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BAY AREA
AIR QUALITY
MANAGEMENT
DISTRICT

TECHNICAL SERVICES DIVISION

QUALITY ASSURANCE PROJECT PLAN

MET SOP 504

TEMPERATURE / RH

REVISION 504.1.00 9/13/2007

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STANDARD OPERATING PROCEDURE
BAAQMD TECHNICAL SERVICES DIVISION

TEMPERATURE AND RELATIVE HUMIDITY AUDIT PROCEDURES

(Vaisala HMP45 Temperature and Relative Humidity Sensor)

SEPTEMBER 13, 2007

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INTRODUCTION

Humidity is a general term for the water vapor content of air. This term may be expressed as relative humidity or dew point. Relative humidity (RH) is the ratio of the existing amount of water vapor in the air at a given temperature to the maximum amount that could exist at that temperature. This value is usually expressed in percent relative humidity (%RH). Percent relative humidity is a variable parameter which is affected by atmospheric conditions during its measurement. This creates a difficult auditing situation. If the auditing day is cloudy and calm, equilibrium of the percent relative humidity auditing sensor can occur within 10 minutes. However, if the conditions are sunny and windy, there will be quick moving pockets of air showing a high degree of variation in percent relative humidity. This variation can occur in both a horizontal and vertical profile. Thus, it is critical that the instrument auditing relative humidity is positioned as near the ambient measurement sensor as possible. An operator who is familiar with the meteorological equipment should be present during the audit to perform the required manipulations of the tower and sensors.

GENERAL OPERATING PROCEDURES

A Vaisala HMP45 sensor is used at field stations and as an audit reference (summer and winter calibrations) to measure temperature (ºC) and relative humidity (%RH). The temperature is measured with a thin-film platinum-chip sensor which is accurate to within ±0.3ºC between 0ºC and 40ºC and has a range of -39.2ºC to 60ºC. The %RH is measured with a capacitive thin-film polymer sensor with a range of 0.8% to 100%RH which, if calibrated at the factory, is accurate to ±1%RH. An Assmann 2530 Psychrometer typically serves as the audit reference during spring and fall audits. It utilizes two precision mercury thermometers with an accuracy of within ±0.1°C. The double-tube thermometers are each supported and protected by a chrome-plated brass case. The thermometer bulbs are guarded by double-walled radiation shields thermally isolated from the main housing by a plastic bushing. Aspiration of the bulbs is accomplished by a spring-wound fan which provides 8 minutes of aspiration per winding.

The audit HMP45 is connected to a Campbell 21X datalogger which collects and displays temperature and %RH. Station HMP45 sensors are attached to 10m meteorological towers and are connected to Campbell CR10 dataloggers. Station temperature and %RH can be displayed continuously on the CR10KD keypad. The audit and station sensors are typically compared by inserting both sensors into a motorized aspirator. Temperature and %RH samples are recorded by both of the dataloggers (1-second measurements). After both sensors have stabilized, four 5-minute averaged test points are collected and compared. The temperature tolerance is ±1.0ºC; the dew point tolerance is ±1.5ºC.

The Assmann 5230 Psychrometer is secured near the aspirator shield and is shielded from the sun by a styrofoam heat shield. A wet sock is placed over one of the thermometer bulbs – this serves as the *wet bulb*. The other thermometer serves as the *dry bulb*. 9 temperature readings are made with the dry bulb thermometer and compared simultaneously with the station temperature displayed on the CR10KD keypad. 4 wet bulb and 4 dry bulb temperature readings, and station %RH is simultaneously recorded. Audit %RH and dewpoint is calculated from these readings; station dewpoint is calculated from station %RH and dry bulb temperature. Station and audit dewpoints are then compared. The temperature tolerance is ±1.0ºC; the dew point tolerance is ±1.5ºC.

Figure 1:
Campbell Scientific 21X Datalogger and HMP45 Temperature/RH Sensor

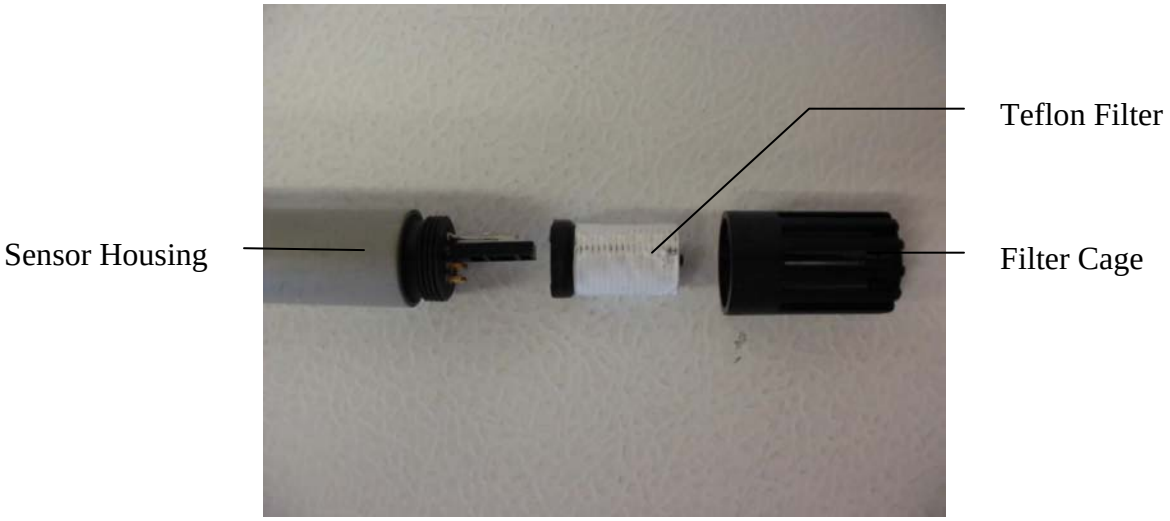

Figure 2:
HMP45 Filter Assembly

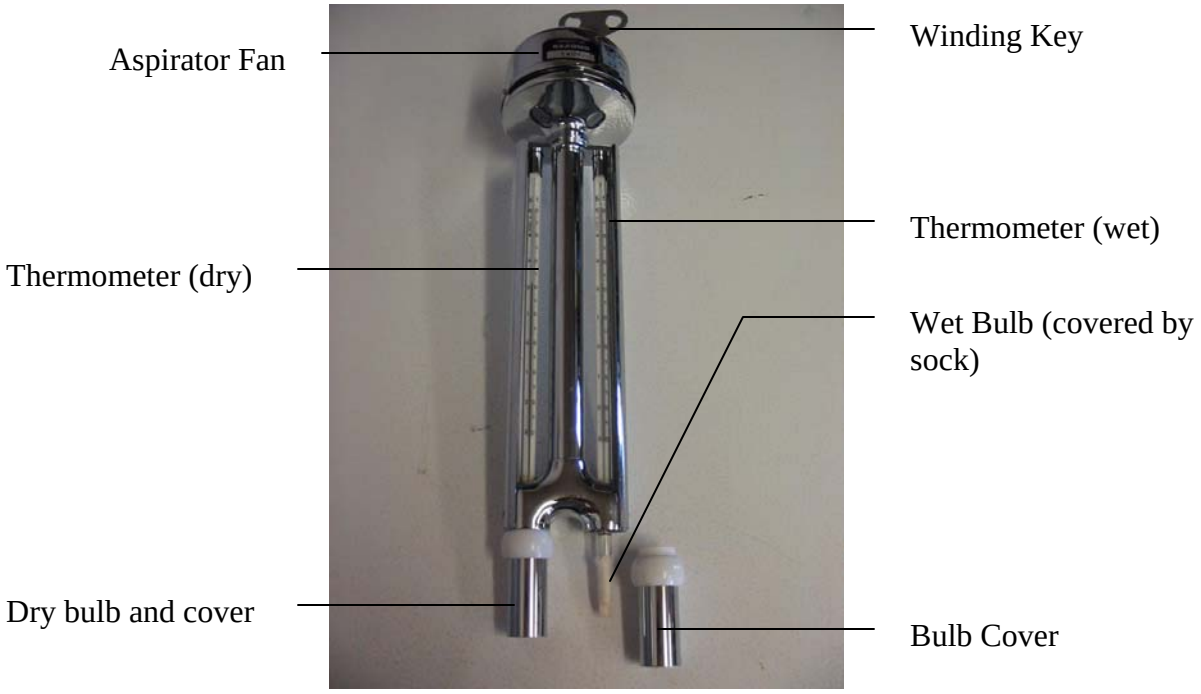

Figure 3:
Assmann 5230 Psychrometer

Figure 4:
Rotronics SMP41002 Aspirated Radiation Shield (left),
and R.M. Young 41002P Multi-Plate Radiation Shield (right)

AUDIT EQUIPMENT

1. Audit Temperature/RH instrument.
    - Vaisala HMP45 Temperature/RH sensor and Campbell Scientific 21X datalogger (Figure 1) OR
    - Assmann 5230 Psychrometer (Figure 3) and a small bottle of distilled water.

2. Laptop computer with LoggerNet software and 21XCal.dld program.

3. Styrofoam Heat Shield and bungee cords (for use with Assmann 5230 Psychrometer or at sites with fold-down towers).

4. Multi-plate shield (when using the audit HMP45 at sites with a multi-plate shield attached to the tower) (Figure 4).

5. Temperature and RH Audit Worksheet.
    - Vaisala HMP45 (Appendix A)
    - Assmann 5230 (Appendix B)

AUDIT PROCEDURES

Vaisala HMP45

1. Clean the station HMP45 sensor. Remove the sensor from the radiation shield and clean the casing. Use a toothbrush to clean the exterior of the filter cage. unscrew the filter cage from the casing, then unscrew the inner filter retainer and gently clean the outside of the teflon filter and the cage interior with a clean cloth (Figure 2). Re-attach the filter retainer to the filter cage, and then re-attach the cage onto the sensor casing.

2. Set up the audit HMP45 sensor. Loop the cable of the audit HMP45 over a tower support rung (1 or 2 rungs higher than the radiation shield) and insert the sensor upwards into the lower opening of the shield until the sensor head of both units touch. The tension from carefully eliminating the cable slack between the support rung and the sensor will pull the bottom of the sensor casing towards the inner wall of the opening, thereby holding the sensor in place. Secure the heat shield to the tower so that both the radiation shield and sensor casings are covered from the sun.

    Fold-Down Towers
    If the radiation shield is mounted above a height of 4 meters, disable data recording (see Wind Speed or Wind Direction Audit SOP), and fold the tower down to access the radiation shield

R.M. Young Naturally Aspirated Radiation Shield

The lower opening of the R.M. Young naturally aspirated shields are not large enough for two sensors. In this case, install a second shield near the tower shield and place the audit HMP45 in it (Note: avoid installing the shield upwind or downwind of the tower shield). If a non-aspirated shield is not available, you may test the sensors outside the aspirator. To do this, remove the station sensor from the aspirator. Using bungee cords, secure the station sensor and audit sensor against the heat shield, then the heat shield to the tower. Position the heat shield so that the sensors are shielded from the sun.

3. Connect the audit HMP45 to the 21X datalogger. Using a small flat head screwdriver, connect the white wire to 2L, the yellow wire to 2H, the blue wire to 3H, the red wire to 12V, both the black and clear wires to G, and a jumper from 1L to 2L.

4. Turn on the 21X via a small toggle switch located on the side of the datalogger. "HELLO" will appear on the display. Wait until the display no longer shows this, and then attach the 9-pin cable to the datalogger on one end and to the SC32A Optically Isolated Interface device on the other. **The datalogger will "lock up" if the cable is attached to it while "HELLO" is displayed**. Attach the 9-to-25 pin adaptor cable to the computer's serial port on one end (9-pin side) and to the SC32A on the other (25-pin side). **Do not attempt to connect the datalogger to the computer directly via a 9-pin-to-9-pin cable as damage may occur to either unit.**

5. Upload the calibration program from the laptop computer to the 21X datalogger. Turn on the computer and run LoggerNet. At the main screen, click "Connect." Select "21X" under the Station List and click "Connect." Once connected, click "Set Station Clock" to synchronize the day and year (the day and year must be correctly set in the computer). Now click "Send", and then select the program "21XCal.dld." Depending on which directory was accessed last, you may have to look for the file in "C:\Campbellsci\LoggerNet\DLD." Select, and then download the file to the datalogger. If the download is successful, a confirmation box will appear. Click "Ok", then "Disconnect." **Failure to click "Disconnect" will cause the 21X to "lock up."** Now, unplug the 9-pin cable.

6. Synchronize the 21X clock with the station's CR10 clock. To access the station clock, connect one end of the 9-pin cable to the CR10 datalogger and the other end to a Campbell CR10KD Keyboard Display. Press *5 - the time should appear on the keyboard display. On the 21X, press *5 to display the time, then press the "A" button 3 times for the "time set" menu. Synchronize the 21X datalogger clock to within one second of the station's CR10 datalogger clock. To do this, note the station time, add one minute to this, then key in the four digit time in an HH:MM format. Press "A" on the 21X once the station time reaches the time displayed on the 21X.

7. At some district sites, flag 3 must be set *high* on the station's CR10 to enable 5-minute data logging. To verify the flag status, connect the CR10KD keypad to the station datalogger. Press *0, *C 1955 A,*6 A D. The left-most digit from the left represents flag 1; the second digit from the left represents flag 2, and so on. *0* represents *low*, *1* represents *high*. Pressing 3 toggles flag 3 between *high* and *low*. If this flag is *low*, press 3 to set it *high*.

8. Display temperature and %RH on the CR10KD and 21X. Press *6A on both keypads. The first input location should be displayed. Press A repeatedly to scroll to the temperature and %RH input location for each unit. The temperature and %RH input locations for the 21X datalogger are 02 and 03, respectively. Input locations for the CR10 dataloggers are 03 and 04.

9. Allow up to 30 minutes (depending on conditions) for both HMP45 sensors to stabilize before collecting *valid* data. When temperature and RH differences between the station and audit sensors become relatively constant, allow four 5-minute averaging periods to pass. **Note that 5-minute periods begin automatically at 5-minute multiples referenced from 0000 (i.e. 1345, 1350, etc.) and are identified by their ending-time.** For example, a data point associated with a time of 1200 represents the average of all samples with 1-second intervals recorded from 1155 to 1200.

10. Collect and record data from the 21X datalogger:

    If the data does not need to be saved to a file, data points from its *output array* (please see Appendix C) can be displayed directly on the 21X. Press *7A to access the first recorded data point in the first output array. Since we will usually want the *latest* recorded data, pressing B repeatedly will allow us to scroll through memory in *reverse* order of beginning with the last data point of the last output array. You may now scroll to and record the appropriate temperature and RH data points for each 5-minute period (Hint: data points can be easily found by scrolling back to the desired 5-minute ending time, then scrolling forward to the desired data point). On the 21X, *Temperature* and *RH* are the second and third data points, respectively, after *ending time*. The order of data can be found in the file 21XCal.CSI in the laptop. Record the values onto the audit form (see attachment).

    To download the logged data onto a computer file, establish a connection between the 21X datalogger and the computer (step 4), then click "Collect Now." The output file, 21X_1.dat, can be found at "C:\Campbellsci\LoggerNet\Data\21X." Before opening this file, rename it to the station's name so that it will not be over-written during the next download. The data may be viewed on any text editor such as *Notepad* or *View* in LoggerNet. Record the values onto the audit form (see attachment).

11. Station data is collected using the same methods. To display data points directly on the CR10KD keypad, connect the keypad to the 9-pin connector on the CR10 datalogger and press *7A, then B repeatedly to scroll through data points in reverse. Note that the order of data is different from that of the 21X program. Refer to the .CSI file associated to the specific location being audited or calibrated. In general, *temperature* and *RH* are the fourth and fifth data points, respectively, after *ending time*.

    To download station data to the laptop computer, connect it to the CR10 datalogger (step 4). Again, make sure the computer and datalogger are isolated by using the SC32A Optically Isolated Interface. **Do not attempt to connect the datalogger to the computer directly via a 9-pin-to-9-pin RS232 cable as damage may occur to either unit.** Establish a connection to the station datalogger and download the data. After collection, the file can be found at "C:\Campbellsci\LoggerNet\Data." Record the same ending times as before and the corresponding values on the audit form.

12. Calculate the temperature difference, dew point, and dew point difference corresponding to each 5-minute period. To calculate dew point, run the TDC program from the laptop. To calculate audit dew point, enter the corresponding *audit* temperature and *audit* %RH for each ending time. To calculate station dew point, enter the *audit* temperature and *station* RH. **The audit temperature is used to calculate both audit and station dew points because it is considered to be the most accurate temperature available.** The temperature tolerance is ±1.0º; the dew point tolerance is ±1.5ºC.

<u>Assmann 2530 Psychrometer</u>

1. If the site has a fold-down tower and the radiation shield height is above 4m, fold the tower down.

2. Clean the station HMP45 sensor (Vaisala HMP45 step 1).

3. Remove the wet bulb cover and check that the sock is not soiled. With the sock over the bulb, soak the sock thoroughly in the bottle of distilled water and re-attach the bulb cover.

4. Secure the psychrometer with bungee cords near the radiation shield so that the bulbs are close to the bottom opening of the shield.

5. Secure the styrofoam heat shield to the tower and radiation shield so that the radiation shield, station sensor casing, and the psychrometer are shielded from the sun.

6. Display temperature on the CR10KD keypad display by pressing *6, then A repeatedly to input location 3.

7. Wind the psychrometer with the winding key (clockwise). This will provide 8 minutes of aspiration. Re-wind the psychrometer as necessary.

8. The psychrometer and station temperature readings should be recorded simultaneously. The procedure to do this is as follows: a *tower person* at the psychrometer should watch the *dry bulb thermometer* until it is stable, take a reading (using a magnifying glass if necessary), and say "read it" to the *ground person* reading the CR10KD keypad display. The ground person should then record the station temperature on the worksheet and say "got it." Upon hearing this, the tower person should say the psychrometer temperature while the ground person records this in the worksheet. Repeat this process a total of 9 times.

9. From the temperature display (input location 3), press A to display relative humidity at input location 4 (%RH).

10. Take the psychrometer wet and dry bulb temperatures and station %RH using the same procedure described in step 8 a total of 4 times.

11. A table of correction factors at 4 points in the psychrometer worksheet (Appendix B) is used to correct for temperature nearest these specified temperatures. These values are determined during the pre-calibration check (see *calibration procedures*). The dry bulb thermometer S/N is 4962; The wet bulb thermometer S/N is 4979. To apply the correction, check the *adjustment (adj)* box and add the correction value to the psychrometer temperature reading (the correction factor may be negative). Refer to Table 1 below to determine correction factors:

Temperature (ºC)	**Action**
Less than 12.5	Apply 10ºC correction factor
Between 12.5 and 17.4	Apply 15ºC correction factor
Between 17.5 and 22.4	Apply 20ºC correction factor
Greater than 22.5	Apply 25ºC correction factor

Table 1:
Psychrometer Correction Factors

13. Calculate temperature differences (*audit temp + correction factor – station temp*).

14. Calculate and record the psychrometer %RH and dew point. Run the RHC program from the laptop. For each calculation, enter the wet and dry bulb temperature after the applicable correction factors have been applied.

15. Calculate and record the station %RH and dew point. Run the TDC program from the laptop. For each calculation, enter the dry bulb temperature (after the applicable correction factors have been applied) and the station %RH.

16. Calculate dew point differences and determine pass/fail for temperature and dew point. The temperature tolerance is ±1.0º; the dew point tolerance is ±1.5ºC.

PREVENTATIVE MAINTENANCE

Audit HMP45 Temperature/RH Sensor

1. The HMP45 should always be stored in its case to prevent damage to the sensor.
2. Periodically clean the casing and filter assembly so that it is free of dirt. Be sure to do this quarterly before each audit season.

Campbell 21X Datalogger

1. Charge the 21X overnight after about 12 hours of use.
2. The 21X should always be stored in the calibration case when not charging or in use.
3. Test the internal nickel-cadmium rechargeable battery once per year (see Battery Testing SOP)
4. Replace the battery when it no longer can hold an adequate charge.

Assmann 5230 Psychrometer

1. The Assmann 5230 Psychrometer should be stored in its case to prevent damage.
2. Clean or replace the wet bulb sock if it becomes soiled.

CALIBRATION PROCEDURES

1. The Audit HMP45 Temperature/RH Sensor is sent to the factory for calibration annually.

2. The Campbell 21X Datalogger is sent to the factory for calibration every 5 years.

3. The Assmann 5230 Psychrometer is calibrated in the lab against a NIST mercury thermometer before each season of audits. The temperature comparisons are made in a 10ºC, 15ºC, 20ºC, and 25ºC water bath. A correction factor is placed in the Psychrometer audit worksheet correction table if any of the psychrometer temperature readings deviate from those of the NIST mercury thermometer.

AUTHORS, REVISIONS, AND APPROVALS

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1. State of California Air Resources Board. August 2002. *Air Monitoring Quality Assurance Volume V: Audit Procedures For Air Quality Monitoring*. Appendix S, Performance Audit Procedures For Meteorological Sensors. http://www.arb.ca.gov/aaqm/qmosqual/qamanual/vol5/v5apxs.pdf

APPENDIX A

BAAQMD AUDIT RECORD

(VAISALA HMP45)

BAAQMD AUDIT RECORD

Site Name _____

Auditor _____

Date __/__/__ Start Time: _____(pst) End Time: _____(pst)

==========

Temp/RH Sensor Information:

Sensor Mfg **Vaisala**
Model No **HMP 45C**
Serial No _____
Sensor Ht _____

Last Calibration Date _____
Is the Fan Running? No ☐ Yes ☐
Calibration Sensor Used: Vaisala HMP45C

Temperature Readings:

No.	Standard	Ending Time	Tower Sensor	Difference
1	_____**ºC**	_____	_____**ºC**	_____
2	_____**ºC**	_____	_____**ºC**	_____
3	_____**ºC**	_____	_____**ºC**	_____
4	_____**ºC**	_____	_____**ºC**	_____

Tolerance: ±1.0C Results: Pass/Fail

Relative Humidity Readings:

No:	Standard RH:	Dew Pt.	Ending Time:	Tower sensor RH:	Dew Pt.	Difference
1	_____**%**	_____**ºC**	_____	_____**%**	_____**ºC**	_____
2	_____**%**	_____**ºC**	_____	_____**%**	_____**ºC**	_____
3	_____**%**	_____**ºC**	_____	_____**%**	_____**ºC**	_____
4	_____**%**	_____**ºC**	_____	_____**%**	_____**ºC**	_____

Tolerance: Dew point ±1.5°C Results: Pass/Fail

COMMENTS:

APPENDIX B

BAAQMD AUDIT RECORD

(ASSMANN 5230 PSYCHROMETER)

BAAQMD AUDIT RECORD

Site Name _____

Auditor _____

Date __/__/__ Start Time _____(pst) Finish Time _____(pst)

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TEMPERATURE SENSOR

Temp Sensor Mfg	**Vaisala**	Last Calibration Date:	_____
Model No	**HMP45C**	Calibration Sensor Used:	**Assmann**
Serial No	_____	Is the Fan Operating:	Yes ☐ No ☐ N/A ☐
Sensor Ht	_____		

TEMPERATURE SENSOR

No.	Unadj Psychrometer Temperature (4962)			Logger Temperature			Adj*	Difference		
1							☐			
2							☐			
3							☐			

Temperature Tolerance: 1.0^{o} C for ambient comparisons.

Results: Pass/Fail

HUMIDITY SENSOR

No.	Unadj Psychromerter T_{dry}	T_{wet}	Adj*	Calc RH	Calc Dewpt	Logger RH	Calc Dewpt	Dewpt Diff
1			☐	%		%		
2			☐	%		%		
3			☐	%		%		
4			☐	%		%		

*Adjustments

Temp	4962	4979
10°C	0	-0.1
15°C	0	0
20°C	0	0
25°C	0	0

T_{dry}: 4962; T_{wet}: 4979

Dewpoint Tolerance: 1.5^{o} C

Results: Pass/Fail

Comments:

APPENDIX C

CAMPBELL SCIENTIFIC 21X DEFINITIONS

Instruments are sampled once per second and its data are stored in specific *input locations* in the CR10 and 21X dataloggers. This data can be displayed in real-time on the 21X and CR10KD display. Press *6, then A repeatedly to scroll forward through the input locations and corresponding data. Refer to Table 2 for the input location definition.

Table 1: 21X Input Location Definition

I.D.	Data Description
01	Eppley PSP Pyranometer (L/min)
02	**Vaisala HMP45 Temperature (ºC)**
03	**Vaisala HMP45 Relative Humidity (%RH)**
04	Licor LI-200 Pyranometer (L/min)
05	Hycal PRT Temperature Sensor (ºC)
06	21X Battery Voltage

Sampled data are then processed and stored in sequential memory known as *output arrays*. Each array consists of data associated with each time-averaged interval. The memory arrays are accessed by pressing *7A on either the CR10KD or 21X keypads. Data points consist of *I.D.* displayed to the left, and *Data* to the right. The first data point displayed is the last data point recorded by the datalogger. Pressing B repeatedly scrolls through memory in *reverse* order. Refer to table 2 for the output array definition.

Table 2: 21X Output Array Definition

I.D.	Data Description
01	Array: (05) = 5-minute average data
02	Year
03	Julian Day
04	Time (HH:MM:SS)
05	Eppley PSP Pyranometer (L/min)
06	**Vaisala HMP45 Temperature (ºC)**
07	**Vaisala HMP45 Relative Humidity (%RH)**
08	Licor LI-200 Pyranometer (L/min)
09	Hycal PRT Temperature Sensor (ºC)
10	21X Battery Voltage