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Surface Meteorology (SMET) Handbook

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1. General Overview

The TWP Surface Meteorology station (SMET) uses mainly conventional *in situ* sensors to obtain 1-minute statistics of surface wind speed, wind direction, air temperature, relative humidity, barometric pressure and rainfall amount.

2. Contacts

2.1 Mentor

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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
Web page: http://www.campbellsci.com

Wind Monitor & Aspirated Radiation Shield
R. M. Young Company
2801 Aero Park Drive
Traverse City, MI 49686
Phone: 231-946-3980
Fax: 231-946-4772
Web page: http://www.youngusa.com/

Temperature-Relative Humidity Probe & Digital Barometer
Vaisala
100 Commerce Way
Woburn, MA 01801-1068
Phone: 617-933-4500
Fax: 617-933-8029
Web page: http://www.vaisala.com

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

Tipping Bucket Raingauge
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

3. Deployment Locations and History

ARCS site C1 was installed on Manus Island, Papua New Guinea in October 1996.
ARCS site C2 was installed on the island of Nauru (republic) in November 1998.
ARCS site C3 was installed at Darwin, Australia in April 2002. In 2004 the data collection system was changed.

Table 1. Locations and history.

Location	Date Installed	Date Removed	Status
ARCS C1 Manus	08/2004		Operational
ARCS C2 Nauru	07/2004		Operational
ARCS C3 Darwin	05/2004		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. Primary variables.

Quantity	Variable	Unit	Measurement Level	Measurement Interval	Resolution
Precipitation Mean	precip_mean	mm/hr	1m	1 min	0.1
Precipitation Maximum	precip_max	mm/hr	1m	1 min	0.1
Precipitation Minimum	precip_min	mm/hr	1m	1 min	0.1
Tipping bucket raingauge total	tbrg_total	mm	sfc	1 min	0.2
Temperature Mean	temp_mean	C	2m	1 min	0.1
Relative Humidity Mean	relh_mean	%	2m	1 min	0.1
Vapor pressure mean	vappress_mean	kPa	2m	1 min	0.1
Upper wind speed arithmetic average	up_wind_spd_arith_avg	m/s	10m	1 min	0.1
Upper wind speed vector average	up_wind_spd_vec_avg	m/s	10m	1 min	0.1
Upper wind direction vector average	up_wind_dir_vec_avg	deg	10m	1 min	1
Upper wind direction standard deviation	up_wind_dir_sd	deg	10m	1 min	1
Upper wind speed maximum	up_wind_spd_max	m/s	10m	1 min	0.1
Upper wind speed minimum	up_wind_spd_min	m/s	10m	1 min	0.1
Lower wind speed arithmetic average	lo_wind_spd_arith_avg	m/s	10m	1 min	0.1
Lower wind speed vector average	lo_wind_spd_vec_avg	m/s	10m	1 min	0.1
Lower wind direction vector average	lo_wind_dir_vec_avg	deg	10m	1 min	1
Lower wind direction standard deviation	lo_wind_dir_sd	deg	10m	1 min	1
Lower wind speed maximum	lo_wind_spd_max	m/s	10m	1 min	0.1
Lower wind speed minimum	lo_wind_spd_min	m/s	10m	1 min	0.1
Atmospheric pressure	atmos_pressure	hPa	1m	1 min	0.1

The following variables were removed when the systems were changed to the new data collection system. See *Deployment Locations and History* for exact dates.

Table 3. Removed variables.

Quantity	Variable	Unit	Measurement Level	Measurement Interval	Resolution	Status
Temperature Maximum	temp_max	C	2m	1 min	0.1	Removed
Temperature Minimum	temp_min	C	2m	1 min	0.1	Removed
Relative Humidity Maximum	relh_max	%	2m	1 min	0.1	Removed
Relative Humidity Minimum	relh_min	%	2m	1 min	0.1	Removed

5.1.1.1 Definition of Uncertainty

This definition should probably be included in a Definitions web page, and only linked to from here.

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

Table 4. Diagnostic variables.

Quantity	Variable	Measurement Interval
Precipitation standard deviation	precip_sd	1 min
Temperature standard deviation	temp_sd	1 min
Relative Humidity standard deviation	relh_sd	1 min
Vapor pressure standard deviation	vappress_sd	1 min

Table 4. (contd)

Upper wind speed standard deviation	up_wind_spd_sd	1 min
Lower wind speed standard deviation	lo_wind_spd_sd	1 min
Internal Voltage	internal_voltage	1 min
Logger Temperature	logger_temp	1 min
Tipping bucket raingauge count total	tbrg_count_total	1 min

5.1.4 Data Quality Flags

Table 5. Quality control variables.

Quantity	Variable	Measurement Interval	Min	Max
sample time	qc_time	1 min		
Precipitation mean	qc_precip_mean	1 min	0	500
Precipitation maximum	qc_precip_max	1 min	0	500
Precipitation minimum	qc_precip_min	1 min	0	500
Tipping bucket raingauge total	qc_tbrg_total	1 min	0	10
Temperature mean	qc_temp_mean	1 min	0	50
Relative Humidity mean	qc_relh_mean	1 min	0	104
Upper wind speed arithmetic average	qc_up_wind_spd_arith_avg	1 min	0	100
Upper wind speed vector average	qc_up_wind_spd_vec_avg	1 min	0	100
Upper wind direction vector average	qc_up_wind_dir_vec_avg	1 min	0	360
Upper wind speed maximum	qc_up_wind_spd_max	1 min	0	100
Upper wind speed minimum	qc_up_wind_spd_min	1 min	0	100
Lower wind speed arithmetic average	qc_lo_wind_spd_arith_avg	1 min	0	100
Lower wind speed vector average	qc_lo_wind_spd_vec_avg	1 min	0	100
Lower wind direction vector average	qc_lo_wind_dir_vec_avg	1 min	0	360
Lower wind speed maximum	qc_lo_wind_spd_max	1 min	0	100
Lower wind speed minimum	qc_lo_wind_spd_min	1 min	0	100
Atmospheric pressure	qc_atmos_pressure	1 min	850	1030
Tipping bucket raingauge count total	qc_tbrg_count_total	1 min	0	50

5.1.5 Dimension Variables

Table 6. Dimension variables.

Quantity	Variable	Measurement Interval	Unit
Base time in Epoch	base_time	1 min	seconds since YYYY-mm-dd XX:XX:XX X:XX
Time offset from base_time	time_offset	1 min	seconds since YYYY-mm-dd XX:XX:XX X:XX
Time offset form midnight	time	1 min	seconds since YYYY-mm-dd XX:XX:XX X:XX
north latitude	lat	1 min	degrees
east longitude	lon	1 min	degrees
altitude	alt	1 min	meters above sea level

5.2 Annotated Examples

This section is not applicable to this instrument.

5.3 User Notes and Known Problems

Induced Voltage on Wind Speed Cable Caused Offsets in Wind Speed Data

The marine model of the RM Young wind sensor needs twisted pair shielded cable. The manufacturer did not originally supply the pigtail with twisted pair shielded cable. Use of twisted pair shielded cable for the rest of the cable run to the logger was also not specified. This caused an induced voltage in the wind speed line from the wind direction excitation. The induced voltage varied from sensor to sensor and probably changed anytime the cable was replaced or parts of the wind sensor were repaired or replaced. The induced voltage has been seen to vary from 0.15 m/s to as much as 1.08 m/s. To complicate matters until 2006 or 2007 depending upon site, the calibration coefficients of the wind monitors included an offset. This offset would change with the sensor. These offsets were not always captured until 2004 when the System changed over to the Campbell Scientific dataloggers (see Table 1). The following table lists when the various sites stopped using the sensor specific calibration coefficients.

Table 7. Dates coefficients were removed.

Site	Date coefficient removed
C1	09/26/06 @ 1438 GMT
C2	09/26/06/ @ 1400 GMT
C3	09/25/06 @ 1435 GMT

The following is a plot of the wind speed and direction data showing the induced offset caused by the excitation voltage of the wind direction at TWP C3. This offset does NOT include any calibration coefficient offset.

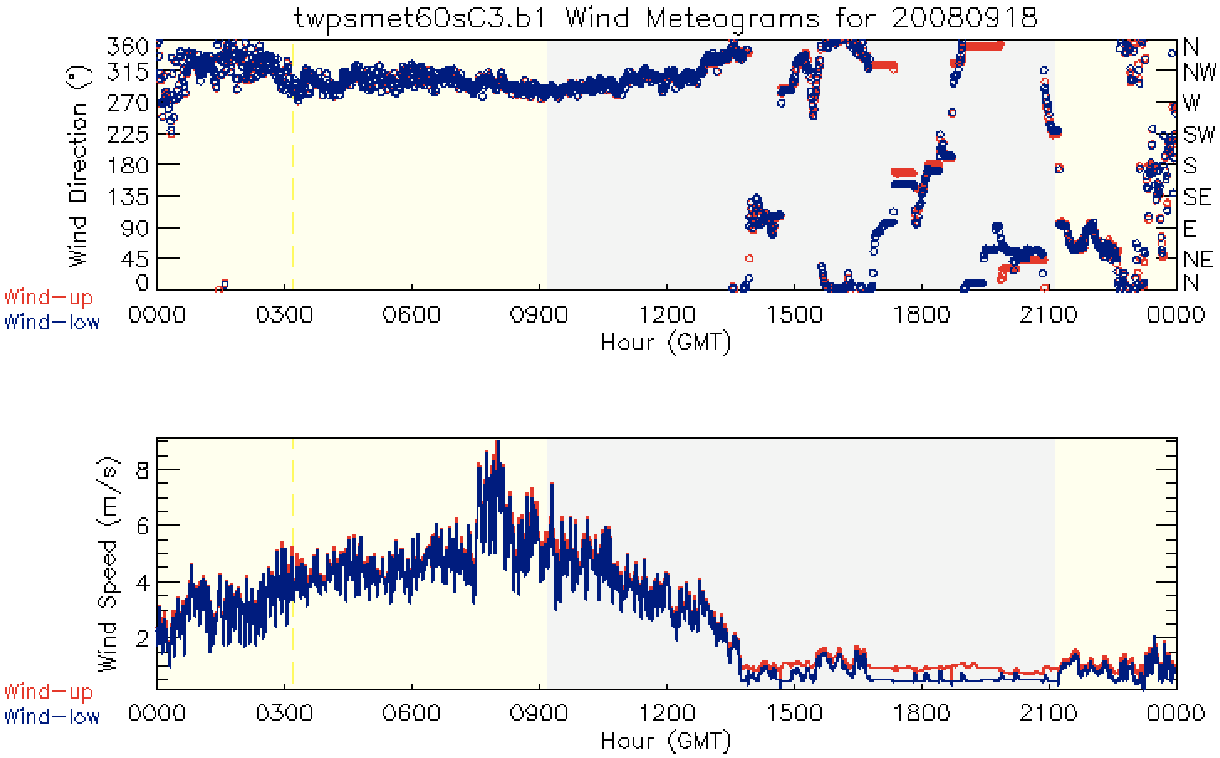

Figure 1. Induced voltage in the wind speed data.

Tipping Bucket Raingauges Added at Different Times

Tipping bucket raingauges were added at each site at different times. The following table lists the location and the date the gauge was installed. Tipping bucket raingague data prior to the installation date was filled with -9999.

Table 8. Dates gauges were installed.

Site	Date Installed
C1	10/16/2006
C2	11/29/2006
C3	09/26/2006

Incorrectly Listed Units for Vapor Pressure in Data Object Design

The Data Object Design incorrectly listed the units of hPa for Vapor Pressure. When the new collection system was installed at each site (see Table 1) the units were actually reported in kPa.

Naming Convention of the Two Wind Monitors

The two wind monitors (speed & direction) are mounted such that one sensor is slightly higher than the other to minimize interference. The higher wind monitor is designated as sensor #1 or “hi” so that all data streams associated with wind speed or direction that have a “1” or “hi” in the name are from the higher of the two sensors. Any variables associated with wind speed or direction that have a “2” or “lo” in the name are from the lower of the two sensors.

Error in Calibration Factors for Wind Speed at ARCS1 Manus

Calibration factors between wind speed sensor C1 and C2 were reversed causing a less than 1% error in recorded wind speeds. A correction factor may be used. For sensor C1 (add) + .03 m/s and for sensor C2 (subtract) - .03 m/s. The errors in calibration factors were for data from 10/25/1996 - 03/02/1999.

Optical Rain Gauge (ORG) Reporting Values Less Than 0.1 mm/hr

For the data prior to installation of the new data collection system the following incorrect data was ingested. After installation of the new collection system, this problem was corrected:

During normal operation, the sensor always puts out some voltage (background noise), even during clear sky conditions. The rain rate equation that is used to convert voltage to rain rate should only be applied to voltages equal to or above a certain fixed threshold. This threshold is different for each model (ORG-815 or ORG-115-DA mini-ORG). At values below the fixed threshold the equipment will report small values (some negative) at all times. Currently, the rain rate equation is used for all voltages reported by the sensor. The rain rates that correspond to voltages below the thresholds are between -0.1 mm/hr and +0.1 mm/hr. Therefore, such values should be considered by the data user to be 0 mm/hr. It is also possible that values between -0.15 mm/hr and -0.1 mm/hr may be reported as a result of very low voltages. These values should also be considered as 0 mm/hr. If values less than -0.15 mm/hr are reported then negative voltages are being used and this is an indication of a problem with the sensor. These values should be discarded. Any value equal to and above 0.1 mm/hr that are reported are good values since positive voltages above the thresholds are being reported and the rain rate equation is valid.

Optical Rain Gauges Upgraded at Sites C1 and C2

The Optical Rain Gauges (ORG) at Manus site C1 and Nauru site C2 were the older model ORG-115. At Darwin site C3 the ORG is the model ORG-815. For the sake of consistency and due to problems with the aging models the ORGs at Manus and Nauru were upgraded to the ORG-815 models. Due to changes and upgrades the rain rate calculation is different for the ORG-815 and the ORG-115. See the section **System Configuration and Measurement Methods** for the different formulas used.

Nauru site C2 was upgraded on 12/14/2004.
Manus site C1 was upgraded on 01/19/2005.

Optical Rain Gauges Reporting Values less that 0.2 mm/hr

The Optical Rain Gaures make continuous measurements. They are sampled once a second and the 1-sec values are averaged each minute. Very small values resulting from dust, dirt, insects are sometimes included in the averaged values. These values can be recognized when the average precipitation rate for a minute is less than 0.01 mm/hr. Any value less than that should be removed from study. Future reprocessing tasks will remove those from the data record. More importantly it has been determined that values between 0.01 mm/hr and 0.2 mm/hr are not necessarily precipitation. Instead values less than 0.2mm/hr likely represent fog and/or haze and individuals should view the data critically before assuming all values are precipitation. The below plot shows the typical response of the ORG to fog situations. However, it should be noted that the fog may not be visually present and it is possible that the ORG is responding to the moisture content of the air during high RH situations.

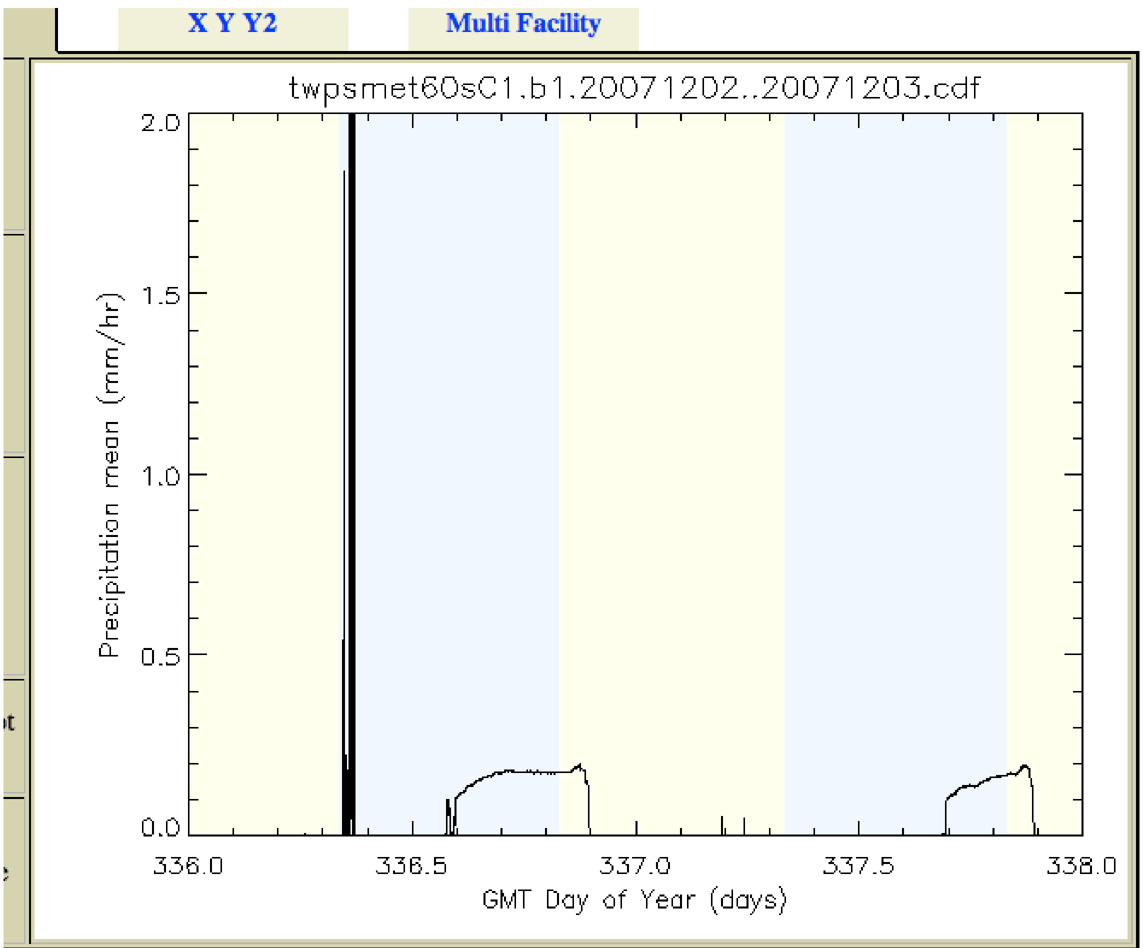

Figure 2. Sample data plot of ORG.

5.4 Frequently Asked Questions

This section is not applicable to this instrument.

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

The Instrument Mentor (Michael Ritsche) performs a number of tasks to assure the quality of AMFMET data. Data quality control procedures for this system are considered **mature**.

- **QC frequency**: Weekly
- **QC delay**: Real-time; weekly
- **QC type**: Min/max/delta flags; graphical plots; mentor reviews
- **Inputs**: Collected data
- **Outputs**: Monthly Mentor Reports, DQR, BCR, ECO, PIF, DQPR (as needed)
- **Reference**: None

Standard AMFMET data are subject to several levels of quality control and quality assurance. When the data are collected each variable has various automated QC checks that look for values outside defined max/min/delta. Any variable outside these parameters are flagged in the QC variable. The mentor recieves weekly reports, called Data Quality Assessment Reports (DQAR) from the DQ Office and reviews them for problems. Any problems listed in the weekly DQAR's are checked and spot checks are also performed to verify the DQAR's are accurate.

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 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 CART 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 in order to fill unmet measurement needs, but instead 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. Rather, 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.

7. Instrument Details

7.1 Detailed Description

7.1.1 List of Components

Wind speed and direction sensors: A pair of propeller anemometers and wind vanes, R. M. Young Model 05106 Wind Monitors.

Temperature and relative humidity sensor: Platinum RTD and RH, Vaisala Model HMP45 D Temperature and Relative Humidity Probe.

Barometric pressure sensor: Digital barometer, Vaisala Model PTB201A.

Precipitation:
Optical Raingauge: Optical Scientific, Inc. Model ORG-115-DA MiniOrg or ORG-815-DA MiniOrg.

Tipping Bucket Raingauge: RIMCO 7499 Series.

Data logger: Campbell Scientific, Inc. Model CR23X.

7.1.2 System Configuration and Measurement Methods

The SMET sensors are mounted on a 10-meter mast, except for the rain gauge.

The wind monitor propeller anemometers produce a magnetically controlled AC output whose frequencies are proportional to the wind speed. The Wind Monitor direction vanes drive potentiometers, which are part of resistance bridges.

Two Wind Monitors are mounted on a cross-arm at a height of 10 m. One is mounted slightly above the other in order to minimize interference. The higher wind monitor is designated sensor #1 and the lower wind monitor is designated sensor #2.

The T-RH probe 4-lead, platinum resistance thermometer 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 T-RH probe is mounted in an R. M. Young Model 43408 Gill Aspirated Radiation Shield at a height of 2 m.

The barometric pressure sensor uses a silicon capacitive pressure sensor and is housed in an enclosure along with the data logger.

The optical precipitation gauge detects scintillation of an infrared beam caused by liquid water in the path. It is located near the tower. The following equations are used to convert the voltage signal to a rainrate.

For the ORG-815:
Rainrate (mm/hr) = $(25*(V^{1.87}) – 0.15$

For the ORG-115:
Rainrate (mm/hr) = $(20*(V^{2}) – 0.05$

The tipping bucket raingauges is a siphon controlled tipping bucket raingauge. It is designed and constructed for long-term operation with minimal maintenance required. Any rain falling on the 203mm collecting funnel is directed through a siphon control unit and discharges as a steady stream into a two compartment bucket mounted in unsable equilibrium. As each compartment fills the bucket tilts anternately about its axis. Each tip forces a momentary contact closure by magnetic means. The datalogger senses each contact closure and applies 0.2 mm for each contact closure. At site C3 the raingauge is connected only to the SMET system and is only part of the SMET system. At sites C1 and C2 the raingauge is connected to the Bureau of Australina Meteorology (BoM) Automated Weather Station (AWS) and also the SMET systems at each site. The raingauges as sites C1 and C2 belong to the AWS system and not to the SMET system.

The CR23X data logger measures each input once per second except for barometric pressure, which is measured once per minute, and logs 1-min averaged data. Vapor pressure is computed from the air temperature and relative humidity. The data logger produces 1-min averages, minimums, maximums, and standard deviations of wind speed, air temperature, relative humidity, and rain rate. It also produces 1-min vector-averaged wind speed and direction, a 1-min standard deviation of the wind direction computed by an algorithm, 1-min averages and standard deviations of vapor pressure, and a reading of the barometric pressure, logger panel temperature, and the internal supply voltage.

7.1.3 Specifications

Wind speed at 10 m: Precision: 0.01 m/s; Uncertainty: +/-2% for 2.5 to 30 m/s (see *Assessment of System Uncertainties for Primary Quantities Measured* for wind speeds below 2.5 m/s).

Wind direction at 10 m: Precision: 0.1 deg; Uncertainty: +/-5 deg.

Air temperature at 2 m: Precision: 0.01 C; Uncertainty: +/-0.57 C.

Relative humidity at 2 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.

Precipitation:
Optical Raingauge: Precision: 0.1 mm/hr; Uncertainty: +/-0.1 mm/hr.
Tipping Bucket Raingauge: Precision: 0.2 mm; Uncertainty +/- 0.2 mm (unknown during strong winds).

Overall Uncertainties for Primary Quantities Measured

All SMET uncertainty analyses are based on manufacturer's specifications. Manufacturers specify accuracies in several ways. Some give absolute range of error, some give uncertainties as defined above, while others give rms errors. In this analysis, rms errors are multiplied by 2. This results in confidence limits of approximately 95%.

Data Acquisition Errors

The Campbell Scientific, Inc CR23X datalogger A-D converter accuracy is +/- 0.025% FSR for 0 – 40 C, +/- 0.05% FSR –25 to 50 C, +/- 0.075% FSR –40 to 80 C. The clock accuracy is +/- 1 minute per month –25 to 50 C, +/- 2 minutes per month –40 to 80 C. The LoggerNet software checks the clock of the logger once per day and adjusts it if it off by more than 2 seconds. The computer continuously maintains time synchronization with a GPS based time reference using the NTPD protocol. The GPS based reference is local to each site.

For the system initially installed, the Coastal Environmental Systems ZENO-3200 A-D converter accuracy is +/-0.05% of full-scale range. The time base accuracy is +/-0.005%. The Site Data System checked the time-of-day clock once per day and corrected the logger clock if it is off by more than a minute.

Wind Speed

The calibration uncertainty is specified as +/-2% 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:

+/- 2%	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 deg. The A-D conversion accuracy is equivalent to 0.7 deg over a temperature range of 0 to 40 deg C for a period of one year. I have estimated sensor alignment to true north to be accurate within +/-3 deg. The uncertainty with 95% confidence is, therefore, approximately +/-5 deg.

Temperature

The accuracy of the temperature measurement is +/-0.4 C. 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 RH 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, which is negligible.

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 data logger. The specified uncertainty with 95% confidence is +/-0.035 kPa. Note that the pressure behaves anomalously during rain events - even very mild ones. Normally, the pressure undergoes a smooth semi-diurnal oscillation with little higher frequency variability. However, during and shortly after rain events, the pressure signal exhibits abrupt changes until the collection system was changed from the Zeno loggers in a pressure sealed container to the Campbell Scientific loggers in a fiberglass enclosure. See Table 1 for dates when the Campbell loggers were installed.

Precipitation/Rainfall Rate

The Optical raingauge has an uncertainty of +/-0.1 mm/hr. Values that fall between -0.1 mm/hr and +0.1 mm/hr should be considered 0 mm/hr. In other words, no rainfall is occurring. See the *User Notes and Known Problems* section for a more comprehensive explanation.

The tipping-bucket rain gauge produces a pulse output. The data logger counts the pulses for the period of integration. The uncertainty is, therefore, a minimum of one full bucket or 0.2 mm. For rain rates up to 250 mm/hr the manufacturer states the accuracy is +/- 1% and for rainrates above 250 mm/hr up to 500 mm/hr the manfacturer states the accuracy is +/- 3%.

During heavy rain or strong, gusty winds, the collection efficiency is reduced. Manufacturers have not attempted to specify accuracies for these conditions.

7.2 Theory of Operation

Each of the primary measurements of wind speed, wind direction, air temperature, relative humidity, barometric pressure, and rate of rainfall are intended to represent self-standing data streams that can be used independently or in combinations. The theory of operation of each of these sensors is similar to that for sensors typically used in other conventional surface meteorological stations. Some details can be found under *System Configuration and Measurement Methods* but further, greatly detailed description of theory of operation is not considered necessary for effective use of the data for these rather common types of measurements. The instrument mentor or the manufacturers can be contacted for further information.

7.3 Calibration

7.3.1 Theory

The SMET's are not calibrated as systems. The sensors and the data logger (which includes the A-D converter) are calibrated separately. All systems are installed using components that have a current calibration. RESET personnel check the sensor and data logger calibrations in the field by comparison to calibrated references. Any sensor or data logger that fails a field check is returned to the manufacturer for recalibration. The Wind Monitors are returned to the manufacturer for recalibration after two years of use.

7.3.2 Procedures

Wind speed calibration is checked by rotating the propeller shaft at a series of fixed rpm's using an R. M. Young Model 18810 Anemometer Drive. The reported wind speeds are compared to a table of expected values and tolerances. If the reported wind speeds are outside the tolerances for any rate of rotation, the sensor is replaced by one with a current calibration.

Wind direction calibration is checked by using a vane angle fixture, R. M. Young Model 18212, to position the vane at a series of angles. The reported wind directions are compared to the expected values. If any direction is in error by more than 5 degrees, the sensor is replaced by one with a current calibration. Air temperature and relative humidity calibrations are checked by comparison with a reference Vaisala Model HMI31 Digital Relative Humidity and Temperature Meter and HMP35 Probe and a YSI 4600 Precision Thermometer. If the reported temperature and relative humidity vary by more than the sensor uncertainty from the reference, the probe is replaced by one with a current calibration.

Barometric pressure calibration is checked by comparison with a reference Vaisala PA-11 Barometer. If the reported pressure varies by more than the sensor uncertainty from the reference, the sensor is replaced by one with a current calibration.

The data logger A-D converter is checked by using a Valhalla 2707A Programmable Precision DC Voltage/Current Standard as an input voltage reference or they are sent in to the manufacturer for checks and repair.

7.3.3 History

ARCS C1
-10/8/1996 system installed
-04/25/1998 Field Calibration Check
-05/01/1998 Field Calibration Check.
-03/10/1999 Field Calibration Check. Upper wind sensor replaced.
-08/12/1999 T/RH probe replaced.
-04/02/2000 Field Calibration Check.
-04/06/2000 T/RH probe replaced.
-10/21/2001 Field Calibration Check. T/RH probe was replaced.
-10/16/2002 Field Calibration Check. Lower wind sensor and T/RH probe replaced.
-12/12/2003 Field Calibration Check.
-08/02/2004 Datalogger changed.
-08/07/2004 Barometer replaced.
-08/09/2004 Barometer replaced.
-11/04/2004 Field Calibration Check.
-01/20/2005 ORG-115 upgraded to ORG-815.
-06/15/2006 Lower wind sensor replaced.
-10/14/2006 Field Calibration Check. Upper wind sensor replaced.
-06/11/2007 Cr23X datalogger 7115 installed.

ARCS C2
-11/20/1998 System installed.
-03/14/1999 Upper wind sensor replaced.
-08/10/1999 Field Calibration Check.
-07/01/2000 Field Calibration Check.
-01/20/2001 T/RH probe replaced.
-05/11/2001 Field Calibration Check. T/RH probe replaced.
-10/31/2001 Field Calibration Check
-11/01/2001 T/RH probe replaced.
-09/15/2002 Field Calibration Check. T/RH probe replaced.
-02/07/2003 T/RH probe replaced.
-08/14/2003 Both wind sensors replaced.
-09/17/2003 Field Calibration Check.
-04/24/2004 Lower wind sensor replaced.
-07/08/2004 Barometer replaced and Datalogger changed.
-12/13/2004 ORG-115 upgraded to ORG-815.

-03/03/2005 Upper wind sensor replaced.
-04/17/2005 Upper wind sensor replaced.
-07/15/2005 T/RH probe replaced.
-09/19/2005 Field Calibration Check.
-06/15/2006 T/RH probe replaced.
-11/30/2006 Field Calibration Check.
-12/01/2006 Lower wind sensor and barometer replaced.
-01/23/2007 barometer replaced Y1330002 installed.

ARCS C3
-04/01/2002 System installed.
-08/22/2002 Field Calibration Check.
-03/11/2003 T/RH probe replaced.
-07/22/2003 Field Calibration Check.
-05/17/2004 Barometer(V044001) replaced and Datalogger(5964) changed.
-09/07/2004 Field Calibration Check.
-08/09/2005 Field Calibration Check.
-11/16/2005 T/RH probe replaced. Upper wind sensor replaced.
-11/23/2005 ORG replaced.
-04/27/2006 Lower wind sensor replaced.
-05/18/2006 ORG replaced.
-09/06/2006 Field Calibration Check.
-04/20/2007 CR23X #5972 installed.

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

See the following links:

- http://www.twppo.lanl.gov/internal/pages/operations_manus.html
- http://www.twppo.lanl.gov/internal/pages/operations_nauru.html
- http://www.twppo.lanl.gov/internal/pages/operations_darwin.html.

7.4.3 Software Documentation

See http://science.arm.gov/tool/dod/showdod.php?Inst=smet.

7.4.4 Additional Documentation

See http://www.twppo.lanl.gov/internal/pages/operations.html.

7.5 Glossary

Barometric pressure - Local station pressure measured at the SMOS station at a height of 1 m.

Precipitation - All forms of water meteors.

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 one-second sample of wind speed and direction. The wind directions reported by the SMOS are determined from the vector-averaged winds.

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

Also see the ARM Glossary.

7.6 Acronyms

A-D: Analog to Digital converter
RH: Relative Humidity
SGP: Southern Great Plains
SMOS: Surface Meteorological Observation System
T-RH: Temperature-Relative Humidity

Also see the ARM Acronyms and Abbreviations.

7.7 Citable References

None.