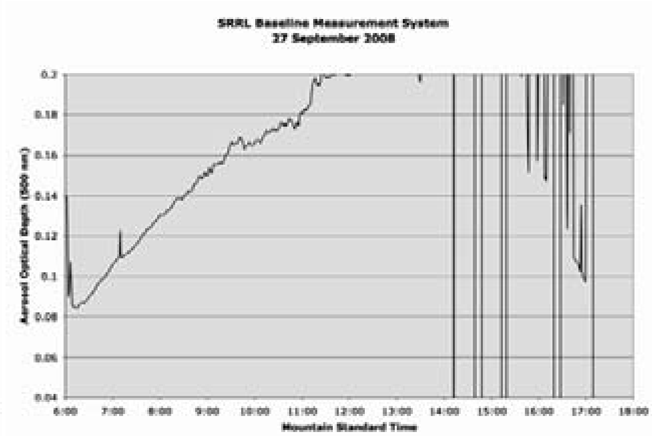


Barometric Pressure

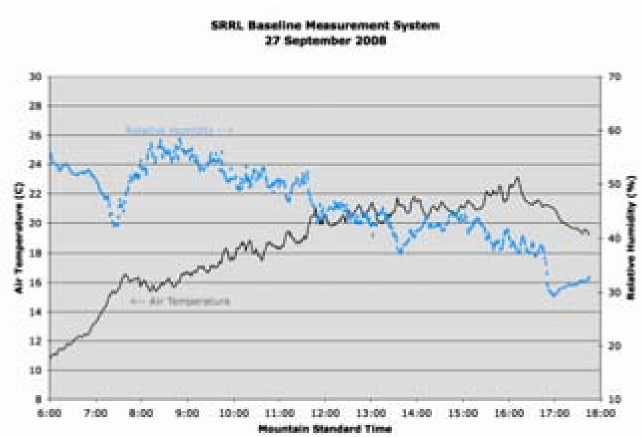
Baseline Measurement System Data for September 27, 2008



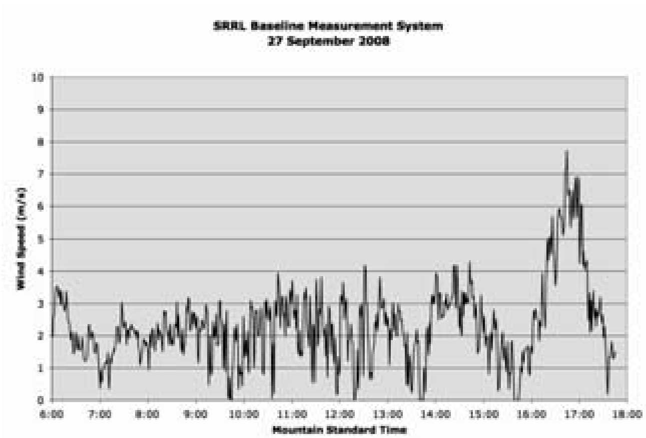
Broadband Irradiances



Aerosol Optical Depth

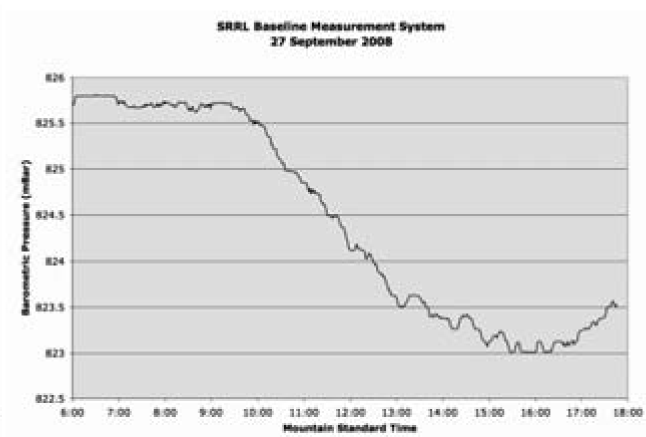


Temperature & Relative Humidity



Wind Speed

Direct-Normal Solar Spectrum (11:00 MST)



Barometric Pressure

Appendix C: Operational Notes

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

2008 NREL Pyrheliometer Comparisons (NPC-2008)
Solar Radiation Research Laboratory
Protocol Summary
Tom Stoffel and Ibrahim Reda

1. Schedule

Daily Please call Tom's voice mail (303-384-6395) for recorded announcements.

DAY # 1 Sept. 22nd (morning)

a. Visitor check-in at Site Entrance Building.
   Please plan to arrive at NREL between 07:30 and 08:30 MDT.
b. Transport equipment to SRRL (dry weather) or to indoor lab (TBD) if it's wet outside.
   (You should have heard from Bev or Tom about any items received prior to the NPC.)
c. Safety and SRRL orientation briefing.
d. Equipment Installation & tests:
   - -ALL personal computers can be *scanned for viruses* prior to their use at SRRL. NREL will provide this service.
   - -We will have a ***seating diagram*** to accommodate operator/solar tracker assignments, but we'll see how this works once every one has arrived.
e. Continue equipment tests as needed.
f. Review measurement protocol and procedures.
g. Dry-run(s) of comparison measurements (weather permitting)

Sept. 23rd – Oct. 3rd (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 of previous day's data analyses
   - -Technical Briefings on Radiometry, Measurement Network Operations, etc.
   - -Equipment Tests
   - -NREL Tours
   - -Office Time (e-mail connection 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 again be our time keeper (as long as his voice holds out!)
-All time records will be Mountain Standard Time (MST)
-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 OK). 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 sec of announcement at 20-sec intervals.

"Run" = Collection of 37 readings taken in sequence.

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 sec 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,

YYYY	=	Year
MM	=	Month
DD	=	Day of Month
HH	=	Hour (Mountain Standard Time)
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 tear-down, our Data Keeper (Reda) will circulate a *master USB Flash Drive or Diskette* for you to copy all of your corrected 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.
-A final report will be published by NREL within two 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 get 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 24th)** ***Note New Date***

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

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14. ABSTRACT *(Maximum 200 Words)*
NREL Pyrheliometer Comparisons (NPCs) are held annually at the Solar Radiation Research Laboratory (SRRL) in Golden, Colorado. Open to all pyrheliometer owner/operators, the NPC provides an opportunity to determine the unique WRR transfer factor for each participating pyrheliometer. This paper reports on the results of NPC-2008, which was scheduled from September 22 to October 3, 2008.

15. SUBJECT TERMS
NREL; National Renewable Energy Laboratory; SRRL; pyrheliometer; World Radiometric Reference; WRR; World Standard Group; WSG; solar irradiance

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