

# 3-D sonic anemometer Standard Operating Procedure (SOP) for the Baltimore PM Supersite



January, 2001

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# Measurement of wind speed and air temperature and computation of sensible heat and momentum fluxes using a 3-D sonic anemometer

## 1. Introduction

This SOP describes the basic working principle of the Campbell Scientific CSAT3 three dimensional sonic anemometer used for wind speed and air temperature measurements during the Baltimore PM Supersite project intensives. In addition, theoretical background is given on the computation of momentum and sensible heat fluxes.

## 2. Method

A Campbell Scientific CSAT3 three-dimensional (3-D) sonic anemometer is used for this study. It measures wind speed and the speed of sound on three nonorthogonal axes. The wind speeds are then transformed into the orthogonal wind components  $u$ ,  $v$  and  $w$  and are referenced to the anemometer head. The speed of sound,  $c$ , is the average between the three nonorthogonal sonic axes. From the sonically determined speed of sound the ambient air temperature is deduced. Errors caused by wind blowing normal to the sonic path are corrected before the wind speed is transformed into orthogonal coordinates. The CSAT3 can be used to measure average horizontal wind speeds and direction and the turbulent fluctuations of horizontal and vertical wind. From turbulent wind fluctuations, momentum flux is calculated. As an example, the vertical flux of horizontal x-momentum is defined as

$$\tau_{xz} = -\rho \langle u' w' \rangle \quad (1)$$

where  $\langle . \rangle$  denotes the averaging operation,  $\rho$  is the density of air and  $u'$  ( $= \langle u \rangle - u$ ) and  $w'$  ( $= \langle w \rangle - w$ ) are the fluctuating wind components in the x- and z-direction, respectively. Similarly, the vertical flux of y-momentum  $\tau_{yz}$  can be computed. Combining this information furnishes the friction velocity  $u_*$ . By finding the covariance between the vertical wind speed fluctuations and temperature the sensible heat flux  $H$  can be computed. The sensible heat flux is given as

$$H = \rho c_p \langle w' T' \rangle \quad (2)$$

where  $c_p$  is the specific heat of air at constant pressure and  $T'$  ( $= \langle T \rangle - T$ ) is the fluctuating temperature. In addition to the fluxes of momentum and heat, the information acquired with the sonic anemometer allows to characterize atmospheric stability. Furthermore, from the horizontal wind components  $u$  and  $v$ , the wind direction can be determined.

The sonic transducers are sealed and will not be damaged should they become wet. The wind measurements, however, will not be valid because the water droplets, on the face of the transducer, will scatter the sonic signal. As soon as the transducer faces dry, the CSAT3 will lock on to the wind signal and begin making measurements.

The CSAT3 will be operated using a SDM (Synchronous Device for Measurements) communications and a Campbell Scientific CR23X datalogger. The data remains on the internal datalogger memory and will be downloaded on a daily basis using Campbell Scientific data communication software package PC208.

### 3. Data Quality Objectives

Campbell Scientific CSAT3s have been used in numerous field experiments (e.g. Albertson et al., 1997; Porte-Agel et al., 2000; Pahlow et al., 2001) and prove to be a reliable tool to obtain information on wind speed and air temperature at high resolution. The measurements of wind speed and air temperature using the CSAT3 underlie some limitations. These limitations can be summarized as follows:

- Operating temperature range:  $-30^{\circ}\text{C}$  to  $+50^{\circ}\text{C}$
- Speed of sound:  $300$  to  $366\text{ m s}^{-1}$ ; least significant bit is  $1\text{ mm s}^{-1}$
- No data can be recorded during rain.

Our objectives for the Baltimore PM Supersite project are:

1. Wind and temperature data at high resolution during intensive measurement periods.
2. Characterize air turbulence transport at the field site in terms of momentum and heat fluxes. The data will be collected at 10Hz.

Precision:

- rms of u and v is  $1.0\text{ mm s}^{-1}$
- rms of w is  $0.5\text{ mm s}^{-1}$
- rms of c is  $1.0\text{ mm s}^{-1}$  ( $0.002^{\circ}\text{C}$ )

Values are the root mean squared (rms) of instantaneous measurements made of a constant signal. These values are not affected by the sampling rate.

Accuracy:

*Offset error:*

- u,v:  $< \pm 4.0\text{ cm s}^{-1}$
- w:  $< \pm 2.0\text{ cm s}^{-1}$

*Gain error:*

- Wind vector within  $\pm 5^{\circ}$  of horizontal  $< \pm 2$  percent of reading
- Wind vector within  $\pm 10^{\circ}$  of horizontal  $< \pm 3$  percent of reading
- Wind vector within  $\pm 20^{\circ}$  of horizontal  $< \pm 6$  percent of reading

Data completeness: At least 85 percent data completeness (depending on rain/no rain).

Operating range:  $-30$  to  $+50^{\circ}\text{C}$ ; wind speeds  $< 30\text{ m s}^{-1}$ ; wind angles between  $\pm 170^{\circ}$

## **4. Installation**

### **4.1 Orientation**

The three wind components are defined by a right handed orthogonal coordinate system. The CSAT3 points into the negative x direction. If the anemometer is pointing into the wind, it will report a positive u-velocity. In general, point the anemometer into the prevailing wind to minimize the amount of data that is contaminated by the anemometer's arms and other supporting structures.

### **4.2 Mounting**

The sonic anemometer is mounted to the top of the CM6/CM10 tripod (or any vertical 3/4" diameter US bore pipe) with a 3/4" by 3/4" Nu-Rail (P/N 1017), the Nu-Rail is included with the CSAT3. The Nu-Rail will accommodate up to a 1" outside pipe diameter. Attach the Nu-Rail to the vertical pipe and lightly tighten the vertical set screws. Insert the horizontal mounting arm into the Nu-Rail and lightly tighten the horizontal set screws. Point the horizontal arm into the prevailing wind. Tighten all the Nu-Rail set screws. Mount the anemometer head to the horizontal arm. Lightly tighten the bolt underneath the anemometer block. Attach the electronics box to the body of the tripod (or 3/4" US bore pipe). Use a 1/2" wrench to tighten the nuts. Connect the cable from the anemometer head to the connector on the electronics box labeled "Transducer Head".

### **4.3 Leveling**

Over flat terrain, adjust the anemometer head so that the bubble within the level is in the bullseye. Over sloping terrain, adjust the anemometer head so that the horizontal surface that the bubble is mounted on, is parallel to the terrain. Firmly grasp the anemometer block, loosen the bolt underneath the block, and adjust the head accordingly. Finally, tighten the bolt with a 9/16" wrench.

A copy of the Campbell Scientific Instruction Manual "CSAT3 Three Dimensional Sonic Anemometer", Revision 3/98 will be kept on site.

The anemometer will be installed on site by Johns Hopkins University personnel.

## **5. Wiring**

There are four military style connectors on the CSAT3 electronics box. They are labeled as +12 SDM, RS-232, Transducer Head, and Analog Output. Connect the cable from the anemometer head to the electronics box labeled Transducer Head. The anemometer head cable is 2.13m (7ft) in length. Each of the signal cable is 7.62m (25ft) in length. Connect the appropriate signal cable to the electronics box. For this experiment, the SDM Output will be connected to a CR23X datalogger. The wire color scheme is given in Table 1 and Table 2.

Battery Terminal	Description	Color
Positive	12 VDC	Red
Negative	Ground	Black

Table 1. CSAT3 Power

Channel	Description	Color
C1	SDM Data	Green
C2	SDM Clock	White
C3	SDM Enable	Brown
G	Digital Gnd	Black
G	Shield	Clear

Table 2. CSAT3 SDM Output to a CR23X datalogger

## 6. CSAT3 Output

The CSAT3 has three signal outputs: SDM, RS-232, and analog. During the Baltimore Supersite Project the SDM output is used. SDM is a Campbell Scientific communication protocol used between a Campbell Scientific datalogger and a smart sensor. This protocol uses control ports 1,2, and 3 to communicate with the CSAT3. The datalogger instruction, SDM-CSAT3 (P107), is used to communicate with the CSAT3 over SDM bus.

## 7. Datalogger Programming using SDM

SDM-CSAT3 (P107) is an Input/Output instruction that controls and retrieves data from the CSAT3. The wind data and the speed of sound (sonic virtual temperature) is scaled by Instruction 107 into m/s or degree Celsius.

In Table 3 the SDM-CSAT3 (P107) instruction parameters are listed.

Parameter number	Data type	Default description
1	Integer	Reps
2	Integer	SDM Address
3	Integer	Option
4	Real	Ux input location

Table 3. SDM-CSAT3 (P107) instruction parameters

Reps: The number of CSAT3s on the SDM bus that will be sequentially addressed with the SDM-CSAT3 (P107) instruction. For this experiment, one CSAT3 will be in operation.

SDM Address: The unique SDM Address of the CSAT3 that the datalogger will communicate with. The SDM Address is 3.

Option: Option 91 "trigger and get wind and speed of sound data" is used, which sends a measurement trigger to the CSAT3 whose SDM address is specified in parameter 2. The

CSAT3 will send wind speed and the sonic virtual temperature via the SDM bus to the datalogger.

Ux input location: The input location to store the first of five data values. The CSAT3 returns the following data after receiving the "trigger and get data" command in parameter 3: u, v, w, T and a diagnostic word.

Diagnostic word: The fifth output from the CSAT3 is the diagnostic word. The diagnostic word describes the status of the anemometer and is useful in filtering data. For example, when the anemometer is locking in on the ultrasonic signals after receiving the acquire signals command, the -99999's it sends to the datalogger can be filtered out of the statistics based on the diagnostic word.

Appendix 1 shows a sample program for the SDM-CSAT3 (P107) used with a CR23X datalogger.

## 8. Data collection

To start data collection, connect the CSAT3 to power (see Table 1). The CSAT3 will start taking data if the data logger program has been transferred to the internal memory. The data logger program will be on the CR23X before the experiment starts and it will reside in the internal memory for the entire duration of the experiment. In case of a power outage, the data logger will resume taking data after it has been reconnected to power. To stop data collection, disconnect the power line.

## 9. Data Transfer

- The data is stored on the internal memory of the CR23X datalogger. Once per day, the data needs to be retrieved from the datalogger. A laptop is used for this purpose. Connect the laptop via the RS232 cable (stored in the enclosure of the metstation) - use the parallel port of the laptop - to the CR23X. Start Campbell Scientific data communication software package PC208 (shortcut is on desktop of the laptop; PC208.exe file is located under C:\PC208).
- Do the following to save the data on the hard drive of the laptop: **Open** datalogger session. **Retrieve** data. **Save** (user will be prompted to give file name; default format: Year, Day, Hour/Minute, Seconds (2400 at midnight) - accept); Data logger will send data from time since last data has been retrieved by user;
- Transfer data with portable zip drive/disk to desktop computer in lab. Do NOT remove the data from the hard drive of the laptop in the field.
- Write data to cd.
- Note date/time of data transfer and storage in field logbook.
- Data validation and transfer to data manager Ziad Ramadan at Clarkson University (ramadan@clarkson.edu): The data will be validated at Johns Hopkins University (in charge for this operation are Markus Pahlow and Jan Kleissl). A completeness check will be performed and missing data will be designated as -99999. After data validation the data will be sent (via email) once per week to the data manager. One file for every day in ASCII format.

## 10. Daily Checks

Check if current time is displayed on CR23X. This means that data logger has power and that it is taking data.

After transfer of data to laptop, do the following:

- Open data file with spreadsheet program. Check that there is no data missing between data transfer from previous day and current data transfer. If there is data missing, retrieve data once more from CR23X. If data is still missing, record missing time period in field logbook.
- If no data has been recorded, first check connection to power. If power is connected and if the current time is displayed on the CR23X, but still no data, notify Markus Pahlow (410-516-4483; mpahlow@jhu.edu) or Jan Kleissl (410-516-5031; jan@kleissl.com). Make a note in the field logbook.

The data will be checked for completeness at Hopkins (either Markus Pahlow or Jan Kleissl will do this every day) using computer programs especially written for this purpose.

No calibration is necessary for the CSAT3. It only needs to be recalibrated if any of the transducers of the 3-D sonic have been bent. If that is the case, the instrument has to be shipped to Campbell Sci., Logan, Utah. Replace instrument with spare JHU 3-D sonic anemometer, which is stored at Johns Hopkins Univ. Call Markus Pahlow or Jan Kleissl.

## 11. Maintenance

The CSAT3 is unable to measure wind when water droplets are present on the face of the transducers. The CSAT3 will be ready to measure wind as soon as the water droplets evaporate or are removed by the station operator. Remove the water droplets by dabbing a cotton swab or tissue on the face of the transducer.

## 12. Safety issues

None.

### References:

- Albertson JD, Parlange MB, Kiely G, Eichinger WE, 1997: The average dissipation rate of turbulent kinetic energy in the neutral and unstable atmospheric surface layer, *J. Geophys. Res.*, 102, 13423-13432.
- Porte-Agel F, Parlange MB, Meneveau C, Eichinger WE, Pahlow M, 2000: Subgrid-scale dissipation in the atmospheric surface layer: Effects of stability and filter dimension, *J. Hydromet.*, 1, 75-87.
- Pahlow M, Parlange MB, Porte-Agel F, 2001: On Monin-Obukhov Similarity in the Stable Atmospheric Boundary Layer, *Bound. Layer Meteor.*, in press.

## Appendix 1.

Sample Program for SDM-CSAT3 (P107) used with CR23X

;{CR23X}

;

\*Table 1 Program

01: 0.1 Execution Interval (seconds)

1: SDM-CSAT3 (P107)

1: 1 Reps  
2: 3 SDM Address  
3: 91 Trigger and Get wind & Ts data  
4: 1 Ux Input Location [ Ux ]

2: IF (X<=>F) (P89)

1: 5 X Loc [ diag ]  
2: 1 =  
3: 61440 F  
4: 21 Set Flag 1 Low

3: If Flag/Port (P91)

1: 21 Do if Flag 1 is Low  
2: 30 Then Do

4: IF (X<=>F) (P89)

1: 5 X Loc [ diag ]  
2: 3 >=  
3: 0 F  
4: 30 Then Do

5: IF (X<=>F) (P89)

1: 5 X Loc [ diag ]  
2: 2 <>  
3: 61503 F  
4: 30 Then Do

6: Do (P86)

1: 11 Set Flag 1 High

7: SDM-CSAT3 (P107)

1: 1 Reps  
2: 3 SDM Address  
3: 1 Set Execution Parameter  
4: 1 Ux Input Location [ Ux ]

8: End (P95)

9: End (P95)

10: End (P95)

11: Do (P86)

1: 10 Set Output Flag High (Flag 0)



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12:  If Flag/Port (P91)
    1: 10      Do if Output Flag is High (Flag 0)
    2: 10      Set Output Flag High (Flag 0)

13:  Set Active Storage Area (P80)
    1: 1       Final Storage Area 1
    2: 110     Array ID

14:  Real Time (P77)
    1: 1121    Year,Day,Hour/Minute,Seconds (2400 at midnight)

15:  Resolution (P78)
    1: 1       High Resolution

16:  Sample (P70)
    1: 5       Reps
    2: 1       Loc [ Ux      ]

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*Table 2 Program
  02: 0.0      Execution Interval (seconds)

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*Table 3 Subroutines
End Program

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-Input Locations-

```

1 Ux      5 1 2
2 Uy      9 1 2
3 Uz      9 1 2
4 Ta      9 1 2
5 diag    17 4 2
6 _____ 0 0 0
7 _____ 0 0 0
8 _____ 0 0 0
9 _____ 0 0 0
10 _____ 0 0 0
11 _____ 0 0 0
12 _____ 0 0 0
13 _____ 0 0 0
14 _____ 0 0 0
15 _____ 0 0 0
16 _____ 0 0 0
17 _____ 0 0 0
18 _____ 0 0 0
19 _____ 0 0 0
20 _____ 0 0 0
21 _____ 0 0 0
22 _____ 0 0 0
23 _____ 0 0 0
24 _____ 0 0 0
25 _____ 0 0 0
26 _____ 0 0 0
27 _____ 0 0 0
28 _____ 0 0 0

```

-Program Security-

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0000
0000
0000

```

-Mode 4-

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-Final Storage Area 2-
0

```

-CR23X ID-

```

0

```

-CR23X Power Up-

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3

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