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ARM Surface Meteorology Systems (MET) Handbook

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Contents

1.0	General Overview.....	1
2.0	Contacts.....	2
2.1	Mentor.....	2
2.2	Vendor / Instrument Developer.....	2
3.0	Deployment Locations and History.....	4
4.0	Near-Real-Time Data Plots.....	6
5.0	Data Description and Examples.....	6
5.1	Data File Contents.....	6
5.1.1	Primary Variables and Expected Uncertainty.....	6
5.1.2	Diagnostic Variables.....	7
5.1.3	Data Quality Flags.....	8
5.1.4	Dimension Variables.....	8
5.2	Annotated Examples.....	9
5.3	User Notes and Known Problems.....	9
5.4	Frequently Asked Questions.....	9
6.0	Data Quality.....	10
6.1	Data Quality Health and Status.....	10
6.2	Data Reviews by Instrument Mentor.....	10
6.3	Data Assessments by Site Scientist / Data Quality Office.....	11
6.4	Value-Added Procedures and Quality Measurement Experiments.....	11
7.0	Instrument Details.....	11
7.1	Operation and Maintenance.....	12
7.1.1	User Manual.....	12
7.1.2	Software Documentation.....	12
7.1.3	Additional Documentation.....	12
7.2	Glossary.....	12
7.3	Acronyms.....	13
7.4	Citable References.....	13

Figures

1	Ultrasonic data spikes	10
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Tables

1	Variables and sensors listed by site	1
2	Tower datastream variables	2
3	Deployment locations and history	4
4	TWP Deployment History	4
5	NSA Deployment History	5
6	AMF1 Deployment Locations and History	5
7	Dimension Variables	8

1.0 General Overview

The ARM Surface Meteorology Systems consist mainly of conventional in situ sensors that obtain a defined “core” set of measurements. The core set of measurements is: Barometric Pressure (kPa), Temperature (°C), Relative Humidity (%), Arithmetic-Averaged Wind Speed (m/s), Vector-Averaged Wind Speed (m/s), and Vector-Averaged Wind Direction (deg). The sensors that collect the core variables are mounted at the standard heights defined for each variable:

- Winds: 10 meters
- Temperature and Relative Humidity: 2 meters
- Barometric Pressure: 1 meter.

Depending upon the geographical location, different models and types of sensors may be used to measure the core variables due to the conditions experienced at those locations. Most sites have additional sensors that measure other variables that are unique to that site or are well suited for the climate of the location but not at others. The following table lists the variables and the sensors by site.

Table 1. Variables and sensors listed by site.

	Barometer	Temp	Relative Humidity	Wind Speed	Wind Direction	Visibility & Present Weather	Liquid Precip	Frozen Precip	Chilled Mirror
SGP Met	Vaisala PTB220	Vaisala HMP45C	Vaisala HMP45C	RM Young 05103	RM Young 05103	Vaisala PWD22 (E13 only) starting 9/9/10	NovaLynx TBRG & Vaisala PWD22 (E13 only) starting 9/9/10	Vaisala PWD22 (E13 only) starting 9/9/10	N/A
NSA Met	Vaisala PTB220	Vaisala HMT337	Vaisala HMT337	Vaisala Ultrasonic WS425	Vaisala Ultrasonic WS425	Vaisala FD12P PWS replaced by PWD22 (C1 only) starting 10/6/10	Vaisala FD12P PWS replaced by PWD22 (C1 only) starting 10/6/10	Vaisala FD12P PWS replaced by PWD22 (C1 only) starting 10/6/10	TSL 1088 CMH
TWP Met	Vaisala PTB220	Vaisala HMP45D	Vaisala HMP45D	RM Young 05106	RM Young 05106	Vaisala PWD22 (C1 and C3 only) starting 8/26/10 (C1) and 8/17/10 (C3)	Optical Sci ORG 815 & RIMCO 7499 TBRG & Vaisala PWD22 (C1 & C3 only) starting 8/26/10 (C1) and 8/17/10 (C3)	Vaisala PWD22 (C1 and C3 only) starting 8/26/10 (C1) and 8/17/10 (C3)	N/A
AMF Met	Vaisala PTB220	Vaisala HMP45D	Vaisala HMP45D	RM Young 05106	RM Young 05106	Vaisala PWD22	Vaisala PWD22 & Optical Sci ORG 815	Vaisala PWD22	N/A
AMF 2 Met	Vaisala PTB330	Vaisala HMP155	Vaisala HMP155	Vaisala Ultrasonic WS425	Vaisala Ultrasonic WS425	Vaisala PWD22	Vaisala PWD22 & Optical Sci ORG 815-DA	Vaisala PWD22	N/A

Additionally, the North Slope of Alaska surface meteorology systems are collected from towers. The tower at Barrow has four levels, and the tower at Atkasuk has 2 levels. Two additional datastreams are created using the sensors on the different levels of the towers. The datastreams are arrays with the first value for each variable being the lowest level. The following table describes the variables in the tower datastreams.

Table 2. Tower datastream variables.

	Temp	RH	WS	WD
NSATWRC1	2, 10, 20, 40 m	2, 10, 20, 40 m	2, 10, 20, 40 m	2, 10, 20, 40 m
NSATWRC2	2 m and 5 m	2 m and 5 m	N/A in Met data	N/A in Met data

2.0 Contacts

2.1 Mentor

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 Email: jprell@anl.gov

2.2 Vendor / Instrument Developer

Data loggers (CR10, CR10X, CR1000, CR23X, CR3000)
 Campbell Scientific Inc.
 815 W. 1800 N.
 Logan, UT 84321
 Phone: (801) 753-2342
 Fax: (801) 750-9540
 Website: <http://www.campbellsci.com>

Aspirated Radiation Shields and Wind Speed/Direction Sensors

R. M. Young Company
2801 Aero Park Drive
Traverse City, MI 49686
Phone: (231) 946-3980
Fax: (231) 946-4772
Website: <http://www.youngusa.com/>

Present Weather Sensor (PWS), Present Weather Detector (PWD), Ultrasonic Wind Sensor, Barometer and Temperature/Relative Humidity Probe,

Vaisala
100 Commerce Way
Woburn, MA 01801-1068
Phone: (617) 933-4500
Fax: (617) 933-8029
Website: <http://www.vaisala.com>

Tippping Bucket Rain Gauge for Southern Great Plains (SGP TBRG)

NovaLynx Corporation
PO Box 240
Grass Valley, CA 95945-0240
Phone: (530) 823-7185
USA Toll Free: (800) 321-3577
Fax: (530) 823-8997
Web: <http://www.novalynx.com>

Optical Rain Gauge (ORG)

Optical Scientific, Inc.
205 Perry Parkway, Suite 14
Gaithsburg, MD 20877-2141
Phone: (301) 948-6070
Fax: (301) 948-4674

Tippping Bucket Rain Gauge for Tropical Western Pacific sites (TWP TBRG)

McVan Instruments
58 Geddes Street
PO Box 298, Mulgrave
Victoria, Australia, 3170
Phone: (+61-3) 9582-7333
Fax: (+61-3) 9560-1164
Web page: <http://www.mcvan.com>

Chilled-Mirror Hygrometer for the North Slope of Alaska (NSA CMH)

Technical Services Laboratory, Inc.
95 Ready Ave.
Fort Walton Beach, FL 32548
Phone: (850) 243-3722

Fiber Driver

Allied Telesys

19800 North Creek Parkway, Suite 200

Bothell, WA 98011

Phone: (425) 487-8880

Fax: (425) 489-9191

Toll-free: 1-800-424-6596 (U.S. only)

Web page: <http://www.alliedtelesis.com/>

3.0 Deployment Locations and History

Table 3. Deployment locations and history.

Location	Date Installed	Date Removed	Status
E1-Larned, KS	1995/08/29	2010/10/15	Decommissioned
E3-LeRoy, KS	1995/12/12	2010/10/28	Decommissioned
E4-Plevna, KS	1995/03/28		Operational
E5-Halstead, KS	1996/05/30	2010/11/2	Decommissioned
E6-Towanda, KS	1995/12/14		Operational
E7-Elk Falls, KS	1995/03/09		Operational
E8-Coldwater, KS	1993/03/30	2010/11/10	Decommissioned
E9-Ashton, KS	1993/03/31		Operational
E11-Byron, OK	1995/06/23		Operational
E13 (CF)-Lamont, OK	1993/03/29		Operational
E15-Ringwood, OK	1993/04/01		Operational
E20-Meeker, OK	1993/04/02		Operational
E21-Okmulgee, OK	1999/07/27		Operational
E24-Cyril, OK	1995/08/23	2010/11/24	Decommissioned
E25-Seminole, OK	1996/12/13	2002/04/08	Decommissioned
E27-Earlsboro, OK	2002/05/02	2010/01/20	Decommissioned

Table 4. TWP Deployment History.

Location	Date Installed	Date LoggerNet Upgrade	Date Removed	Status
TWP C1 Manus	10/1996	08/2004		Operational
TWP C2 Nauru	11/1998	07/2004		Operational
TWP C3 Darwin	04/2002	05/2004		Operational

Table 2 contains the additional column of “Date LoggerNet Upgrade”. On this date major changes were made to the way the data were collected, which included adding new variables and removing others.

Table 5. NSA Deployment History.

Location	Date Installed	Date LoggerNet Upgrade	Date T/RH and Ultrasonic Upgrade	Date Removed	Status
NSA C1 Barrow, AK	03/1998	10/2003	09/2008		Operational
NSA C2 Atqasuk, AK	07/2000	10/2003	09/2008	01/16/2011	Decommissioned

Table 3 contains two additional columns of “Date LoggerNet Upgrade” and “Date T/RH and Ultrasonic Upgrade”. On these date major changes were made to the way the data were collected, which included adding new variables and removing others. In the case of the Date of LoggerNet Upgrade, some sensors were removed altogether. At NSAC1 the Optical Rain Gauge was removed and one that measured every minute replaced the CMH that measured once every 15 minutes. At NSAC2 the ultrasonic snow depth sensor was removed.

Table 6. AMF1 Deployment Locations and History.

Location	Start Date	End Date	Sensors Deployed
Pt. Reyes, Ca (PYE M1)	02/01/2005	09/15/2005	HMP-45D T/RH probe, 05106 Wind Monitor, PTB-220 Barometer, 815 and 115 Optical Rain Gauge
Niamey, Niger (NIM M1)	01/05/2006	01/07/2007	HMP-45D T/RH probe, 05106 Wind Monitor, PTB-220 Barometer, 815 and 115 Optical Rain Gauge, PWD-22 Present Weather Detector
Niger Ancillary Site (Bazimboubou, Niger) (NIM S1)	01/05/2006	12/08/2006	HMP-45AC T/RH probe, 05106 Wind Monitor, PTB-220 Barometer, 815 and 115 Optical Rain Gauge,
Hasselbach, Germany (FKB M1)	04/02/2007	01/01/2008	HMP-45D T/RH probe, 05106 Wind Monitor, PTB-220 Barometer, 815 and 115 Optical Rain Gauge, PWD-22 Present Weather Detector
Shouxian, China (HFE M1)	05/2008	12/2008	HMP-45D T/RH probe, 05106 Wind Monitor, PTB-220 Barometer, 815 and 115 Optical Rain Gauge, PWD-22 Present Weather Detector
China Ancillary Site (Taihu, China) (HFE S1)	05/2008	12/2008	HMP-45AC T/RH probe, 05106 Wind Monitor, PTB-220 Barometer, 815 and 115 Optical Rain Gauge,
Graciosa, Azores	05/2009	01/07/2011	HMP-45D T/RH probe, 05106 Wind Monitor, PTB-220 Barometer, 815 and 115 Optical Rain Gauge, PWD-22 Present Weather Detector

Table 4 contains the additional column for “Sensors Deployed”. This is a result of the fact that the AMF has an ancillary site that is deployable in case the main site does not have an optimal location. The ancillary site typically does not have all the same sensors and so the variables are different. Additionally, given the climate of the region certain sensors may not be useful. For example, the ORG should not be used for frozen precipitation measurements and will be removed from the instrument list during arctic deployments.

4.0 Near-Real-Time Data Plots

Near-real-time data plots can be found at the following locations:

<http://www.arm.gov/data/plots>

5.0 Data Description and Examples

5.1 Data File Contents

5.1.1 Primary Variables and Expected Uncertainty

The following links lead to tables that list the information for the primary variables, their long names, units, measurement level and interval and resolution. Primary Variables are different than the “Core” variables in that they are all the variables measured at the given location from all the meteorological system sensors. For example, the SGP MET “Core” variables are Barometric Pressure (kPa), Temperature (°C), Relative Humidity (%), Arithmetic Averaged Wind Speed (m/s), Vector-Averaged Wind Speed (m/s), and Vector-Averaged Wind Direction (deg). The SGP Primary Variables also contain the precipitation measured from the tipping bucket rain gauge and a corrected precipitation measurement and the calculated vapor pressure.

- [SGP MET Primary Variables](#)
- [NSA MET Primary Variables](#)
- [NSA TWR C1 Primary Variables](#)
- [NSA TWR C2 Primary Variables](#)
- [TWP MET Primary Variables](#)

AMF MET Primary Variables

- [Point Reyes, California](#)
- [Niamey, Niger](#)
- [Niger Ancillary Site](#) (Bizamboubou, Niger)
- [Heselbach, Germany](#)
- [Shouxian, China](#)
- [China Ancillary Site](#) (Taihu, China)
- [Graciosa, Azores](#)
- Steamboat Springs, Colorado (currently unavailable)

5.1.1.1 Definition of Uncertainty

We define uncertainty as the range of probable maximum deviation of a measured value from the true value within a 95% confidence interval. Given a bias (mean) error B and uncorrelated random errors characterized by a variance σ^2 , the root-mean-square error (RMSE) is defined as the vector sum of these,

$$RMSE = (B^2 + \sigma^2)^{1/2}.$$

(B may be generalized to be the sum of the various contributors to the bias and σ^2 the sum of the variances of the contributors to the random errors). To determine the 95% confidence interval we use the Student's t distribution: $t_{n,0.025} \approx 2$, assuming the RMSE was computed for a reasonably large ensemble. Then the *uncertainty* is calculated as twice the RMSE.

5.1.1.2 Secondary/Underlying Variables

This section is not applicable to the ARM surface meteorology systems.

5.1.2 Diagnostic Variables

Diagnostic variables are typically variables that do not have a scientific value but instead allow for determination of the proper function of the sensors and system components. For example, Battery Voltage, Error Codes, and standard deviations of the Primary Variables are contained in these tables.

- [SGP MET Diagnostic Variables](#)
- [NSA MET Diagnostic Variables](#)
- [NSA TWR C1 Diagnostic Variables](#)
- [NSA TWR C2 Diagnostic Variables](#)
- [TWP MET Diagnostic Variables](#)

AMF MET Diagnostic Variables

- [Point Reyes, California](#)
- [Niamey, Niger](#)
- [Niger Ancillary Site](#) (Bizamboubou, Niger)
- [Heselbach, Germany](#)
- [Shouxian, China](#)
- [China Ancillary Site](#) (Taihu, China)
- [Graciosa, Azores](#)
- Steamboat Springs, Colorado (currently unavailable)

5.1.3 Data Quality Flags

Data Quality Flags are additional variables inserted into the datastream during routine collection and ingest. These variables are a flag to assist in the checking the quality of the data collected. The following tables list the maximum, minimum, and delta values for each variable that will cause the QC variable to be set.

- [SGP MET Data Quality Flags](#)
- [NSA MET Data Quality Flags](#)
- [NSA TWR C1 Data Quality Flags](#)
- [NSA TWR C2 Data Quality Flags](#)
- [TWP MET Data Quality Flags](#)

AMF MET Data Quality Flags

- [Point Reyes, California](#)
- [Niamey, Niger](#)
- [Niger Ancillary Site](#) (Bizamboubou, Niger)
- [Heselbach, Germany](#)
- [Shouxian, China](#)
- [China Ancillary Site](#) (Taihu, China)
- [Graciosa, Azores](#)
- Steamboat Springs, Colorado (currently unavailable)

5.1.4 Dimension Variables

The dimension variables are the same for all datastreams regardless of site.

Table 7. Dimension Variables

Variable	Measurement Interval	Unit
base_time	1 min	seconds since YYYY-mm-dd XX:XX:XX X:XX
time_offset	1 min	seconds since YYYY-mm-dd XX:XX:XX X:XX
time	1 min	seconds since YYYY-mm-dd XX:XX:XX X:XX
lat	1 min	degrees
lon	1 min	degrees
alt	1 min	meters above sea level

NOTE: lat/lon/alt refers to the ground where the instrument is sited, NOT the height of the sensor. The Dimension Variables are not separated out by site since these are common to all locations.

5.2 Annotated Examples

None.

5.3 User Notes and Known Problems

This section contains detailed information about known problems and issues with the sensors or system that may be of importance to the end data user. Examples of data during problems and data plots are sometimes included in order to better explain the problem. In most cases, the known problems are cases of poor data that occur due to routine maintenance, self-cleaning by sensors, etc. that affect the data quality.

- [SGP MET User Notes and Known Problems](#)
- NSA MET User Notes and Known Problems
 - [2003–2008](#)
 - [2008–present](#)
- NSA TWRC1 User Notes and Known Problems
 - [2003–2008](#)
 - [2008–present](#)
- NSA TWRC2 User Notes and Known Problems
 - [2003–2008](#)
 - [2008–present](#)
- [TWP MET User Notes and Known Problems](#)
- [AMF1 MET User Notes and Known Problems](#)
- [AMF2 MET User Notes and Known Problems](#)

5.4 Frequently Asked Questions

1. Where can SGP MET-like data be obtained for extended facilities that do not have SGP MET systems?

Several sources of surface meteorological data exist and are available as “external data” to ASR science team members. The Oklahoma Mesonet has more than 50 surface stations within the boundaries of the SGP site, the Kansas State network has 4–5 stations, and each of the boundary facilities has a surface meteorological station associated with the 404-MHz radar wind profiler operated by the National Oceanic and Atmospheric Administration. The status and contacts for external data can be found on the Web at location <http://www.arm.gov/instruments/okm>.

2. Where can I find Ultrasonic Wind Data at the NSA C1 site prior to 2008?

A Vaisala WS425 Ultrasonic wind sensor was mounted at the 2m level on the Barrow Met tower from 2003 through 2008 as a preliminary test to determine its robustness and capabilities in an arctic environment. The data from this sensor can be found here:

<https://engineering.arm.gov/tool/dod/showdod.php?Inst=mettwr4h&View=devA>.

The WS425 uses ultrasound to determine the horizontal wind speed and direction. It measures the transit time it takes for the pulse to travel from one transducer head to another. For wind speed, Vaisala quotes a starting threshold and delay distance of virtually zero, measurement range of 1 to 65 m/s, resolution of 0.1 m/s, and an accuracy of +/- 0.135 or 3% of reading (whichever is greater) over the measuring range. For wind direction, Vaisala quotes the same starting threshold and delay distance as above, a resolution of 1°, and an accuracy of +/- 2°. The maximum reading rate for this sensor is once per second.

At times the data from the Ultrasonic wind speed and direction sensor is poor due to heavy, wet snow. When this occurs the Ultrasonic sensor outputs -6999 or -9999. The datalogger attempts to convert the poor or missing data values to vector averages. As the missing or poor data may only be a few seconds in a minute the values are averaged into the minute values and show up as spikes in the data. See Figure 1 below.

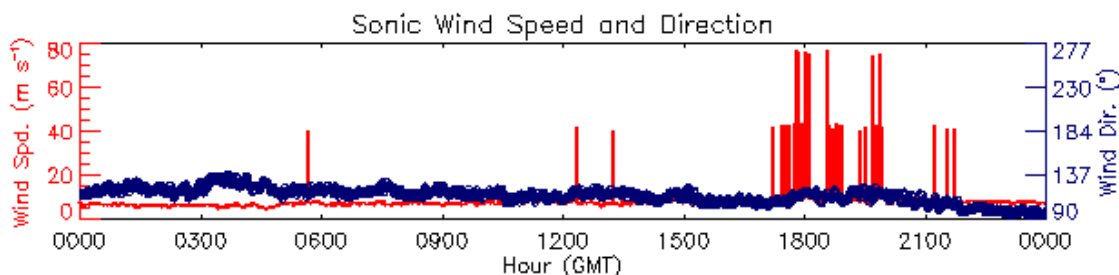


Figure 1. Ultrasonic data spikes.

6.0 Data Quality

6.1 Data Quality Health and Status

Data Quality Health and Status (DQ Hands), <http://dq.arm.gov>.

NCVweb - for interactive data plotting using, <http://dq.arm.gov/ncvweb/ncvweb.cgi>.

6.2 Data Reviews by Instrument Mentor

The Data Quality Office sends out weekly reports on each system on a weekly basis. These reports are viewed by the mentor. Any issues requiring mentor intervention or actions are handled at this time. Mentor Reports that include the Data Quality Office reports and spot checking of all systems are created monthly.

6.3 Data Assessments by Site Scientist / Data Quality Office

The ARM Data Quality Office uses the Data Quality Assessment (DQA) system to inform the ARM Site Operators, Site Scientists, and Instrument Team members of instrument and data flow problems as well as general data quality observations. The routine assessment reports are performed on the most recently collected ARM data and used with the Data Quality Problem reports tool to initiate and track the problem resolution process: <http://www.db.arm.gov/DQA/>

6.4 Value-Added Procedures and Quality Measurement Experiments

Many of the scientific needs of the Atmospheric Radiation Measurement (ARM) Climate Research Facility are met through the analysis and processing of existing data products into “value-added” products (VAPs). Despite extensive instrumentation deployed at the ARM sites, there will always be quantities of interest that are either impractical or impossible to measure directly or routinely. Physical models using ARM instrument data as inputs are implemented as VAPs and can help fill some of the unmet measurement needs of the program. Conversely, ARM produces some VAPs not to fill unmet measurement needs, but to improve the quality of existing measurements. In addition, when more than one measurement is available, ARM also produces “best-estimate” VAPs. A special class of VAP, called a Quality Measurement Experiment (QME), does not output geophysical parameters of scientific interest. Instead, a QME adds value to the input datastreams by providing for continuous assessment of the quality of the input data based on internal consistency checks, comparisons between independent similar measurements, or comparisons between measurement with modeled results, and so forth. For more information, see the VAPs and QMEs web page at <http://www.arm.gov/data/vaps>.

7.0 Instrument Details

The following detailed information about the instrument can be viewed by clicking on the appropriate link for each individual system.

- [SGP MET Instrument Details](#)
- NSA MET Instrument Details
 - [2003–2008](#)
 - [2008–present](#)
- NSA TWRC1 Instrument Details
 - [2003–2008](#)
 - [2008–present](#)
- NSA TWRC2 Instrument Details
 - [2003–2008](#)
 - [2008–present](#)
- [TWP MET Instrument Details](#)

- [AMF1 MET Instrument Details](#)
- [AMF2 MET Instrument Details](#)

7.1 Operation and Maintenance

7.1.1 User Manual

Users can click on the following links in order to view the very detailed User Manual for each system. These user manuals contain information such as wiring diagrams, calibration procedures, daily and weekly checks. Examples of the program that resides on the data logger and setup procedures are also located here.

- [SGP MET User Manual](#)
- [NSA C1 MET & TWR User Manual](#)
- [NSA C2 MET & TWR User Manual](#)
- [TWP MET User Manual](#)
- [AMF1 MET User Manual](#)
- AMF2 MET User Manual (not available)

7.1.2 Software Documentation

ARM netCDF file header descriptions may be found for each of the systems can be found by following the link below

- <https://engineering.arm.gov/tool/dod/showdod.php?Inst=met&View=dev>

7.1.3 Additional Documentation

This section is not applicable to this instrument.

7.2 Glossary

Barometric pressure: Local station pressure measured at station at a height of 1 m.

Relative humidity: Percentage of saturated vapor pressure at the specified temperature.

Vector-averaged wind speed: Wind speed computed as the vector sum of the orthogonal u and v components that are computed for each sample of wind speed and direction. The wind directions reported are determined from the vector-averaged winds.

Wind Monitor: Trade name for R.M. Young propeller anemometer and wind vane.

See the ARM Glossary at <http://www.arm.gov/about/glossary>.

7.3 Acronyms

AC	alternating current
A/D	Analog to Digital converter
CMH	chilled mirror hygrometer
DQA	Data Quality Assessment
DQO	Data Quality Office
NIST	National Institute of Standards and Technology
QME	Quality Measurement Experiment
RH	Relative Humidity
rms	root mean square
SGP	Southern Great Plains
T/RH	temperature/relative humidity (sensor)
VAP	value-added product
TBRG	tipping bucket rain gage
ORG	optical rain gauge
PWD	Present Weather Detector
PWS	Present Weather Sensor

Also see the ARM Acronyms and Abbreviations at <http://www.arm.gov/about/acronyms>.

7.4 Citable References

None.



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