

Center for Urban Environmental Research and Education
University of Maryland, Baltimore County

Methodology for Installation of Eddy Covariance Meteorological Sensors and Data Processing

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June 2009

Christiane Runyan



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University of Maryland, Baltimore County
Center for Urban Environmental Research and Education
1000 Hilltop Circle, Technology Research Center
Baltimore, Maryland 21250

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ON THE COVER

Christiane Runyan, Jeff Campbell and Chris Wilson deploying and programming eddy covariance sensors, October 10, 2008. Photograph by Philip Larson.

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1. Basic Principles of Operation of Eddy Covariance Meteorological Sensors

The extended eddy covariance equipment measures temperature, air pressure, humidity, the magnitude of wind speed components (U_x , U_y and U_z), wind direction, and concentrations of carbon dioxide and water vapor. These measurements can be used to compute sonic temperature, sensible heat flux, latent heat flux, carbon dioxide flux, momentum flux of wind, turbulent kinetic energy, Bowen ratio, Obukhov length, stability, vapor pressure, vapor density and air density. Further detail pertaining to theory and equations that relate physical properties to the sensors' operation can be found in their respective manuals. The following document is a guide to deployment of the meteorological components required for the eddy covariance technique. For a guide to the accompanying soil sensors CUERE's soil methodology document can be consulted.

1.1 CSAT3

The CSAT3 is a three-dimensional sonic anemometer that measures wind speed and the speed of sound on three nonorthogonal axes. Each of three pairs of transducers obtains a measurement by transmitting and receiving an ultrasonic signal. The signal's time of flight is directly related to wind speed along the sonic transducer axis. From these high frequency measurements, the orthogonal wind speed components (U_x , U_y and U_z) and sonic temperature (T_s) can be computed.

1.2 LI-7500

The LI-7500 is a nondispersive, high speed, open path infrared $\text{CO}_2/\text{H}_2\text{O}$ gas analyzer (IRGA) that measures in-situ densities of carbon dioxide and water vapor in turbulent air structures. An infrared beam is transmitted through a single optical path that continuously alternates between absorbing and non-absorbing wavelengths passing through the sample path (LI-COR, 2004). Absorption is related to density through the following equation:

$$\rho = P * f_w(\alpha_w S_w / P)$$

where

ρ is density [ML^{-3}]

P is pressure [$\text{ML}^{-1}\text{T}^{-2}$]

α_w is absorptance of water, where absorptance is the ratio of absorbed to incident radiation [dimensionless]

S_w is the span adjustment term for water [dimensionless]

$f_w(\)$ is the calibration function generated by measuring a range of known densities and fitting a curve to ρ/P plotted against $\alpha_w S_w / P$

This equation holds true for water because the absorption of radiation by water vapor is not significantly influenced by any other gas, and therefore the effective water vapor pressure is simply measured as the total pressure (LI-COR, 2004). The same equation is used to obtain CO_2 density, however the absorption

of radiation by CO₂ molecules is influenced by several other gases, therefore the equation changes to the pressure equivalent of CO₂ instead of pressure (LI-COR, 2004).

1.3 Net Radiometer (Q7.1)

The Net Radiometer is a high output thermopile sensor that obtains a measurement of net all-wave radiation by generating a millivolt signal proportional to the net radiation level (Campbell Scientific, Inc., 1996). Net all-wave radiation is the sum of incoming shortwave radiation, outgoing shortwave radiation, incoming longwave radiation and outgoing longwave radiation. The sign for net radiation is positive towards the surface and negative away from the surface. Common definitions of the components of the energy budget can be found in, e.g., Arya (2001), and are summarized here for the convenience of the reader. Incoming shortwave radiation consists of both direct beam radiation and diffuse radiation that reaches the earth's surface after having been scattered by molecules and suspended particulates in the atmosphere. Outgoing shortwave radiation is the fraction of shortwave radiation that is reflected by the surface. Incoming longwave radiation is contributed primarily by clouds that radiate like blackbodies at their cloud base temperatures. Incoming longwave radiation is also contributed to by atmospheric gases and aerosols that both absorb and emit energy as a function of their wavelength band. Outgoing longwave radiation from the surface is primarily a function of surface temperature.

1.4 HMP45C

The HMP45C contains a platinum resistance temperature detector and a Vaisala HUMICAP 180 capacitive relative humidity sensor to obtain air temperature and relative humidity measurements. The probe is deployed inside a radiation shield to reduce the effect of direct solar heating.

1.5 CR5000

The CR5000 datalogger can record up to 5,000 measurements per second with 16-bit resolution. The operating system includes measurement, processing and output instructions for programming the datalogger using a BASIC-like syntax. Measurement instructions support bridge configurations, voltage outputs, thermocouples and pulse/frequency signals, while processing instructions support algebraic, statistical and transcendental functions. A voltage differential measurement instruction, which is used for the HMP45C, net radiometer and soil heat flux plates, obtains the voltage difference between the high and low inputs of a differential channel (Campbell Scientific Inc., 2007). The thermocouple differential instruction, which is used for the soil thermocouples, adds the measured voltage to the voltage calculated for the reference temperature relative to degrees Celsius and converts the combined voltage to temperature in degrees Celsius (Campbell Scientific Inc., 2007).

1.6 HUB-SDM8

The HUB-SDM8 is an 8-channel hub for Synchronous Device for Measurement (SDM) peripherals and power connectors. The HUB SDM-8 is used to daisy-chain multiple sets of SDM devices to a single datalogger. The HUB SDM-8 encloses the SDM and power wires in eight compression fittings and eight

terminal strips. Compression fittings form a tight seal by applying a compressive force to the cables and cable fitting. A terminal strip is an insulated bar that contains a set of screws to which wires are attached.

2. Lab Testing

The following is a supplement to the manuals to guide the user through the process of sensor testing.

Upon receipt of ordered eddy covariance equipment, the user should ensure that ordered components on the itemized quote from the vendor match the contents of the boxes. Next, the user should become familiarized with the manuals, sensors and purchased Campbell Scientific computer program for the eddy covariance system.

2.1 Loggernet

Loggernet is software produced by Campbell Scientific that aids in writing and editing of data logging programs, and viewing, graphing and downloading data from stored program tables. Stored program tables are called to in the computer program so the output from measurements can be saved. Loggernet should be installed on the field laptop and the computer that will be used to download the data. A connection between the computer and datalogger can be established with a RS-232 null modem cable where the cable's transmit and receive lines are crosslinked. Next, a connection setting is established between the datalogger and computer by selecting either the EZSetup or setup option. The EZSetup option allows the user to scroll through a series of prompted menus to ensure that required connection settings have been identified. Connection settings include: identification of datalogger type (i.e. CR5000), communication port that will be used between the computer and datalogger (i.e. COM1), the option to define a collection schedule and datalogger settings such as baud rate (number of signaling events made to the transmission medium per second using a digitally modulated signal or line code), pak bus address, security code, extra response time and maximum time online (Campbell Scientific, Inc., 2007). Schedule collection enables Loggernet to connect with the datalogger to download data at specified times. Certain Campbell Scientific dataloggers use PakBus communication (i.e. CR1000) however the CR5000 does not use this type of communication method. If a connection setting has already been established as previously described, the desired datalogger model should be selected and the existing setup settings checked.

In the setup settings of Loggernet, both the eddy covariance data tables to be downloaded and the desired formats for those tables should be selected. The tables selected for download and their output format should be selected as Binary (TOB1) for the ts_data table and ASCII (TOA5) for the flux data table. The tables, ts_data and flux, are the two tables where data are stored. The comp_cov and dly data tables are working data tables that do not need to be downloaded. A working data table is one where the data is not stored permanently, but instead stored temporarily for use in flux calculations. In order for the two stored tables to be downloaded using Loggernet, the 'Include for Collection' checkbox is selected. This selection can be enabled/disabled in the setup tab of Loggernet under the tab 'Data Files'. After selecting this tab, the file output option, the output format, the name of the output file and the

collection mode can be selected. The file output option should be selected as 'Append to End of File'. If any connection settings are changed, the 'Apply' icon should be selected to activate and save the changes. Appendix D of this document can be consulted for further information on downloading data and the use of EdiRe.

To obtain and log measurements, a computer program is written (or obtained) and uploaded to the datalogger through Loggernet. For the extended eddy covariance sensors, the Campbell Scientific Program titled 3D_LI_FW_NRL_4HFP_V2_2.CR5 can be used. This program, hereafter referred to as the original program, was purchased by CUERE from Campbell Scientific. This program is located in CUERE's U drive in the Eddy Covariance folder (U:\Eddy Covariance\Programs).

If the soil sensors are not collocated with the meteorological sensors, the program SansSoil.CR5 should be used instead of the original program. SansSoil.CR5 is a modified version of the original program. Prior to uploading, the program should be reviewed and updated if any equipment changes took place and/or if other program changes need to be made such as the variables stored in data tables or the azimuth of the anemometer. Also, the word 'unique' should be searched for within the program and when encountered, the calibration value for the specified instrument should be entered. The instruments that require a unique calibration value include: the net radiometer, the soil heat flux plates and the azimuth for the CSAT3. If the instruments are sent back to Campbell Scientific to be recalibrated, a new calibration value should be entered into the program being used prior to redeployment. The program wiring description that is found in the beginning portion of the program file should be checked to make sure this description (which should be the same as the sensor wiring) matches the differential or single ended channel called during a measurement instruction. A single ended voltage measurement is made on a single input which is measured relative to ground (Campbell Scientific, Inc., 2006). A differential channel measures the differences in voltage between two inputs (Campbell Scientific, Inc., 2006). Measurement instructions are contained within brackets and will vary by instruction type but often include: destination of the measured data variable, the number of repetitions, the SDM address (i.e. the single or differential channel the sensor is wired to) and the command type (i.e. what the processing system should do with the data). Once the program has been uploaded, the name of the program should appear on the main LCD screen of the datalogger (for the CR5000). If any further changes are made to the program on the computer, the new version of the program will need to be uploaded.

2.2 Datalogger Wiring

As a general guide, before wiring all the eddy covariance sensors collectively to the datalogger, each sensor should be powered (when necessary) and wires connected to the data logger individually. Appendix A provides a list of each sensor's power requirements. Throughout the duration of sensor testing, the datalogger's lead acid battery base should be charged using its AC adaptor. The battery must be fully charged in order to maintain a non-fluctuating power source. The individual sensors should be tested using either a sample program written by the user in Loggernet's application CRBasic or using/retrofitting the Campbell Scientific eddy covariance program. Retrofitting the original Campbell Scientific program entails declaring the variable as public and defining the variable's units, and selection

of the variable being tested, measurement instruction and wiring description. This program should be saved with a new name and uploaded to the datalogger. Testing each sensor individually enables identification of any problems with sensor hardware and/or errors within the original program. Once the program has been uploaded, the measurement can be viewed in Loggernet by connecting to the datalogger using the 'Connect' application. Once the 'Connect' screen is open, select the datalogger model to connect with and select 'Connect'. Data can be viewed either numerically or graphically. To view data, the numeric or graphic icon is selected in the data display box. Once selected, a window will open with empty cells that are similar in appearance to those in a Microsoft Excel spreadsheet. To view a particular variable, the 'Add' option is selected. A window will open with the data tables that are being recorded by the program. The table and variable of interest are selected, in this case it will be the variable being tested in the table 'Public'. The variable must be dragged into an open cell in the numeric data display to view the output. Viewing data from the selected sensors in real time allows the user to judge whether the sensor is obtaining reasonable readings. The image in Figure 1 shows the wiring for the meteorological components of the eddy covariance system.

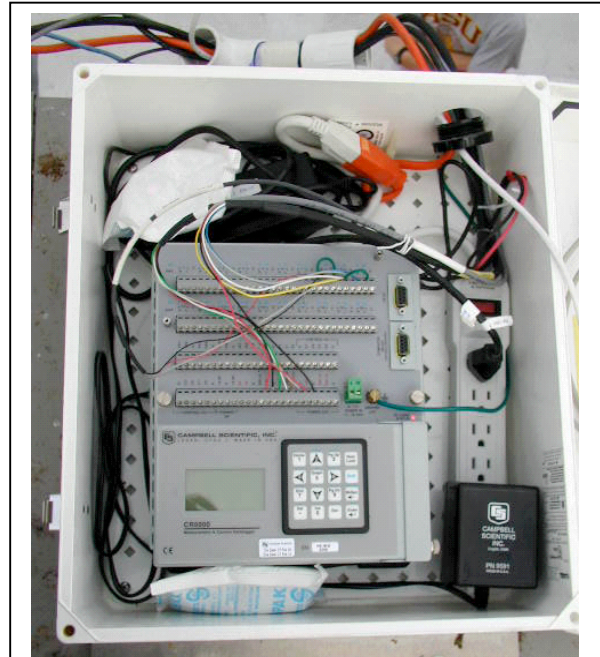


Figure 1. CR5000 Wiring of meteorological sensors.

The following provides a guide to instrumentation of each component and a suggested order for sensor testing.

2.2.1 Thermocouple

The original Campbell-Scientific eddy covariance program assumes use of a fine wire thermocouple to calculate latent and sensible heat flux (variable name 'H' in the program); however, the eddy covariance equipment ordered for CUERE uses sonic temperature to calculate sensible heat flux (variable name 'Hs').

The provided thermocouple (not fine wire) should NOT be deployed with the eddy covariance equipment, because measuring the temperature inside the Hoffman Box as opposed to the ambient air temperature could be deceptive within the data record. The Hoffman Box is the fiberglass, weatherproof enclosure where the datalogger, NL-100 and power strip are housed. A measurement of the Hoffman box temperature is not warranted because the program is already setup to record the datalogger's panel temperature from an internal thermistor.

Programming the thermocouple is a good starting point for the non-experienced programmer. A basic program for the thermocouple will declare the sensor being measured, its units, instruct the sensor to take a measurement and output the measurement into a table. The thermocouple uses one differential channel and does not require a power source other than the datalogger. A simple way to determine which wire should go into the high or low channel is by viewing the output data. The measurements can be viewed in Loggernet as described above. The table and variable of interest are selected; in this case it will be the table 'Public' and variable 'fw', and the variable is dragged into an open cell in the numeric data display. If the output is negative (and the ambient air temperature in the laboratory is not) the wiring connections need to be reversed, if it is positive than the thermocouple has been successfully connected.

2.2.2 HMP45C

The HMP45C draws power from the datalogger and does not require an external power source. The HMP45C sensor should be connected to the data logger according to the wiring diagram specified in the eddy covariance program. Once the program has been uploaded to the datalogger and the sensor wired, the variables 't_hmp' and 'r_hmp' are dragged into the cells of the numeric data display to view the data output. The user should ensure that reasonable readings are being output from the sensor by comparing the HMP45C temperature output to the thermocouple output. As an additional check, the user should obtain an ambient air temperature with a thermometer. When comparing the output of these tests, the user should check that the units (listed in the program) for the tested variables match the output of the sensors.

2.2.3 Q 7.1 (Net Radiometer)

Within the main program, the two output variables for the net radiometer are 'rn_meas' and 'rn_cor'. Rn_meas is the raw output from the net radiometer; rn_cor is the radiometer output corrected for the effects of wind. Sensors measuring long-wave radiation are subject to error caused by convective cooling as air moves past the sensors (Campbell Scientific, Inc., 1996). The magnitude of the correction for wind speed will vary in relation to air density and heat capacity of the air.

Prior to connecting the wires between the net radiometer and datalogger, the sensor should be secured and leveled. Next, the net radiometer should be connected to the data logger in accordance with the program's wiring description and its program, uploaded to the datalogger. The variables 'rn_meas' and 'rn_cor' should be dragged into the cells of the numeric data display. The accuracy of output data can be ensured by holding a light bulb close to (but not touching) the top side of the sensor where the bubble level is located. If the sensor and program are operating properly, the variables 'rn_meas' and 'rn_cor' should increase as a function of the watts emitted by the light bulb. Next, the light bulb should be held underneath the net radiometer. If the test is reasonable, the output will be negative for this portion of the test.

2.2.4 LI-7500

The LI-7500 should be tested with a direct connection to the LI-7500 electronics box. The LI-7500 software should be downloaded and installed from either the provided cd or LI-COR's website. The LI-7500 software enables direct connection between the IRGA sensor and a computer, which is useful for lab testing purposes.

Once this software has been installed on the computer, the sensor head should be connected to the electronics box using the shielded cable. When connecting the sensor head, the red marks on the cable should be aligned with the red dot on the sensor head and pushed straight in. Twisting of the cable must be avoided when connecting, because the cable and/or sensor head could be damaged.

The power supply cables from the circular connector that is attached to the electronics box must be connected to a power source. A 12 V car battery can be used between the bare end of the power supply cable and the electronics box. The power connection to the car battery must be snug and covered with electrical tape.

The RS-232 cable should be connected internally between the electronics box and the COM1 port in the back of the computer. To connect internally with the electronics box, the internal RS-232 connector must be unplugged, and then the supplied LI-COR RS-232 cable must be connected (Figure 2). If the user has trouble making the connection, ensure that the cable is connected to the correct COM port.¹

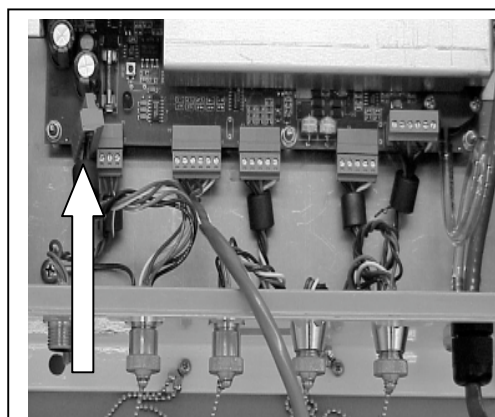


Figure 2. Disconnected internal LI-7500 RS-232 cable

¹ Upon initial receipt of the LI-7500 (April 2008) a connection between the LI-7500 and the COM port could not be established. After contacting LICOR, the following was recommended and tried: ensure the most recent version of the software is installed; connect using the 997-015 cable instead of the USB-RS-232 adaptor; test to ensure the COM port on the laptop is working properly; examine the cable running from the Electronics Box to the sensor head for buildup of film and/or corrosion inside the connection around the pins (connecting/ disconnecting a few times can help to remove some of this build-up and if the connection is not snug it is possible that the hot/cold weather changes during the nights/days can cause the cable and wiring to expand/contract possibly causing the wires to intermittently disconnect); check that all wires/cables are connected properly inside the Electronics Box (use the diagram in Appendix B of the Manual); make sure the 5 separate green connectors are pressed tightly and are not loose or uneven; check all wires going into those green connectors to ensure that the colors match and try lightly pulling on the wire to make sure none of the wires worked loose from their connections; check that the screw terminals are not loose; examine the wires that connect from the Sensor Head to the Control Box (remove the metal shield cover to examine these connections, see page B-2 in the Manual's appendix); and finally, reset the LI-7500 by pressing the 'Reset' button inside the Electronics Box to reboot the instrument. However, none of these options worked as it turned out the problem was due to a faulty 997-015 cable, which LI-COR replaced promptly.

To ensure that readings seem reasonable, the user can breathe into the LI-7500. The readings should increase to approximately 1300 mg/m³. If outside with the instrument, a reading of approximately 700 mg/m³ could be considered reasonable for a winter day in Maryland.

2.2.5 CSAT3

The CSAT3 should never be picked up and/or carried by either its arms or the strut in between its arms. The CSAT3 should always be held by the block where the upper and lower arms connect.

There are three sets of communication cables (between their respective electronics boxes and the instruments) that are included with the CSAT3 and LI-7500. It is only necessary to use the communication cables for the chosen communication method (i.e. SDM, analog, or RS-232). The preferred communication method for both instruments is SDM, followed by RS-232 and analog. The anemometer head must be connected to the electronics box labeled transducer head. Next, the appropriate signal cables must be connected to the electronics box. The CSAT3 will need to be connected and powered through the HUB SDM-8, which is discussed in further detail in the next section. Appendix B provides documentation on the HUB SDM-8 wiring.

Once these steps have been completed, the extended eddy covariance program can be uploaded to the datalogger and the CSAT3's public variables can be viewed (i.e. Ux, Uy, Uz and diag_csat).

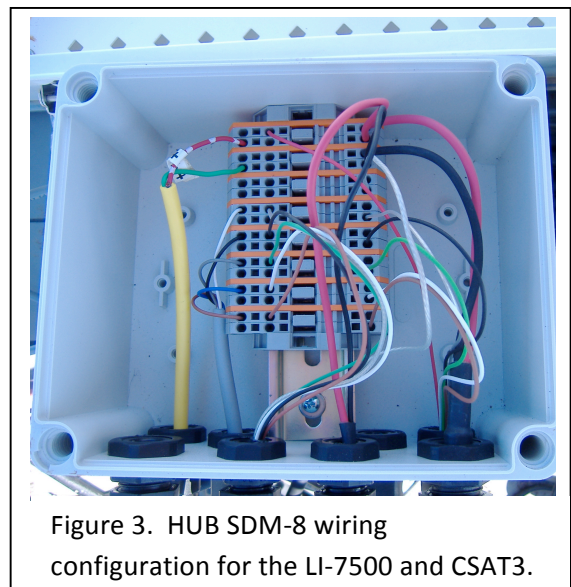
The diag_csat variable is a diagnostic value that when unequal to zero indicates the CSAT3 is not operating properly. This will usually occur during periods of rain and/or if birds are perched on the anemometer.

2.2.6 Daisy Chain Wiring between the HUB SDM-8 and Sensors

Once the LI-7500 has been tested with a computer connection, both the CSAT3 and LI-7500 should be tested together with a direct connection to the datalogger. This connection is facilitated by the HUB-SDM8.

Before connecting the wires into the terminal, the wire insulation back should be stripped to expose ¼ inch of bare wire. This step should not be necessary if the wires were ordered with ¼ inch exposed. However, if the wires are corroded and/or otherwise compromised, the unusable portion should be cut off so it does not interfere with data transmission.

To insert a wire into the hub, open the spring-loaded guillotine located to the right of the wire port for ports located on the left hand side (and vice versa for those located on the right) with the small Campbell Scientific flat blade screwdriver (Figure 3). The edge



of the blade should be inserted perpendicular to the orange separators. The spring-loaded connections require the user to push down with the screwdriver to open the terminal, insert the wire and then remove the screwdriver. This requires more force than one would presume, but caution should be exercised with the amount of pressure applied.

The SDM wires for the CSAT3 and LI7500 must be inserted to the left of the HUB divider while the SDM out cable that connects to the datalogger is inserted to the right of the divider. Figure 3 shows the wiring for both these sensors within the HUB. Appendix B can be consulted for a table containing the location where each wire should be inserted.

Upon completion of wiring the individual components successfully, the next step is to wire all the components together and test in the lab, using the same program and wiring scheme that will be used during field deployment.

3. Field Deployment

3.1 Placement along Tower

Placement of equipment along the tower is dependent on tower characteristics (i.e. tower height and telescoping limitations) and the length of the various sensor cables. Prior to deploying the equipment, the user should ensure that the tower can support the weight of the eddy covariance equipment. Appendix C provides a list of each sensor and their respective cables weight.

Ideally, the sonic anemometer and the LI-7500 should be placed at the highest section along the tower. Their electronics boxes should be placed approximately 6 to 9 feet beneath the sensors on opposite sides of the tower so their weight is evenly distributed. The HMP45C and its solar radiation shield should be placed in between the sonic anemometer and LI-7500 and their respective boxes. The Net Radiometer must be deployed at either eye level or a level accessible by a ladder so that it can be leveled. If installing the net radiometer in the Northern Hemisphere, the sensor head should be pointed facing south. The HUB-SDM8 should also be placed at an accessible level on the tower, as this will facilitate any troubleshooting issues that may arise. The location of the HUB will be limited by the distance of the SDM cables from the electronics boxes. The Hoffman box and stored datalogger does not need to be deployed on the tower, but should be deployed securely at an accessible level off of the ground. In the case with the UMBC Physics building, the Hoffman box was secured to the roof on a



Figure 4. Placement of eddy covariance sensors along a folding hinge tower.

metal platform. For a telescoping tower, the user should ensure that placement of cables alongside the tower will not interfere with the airplane cables supporting the tower.

3.2 Equipment Mounting and Deployment Considerations

3.2.1 Net Radiometer

A square mounting plate should be secured with two u-bolts to one of the vertical tower legs. Next, the net radiometer support arm should be attached to the mounting plate with two smaller sized u-bolts. The sensor's cable should be fastened to the support arm and tower poles with cable ties to minimize excess strain on the instrument.

3.2.2 CSAT3

During deployment, it is important to point the sonic anemometer into the prevailing wind direction to minimize the amount of data that is influenced by the tower, the anemometer's support arms and other supporting hardware. The CSAT3 should be mounted to one of the vertical tower legs with the ¾-inch by ¾-inch crossover fitting that comes with the sensor. Attach the crossover fitting to the vertical pipe and lightly tighten the vertical set screws. Next, insert the horizontal mounting arm into the crossover fitting and lightly tighten the horizontal set screws. Point the horizontal arm into the prevailing wind and then tighten all the fitting set screws. Mount the anemometer head to the horizontal arm and secure it by lightly tightening the bolt underneath the anemometer block. Be careful not to over-tighten the bolts as this will damage or deform the mounting hardware.

The electronics box for the CSAT3 should be attached approximately 6 feet beneath the CSAT3 sensor. This distance is limited by the length of the connecting CSAT3 cables. The electronics box should be secured to the tower legs with u-bolts connecting through the openings of the mounting hardware. Once the box is mounted, the cable from the anemometer head should be secured to the connector on the electronics box labeled Transducer Head.

3.2.3 HMP45C

The HMP45C sensor should be deployed over an open level area at least 9 m in diameter. The sensor should be located at a distance at least four times the height of any nearby obstruction and at least 30 m from large paved areas. When deployed, the sensor should be protected from thermal radiation and adequately ventilated within the solar radiation shield.

Prior to deployment, the split nut should be loosened on the bottom plate of the radiation shield and the yellow protective cap removed to insert the sensor into the shield. Once the sensor has been inserted into the shield, the split-nut should be tightened to secure the sensor in the shield. The radiation shield has two openings which allow the sensor and shield to be secured to the vertical



Figure 5.
Deployed HMP
45C.

tower leg with the provided u-bolt. The cables should be secured to a tower leg using UV resistant cable ties. Figure 5 shows the setup.

3.2.4 LI-7500

The LI-7500 should be mounted downwind of the sonic anemometer at a slight vertical angle. Although the LI-7500 can be mounted in any orientation, orientation should be based on research goals of the project.

The LI-7500 comes with a mounting post that should be used as a mount for the sensor. The sensor should be secured to the mounting post with the provided 3/8-3/16-inch screws. The mounting post for the sensor head should then be attached to the provided U-rail type holder and fastened with the 3/8-3/16-inch screws to a vertical tower leg.

The electronics box can be placed up to 10 feet away from the sensor. This limitation is due to the length of the cable that connects the sensor to its electronics box. Brackets and u-bolts included with the LI-7500 sensor should be used to mount the electronics box to the vertical tower leg. The mounting brackets are designed to accommodate a mounting area of up to 1 1/4-in diameter. A 3/16-inch hex key can be used to attach the mounting brackets to the control box. The U-bolt can then be inserted through the holes in the mounting bracket and secured to the tower leg.

4. Logistics

4.1 Interference

The eddy covariance sensors should not be sensitive to interference from radio transmitter aerials or cell towers. Usually there is not a problem with other communication frequencies because they are over 1000 kHz or just closely below that range.

During periods of rain, data from the CSAT3 and LI-7500 may be unusable. Data from the CSAT3 may be unusable due to the low signal to noise ratio caused by rain drops obscuring the transducer face where the sonic signals are transmitted and received. Data from the LI-7500 may be unusable due to accumulation of moisture and/or rain on the optical path window. Moving objects in the LI-7500's sample path, but not in the path for a reference measurement (or vice versa) will also influence the measurement. In some cases both CO₂ and H₂O are affected and at other times just one. However, mounting the sensor head at a slight angle from vertical (~10-15°) may help prevent water droplets from remaining on the windows during rainstorms.

4.2 Grounding

The datalogger should be grounded by connecting the green plastic covered copper ground wire to the ground lug on the datalogger. The ground wire is the visible wire that is attached to the Hoffman Box (Figure 6).

In addition to grounding the datalogger, the tower also needs to be grounded. The copper or copper coated steel grounding rod should be at least 5/8-inch in diameter and 8-ft in length. This rod should be driven into the ground with approximately 1ft visible above ground. The rod should be connected to the vertical tower leg with a 5-ft long copper wire that attaches to the tower with a split bolt. The connecting copper wire should be attached to the grounding rod with another copper split bolt.

When long cables are used or a site has frequent lightning strikes, spark gaps may be required to protect the datalogger from transient voltages.

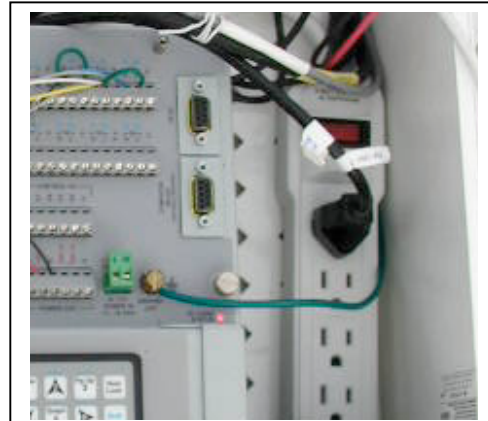


Figure 6. Ground wire from Hoffman Box to the CR5000 ground.

4.3 Leveling

It is important that both the sonic anemometer and net radiometer are level when deployed. Both sensors have an eye bubble to aid with leveling. When the anemometer is deployed on a folding hinge tower, it may not be possible to be at eye level with the sonic anemometer. Therefore, to obtain the most accurate representation of level, a framing square can be used to assist with deployment.

If the net radiometer is not level, a 5 degree error in leveling may cause a cosine response error of 6% under normal conditions, but the potential for much greater errors arise under other conditions. During measurement, a net radiometer must comply with two properties: 1) the sensor surface absorbs all radiation from all wavelengths and 2) its true field view is 180 degrees (Campbell Scientific, Inc., 1996). These two properties are known as cosine response, thus a cosine response error occurs when the angle of incidence deviates from 90 degrees (Campbell Scientific, Inc., 1996). Maximum sensitivity will occur when the angle of incidence is at zero degrees (i.e. perpendicular to the sensor surface) (Campbell Scientific, Inc., 1996). To level the net radiometer a 5/8-in wrench can be used on the hexagonal coupling nut on the instrument stem to bend the ball joint between the support arm and the instrument. When leveling the instrument, the ball joint should not be bent by holding the instrument head, as this may break the stem. If the net radiometer is to be installed at a height greater than the user's eye level, the instrument can be mounted upside down so the bubble level is in view. If the instrument is mounted upside down, the program should be changed so the variable 'rn_meas' is multiplied by -1 after the measurement instruction. 'Rn_cor' does not need to be adjusted as 'rn_meas' is the input to the correction formula for 'rn_cor'.

4.4 Power Supply

The eddy covariance sensors should be powered by a constant, regulated power supply. Regulated means that it is designed to deliver 12 volts across a wide range of current. Without this design, the adapter provides constant power, so as current (amps) goes up voltage goes down and vice versa. It is also described as "low ripple" which means that the output is closer to a constant voltage over time. Since the AC input voltage is a sine wave that gets converted to a straight line, constant value (hence "direct current") eliminates the periodic variation from the input. The meteorological components require a 12 volt DC power supply rated at 4.2 amps.

A power cord from a computer (or other electronic device) with one end that is an electrical prong can be used as the connector between the power cable wired into the HUB SDM-8 and power source. The portion of the cord that originally would have connected to either the laptop or computer should be cut off to expose the bare wires. The bare 12v and ground (red and black respectively) wires should be soldered to the power cable whose other end is wired into the HUB SDM-8. The cord should then be plugged into the power strip stored in the Hoffman Box, which is connected to an extension cord plugged into an outlet. The datalogger should be powered directly from the adaptor to the power strip for continuous battery charge. Appendix A should be consulted for a complete description of each sensor's power requirements.

4.5 Communication

If the eddy covariance system is deployed less than 100 feet away from an Ethernet jack, the NL-100 allows access to the data from a computer with Loggernet. The NL-100 Network Link interface is a 10base T Ethernet communication peripheral that allows any Campbell Scientific datalogger with an RS-232 to communicate with a computer using TCP/IP. The Internet Protocol Suite, TCP/IP, is a set of communication protocols used to transmit data over the internet. The NL-100 draws 140 mAMPs of power and thus can be wired to draw power from the datalogger. The communication settings for Loggernet should be selected as IP Port. For connecting to the jack on the roof of the UMBC Physics building, the following information should be used:

Phys-roof-converter.umbc.edu

IP: 130.85.163.183

Mask: 255.255.255.192

Gateway: 130.85.155.193

TCP IP port 6784

MAC address 00:d0:2c:00:11:3e

115K bps between NL100 and data logger

An industrial grade San Disk or better PCMCIA card and converter should be used to act as a backup for any communications issues that may arise. The card should have at least 2 GB of memory available.

4.6 Birds and Pests

Roosting and flying birds in the pathway of the sonic anemometer's transmitting and receiving acoustic signals can result in unusable data (Figure 7). Bird spikes have been found to be effective at deterring birds from perching on the eddy covariance sensors. Placement of the bird spikes should minimize interference with air flow, yet maximize the area rendered non-perchable to birds. Bird spikes have been observed to work well when placed along: the boom of the sonic anemometer, the uppermost ledge of the sonic anemometer, the boom of the LI-7500 and the arm of the net radiometer. In addition, two or three eight inch cable ties can be attached to the end of the support arm near the net radiometer's sensor head. Bird spikes are deployed on the equipment at UMBC.

All connecting sensor wires, the Ethernet cable and extension cord should be fed through the circular opening on the Hoffman box. Once the sensors have been tested, the box opening should be sealed with putty. Sealing the box opening with putty will prevent water, insects and nesting rodents from entering into the box.



Figure 7. Birds roosting in the pathway of the sonic anemometer.



Figure 8. Using a laser level to determine the azimuth of the sonic anemometer.

4.7 Azimuth

The azimuth is the direction in which the sonic anemometer is pointed. This value needs to be entered into the eddy covariance program. Prior to determining the azimuth, the site-specific magnetic declination must be calculated. The magnetic declination is the angle between the local magnetic field and true north. The magnetic declination will be the offset used when calculating true north. Magnetic declination can be calculated from NOAA's website:

<http://www.ngdc.noaa.gov/geomagmodels/Declination.jsp>.

In general, the azimuth can be determined using a compass. If a compass will not work at the site due to magnetic fields or other interference sources the following option can be used to obtain the azimuth.

A GPS unit with survey-grade resolution can be used in conjunction with a laser to mark two points beneath the anemometer and the direction in which the anemometer struts are facing (Figure 8). After lining up the laser with the anemometer struts, two points on the ground surface are marked. Next, a GPS measurement is obtained at each marked point and the base of the vertical tower leg the anemometer is deployed on. The azimuth will be the direction in which the points line up from the tower. The distance between points should be maximized for increased accuracy.

5. Maintenance

5.1 LI-7500

In order to calibrate the LI-7500, the sensor will need to be spanned and zeroed with air of a known dew point. If a portable dew point generator (i.e LI-COR LI-610) is available, this will enable the user to calibrate the LI-7500 in the laboratory. Use of the LI-610 is recommended because gas tanks are not available with air of a known water concentration. Calibration requires zero and span adjustments of water vapor and CO₂ to bring the LI-7500's actual response into line with its previously determined factory response in at least two spots (LI-COR, 2004). The instrument should be CO₂ spanned with a CO₂ concentration at the higher end of the concentrations encountered in daily measurements. The zeros and spans should be checked once a year and re-calibrated if they deviate by more than 10%. If the LI-7500 is deployed in a dry climate, recalibration is only needed after the third or fourth year of usage. This is not true for humid conditions, where the sensor should be re-calibrated at least once annually (or even twice a year is preferred).

5.2 HMP45C

The HMP45C probe requires minimal maintenance. If the unit is accessible, monthly maintenance checks can help to ensure that the radiation shield is free from debris and the black filter screen at the end of the sensor is free of contaminants. To clean the filter, it can be gently rinsed in distilled water and if necessary, the chip can be removed for rinsing, ensuring the chip is not scratched in the process.

5.3 Net Radiometer (Q-7.1)

During service visits, the desiccant tube should be checked to ensure that internal condensation is not affecting sensor performance. The desiccant tube is located in the support arm and is accessed by removing the end plug and vinyl cap. If the color is observed to be pink, the wet silica gel should be replaced with dry silica gel. Wet silica gel can be dried by placing it within a 130° C oven until it turns blue. After replacing the desiccant tube, the end plug and vinyl cap should be installed with the holes in the vinyl cap pointing downward.

Condensation on the net radiometer windshields can cause incorrect measurements because water does not transmit longwave energy. If condensation develops, the desiccant can be checked as

indicated above. If the desiccant is dry, check that windshields and o-rings are in good condition and properly seated against the net radiometer frame. This can be done by removing the desiccant, immersing the net radiometer in water and gently blowing into the open end of the support arm. A stream of bubbles will locate any leaks. The sensor should be thoroughly dried with a soft tissue and reinflated by blowing into the open end of the support arm.

The windshields should be cleaned with a camel hair brush or a paper tissue with distilled water. Coarse paper or cloth may scratch the windshields and should therefore be avoided. When checking the desiccant, the windshields should be checked for any cracks. If condensation is continual or cracks are apparent within the windshields, they should be replaced immediately as a set to ensure proper functioning of the instrument. The net radiometer manual should be consulted for further instructions on how to replace the windshields.

During site maintenance visits, the user should also check the levelness of the instrument. Adjustments should be made and the date/times of adjustments should be recorded.

The manufacturer recommends a calibration check every six months dependent upon the local climate.

5.4 CSAT3

The wicks of the CSAT3 should be removed during winter, because freezing rain and snow that accumulates on the wicks will obscure the transducer face. If prolonged winter conditions are not a concern, the wicks can be permanently secured to the transducer with a drop of adhesive. They should be glued in the proper position with the top wick flush with the transducer face, the tail wick located at the lowest point along the bottom transducer and the end of the bottom transducer wick extended above the transducer face by between one half and one mesh lines.

If the CSAT3 requires a new calibration, it will develop a wind offset greater than the specifications and/or set diagnostic flags under dry conditions with little to no wind and with no obstruction in the ultra sonic paths. To test the wind offset within the lab, an environment must be created where there is no wind. To do this, the CSAT3 head should be mounted and covered with a medium-sized (13-gallon) kitchen waste-bin liner. The opening of the liner should be folded, taped or tied closed to prevent air from moving in and out of the liner. The user should ensure that the liner does not obscure any of the three CSAT3 sonic paths. Connection to the CSAT3 can be made using the RS232 port on the datalogger. The CSAT3 software can be downloaded from Campbell Scientific's website and used to directly connect to the sensor. To prevent erroneous measurements due to ultrasonic reflection within the plastic bag, a 1 Hz measurement rate should be selected. One minute of wind data should be collected while it is taking measurements in this environment. The wind offset should be less than $\pm 4 \text{ cm s}^{-1}$ for U_x and U_y and less than $\pm 2 \text{ cm s}^{-1}$ for U_z . If the wind offset is greater than any of these values, Campbell Scientific should be contacted for an RMA number to recalibrate the CSAT3.

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Appendix A: Power Requirements

CR5000: Datalogger

11-16 Vdc operation

CSAT3: Three dimensional sonic anemometer

Voltage Supply: 10 to 16 Vdc

Current: 200 mA @ 60 Hz measurement rate; 100 mA @ 20 Hz measurement rate

LI-7500: Open path infrared gas analyzer (CO₂ and H₂O)

Power Requirements: 10.5 to 30 volts DC.

Bandwidth: 5, 10, or 20 Hz, software selectable.

Power Consumption: 30 W during warm-up, 10 W in steady state.

HMP45C: Temperature and relative humidity probe

Supply Voltage: 12V DC nominal (7 to 35VDC possible)

Power Consumption: <4mA

NRLite: Net radiometer REBS Q7

No power required

Appendix B: Wiring Diagram for the HUB SDM8

	Wire Port L1	Wire Port L2	Divider	Wire Port R1
1H		+ SDM out Power		+ Power In CSAT3
1L	+ LI-7500 power			+ Power Out (to datalogger)
2H				- Power In CSAT3
2L	- LI-7500 power			- Power Out (to datalogger)
3H				Clear CSAT3 Power
3L				
4H	White SDM LI-7500	Grey SDM CSAT3		
4L				Clear SDM out
5H	Black SDM LI-7500	Black SDM CSAT3		
5L				Black SDM out
6H	Grey SDM LI-7500	Green SDM CSAT3		
6L				Green SDM out
7H	Blue SDM LI-7500	White SDM CSAT3		
7L				White SDM out
8H	Brown SDM LI-7500	Black SDM CSAT3		
8L				Brown SDM out

Appendix C: Weight of Eddy Covariance Sensors

Item	Weight	Units
HMP45C and Radiation Shield	2	Pounds
CR5000	12.2	Pounds
CSAT3 Anemometer Head	3.7	Pounds
CSAT3 Electronics Box	8.4	Pounds
LI-7500 Head	1.65	Pounds
LI-7500 Box and Cables	10.5	Pounds
NR-Lite	4.1	Pounds
Mounting Arm	5	Pounds
Total	47.55	Pounds

Appendix D: Using EdiRe to Calculate Fluxes Employing an Open Path Sensor

The following is a list of instructions for calculating momentum flux of wind, sensible heat, latent heat and trace gas fluxes using EdiRe. An open path sensor is assumed to be used for measuring water vapor and trace gas (CO₂). ***These instructions in for processing data using EdiRe were compiled from the University of Edinburgh's EdiRe website. EdiRe is free software that is available from the University of Edinburgh at the following website: <http://www.geos.ed.ac.uk/abs/research/micromet/EdiRe/>.***

The following briefly describes the basic order to process eddy covariance data that will be expanded on in this document: extracting the raw wind velocity components (Ux, Uy, Uz), Sonic Temperature (Ts), CO₂, H₂O, pressure and diag csat variables; de-spiking the Ux, Uy, Uz, Ts, CO₂, and H₂O signals; computing the standard deviation, mean and variance for these signals; computing the wind direction; computing virtual temperature; rotating the U, V and W signals (processed raw wind velocity components); calculating the density of air; calculating the turbulent intensity for the unrotated U, V and W signals; computing the friction velocity (ustar); calculating the sensible heat flux coefficient and computing the sensible heat, latent heat and CO₂ flux.

D1. Data Download

Data is downloaded from the CR5000 datalogger with the Campbell Scientific applications software, Loggernet. Section 2.1 of this document can be consulted for information on establishing an initial connection between the datalogger and Loggernet. Data is downloaded by selecting the connection setting previously established between the datalogger and computer in Loggernet's 'Connect' screen, pressing the 'Connect' icon and selecting 'Collect Now'.

Once the data download is complete, the downloaded file will be moved to a different folder, saved and given a name ending with the download date. Because the file was moved, at each subsequent download a new file will be started, so the command 'Append to End of File' will not actually append to the end of a file but will instead create a new file if the previously downloaded file does not exist. For general purposes, the collection mode should be selected as 'Data Logged Since Last Collection' and the 'Collect All on First Collection' box should be checked. This setting will collect all data logged since the last time the data was downloaded. Data should be downloaded on a weekly basis due to the size of the files being downloaded and storage limitations (i.e. 2 GB). The size of the ts_data file downloaded each week will be approximately 500 MB.

If data needs to be converted to a different format, the Card Convert application within Loggernet enables conversion between recognized Campbell Scientific formats (i.e. TOB1 and TOA5). The binary TOB1 format is required for processing Campbell Scientific data using EdiRe and it is the only raw data table collected to be processed using EdiRe.

D2. Preprocessing

This section discusses settings within EdiRe that should be enabled before data processing, and reasons for their selection.

D2.1 Format and Processing Lists

Prior to processing data, a format list must be uploaded for the files being processed. A format list extracts recorded signals from the binary data file while a processing list defines the steps for processing data. If a format list does not exist, a new format list can be created by selecting the Interpreter option found on EdiRe's processing toolbar. Interpreter can be used to create a format list based on the raw data file. A new format list should be created if changes occur with any of the following: the number of signals being recorded, the sampling rate and the file name structure. After selecting the Interpreter option, a dialog box will open that requires the user to select the 'New Lists to be Created' checkbox, the raw data file type, the location of the file that will be processed and whether the lists will be loaded. To create the lists, 'Create' is selected. A sampling frequency verification window will prompt, whereby the user should verify or input the correct sampling frequency. The sampling frequency can be found within the program used to log data. CUERE uses a sampling frequency of 10 Hz. For most standard processing applications, the processing list will remain the same. At the end of each session in EdiRe, changes to the processing and format lists are automatically saved.

D2.2 Output Files

To retain the output of calculated values, the path name of the file must be specified. This is done using the 'Location Output Files' processing item. When specifying the output path, the corrected ts (time series) data file with the appropriate month and year extension is selected. A new processed data file for each month should be created that ends in the first three letters of the month's name and the last two digits of the year. A file name with a .dat extension enables the user to view the output within Loggernet's 'View' application. The extension can be changed to .csv to view data in Excel without destabilizing the file type.

D2.3 File Options

The time output interval for the processed data can be changed using the run length option found on the file options tab. In order to process data in EdiRe on the same time format (i.e. each minute of the hour ending with 00 and 30), the Card Convert application in Loggernet can be utilized to extract files into individual files of a defined duration (i.e. 30 minutes, 1 day etc.). If the raw data file starts in the middle of the desired output processing period, the timestamp for the processed data will appear skewed. To prevent this from happening, the start time can be changed so the minutes end in either 00 or 30. If the start time is changed but actual raw data started after this time, EdiRe will use the data from this time to the nearest half hour for processing. In order to avoid losing data previously collected from an earlier download, the last <30 minute file from the previously downloaded weekly file should be combined with the first <30 minute data file from the most recently collected data file.

Selecting the NAN test to replace NAN with -9999 enables continuous data processing that includes data collected when IRGA and CSAT3 diagnostic variables were flagged as true. Data can later be removed from the processed record file that was flagged as true within the data record. There are several indicators within the data record that can be used to assess the quality of the data. For instance, the

AGC value can be used as a quality indicator of the LI-7500 data because it represents the cleanliness of the window as a percent. Typical clean values range from 50-65%. Other indicators of data quality can be found in the flux file and include the total number of CSAT and IRGA warnings during the half-hour period.

D2.4 Importing values

The 'Preprocessed Files' processing item can be used to import time series of mean values of environmental and system variables for use in calculating and correcting fluxes. These variables may originate from the stored flux file processed using the original eddy covariance program during data collection.

D2.5 Set Values

If used, set values are defined in the beginning of the processing list and the value of a storage item is set to a defined value. CUERE defines the following set values: orientation of the sonic anemometer, latitude and vertical height of deployed eddy covariance sensors, boundary layer height, canopy height and zero plane displacement. The orientation of the sonic anemometer is the same as the azimuth that was entered into the CR5000 program to collect the data. This is the direction the sonic anemometer is pointed into, which should be the same as the prevailing wind direction. Zero-plane displacement is the height scale in turbulent flow over tall roughness elements associated with the average level of action of momentum transfer between the air flow and the roughness elements.

D3. Data Processing

D3.1 Signal Extraction

The three raw velocity components U_x , U_y , U_z temperature (T), water vapor (Q), trace gas (C), pressure and diag_csat signals must be extracted before processing the data. This procedure is specified as follows.

D3.1.1 "Add Extract" processing item

- The 'Extract' item is selected from the Processing Items drop down list on the Processing Steps page of the Options dialogue.
- The 'Add' button is used to add the Extract item to the processing list.
- Although the order in which the items are extracted is not an important factor, they should be placed near the beginning of the processing list.

D3.1.2 Specify item parameters

- The Extract item is opened by selecting the plus icon to the left of the item. This will expand the item and show the four Extract item parameters: 'Channel', 'Label for Signal', 'To Time' and 'From Time'.

- 'Channel' parameter. The channel number is selected corresponding to the recorded signal that will be extracted from the raw data files. The number of channels available is determined by the number of channels specified in the 'Raw File Format List'.
- 'Label for Signal' parameter. A label should be provided describing the extracted signal. Although any string can be used as a signal label, a short character string without commas should be used. EdiRe does not accept parentheses within label names. When using 'User Defined Fast' processing items in the processing list, spaces or symbols and character strings should not be used that could be interpreted as mathematical operators.
- Unless there is a need to define the 'To time' and 'From time' for the signal being extracted, these two parameters should be left blank. This would be required if the item were only to be extracted during a specified time period.

D3.1.3 Multiple Channels

- An 'Extract' item should be added for each signal processed. It is not necessary to extract all signals recorded in a raw data file, only the signals that will be used to process data. A signal can be extracted more than once for different processing operations.
 - For example, to perform three different processing methods on the W and T signals in a file containing the signals U, V, W, and T, six 'Extract' items are added with the signals labeled W1, W2, W3, T1, T2, and T3.

D3.2 Converting signals and sensor calibrations

The extracted signals should be converted from the units in which they were recorded to values of m/s for velocity and degrees Centigrade for temperature. Two additional 'add extract' items should be used to extract the relative humidity sensor signal so vapor pressure and vapor deficit can be calculated. A gas conversion time series item is used to convert these signals from partial pressure (KPa) to absolute density (g/m^3).

D3.2.1 Logic of conversion routines

Some signal conversion routines apply a second order polynomial either before the targeted signal conversion, after the conversion, or both before and after the conversion. These polynomials allow for conversion from the units in which the signal was recorded to the units in which it was calibrated (eg. bits to volts).

D3.2.2 Simple single signal conversion routines

- The linear processing item is used in two stages. First, raw data is converted from its recorded format to a voltage signal and second, the voltage signal is converted to the desired quantity. It is not required that both stages are used. For example, a linear processing item is used to convert a signal to degrees Kelvin by setting the first polynomial offset equal to 273.16 and the first polynomial gain to 1.
- Speed of sound (m/s) is converted to sonic temperature (degrees C) using the 'sonic temperature' item.

D3.2.3 Error tested single signal conversion routines

Single signal conversion routines can be used to test signals for negative values to eliminate conversion errors. Examples of mathematical functions that can be used to test for conversion errors include taking the natural log, square root or log base 10 of the signal.

D3.2.4 Simple two signal conversion routines

These routines combine two signals using the specified mathematical operations. The second order polynomial is applied to the result of the signal combination operation.

- Ratio – The ratio is taken of two extracted channels.
- Difference -The second signal is subtracted from the first signal.
- Sum - The first signal is added to the second signal.
- Product - The first signal is multiplied by the second signal.

D3.2.5 Specialized multiple signal conversion routines

- Turbulent Kinetic Energy (TKE) - Used to assess the turbulent portion of buoyancy. It is the mean kinetic energy per unit mass associated with eddies in turbulent flow.
- Velocity and Direction- Used to convert unrotated U and V component velocity signals to a velocity magnitude signal and a velocity direction signal.

D3.3 Despiking and low pass filtering

Some sensors are subject to spikes in the signal time series that are unrelated to the desired signal. Although their effects on fluxes may be small, these spikes should be removed early in the data processing stream to avoid cross-contamination of signals through correction or other signal manipulations. Despiking is used to assess the quality of individual data points or consecutive sets of data. Data is removed from the processed record if the standard deviation of the difference between consecutive data points is greater than 6. Low pass filtering bypasses low-frequency signals but attenuates signals with frequencies greater than the cutoff frequency.

D3.4 Sonic Temperature Path Correction

Air temperature derived from the speed of sound is subject to errors caused by measurement path elongation by cross-path wind flow. Corrections can be applied either before or after sensible heat flux calculation. Sonic temperature path corrections should be carried out before coordinate rotations are applied.

D3.5 Sonic flow distortion

Sonic anemometer velocity signals may require correction that is instrument-specific for distortion of the velocity signals caused by sensor head design.

D3.6 Rotating velocity signals

Velocity signal coordinate rotation is applied to ensure that the vertical velocity signal is orthogonal to the plane of mean airflow above the surface. This is necessary because installation of the anemometer is difficult within the appropriate coordinate frame. Coordinate rotation may be done in EdiRe using either the planar fit or 2/3 angle rotation method. Currently the planar fit method is the preferred method of rotation, but experimental circumstances may dictate the method used.

D3.6.1 Two Thirds Angle Rotation Method

This velocity rotation method produces a set of velocities for which the run mean vertical (W) and lateral (V) velocity components are zero after transformation through two angles. The third angle transformation minimizes the lateral component flux (i.e. mean $w'v'$, whereby w' is the instantaneous deviation of vertical velocity and v' is the instantaneous deviation of lateral velocity). This method is convenient because it can be carried out coincident with flux reprocessing. A potential weakness of this method is the assumption that the mean vertical velocity is zero over the period of a run (e.g. 1/2 hour). Application of the third rotation to minimize mean $w'v'$ is not recommended for data collected over non-ideal measurement sites. Kaimal and Finnigan (1994) can be consulted for a further description.

D3.6.1.1 Defining rotation angle

- The run rotation method is applied by first, calculating the rotation coefficients and second, by applying the rotation coefficients.
- To calculate rotation coefficients, a 'Rotation coefficients' processing item is added to the processing list. This item should be placed after calibration or de-spiking processing items have been applied to the velocity components.
- The three velocity component signal parameters (i.e. U , V and W) are specified. These raw signals are used to calculate run mean values for the run rotation coefficients.
- Alternately, previously calculated mean velocity components can be specified in the 'Optional Mean' U , V and W parameters. If specified, these precalculated means will override the mean velocity components determined from the raw data signals.

- Specification of storage labels for the rotation coefficients Alpha, Beta, and Gamma is optional if no other 'Rotation coefficients' processing items are encountered before the rotation is applied.

D3.6.1.2 Applying rotation

- To rotate the velocity signals using the rotation coefficients calculated in the previous step, a 'Rotation' processing item is added to the processing list. This item should be located after the 'Rotation coefficients' item.
- The three velocity component signal parameters (i.e. U, V and W) are specified. These are the raw signals that will be rotated using the previously calculated rotation coefficients.
- If labels were given to the Alpha, Beta and Gamma rotation coefficients, these coefficients may be selected in the 'Alpha', 'Beta' and 'Gamma' parameters. If these parameters are left blank, the most recently calculated rotation coefficient values will be used to rotate the velocity components.

D3.6.1.3 Applying Rotation Variations

- To apply the rotation, a character is placed in the 'Do 1st rotation', 'Do 2nd rotation' and 'Do 3rd rotation' parameters. If application of a rotation is not desired, its parameter is left blank, however application of the second rotation requires the first rotation to have been applied and the third rotation requires the second rotation to have been applied.
- It is not necessary to apply all rotations in the same step. The three rotations may be applied in separate steps, but they must be applied in order and should not be applied repeatedly. For example, if the 'Do 1st rotation' and 'Do 2nd rotation' are applied in the first step they should be left blank in subsequent 'Rotation' processing items that are applied to the velocity components.

D3.6.2 Planar Fit Rotation Method

The planar fit rotation method assumes that over longer periods the mean flow past the anemometer at a site can be described by a plane. For this method it is necessary to have a measurement period of generally a week or more at sufficiently high wind speeds (generally greater than 1 m/s) and that the position of the anemometer not change over the data period. If the measurement period is too short, this method may be imprecise. This method defines three rotation coefficients that are applied to the raw data to transform the existing anemometer reference frame into that of the mean flow plane.

D3.6.2.1 Preparation

- Before the planar fit rotation can be applied to the anemometer's signals, the unrotated, run-mean, component velocities for that anemometer must be calculated.
- To determine the mean U, V and W signals, a simple processing list can be created in which these three signals are extracted, converted to the appropriate units, despiked if necessary and run means calculated. This processing list should be applied to all data processed by the planar fit rotation. The output of this processing list is used in the next step of rotation coefficient calculations.

D3.6.2.2 Calculating Coefficients

- Planar fit rotation coefficients are calculated using the run mean values from the preceding step. A new set of rotation coefficients will need to be calculated any time the orientation of the anemometer changes with respect to the underlying surface, therefore a field log of any anemometer repositioning should be kept.
- To calculate the planar fit rotation coefficients the user should refer to the methods of Wilczak et al. (Sonic Anemometer Tilt Correction Algorithms, Boundary-Layer Meteorology, v99, p127-150).
- The EdiRe website can be used to download the necessary worksheet to calculate the planar fit coefficients. Because flow at low wind speeds may be prone to contamination, only mean velocity components from higher wind speed conditions should be used to determine rotation coefficients. This is accomplished by defining the lower limit of wind speeds. Calculation of the worksheet will produce rotation coefficients.

D3.6.2.3 Applying rotation

- The planar fit method is applied by selecting and adding the 'Rotation - Planar' item from the 'Processing Items' drop down list to the processing list. This item should be placed after any velocity signal calibration conversions, despiking and wind direction calculations.
- The anemometers' three orthogonal, unrotated, velocity components should be selected in three corresponding signal parameters.
- The rotation coefficients should be obtained following Wilczak's method or using the worksheet method given above. These coefficients should be entered into the corresponding coefficient parameters of the 'Rotation - Planar' item, or may be used to create a time series of rotation coefficients in an external file which are subsequently imported to EdiRe and used to set the 'Rotation - Planar' rotation coefficient parameters.

D3.7 Statistics of one, two or three signals

Separate processing items are available for calculating basic statistics using one, two or three signals, which are named respectively: '1 channel statistics', '2 channel statistics' and '3 channel statistics'.

D3.7.1 Single signal statistics processing item

This processing item is used to calculate the statistical moments and relevant characteristics of a single time series.

- The value of kurtosis is zero based, so platykurtotic distributions (i.e. flatter) will be less than zero while leptokurtotic distributions (more peaked) will be greater than zero. Kurtosis is a measure of the 'peakedness' of the probability distribution of a real-valued random variable. Higher kurtosis means more of the variance is due to infrequent extreme deviations, as opposed to frequent modestly-sized deviations.
- The turbulent intensity is calculated as the standard deviation of the signal divided by the signal mean. If an alternate value for the denominator is specified, the mean value of x in the denominator will be replaced with the specified value.

D3.7.1.1 Mean Values Item

Mean values of wind speed, air temperature, humidity and trace gas are used in flux corrections. Mean values are calculated using the 1 channel statistics item. The run mean wind speed should be calculated using the U component of the rotated velocity signals. Mean temperature should be calculated from the corrected sonic temperature signal. Means of humidity and trace gas may need further conversions for use in some processing items.

D3.7.2 Two signal statistics processing item

This processing item is used to calculate the covariant statistics of a pair of time series. The flux value is calculated as the product of the covariance and flux coefficient.

D3.7.3 Three signal statistics processing item

This processing item is used to calculate the covariant statistics of three time series.

- The product is the mean over the run of the triple product of the instantaneous deviations from the mean of the three time series.
- The normalized product is the product divided by the triple product of the standard deviations of the three signals.
- The flux product is the product multiplied by the flux coefficient.
- Turbulent Kinetic Energy is one half the mean of the triple product of the square of instantaneous deviations from the mean of the three time series.

D3.8 Calculating mean virtual temperature

Virtual temperature is calculated from air temperature and water content of the air. The virtual temperature is the temperature of dry air that would have the same density and pressure as the moist air. Mean air virtual temperature is used in stability calculations. Virtual air temperature should be calculated using the one channel statistics item with the sonic temperature signal.

D3.9 Sonic Temperature Density Correction

Air temperature derived from speed of sound is subject to errors caused by density variations resulting from humidity fluctuations. Sonic temperature density corrections may be applied either before or after the sensible heat flux calculation.

D3.10 Highpass Filtering signals

High pass filtering is required when a sensor exhibits slow changes in the accuracy of its output (i.e. signal drift). This processing item should be applied after applying the coordinate rotation and calculating all required mean values.

D3.11 Water Vapor Partial Pressure Calculation

The water vapor partial pressure processing item is required for coefficients and corrections. Conversions of trace gas mean values should be computed using the 'Gas Conversion' processing item. Storage labels for the conversion output, conversion units, the molecular weight of water and previously determined run mean values of temperature and pressure are required as input to this processing item.

D3.12 Sensible Heat Flux Coefficient Calculation

The sensible heat flux coefficient item converts units of the vertical velocity and temperature ($^{\circ}\text{C m s}^{-1}$) covariance into energy flux units (W m^{-2}). This coefficient is calculated by selecting the 'Sensible Heat Flux Coefficient' processing item. This item requires values of run mean temperature, pressure and water vapor partial pressure. These values may be obtained as means of time series signals or may be imported from a pre-processed data file.

If the temperature and vapor pressure values are unknown use: $1296.0243 \text{ J m}^{-3} \text{ K}$ for the sensible heat flux coefficient, 1.29 kg m^{-3} for the mean air density and $1004.67 \text{ J kg}^{-1} \text{ K}$ for the heat capacity of air.

D3.13 Latent Heat Flux Coefficient Calculation

The latent heat flux coefficient converts units of the vertical velocity covariance and absolute humidity (g m s^{-1}) into energy flux units (W m^{-2}). Use of the latent heat of evaporation processing item requires values of run mean temperature and pressure. These values may be obtained as means of time series signals or may be imported from a pre-processed data file.

D3.14 Friction Velocity Calculation

Friction velocity (u^* or u_{star}) is a characteristic velocity of the surface layer that is used in corrections and other derived values. To use the 'Friction Velocity' item select the appropriate horizontal (U and V) and vertical (W) velocity signals and specify a label for the friction velocity output.

D3.15 Air Density Calculation

Air density is used to calculate the momentum flux of wind. Momentum flux is the vertical flux of horizontal momentum that is equal to the force per unit area. The 'Density of Moist Air' item requires mean values of temperature, pressure and vapor pressure.

D3.16 Humidity and Trace Gas Unit Conversion

Closed path sensors commonly produce a concentration value (e.g., mmol/mol) that needs to be converted to a density (e.g., mmol/m³ or g/m³) in order to obtain appropriate flux units. This processing step is not necessary for open path sensors as the output is in mg/m³ for CO₂ and g/m³ for H₂O.

D3.17 Preliminary Flux Calculation

The output of this calculation is the preliminary (uncorrected) flux values. A '2 Channel Statistics' item is used to calculate preliminary fluxes. The flux for two signals is calculated by specifying a vertical velocity (W) and a second signal whose flux you are trying to determine. Labels for all four fluxes in the 'Storage Label Flux' parameter must be specified as well as a label for covariance in the 'Storage Label Covariance' parameter. In the Flux coefficient parameter, the sensible heat flux coefficient should be selected, as well as the latent heat of evaporation and the air density for the sensible heat flux, latent heat flux and momentum flux calculations, respectively.

D3.18 Monin Obukhov Stability Calculation

Obukhov length is the characteristic height scale of the dynamic sublayer, which is zero for neutral stratification and positive (negative) for stable (unstable) stratifications (AMS, 2009). The dimensionless Obukhov length z/L (where z is height above the surface) is used as a stability parameter, with $z/L = 0$ for statically neutral stability and values ranging from 1 to 5 (–5 to –1) for stable (unstable) stratification (AMS, 2009). Greater virtual surface temperatures in comparison to values at the height of instrumentation indicate a more negative change in virtual temperature with increasing height and greater surface layer instability.

Monin-Obukhov stability is used to calculate model co-spectra for the frequency response correction item. The stability parameter is calculated with the 'Stability - Monin Obukhov' processing item by adding this item to the processing list and specifying the measurement height above ground and the canopy zero plane displacement. The previously calculated values of sensible heat flux, sensible heat flux coefficient, friction velocity must be selected as well as an appropriate mean temperature, which should be either sonic or virtual temperature and not true temperature. A storage label must be specified in which the stability value will be stored.

D3.19 Frequency Response Correction Calculation

The frequency response correction accounts for the inability of the measurement system to capture very high frequency or low frequency fluctuations in signals. It is calculated using the 'Frequency Response Correction' item and should be calculated for all four of the calculated fluxes. The following is a description of the parameters required for this correction.

- Correction type - The form of covariance or variance for which the correction is being calculated, with X representing any scalar variable.
- Height values - Measurement height and zero plane displacement are required for all corrections. Boundary layer height is only required for corrections applied to horizontal velocity variance.
- Stability - Monin-Obhukov stability parameter.
- Wind speed and flow velocity - Wind speed is the ambient wind speed and sensor flow velocity is the flow speed of the sample through the sensing volume, which is equivalent to wind speed.
- Sensor Sample Frequency - is the rate at which the sensor output is updated and not the rate at which all signals are sampled by the analog to digital conversion.
- Filter parameters - If signals have been filtered, the appropriate filter parameters should be represented.
- Path length of the sensor - for sensors with a folded path this should be the primary length of the path and not the total unfolded length.
- Time constant of continuous response sensors (e.g., thermocouples). For discrete sensors this value may be set very small.
- Tube attenuation coefficient – this parameter is required for signals sampled through a tube. This item is not required for open path sensors.
- Path separation is the maximum separation between the two sensors if the correction type is a covariance/flux correction. Note that if lag removal has been employed the path separation will have been altered by the removal of a signal time lag. Either a mean minimum time lag should be used or a wind direction dependent upon path separation should be calculated for use in this parameter.
- Spectral and response models - Spectra and frequency response transformations are obtained either from model or from spectra/transformations which have been calculated or referenced and loaded into memory.
- Distribution adjustments - beta feature that accounts for signal non-stationarity.

D3.20 Applying Frequency Response Corrections

Corrections may be applied to fluxes during initial calculation, however if applied in a separate step the uncorrected flux value is retained for comparison. To apply a frequency response correction for each of the fluxes, a label for the corrected flux is specified and the Mathematical operation item is used. The uncorrected flux is selected as measured variable A, the operator selected as * and the frequency response correction selected as variable B.

D3.21 Sonic Temperature Correction (post flux calculation)

Applying the sonic temperature correction after a flux calculation may result in an improved correction if the humidity signal is severely affected by frequency response attenuation. After the 'Sonic Temperature Heat Flux' correction item is used to calculate the correction, the correction is applied by adding it to the frequency-response–corrected sensible heat flux using the Mathematical operation item with the + operator.

D3.22 Applying Density Corrections

Fluxes of trace gases are affected by the expansion of air in contact with the surface, which results if the magnitude is large and trace gas fluxes are small. Separate corrections are required for each trace gas flux as the correction is additive.

The density correction is calculating and applied with the Webb (WPL) correction processing item. The WPL correction is required with open path sensors used for computing flux densities. A storage label is specified for the correction value. Next, mean values of temperature, pressure, sensible heat flux, latent heat flux, the sensible heat flux coefficient and the latent heat of evaporation are selected. The mean values of the scalar of transport and water vapor and their units are also defined. If necessary, the molecular weight of the transport scalar is specified, as well as the scalar flux type and its flux conversion coefficient. After calculating this correction, it is applied by adding it to the frequency response corrected flux using the Mathematical operation item with the + operator.

If the signal used to calculate the flux has been brought to a constant temperature before being measured by the open path sensor, then the sensible heat flux value in this correction should be set to a value of zero. Similarly, if the signal used to calculate the flux has been brought to a constant humidity before being measured by the open path sensor, then the latent heat flux value in this correction should be set to a value of zero.

D3.23 Footprint Calculations

Footprint calculations within EdiRe are carried out using the Kormann and Meixner footprint model (Boundary Layer Meteorology, vol. 99 page 207). Users should be familiar with the strengths and weaknesses of footprint estimation and consider these aspects when interpreting any results. There are four footprint related procedures available in EdiRe.

D3.23.1 Footprint Procedure

- The footprint procedure is the primary procedure to calculate the footprint model. It calculates a flux footprint for the given conditions and stores that footprint in temporary memory for further calculations.
- To use this item, previously determined values of measurement height, wind speed, wind direction, friction velocity, Monin-Ohbukov stability and the standard deviation of lateral (V) wind velocity are specified. Also a value of fetch must be specified which describes the

maximum distance from the tower for which footprint probabilities will be calculated. To simplify the interpretation of results, the value of the fetch parameter for a 'Footprint' processing item should be the same for all runs.

- Note that footprint probabilities are calculated at 200 points along the fetch and 200 points to either side of the fetch. If large footprints are specified (e.g. 10,000 m) resolution will be lost when footprints are small. Similarly, if a short fetch is specified (e.g. 100 m), under certain conditions no footprint information may fall within the fetch. The calculated footprint is then rotated to match the mean wind direction and interpolated to a 200 by 200 element cell with the centrally located flux tower.
- The wind speed, friction velocity and stability limit parameters allow the user to set a lower limit for these inputs, below which the footprint will not be calculated. This circumvents the possibility of instabilities in the footprint calculation at low wind speeds.
- A reasonable lower limit for wind speed will be slightly higher than the resolution of the anemometer, e.g. a few centimeters per second. A reasonable lower limit for friction velocity will be about an order of magnitude smaller than the wind speed limit. A reasonable limit for stability will be between 5 and 50.
- The value from this item, which is stored in the specified 'Storage Label' is the cumulative fraction (0 to 1) of footprint that falls within a square around the tower with each side of the square being twice the specified fetch.

D3.23.2 Footprint Average

- The footprint average procedure calculates a time averaged flux footprint for the given conditions and stores that footprint in tagged memory for plotting.
- The footprint average item will use the most recently calculated footprint to add to its average footprint. The conditional variable and other condition parameters are used to define the conditions under which the footprint is added to the average footprint.
- If a character is placed in the variable footprint parameter, the footprint is multiplied by the value specified in the variable before being averaged.
- The unique footprint tag is used to identify the averaged footprint for plotting.
- If specified, the averaged footprint is output at the end of a processing run. The value assigned to the 'Storage Label' is the cumulative footprint probability within the fetch multiplied by the variable to average.
- To re-initialize an average footprint EdiRe must be restarted.

D3.23.3 Footprint Spot Probability

- This item calculates the cumulative footprint probability that falls within a specified sub-region of the footprint from the most recent footprint item calculation.
- The sub-regions are specified using the comma-delimited file specified in the spot matrix file parameter. This file must contain a 200 by 200 element array of zeros and ones. Each element of the array represents a square area, with its dimensions corresponding to 1/100th of the

length of the fetch specified in the preceding footprint item calculation. The tower is notionally located at the center of this array.

- The footprint probability array is multiplied, element by element, by the spot matrix file so that only footprint probabilities corresponding to positions in the spot matrix array with values of one are retained. The resulting probabilities are summed and stored in the storage label variable, which represents the probability of the flux falling within the specified sub regions.
- If probabilities for multiple sub regions are needed the user should employ multiple footprint spot probability items in the processing list.

D3.23.4 Footprint Plot

- This item allows the user to plot either the most recently calculated footprint probability, or the most recently calculated averaged footprint probability. To plot an averaged footprint the user must select the unique footprint tag specified in the footprint average processing item.

D4. Integrating Soil Data from a Separate Datalogger with Flux Data

If a separate datalogger is being used to log soil data, this data needs to be combined with the flux data variables. The soil variables necessary for the flux data table are: the average heat flux values (shf), the change in soil temperature (del_Tsoil), the average temperature corrected volumetric soil water content (soil_water_T), the average soil temperature (Tsoil_avg) and the average water content reflectometer period (cs616_wcr). Because soil data is collected on a 15 minute interval, it will be easier for the user to combine the soil and flux data if a final (additional) thirty minute data table is included in the program used to log the soil sensor data that contains the previously listed, required variables for the eddy covariance flux table. This data table should be programmed so the variables are collected on the same time interval (i.e., 30 minutes), which start at each half hour (i.e., 00:00 and 00:30). In Loggernet, the later should occur automatically. Variables for both flux and soil data should be collected in the TOA5 format. The ts_data is the only table collected in the TOB1 format and does not require further data processing.

D5. Data Management

After the data download is complete, the data file should be moved into the raw format folder and renamed based on the download date. Both the downloaded ts_data (TOB1) and flux (TOA5) tables should be copied onto the folder in the CUERE Urban Hydro drive under the eddy covariance folder titled raw data. The files should be saved with the same name that includes the table name and the date of download. At the end of each month the monthly processed files (specified within the EdiRe output) are loaded onto the urban hydro drive. In addition, fill in the processing log once the ts data has been processed.

Both the EC soil data and the processed EdiRe data are used as input to a Matlab program that produces an output in a format compatible with php script for web visualization.