INSTRUCTIONS FOR

# TURBULENT FLUX MEASUREMENTS OF $CO_2$, ENERGY AND MOMENTUM

| Version | Release date | Summary of changes |
|---|---|---|
| 20171020 | 20171020 | Changed maximum uncertainty in the calibration gas to 4 ppm; added information about the wind sector to be excluded; clarified the link with the BADM groups for the different info. Clarified and changed the reason and limits for pressure drop in the IRGA cell. |
| 20180810 | 20180810 | Better defined the volume where the inlet of the IRGA must be placed respect to the sonic. Clarified that variables related to an external pump, if used, can be collected at lower frequency |
| 20200316 | 20200316 | Added information on the O-ring sealing the sensor head and tube in order to reduce the risk of water entering in the cell. Added information of the maintenance and on the need to switch off the sensor for certain operations. |
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The ICOS protocols and the derived Instructions documents can be changed and amended in time, because new technical methods/scientific knowledge become available, or to improve their clearness. For this reason, it is crucial to keep track of the versions and differences.

# CONTENTS

# SUMMARY

The eddy covariance (EC) technique allows the calculation of the turbulent fluxes of momentum, energy and matter. $CO_2$, energy and momentum fluxes are covered by this Instruction document. The main variables to be measured are horizontal and vertical wind speed, wind direction, $CO_2$ and $H_2O$ density, and sonic temperature. Other variables used for the calculation of the fluxes but not directly linked to the EC measurement stage (e.g. air temperature and pressure), are included in the Instruction document of low frequency meteorological variables. Variables measured in vertical profiles and used to calculate the change in storage fluxes (e.g. $CO_2$, $H_2O$, $CH_4$, $N_2O$ concentrations, air characteristics) are reported in a dedicated Instruction document. The present document deals with the application of EC measurements at ICOS stations, describing the steps needed from the installation of the sensors to the data collection, including maintenance, calibration and data submission. The info is contained in the following sections:

- System setup: in this section the sensors are described, and the steps to perform from the installation to the data collection illustrated.
- Maintenance and calibration: in this section all the maintenance and calibration guidelines are described, including the general timeline and how to deal with repairs.
- Submission: this is the section related to data preparation and submission to the ETC. It includes a summary of the submission workflow described in a dedicated document, and list all metadata and ancillary parameters to be sent to the ETC, and how to submit them

It is important to remind that the exact application of the protocol at station level must be also discussed with the ETC in order to reach agreed solutions for specific cases.

This Instruction document is based on the following ICOS Ecosystem protocols:

Rebmann C, Aubinet M, Schmid H, et al. ICOS eddy covariance flux-station site setup: a review. Int. Agrophys. 2018;32(4):471-494. doi:10.1515/intag-2017-0044.

# SYSTEM SETUP

## Sensors and Material needed

**Sonic Anemometer**: horizontally symmetrical research ultrasonic anemometer, model Gill HS-100 or HS-50 (Gill Instruments Ltd, Lymington, UK). This is a non-orthogonal 3-axis anemometer that features a horizontal head design in stainless steel construction. The head of the anemometer contains a built-in inclinometer (rated accuracy of ±0.3° from -10° to +10° of inclination).

**Gas analyser**: non-dispersive infrared (NDIR) absorption analyser, also known as infrared gas analyser – IRGA, model LI-7200 (LICOR Biosciences, Lincoln, USA). This is a high performance, non-dispersive, closed path infrared $CO_2$/$H_2O$ analyser designed for use in EC flux measurement systems. It uses an enclosed path sampling cell. Unlike other closed path instruments, the LI-7200 is designed to be used with a short intake tube (Figure 2).

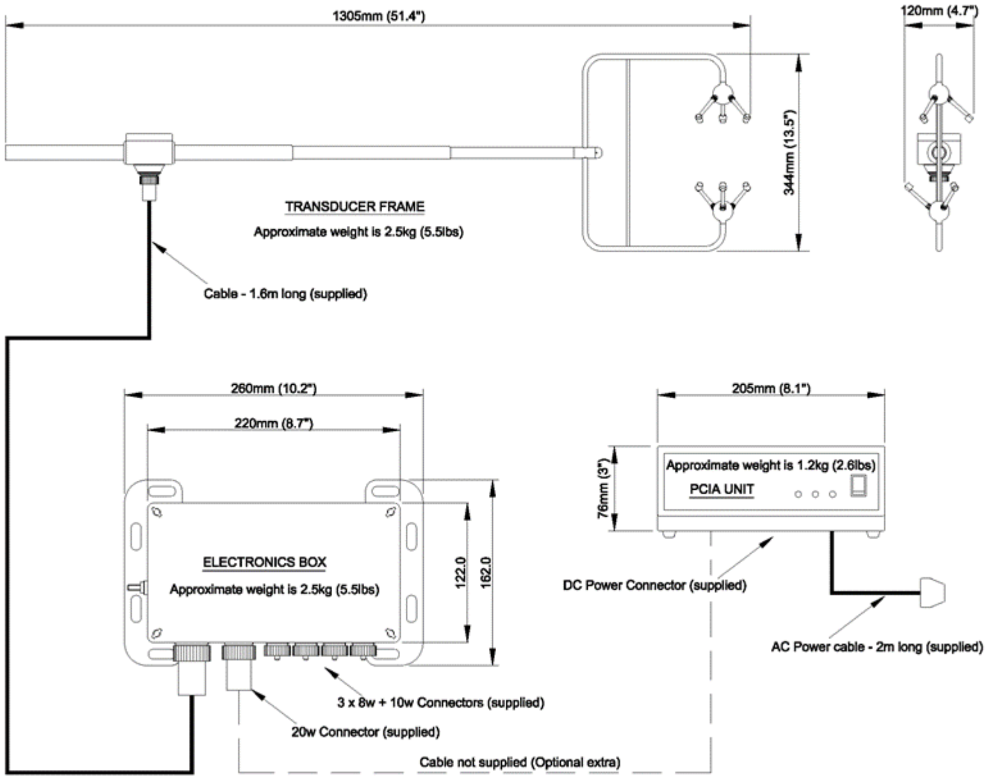


*Figure 1. Mounting Instruction. Source: Gill HS-100 brochure*

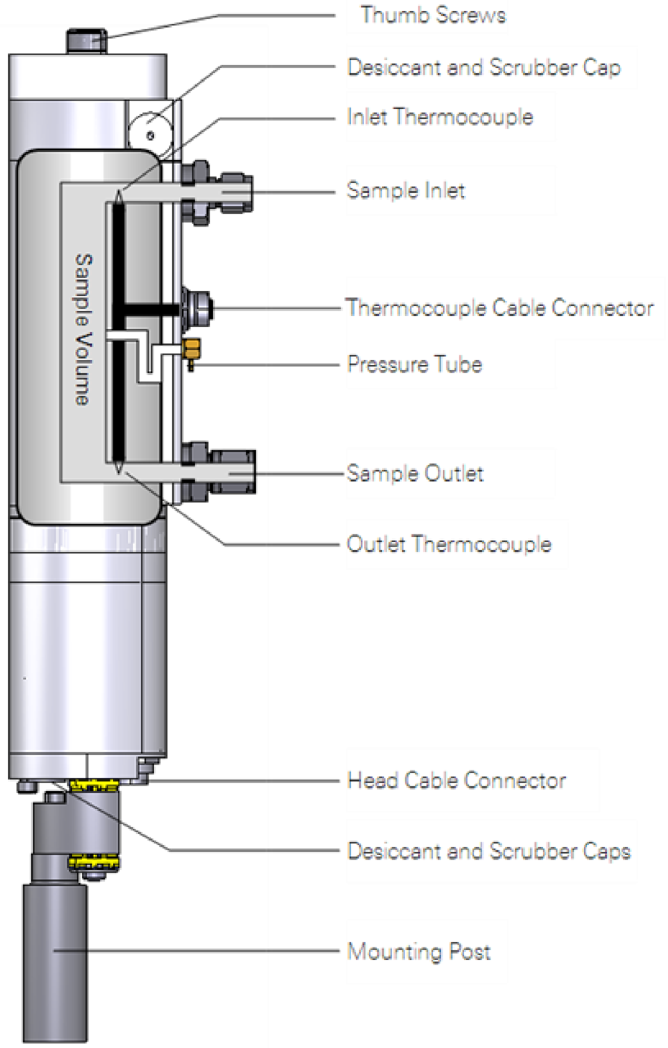


*Figure 2. LI-7200 composition scheme. Source: LI-7200 manual*

**Additional sonic anemometer material**: The sonic anemometer requires an additional element to work, which is provided by the manufacturer with the instrument (Figure 1), i.e. an electronic unit. Recommended but not mandatory is also the use of a power and communication interface unit. Moreover, an optional heating tape can be used in very cold climates to avoid/reduce icing.

*Electronic unit*: it simply contains the electronics of the instrument for data acquisition, embedded elaboration, and transmission. It must be installed at cable distance from the sonic head.

*Power and Communication Interface (PCI)*: it is needed to power the instrument and to convert the signal from the RS-422 format sent by the Electronic box to the RS-232 format. It is an indoor device so a proper case must be provided to housing it. Alternative approaches to power the sensor and collect the data, e.g. either directly using the RS-422 sensor output or a converter to RS-232, are possible, provided they ensure homogeneity and integrity of data collection. These alternatives should be agreed with ETC.

*Heating tape*: it can be applied to the sensor arms at very cold locations that frequently experience conditions of high relative humidity and low temperature in order to avoid or remove frequent snow, ice or rime build-up. Care must be taken that (i) the heating tape does not affect the flow around the sensor structure, and (ii) the sensor heads are not heated beyond the operating temperature range specified by the manufacturer. The heating tape must be connected to a controller to regulate the power and allowing switching heat on when needed and off when not needed, as well as recording of heating periods. Tape application must be discussed and agreed with the ETC.

*Platinum resistance thermometer (PRT)*: an optional sensor to be installed in the vicinity of the sonic head to measure absolute temperature. Not mandatory, several models possible. Must conform to IEC 751 or DIN 43760, have resolution of 0.01°C and accuracy <±0.1°C (range: 0°C to +50°C); <±0.15°C (range -40°C to +60°C). A clean screen is mandatory for the PRT, to protect it from radiation. White screen (double cylinder) with forced ventilation (5 – 7 m s-1) is required to ensure proper air circulation. The volume of the screen must be large enough to guarantee air circulation, but as small as possible to reduce the risk of flow distortion to the sonic anemometer. For the housing only appropriate materials must be used, non-adsorbing or non-desorbing liquid water and water vapour (e.g. plastic materials).

**<u>Additional IRGA material</u>**: apart from the IRGA itself, the gas sampling system (GSS) is composed of a sampling line bringing the air sample from the sampling point to the analyser cell. The GSS is composed of an inlet rain cap, a filter, a sampling tube, the IRGA, a buffer, a flow controller and a pump whose output is returned to the open air.

*Sampling tube*: it is supplied by LICOR with the LI-7200, and is the only tube considered compliant. Only the last version of the tube shall be used: this means the heated tube which comes in the LICOR package 7200-040 and 7200-050 (inner diameter = 5.33 mm; total length = 71.1 cm. See Fig. 3 and box below).

*Rain cap*: it includes a bug screen and is provided by LICOR with the LI-7200. It must be installed at the tube entrance. Only the one indicated as part number 9972-072 by LICOR shall be used.

*Filter*: LICOR provides with the LI-7200 a Swagelok® FW stainless steel filter with 2 µm pore diameter placed in the tube downstream of the rain cap to avoid aerosols entering the analyser, minimizing perturbations to the air flow and concentration measurements. Only the model reported here and not heated is considered compliant (indicated by LICOR as number 9972-073). However, due to specific conditions a different pore diameter may be required, only if agreed with the ETC.

*Buffer volume*: in case the integrated flow module especially suited to the LI-7200 (LI 7200-101) is used, no buffer is needed. Alternatively, a dead volume of about 5 litres placed between the flow controller and the pump, necessary to attenuate the pressure fluctuation induced by the pump, must be present. Spherical buffers are recommended, extended buffers along the direction of the sampling flow also accepted. A different volume can be accepted in specific cases and only if agreed with the ETC.

*Flow controller*: in case the LI 7200-101 is used, a flow controller is embedded. The flow module provides a constant flow between 10 and 18 standard litres $min^{-1}$, under pressure drops between 0.5 and 4.5 kPa. In this case the flow rate should be set to 12 litres $min^{-1}$. Alternatively, a flow controller shall be able to maintain the flow rate between 12 and 15 litres $min^{-1}$. The use of a thermostat is recommended to prevent damage when the flow is off.

*Pump*: in case the LI 7200-101 is used, the pump with a fan is included, so no other pumps or fans must be used. Alternatively, the pump should provide a flow rate higher than 9.6 litres $min^{-1}$ and its capacity must significantly exceed the nominal flow rate selected for the system. Brushless pumps have been identified as a suitable option for continuous operation. The pump must be ventilated to avoid overheating. A water collector (automatic emptying recommended) should be placed between the head of the analyser and the pump or flow controller. Also in case of LI 7200-101 use a water collector can be used and placed just before the air filter of the LI 7200-101.

*Thermocouples*: the head of the LI-7200 is provided with two fine-wire thermocouples measuring the air temperature at the inlet and the outlet of the cell. Only the sensors provided by LICOR (part number 9972-007) are considered compliant.

*Pressure sensors*: the IRGA is also provided with two pressure sensors, one in the LI-7550 and one in the head of the LI-7200. These are embedded sensors, impossible to replace.

*O-rings*: the cell of the IRGA is sealed on the insertion of the two optical windows using two O-rings. They are installed when the sensor is bought, and replaced at each factory calibration as required. In case of need, they can also be ordered separately (part 192-08408 O-ring)

*Analyser Interface Unit (AIU)*: also known as LI-7550, it contains the electronics of the instrument, powers the LI-7200, sends the instruction for the measurements, receives and transmits the data-streams.

*T-junction*: this is needed to be plugged to the “accessory” plug in the AIU to allow both the tube heating signal and the flow-module signal (if used) to be transmitted.

*Special cabling*: In case an AIU with a serial number (SN) below AIU-1279 is used, two split cables are needed for power and communication cable.

Note on heated tube**:** the LICOR heated tube for the LI-7200 has no serial number or other marks on its surface. It comes in a package, including cables and connectors. The packages are numbered and to these numbers refer the codes reported in the tube sub-section above. The difference between them is in the way the power is supplied to the tube for the heating: the 7200-040 package is compatible with AIU serial number *below* AIU-1279; the 7200-050 package is compatible with AIU serial number AIU-1279 and *above*. The tube itself is the same, but the power is provided through the "power" port in the older versions, and through the "accessory" port in the newer version. For that reason the 7200-040 package contains cable splitters to ensure the functioning of the heating also with the previous versions of the AIU. In both cases a T-junction is needed to attach to the accessory port, as both the tube and the flow module are connected to it.

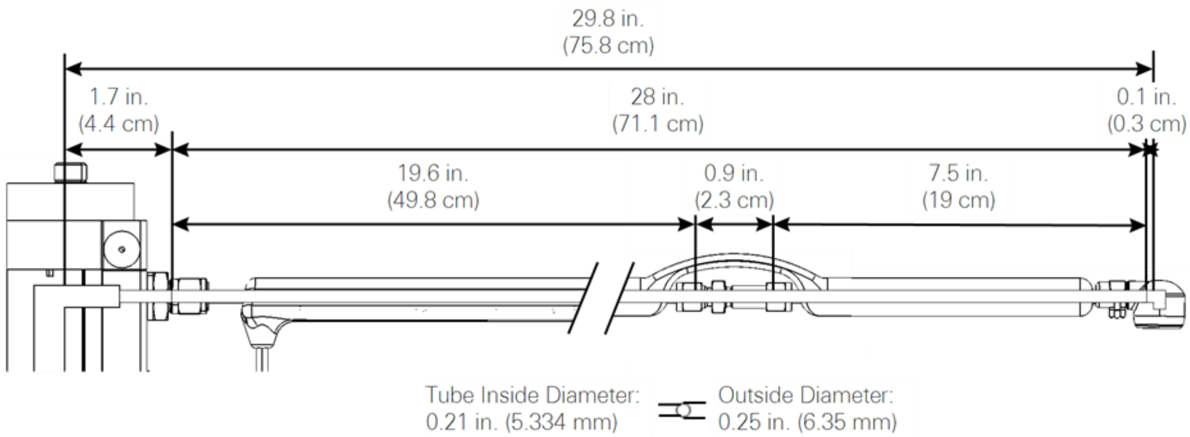


*Figure 3. Scheme of the latest version of the 7200 heated tube. Source: LICOR installation guide of the heated tube (https://www.licor.com/documents/tgzng1d9wj50qxxpm26a25gn5jbp8z6h)*

## Instrument setup and data collection

### *Setup*

The sonic anemometer and the IRGA must be mounted well above the canopy (see below) for the EC system to work. A mast to host the sensors has to be built at the site, and the two sensors to be mounted on a supporting boom attached to the mast to minimize disturbances from the mast. The sonic comes with a boom which is deemed long enough in most cases. However, in case of voluminous towers an extension of this boom shall be used. The supporting boom for the sonic anemometer and gas analyser inlet should be directed into the prevailing wind direction and discussed with the ETC in order to find the optimal site specific solution.

#### System height

The height above the canopy of the measuring system ($h_m$) must be identified with the centre of the sonic anemometer path and its value depends on the canopy height of the ecosystem of interest. Canopy height ($h_c$) value used to establish $h_m$ doesn't need to be particularly accurate: the average expected height of the dominant canopy layer is considered compliant. For grasslands, croplands and shrublands with $h_c$ not higher than 1.75 m, $h_m$ must be comprised between [$h_m = 1.67 \times h_c$] and [$h_m = 6 \times h_c$]. For forested or more structurally complex ecosystems, $h_m$ should be between [$h_m = 1.67 \times h_c$] and [$h_m = 2 \times h_c$]. Anyhow, $h_m$ cannot be lower than 2 m, and must always be discussed and agreed with the ETC, especially when a trade-off may be needed (e.g. very tall canopies).

For croplands, grasslands and plantations with a fast and markedly changing canopy or snow cover heights, the tower design should allow for changing eddy covariance system heights. EC measurement height should be changed during the vegetation growing or during the snow pack season. Changes in the EC system height cannot be more frequent than every 2 weeks. The criterion on how to change eddy covariance system height is to maintain the value [$h_m – 0.67 \times h_c$] as much as possible constant (±10%) during the measurement period. Assuming a bare soil at the beginning of the vegetation cycle and a $h_m$ = 2m, no changes are needed until $h_c$ reaches 1.2m (after this $h_m$ becomes smaller than $1.67 \times h_c$ and the EC system height must be increased). In this period also the [$h_m – 0.67 \times h_c$] cannot be constant. However it is recommended to start raising $h_m$ before the vegetation reaches 1.2m (e.g. around 0.5 - 0.8 m) and then keep the [$h_m – 0.67 \times h_c$] constant. If the growing is particularly fast it is important to have a minimum of 2 weeks with the same height even if the explained rule is not respected.

**Boom length**

The boom of the sonic anemometer must face away from the mast structure. The minimum length of the boom is a function of the maximum tower section size (max of the two sizes in case of rectangular section). For towers with a max section ≤ 60 cm it is sufficient to use the sonic boom (that must exit from the tower for at least 85 cm). For towers with larger sections the boom must be long enough to have the transducers at minimum 1.2 times the max section size (e.g. for a tower 2.5 × 1.5 m the transducers must be at minimum 3 m). The maximum boom length is however 4 m independently of the tower size. No other sensor or equipment shall be mounted on the boom supporting the sonic anemometer and the IRGA, nor shall be within a distance of 1 m from the centre of the sonic anemometer path in any direction. When using extension booms, the mounting must be stiff enough to prevent oscillations of the measuring system even under high wind speed and contamination of anemometer readings.

**Inlet position relative to the sonic anemometer**

The centre of the (virtual) sphere that encloses the IRGA rain-cap must be placed in a volume with dimensions (*X*, *Y*, *Z*) 6.5 × 5 × 16 cm and corresponding to:

- *X* = the distance between the two vertical sonic arms (see Figure 4);
- *Y* = the distance between the horizontal boom and the lower transducers level (Figure 4);
- *Z* = a range of tolerance around the axis of the horizontal boom (8 cm per part).

The tube should be fixed to the boom to avoid oscillations and tilt towards the inlet.

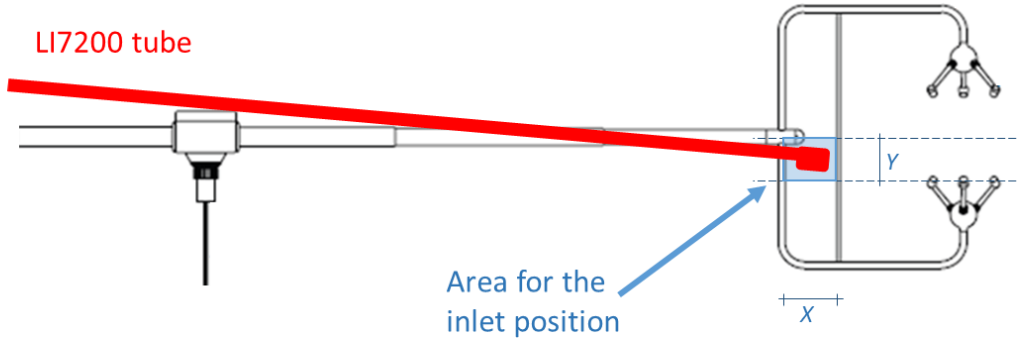


*Figure 4. Scheme of the mounting of the LI7200 inlet. The rain cap must be placed in the light blue area reported in the scheme, between the two vertical arms and between the sonic boom and the bottom transducers*

**Note on the flow distortion**: the Gill HS has a horizontal geometry: this means that all the supporting structures (sonic arm etc.) are placed on the same side and at the same level of the sonic head, i.e. on the opposite of the alignment direction. For that reason the wind coming from “behind” in the sonic reference system is severely disturbed by flow distortion, and must be discarded. By default, considering only the sonic structure, this sector is 20° wide, 10° on each side of the direction of the sonic arm. This is the default wind sector discarded during the processing and does not need to be communicated by the PI. However, in case of large towers, other disturbances present in the footprint, different land uses than the target one, etc., this sector can be enlarged, or one or more sectors can be added, communicating them to the ETC via the BADM system

## Mounting of sensors

**Sonic Anemometer mounting**: fix the head to the dedicated boom clumping onto the shaft in front and behind of the junction box. Ensure that the head is aligned so that the upper transducer sphere is directly above the lower transducer sphere: use sonic embedded inclinometer readings to test this (read zero on both axes). Fix the electronic box anywhere at cable distance, ensuring that the connectors are on the underside. In case the PCI unit is deployed, use a watertight box for housing it. Connect the sonic anemometer to the electronic box, then connect the electronic box to the PCI. Connect the PCI to the logging system via the RS-232 exit, and to the power supply using the cable provided by the manufacturer. If PCI unit is not used, directly connect the RS-422 exit of the electronic unit to the logging system, or use an alternative converter to RS-232 protocol. The optional PRT sensor inside the screen, if used, should be placed on the back of the sampling volume, such as to avoid disturbances: install it inside the screen, paying attention to avoid contact. This is not necessary if the sensor is provided already inside the screen by the producer. The screen can be used as support for the sensor: just fix it to the boom using a proper support.

**IRGA mounting:** install the rain cap with the bug screen on the tube, then mount the filter in the tube and install the tube in the head. When installing the filter, be sure to respect the direction of the arrow (air should flow in that direction). Install the head of the IRGA on the boom, mast or other support, caring that the inlet is placed as described above. Be sure the tube is fully seated in the filter. Install the rain cap using the clamp provided. The head is furnished with a mounting kit: just fix it to a support and mount it on the support. Attach the intake tube to a secure mount (e.g. the sonic boom) so that the analyser is not bearing its weight. Tilt the head of the IRGA towards the inlet (minimum 5°). The AIU must be installed at cable distance from the IRGA head, securing it to a robust structure of the mast using the kit as provided by the manufacturer. The same holds true for the LI 7200-101 if used. If instead a different pump and flow controller are used, they have to be placed at cable distance from the head and from the AIU. They must be provided with a housing to avoid atmospheric agents to damage them, and a fan must be installed in the housing to avoid overheating of the pump. The buffer volume must be placed in a safe position between the flow controller and the pump. Connect the Sensor Head, the pressure tube and the thermocouple to the corresponding plugs of the LI-7550. Install the T-junction to the accessory port, and connect the Flow Module LI 7200-101, if in use, to the IRGA through the tubing, and plug it to the T-junction to send the flow rate variables. Alternatively, connect the pump, the buffer and the flow controller to the system, and connect the heated intake tube connector directly to the accessory port, without the T-junction adapter. For the older AIU boxes, use two splitter cables as in Figure 5, just without T-junction adapter. Connect the power cables to the LI-7550 and to the pump + flow controller or to the flow module. If using an AIU older than SN AIU-1279, connect the power supply splitter to the power cable that goes to the IRGA head, then one way to the power plug and the other to one end of the split of the serial cable. Then connect the other end of the communication cable to the accessory port via the T-junction, and the cable itself to the IRGA head (Fig. 5). Set the power for the heating at 4 W. Connect the LI-7550 to the logging equipment through the Ethernet port.

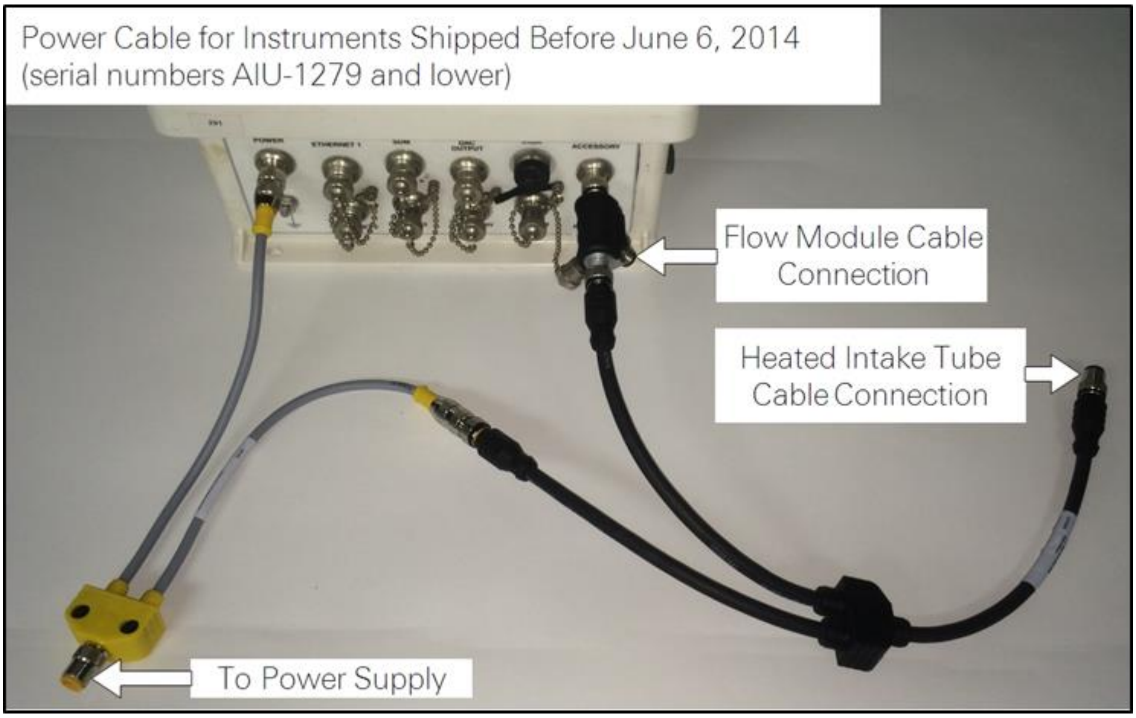


*Figure 5. Cabling the AIU with serial number below AIU-1279. From LICOR installation guide.*

## *Data collection*

Raw data must be collected at a frequency of 10 Hz or 20 Hz, depending on site characteristics (e.g. canopy height) and PI preference. In case of use of an external pump it is possible to agree with the ETC for a lower acquisition frequency of the flow related variables (see the Instruction on raw data format for EC, doi:10.18160/v5jt-9f66). All the data must be collected digitally and the data streams from the two sensors synchronized as best as possible. For these reasons, it is recommended to collect the data streams from the two sensors with the same logger or computer device, using systems that have been tested and that ensure proper synchronization and collection of all the requested variables. Logging solutions proposed by the companies are available at the ETC.

Possible solutions are to acquire the sonic anemometer via RS-232 or RS-422 ports and the IRGA via Ethernet at a frequency at least double than that of the set acquisition frequency, and then resampling them at the desired frequency based on the logger clock. Alternatively, it is possible to use the logger clock to poll the records from the buffer of the serial port. Note that the use of the SDM protocol from Campbell Scientific is currently not an accepted option because it is not open source and because not all the mandatory variables are transmitted using this connection. Please also note that the analogue inputs of the LI-7550 cannot be used to log sonic data.

The data collection solution chosen must be discussed with the ETC that could also perform specific tests in order to evaluate the performances of the synchronization. Data must be stored in 30 minutes ASCII files (better if compressed in a .zip format) or binary files (with an appropriate ASCII header documenting variables and datatypes), both shaped as described in the Instruction document of the data format.

In case the sonic anemometer heating is used, it should be applied only the minimum time possible needed to prevent or remove ice formation. Information on the time when the heating is operating and its power intensity must be recorded and reported.

# MAINTENANCE AND CALIBRATION

## Sensor maintenance

**Sonic anemometer**: the instrument and sensor heads need to be kept clean and free of debris, insect deposits or bird droppings. Cleaning frequency is different in different conditions: the presence of dirt shall be checked once per month, and cleaning performed only when necessary based on visual inspection. Use only clean or distilled water and no solvents or mechanical force must be applied. Occasional presence of ice can also be removed with particular care. All maintenance periods must be reported in the metadata.

**IRGA**: the gas sampling system requires maintenance in all its components. All the maintenance operations must be timely reported to the ETC (same day of operation).

*Pump*: If diaphragm pumps are used, the diaphragm should be changed once a year.

*Filters*: The criterion of filter change is given by the differential pressure that should be kept below 9 kPa. In case the LI 7200-101 flow module is used, the recommended threshold is 2.5 kPa to reduce the pump consumption and decay. It is however possible increase it to 4kPa, in particular in case of stations where dirt is frequent but must be considered that the pump in this case would work close to its limit. The Swagelok FW filter and its parts can be cleaned and reused. When the filters need more than three cleanings in a month it has to be replaced with a new one. The recommended cleaning procedure is as follows:

1) Use clean filtered compressed air (zero grade air or ultra-pure nitrogen) to blow out the large particulate matter, around 300 kPa of pressure, in the reverse flow direction.
2) Flush the filter with distilled water, first in the reverse flow direction and then in the flow direction.
3) Use clean compressed air to blow out the large particulate matter, about 300 kPa, first in the reverse flow direction and then in the forward direction.
4) Allow the filter to dry for at least 24 hours in a clean and dry location.

After these steps, visually inspect the retainer screens on both sides of the filters inlet/outlet for corrosion. If corrosion/rust appears on the retainer screens, replace the filter with a new one. If the differential pressure after the cleaning is still above 9 kPa (4 kPa if the LI 7200-101 flow module is used), 2 options are possible: (i) replace the filter with a new one. (ii) Place the filter in a sonic bath filled with chemistry grade glassware cleaner. Leave in bath for about two hours. Then repeat steps 2 and 3, and then rinse again in the sonic bath filled with clean distilled water for one hour. Repeat step 3 and 4. Check again the differential pressure: if the issue is not solved, replace the filter with a new one (option (i)). When the replacement of the filter is necessary, the new filter must be a Swagelok® FW stainless steel filter with 2 µm pore diameter, unless differently agreed with ETC.

*Rain cap*: Both rain cap and bug screen need to be cleaned regularly to reduce interaction with water vapour and dirt. In occasion of filter cleaning, remove the rain cap with the bug screen and using back-flush compressed air or water. If needed it is possible to immerse the rain cap with the bug screen in boiling water for a few minutes or soak it in an ultrasonic water bath.

*Intake tube*: in case the intake tube is not firmly secured to the head of the IRGA, water may enter the cell and the whole system, causing bad readings and damaging the pump. An inspection on the bolt of the tube is recommended in occasion of zero readings (see below), or at least every two months. The bolt must be tightened carefully, without forcing it, but firmly.

*Analyser optics*: analyser cell must be cleaned when calibrations are performed (see below). Loosen the two knurled knobs on the top of the sensor head, and then pull the top of the sensor head out away from the optical bench. Use cleaning swabs provided with the instrument, or a soft, lint-free cloth. It is possible to use a mild detergent or glass cleaner to clean the windows. To clean the optical bench and the optical path do not use acetone, ammonia, chlorine, or wire brushes to avoid damage to the PVC insert and to the O-rings (see below). You can use mild soap and water, isopropyl alcohol, vinegar, or water. Shade the windows from direct Sun with an opaque cloth or your hand when the optical path is open, especially the upper window. Exposure to direct sunlight will result in an artificial reduction of the signal strength that will take time to low down (hours to days). At last reassemble the sensor head. Whenever a sharp decrease in the signal strength is noticed, a supplementary cleaning of the optics may be required.

*O-rings:* O-rings sealing the cell around the mirrors are checked and replaced as required by the producer at any factory calibration, e.g. every 2 years. In normal conditions, they are expected to maintain the sealing much longer than 2 years. However, aggressive cleansers and harsh atmospheric conditions (e.g. high salinity, dust, etc.) may affect the durability of the O-rings, causing water to enter the cell up to the pump. This usually results in bad data, and can also cause important damages to the pump system. For those reasons the following maintenance scheme is recommended:

1) On a regular basis, remove the cell as described above, and perform a visual inspection of the O-rings. In case of evident damages (consumption, presence of cracks) their replacement is needed. ETC recommends to combine this check with the zero reading event (see below), or anyway to perform this visual check at least once every two months.

2) Regular application of a thin layer of silicon grease over the O-rings is recommended with a scheduled time of at least 6 months. When applying the silicon grease, special attention must be payed that this doesn't reach the lenses of the mirror.

*Chemicals*: In the head of the IRGA there are three small plastic bottles, each containing Ascarite II and magnesium perchlorate, in the upper and lower analyser housings (referred to as "chemicals" hereafter). Chemicals must be changed once per year: as the instrument must be sent to the factory for calibration and chemical replacement every two years (see below), it should be made in the field every second year. In very humid environments replacement should be made every six months. Operate as follows: 1. Remove the chemical bottles in the lower analyser housing in the sensor head. Remove the mounting bracket from the analyser. Then remove the thumbscrew and thread it into a cap. Pull straight out to remove the plug. 2. Fill the bottles half full with Ascarite II first, followed by the magnesium perchlorate. 3. Place the Teflon membrane in the lid. 4. Insert the recharged bottles into the analyser housing cap first. Replace the bottle covers. 5. Use the retention screw to remove the bottle cover on the upper sensor head housing and insert the new, recharged bottle, cap first. 6. Replace the cover retention screw and reattach the mounting bracket. Avoid to calibrate the IRGA in the 72 hours after chemicals replacement.

*Zero readings*: Periodic zero readings must be performed in between IRGA field calibration events. The reading must be done following the same procedure described in point 1 of the IRGA calibration (below) without cleaning the sensor and readings reported. Recommended frequency is once every two months.

*Software updates*: Install the latest version of both the embedded software and PC software, unless differently recommended by the ETC. An notification will be sent to the station PI by the ETC when an update is available; the ETC will also check the compatibility with the sensor in use and advise on the opportunity to install it or not. In addition, it is recommended to update the PC software each time a sensor is returned from factory calibration.

## Sensor calibration

### *Field calibrations*

**Sonic anemometer**: An actual calibration in the field for the sonic is not possible, and hence is not required.

**IRGA**: Field calibration must be performed at least 4 times per year after the first installation of the LI-7200. After one year, a minimum of one calibration per year has to be assured, to be done at the beginning of the growing season. More frequent field calibrations are possible if significant drifts in the zero are observed but must be discussed and agreed with the ETC. Identification of significant drifts shall be based on $CO_2$ concentration because more stable (drifts >30 µmol mol$^{-1}$ $CO_2$ are considered significant). As an indication, also $H_2O$ drifts > 1.5 mmol mol$^{-1}$ are considered significant. Avoid calibrating during rainy and windy days. Performing the “field” calibration in a laboratory is acceptable where de-installation, calibration and re-installation can be achieved within one day or where a calibrated spare sensor is available to bridge the data gap. Proceed in the following way:

1. Perform a zero reading of $CO_2$ and $H_2O$: record the value measured by the instrument ($CO_2$ and $H_2O$ zero offset) flowing a $CO_2$-free and dry gas. $CO_2$-free dry air, also known as “synthetic air”, is to be preferred.
2. Clean the optical cell and reassemble it (see above).
3. Disconnect the intake tube at the air inlet on the sensor head.

4. Connect the calibration gas to the air inlet. Flow $CO_2$-free dry air at a rate of about 0.5 to 1.0 litres min$^{-1}$ or slightly more. When the reading has stabilized in the dashboard of sensor software, click “Zero $CO_2$” to set the $CO_2$ zero.
5. Do the same for $H_2O$.
6. Flow a $CO_2$ span gas ($CO_2$ in dry air with a concentration at the higher end of environmental range, i.e. 400-500 µmol mol$^{-1}$ at maximum 4 µmol mol$^{-1}$ uncertainty) through the optical path at 0.5 to 1 litres min$^{-1}$. Record the value read by the IRGA. Click on the Span tab in the software and enter the mole fraction of the $CO_2$ of the tank. When stable click “Span $CO_2$”.

Record also air and cell temperature during calibration and the time of beginning and end. No $H_2O$ span calibration should be performed.

### *Factory calibrations*

**Sonic anemometer**: the sonic anemometer must be sent to the factory for calibration every two years following a calendar defined by the ETC. In case the heating tape is applied, the instrument needs to be factory re-calibrated with heating device installed.

**IRGA**: the IRGA must be sent to the factory for calibration every two years following a calendar defined by the ETC. Factory calibration includes, among others: check of drift and stability; $CO_2$, $H_2O$, and pressure calibration (and then a new set of polynomial coefficients); temperature sensors and flow module (if used) verification; chemical replacement; software upgrade; various maintenance and repairs as needed.

## Sensor repair and substitutions

**Minor repairing:** some minor damages can be easily solved by the technical staff of the station. The information on the repairing must be submitted to the ETC via the BADM system on the same day they are made.

1. One of the fuses in the LI-7550 burns. *Symptoms*: the battery or other power source fails; the heated intake tube will not power on or continuously triggers an error. *Solution*: Check the fuses and replace that/those burnt. Be sure to choose the proper amperage. If the problem is not solved, check the power cable and connection.
2. One of the air temperature thermocouples in the head of the LI-7200 breaks. *Symptoms*: error message from the LI-7200, bad diagnostic value, implausible values of the mean cell temperature and from one of the two thermocouples (temperature cell in or cell out). *Solution:* replace the broken thermocouple. Use one of the spare thermocouples provided by LICOR with the IRGA. To replace the thermocouple do the following:

a) Loosen the two knurled knobs on the top of the sensor head and remove the optical bench. Shade the optical windows from direct Sun with an opaque cloth or your hand when the optical path is open, especially the upper window.

b) Remove the eight hex screws on the back of the optical bench.

c) Remove the small thermocouple circuit boards. There are 2 pins on the underside of the circuit board. Lift up on the end of the board to remove the thermocouple assembly and discard. Make sure the 2 o-rings of the thermocouples are present on the new board (the upper one is tacked on), and insert the new assembly, making sure the 2 pins are inserted into the connector.

d) Reassemble the optical bench and the analyser.

3. One or both the O-rings in the cell are consumed. *Symptoms*: implausible or error values in the data from the IRGA, in particular CO2 and H2O concentrations, air flow characteristics, pump variables, signal strength; water in the tube, cell, air filter, pump from visual inspection; damage to the pump motor; O-rings present missing parts or appear consumed by visual inspection. *Solution:* replacement of both the O-rings is necessary. New ones can be ordered at LICOR, or can be purchased locally, or even built at the station. In the latter two cases, however, extra care must be taken on the fact that the size must be exactly the same of the original O-rings. Differences due to different unit systems should not be underestimated. Replacements should be done according to the following steps:

   a) Remove the optical bench as described at point 2. Remove the consumed O-ring. A small flat-blade screwdriver can help, however extra care must be taken not to damage the lenses during this operation

   b) Apply a thin layer of silicon grease on the new O-rings before placing them.

   c) Insert the new O-ring removing any excess of silicon, always paying attention to keep it away from the lenses.

   d) Repeat for the second O-ring.

   e) Reassemble the optical bench and the analyser.

4. Environmental disturbances to measurements: any obstacle which is found in the measuring path of the sonic or its vicinity, or in the bug screen of the rain cap of the IRGA, must be removed as soon as possible. *Symptoms:* disturbed signals and bad diagnostic from the sonic anemometer; increase in the pressure drop of the IRGA; increase of the power consumption of the pump/LI 7200-101 flow module; evidence from regular visual checks. *Solution:* natural obstacles can be spider webs, bird nests, wasp nests, and so on. Remove the obstacle and clean the part according to the recommendations in the maintenance section.

Please note that in case of operations on the IRGA involving the unplugging of electronic parts, such as thermocouples, cables, etc., the LI-7200 analyzer (LI-7550 AIU box and flowmodule) must be switched off. If the EC system is logging data in the LICOR SmartFlux2, this latter also has to be switched off. Not respecting this recommendation will result in bad timestamp assigned to the records in the ICOS files.

For all the problems please always refer to the original manuals of the sensors. Contact ETC in case you need assistance in understanding the issue present.

# SUBMISSION

## Data format

The file format, variable names to be used, their units, the filenames, and other details on the data format and the data submission are reported and explained in the Instructions on Raw data format for EC (doi: 10.18160/v5jt-9f66). Summarizing the content of the format instructions, EC data are continuous high frequency data organized in half-hourly files, either comma-separated ASCII (compressed or not) or binary (with an ASCII header). The header line must report variable names according to the standard names. The order of the column is in general not prescribed, except the timestamp which must be reported in the first column.

## Variables to be submitted using BADM system

EC data must be accompanied by fundamental metadata, which are sporadic data to be sent to the ETC using the BADM system. These info must be sent at the installation of the station, and each time a change in the setup occurs, an event happen (including calibrations and disturbances) or there is a change in the ecosystem characteristics relevant for EC calculations. To get the full and updated list of variables refer to the BADM templates. In general however the BADM variables related to the EC are:

- Variables that list the sensors available and their characteristics (INST group). Only the sensors reported using this BADM variable can be accepted as installed at the site.
- Variables to describe the setup of the sensors such positions, acquisition system, file type (EC, ECSYS, LOGGER and FILE groups)
- Variables to describe the management and disturbances to the system such calibrations, damages, other problems (EC group)

Refer also to the website and the BADM FAQ for more information and a correct BADM filling.