ARM TR-050

Tower Temperature and Humidity Sensors Handbook

January 2005

Atmospheric Radiation Measurement
Climate Research Facility
U.S. Department of Energy

Work supported by the U.S. Department of Energy
Office of Science, Office of Biological and Environmental Research

ARM TR-050

Towers Instrument Handbook

January 2005

D.R. Cook

Work supported by the U.S. Department of Energy,
Office of Science, Office of Biological and Environmental Research

Contents

Figures

Tables

1. General Overview

Three tall towers are installed at Atmospheric Radiation Measurement Climate Research Facility (ACRF) sites: a 60-m triangular tower at the Southern Great Plains (SGP) Central Facility (CF), a 21 m walkup scaffolding tower at the SGP Okmulgee forest site (E21), and a 40-m triangular tower at the North Slope of Alaska (NSA) at Barrow. The towers are used for meteorological, radiological, and other measurements. Instrument systems installed on the towers are listed in section 7, Instrument Details, although only the Temperature/Relative Humidity/Vapor Pressure (T/RH/VP) measurements made on the SGP CF tower are described in detail. Information on measurements made by the other instrument systems on the towers can be found at individual instrument systems web pages. Photographs of each tower are shown Figures 1-3.

Figure 1. NSA Barrow 40-m Tower

Figure 2. Southern Great Plains Central Facility 60-m Tower

Figure 3. Southern Great Plains Okmulgee 21-m Tower

2. Contacts

2.1 Mentor

David R. Cook
Environmental Research Division
Argonne National Laboratory, Bldg. 203
Argonne, Illinois 60439
Phone: (630) 252-5840
Fax: (630) 252-5498
drcook@anl.gov

2.2 Instrument Developer

The three towers were provided by different tower manufacturers and installers. For more information on the tower manufacturers and installers than is provided in the text and table below, please contact the tower mentor. For information on the vendors of the individual instrument systems mounted on the NSA and SGP Okmulgee towers, please contact the mentors for those instrument systems. Each tower receives a thorough inspection every two years; this inspection is conducted by Tower Systems, Inc. for the SGP CF and NSA Barrow towers, and by the mentor for the SGP Okmulgee tower.

The vendors for the T/RH probes, aspirators, and datalogger equipment on the SGP CF 60-m tower are:

T/RH: Vaisala, Inc. on the west and southeast elevators, 25-m and 60-m levels. Platinum Resistance Temperature Detector (PRTD) temperature: inco Products, Inc. on the west elevator 25-m and 60-m levels. Aspirators: Qualimetrics, Inc. on the west elevator 25-m and 60-m levels; R.M. Young, Inc. on the southeast elevator, 25 m and 60 m levels.

Flow Sensors: Qualimetrics, Inc. on the west elevator 25-m and 60-m levels.

Dataloggers: Campbell Scientific CR21X dataloggers were used for the west side measurements until about 2001; CR10X dataloggers have been used since then. A CR10X datalogger has been used for the east side measurements since their inception in 1996.

Note: Qualimetrics, Inc. T/RH probes were used on the west elevator levels until September 1996. They were inadequate and inaccurate. All west elevator T/RH data from 1993 through August 1996 is of questionable quality.

3. Deployment Locations and History

Table 1.

ARM ACRF	Location	Tower Structure	Manufacturer	Installer	Date Installed
NSA	Barrow, AK	44-in triangular	Sabre Communications, Inc.	Tower Systems, Inc.	May 1997
SGP	Central Facility, (Lamont, OK)	42-in triangular	Rohn, Inc.	Tower Systems, Inc.	December 1992
SGP	Okmulgee, OK	aluminum scaffolding	UpRight, Inc. (provided by Horizon High Reach, Inc.)	East Coast Rigging and Contracting Company, Inc.	July 1997

4. Near-Real-Time Data Plots

To view near real time plots of data from instrument systems on the towers, visit the NCV web site at http://dq.arm.gov/ncvweb/ncvweb.cgi.

5. Data Description and Examples

5.1 Data File Contents (SGP CF 60-m tower only)

Only data from the T/RH/VP measurements made on the SGP CF 60-m tower are described below. Although the tower was erected in December 1992, T/RH instruments were not installed until March 1993. For other measurements made on this tower or on the SGP Okmulgee and NSA 40-m towers, see the web sites of the individual instrument systems.

5.1.1 Primary Variables and Expected Uncertainty

West elevator, 25-m level (sgp1twr25m, sgp30twr25m datastreams):

1 and 30 minute:
Temperature (temp): +/- 0.2°C
Relative humidity (rh): +/- 2% (0-90% RH), +/- 3% (90-100% RH)
Vapor Pressure (vap_pres)

West elevator, 60-m level (sgp1twr60m, sgp30twr60m datastreams):

1 and 30 minute:
Temperature (temp): +/- 0.2°C
Relative humidity (rh): +/- 2% (0-90% RH), +/- 3% (90-100% RH)
Vapor Pressure (vap_pres)

Southeast elevator, 25-m and 60-m levels (sgp1twr10x, sgp30twr10x datastreams):

1 and 30 minute:
Temperature (temp_25m, temp_60m): +/- 0.2°C
Relative humidity (rh_25m, rh_60m): +/- 2% (0-90% RH), +/- 3% (90-100% RH)
Vapor Pressure (vap_pres_25m, vap_pres_60m)

Notes: Vapor pressure is calculated from the temperature and relative humidity measurements. Uncertainties have not been provided by the sensor manufacturers; therefore, T and RH accuracies provided by the manufacturer have been quoted instead.

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

This section is not applicable to this instrument.

5.1.3 Diagnostic Variables

West elevator, 25-m level (sgp1twr25m, sgp30twr25m datastreams):

1 minute:
Aspirator status (aspirator)
Battery voltage (vbat)

30 minute:
Standard deviation of temperature (sd_temp)
Standard deviation of relative humidity (sd_rh)
Standard deviation of vapor pressure (sd_vap_pres)
Aspirator status (aspirator)

West elevator, 60-m level (sgp1twr60m, sgp30twr60m datastreams):

1 minute:
Aspirator status (aspirator)
Battery voltage (vbat)

30 minute:
Standard deviation of temperature (sd_temp)
Standard deviation of relative humidity (sd_rh)
Standard deviation of vapor pressure (sd_vap_pres)
Aspirator status (aspirator)

Southeast elevator, 25-m and 60-m levels (sgp1twr10x, sgp30twr10x datastreams):

1 minute:
Battery voltage (vbat)

30 minute:
Standard deviation of 25 m temperature (sd_temp_25m)
Standard deviation of 25 m relative humidity (sd_rh_25m)
Standard deviation of 25 m vapor pressure (sd_vap_pres_25m)
Standard deviation of 60 m temperature (sd_temp_60m)
Standard deviation of 60 m relative humidity (sd_rh_60m)
Standard deviation of 60 m vapor pressure (sd_vap_pres_60m)

Note: The aspirator status levels for the west elevator are set in the CR10X datalogger programming to a level that will always indicate that the aspirators are working. It was found that a reliable indication of aspirator status was not possible with the long cable lengths on the tower. Therefore, the aspirator status diagnostic variable is of no practical use; it is maintained only to preserve the datastream form used since the T/RH system was installed in 1993.

5.1.4 Data Quality Flags

West elevator, 25-m level (sgp30twr25m datastream):

30 minute:
qc_temp
qc_rh
qc_vap_pres
qc_aspirator

West elevator, 60-m level (sgp30twr60m datastream):

30 minute:
qc_temp
qc_rh
qc_vap_pres
qc_aspirator

Southeast elevator, 25-m and 60-m levels (sgp30twr10x datastream):

30 minute:
qc_temp_25 m
qc_rh_25 m
qc_vap_pres_25 m
qc_temp_60 m
qc_rh_60 m
qc_vap_pres_60 m

5.1.5 Dimension Variables

Note: lat, lon, and alt refer to the ground surface, not to the instrument system height

1 and 30 minute:
lat
lon
alt
base_time
time_offset

5.2 Annotated Examples

The following plots (Figures 4-6) of 25-m and 60-m temperature, relative humidity, and vapor pressure on August 1 and 2, 2004, show normal diurnal variations for summertime. During nighttime hours, a temperature inversion sets up, resulting in a reversal in sign of the daytime relative humidity profile. Note the lack of dependence of vapor pressure on temperature and relative humidity.

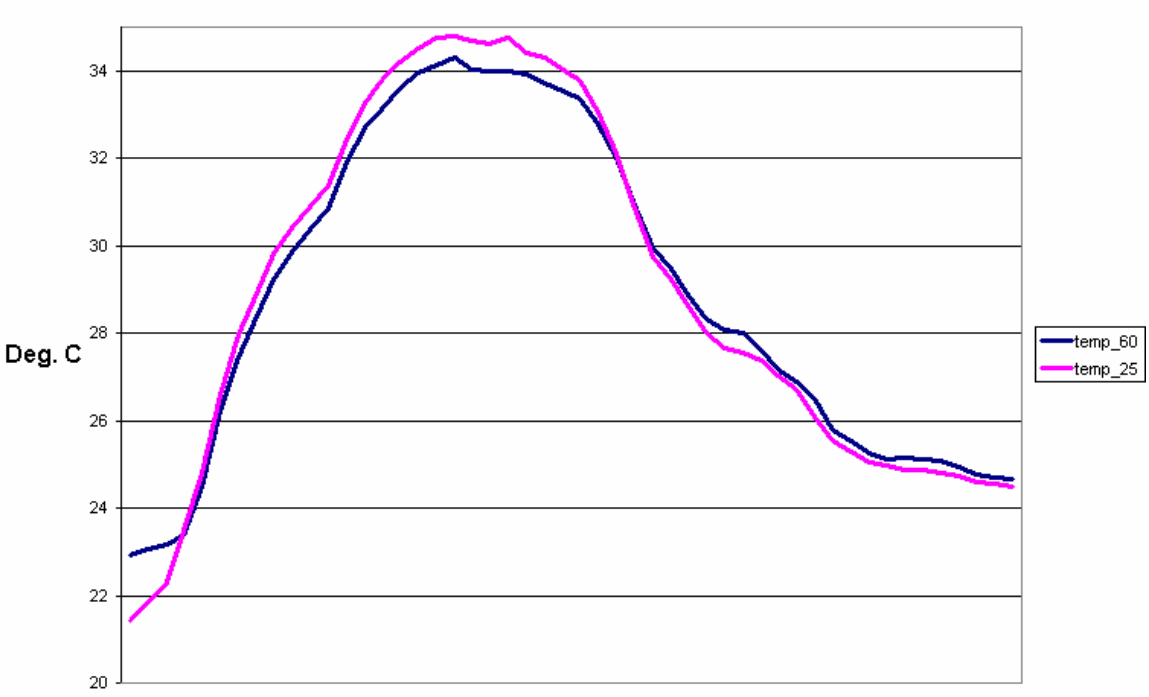

Figure 4. Southeast Site Temperature

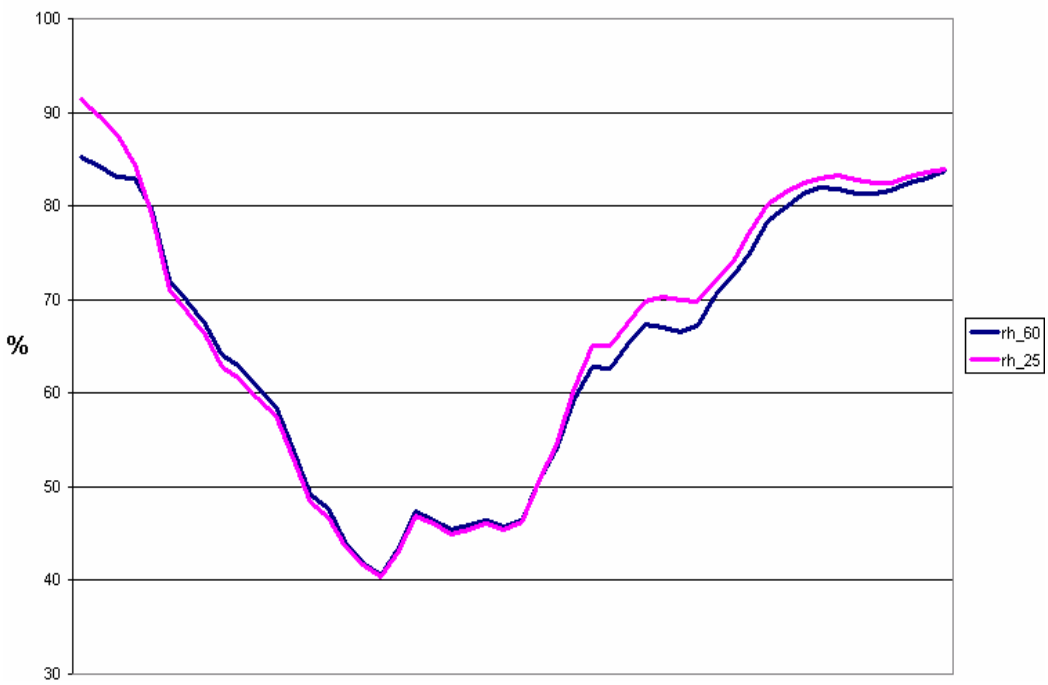

Figure 5. Southeast Side Relative Humidity

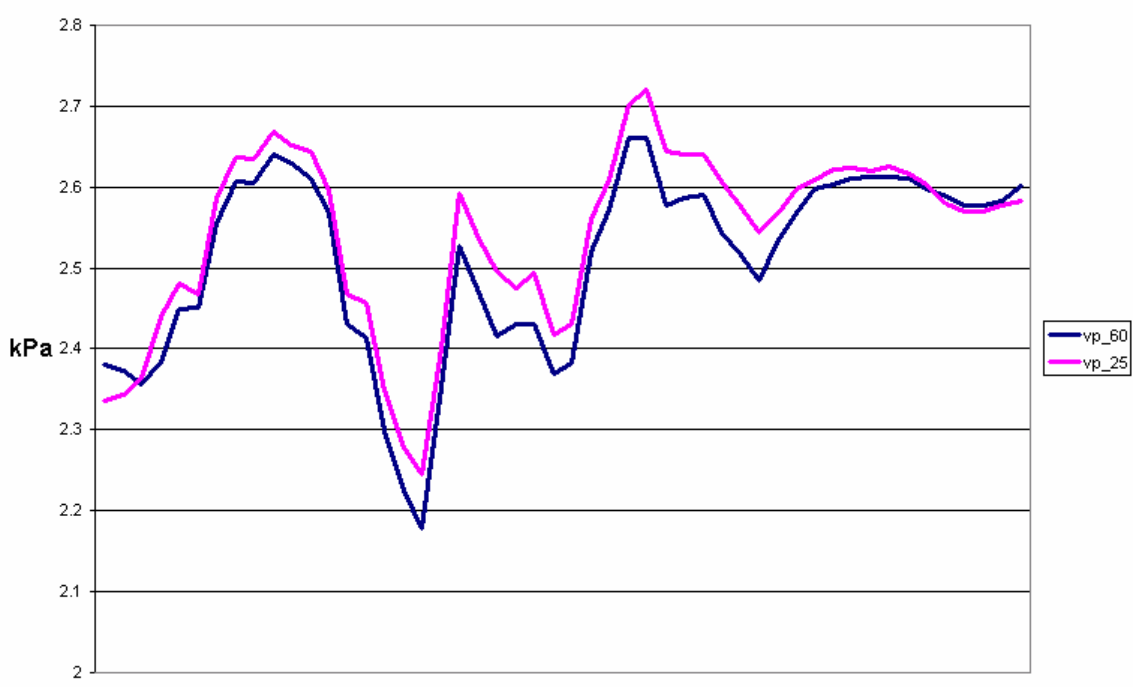

Figure 6. Southeast Side Vapor Pressure

5.3 User Notes and Known Problems

The elevator systems used on the SGP CF 60-m tower and the NSA Barrow 40-m tower are fairly robust, but the receiver brackets on the SGP CF tower have at times bent under frequent use. This causes a loss of ability to make an electronic connection between an elevator carriage connector and the tower receiver and therefore some data loss. Maintenance by the installer has been required to fix this problem on several occasions. Fortunately, this situation has not happened at the NSA Barrow tower yet.

There were significant periods of poor relative humidity measurements on the SGP CF tower before September 1996, when the Qualimetrics probes that were in use on the west elevator system did not have the correct conversion to engineering units in the datalogger programming. Much of this stemmed from incorrect calibrations performed by the manufacturer. These inconsistencies were normally discovered in the data after installation of the relative humidity probe. Sometimes this was recognized during the six-month calibration, and the calibration was adjusted in the datalogger programming. However, at times, these adjustments have only corrected the data below about 90% relative humidity, with no sensitivity resulting for relative humidity above 90%. One reason for this has been determined to be the calibration procedure used by the manufacturer, who calibrated the sensors at three relative humidities, but did not check the performance at 0% or 97%. Since the sensor is less linear above 90%, a check above 90% must be used to ensure that the slope has been properly set for the entire operating range of the sensor. Since September 1996, Vaisala, Inc. HMP35D or HMP45D T/RH probes have been used on the tower; these sensors are sent to Vaisala, Inc. for calibration annually. Each RH probe is now replaced and recalibrated annually. The Vaisala Inc. probes do not usually exhibit any abnormal characteristics. However, the Vaisala, probes installed on the west side of the tower in August 2003 had an abnormally high RH bias, which ramped up to 13% excess RH at 60 m on the west elevator after a few months. This probe had to be replaced to ensure accurate measurements.

Temperature comparisons between the southeast and west sensors on the SGP CF tower can show some differences. Strong solar heating can cause the west side temperatures to be slightly higher than the southeast side temperatures and the west side relative humidities to be lower than the southeast side humidities. This is most frequently seen during the summer.

The connections between the SGP CF tower west side tower instruments at 25 m and 60 m and the dataloggers were accidentally reversed from May 19, 1999, until September 20, 2000, (see discussion in DQR D001011.1). This caused measurements from 25 m to be recorded in datastreams, files, and data fields labeled as 60 m, and vice versa. Because the data values were valid measurements, but were labeled incorrectly, it was difficult to identify this error during data analysis. The data have been reprocessed and placed at the correct levels; the corrected data are found in the ARM archive.

The sensors on the NSA Barrow tower are subject to freeze-up at times during the winter. Rime ice easily builds up on the instrumentation, causing blocking of the inlet to the T/RH probes and interference of the measurements of the chilled mirror hygrometer, present weather sensor, and sonic anemometer. The wind speed and direction sensors on the tower are heated and therefore do not ice up.

The SGP Okmulgee tower is situated in a forest and is therefore subject to vulture roosting. The bird poop caused a deterioration of a number of measurements, including radiometry, precipitation, sonic anemometry, etc. Numerous deterrents were tried without much success until bird spikes and rotating shafts were installed; these have worked well since early 2004.

The original booms on the SGP Okmulgee tower were difficult to operate. Therefore, new booms manufactured by Tower Systems, Inc. were installed in 2003 and have worked much better. Frequently Asked Questions

1. **What does the aspirator value represent?**

   The aspirator status value on the west side of the SGP CF tower indicates whether aspiration of the T/RH and PRTD probes is sufficient to produce quality measurements of temperature and relative humidity. The aspiration rate must exceed a certain value to prevent errors from sensor heating of the sensors by solar radiation impinging on the aspirator radiation shield. A complication prevents the aspirator value from accurately indicating aspiration status; long cable lines on the tower introduce the need to use a marginal limit value for aspiration status in the datalogger program that serves the tower temperature and relative humidity system. Therefore, wind speeds in excess of 10 m per second are used to (before 24 May 1996) produce a false aspirator status indication. A change in the aspiration limit value in the CR10X programs has effectively resulted in aspiration status being continuously good. See the discussion of this issue in the note at the bottom of section 5.1.3.

2. **Which measurements are the most accurate, from the southeast side or from the west side?**

   Data users are generally advised to use the southeast side measurements, unless only the west side measurements are available or correct. This is because the aspiration and radiation shielding of the probes on the southeast side is usually better than on the west side. The aspiration rate of the aspirators on the west side is barely adequate, resulting in west side temperatures being up to a degree too high and therefore relative humidities being too low during low wind and high solar radiation conditions, particularly during the summer.

6. Data Quality

6.1 Data Quality Health and Status

The status of the measurements made by the T/RH/VP system on the SGP CF tower can be found by going to the ARM Data Quality (DQ) HandS web site at dq.arm.gov/cgi-bin/dqmenu.pl.

6.2 Data Reviews by Instrument Mentor

Monthly reviews of the SGP CF tower T/RH/VP data are prepared by the mentor and posted here.

6.3 Data Assessments by Site Scientist/Data Quality Office

The Data Quality Office performs checks of SGP CF tower T/RH/VP data quality and prepares a weekly report. The mentor reviews the report and the data and makes suggestions for changes, additions, or deletions to the weekly report.

6.4 Value-Added Procedures (VAPs) and Quality Measurement Experiments

Tower-related VAPs, or VAPs that use SGP CF tower data as input, include:

TWRMR (computes water vapor mixing ratio at the surface and at the 25-m and 60-m tower levels; needed as input to RL PROF MR, and hence RLPROF BE)

RLPROF suite, specifically **RLPROF MR** (25-m and 60-m level tower in situ measurements of moisture are used as input)

Tower-related QMEs, or QMEs that use tower data as input, include:

QMEAERIPROF (25-m and 60-m tower in situ measurements of temperature and vapor pressure are used as inputs)

7. Instrument Details

7.1 Detailed Description

7.1.1 List of Components

SGP CF 60-m Tower:

Vaisala HMP35D or HMP45D T/RH probes (west side at 25 m and 60 m, east side at 25 m and 60 m), in aspirators.

Minco Products Inc., Model S853PD60X72 100 ohm PRTD temperature probes at 25 m and 60 m on the west side, in aspirators.

Qualimetrics, Inc. Model 8151-B motorized aspirated radiation shield with Qualimetrics, Inc. Model T450009 flow sensor at 25 m and 60 m on the west side.

R. M. Young Model 43408/43482 motor aspirated radiation shield at 25 m and 60 m on the southeast side.

Campbell CR10X dataloggers, and communication interface equipment; one each per 25 m west level, 60 m west level, southeast side.

Infrared Thermometer (IRT), upwelling, 25 m, southeast side.

Multi-Filter Radiometer (MFR), upwelling, 25 m, southeast side.

Global Positioning System (GPS) repeater antenna, 60 m, southeast side.

Precision Gas System (PGS), attached to tower structure at 2, 4, 25 and 60 m, north side.

Carbon Dioxide Flux Measurement Systems (CO_2FLX), 25 m and 60 m, west side.

SGP Okmulgee 21-m Tower (see individual instrument system sites for details):

Surface Meteorological Observation Station (SMOS)
Eddy Correlation System (ECOR)
Solar and Infrared Station (SIRS)

NSA Barrow 40-m Tower (see Barrow meteorology station [BMET] web site at www.arm.gov/instruments/static/bmet.stm for more details):

Technical Services Laboratory, Inc. Model 1088 chilled mirror hygrometer at 3 m, attached to the north leg of the tower. (previously, Meteolabor AG VTP6 Ventilated Thermohygrometer chilled mirror hygrometer at 3 m, attached to the north leg of the tower, removed in October 2003).

Vaisala, Inc. FD12P present weather sensor measures visibility, precipitation, and precipitation type at 2 m, located south of the tower.

Vaisala, Inc. WS425 sonic anemometer at 2 m, northeast side.

Vaisala, Inc. HMP45D T/RH probes measure T/RH/VP/Dew Point at 2, 10, 20, and 40 m, northeast side.

Vaisala, Inc. WAA251 cup anemometers with heated cups and shafts measure wind speed at 2, 10, 20, and 40 m, northeast side.

Vaisala, Inc. WAV251 wind vanes with heated shafts measure wind direction at 2, 10, 20, and 40 m, northeast side.

Vaisala, Inc. PTB-201A digital barometer measures station atmospheric pressure at 1.5 m, located in an enclosure on the northwest side of tower.

Scientific Technology, Inc. ORG-815-DR optical precipitation sensor attached to the southeast leg of the tower at 3 m (removed from service in October 2003).

Vaisala, Inc. QLI50 sensor collectors used at 2, 10, 20, and 40 m to convert wind speed, wind direction, temperature, and relative humidity signals to digital data.

Vaisala, Inc. WHP25 power supplies used at 2, 10, 20, 40 m to service the sensor collectors and instrumentation.

Campbell Scientific, Inc. CR23X datalogger, multiplexer, and communication equipment, located in an enclosure on the northwest side of the tower.

Camera that takes photographs of the tundra surface south of the tower, installed at 40 m, south side.

7.1.2 System Configuration and Measurement Methods

Duplicate sets of instrumentation are used at heights of 25 m and 60 m on the SGP Central Facility 60-m tower. The probes and aspirated radiation shields are mounted on both the west and southeast elevator systems. A separate Campbell CR10X datalogger (previously, CR21X datalogger) is used for each level on the west elevator to measure sensor outputs, perform conversions to engineering units, and provide serial output for the remote collection of data from the datalogger memory. The same functions are accomplished for both levels on the southeast elevator with one CR10X. The meteorological measurements made with the system are:

Air temperature at two heights (25 m and 60 m)
Relative humidity at two heights (25 m and 60 m)
Aspiration status (west elevator only)

7.1.3 Specifications

The accuracies cited below for the meteorological sensors on the SGP CF 60-m tower are generally those stated by the manufacturer. They are sensor absolute accuracies and do not include the effects of system (i.e., datalogger) accuracies. Although it is not known how some of the manufacturers have determined sensor accuracy, it is properly the root square sum of any nonlinearity, hysteresis, and non-repeatability, usually referenced as percentage of full scale.

The detection limit is normally restricted to the range (sometimes called Calibrated Operating Range) over which the accuracy applies. Some manufacturers also specify an Operating Temperature Range in which the sensor will physically and electronically function, even though the calibration may not be appropriate for use throughout that range. When no detection limits have been listed by the manufacturer, none are stated below.

West Elevator:

Air temperature: Platinum Resistance Temperature Detector (PRTD), 100 ohm, Minco Products Inc., Model S853PD60X72; Detection Limits -30 to 40°C; Operating Temperature Range -40 to 50°C; Accuracy +/- 0.2°C.

Relative Humidity: Before September 1996: Capacitive element, Vaisala Inc. Humicap; probe, Qualimetrics, Inc. Model 5120-E or 5134-E; Detection Limits 0% to 100% RH; Accuracy +/- 2% (0-80% RH) and +/- 3% (80-100%) over a temperature range of -20 to 50°C; uncertainty of RH calibration +/- 1%. After September 1996: Vaisala Inc. HMP35D or HMP45D; Humicap capacitive relative humidity element; Detection Limits 0% to 100% RH; Accuracy +/- 2% (0-90% RH) and +/- 3% (90-100%) over a temperature range of -20 to 50°C; uncertainty of RH calibration +/- 1%.

Motor Aspirated Radiation Shield: Qualimetrics, Inc. Model 8151-B with flow sensor; nominal ventilation rate 1.83 m per sec into inlet; radiation error 0.05°C; operating temperature range -40 to 55°C. Wind speeds over 10 m per sec, particularly from the south can reduce the ventilation rate in the radiation shield; uncertainties are thought to be negligible due to this effect as radiation errors from heating of the radiation shield are reduced in high wind speeds.

Flow Sensor: Qualimetrics Model T450009; this sensor is a heated element type sensor that detects changes in air flow via a relay sensing of a gap that is dependent on the maintenance of a particular temperature in a coil.

Southeast Elevator:

Temperature and Relative Humidity: Vaisala Inc. HMP35D or HMP45D;

Air Temperature: Platinum Resistance Temperature Detector (PRTD), 100 ohm; Detection Limits -30 to 40°C; Operating Temperature Range -40 to 50°C; Accuracy +/- 0.2°C.

Relative Humidity: Humicap capacitive relative humidity element; Detection Limits 0% to 100% RH; Accuracy +/- 2% (0-90% RH) and +/- 3% (90-100%) over a temperature range of -20 to 50°C; uncertainty of RH calibration +/- 1%.

Motor Aspirated Radiation Shield: R.M. Young Model 43408/43482; nominal ventilation rate 3 m per sec into inlet; radiation error 0.05°C; operating temperature range -40 to 55°C. Uncertainties are thought to be negligible.

7.2 Theory of Operation

Temperature and relative humidity are measured at both 25 m and 60 m on both elevators (west and southeast sides) of the SGP CF tower. However, the aspirators used on the two sides are different; the west side aspirators are made of metal and have a fairly low flow rate of 1.8 L/min, whereas the southeast side aspirators are made of plastic and have a flow rate closer to 3 L/min. The temperature sensors on the two sides are also different; the southeast side uses the internal PRTD in the T/RH sensor, whereas the west side uses a PRTD that is separate from the T/RH sensor. Because of these differences, some difference in measurements from the two sides at the same height is expected.

Ambient vapor pressure is calculated for both sides (west and southeast) and measurement heights (25 m and 60 m) from the measurements of temperature and relative humidity. This is accomplished using an instruction in the datalogger that calculates saturation vapor pressure from temperature. Vapor pressure (in kPA) is then calculated from:

Vapor Pressure = Relative Humidity/Saturation Vapor Pressure.

7.3 Calibration

7.3.1 Theory

Standard calibration procedures are followed for all temperature and relative humidity sensors used on the SGP CF 60-m tower. See details below in section 7.3.2.

7.3.2 Procedures

Vendor recommended calibration procedures, and calibration checks by the mentor are used to maintain the accuracy of the temperature and relative humidity sensors on the SGP CF tower.

Four-point relative humidity calibrations (at 0%, 12%, 75%, and 97%) above saturated salt solutions (12% and 75%), zero air (0%), and in almost saturated air (97%) are performed annually on the SGP CF tower HMP35D and HMP45D T/RH sensors by Vaisala, Inc. (after September 1996). The PRTD is also checked for accuracy by Vaisala, Inc. and the electronics adjusted to provide accurate temperature measurements. Previously, calibrations were performed by NovaLynx, Inc. (west elevator only) at 12%, 40%, and 75% above saturated salt solutions. This previous calibration technique often yielded incorrect calibration slopes, zero offsets, and a lack of sensitivity at relative humidity above 85%.

The Minco Products, Inc. PRTD on the west side are calibrated annually by the mentor with an ice bath check in the field (the elevator carriages are lowered to ground level for this procedure). The PRTD data are presently acquired with Campbell Scientific, Inc. CR10X dataloggers, using the built-in resistance-to-temperature polynomial function. The inverse of a normalized resistance ratio at zero degrees Centigrade is entered into the datalogger system software as a multiplier.

The T and RH probes are also annually checked against each other and against ambient values using an aspirated psychrometer as the reference (both carriages from both sides are lowered to ground level for this procedure).

7.3.3 History

All calibration information is kept in the 60-m Tower Temperature - Relative Humidity Manual. Copies of the manual are maintained by site operations personnel at SGP CF and by the mentor. Several calibrations have been performed by the manufacturers and by the mentor and/or site operations personnel (in-field). Calibration of west elevator relative humidity sensors was performed by NovaLynx before October 1996 and both east and west elevator sensors have been calibrated by Vaisala, Inc. since September 1996. The dates of calibration are listed below for each sensor serial number and/or location. W designates the west-facing elevator (side B); S designates the southeast facing elevator (side A). The T/RH sensor serial number is the one that was left installed after calibration. MINCO PRTDs do not have serial numbers. Qualimetrics RH sensor numbers are three digits long. Vaisala T/RH sensor serial numbers are the long numbers. An asterisk indicates when a PRTD was replaced.

Temperature (PRTD):

Vendor Calibrations:

MINCO:	MINCO PRTD: 2 sensors	Mar 1993
	MINCO PRTD: 2 sensors	Mar 1996
Vaisala:	HMP35D: S1720002	Jun 1997
	HMP35D: S1720003	Jun 1997
	HMP35D: unknown	Oct 1997
	HMP35D: S1720004	Jun 1997
	HMP35D: S1720005	Jun 1997
	HMP45D: S4520022	Jan 1998
	HMP45D: S4520023	Jan 1998
	HMP45D: S4930004	Jan 1998
	HMP45D: S4930005	Jan 1998

Annual calibration performed on four Vaisala, Inc. T/RH sensors by Vaisala, Inc. since.

In-field Calibrations (for southeast elevators, see T/RH sensor replacement dates):

W 25 m	6 Feb 1996
	23 May 1996
	21 Oct 1996

		5 Feb 1997
		17 Jul 1998
		19 May 1999
		14 Aug 2000
		8 Aug 2001
		2 Aug 2002
		15 Aug 2003
		27 Sep 2004
	W 60 m	11 Mar 1993
		6 Oct 1993
		11 May 1994
		15 Nov 1994
		19 May 1995
		19 Sep 1995
		6 Feb 1996
		23 May 1996 *
		21 Oct 1996
		5 Feb 1997
		17 Jul 1998
		19 May 1999
		14 Aug 2000
		8 Aug 2001
		2 Aug 2002
		15 Aug 2003
		27 Sep 2004

Relative Humidity:

Vendor Calibrations:

Novalynx	S/N 109	29 Jul 1992
	S/N 109	7 Jul 1993
	S/N 231	? Nov 1995
	S/N 226	5 Apr 1996
	S/N 234	5 Apr 1996
Vaisala, Inc.	S/N 226	3 Dec 1996
	S/N 234	3 Dec 1996
	S/N 109	26 Feb 1997
	S/N 231	26 Feb 1997
	S/N 226	21 Aug 1997
	S/N 234	21 Aug 1997
	HMP35D: S1720002	Mar 1997
	HMP35D: S1720003	Mar 1997
	HMP35D: S1720004	Mar 1997

HMP35D:	S1720005	Mar 1997
HMP45D:	S4520022	Jan 1998
HMP45D:	S4520023	Jan 1998
HMP45D:	S4930004	Jan 1998
HMP45D:	S4930005	Jan 1998

Annual calibration performed on four Vaisala, Inc. T/RH sensors by Vaisala, Inc. since.

In-field Calibrations:

W 25 m	S/N 234	6 Feb 1996
	S/N 226	19 Mar 1996
	S/N 231	25 Mar 1996
	S/N 231	22 May 1996
	S/N 231	21 Oct 1996
	S/N 231	4 Feb 1997
	S/N 234	5 Feb 1997
	S/N 109	13 Aug 1997
	S4930005	5 Nov 1997
	S4930004	17 Jul 1998
	S4930005	19 May 1999
	S4520022	14 Aug 2000
	S1720002	8 Aug 2001
	S4520023	2 Aug 2002
	S1720004	15 Aug 2003
	S2920008	27 Sep 2004
S 25 m	S1720003	13 Aug 1997
	S1720005	26 Sep 1997
	S4520022	17 Jul 1998
	S1720004	19 May 1999
	S1720002	14 Aug 2000
	S1720004	8 Aug 2001
	S4520022	2 Aug 2002
	S4520015	15 Aug 2003 (replaced 10 Feb 2004, S2920011, no cal.)
	S4930004	27 Sep 2004
W 60 m	S/N 109	11 Mar 1993
	S/N 231	6 Oct 1993
	S/N 231	7 Oct 1993
	S/N 231	11 May 1994
	S/N 231	15 Nov 1994
	S/N 109	19 May 1995
	S/N 109	19 Sep 1995
	S/N 109	6 Feb 1996
	S/N 234	22 May 1996

	S/N 226	21 Oct 1996
	S/N 109	4 Feb 1997
	S/N 226	5 Feb 1997
	S/N 231	13 Aug 1997
	S1720004	5 Nov 1997
	S4520023	17 Jul 1998
	S1720003	19 May 1999
	S4930004	14 Aug 2000
	S4930005	8 Aug 2001
	SW0120011	2 Aug 2002
	S4930005	21 Feb 2003
	S1720002	15 Aug 2003
	S2920010	27 Sep 2004
S 60 m	S1720002	13 Aug 1997
	S1720002	17 Jul 1998
	S1720005	19 May 1999
	S4520023	14 Aug 2000
	S1720003	8 Aug 2001
	S4930004	2 Aug 2002
	S1720003	25 Oct 2002
	S4930004	15 Aug 2003 (replaced 10 Feb 2004, S2920009, no cal.)
	S4520015	27 Sep 2004

7.4 Operation and Maintenance

7.4.1 User Manual

Copies of the SGP CF tower and elevator user manuals are kept at SGP CF and at the mentor's office. A copy of the SGP Okmulgee tower user manual is kept at SGP CF and at the mentor's office. Copies of the NSA tower and elevator user manuals are kept at NSA Barrow and at the mentor's office.

SGP CF and Okmulgee maintenance and system checks are performed in accordance with procedures developed by SGP Site Operations and the mentor; these procedures are maintained in print form at SGP CF and in digital form on Site Ops laptops taken into the field and involve maintenance and checks on the various sensors on these towers. A NSA tower maintenance procedures document is maintained at NSA Barrow and includes maintenance and checks on the various sensors on the tower.

Software Documentation:

The SGP CF tower tower25, tower60, and twr2560 programs are maintained on SGP Site Ops computers at the SGP CF, on laptops used by Site Ops, in print form by SGP Site Ops, and by the mentor (print and digital copies).

7.4.2 Routine and Corrective Maintenance Documentation

Print copies of the annual SGP CF tower in-field calibration reports are maintained at SGP CF and by the mentor.

7.4.3 Software Documentation

This section is not applicable to this instrument.

7.4.4 Additional Documentation

This section is not applicable to this instrument.

7.5 Glossary

Also see the ARM Glossary.

7.6 Acronyms

ACRF: ARM Climate Research Facility
ARM: Atmospheric Radiation Measurement (Program)
BMET: Barrow meteorological station
CF: Central Facility
CO_2FLX: Carbon Dioxide Flux Measurement System
DQ: Data Quality
ECOR: Eddy Correlation System
GPS: Global Positioning System
MFR: Mult-Filter Radiometer
NSA: North Slope of Alaska
PGS: Precision Gas System
PRTD: Platinum Resistance Temperature Detector
RMS: root mean square
SGP: Southern Great Plains
SIRS: Solar and Infrared Sation
SMOS: Surface Meteorological Observation Station

Also see the ARM Acronyms and Abbreviations.

7.7 Citable References

Revercomb, H.E., et al., The ARM Program's Water Vapor Intensive Observation Periods - Overview, Initial Accomplishments, and Future Challenges. *Bulletin of the American Meteorological Society*, **84**, 217-236.