ARM TR-030

Temperature, Humidity, Wind, and Pressure System Handbook

January 2005

Atmospheric Radiation Measurement Climate Research Facility
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1. General Overview

The temperature, humidity, wind, and pressure systems (THWAPS) provide surface reference values of these measurements for balloon-borne sounding system (BBSS) launches. THWAPS are located adjacent to BBSS launch sites at the Southern Great Plains (SGP) Central Facility and its four boundary facilities. The THWAPS system is a combination of calibration-quality instruments intended to provide accurate measurements of meteorological conditions near the surface. Although the primary use of the system is to provide accurate surface reference values of temperature, pressure, relative humidity (RH), and wind velocity for comparison with radiosonde readings, the system includes a data logger to record time series of the measured variables.

The THWAPS system is not generally used as a surface meteorological measurement system. Many of the variables measured do not conform to WMO standards for surface meteorological measurements. Instead, the THWAPS system is used to gather reference values for the Balloon Borne Sounding System (BBSS) at the SGP ACRF sites.

2. Contacts

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2.2 Instrument Developer

Data logger
Campbell Scientific Inc.
815 W. 1800 N.
Logan, UT 84321
Phone: (801) 753-2342
Fax: (801) 750-9540
Website: http://www.campbellsci.com

Aspiration 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/

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

3. Deployment Locations and History

THWAPS is located at the SGP site in Oklahoma at the following SGP facilities:

Table 1.

Location	Date Installed	Date Removed	Status
B1-Hillsboro, KS	1998/04/16		operational
B4-Vici, OK	1998/04/17		operational
B5-Morris, OK	1998/04/21		operational
B6-Purcell, OK	1998/04/20		operational
C1-Lamont, OK	1996/09/10		operational

4. Near-Real-Time Data Plots

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

- http://www.nsdl.arm.gov/Visualization/quicklook_interface.shtml
- http://www.nsdl.arm.gov/Visualization/ncvweb.shtml

5. Data Description and Examples

5.1 Data File Contents

5.1.1 Primary Variables and Expected Uncertainty

Table 2.

Quantity	Variable	Unit	Measurement Level	Measurement Interval	Resolution
Pressure	pres	hPa	1 m	5 min	0.1
Temperature	temp	C	1 m	5 min	0.1
RH	RH	%	1 m	5 min	1
Vapor Pressure	vap_pres	kPa	1 m	5 min	0.001
Mean Wind Speed	wspd	m/s	5 m	5 min	0.1

Table 2. (cont'd)

Quantity	Variable	Unit	Measurement Level	Measurement Interval	Resolution
Unit Vector Wind Direction	wdir	deg	5 m	5 min	1
Standard Deviation of Wind Direction	sd_wdir	deg	5 m	5 min	1

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,

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

(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.

5.1.2 Secondary/Underlying Variables

None.

5.1.3 Diagnostic Variables

Table 3.

Quantity	Variable	Measurement Interval
Standard Deviation of Pressure	sd_pres	5 min
Standard Deviation of Temperature	sd_temp	5 min
Standard Deviation of Relative Humidity	sd_rh	5 min
Standard Deviation of Vapor Pressure	sd_vap_pres	5 min
Battery Voltage	vbat	5 min

5.1.4 Data Quality Flags

Quality Check Results on:

Table 4.

Quantity	Variable	Measurement Interval	Min	Max	Delta
Sample Time	qc_time	5 min			
Pressure	qc_pres	5 min	800	1100	n/a
Temperature	qc_temp	5 min	-40	50	n/a
Relative Humidity	qc_rh	5 min	-2	104	n/a
Vapor Pressure	qc_vap_pres	5 min	0	10	n/a
Mean Wind Speed	qc_wspd	5 min	0	45	n/a
Unit Vector Wind Direction	qc_wdir	5 min	0	360	n/a
Standard Deviation of Wind Direction	qc_sd_wdir	5 min	0	90	n/a
Standard Deviation of Pressure	qc_sd_pres	5 min	0	N/A	n/a
Standard Deviation of Temperature	qc_sd_temp	5 min	0	2	n/a
Standard Deviation of Relative Humidity	qc_sd_rh	5 min	0	20	n/a
Standard Deviation of Vapor Pressure	qc_sd_vap_pres	5 min	0	N/A	n/a
Battery Voltage	qc_vbat	5 min	9.6	16	n/a

5.1.5 Dimension Variables

Table 5.

Quantity	Variable	Measurement Interval	Unit
Base time in Epoch	base_time	5 min	seconds since YYYY-mm-dd XX:XX:XX X:XX
Time offset from base_time	time_offset	5 min	seconds since YYYY-mm-dd XX:XX:XX X:XX
Time offset form midnight	time	5 min	seconds since YYYY-mm-dd XX:XX:XX X:XX

Table 5. (cont'd)

Quantity	Variable	Measurement Interval	Unit
north latitude	lat	5 min	degrees
east longitude	lon	5 min	degrees
Altitude	alt	5 min	meters above sea level

NOTE: lat/lon/alt refers to the ground where the instrument is sited, NOT the height of the sensor.

5.2 Annotated Examples

None.

5.3 User Notes and Known Problems

Currently, the THWAPS systems at the four boundary facilities (BF 1, 4, 5, and 6) have incorrect multipliers in the Datalogging program and incorrect calibrations in the Vaisala electronics and data display. The systems at these sites will not record RH% values greater than 100%.

The boundary facility calibrations and datalogging program were changed on the following dates to correct for the incorrect claibrations and multipliers on:

B1 on 08/01/2005 @ 2034 GMT
B4 on 07/30/2005 @ 1722 GMT
B6 on 07/30/2005 @ 2355 GMT
B5 on 07/31/2005 @ 1714 GMT

The program correction was made to the vapor pressure multiplier from .2241 to .2441. This error in multiplier only translates to an error of 0.01 kPa which is well within the uncertainty of the sensor. The calibration error forced the probe to output a maximum of 1V translating to 100%. This did not allow the sensor to overrange as is possible with this sensor and accuracy. Removal of this artificial ceiling will allow for an increased ability to determine a failing sensor.

5.4 Frequently Asked Questions

None.

6. 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

None.

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://dq.arm.gov/weekly_reports/weekly_reports.html

6.4 Value-Added Procedures and Quality Measurement Experiments

Many of the scientific needs of the Atmospheric Radiation Measurement (ARM) Program are met through the analysis and processing of existing data products into "value-added" products or 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 data streams 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.stm.

7. Instrument Details

7.1 Detailed Description

7.1.1 List of Components

Wind speed and direction sensor: Propeller anemometer and wind vane, R.M. Young Model 05103 Wind Monitor

Temperature and relative humidity sensor: Vaisala HMP233 Series Transmitters

Barometric pressure sensor: Digital barometer, Vaisala Model PTB201A

Data logger: Campbell Scientific Model CR10 Measurement & Control Module and Model SM716 Storage Module, Precision: A function of input type and range, Uncertainty: 0.2% of Full-Scale Range for Analog Inputs.

7.1.2 System Configuration and Measurement Methods

The THWAPS system is intended to be used as a ground reference point for radiosonde launches. Therefore, displays are required for the radiosonde operators in addition to the data logger. The temperature and relative humidity (T/RH) sensor is mounted at a height of 1 m. The analog outputs (i.e., T/RH) of the display module are connected to digital displays mounted in the BBSS trailer. The PTB201 barometer is also located in the trailer and is vented to the outside. The wind monitor is mounted on a mast on the BBSS trailer at a height of 5 m.

The wind monitor propeller anemometer produces a magnetically controlled AC output whose frequency is proportional to the wind speed. The Wind Monitor direction vane drives a potentiometer, which is part of a resistance bridge.

The T/RH sensor head is mounted in an R.M. Young Model 43408 Gill Aspirated Radiation Shield. The T/RH electronics, power, and display module (HMP233) is mounted in an enclosure nearby. The temperature RTD is part of a resistance bridge. The Vaisala RH circuitry produces a voltage that is proportional to the capacitance of a water vapor absorbing, thin polymer film.

The barometric pressure sensor uses a silicon capacitive pressure sensor and is housed in a weatherproof enclosure along with a data logger, a storage module, and serial communications equipment; all are mounted at a height of 1 m.

The data logger measures each input once every 3 s. The vapor pressure is computed from the air T/RH. The data logger produces 5-min averages of wind speed, vector-averaged wind speed, vector-averaged wind direction, air temperature, RH, vapor pressure, and barometric pressure. The standard deviations of wind direction, temperature, RH, barometric pressure, and vapor pressure are also calculated.

7.1.3 Specifications

Wind speed at 5 m, Precision: 0.01 m/s; Uncertainty: +/-1% for 2.5 to 30 m/s

Wind direction at 5 m, Precision: 0.1°; Uncertainty: +/-5°

Air temperature at 1 m, Precision: 0.01 C; Uncertainty: a function of wind speed

RH at 1 m, Precision: 0.1% RH; Uncertainty: +/-2.06% RH (0% to 90% RH), +/-3.04% RH (90% to 100% RH)

Barometric pressure at 1 m, Precision: 0.01 kPa; Uncertainty: +/-0.035 kPa

Data Acquisition Errors
The Campbell Scientific CR10 A/D converter accuracy is +/-0.2 % of full-scale range. The time base accuracy is +/-1 min per month, or about 23 ppm. The Site Data System checks the time-of-day clock once per day and corrects the THWAPS clock if it is off by more than a minute.

Wind Speed
The National Institute of Standards and Technology (NIST) calibration uncertainty is specified as +/-1% for wind speeds from the sensor threshold to 30 m/s. The conversion error is negligible. The schedule of routine maintenance and sensor verification is designed to eliminate any long-term stability error.

The sensor threshold is specified as 1 m/s. The following estimates of the range of underestimation caused by the threshold assume a normal distribution of wind speeds about the mean. When the true wind speed is 1.0 m/s, the winds will be below the threshold 50% of the time. This will result in an underestimate of 0.5 m/s. When the true wind speed is 1.5 m/s, assuming the standard deviation will be between 0.25 and 1.00 m/s, the winds will be below the threshold between 2 and 31% of the time. This will result in an underestimate between 0.02 and 0.23 m/s. When the true wind speed is 2.0 m/s with a range of standard deviations between 0.25 and 1.00 m/s, the winds will be below the threshold between 0 and 16% of the time. This will result in an underestimate between 0 and 0.12 m/s.

If the reported wind speed is 0.5 m/s, an underestimate of 0.5 is probable. This would bias the measurement by -0.5. If the reported wind speed is 1.0 m/s, an underestimate of 0.19 to 0.30 m/s is possible. If the reported wind speed is 1.5 m/s, an underestimate of 0.02 to 0.20 m/s is possible. If the reported wind speed is 2.0 m/s, an underestimate of 0 to 0.10 m/s is possible.

The uncertainty range with 95% confidence is approximately:

+/- 1%	for a reported wind speed from 2.5 to 30.0 m/s
-0.12 to +0.02 m/s	for a reported wind speed of 2.0 m/s
-0.22 to +0.00 m/s	for a reported wind speed of 1.5 m/s
-0.31 to -0.20 m/s	for a reported wind speed of 1.0 m/s
-0.51 to -0.49 m/s	for a reported wind speed of 0.5 m/s

Wind Direction
The sensor accuracy is specified as +/-3°. The Analog to Digital Converter (A/D) conversion accuracy is equivalent to +/- 0.7° over a temperature range of 0 to 40°C for a period of one year. The sensor alignment to true north has been estimated to be accurate within +/-3°. The uncertainty with 95% confidence is, therefore, approximately +/-5°.

Temperature
The accuracy of the temperature measurement is specified as +/-0.4 C. Included in this accuracy are sensor interchangeability, bridge resistor precision, and polynomial curve fitting errors. The long-term stability is not known.

The radiation error of the aspirated radiation shield is specified as +/- 0.2 C rms. The uncertainty with 95% confidence of temperature sensors in this radiation shield is, therefore, +/- 0.57 C.

Relative Humidity
The accuracy of the sensor is specified as +/-2% RH for 0 to 90% RH, and +/-3% RH for 90 to 100% RH. Errors considered in this accuracy are calibration uncertainty, repeatability, hysteresis, temperature dependence, and long-term stability over a period of one year. The A/D conversion accuracy is equivalent to +/-0.5% RH.

The uncertainty with at least 95% confidence is, therefore,

+/-2.06 % RH, 0 to 90 % RH
+/-3.04 % RH, 90 to 100 % RH

Barometric Pressure
The manufacturer's technical data contains an uncertainty analysis. Errors included in their analysis are linearity, hysteresis, calibration uncertainty, repeatability, temperature dependence, and long-term stability over a period of one year. Because the sensor has a digital output, no conversion error occurs in the Campbell data logger.

The specified uncertainty with 95% confidence is +/-0.035 kPa.

7.2 Theory of Operation

The THWAPS system is a combination of calibration-quality instruments intended to provide accurate measurements of meteorological conditions near the surface. Although the primary use of the system is to provide accurate surface reference values of temperature, pressure, RH, and wind velocity for comparison with radiosonde readings, the system includes a data logger to record time series of the measured variables.

7.3 Calibration

7.3.1 Theory

The THWAPs have not been calibrated. Work is in progress on creating a 6-month calibration procedure.

7.3.2 Procedures

This section is not applicable to this instrument.

7.3.3 History

This section is not applicable to this instrument.

7.4 Operation and Maintenance

7.4.1 User Manual

This section is not applicable to this instrument.

7.4.2 Routine and Corrective Maintenance Documentation

This section is not applicable to this instrument.

7.4.3 Software Documentation

ARM netCDF file header descriptions may be found for THWAPS at http://science.arm.gov/tool/dod/showdod.php?Inst=thwaps.

7.4.4 Additional Documentation

This section is not applicable to this instrument.

7.5 Glossary

Barometric pressure: Local station pressure measured at the THWAPS 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 which are computed for each three-second sample of wind speed and direction. The wind directions reported by the THWAPS 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.stm.

7.6 Acronyms

AC	alternating current
A/D	Analog to Digital converter
BBSS	balloon-borne sounding system
DQA	Data Quality Assessment
NIST	National Institute of Standards and Technology
QME	Quality Measurement Experiment
RH	Relative Humidity
rms	root mean square
SGP	Southern Great Plains
THWAPS	Temperature, Humidity, Wind, and Pressure System
T/RH	temperature/relative humidity (sensor)
VAP	value-added product

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

7.7 Citable References

None.