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NREL Pyrheliometer Comparisons September 22 – October 3, 2003

(NPC-2003)

Final Report

By

Tom Stoffel
Ibrahim Reda
Steve Wilcox

National Renewable Energy Laboratory
Electric & Hydrogen Technologies & Systems Center
Resource Integration Group
Measurement & Instrumentation Team

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NOTICE

NPC 2003 Participants

Kneeling: John Hickey, Phil Thacher, Bill Boyson, Mike Stein, Craig Webb, Ly Vo, Ray Decker, Steve Wilcox.
Standing: Mike Edgar, Bill Porch, Duncan Maciver, Erik Naranen, Ibrahim Reda, Bev Kay, Tom Stoffel, Fred Denn, Gary Hodges.
[Not Shown: Joe Michalsky & Don Nelson]

Acknowledgements

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NREL Solar Radiation Research Laboratory (SRRL)

North View

South View from Instrument Platform

Absolute Cavity Radiometers on Solar Trackers

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Abstract

Providing reliable measurements of solar irradiance places many demands on 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 solar irradiance measurement. The WRR is a detector-based measurement standard, subject to instrument performance changes with time. Therefore, every five years, the World Radiation Center/Physikalisch-Meteorologisches Observatorium Davos (WRC/PMOD) in Davos, Switzerland hosts an International Pyrheliometer Comparison (IPC) for transferring the WRR to participating radiometers. Representing the U.S. Department of Energy, 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 instruments are then used to transfer WRR to other radiometers.

NREL Pyrheliometer Comparisons (NPCs) are held annually at the Solar Radiation Research Laboratory(SRRL) in Golden, Colorado. Open to any pyrheliometer owner/operator, 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-TF, the operator can establish calibration traceability to the WRR.

NPC-2003 was scheduled from September 22 through October 3, 2003. Nineteen participants operated 27 absolute cavity radiometers and one conventional thermopile-based pyrheliometer to simultaneously measure clear-sky direct normal solar irradiance during this period. The Transfer Standard Group (TSG) of reference radiometers for NPC-2003 consisted of seven radiometers with direct traceability to the WRR having participated in IPC-IX 2000. As the result of NPC-2003, each participating absolute cavity radiometer was assigned a new WRR-TF computed as the ratio of observed irradiance to the corresponding reference irradiance as determined by the TSG. The performance of the TSG during NPC-2003 was consistent with previous comparisons, including the latest IPC-IX. The measurement performance of the TSG allowed the transfer of the WRR to each participating radiometer with an estimated uncertainty of ± 0.32% with respect to SI units.

The comparison protocol is based on data collection periods, or *runs*. Each *run* consists of a six-minute electrical self-calibration, a series of 33 solar irradiance measurements at 20-second intervals, and a post-calibration. More than 1,000 reference irradiance measurements for each participating radiometer were collected during NPC-2003. Clear-sky daily maximum direct normal irradiance levels ranged from less than 967 Wm^{-2} to 1026 Wm^{-2}.

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

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

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 the myriad of other possibilities, requires measurements traceable to a recognized calibration standard. The World Radiometric Reference (WRR) is the internationally recognized standard for solar irradiance measurements [Fröhlich, 1991].

The WRR was established by the World Meteorological Organization (WMO) in 1977 and has been maintained by the World Radiation Center at the Physikalisch-Meteorologisches Observatorium Davos (WRC/PMOD) in Switzerland (http:// www.pmodwrc.ch). This standard of measurement is maintained for broadband solar irradiance with an absolute uncertainty of better than ± 0.3% with respect to the System International (SI) unit [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 WRC/PMOD. The instantaneous measurements from the seven radiometers comprising the World Standard Group (WSG) are compared at 90-second intervals with the data from participating radiometers recorded under clear-sky conditions. Maintaining the mean WRR of the seven WSG radiometers, a WRR Transfer Factor is calculated for each of the participating radiometers [Reda, 1996]. The range of historical WRR Transfer Factors is 1.00000±0.00250. Multiplying the irradiance reading of each radiometer by its assigned WRR Transfer Factor (WRR-TF) will result in measurements that are traceable to WRR and therefore consistent with the international reference of solar radiation measurement.

The 2003 NREL Pyrheliometer Comparisons (NPC-2003) were scheduled from September 22 to October 3, 2003 at the Solar Radiation Research Laboratory (SRRL) in Golden, Colorado. Nineteen participants operated 27 absolute cavity radiometers during the comparisons (see Appendix A for list of participants). The following organizations were represented at NPC-2003:

- Analytical Services and Materials, Inc.
- 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
- National Oceanic and Atmospheric Administration
    - -Climate Monitoring & Diagnostics Laboratory
    - -Surface Radiation Research Branch
- National Renewable Energy Laboratory
    - -Electric & Hydrogen Technologies & Systems Center
    - -Metrology Laboratory
    - -Photovoltaic Research Program

Weather conditions during the period September 22-24 were adequate for this year's NPC (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 three days.

2. Reference Instruments

Seven absolute cavity radiometers that participated in IPC-IX were used as the Transfer Standard Group (TSG) to maintain the WRR for this comparison. Table 2.1 is a list of the TSG absolute cavity radiometers with their *WRR Transfer Factors* and *Pooled Standard Deviations* as determined from the latest International Pyrheliometer Comparisons in 2000 [WRC/PMOD, 2001].

Table 2.1 IPC-IX Results Summary for the NPC-2003 TSG

Serial Number	WRR Factor (from IPC-IX)	Standard Deviation (%)	Number of Readings
AHF 14915	1.00026	0.08	102
AHF 28553	0.99733	0.05	212
AHF 28968	0.99866	0.06	113
AHF 29220	0.99846	0.06	113
AHF 30713	0.99861	0.06	113
TMI 67502	0.99966	0.07	219
TMI 68018	0.99848	0.05	113
Mean WRR for the TSG	0.99878	**Pooled Std Deviation for the TSG** 0.06%	

The Pooled Standard Deviation (SD_p) for the Transfer Standard Group (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-IX

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

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 33 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 the 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 ten Runs should be made over a period of at least two days to provide a variety of temperature and spectral irradiance conditions. Our goal was to build a statistically significant data set from which to derive individual WRR TF.

Data from each radiometer/operator system are collected at the end of the day using diskettes. Daily summaries were produced using a spreadsheet analysis tool. Results were distributed to the participants the following day. 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 Transfer Standard Group (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-2003:

- 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

Seven absolute cavity radiometers, that participated in IPC-IX, were used as the TSG to transfer the WRR in the comparison. The WRR Transfer Factor 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 AHF28553, the instrument with the *lowest* standard deviation with respect to the WRR.

b. Maintaining the mean of WRR for the TSG, a new WRR Transfer Factor for NPC-2003 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 Transfer Factor calculated in step b.

4.3 Data Analysis Criteria

The absolute cavity radiometer AHF30713 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 [WRC/PMOD, 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-2003 was scheduled for September 22 - October 4, 2003. The comparisons were completed on September 24th after 2082 data points were collected by the reference cavities from 63 runs completed during three 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:

- The NPC2003 WRR Transfer Factors did not change by more than a fraction of the standard deviation derived during IPC-IX in 2000 (see Table 2.1 for IPC-IX results).

- The standard deviations of the new WRR Transfer Factors are also smaller than the standard deviations observed for these instruments during IPC-IX.

The WRR Transfer Factor for each participating cavity radiometer is derived using the reference irradiance values derived from the TSG. At each reading, the reference irradiance is divided by the irradiance measured by a participating radiometer. The mean of these ratios is the WRR Transfer Factor for each participating radiometer. Results for each radiometer participating in NPC2003 are presented in Table 4.5.2.

Table 4.5.1 Summary Results for the Reference Transfer Standard Group (TSG) Radiometers Used for NPC2003

Serial Number	WRR (IPC-IX)	WRR (NPC-2003)	St. Dev.	Number of Readings
AHF14915	1.00026	1.00043	0.06	2082
AHF28553	0.99733	0.99713	0.00	2082
AHF28968	0.99866	0.99839	0.05	2082
AHF29220	0.99846	0.99835	0.05	2082
AHF30713	0.99861	0.99829	0.05	2082
TMI67502	0.99966	1.00076	0.08	2082
TMI68018	0.99848	0.99810	0.06	2082
Mean WRR	0.99878	0.99878		

Table 4.5.2 Results for Radiometers Participating in NPC2003

Serial Number	WRR-TF (NPC-2003)	%sd	Number of Readings	%U95	
				w.r.t. WRR	w.r.t. SI
AHF17142	0.99868	0.04	1865	0.15	0.34
AHF21182	0.99978	0.09	1935	0.22	0.37
AHF23734	0.99828	0.04	2019	0.15	0.34
AHF28964	0.99828	0.05	1970	0.17	0.34
AHF29222-Window	1.06039	0.06	1952	0.18	0.35
AHF30494-Window	1.05263	0.07	1325	0.19	0.35
AHF30495	0.99749	0.05	1939	0.16	0.34
AHF30710	0.99959	0.05	1260	0.16	0.34
AHF31041	0.99743	0.05	1972	0.16	0.34
AHF31104	0.99984	0.04	2015	0.15	0.34
AHF31105	1.00309	0.05	1968	0.17	0.34
AHF31108	0.99744	0.08	2010	0.20	0.36
AWX32449-Window	1.04521	0.09	1375	0.22	0.37
AWX32452	0.99909	0.05	2002	0.16	0.34
HF30110-Window	1.06718	0.07	1618	0.19	0.35
TMI67603	1.00013	0.04	2018	0.15	0.34
TMI67811	0.99904	0.05	2007	0.17	0.34
TMI68017	1.00001	0.07	851	0.19	0.35
TMI68022	1.00037	0.10	1983	0.23	0.38
TMI69036	1.00111	0.04	1161	0.15	0.33

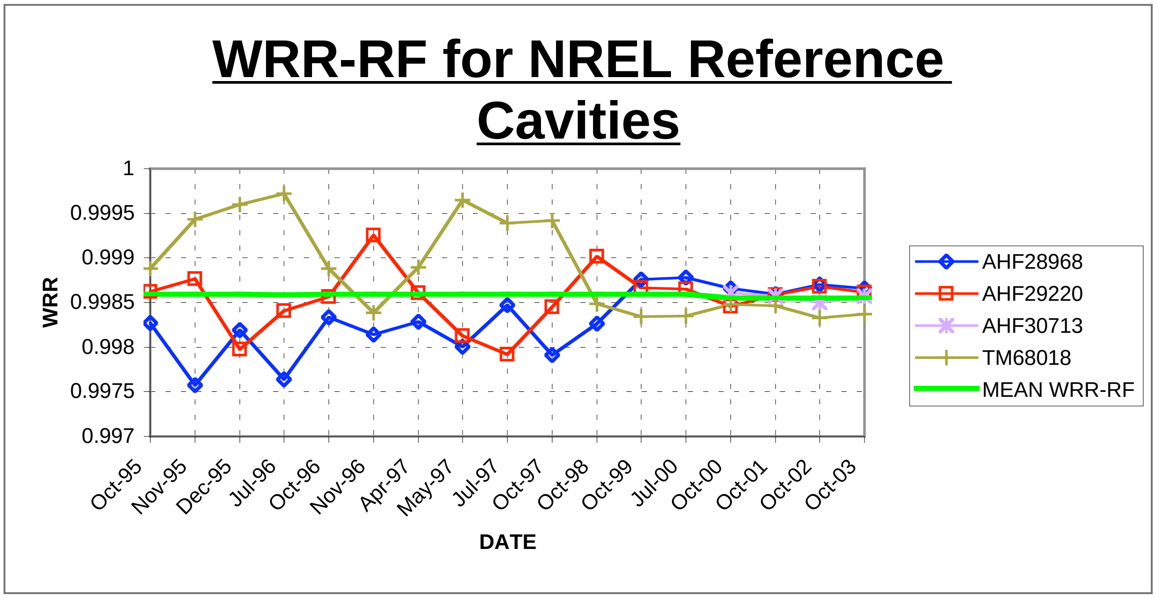

Figure 4.1 – History of WRR Reduction Factors for NREL Reference Cavities.

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

$$U_{95} = \pm [(2 * 0.104)^2 + (2 * SD)^2]^{1/2}$$

where,

U_{95} = Uncertainty of the WRR Transfer Factor (in percent) determined at NPC2003 with 95% confidence level

0.104 = Pooled standard deviation of the six reference radiometers that participated in IPC-IX (September/October 2000).

SD = One standard deviation of the WRR Transfer Factor (in percent) determined at NPC2003 for each participating cavity.

The uncertainty of the WRR Transfer Factors associated with each participating radiometer with respect to SI units was calculated using the following formula:

$$U_{95} = \pm [(0.3)^2 + (2 * 0.104)^2 + (2 * SD)^2]^{1/2}$$

where,

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

The statistical analyses of WRR Transfer Factors for 20 participating radiometers are presented in Figures 4.5.1 through 4.5.20. These graphical summaries indicate the mean, standard deviation, and frequency of occurrence of the WRR Transfer Factors determined during NPC2003.

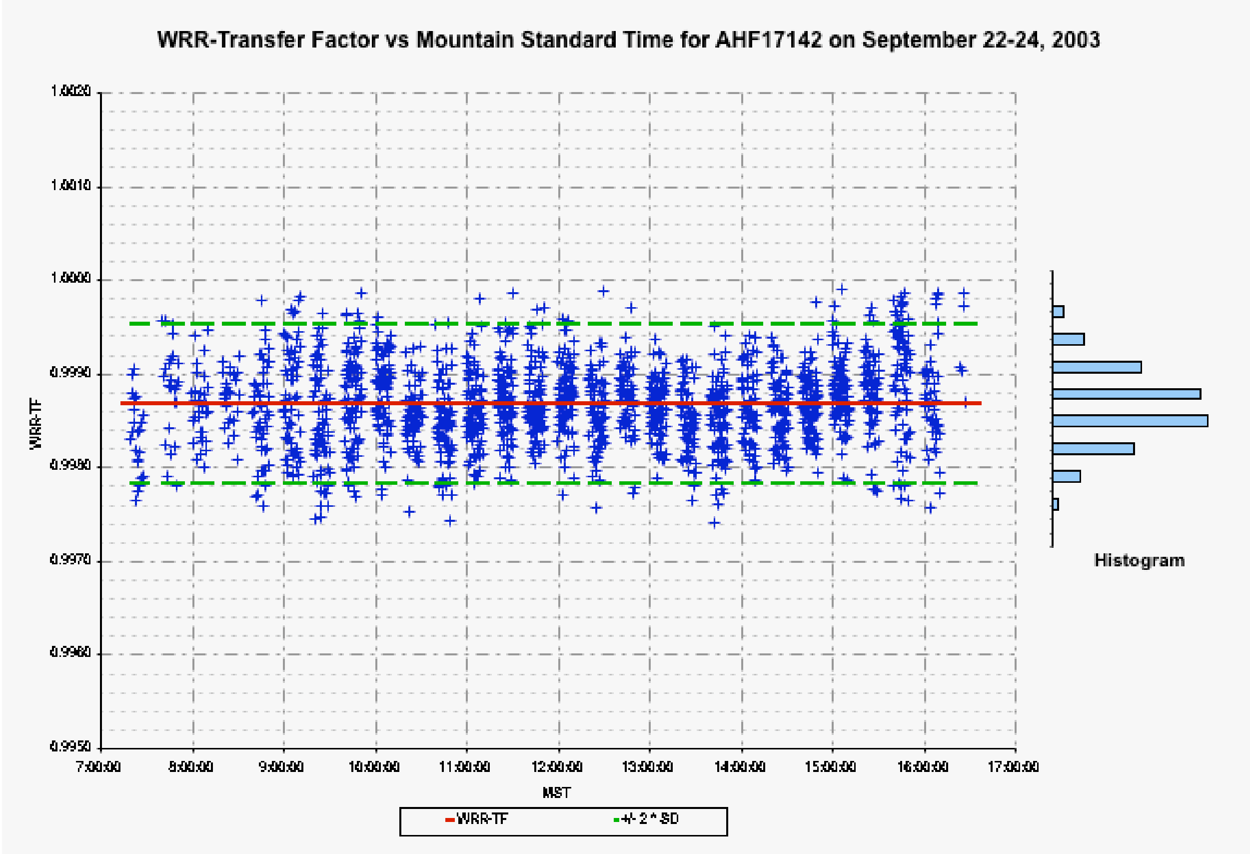

Figure 4.5.1 WRR Transfer Factor vs. Mountain Standard Time for AHF17142 at NPC2003

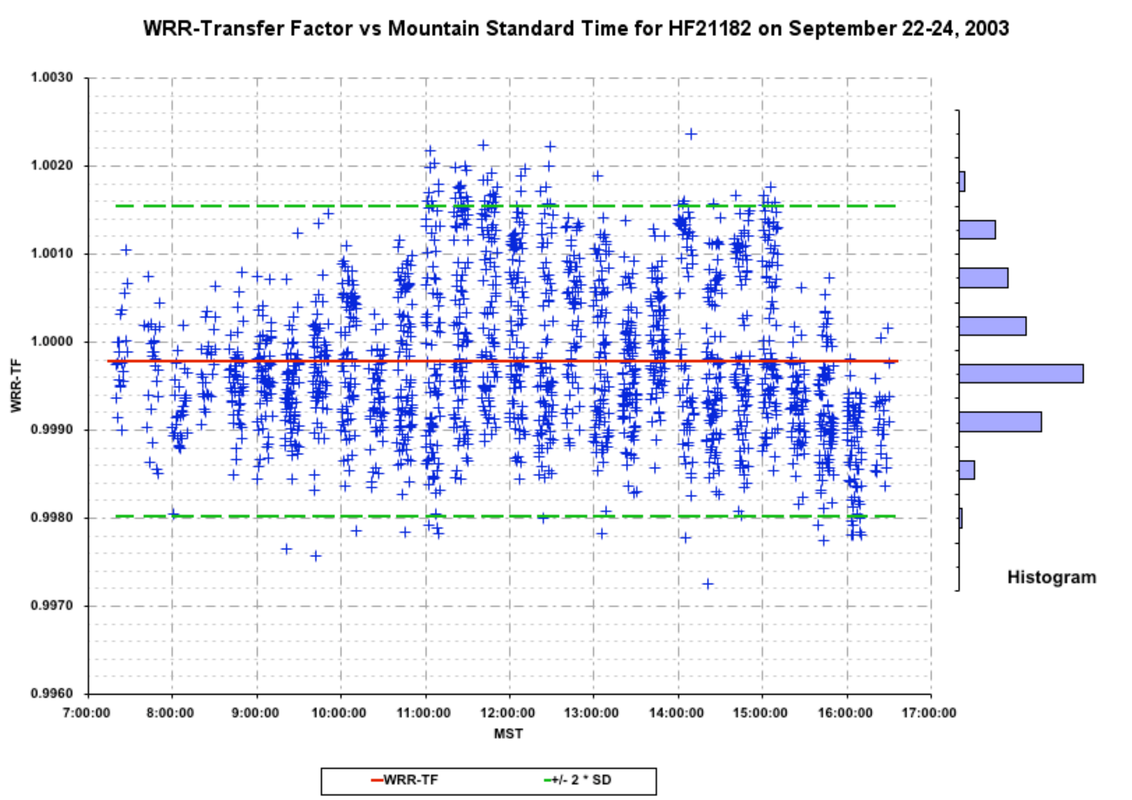

Figure 4.5.2 WRR Transfer Factor vs. Mountain Standard Time for HF21182 at NPC2003

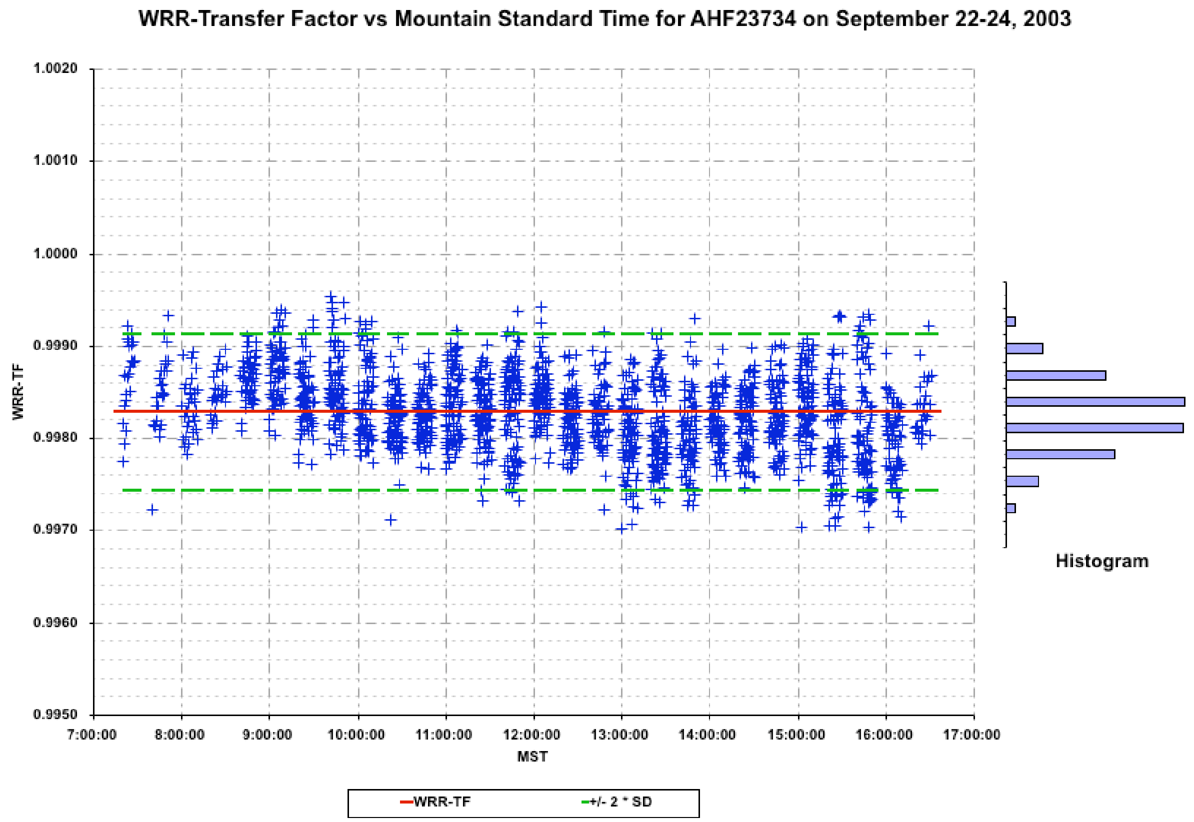

Figure 4.5.3 WRR Transfer Factor vs. Mountain Standard Time for AHF23734 at NPC2003

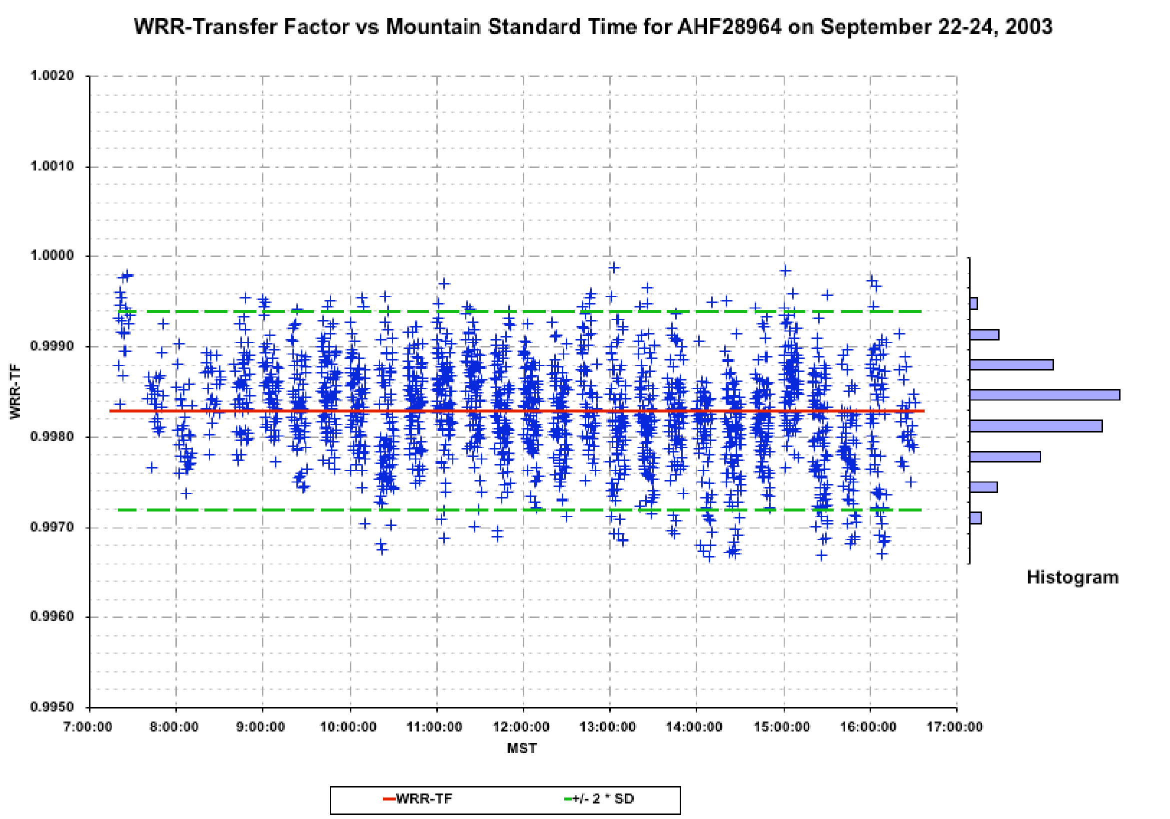

Figure 4.5.4 WRR Transfer Factor vs. Mountain Std Time for AHF28964 at NPC2003

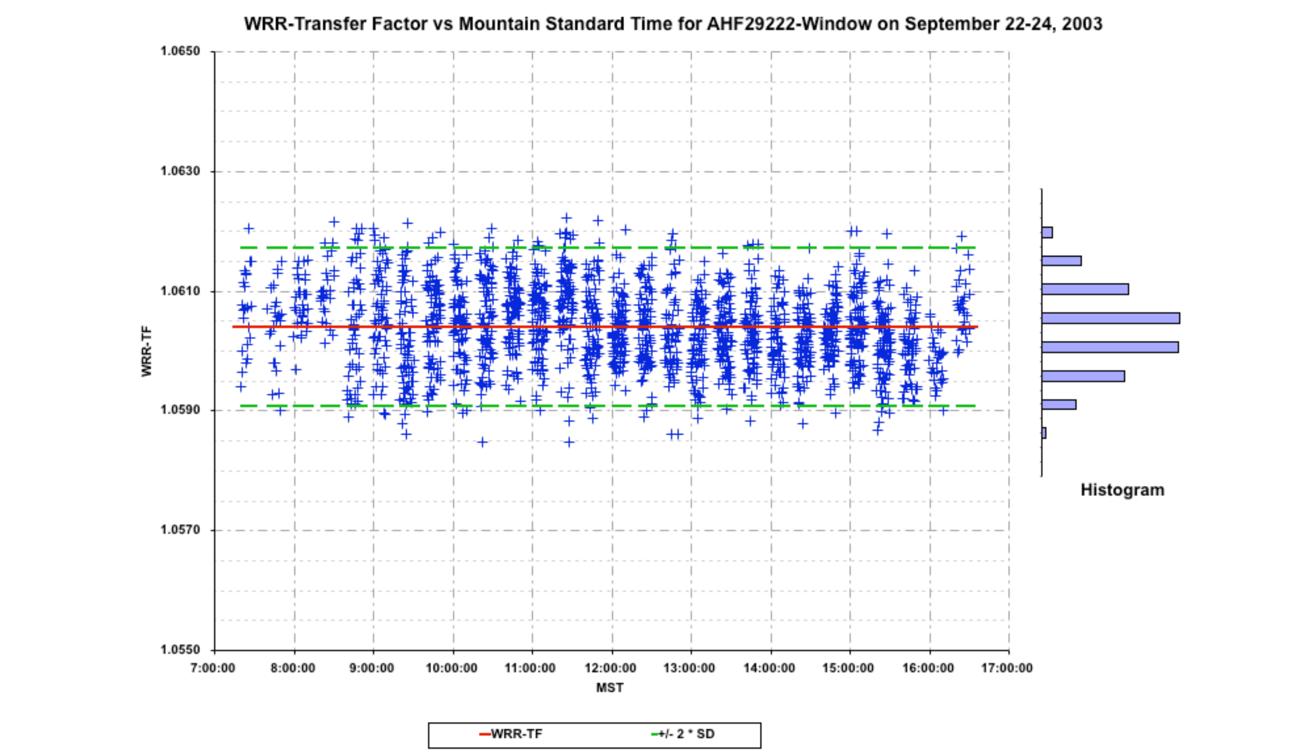

Figure 4.5.5 WRR Transfer Factor vs. Mountain Std Time for AHF29222-Window at NPC2003

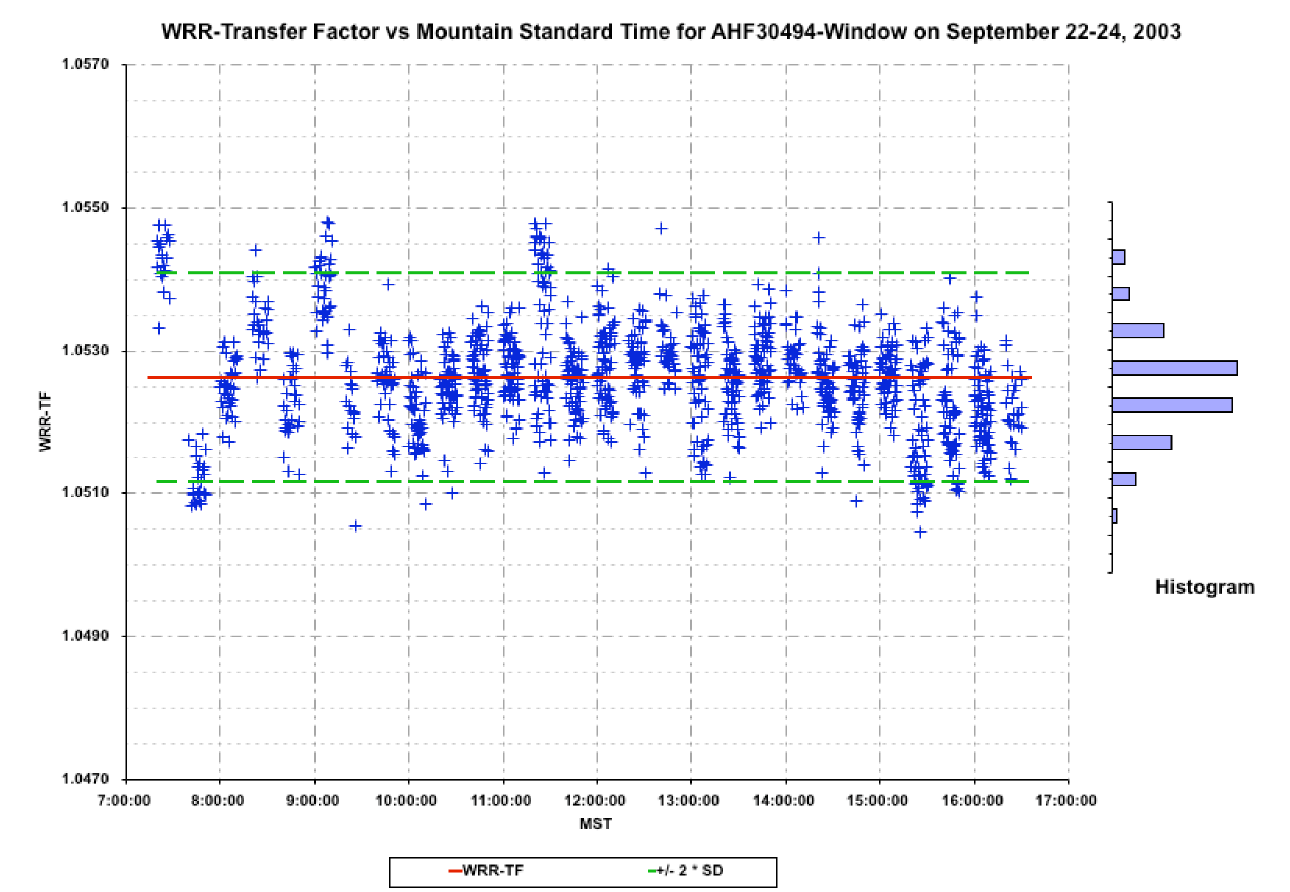

Figure 4.5.6 WRR Transfer Factor vs. Mountain Std Time for AHF30494-Window at NPC2003

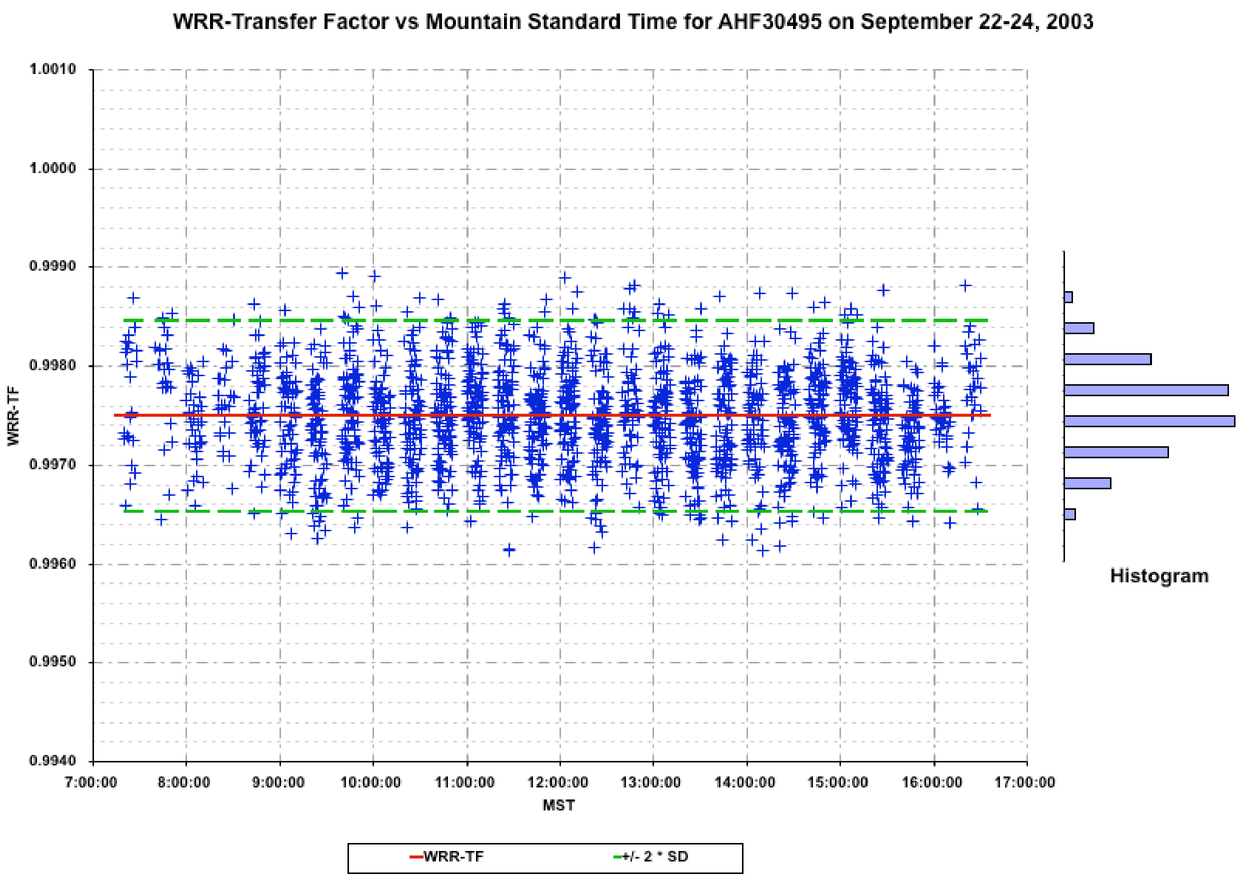

Figure 4.5.7 WRR Transfer Factor vs. Mountain Standard Time for AHF30495 at NPC2003

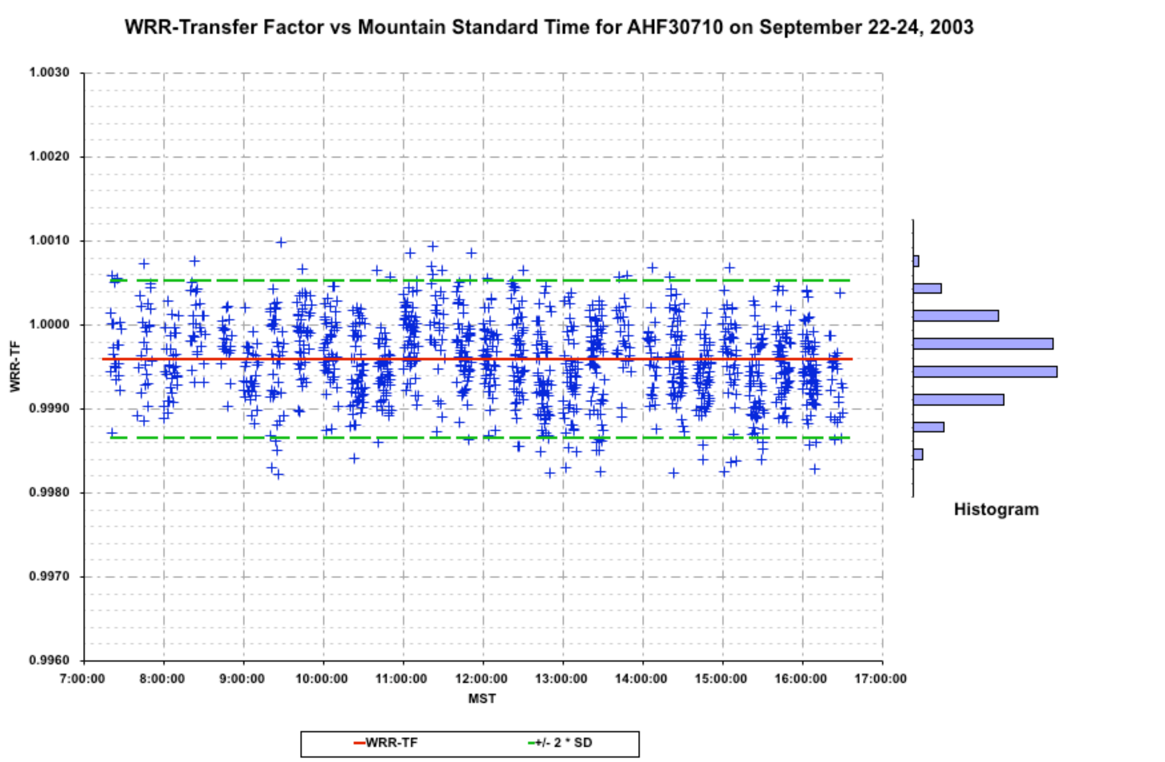

Figure 4.5.8 WRR Transfer Factor vs. Mountain Standard Time for AHF30710 at NPC2003

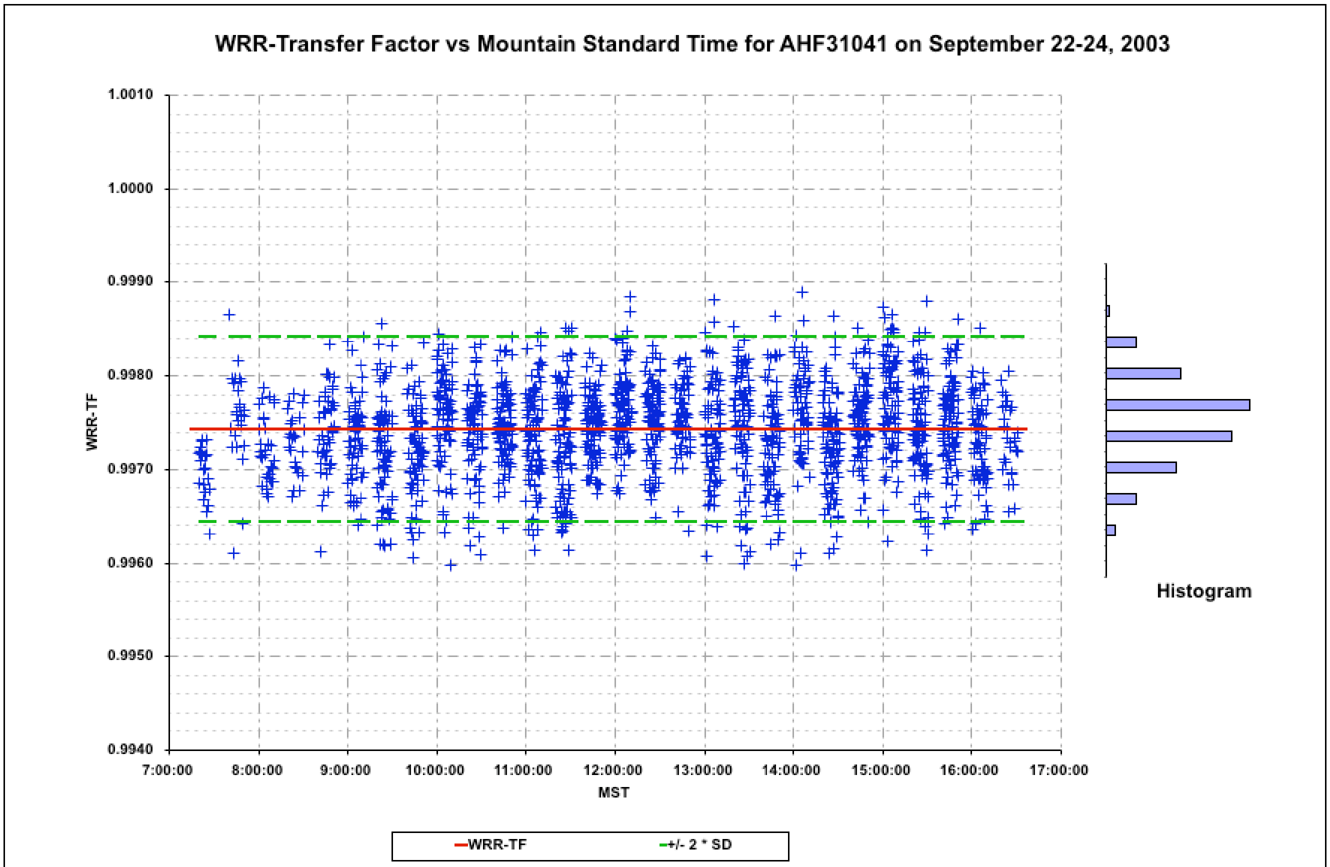

Figure 4.5.9 WRR Transfer Factor vs. Mountain Standard Time for AHF31041 at NPC2003

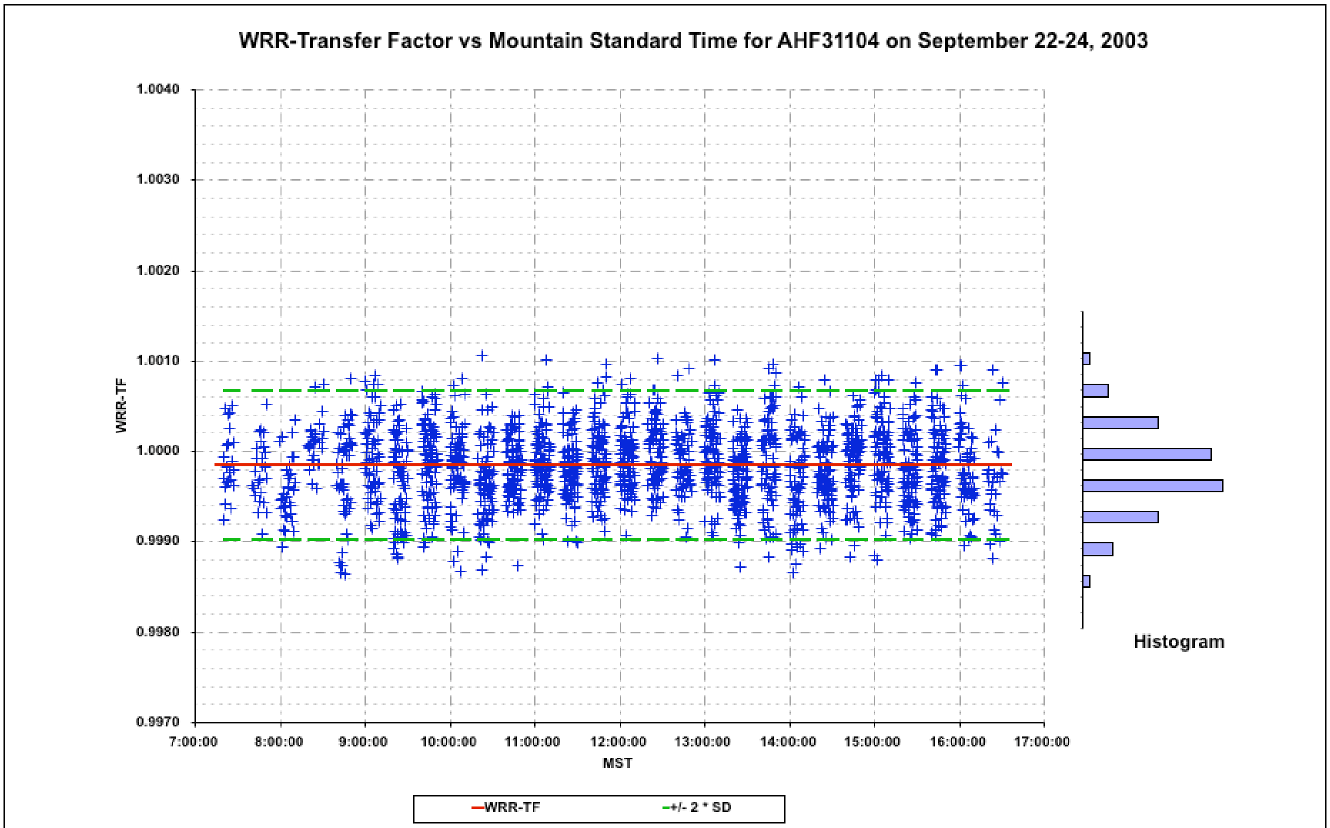

Figure 4.5.10 WRR Transfer Factor vs. Mountain Standard Time for AHF31104 at NPC2003

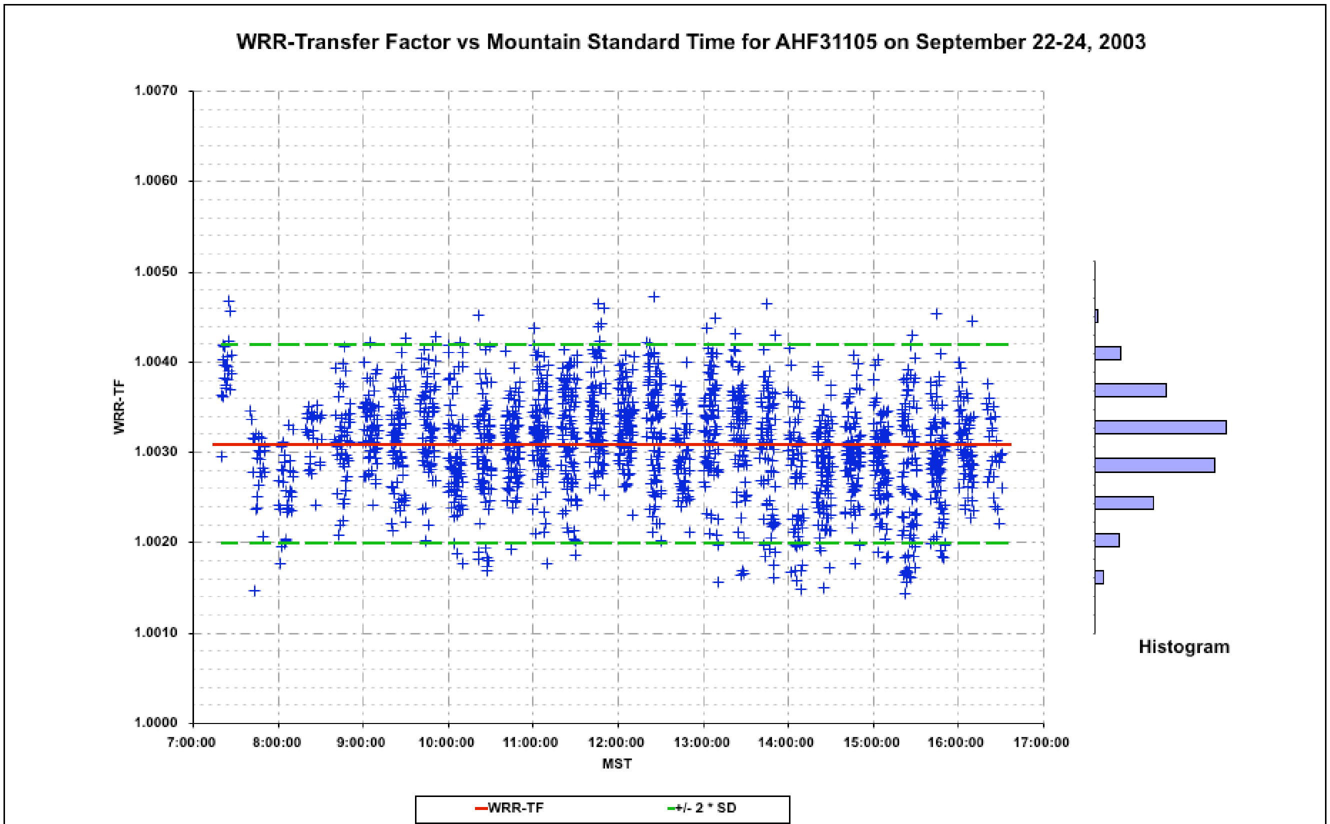

Figure 4.5.11 WRR Transfer Factor vs. Mountain Standard Time for AHF31105 at NPC2003

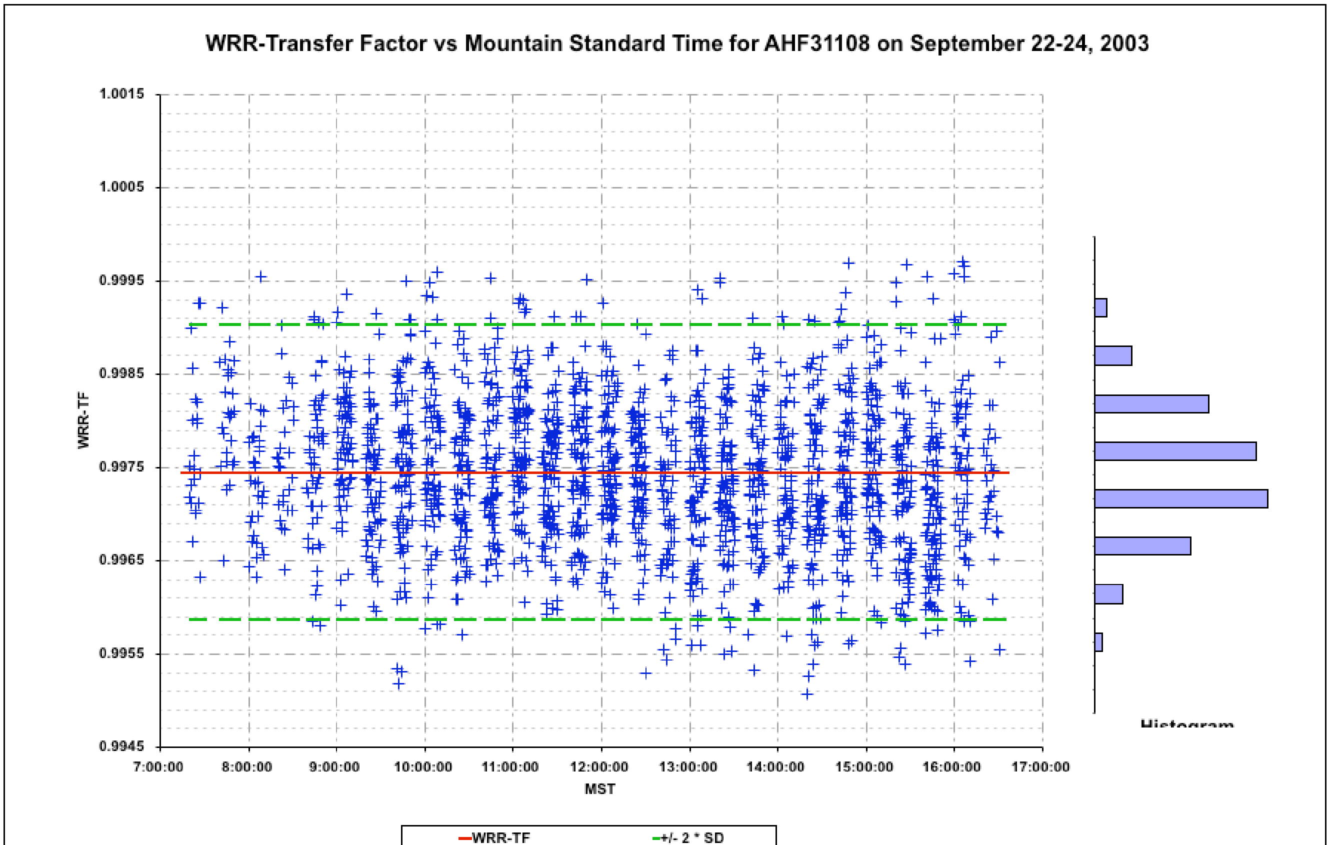

Figure 4.5.12 WRR Transfer Factor vs. Mountain Standard Time for AHF31108 at NPC2003

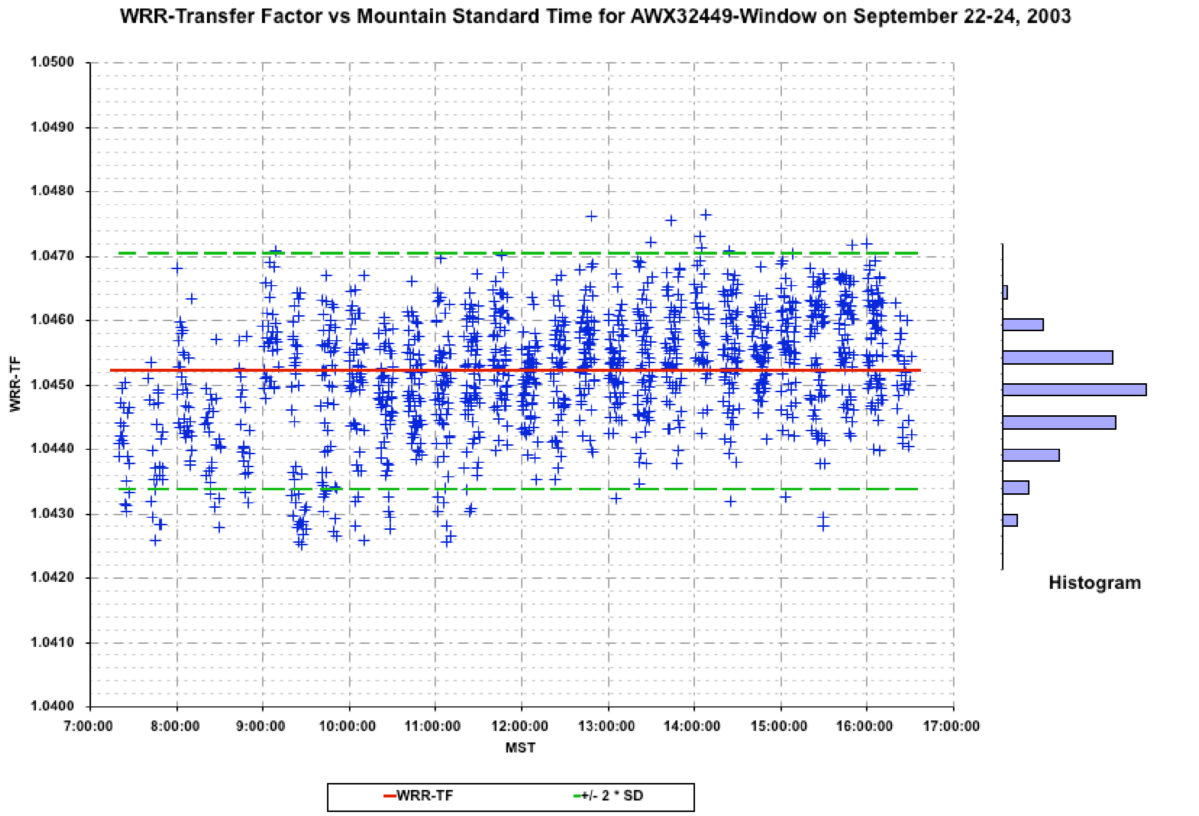

Figure 4.5.13 WRR Transfer Factor vs. Mountain Sdt Time for AHF32449-Window at NPC2003

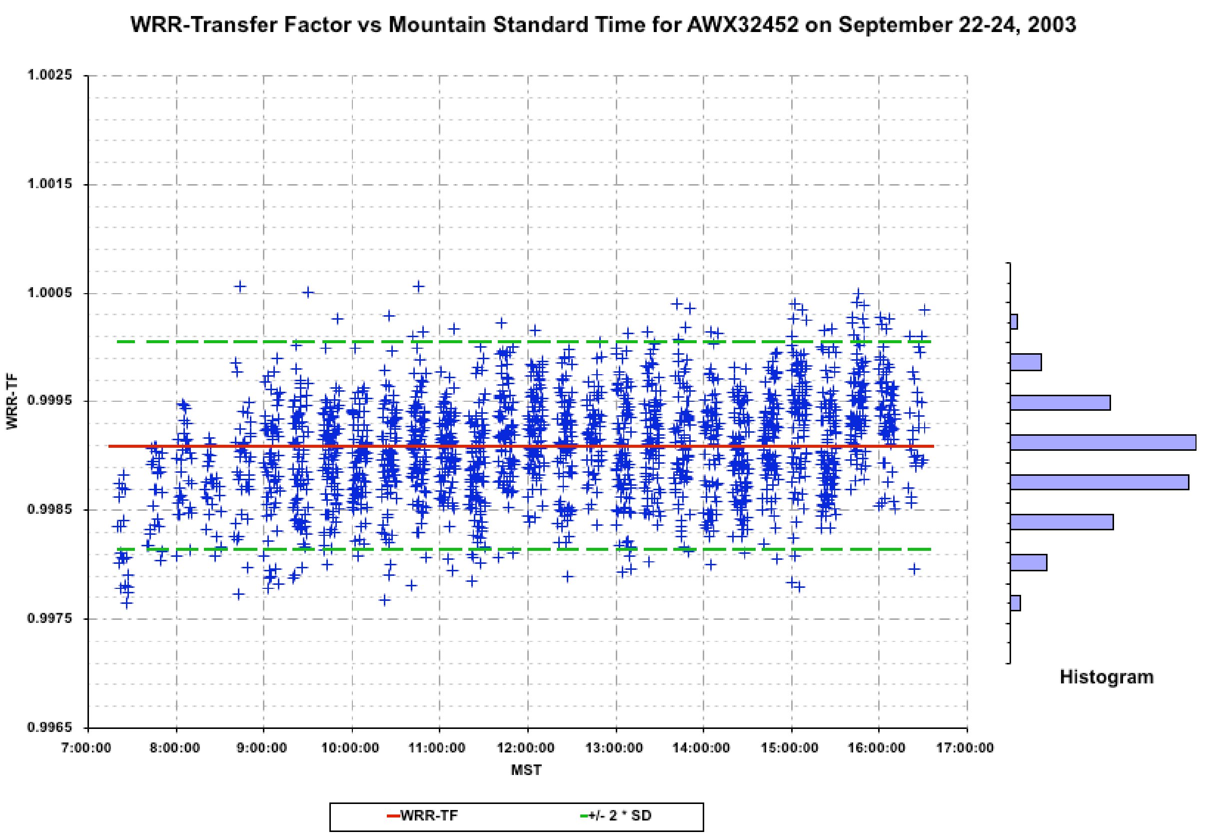

Figure 4.5.14 WRR Transfer Factor vs. Mountain Standard Time for AWX32452 at NPC2003

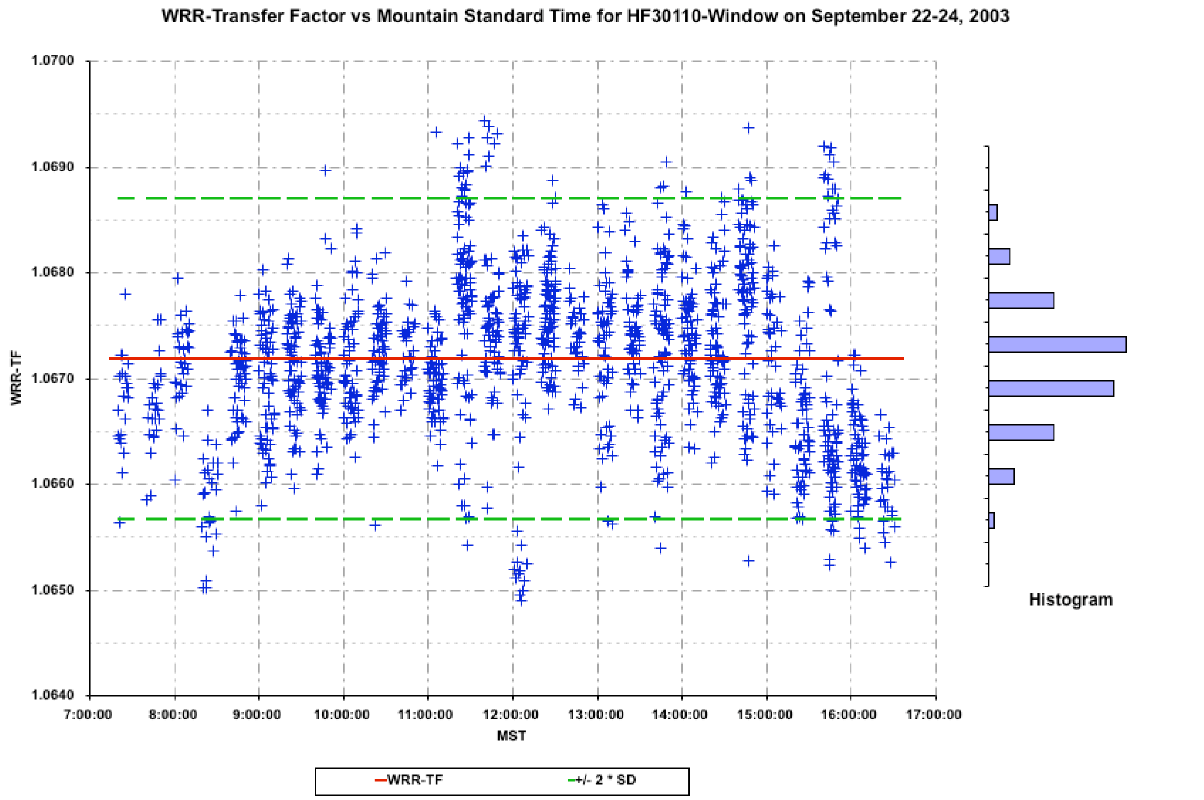

Figure 4.5.15 WRR Transfer Factor vs. Mountain Std Time for HF30110-Window at NPC2003

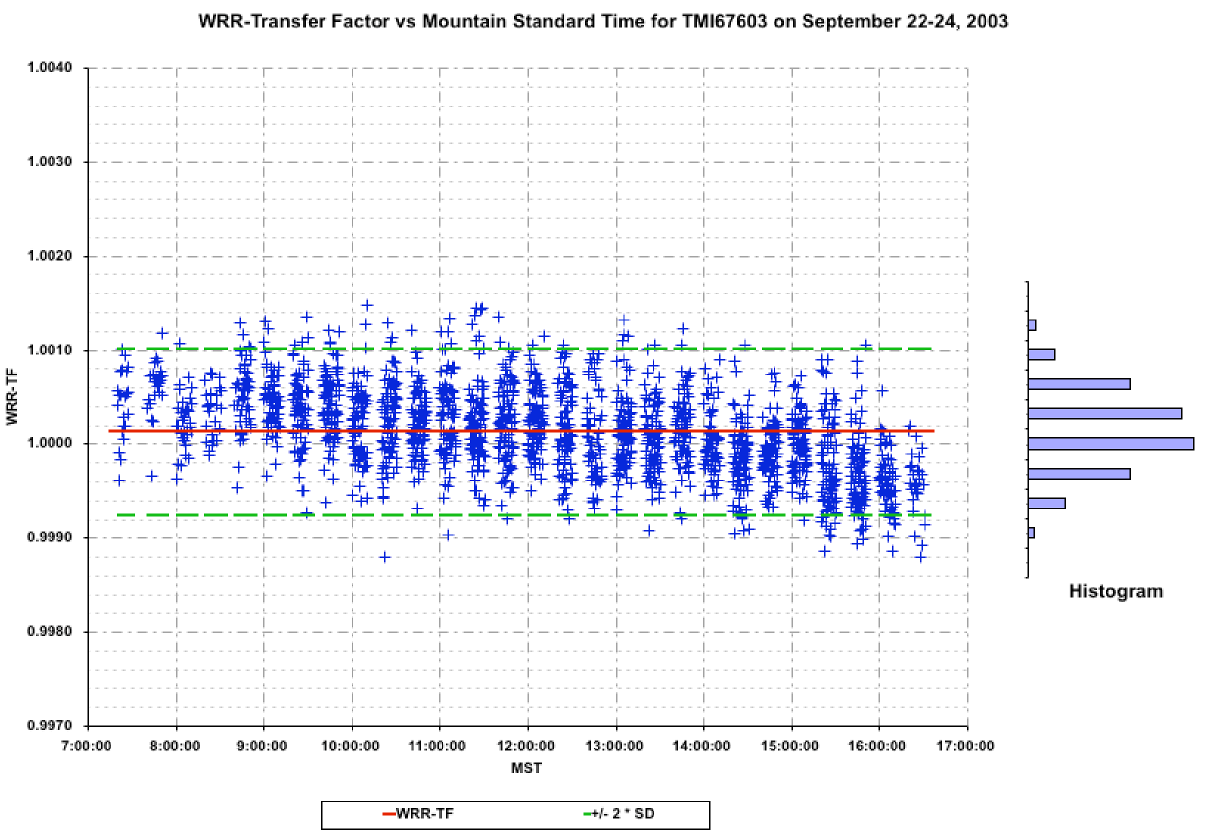

Figure 4.5.16 WRR Transfer Factor vs. Mountain Standard Time for TMI67603 at NPC2003

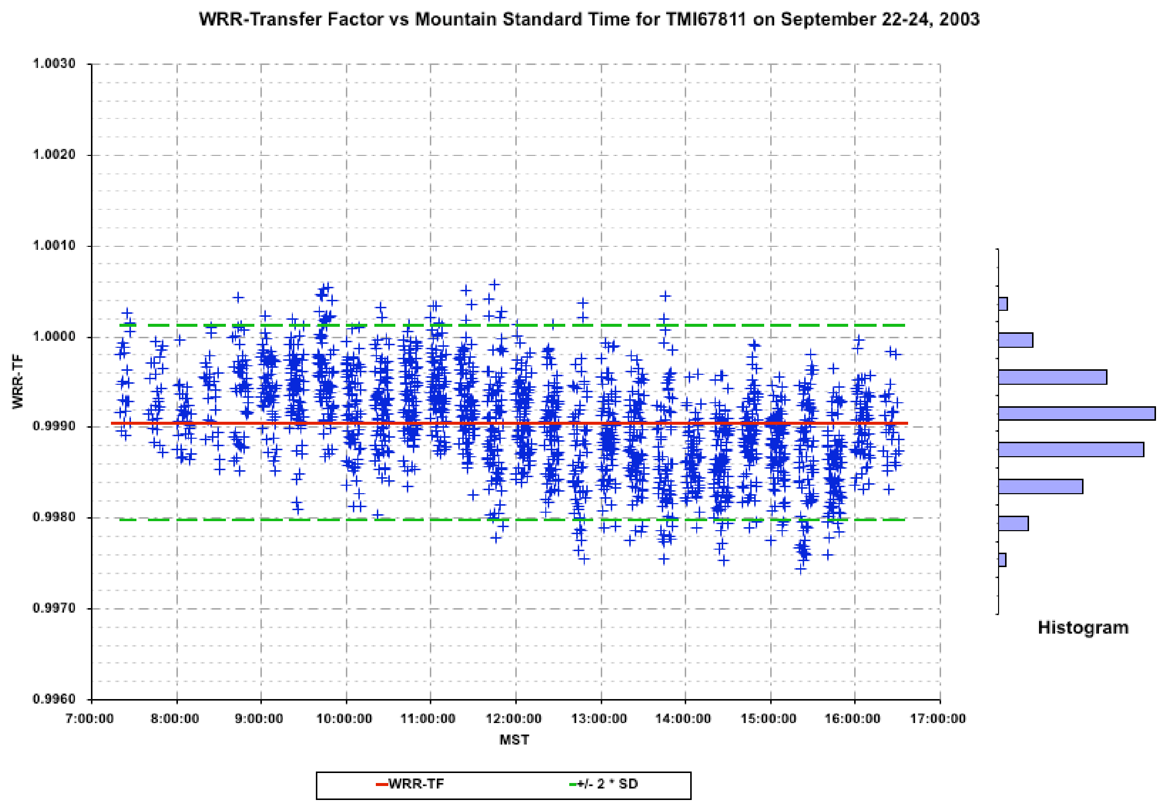

Figure 4.5.17 WRR Transfer Factor vs. Mountain Standard Time for TMI67811 at NPC2003

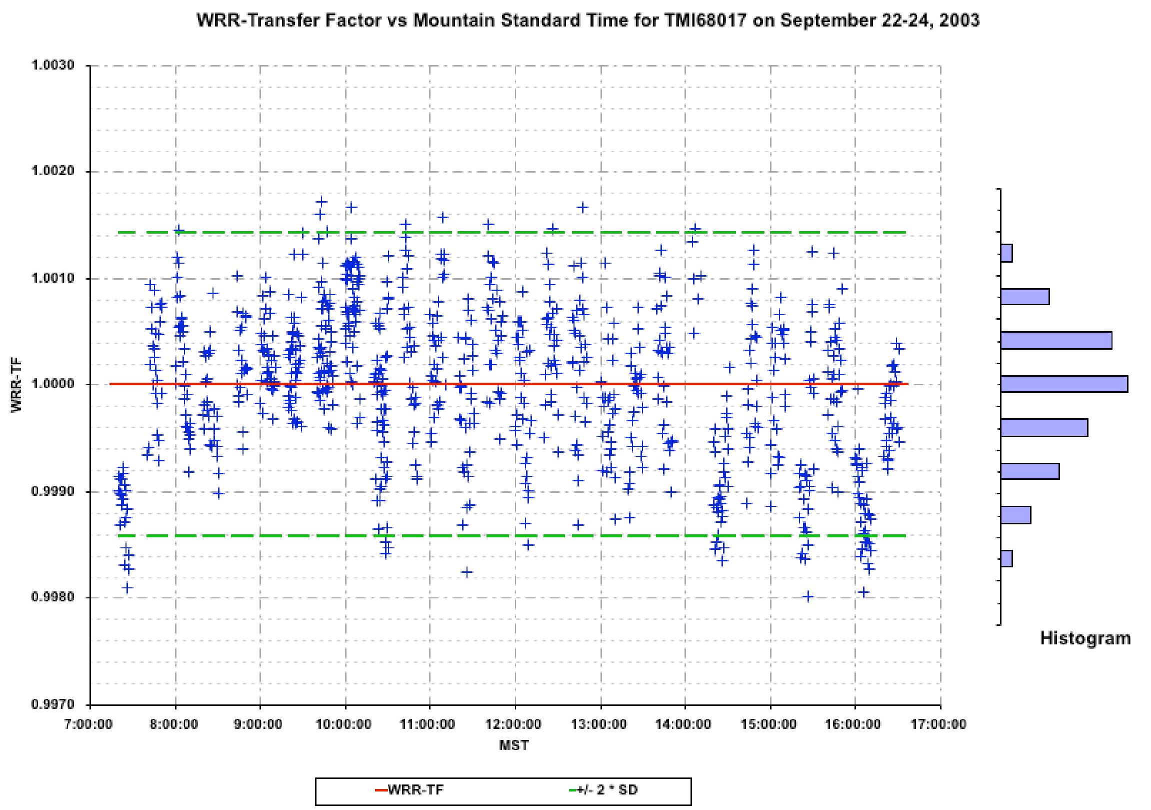

Figure 4.5.18 WRR Transfer Factor vs. Mountain Standard Time for TMI68017 at NPC2003

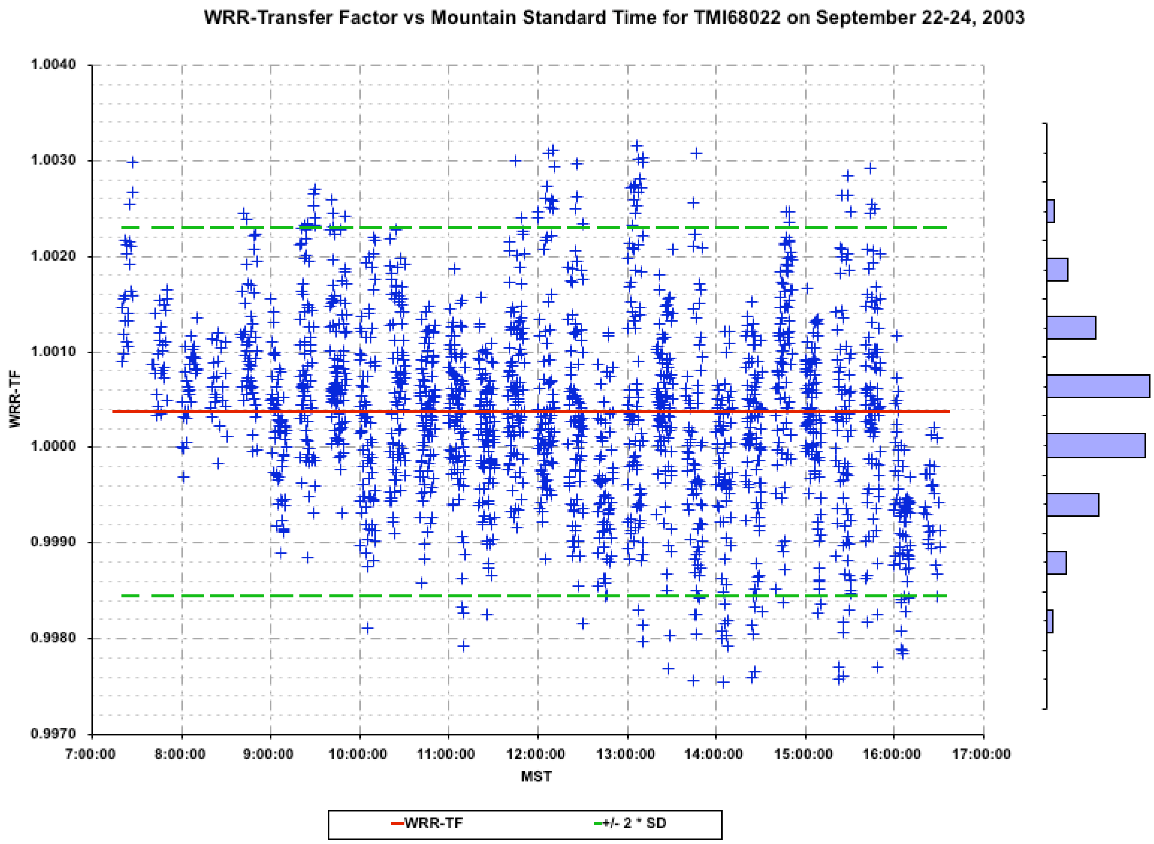

Figure 4.5.19 WRR Transfer Factor vs. Mountain Standard Time for TMI68022 at NPC2003

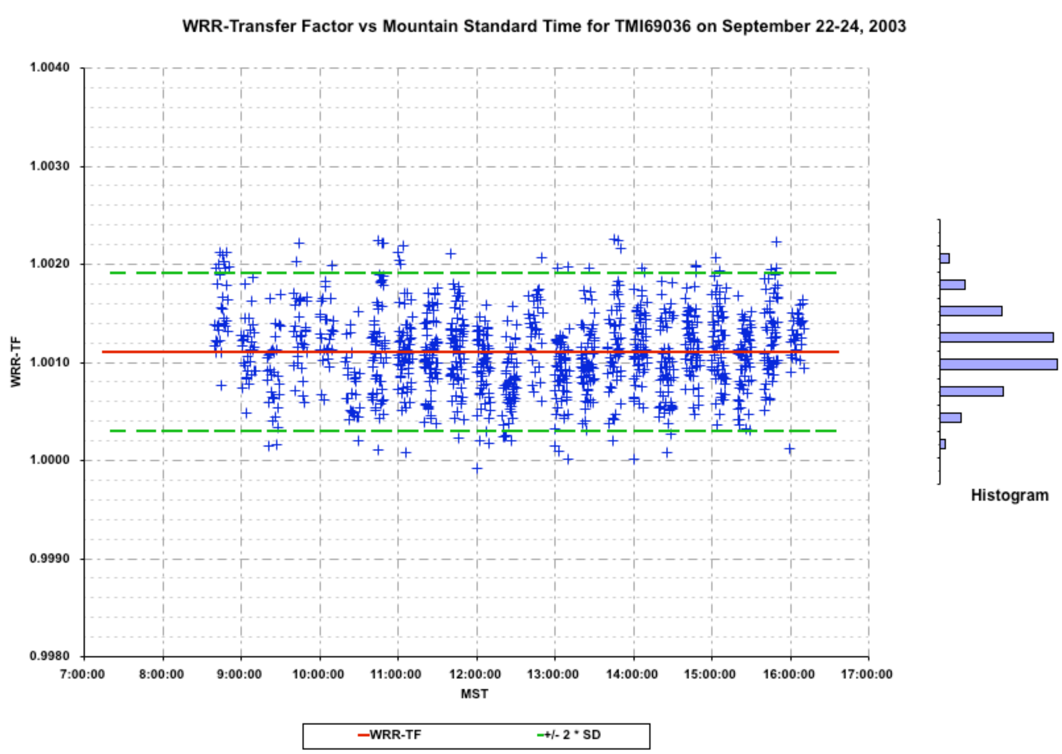

Figure 4.5.20 WRR Transfer Factor vs. Mountain Standard Time for TMI69036 at NPC2003

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 NPC2003, we recommend the user apply only the manufacturer's calibration factor (CF), not the WRR Transfer Factor 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 purposes, the manufacturer's CF is used to calculate the cavity responsivity. Each irradiance reading is then ***multiplied*** by the appropriate WRR Transfer Factor.

For future comparisons, we strongly urge the participants to provide their irradiance readings in the following format:

Serial Number
##, HH:MM:SS, TPs, IRR

where,

Serial Number	=	Instrument serial number (first line only)
##	=	Reading number (1 to 33) within the Run
HH:MM:SS	=	Hour, minute and second of the reading (Local Standard Time, 24-hour clock)
TPs	=	Measured thermopile signal (mV) with resolution of X.XXXXX
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., *AHF307131009.99* would correspond to data from AHF30713 on 10/9/99).

5. Ancillary Data

The meteorological elements of temperature, relative humidity and barometric pressure were measured during the comparisons using the meteorological station at SRRL. A NIP, PSP, and Model 8-48 measured direct, global, and diffuse irradiances respectively. These radiometers are used in SRRL's Baseline Measurement System (BMS). The BMS provides 1-minute averages of 3-second samples. Additional information, including data and graphical summaries, can be found at the Measurements and Instrumentation Data Center:

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

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

6. References

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7. Images

Digital images taken during NPC-2003 are available from the SRRL web site:
http://www.nrel.gov/srrl/npc2003

Appendix A: List of Participants and Pyrheliometers

Name / Address / Phone / Fax / E-mail		Pyrheliometer(s)
1. Naif M. Al-Abbadi	(Sending Radiometer)	HF 30110

Energy Research Institute
KACST, Building 17-E, 4th floor
Prince Abdullah Road
P. O. Box 6086
Riyadh, 11442 Saudi Arabia
Phone: 481-3487
Fax: 4813880
E-mail: nabbadi@kacst.edu.sa

2. Bill Boyson	TMI 67603
Sandia National Laboratories	AHF 31108

Photovoltaic Systems Evaluation Lab
P.O.Box 5800
Albuquerque, NM 87185-0752
Phone: 505-844-5979
Fax: 505-844-4566
E-mail: weboyso@sandia.gov

3. Raymond (Ray) Decker	TMI 67603
Sandia National Laboratories	AHF 31108

Primary Standards Laboratory
P.O.Box 5800
Albuquerque, NM 87185-0665
MS 0665
Phone: 505-844-1357
Fax: 505-844-7699
E-mail: rddecke@sandia.gov

4. Fred Denn	AHF 31041
Analytical Services & Materials, Inc.	AHF 31105

Atmospheric Sciences Group
1 Enterprise Parkway, Suite 300
Hampton, VA 23666-5845
Phone: 757 827 4622
Fax: 757-825-8659
E-mail: F.M.Denn@Larc.NASA.GOV

5. Robert M. (Mike) Edgar — TMI 67811, TMI 68022
Sandia National Laboratories
PO Box 5800 MS 1127
Albuquerque, NM 87185-1127
Phone: 505-845-3441
Fax: 505-845-3366
E-mail: rmedgar@sandia.gov

6. John Hickey — AHF 14915, AWX 32449
The Eppley Laboratory, Inc.
12 Sheffield Ave
Newport, RI 02840
Phone: 401-847-1020
Fax: 401-847-1031
E-mail: jhickeyeplab@ids.net

7. Gary Hodges — AHF 30710
NOAA/OAR/ARL/SRRB
325 Broadway
Boulder, CO 80305
Phone: 303-497-6460
Fax: 303-497-6546
E-mail: gary.hodges@noaa.gov

8. Duncan Maciver — AHF 17142
DSET Laboratories
45601 North 47th Ave.
Phoenix, AZ 85087
Phone: 623-465-7356
Fax: 623-465-9409
E-mail: dmaciver@atlaswsg.com

9. Joe Michalsky — 5° CaF2 NIP, 26356E6
NOAA/OAR/ARL/SRRB
325 Broadway R/ARL
Boulder, CO 80305
Phone: 303-497-6360
Fax: 303-497-6546
E-mail: Joseph.Michalsky@noaa.gov

10. Keith Emery (Sending Radiometer) AHF 23734
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393
Phone: 303-384-6768
Fax: 303-384-6391
E-mail: myersd@tcplink.nrel.gov

11. Erik Naranen AHF 17142
DSET Laboratories
45601 North 47th Ave.
Phoenix, AZ 85087
Phone: 623-465-7356
Fax: 623-465-9409
E-mail: Enaranen@atlaswsg.com

12. Don Nelson AHF 28553
NOAA/CMDL TMI 67502
Climate Monitoring & Diagnostics Laboratory
M/5 R/CMDL1
325 Broadway
Boulder, CO 80305
Phone: 303-497-6662
Fax: 303-497-6290
E-mail: donald.w.nelson@noaa.gov

13. Bill Porch AHF 30494
Los Alamos National Laboratory
Group EES-8, MS J577
P.O. Box 1663
Los Alamos, NM 87545
Phone: 505-667-0971
Fax: 505-667-9122
E-mail: wporch@lanl.gov

14. Ibrahim Reda AHF 23734
National Renewable Energy Laboratory AHF 28968
1617 Cole Blvd. AHF 29220
Golden, CO 80401-3393 AHF 30713
Phone: 303-384-6385 AHF 31104
Fax: 303-384-6391 AWX 32452
E-mail: ireda@tcplink.nrel.gov

15. Michael Stein AHF 14915
The Eppley Laboratory, Inc. AWX 32449
12 Sheffield Ave
Newport, RI 02840
Phone: 401-847-1020
Fax: 401-847-1031
E-mail: mikes@eppleylab.com

16. Tom Stoffel TMI 68017
National Renewable Energy Laboratory TMI 68018
1617 Cole Blvd. TMI 69036
Golden, CO 80401-3393
Phone: 303-384-6395
Fax: 303-384-6391
E-mail: Tom_Stoffel@nrel.gov

17. Phil Thacher TMI 67603
Sandia National Laboratories AHF 31108
MS 0665
Primary Standards Laboratory
P.O.Box 5800
Albuquerque, NM 87185-0665
Phone: 505-898-4345
or 505-844-7599
Email: apthach@swcp.com or pdthach@sandia.gov

18. Ly Vo HF 21182
Florida Solar Energy Center
1679 Clearlake Road
Cocoa, FL 32922
Phone: 321-638-1438
Fax: 321-638-1010
E-mail: Lvo@FSEC.UCF.EDU

19. Craig Webb AHF 28964
Atmospheric Radiation Measurement Program AHF 29222
ARM Program Site Office AHF 30495
309600 EW 28
Billings, OK 74630-2045
Phone: 580-388-4053
Fax: 580-388-4052
E-mail: craigw@ops.sgp.arm.gov

20. Steve Wilcox AHF 30110
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393
Phone: 303-275-4061
Fax: 303-384-6391
E-mail: stephen_wilcox@nrel.gov

NREL Staff

Afshin Andreas	Computer Issues (Virus scan, E-mail, Web Site)
Pete Gotseff	Tools, Parts (Electronics and Hardware), Trackers
Bev Kay	Facilities and services (Phone, Mail, FOOD)
Ibrahim Reda	NPC Data Collection & Processing, Cavity Operations
Tom Stoffel	Host (Security, Safety, Logistics, FOOD)
Steve Wilcox	Computer Issues, Trackers, Cavity Operations

Appendix A (concluded):
List of Pyrheliometers

No.	Serial No.	Owner / Application
1	AHF 14915*	EPLAB / Reference Standard
2	AHF 17142	Atlas Weathering Services-DSET Labs / Reference Standard
3	AHF 23734	NREL / Photovoltaics Program Reference
4	AHF 28553*	NOAA Climate Monitoring & Diagnostics Laboratory (CMDL) / Reference
5	AHF 28964	DOE ARM / Southern Great Plains Site Reference
6	AHF 28968*	DOE ARM / Program Reference
7	AHF 29220*	NREL / Metrology Lab Reference Standard #2
8	AHF 29222	DOE ARM-Southern Great Plains / All-Weather
9	AHF 30494	DOE ARM Tropical Western Pacific Working Standard
10	AHF 30495	DOE ARM-Southern Great Plains Working Standard
11	AHF 30710	NOAA / Surface Radiation Research Branch Reference
12	AHF 30713*	NREL / Metrology Lab Working Standard #1
13	AHF 31041	NASA Clouds and the Earth's Radiant Energy System (CERES) / Reference 1
14	AHF 31104	NREL / Metrology Lab Working Standard #2
15	AHF 31105	NASA Clouds and the Earth's Radiant Energy System (CERES) / Reference 2
16	AHF 31108	Sandia National Laboratories / PV Reference Standard
17	AWX 32449	EPLAB / All-Weather Standard
18	AWX 32452	NREL / All-Weather Standard
19	HF 21182	FSEC / Primary Standard
20	HF 30110	KACST Site Reference & Working Standard
21	TMI 67502*	NOAA CMDL / Reference Standard
22	TMI 67603	Sandia National Laboratories / PSL Reference Standard
23	TMI 67811	Sandia National Laboratories / CRTF Standard #1
24	TMI 68017	NREL / SRRL All-Weather BORCAL Working Standard #2
25	TMI 68018*	NREL / Metrology Lab Reference Standard #1
26	TMI 68022	Sandia National Laboratories / CRTF Standard #2
27	TMI 69036	NREL Metrology Lab / BORCAL Working Standard #3
28	26356E6	NOAA/ARL/SRRB / Research Instrument (5º fov, CaF2 window)

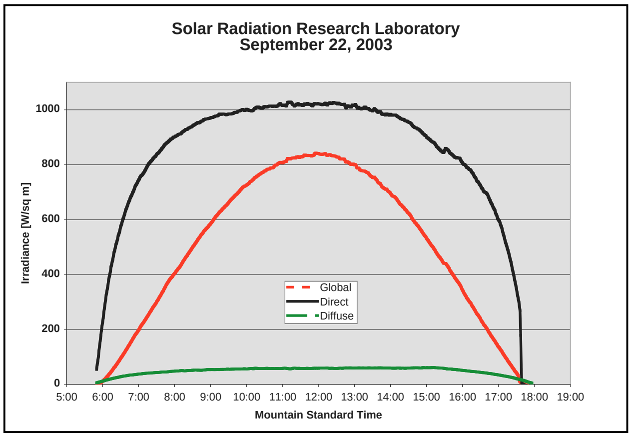
* One of seven radiometers in NPC-2003 Transfer Standard Group

Appendix B: Ancillary Data Summaries

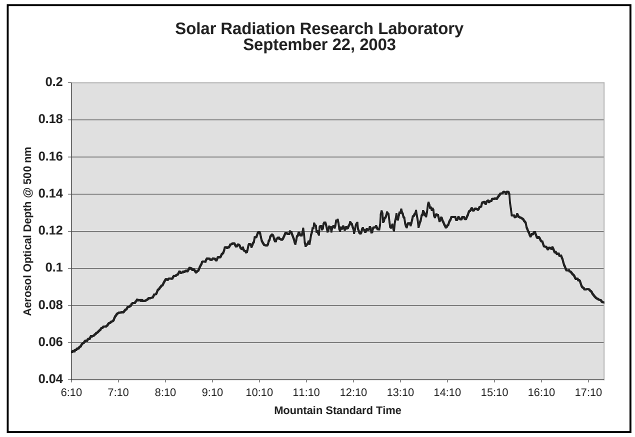
The measurement performance of an absolute cavity can be affected by several environmental parameters. Potentially relevant meteorological data collected during the NPC are presented in this appendix. The Baseline Measurement System (BMS) has been in continuous operation at the Solar Radiation Research 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: http://www.nrel.gov/midc/srrl_bms.

Time-series plots and other graphical presentations of these data acquired during the NPC-2003 measurements are presented here.

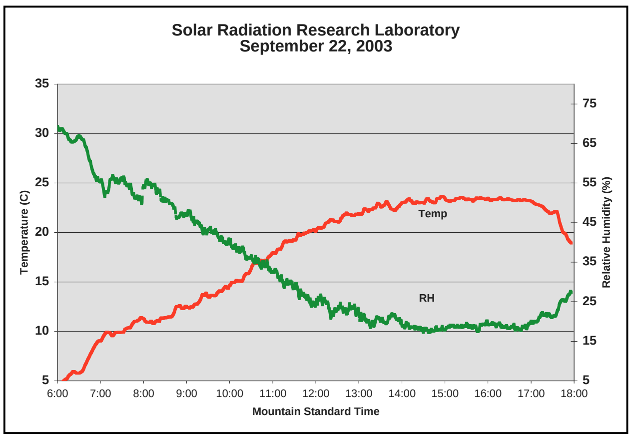
Baseline Measurement System Data for September 22, 2003



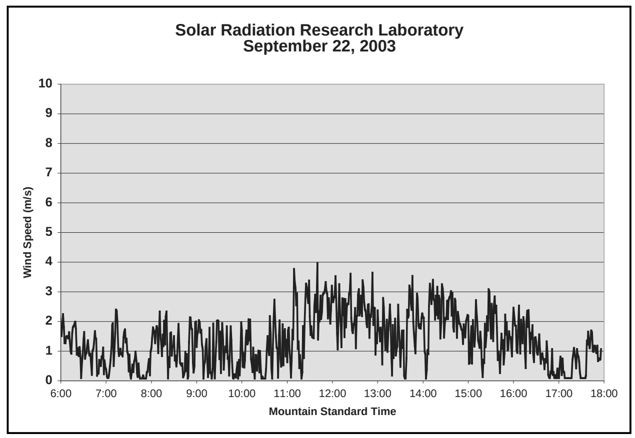
Broadband Irradiance



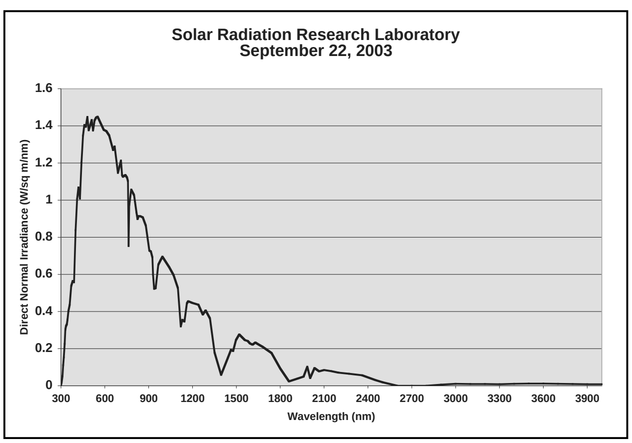
Aerosol Optical Depth



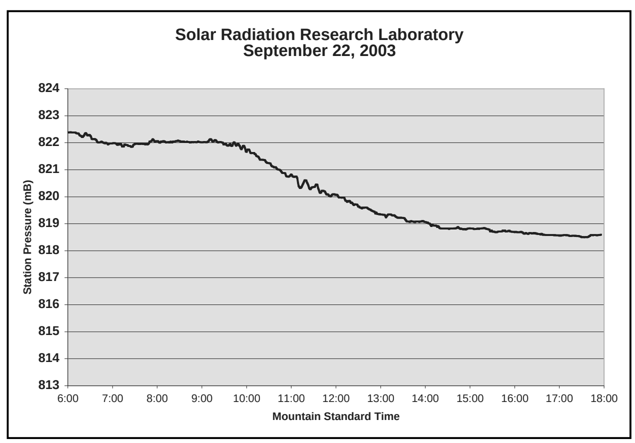
Temperature & Relative Humidity



Wind Speed at 10 m AGL

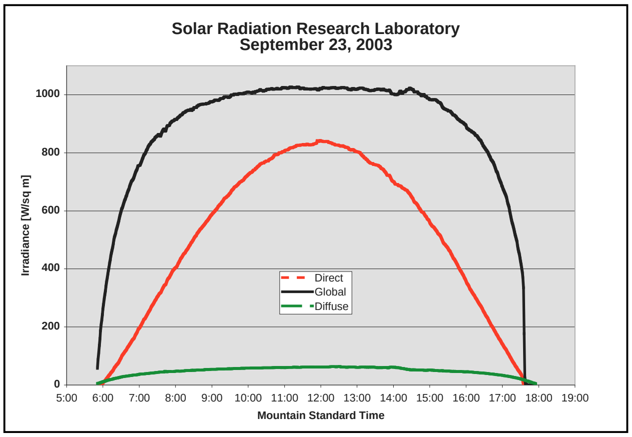


Direct Normal Spectra

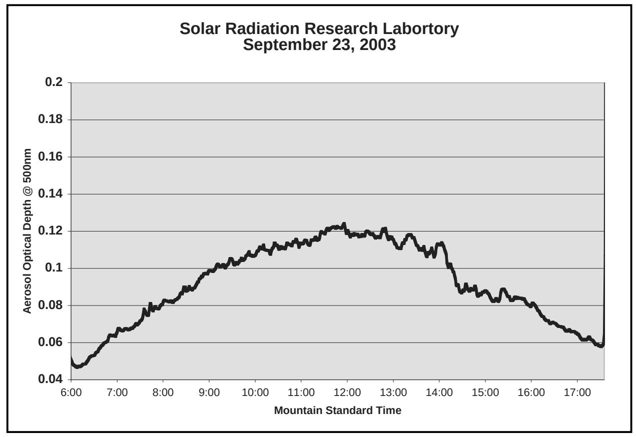


Station Pressure

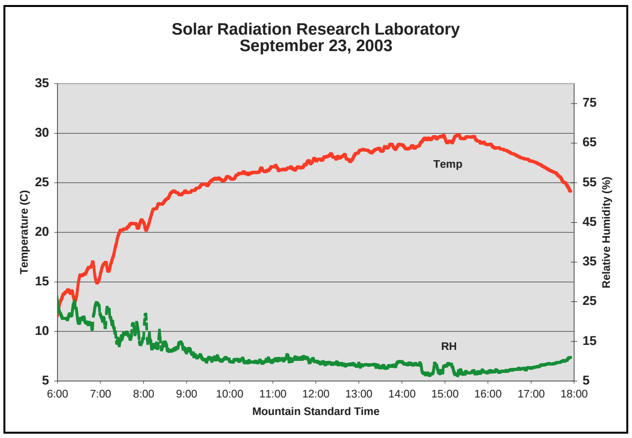
Baseline Measurement System Data for September 23, 2003



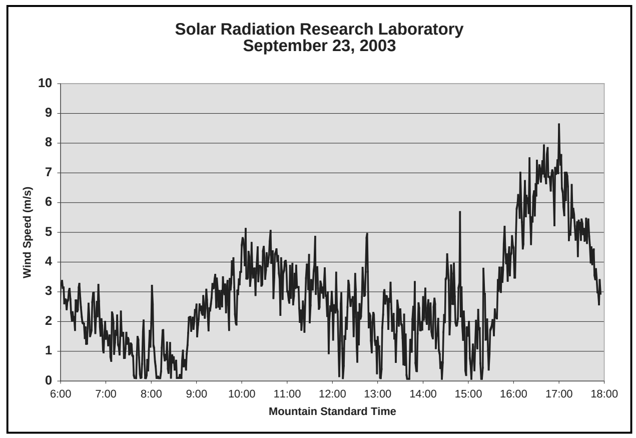
Broadband Irradiance



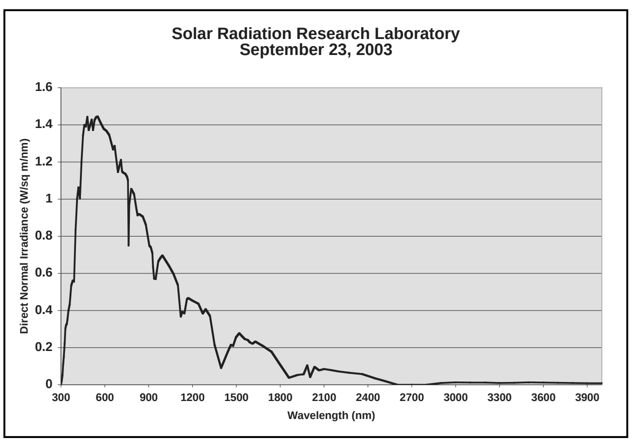
Aerosol Optical Depth



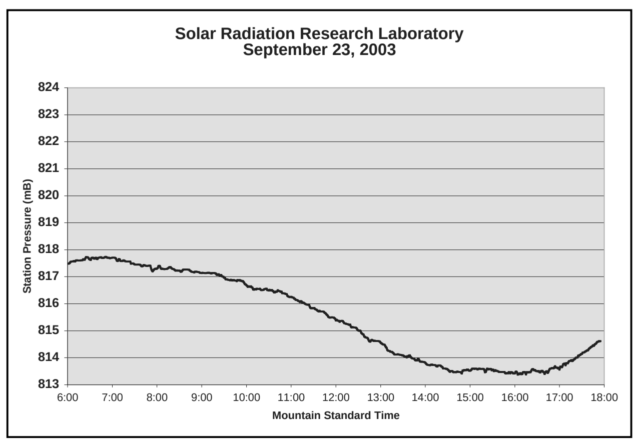
Temperature & Relative Humidity



Wind Speed at 10 m AGL

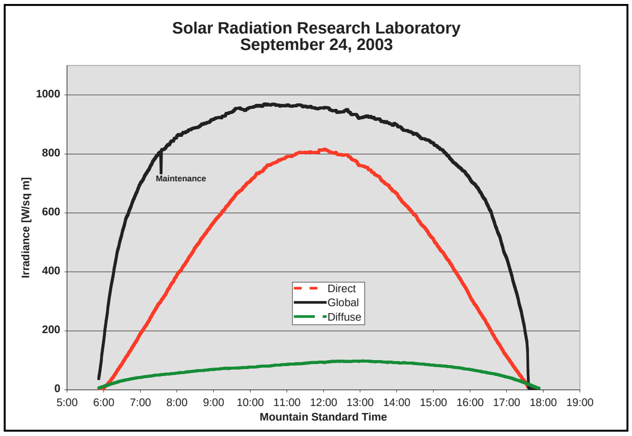


Direct Normal Spectra

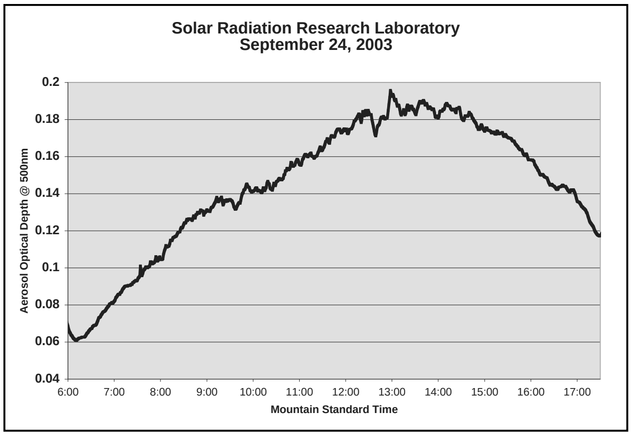


Station Pressure

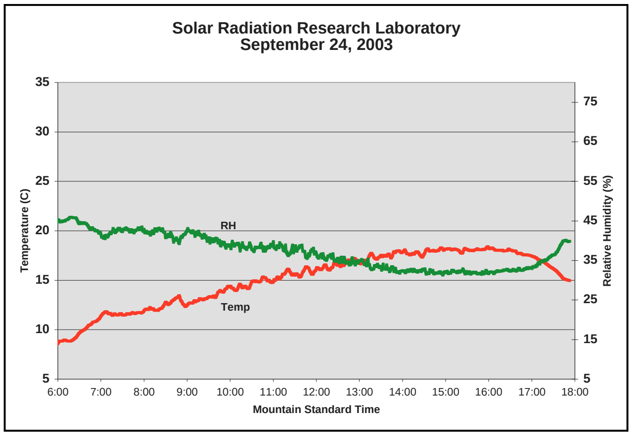
Baseline Measurement System Data for September 24, 2003



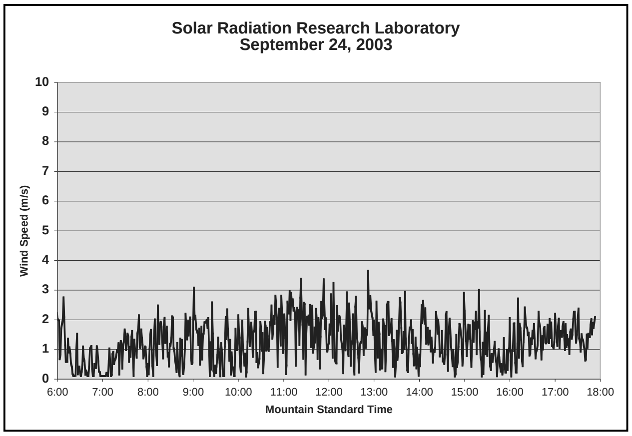
Broadband Irradiance



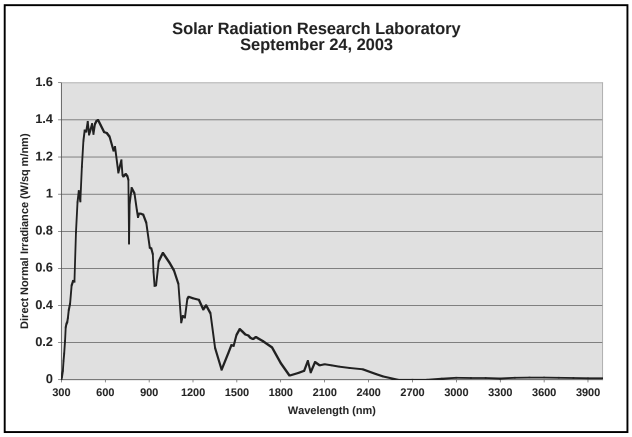
Aerosol Optical Depth



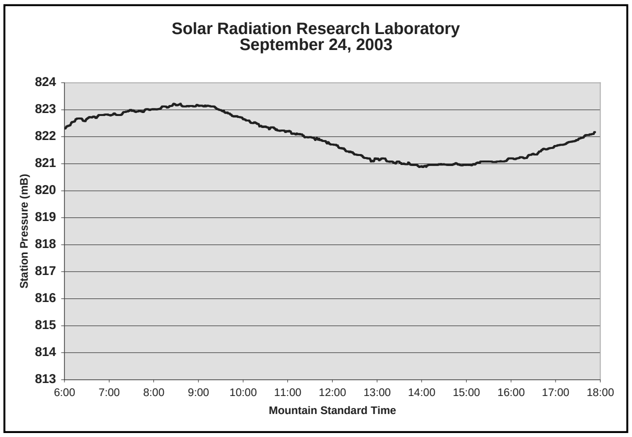
Temperature & Relative Humidity



Wind Speed at 10 m AGL



Direct Normal Spectra



Station Pressure

Appendix C: Operational Notes

The following text was distributed to the participants at the opening of the NPC for discussion to achieve consensus.

2003 Absolute Cavity Radiometer Comparisons at NREL
Protocol Issues Summary

Based on past experiences, we need to agree on the following issues before we begin the comparisons.

1. Title - We will refer to this effort as *NPC-2003* (NREL Pyrheliometer Comparisons 2003).

2. Schedule -

Please call Tom's voice mail (303-384-6395) after 06:30 MDT for recorded announcement of daily plan:

Clear sky forecast = Data! **Cloudy** = Conference Room FTLB 153.

September 23rd :

07:30 - 08:30 -Visitor check-in at Site Entrance Building.

08:00 - 12:00 -Transport equipment to SRRL.
-Equipment Installation & tests.
-ALL personal computers will be scanned for viruses prior to their use at SRRL.NREL will provide this service. A seating diagram is available to indicate operator/solar tracker assignments, but we'll see how this works once every one's there.

12:00 - 13:00 -Lunch
13:00 - 17:00 -Continue equipment tests as needed
-Review measurement protocol, data format and procedures.
-Dry-run(s) of comparison measurements (weather permitting)
-Update Attendance List Information.

September 23rd - October 4th (including weekends):

- **Clear sky** => Measurements!

08:00 -Arrive at SRRL
08:00 - 08:30 -Deploy instruments
08:30 - 09:00 -Equipment warm-up for at least 30-minutes
09:00 - 17:30 -Comparison Data Collection
-Measurements until sundown or clouds.

September 23rd - October 4th (including weekends):

- **Cloudy sky** => No Measurements, but optionally...

  Conference Room 153 in Building "FTLB" is reserved daily for our use:

  -Review of previous day's data analyses
  -Technical Briefings on Radiometry
  -Equipment Tests
  -NREL Tours
  -Office Time (limited e-mail connections at SRRL)

  We will determine the need for more measurements at the end of each day.
  (see item 5 below)

3. SRRL Coordinates

   Program your solar tracker using:

   LAT = 39.7425 N
   LON = 105.1778 W
   ELEV = 1828.8 m AMSL (6,000 ft)
   BARO = 820 mBar (average station pressure)

4. Time Keeping

   -A timekeeper will be identified.
   -All time records will be Mountain Standard Time (MST)
   -The NIST atomic clock is a local call:
   303-499-7111
   -A GPS time source is also available.
   -Set your system clock at the daily start-up or as often as needed for 2 sec accuracy.

5. Minimum Data Set

   A subject for discussion, but 300 data points (your instrument/Reference) could be our goal for a minimum data set for these comparisons.

6. 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 31 readings taken in sequence.
Shade & Calibrate	=	Perform electrical calibration after each run.

The timekeeper will make the following announcements for each Run:

-Next Run Begins at HH:MM (MST)
-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!
-READ! (at T plus 20 sec intervals for 33 readings in a *Run*)

7. Data Transfer
The data format will be discussed on the first day. After the last daily RUN, but before equipment teardown, our Data Keeper (TBD) will circulate a master diskette for you to copy all of your corrected data. Calibration files will not be collected.

8. Data Processing
Reda has developed an Excel spreadsheet system for reducing the data.

9. 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.

10. 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.

11. Common Sense & Courtesy
Please get permission of owner/operator before touching someone else's equipment!
(Turn on/off power strips, move cables, etc.)

12. Clean-up
NPC2003 will conclude after all items are returned to the proper storage locations.

13. Contacts
Daily Voice Mail Announcement: **NREL EMERGENCY Press 1234**
Tom Stoffel ....(303) 384-6395

Questions after normal business hours:
Tom Stoffel ....(303) 666-9719

Other friendly NREL staff:
Reda ....(303) 384-6385 <Metrology Lab>
Pete Gotseff ....(303) 384-6327 <Electronics Lab>
Bev Kay........................(303) 384-6388 <Solar Radiation Research Lab>

SRRL.............................(303) 384-6326 <Let it RING!>