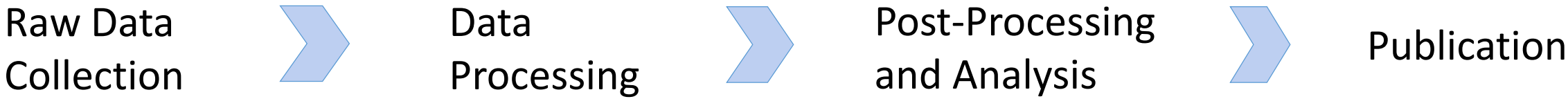
Eddy covariance system integration and operation

Zhongwei, Ningxia, China

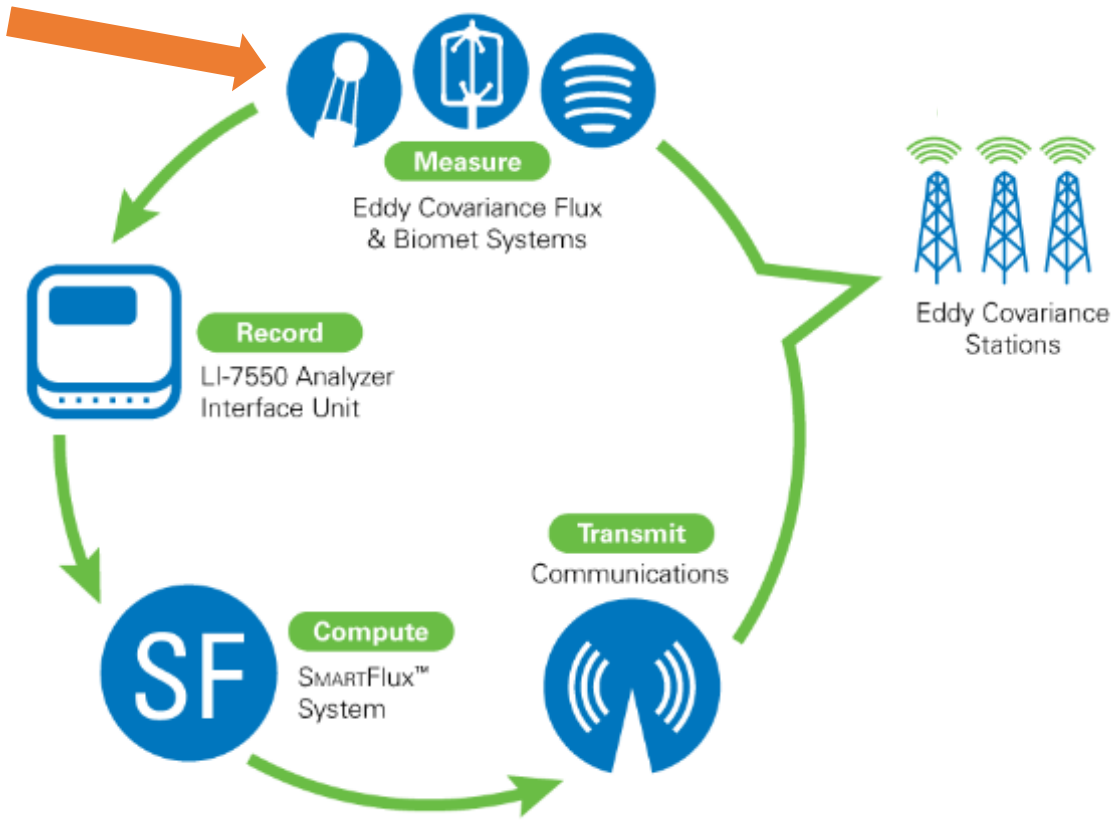
July 2018

Eddy Covariance Data/Workflow Pipeline



Measurements and Computations

- LI-COR Analyzers used in 90% of Flux Sites around the world
- Now with new improvements



The LI-COR Open-Path Analyzer

- LI-7500 → LI-7500A → LI-7500RS
- Engineering and manufacturing Gas Analyzers for **over 25 years**.
- Some LI-7500 analyzers have been deployed in the field for **15+ years**
- Strong scientific and engineering team designs for **best performance** (power, aerodynamics, etc)

New LI-7500DS: Highlights

- Retains new optical design from LI-7500RS
  - Gas Analyzer (head) form-factor is the same
  - More stable concentrations — even when not cleaned for weeks or months
  - Drift can be reduced by orders of magnitude
- New temperature controls for even better stability
- The SmartFlux 3 system becomes the core
- Eliminates LI-7550 Analyzer Interface Unit
- Lower power consumption.
- Improved temperature measurement with sensor embedded in the spar
- Calibration information stored in sensor head

Performance – CO_2

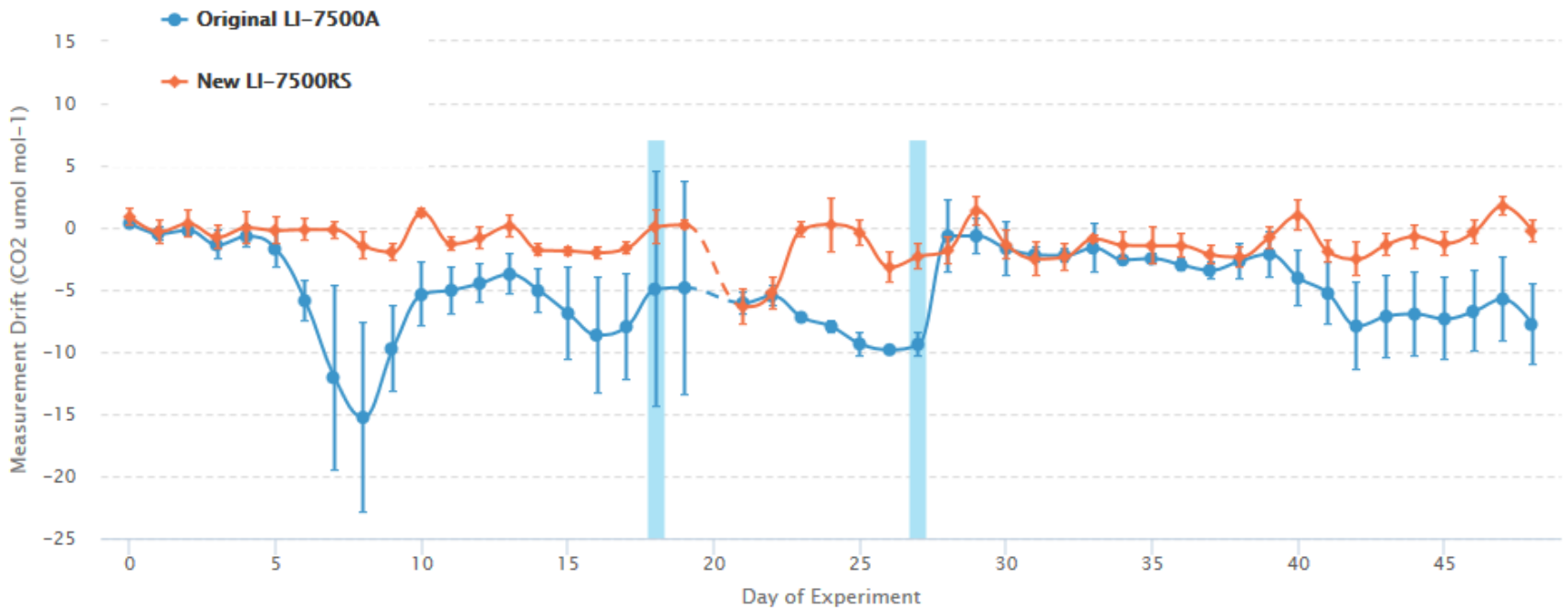


Figure 1. CO_2 measurements from three LI-7500RS analyzers and three LI-7500A analyzers (average and spread). The y-axis shows the deviation from a control reference. CO_2 measurements from the LI-7500RS analyzers drifted considerably less and had smaller instrument-to-instrument variability than those from the original LI-7500A models. Data show the typical improvement expected from the LI-7500RS analyzer.

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Performance – H_2O

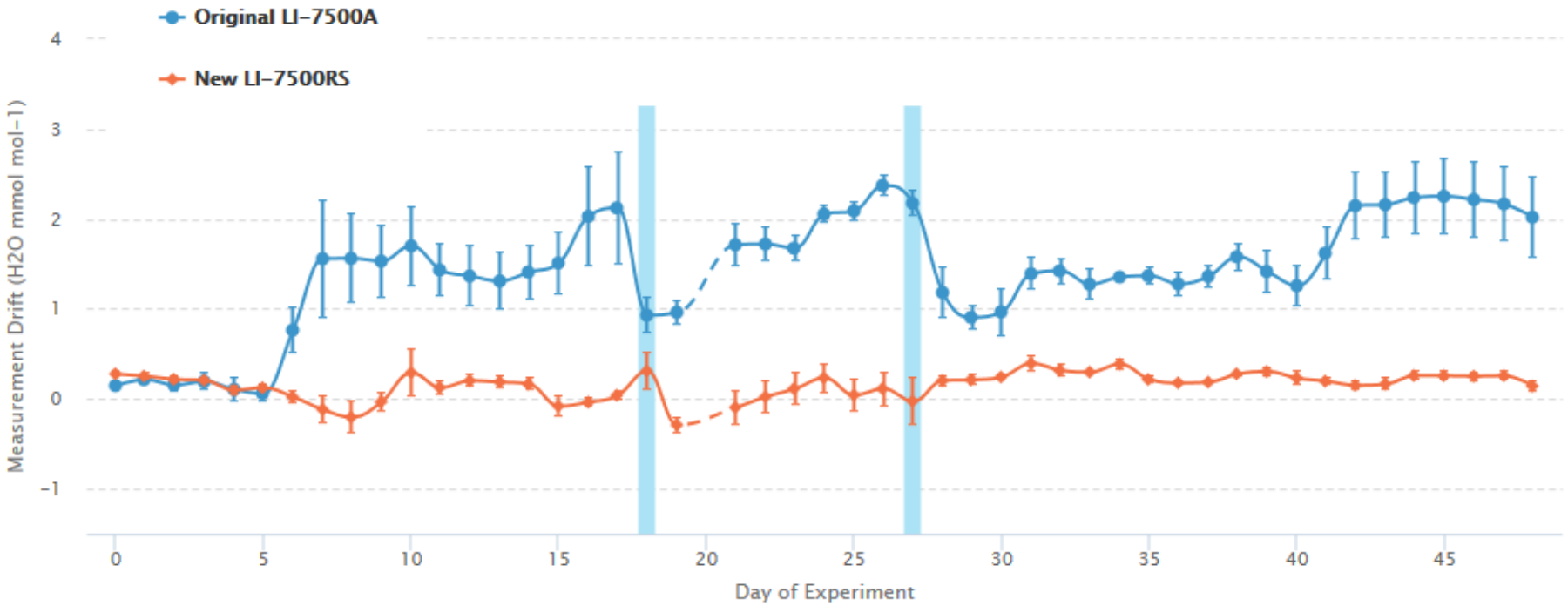

Figure 2. Water vapor measurements from three LI-7500RS analyzers and three LI-7500A analyzers (average and spread). The y-axis shows the deviation from a control reference. Measurements from the LI-7500RS analyzers drifted several times less, and had smaller instrument-to-instrument variability when compared with original LI-7500A models.

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Consistent Performance Across the Full Temperature Range

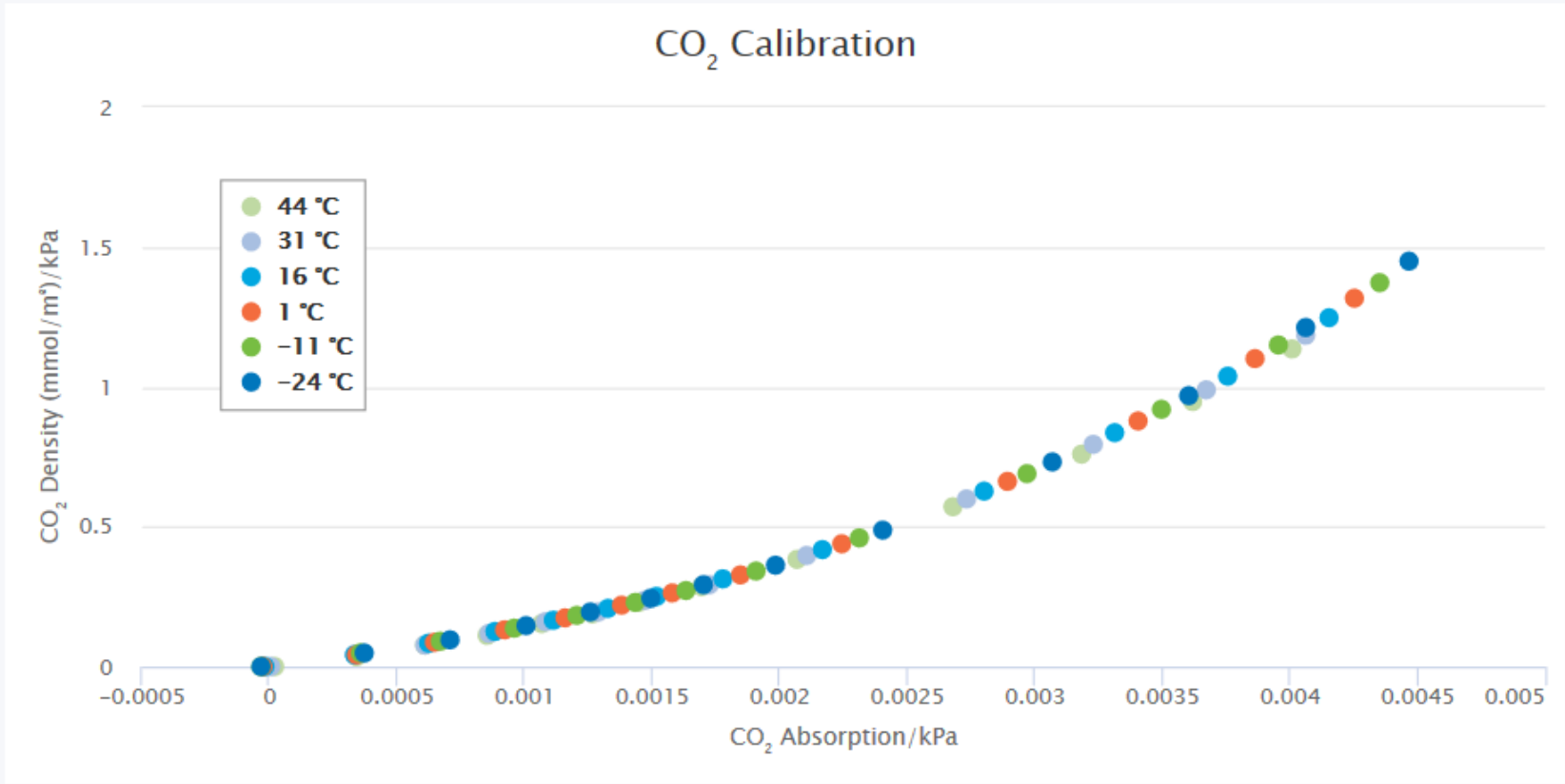


Figure 2. CO_2 calibration curves for an LI-7500RS gas analyzer at 6 temperatures. The relationship between CO_2 density and absorption is consistent across the full temperature range of -24 to 44 °C.

Lower Power

- Now, operation is typically **4-5 watts**

Sonic Anemometers

LI-COR Systems integrate with:

- Gill, CSI, RM Young, Metek…
- Provide u, v, w, Tsonic, and diagnostics
- Digital (Serial) or Analog output

Sensor Arrangement

- Acceptance angles, alignment, flow distortion and sensor separation

Points to remember…

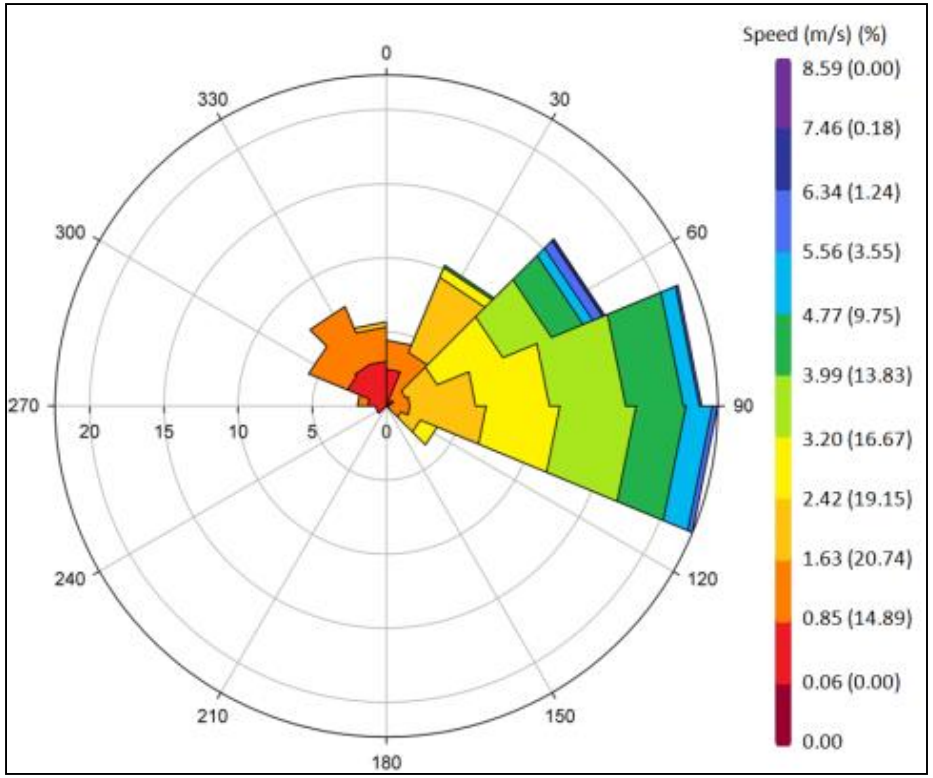
Many of the location requirements follow directly from the EC equations and are intended to satisfy the assumptions made during derivations:

- Represent the ecosystem/area of interest
- Large enough: sufficient fetch/footprint
- Terrain is reasonably flat and uniform

LI-COR

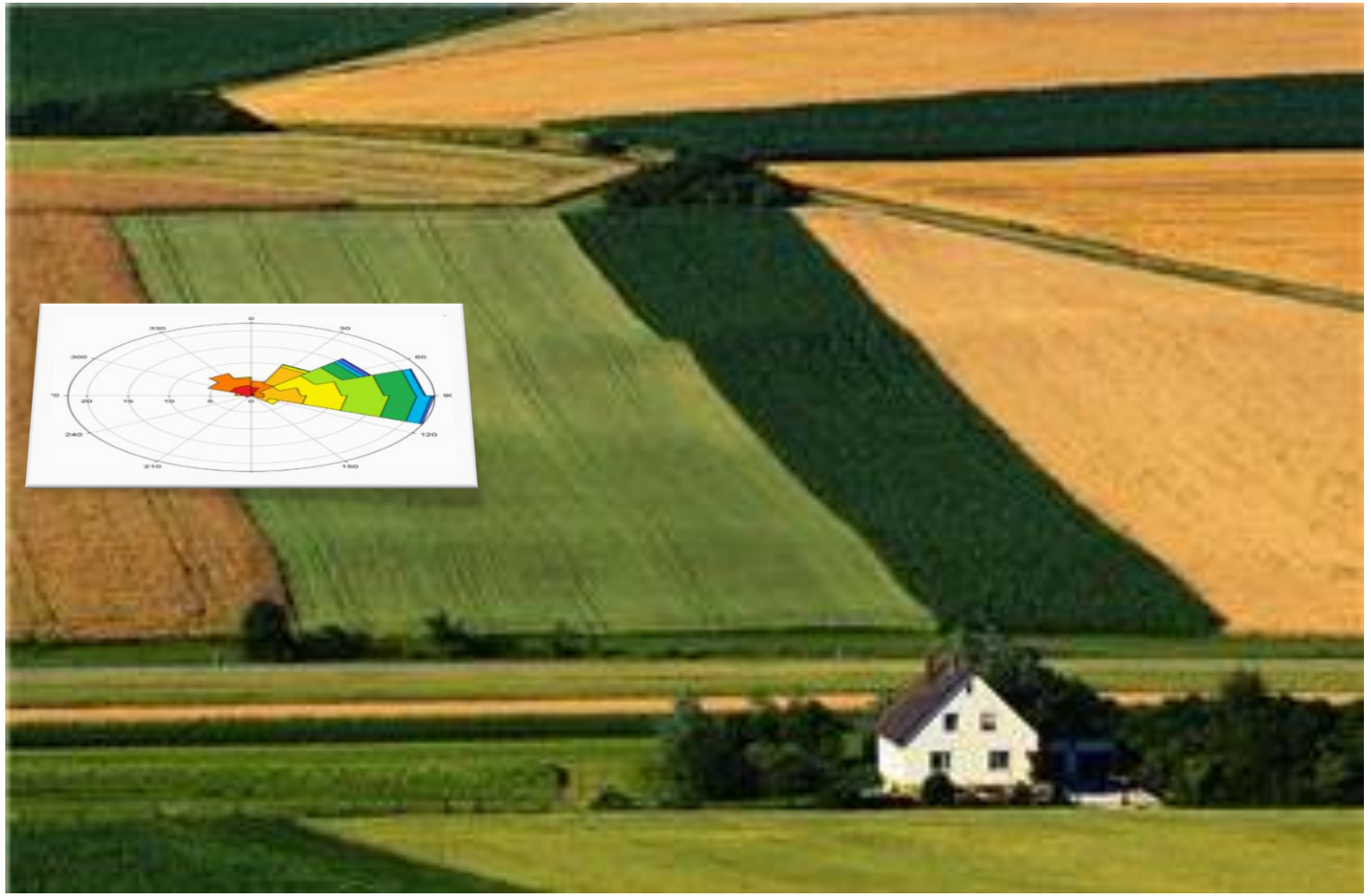
What is the prevailing wind direction?

Determining prevailing wind direction Windrose



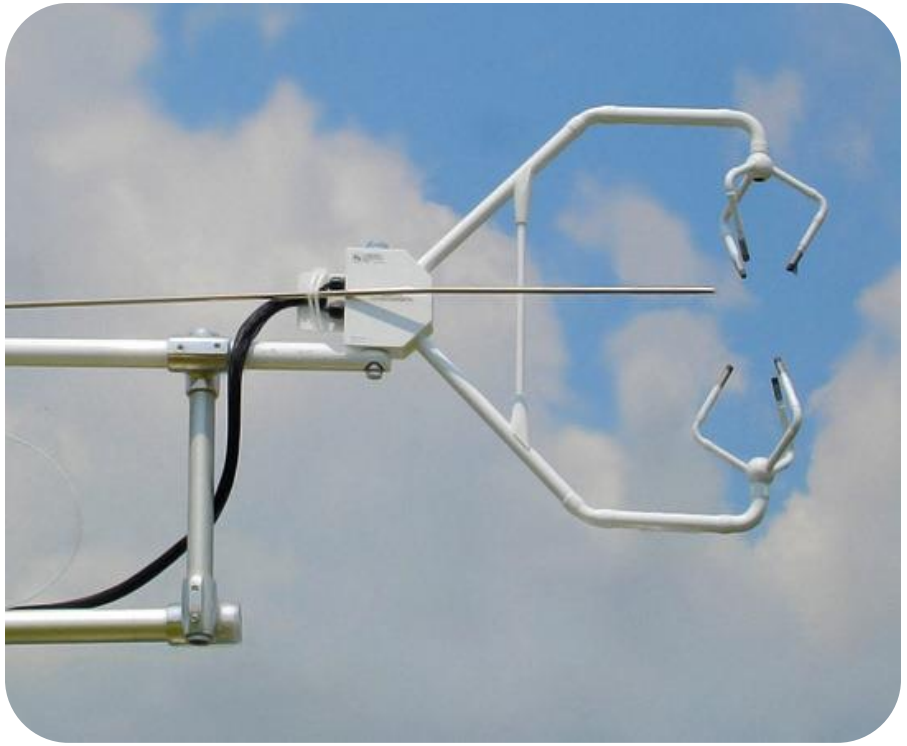
http://mesonet.agron.iastate.edu/sites/locate.php

Locating the tower…



Sonic designs and acceptance angles

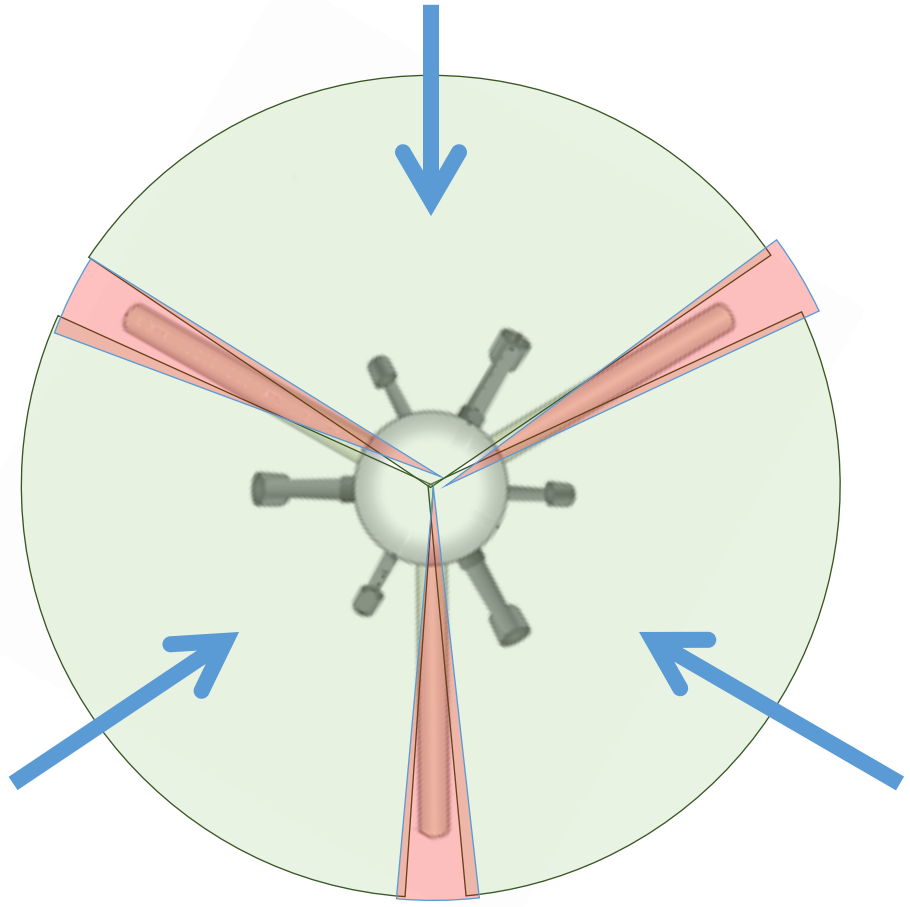
C-clamp



Omnidirectional

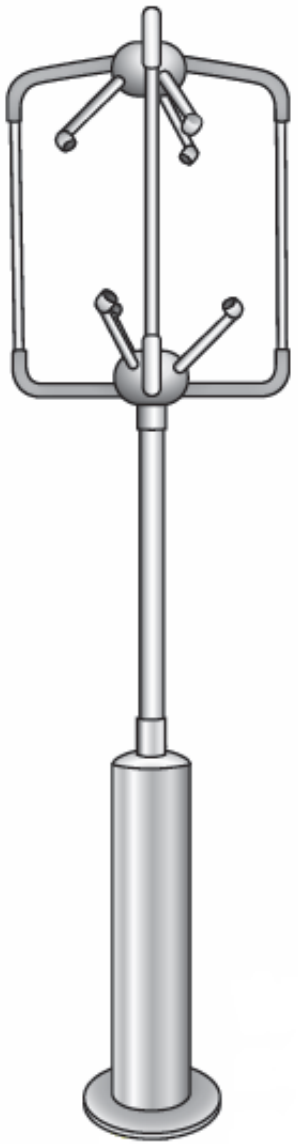
Omni-directional alignment

360 degrees



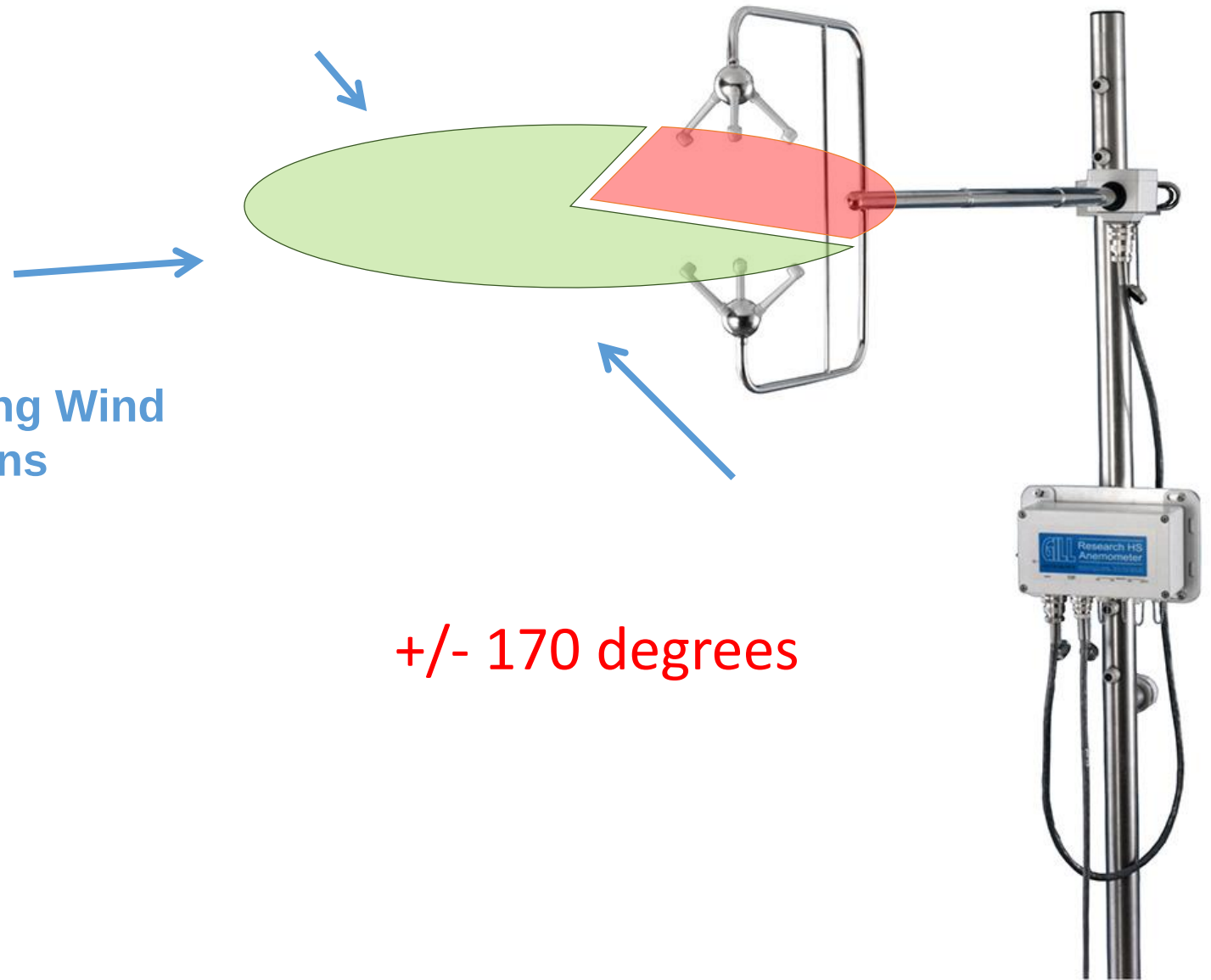
Prevailing Wind Directions

(+/-) 2-to-5 degrees



LI-COR

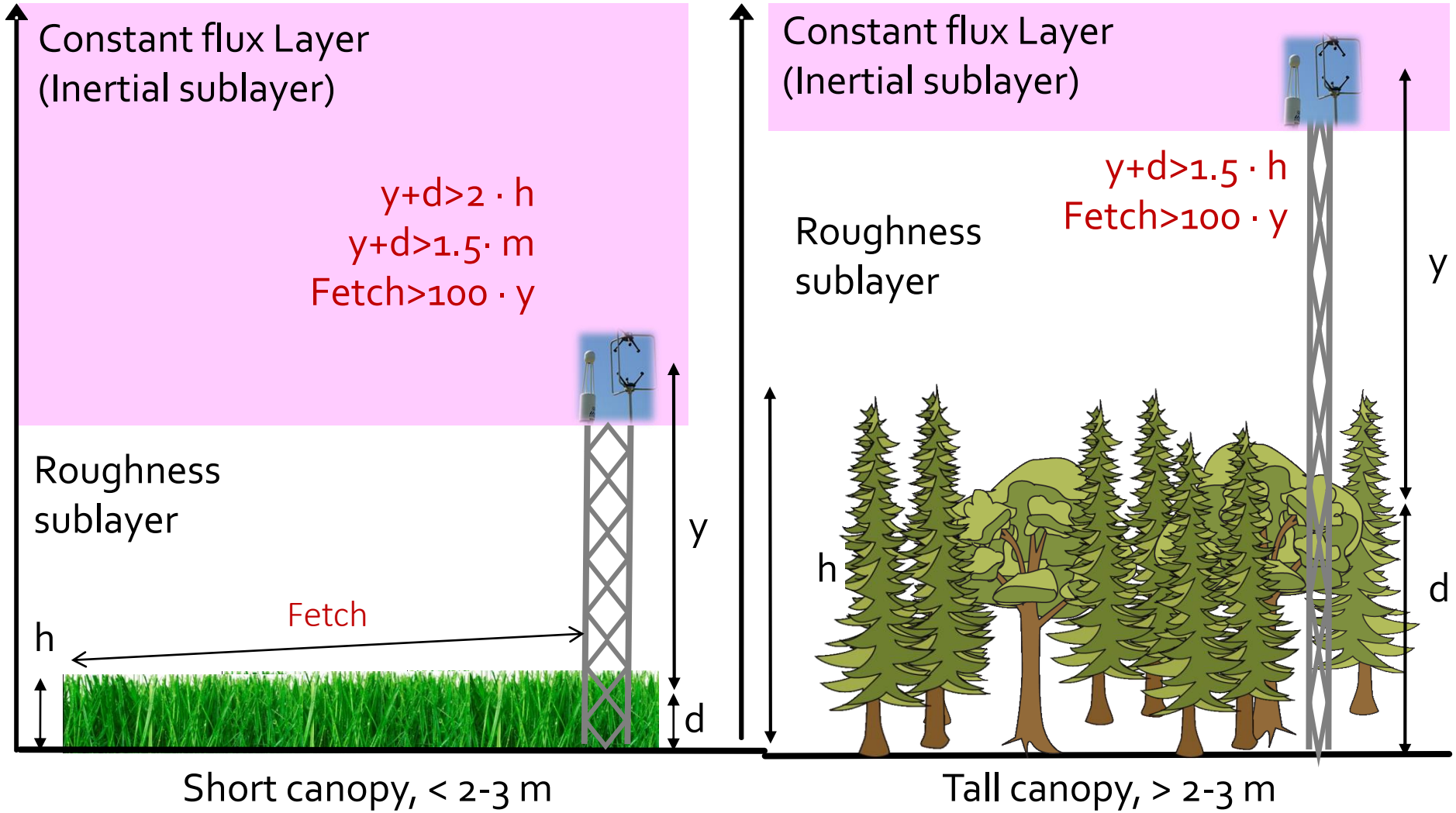
C-Clamp alignment



Prevailing Wind Directions

+/- 170 degrees

Points to remember…the ‘rules-of-thumb’



Sensor separation

- Physical separation between anemometer and analyzer should as small as possible, **but** should not be to close where the analyzer distorts flow through the sonic.

Sensor separation

- Relative to the center point of the measurement volume

- Measured relative to the sonic

Sensor separation

Horizontal:

10 to 30 cm

Sensor separation

Vertical:

- 0 cm when close to the canopy/ground

- Scalar sensors lower than the sonic high above the canopy

- When sampling volume is large relative to sonic, ensure they over lap

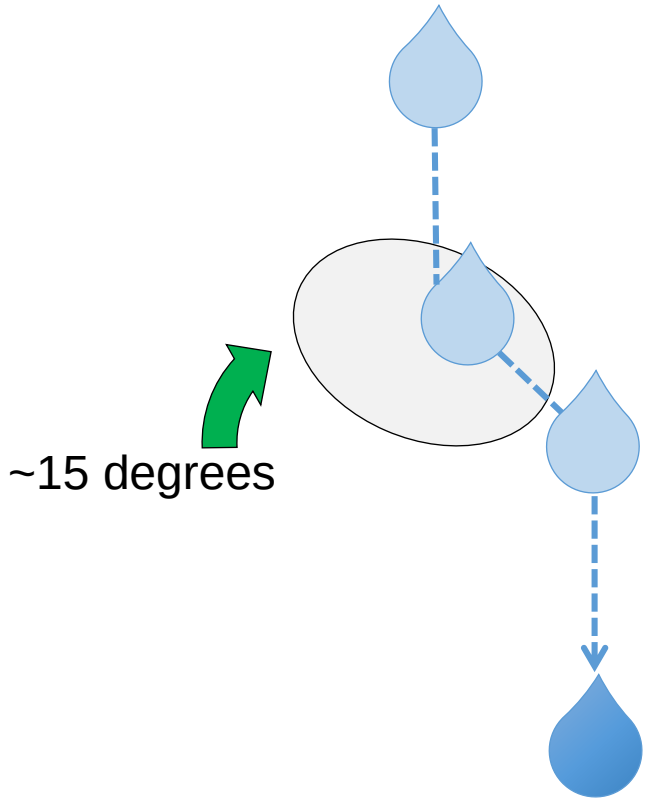
Fittings and pipes are used to get appropriate separations

Deploying the instruments

- Why are all the LI-7500 Analyzers at an angle?

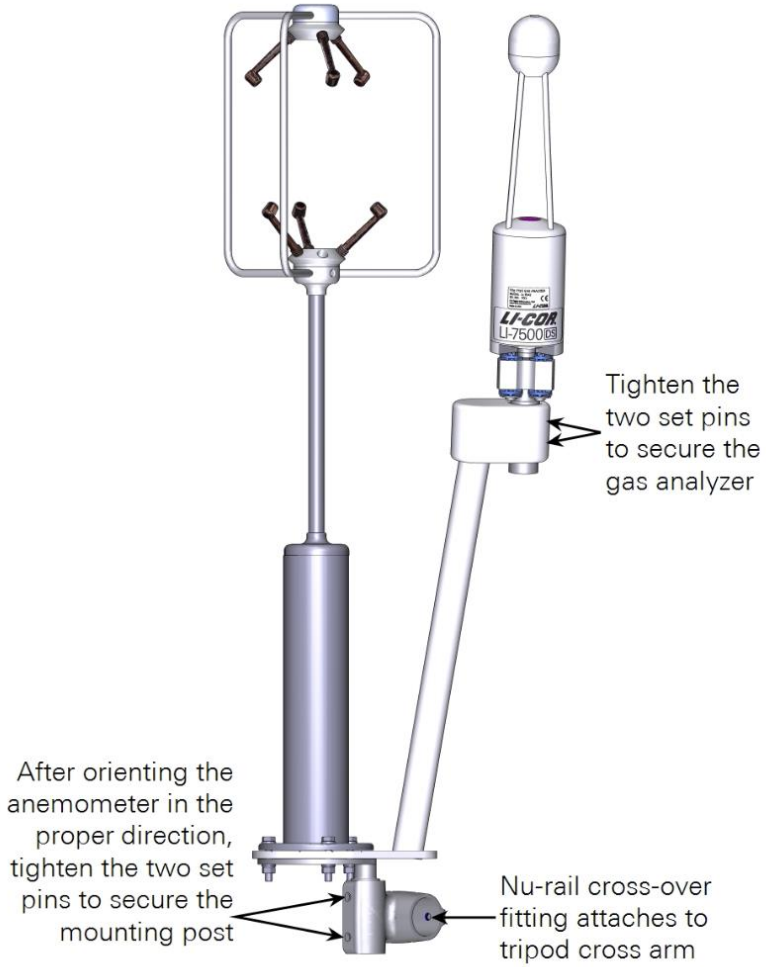
Deploying the instruments

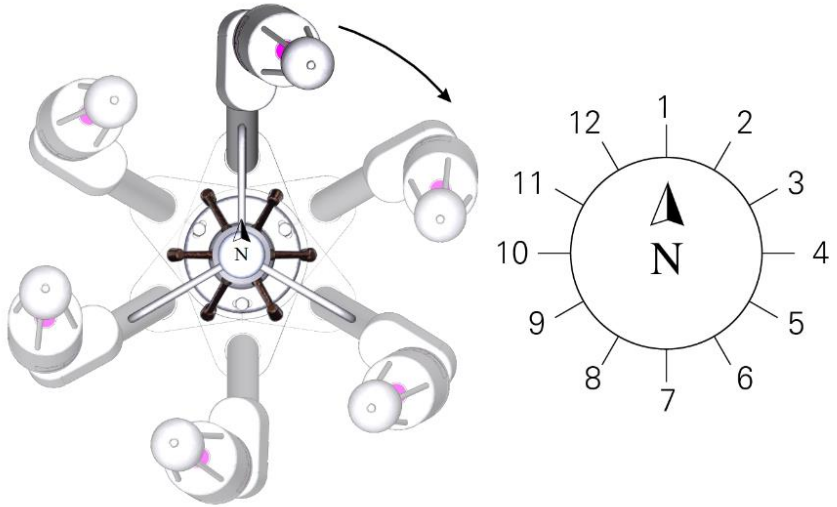
- Orienting the LI-7500RS



New Mounting device

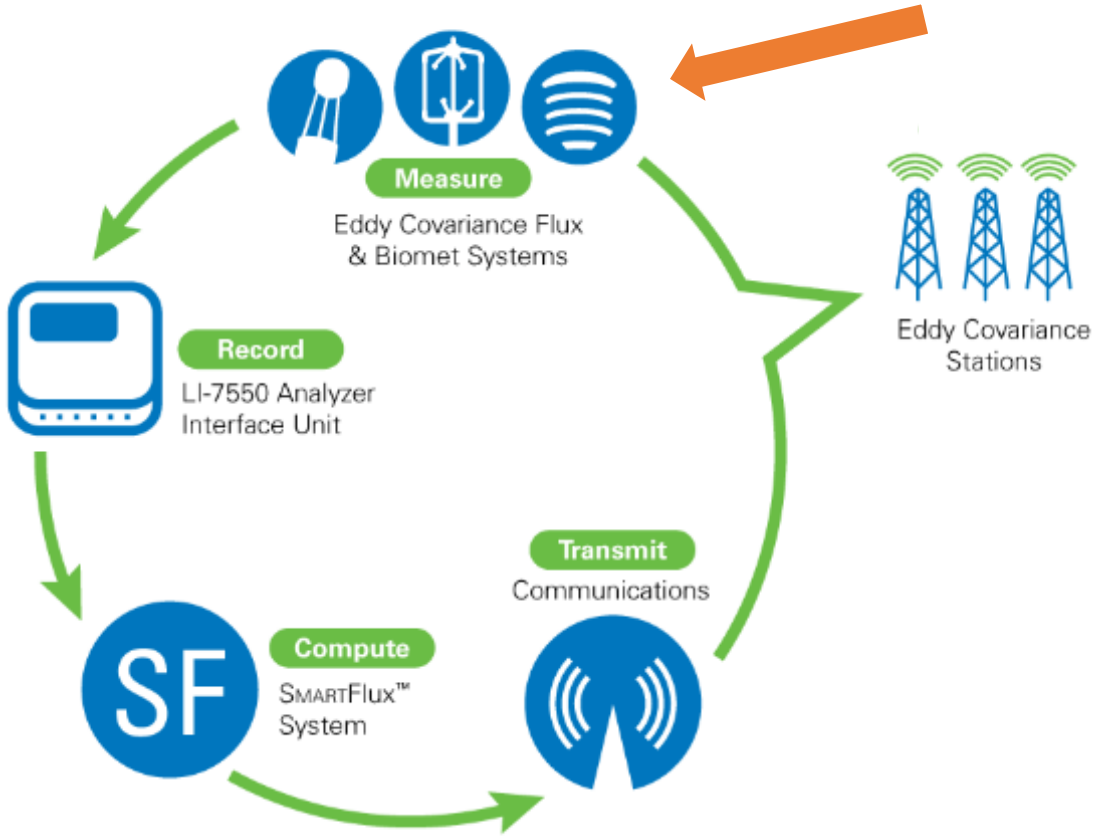
- Combined
- Omnidirectional
- Ease-of-use
- Flexibility





Measurements and Computations

- Integration of Biomet data from Loggers



Slow Sensors (Biomet)

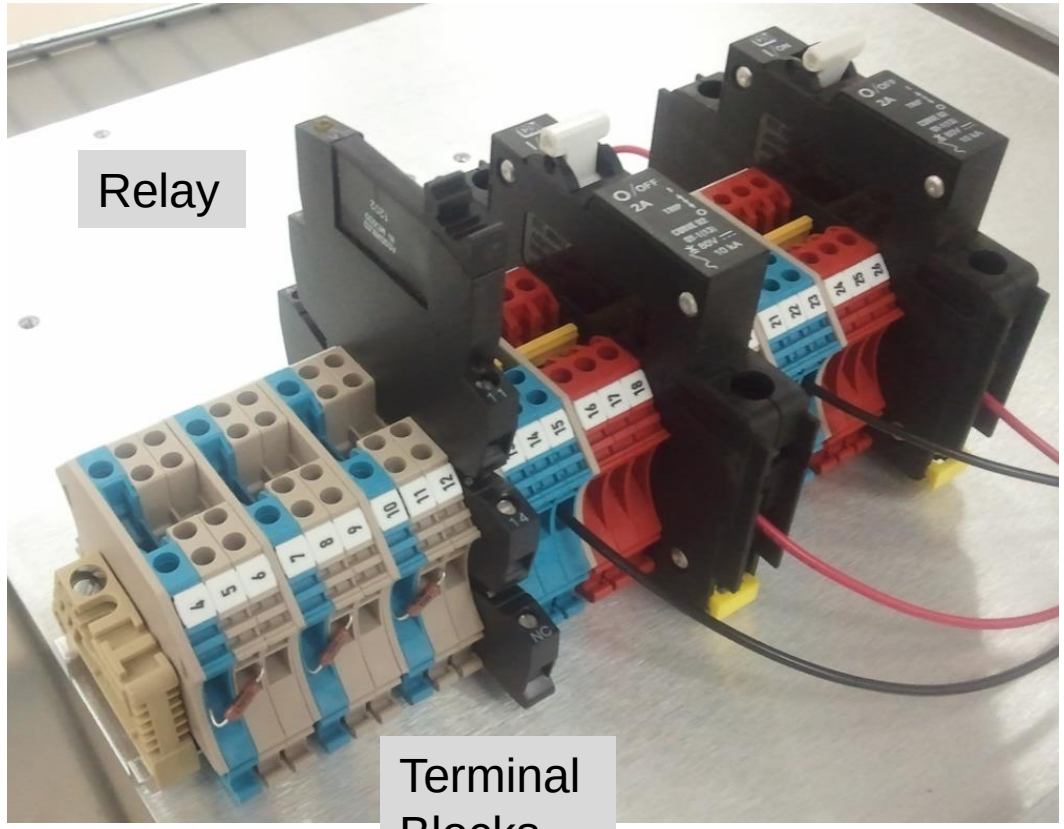
- Several types of sensors from several manufacturers
- Provide Air Temperature, Relative Humidity, Radiation ….
- Output varies by sensor mostly analog some digital (SDI-12)

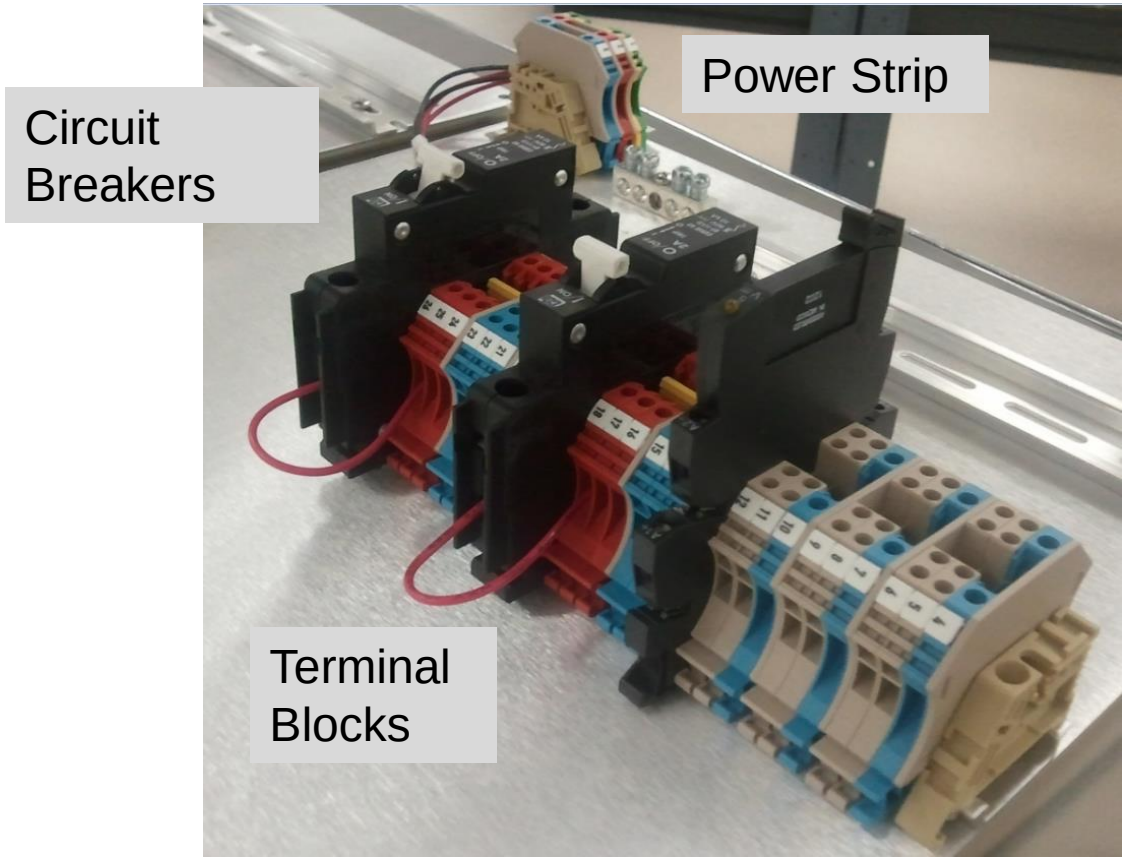
Data Collecting and Processing Components

Biomet Interface (Biomet Data loggers):

- Sutron - 9210
- CSI - CR1000, CR3000, CR6

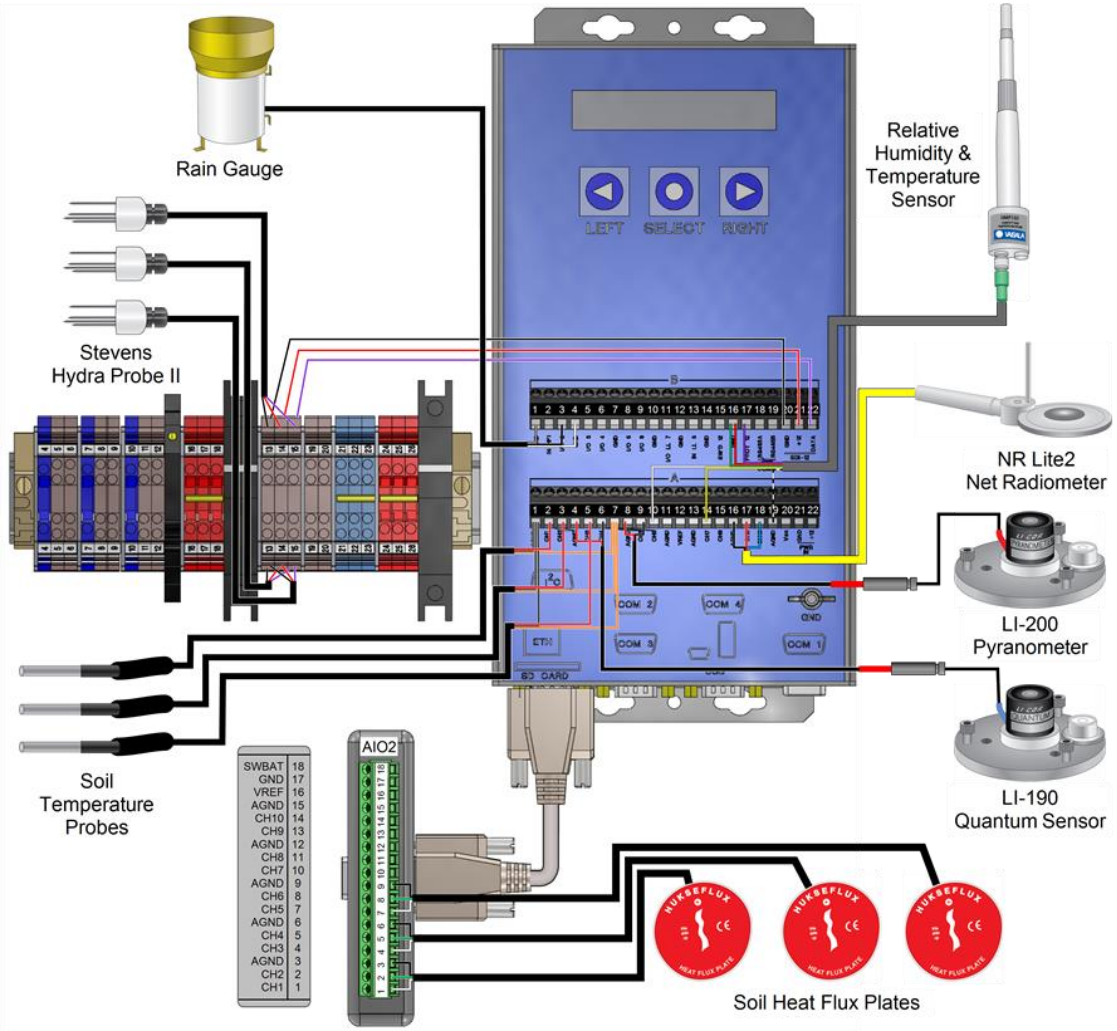
Typical Components in Biomet Enclosure





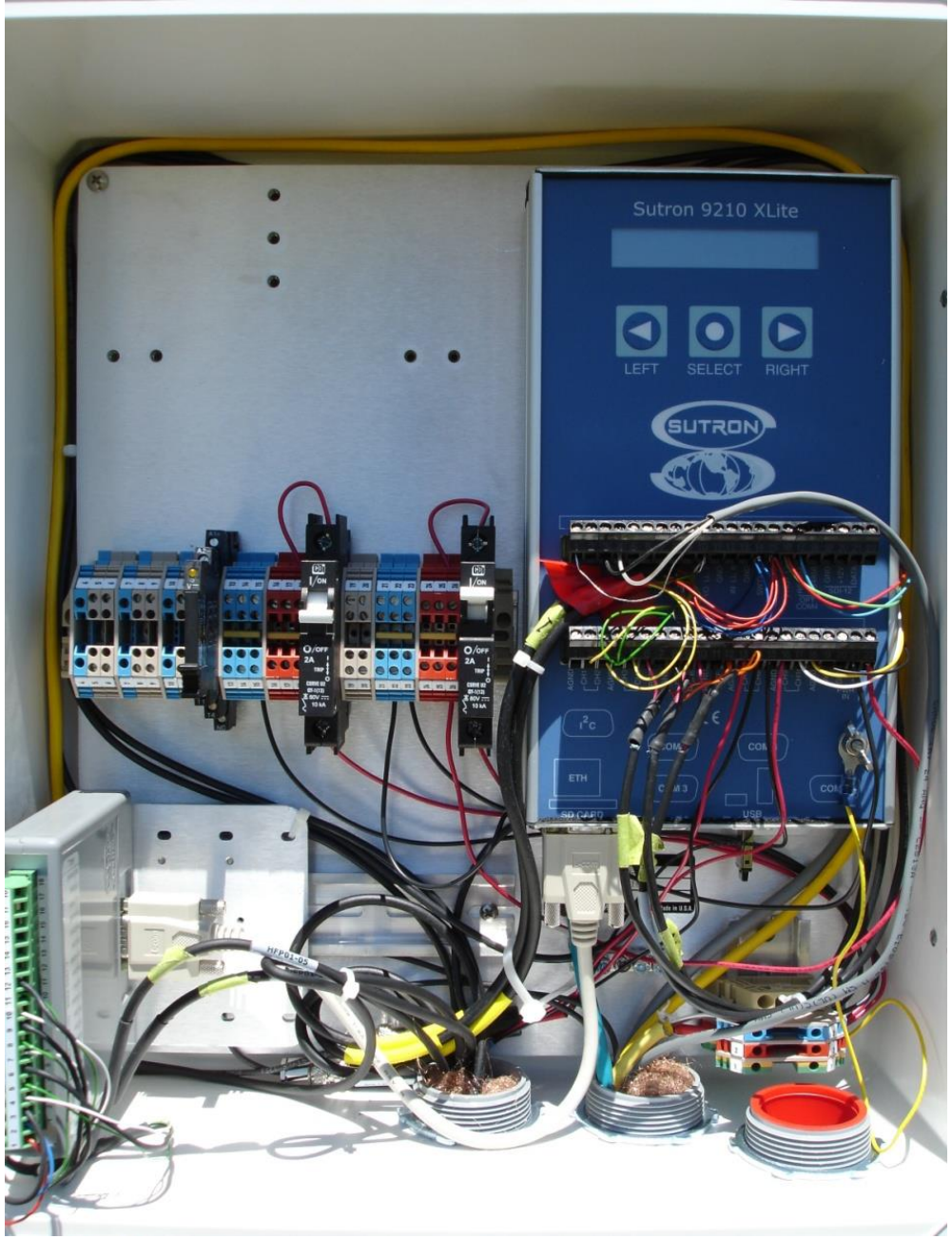
Integrate the Biomet System

- Install the Sensors (as per Installation Guides) and connect them to the Logger.



Typical Program

- Samples 18 analog channels and 1 digital channel
- Samples every 5 seconds
- Logs every minute
- Transmits data via Ethernet



Biomet System Integration

- Biomet Sensors should be installed and integrated.
- Cable lengths (Tripod or Tower)
- The level of integration depends on the Biomet System.

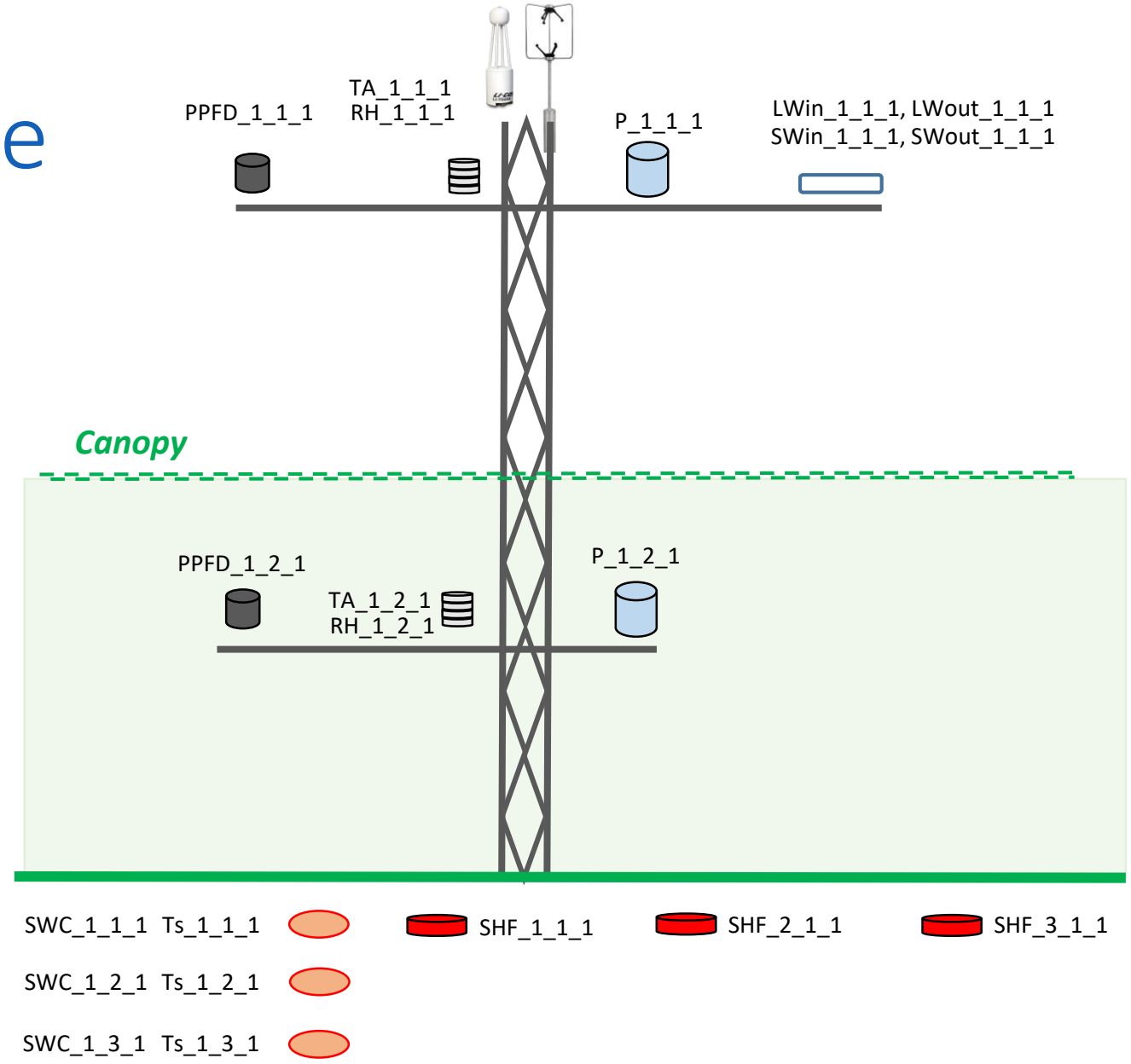
Biomet Nomenclature

VariableName_H_V_R

Horizonal position

Vertical position

Replicate number



= PAR Quantum Sensor

= Air Temperature and Relative Humidity (Ta, RH)

= Total Precipitation

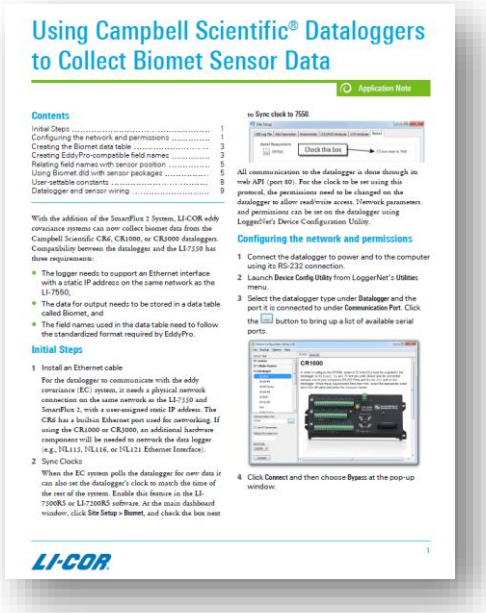
= 4-Component Net Radiometer

= Soil Moisture, Temperature, Salinity

= Soil Heat Flux (SHF)

Integrating CSI Biomet

- CR1000, CR3000 require Ethernet interface NL-121
- Program must be compatible with EddyPro/LI-COR nomenclature
- https://licor.boxenterprise.net/s/y4gseu1o899brj2gmjksgfdtw1h6w72y


Using Campbell Scientific® Dataloggers to Collect Biomet Sensor Data

Application Note

Contents

Initial Steps 1
Configuring the network and permissions 1
Creating the Biomet data table 3
Creating EddyPro-compatible field names 3
Relating field names with sensor position 5
Using Biomet.dld with sensor packages 5
User-settable constants 8
Datalogger and sensor wiring 9

With the addition of the SmartFlux 2 System, LI-COR eddy covariance systems can now collect biomet data from the Campbell Scientific CR6, CR1000, or CR3000 dataloggers. Compatibility between the datalogger and the LI-7550 has three requirements:

- The logger needs to support an Ethernet interface with a static IP address on the same network as the LI-7550,
- The data for output needs to be stored in a data table called Biomet, and
- The field names used in the data table need to follow the standardized format required by EddyPro.

Initial Steps

1 Install an Ethernet cable

For the datalogger to communicate with the eddy covariance (EC) system, it needs a physical network connection on the same network as the LI-7550 and SmartFlux 2, with a user-assigned static IP address. The CR6 has a built-in Ethernet port used for networking. If using the CR1000 or CR3000, an additional hardware component will be needed to network the data logger (e.g., NL115, NL116, or NL121 Ethernet Interface).

2 Sync Clocks

When the EC system polls the datalogger for new data it can also set the datalogger's clock to match the time of the rest of the system. Enable this feature in the LI-7200RS or LI-7200RS software. At the main dashboard window, click Site Setup > Biomet, and check the box next to Sync clock to 7550.

Check this box

All communication to the datalogger is done through its web API (port 80). For the clock to be set using this protocol, the permissions need to be changed on the datalogger to allow read/write access. Network parameters and permissions can be set on the datalogger using LoggerNet's Device Configuration Utility.

Configuring the network and permissions

1 Connect the datalogger to power and to the computer using its RS-232 connection.

2 Launch Device Config Utility from LoggerNet's Utilities menu.

3 Select the datalogger type under Datalogger and the port it is connected to under Communication Port. Click the button to bring up a list of available serial ports.

4 Click Connect and then choose Bypass at the pop-up window.

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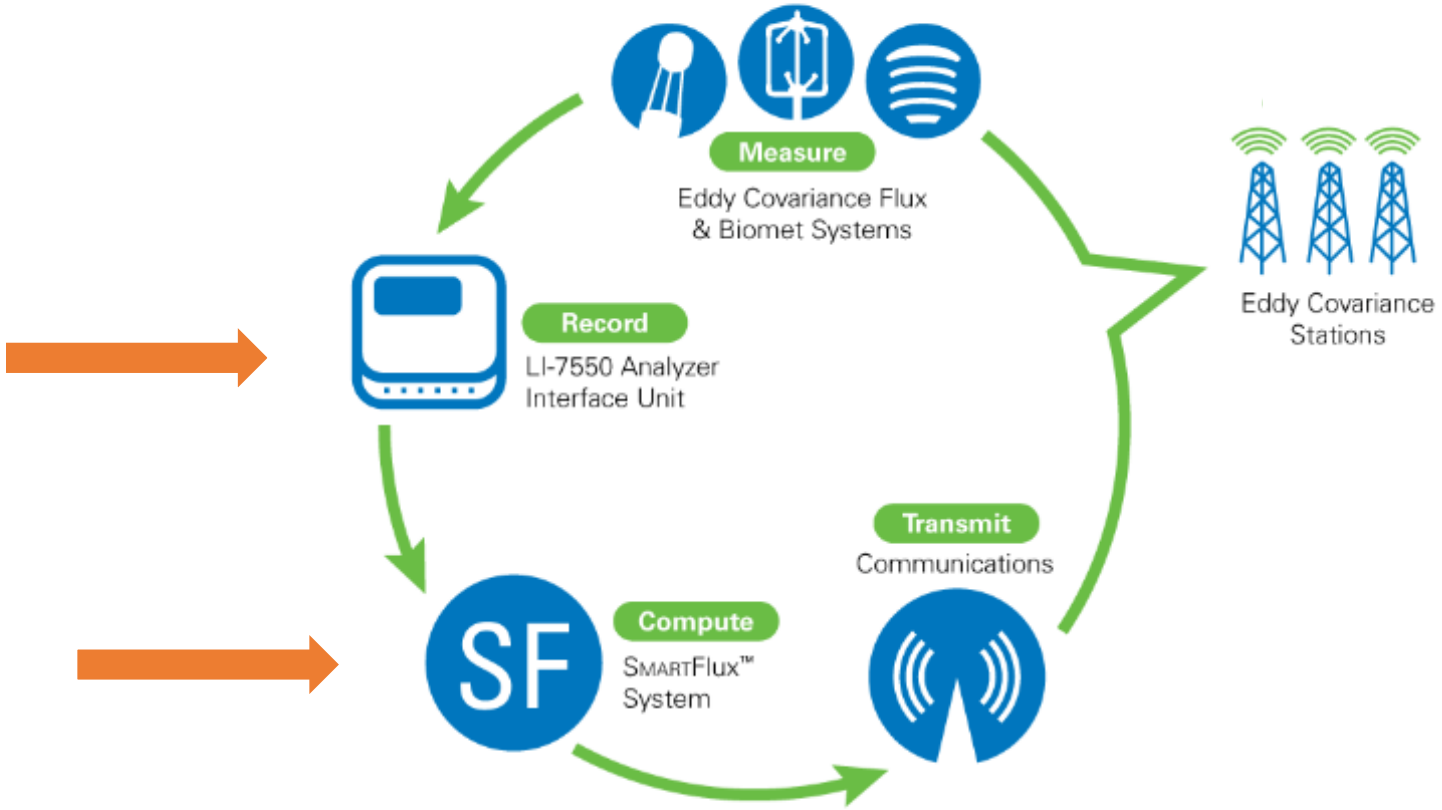
Measurements and Computations

- Recording the data
- SmartFlux for automated, on-site, real-time, fully-processed flux computations (with EddyPro)



Data Collecting and Processing Components

LI-7550 Analyzer Interface Unit

- Data integration and logging
  - 16 GB USB drive
  - .ghg files

- Embedded software
  - **GHG** embedded

Data management

- EC systems generate lots of data
  - 10 Hz sampling
  - 36000 records of raw data per hour → 864,000 per day → $3x10^8$ per year!

EddyPro Data Processing software..

EddyPro® Highlights

- Over 5,500 downloads in 176 countries
- Flux networks have adapted EddyPro® as a standard software for data processing
- Available for free download from LI-COR www.licor.com/eddypro

Available Options in EddyPro®

Data Processing Options in EddyPro (Express Mode selections in italics)

- Axis rotation for sonic anemometer tilt correction
  - *Double rotation*
  - Triple rotation
  - Sector-wise planar fit (Wilczak et al., 2001)
  - Sector-wise planar fit with no velocity bias (van Dijk et al., 2004)
- Detrending of raw time series
  - *Block averaging*
  - Linear detrending
  - Running mean
  - Exponential running mean
- Compensation of time lag between sonic anemometer and gas analyzer measurements
  - *Automatic time lag optimization (optionally as a function of RH for H_2O)*
  - *Maximum covariance with default (circular correlation)*
  - Maximum covariance without default
  - Constant
  - None (option to not apply compensation)
- Statistical tests for raw time series data (Vickers and Mahrt, 1997)
- Compensation for air density fluctuations
  - *Webb et al., 1980 (open path) / Ibrom et al., 2007a (closed path)*
  - Use (or convert to) mixing ratio (Burba et al., 2012)
  - Optional off-season upatake correction for LI-7500 (Burba et al., 2008)
  - None (option to not apply compensation)
- Correction for frequency response (attenuation)
  - *Analytic high-pass filtering correction (Moncrieff et al., 2004)*
  - Low-pass filtering, select and configure:
    - *Moncrieff et al. (1997)*
    - Horst (1997)
    - Ibrom et al. (2007b)
    - Horst and Lenschow (2009)
    - Fratini et. al. (2012)
- Quality control tests for fluxes according to Foken et al. (2004)
  - *Flagging according to Carbo Europe standard (Mauder and Foken, 2004)*
  - Flagging according to Foken (2003)
  - Flagging after Göckede et al. (2004)

Available Options in EddyPro® - continued

- Statistical tests for raw time series data (Vickers and Mahrt, 1997)
  - *Spike count/removal*
  - *Amplitude resolution*
  - *Dropouts*
  - *Absolute limits*
  - *Skewness and kurtosis*
  - Discontinuities
  - Time lags
  - Angle of attack
  - Steadiness of horizontal wind
  - Individually selectable and customizable
- Available outputs
  - *Full (rich) output with fluxes, quality flags and much more (standard format or available results only)*
  - *Ameriflux format*
  - *GHG Europe format*
  - *Raw data statistics*
  - Full length spectra and co-spectra
  - Binned spectra and co-spectra
  - Binned ogives
  - Ensemble averaged spectra
  - Ensemble averaged cospectra, fitted models and ideal (Kaimal) cospectra
  - Details of steady state and turbulence tests
  - Raw data time series after each statistical tests/correction
  - Flagging after Göckede et al. (2004)
- Random uncertainty estimation
  - Mann & Lenschow (1994)
  - Finkelstein and Sims (2001)
- Flux footprint estimation
  - *Kljun et al. (2004)*
  - Kormann and Meixner (2001)
  - Hsieh et al. (2000)
- Other options applied in both Express and/or Advanced Mode include:
  - *Sonic temperature correction for humidity following van Dijk et al. (2004)*
  - *Spectroscopic correction for LI-7700 following McDermitt et al. (2011)*
  - Angle of attack corrections for Gill anemometers following Nakai et al. (2006)
  - *Angle of attack corrections for Gill anemometers following Nakai and Shimoyama (2012)*
  - *Inclusion of biomet data for improved flux computation/correction*

Data Collecting and Processing Components

SmartFlux

SmartFlux 2 and 3

LI-COR

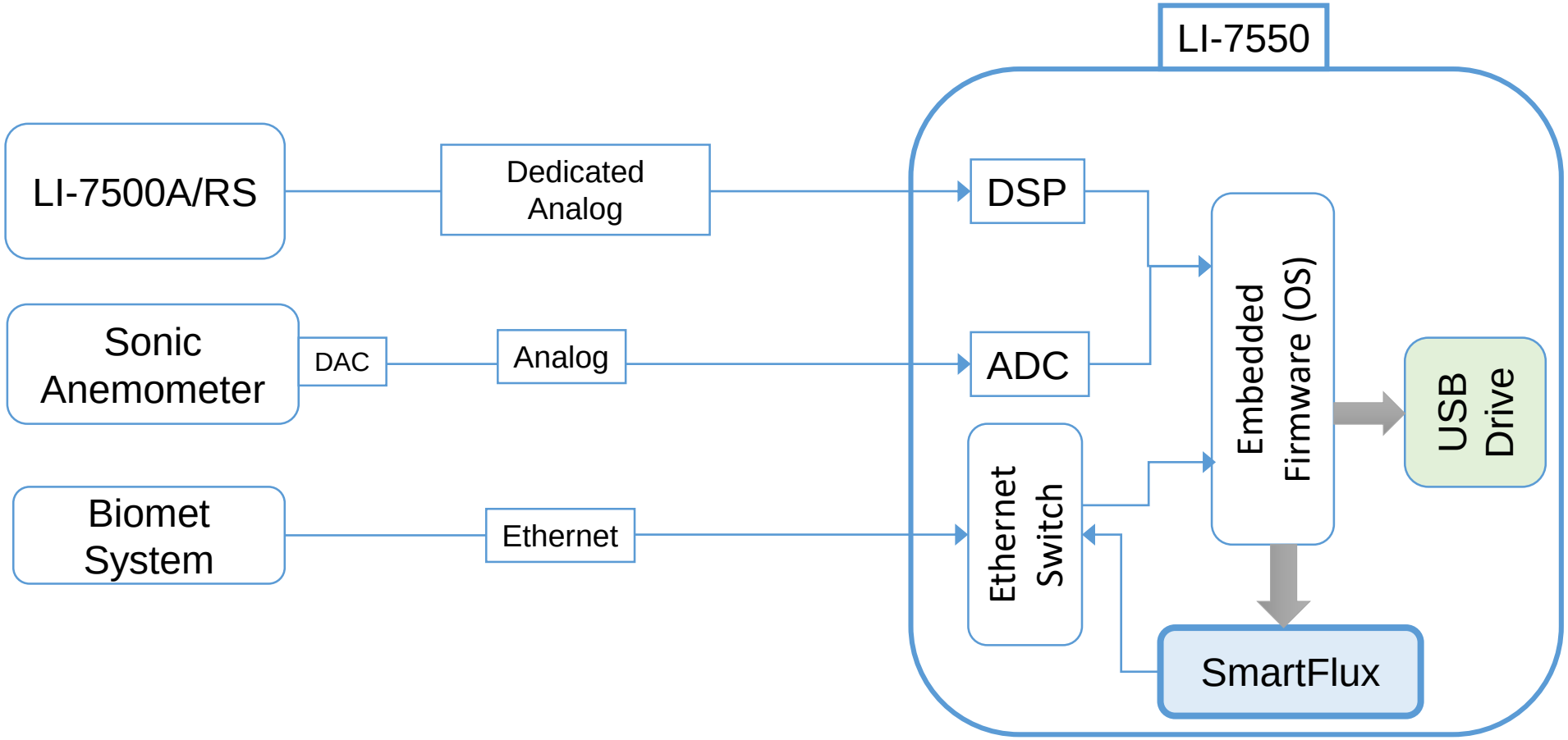
The SmartFlux System … brings EddyPro® to your site

- SmartFlux uses EddyPro® processing engine at the site and in real-time
- Includes **ALL** the corrections and processing options listed
- SmartFlux 2 and 3 - Digital Sonic Data Acquisition

EddyPro® in the Field

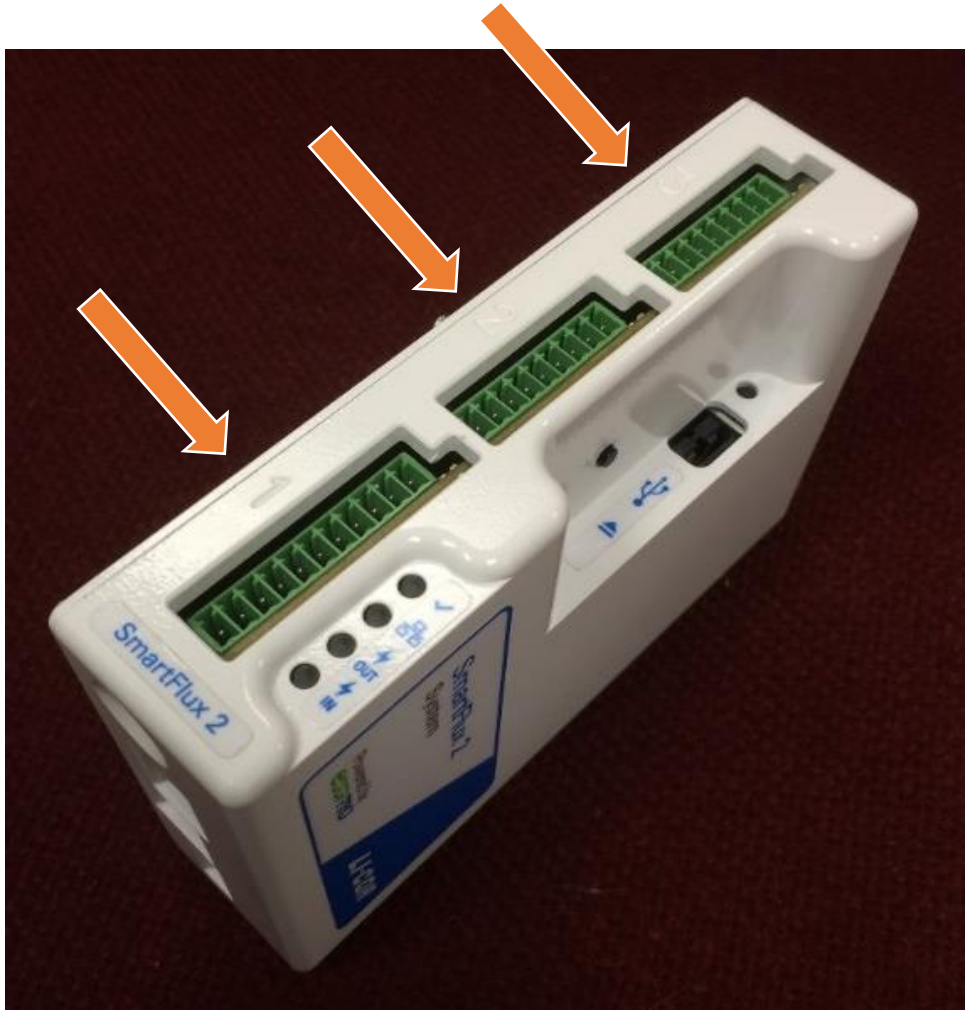
LI-COR®

How does it all come together?



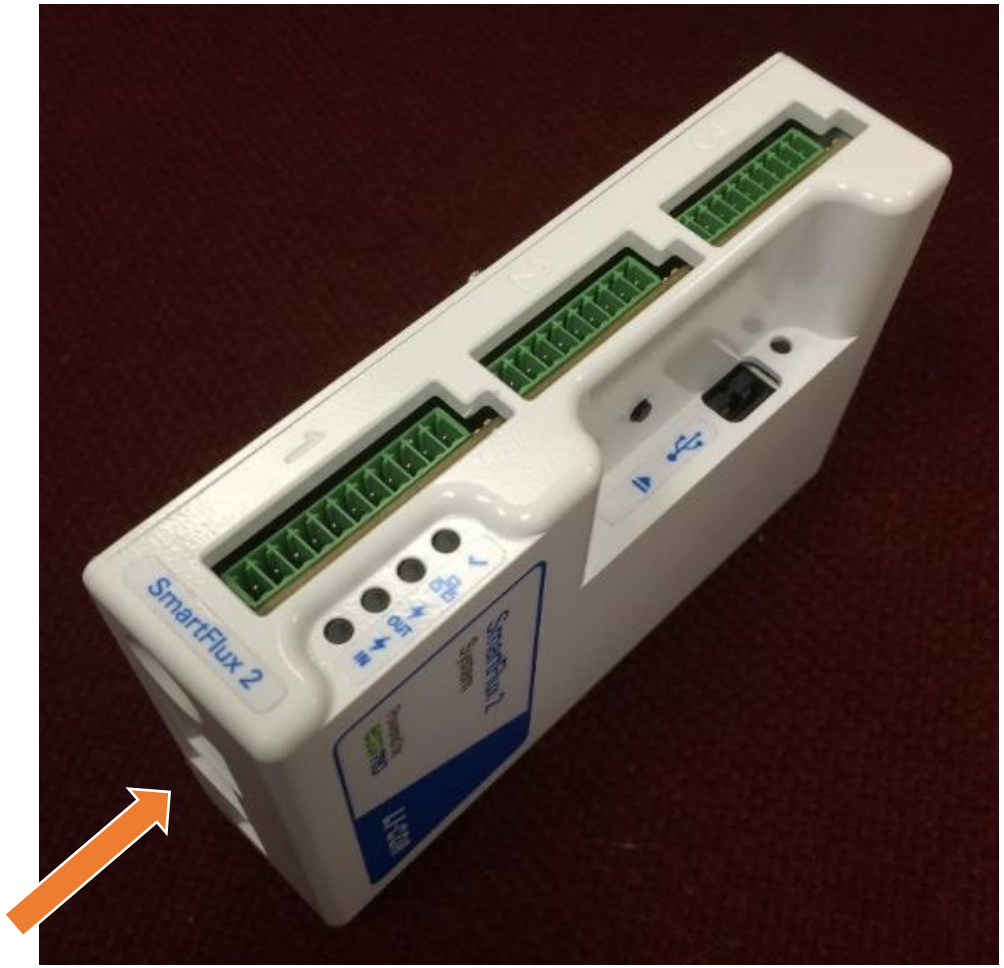
SmartFlux 2: Specifications

- Serial Ports for digital connection of Sonic Anemometer



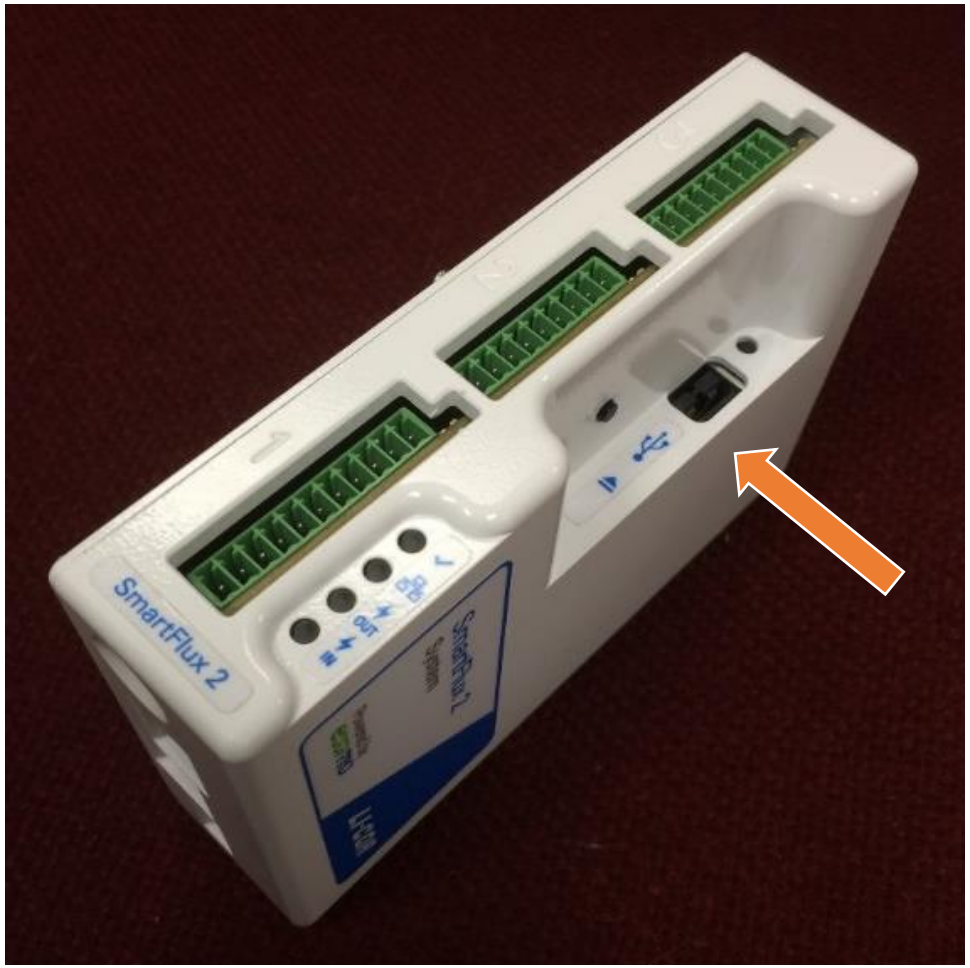
SmartFlux 2: Specifications

- Serial Ports for digital connection of Sonic Anemometer
- GPS used for PTP synchronization
  - Geographical information

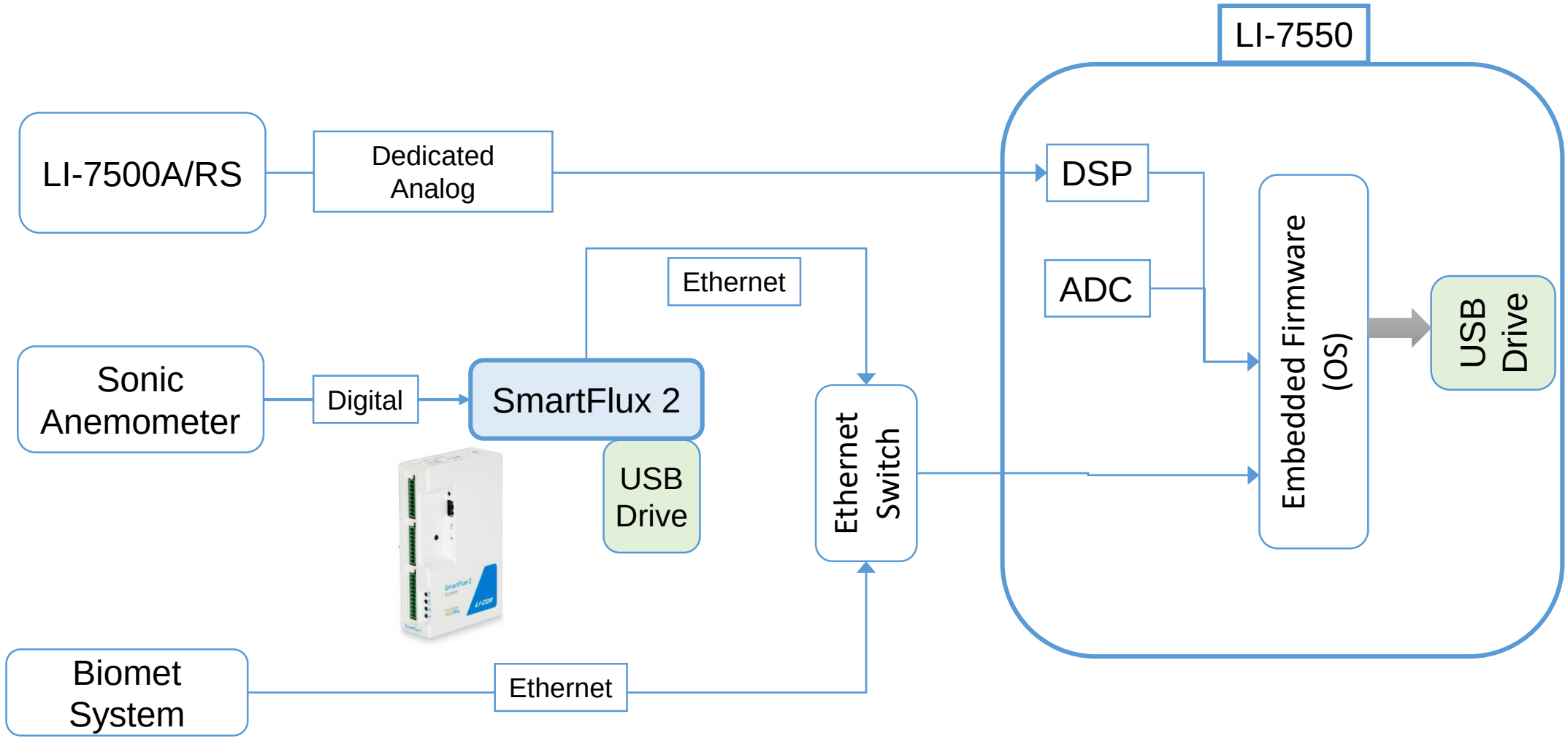


SmartFlux 2: Specifications

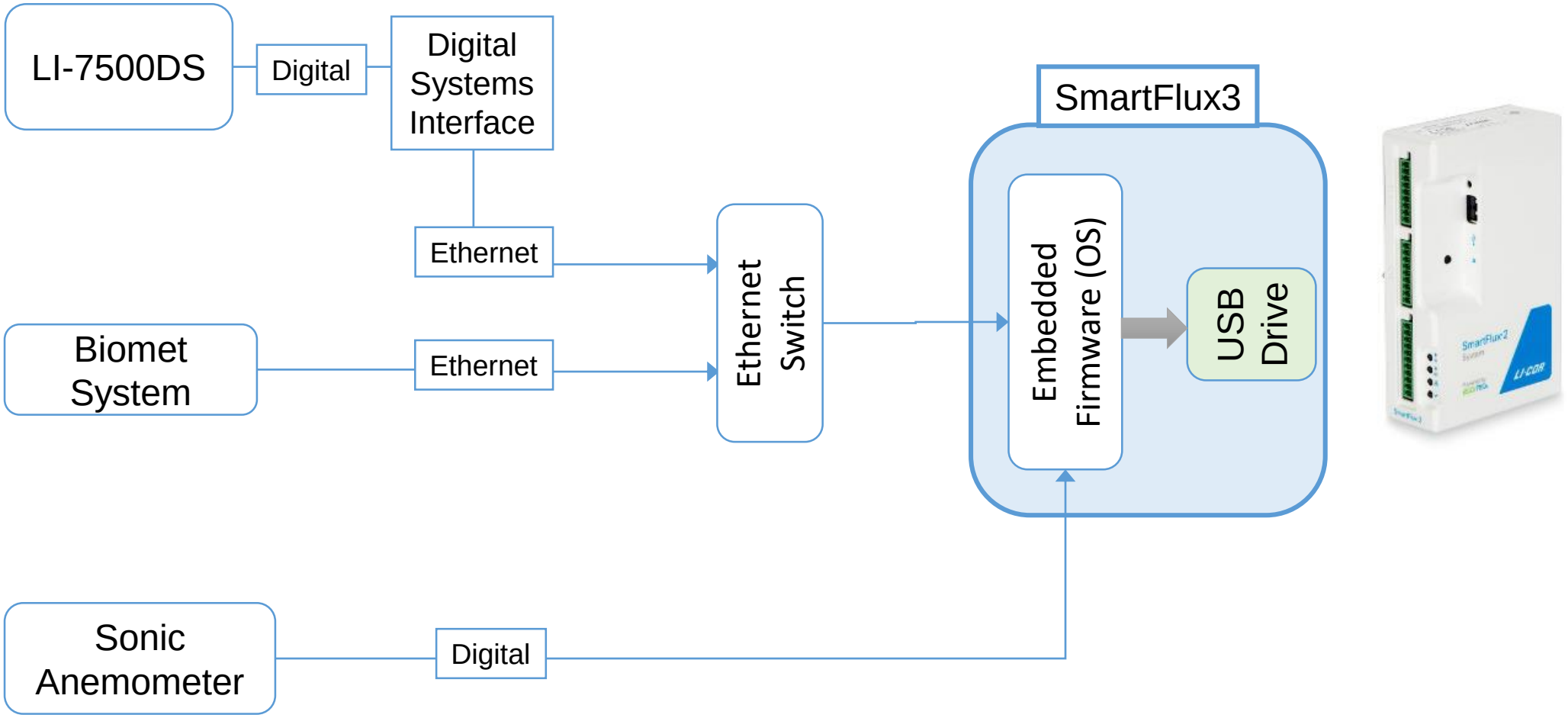
- Serial Ports for digital connection of Sonic Anemometer
- GPS used for PTP synchronization
  - Geographical information
- Another USB drive
  - Secondary back-up
  - Can place at base of tall tower



How does it all come together with SmartFlux 2?



How does it all come together with SmartFlux 3?



Data Flow in the System – LI-7550

High Speed Data and Metadata Logging

LI-7200/RS or

LI-7500A/RS

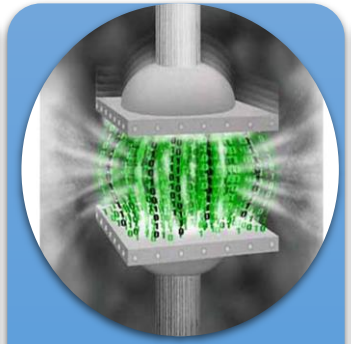
(LI-7700)

Biomet Data and Metadata Logging

Biomet Data Logger Interface

Net Radiation

Soil Moisture etc.



GHG File Creation

Combine Files

Compress to .GHG format

Send .GHG files to SMARTFlux

Data Processing

SMARTFlux processes data

Produces fluxes and biomet averages

Sends output

Keeps raw data and output

Data Storage on USB

Raw Data,

Processed Data,

Summary Data

Raw Data

“ . ghg” files

Raw archives containing four files

EddyPro is optimized for LI-COR GHG data

Flux data

1 High-frequency data

wind,

gas concentration, temperatures, etc

2 Flux metadata

Measurement height,

canopy height ,sensor seperation, etc

Biomet data

3 Low-frequency data

Radiation,

soil heat flux, air temperature, etc

4 Biomet metadata

Variable names,

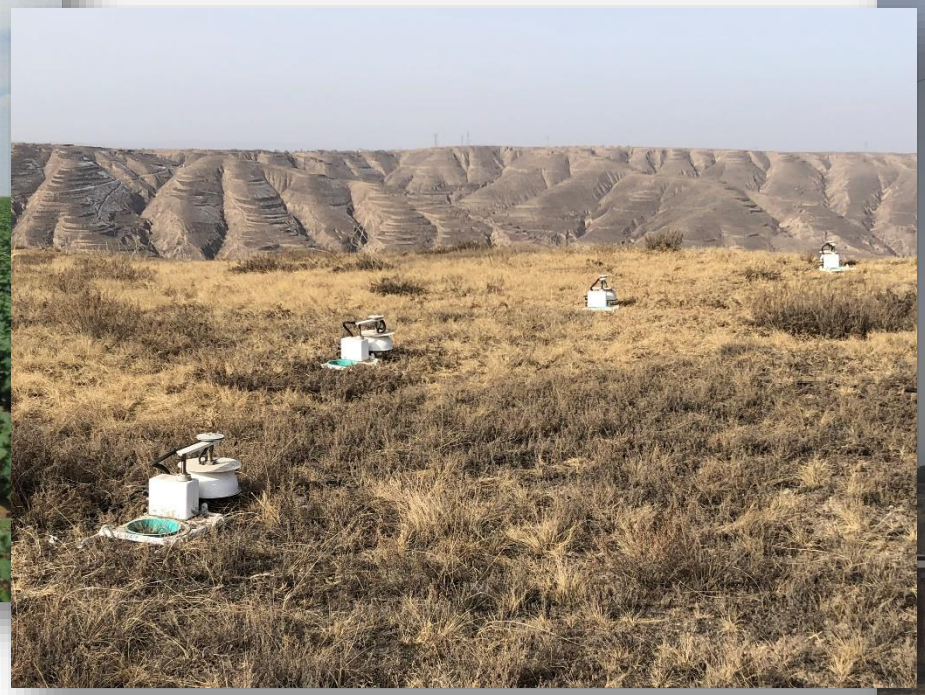
units, sampling rates, etc

LI-COR

Optional Solutions

- SmartFlux 2 and 3 now allow you to expand your research even more…

Integrating Soil Flux (or NEE) measurements with Eddy Covariance Measurement



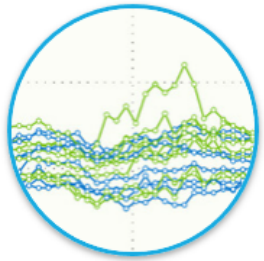
LI-8100/8150 Soil Flux System

LI-8100A Automated Soil Gas Flux System

Results So Powerful You Will Never Look Back

Advanced Chambers

Soil chambers that minimize effects on your measurements — to capture the true flux



Reliable Measurements

Robust datasets with multiple chambers

Continuous Datasets

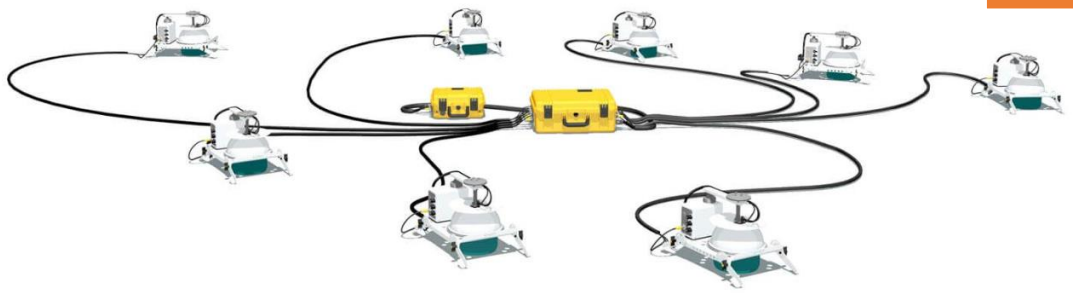
Long-term measurements of unbroken datasets

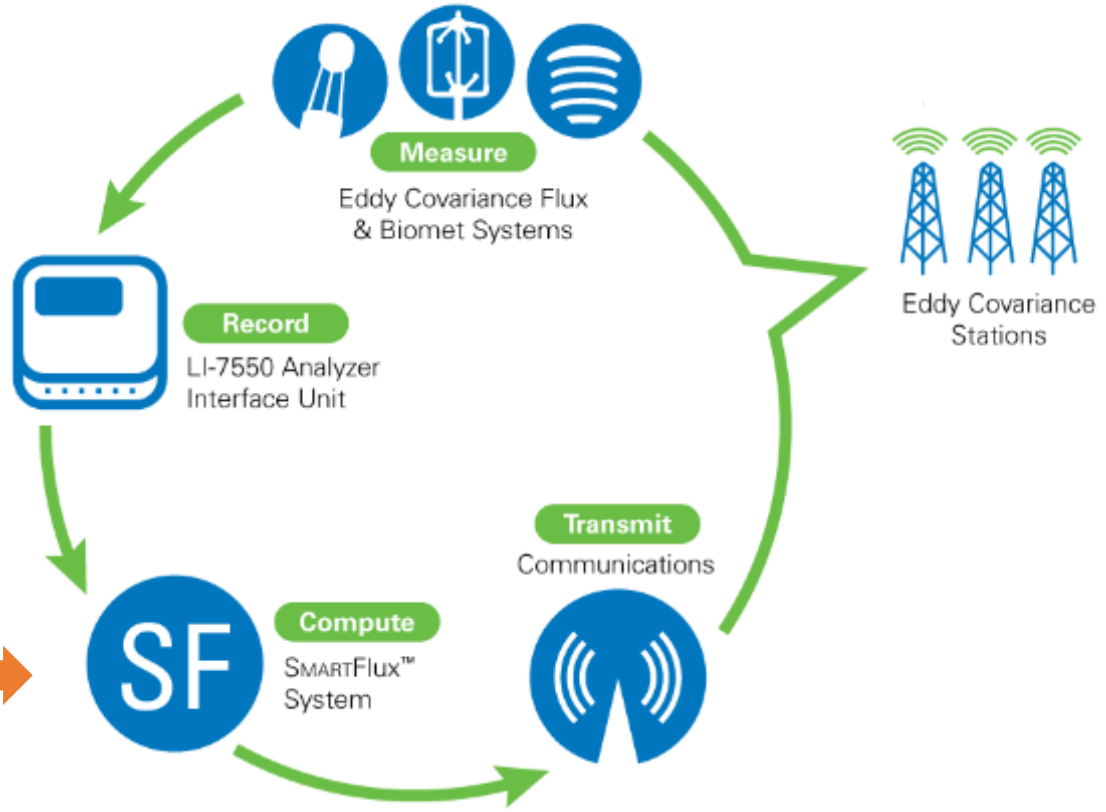
LI-COR

Measurements and Computations

- NEW!

- Integration of **Soil Flux** Measurements

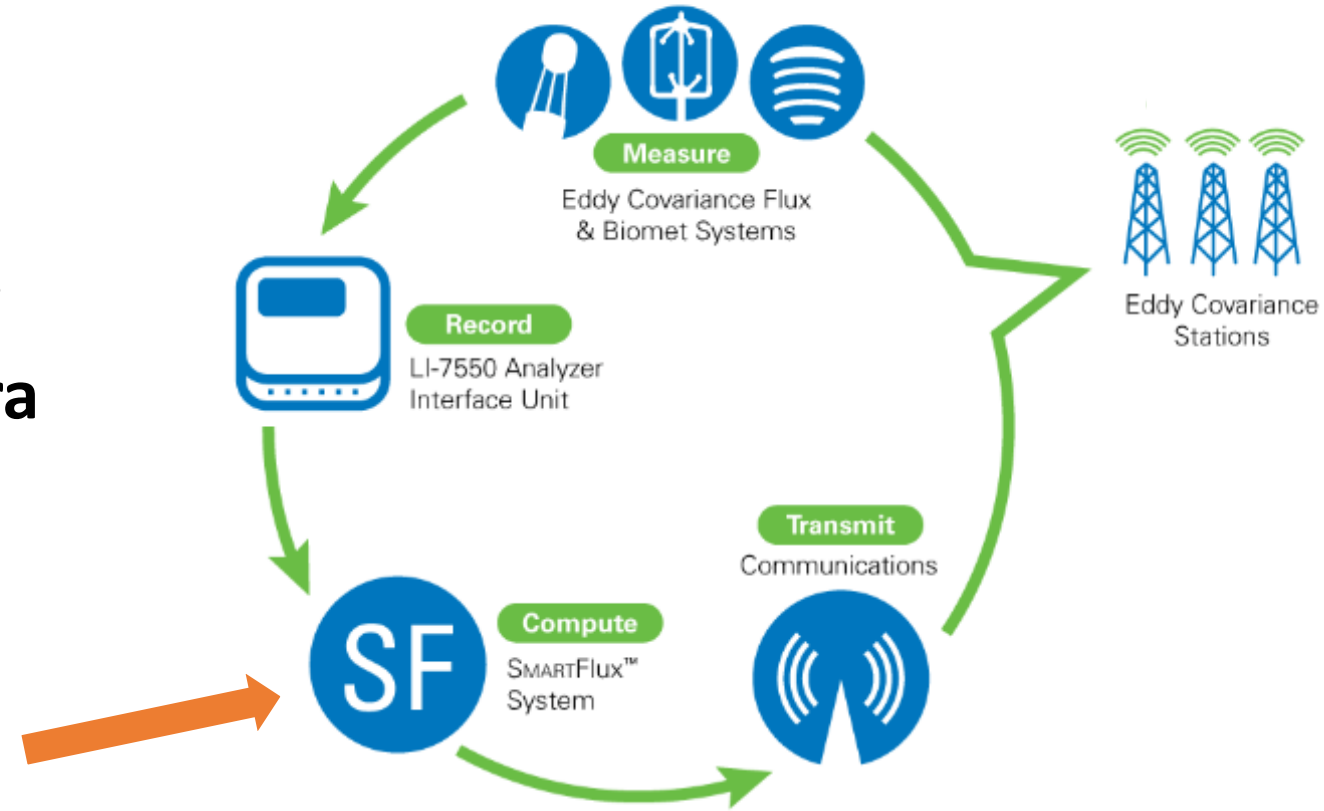




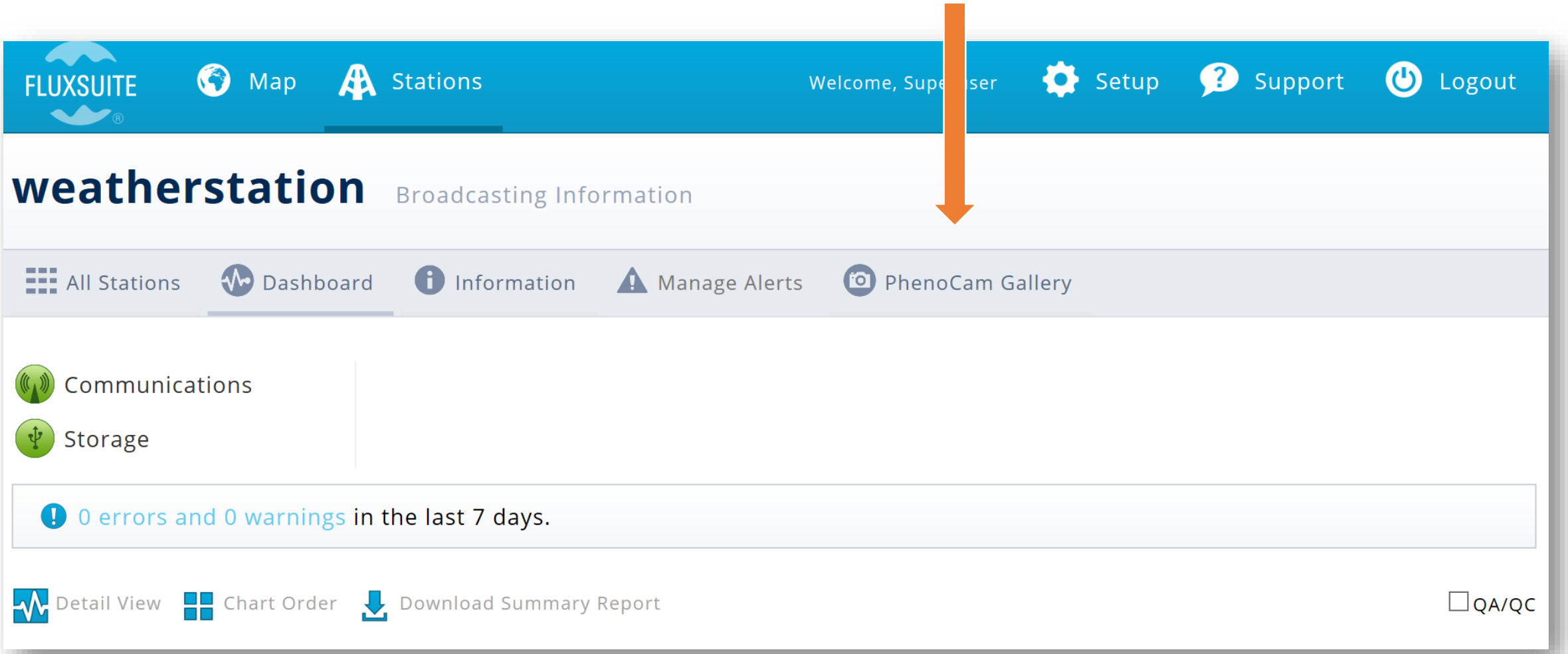
Measurements and Computations

- NEW!

- Integration of **Digital Camera (PhenoCam)** Images

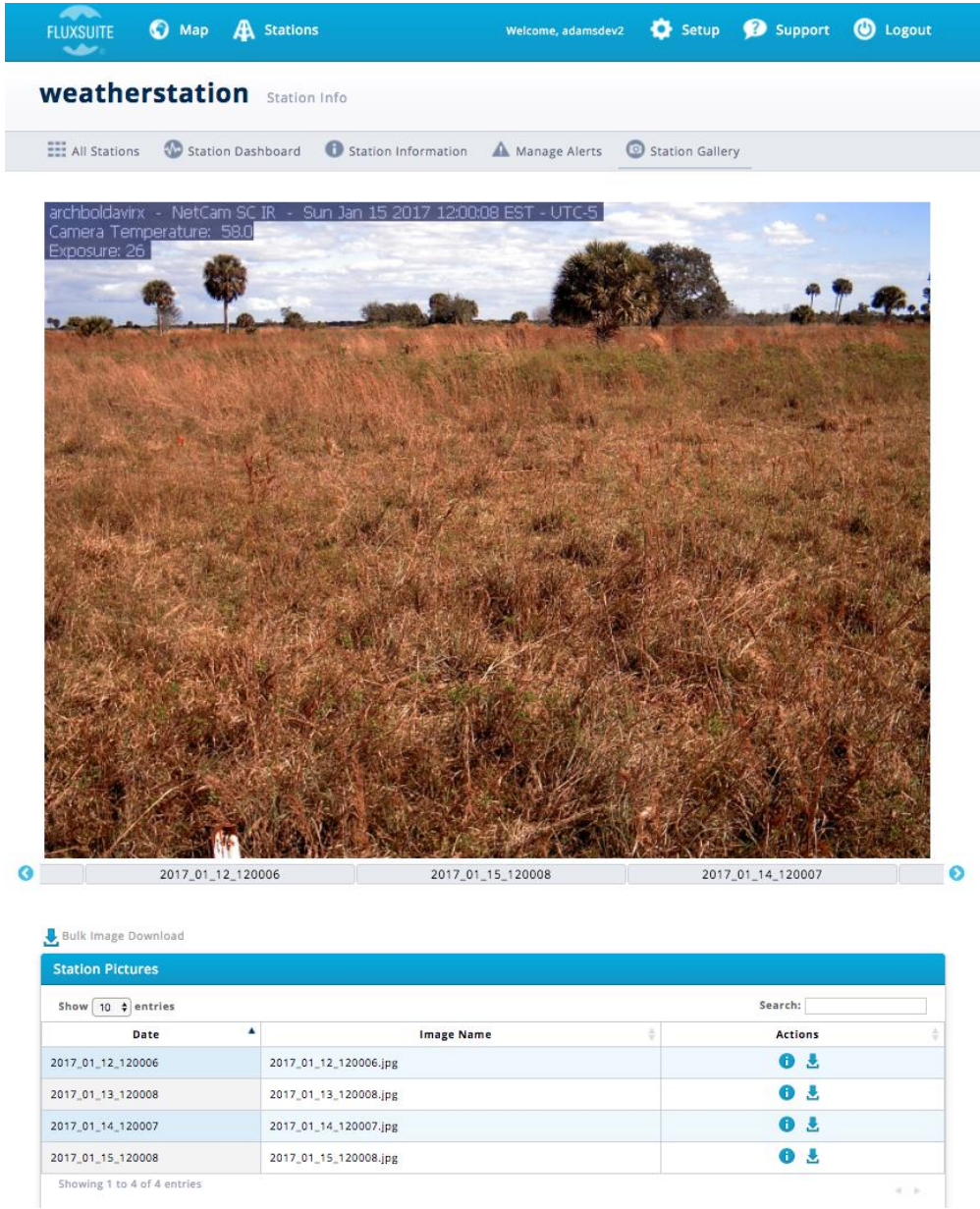


PhenoCam integration

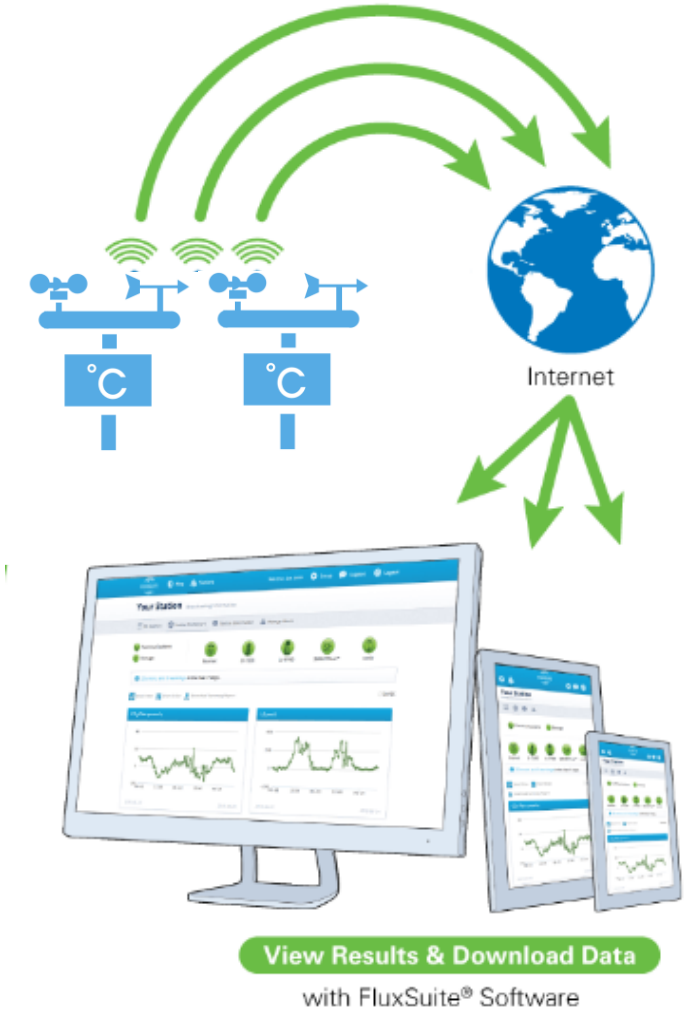


New! Digital Camera (PhenoCam) Image Gallery

Mid-day image uploaded every day at 12 pm. Past day's images also stored.



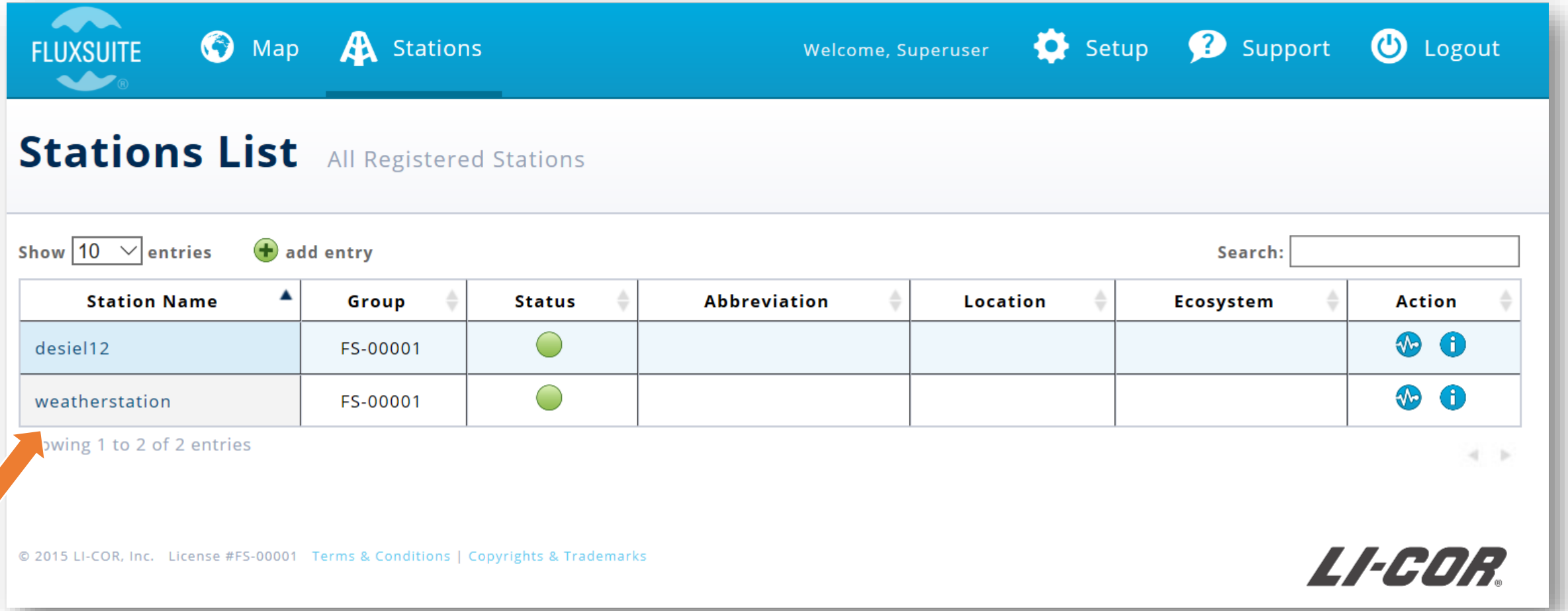
Weather Station Monitoring and Data Management



- NEW!

- Weather Stations report data directly to FluxSuite

Weather Station integration

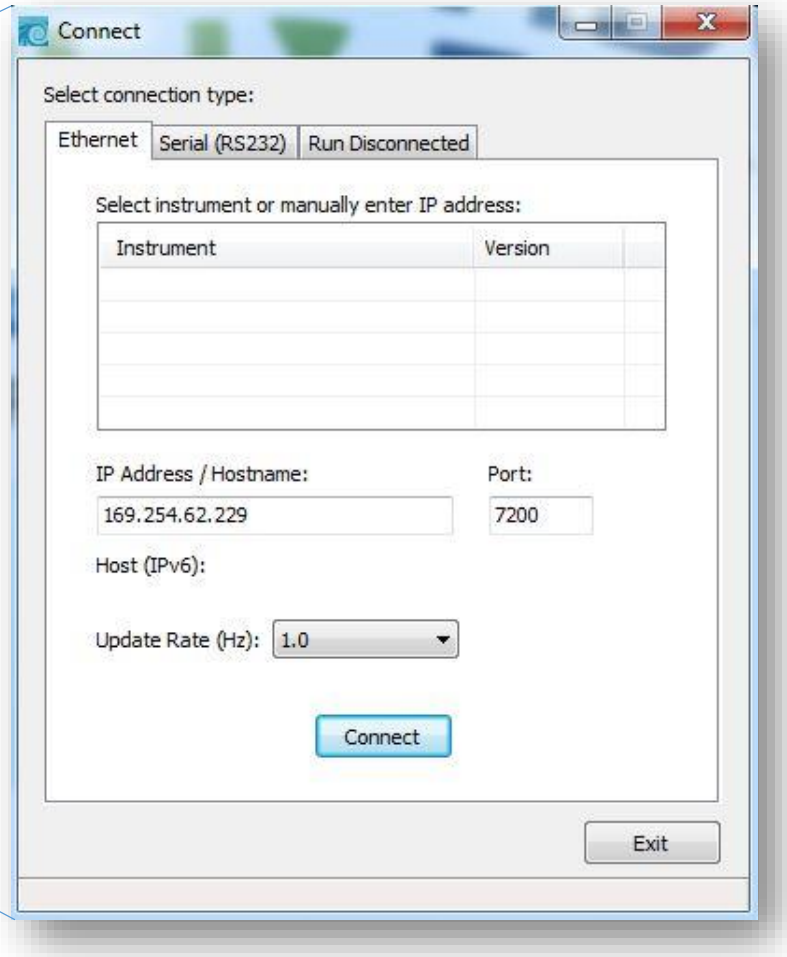


Data Transfer, Monitoring, and Management

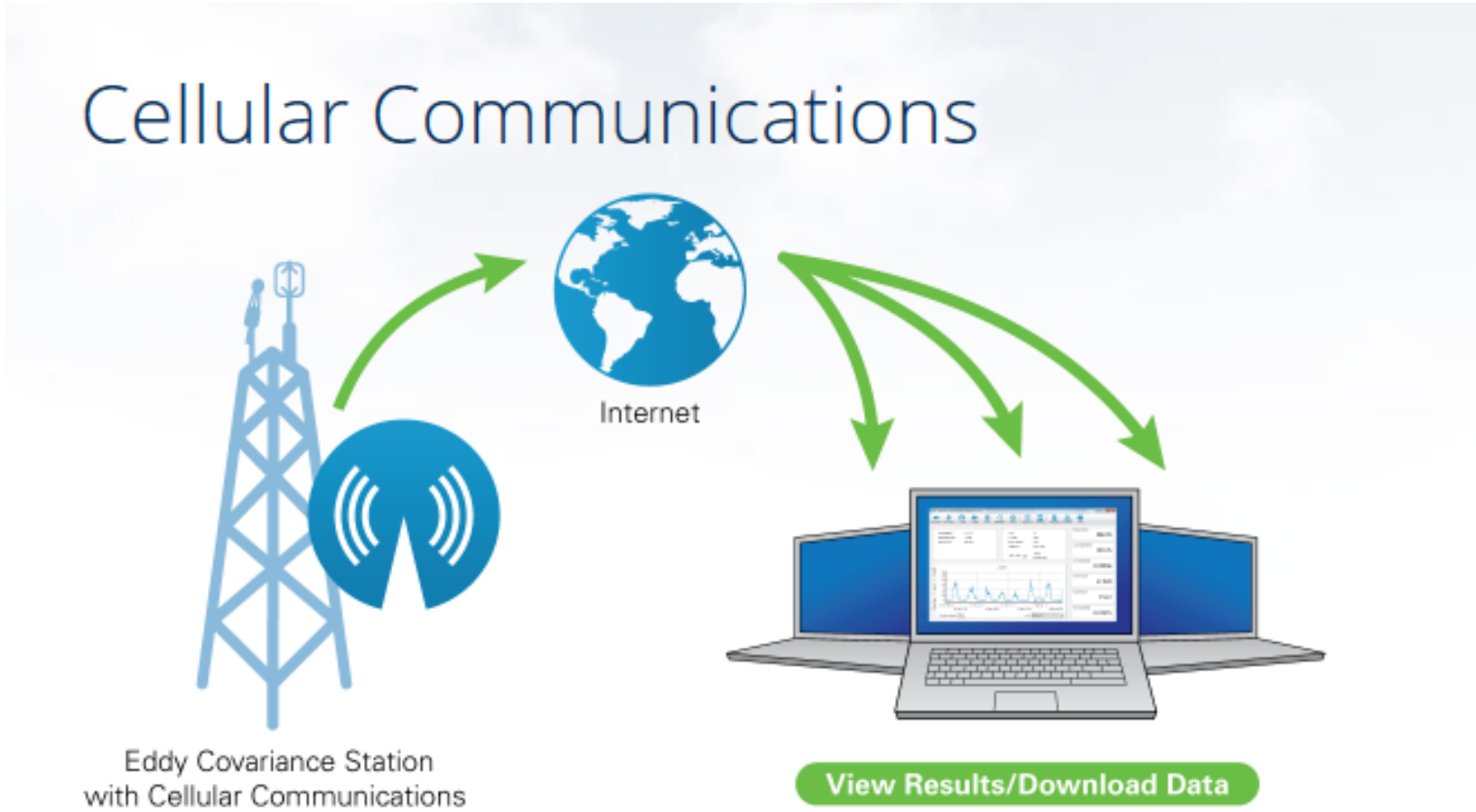
- System Monitoring
- Remote Connection and Data Transfer

System Monitoring – Direct Connection at the Site

- LI-7550 + Computer
- Windows® Interface

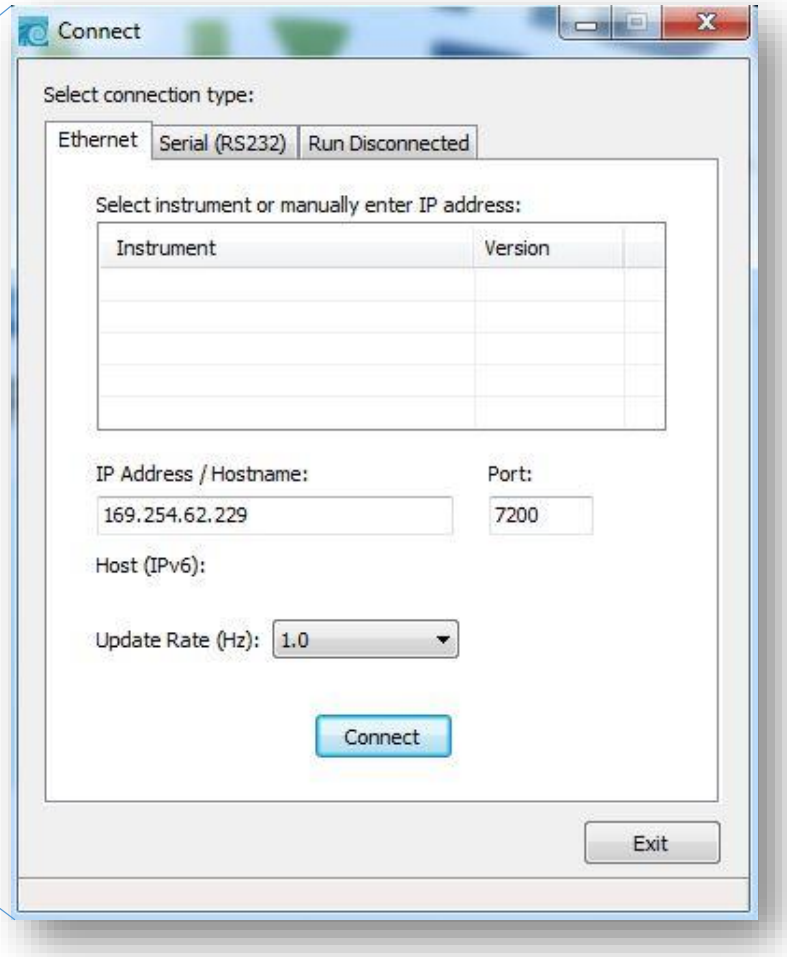


Remote access and communications



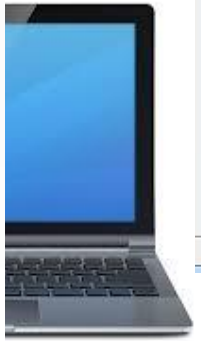
System Monitoring – Remote Connection from office, lab, conference …

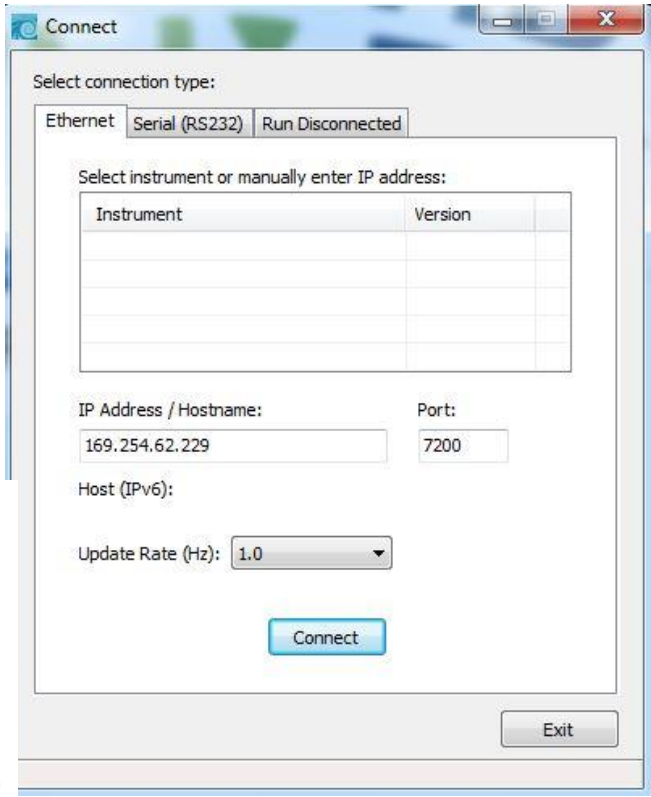
- LI-7550 + Computer
- Windows® Interface



System Monitoring – Remote Connection from office, lab, conference …

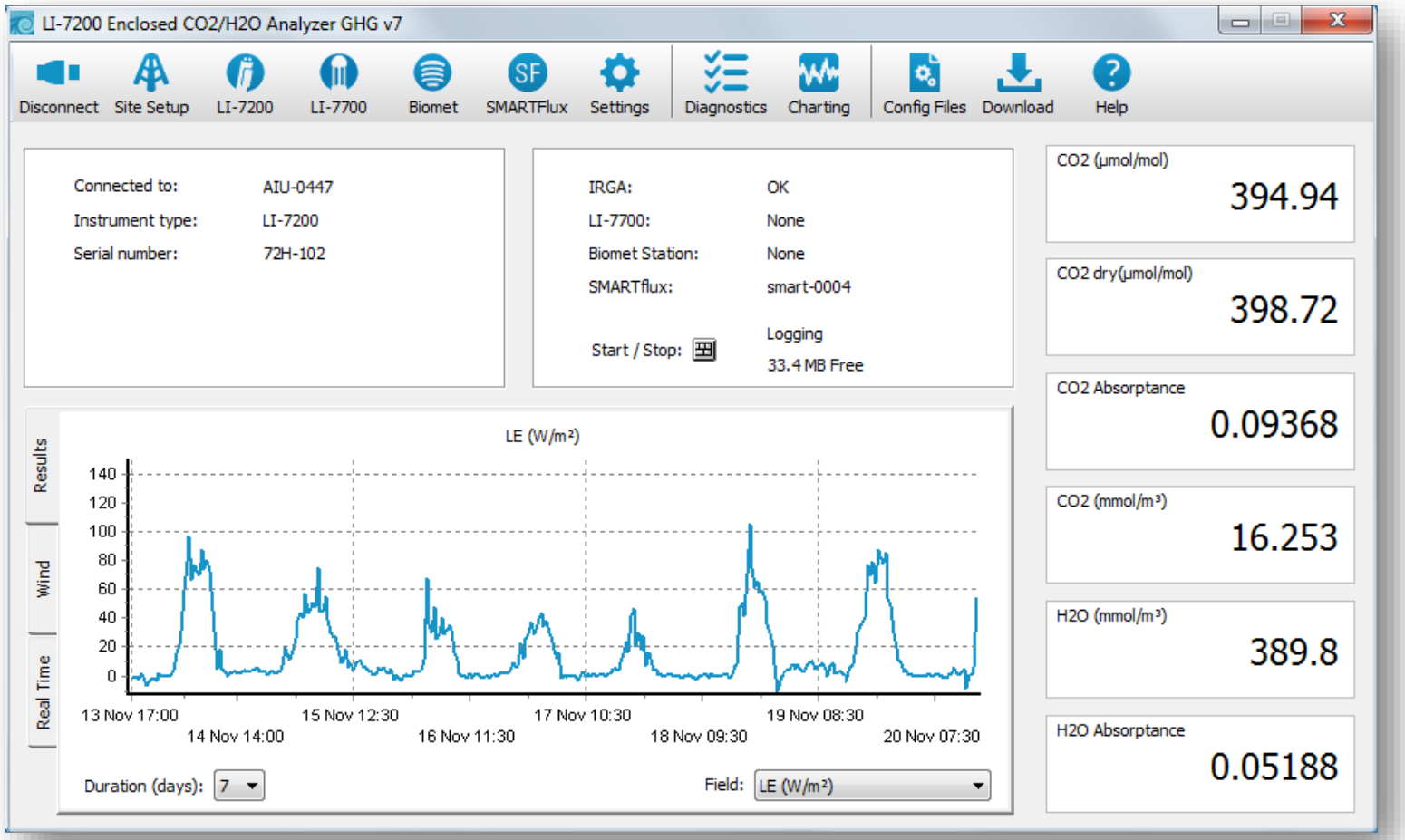
- LI-7550 + Cell Mod
- Windows ® Interfac



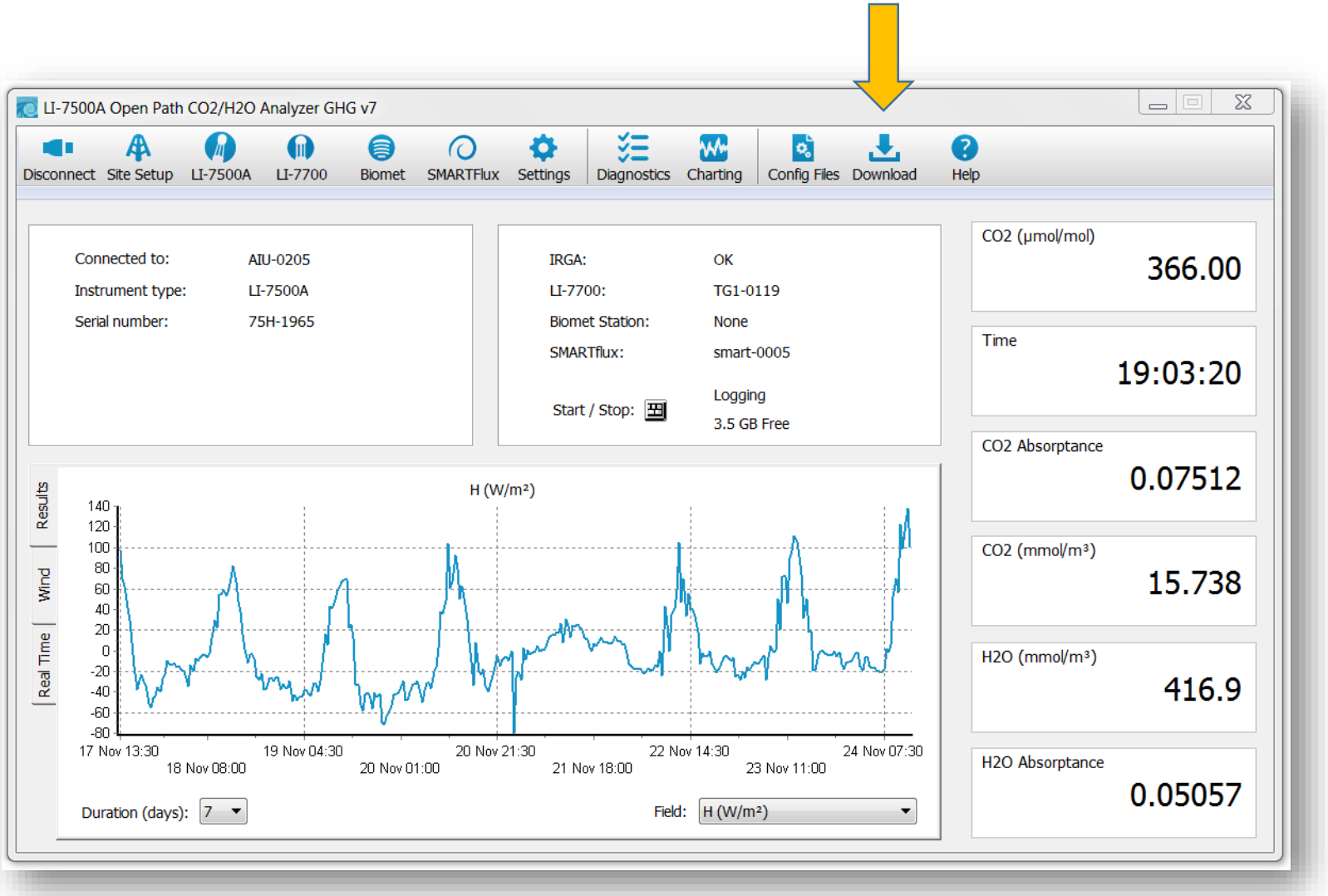


Satellite can be an option, when no Cell Service, or no easy access to IP addresses

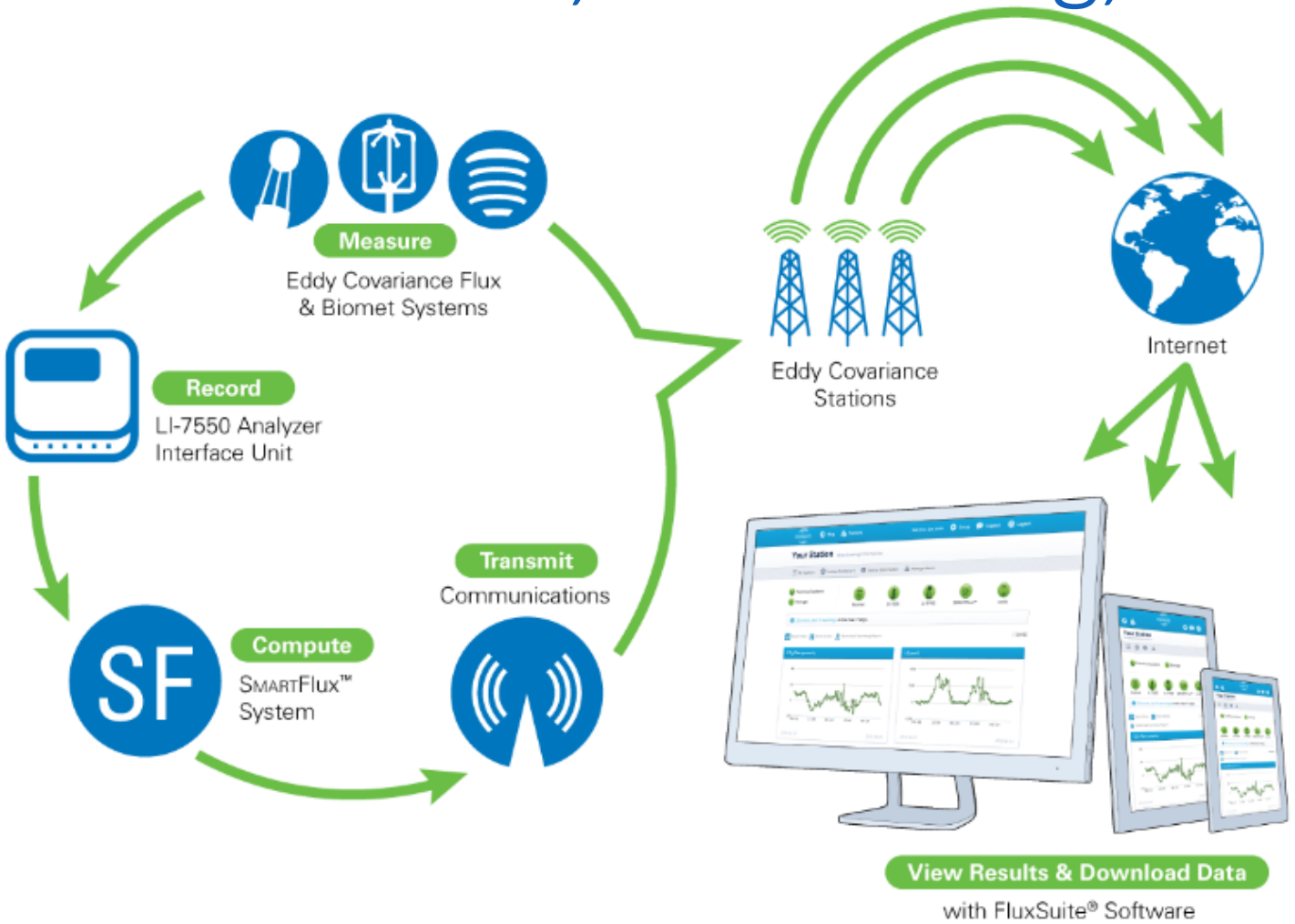
System Monitoring



Automatic file transfer

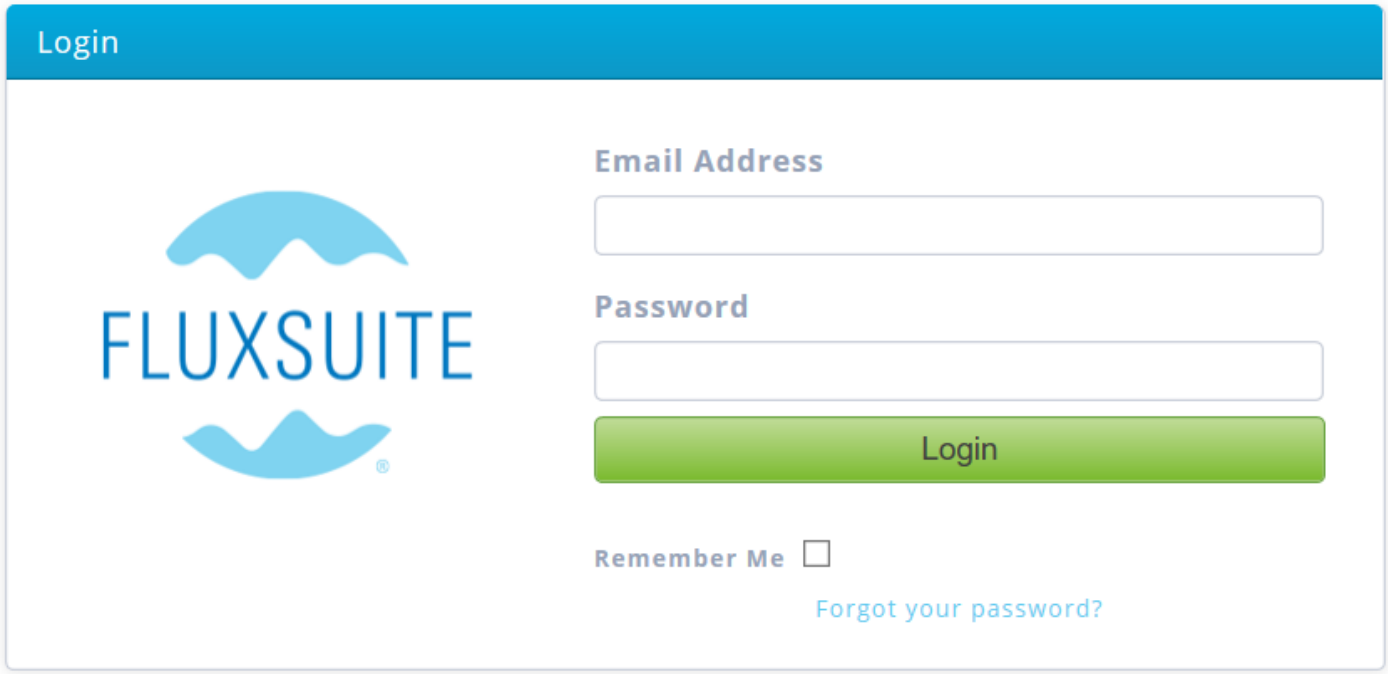


Data Transfer, Monitoring, and Management



- FluxSuite
- NEW improvements and functionality for this Network

FluxSuite Software: Login Screen



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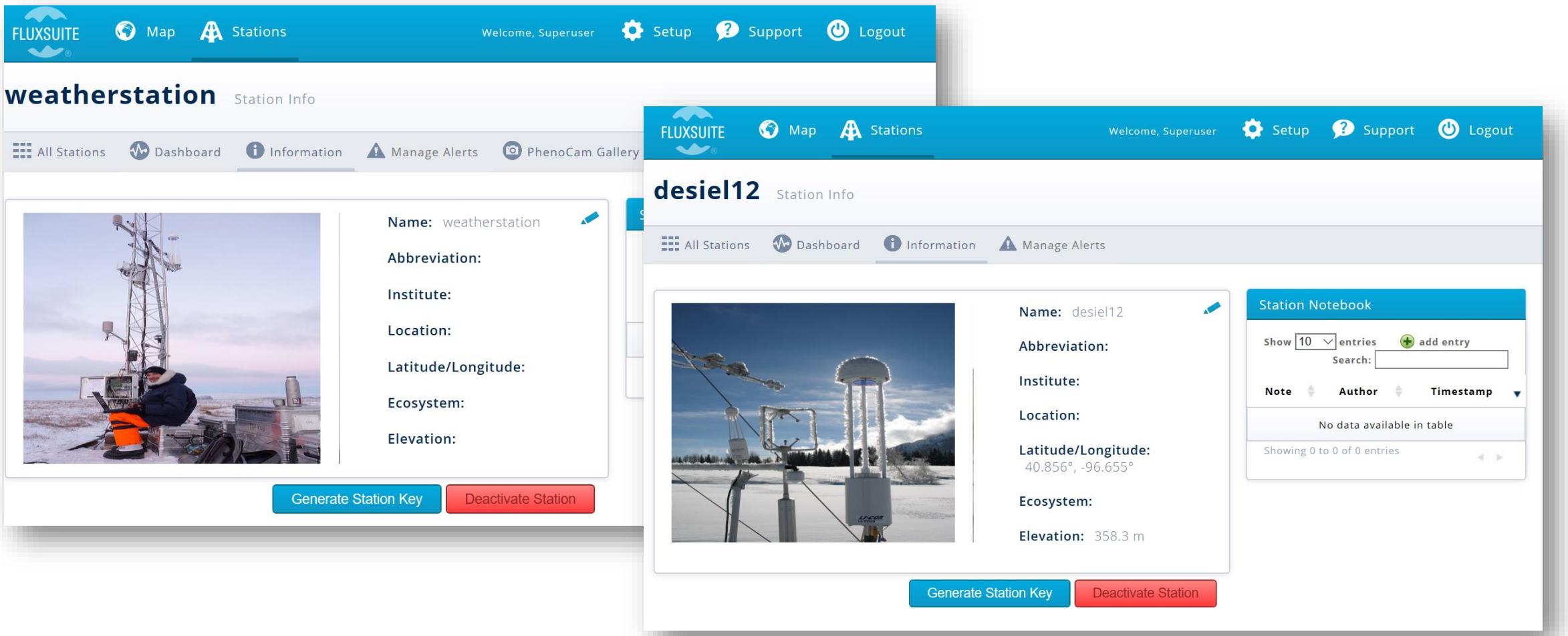
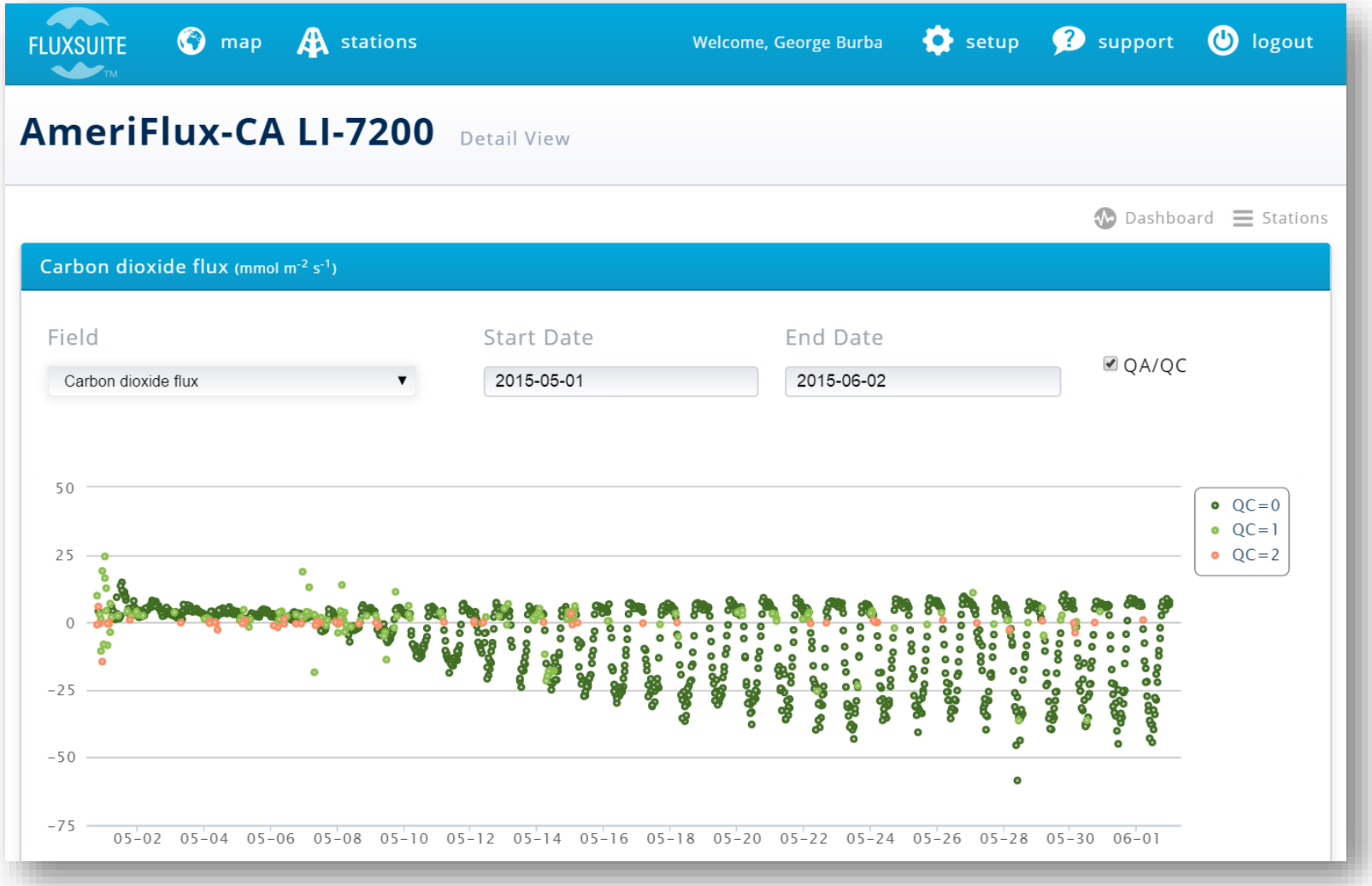
Station Monitoring

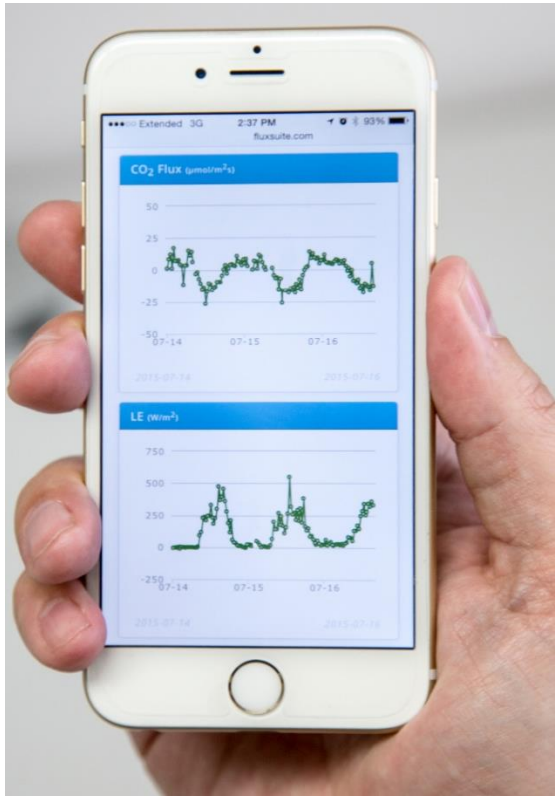


Detailed View

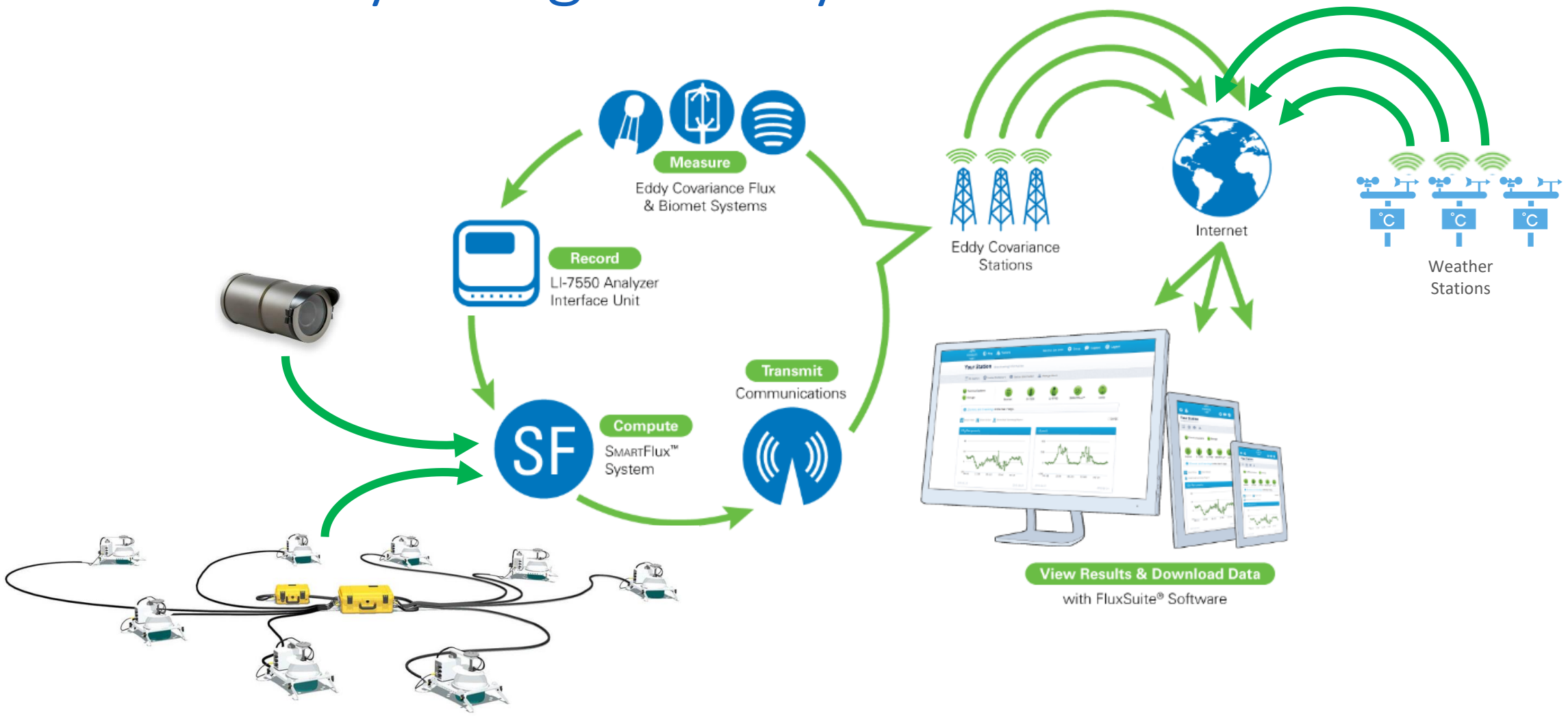


FluxSuite™ Software

- Monitor – Anywhere. Any time. Any device.



The fully-integrated System

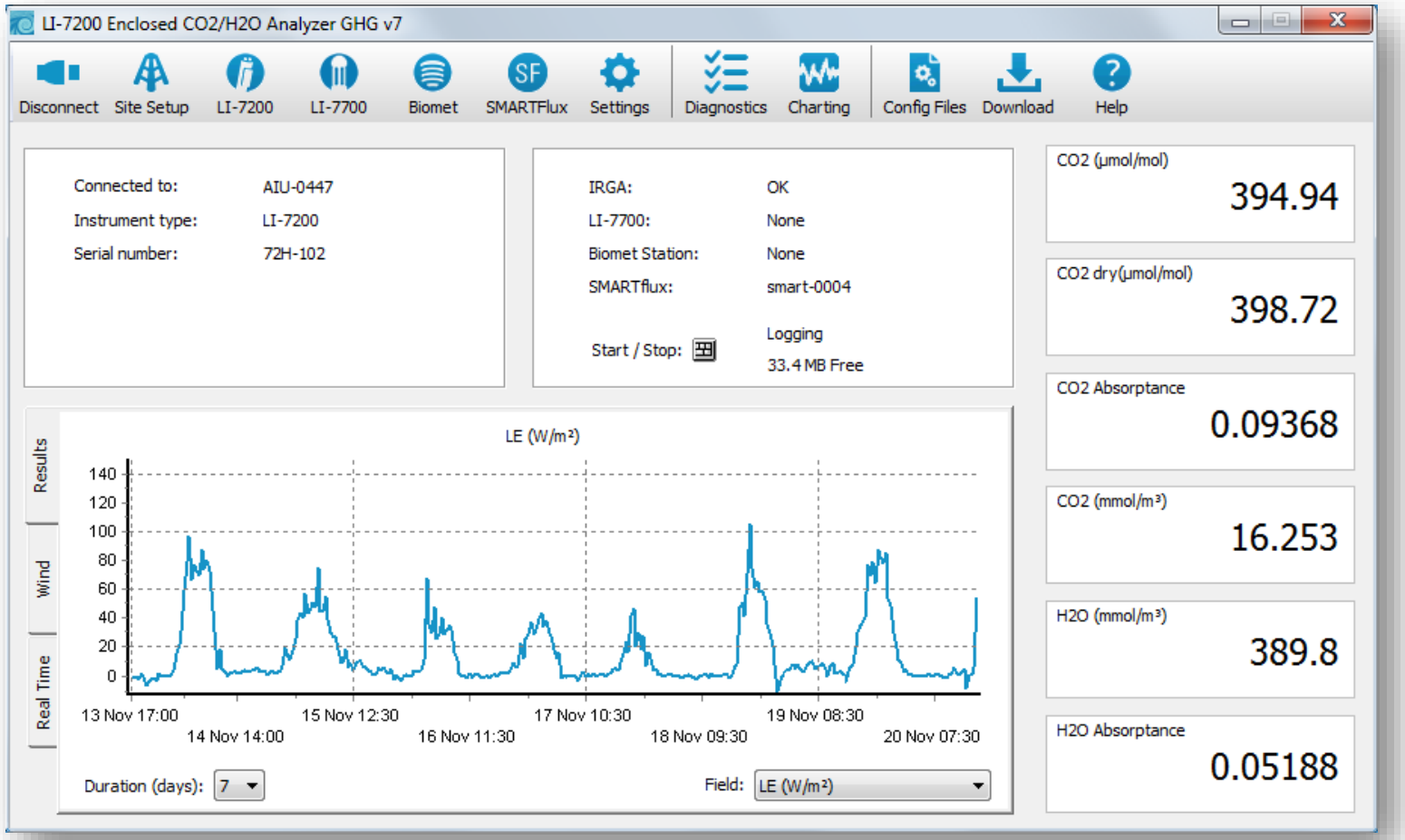


System Configuration

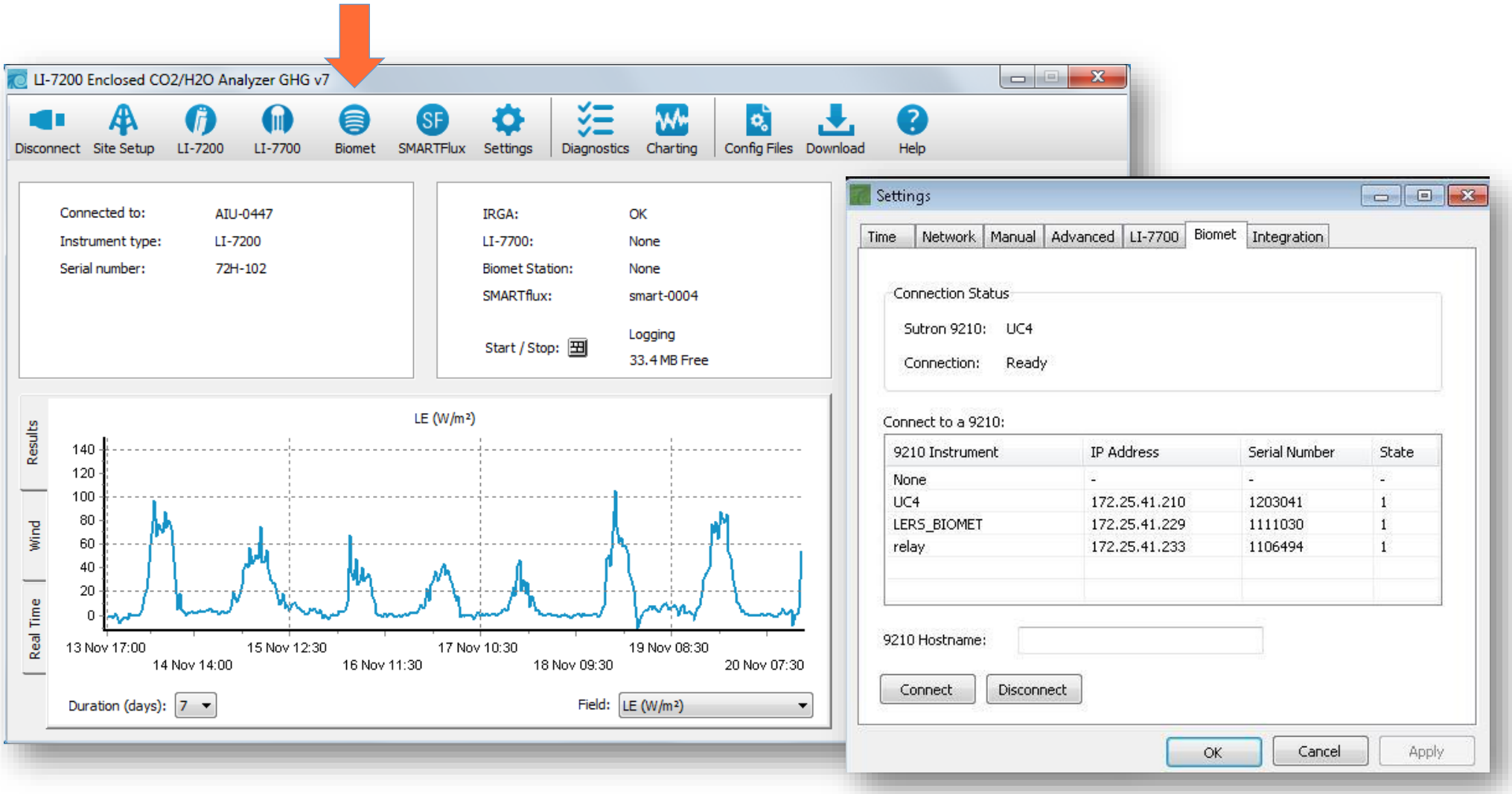
LI-7500RS Interface Software (GHG)

- Configure LI-7550
- Configure Analyzer and Accessories
- Configure Site Setup and Metadata
- Configure data collection
- Connect to other Components
- Calibrate analyzer

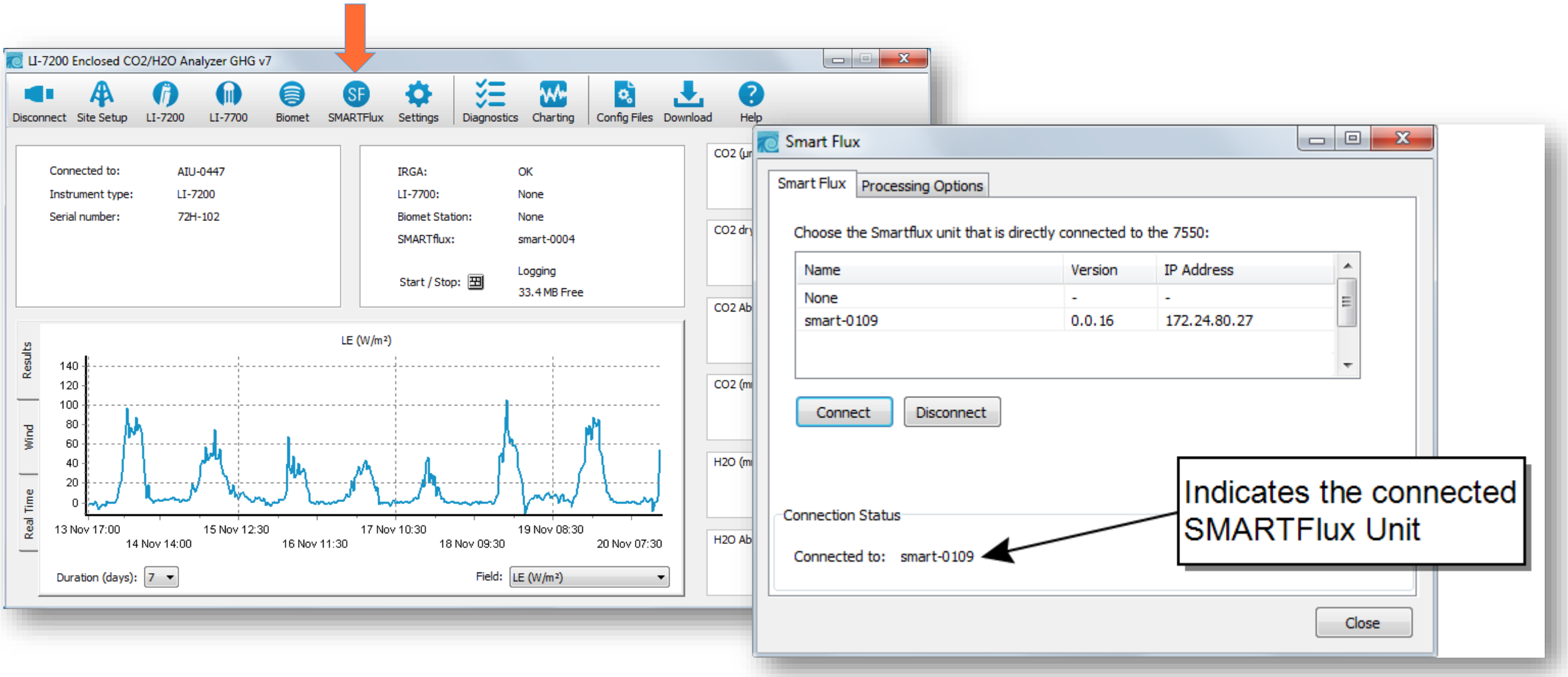
Windows® Interface Software



Connect Biomet to LI-7550



Connect SmartFlux to LI-7550



Collect and record metadata (field-site information)…

- Needed for processing raw data into accurate, computed flux values.
- Can be done manually and entered during post-processing.
- Better…can be done at start up in Instrument software.
- Can easily be read and used by EddyPro and/or SMARTflux.

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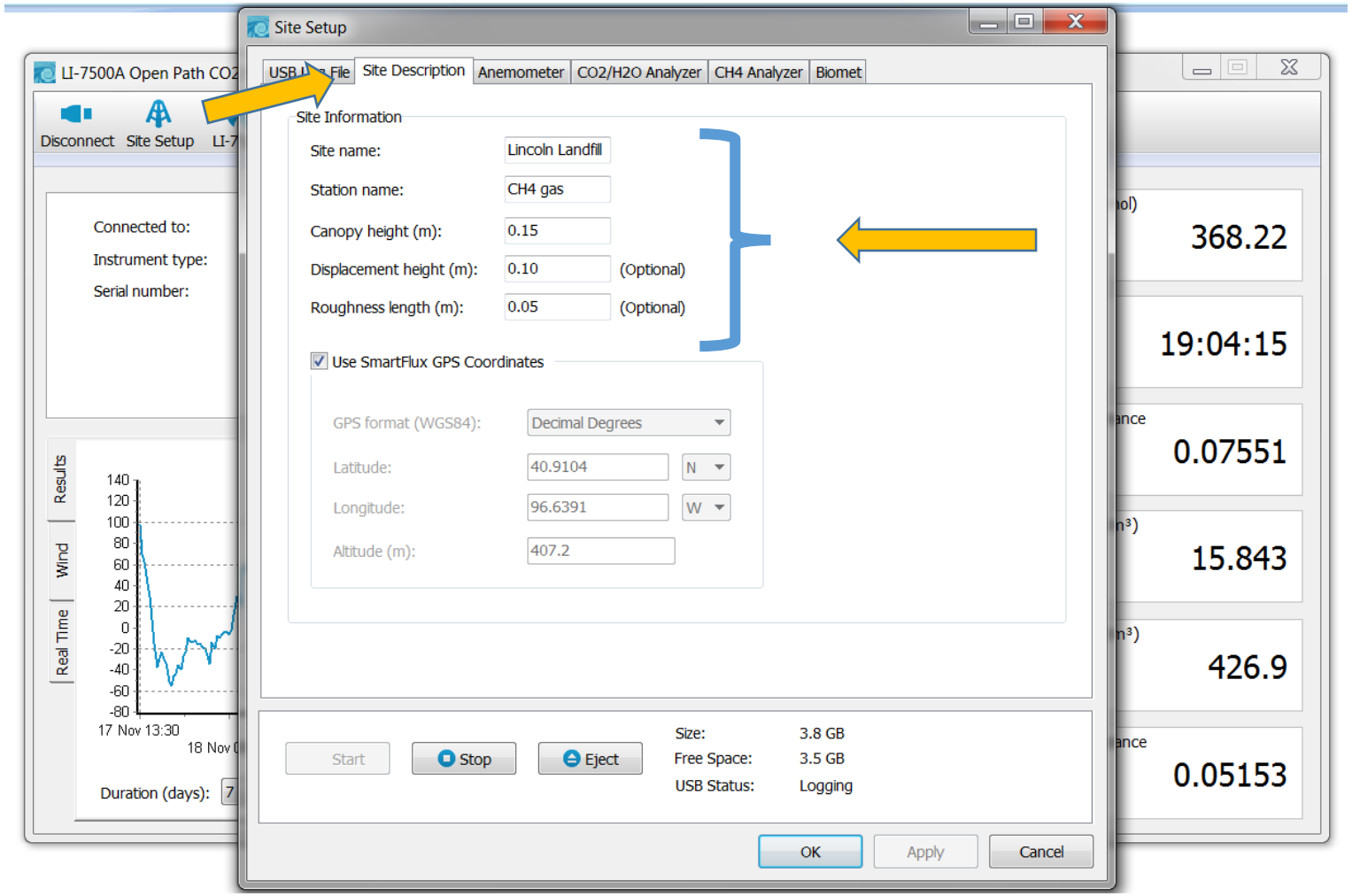
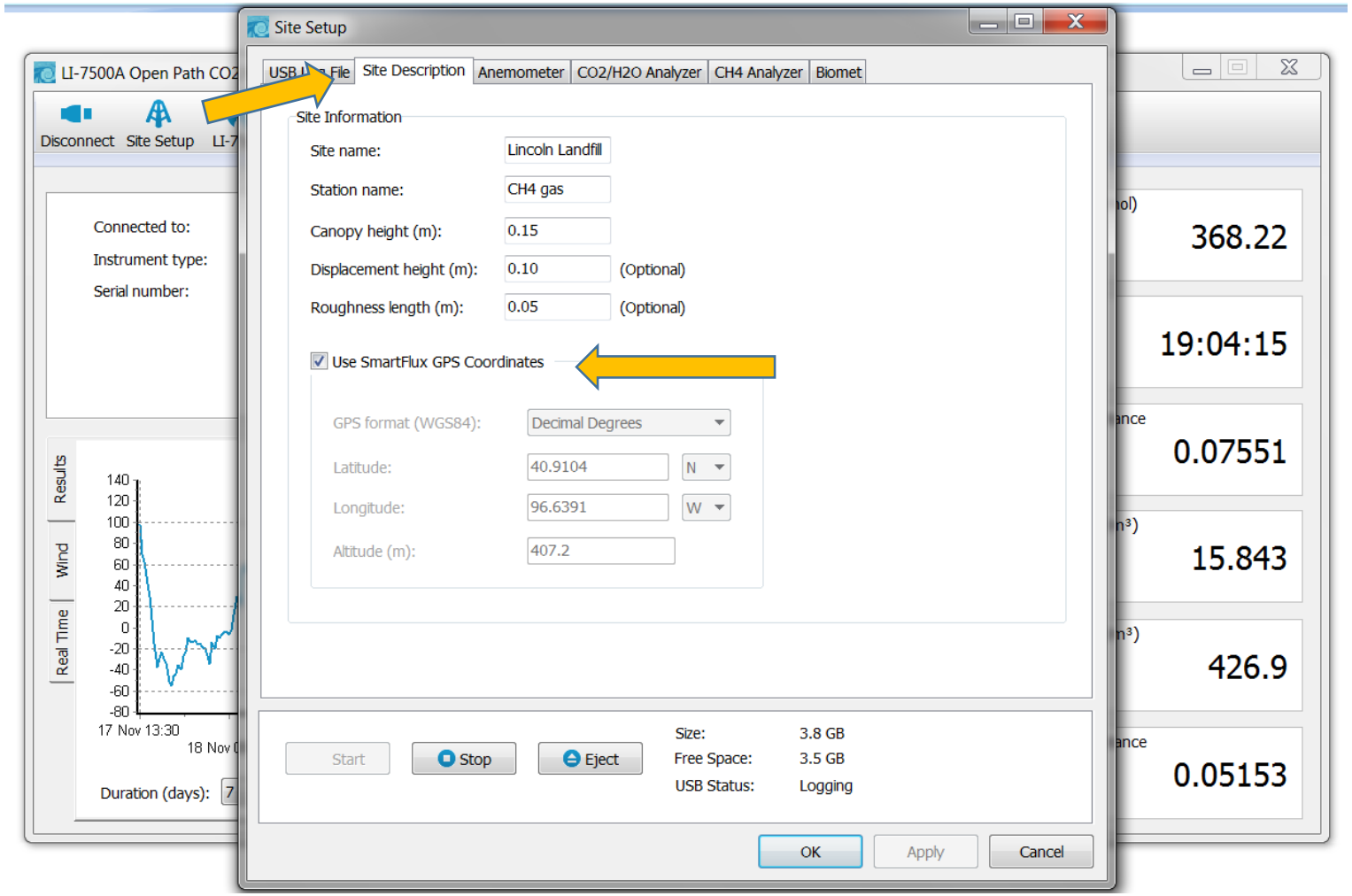
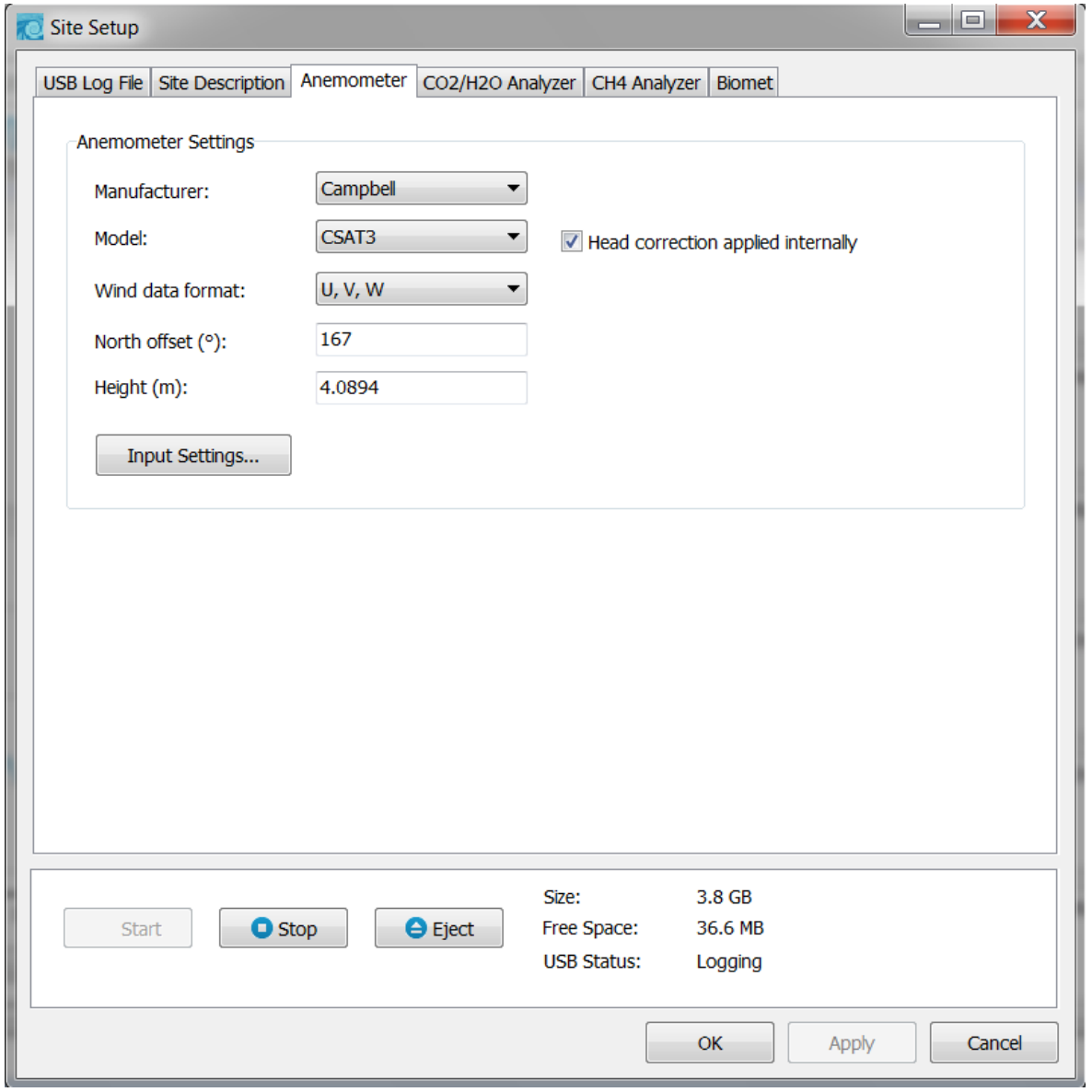
Recording site metadata…



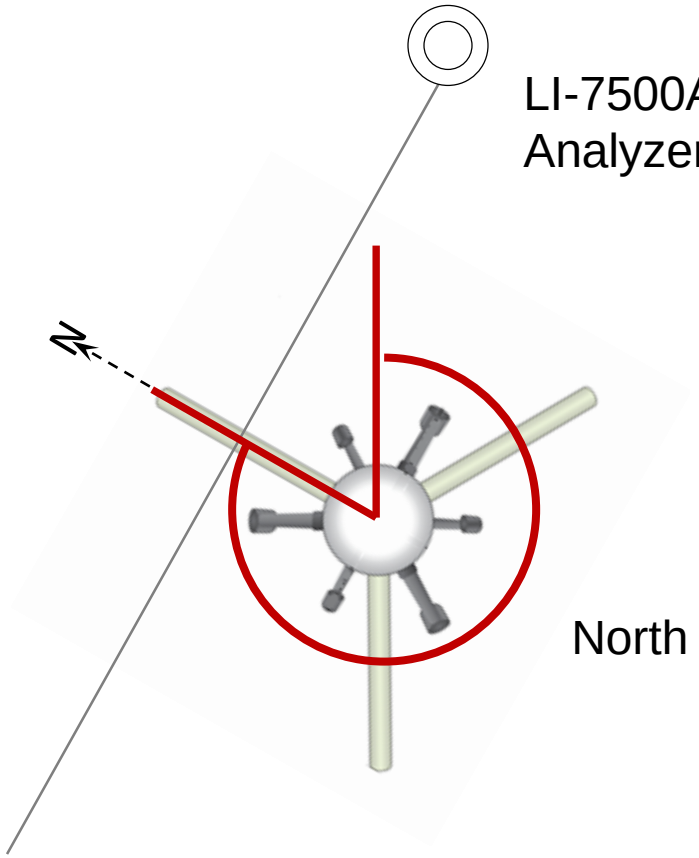
Recording site metadata…



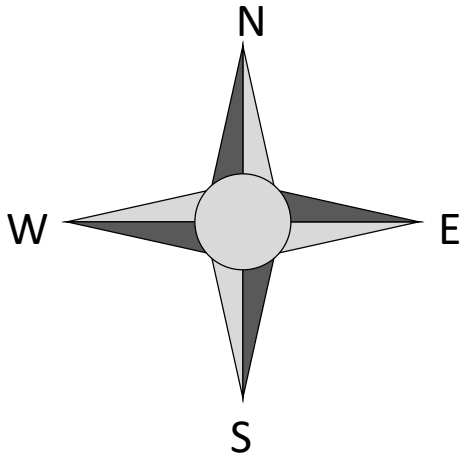
Recording metadata…



Metadata: North Offset

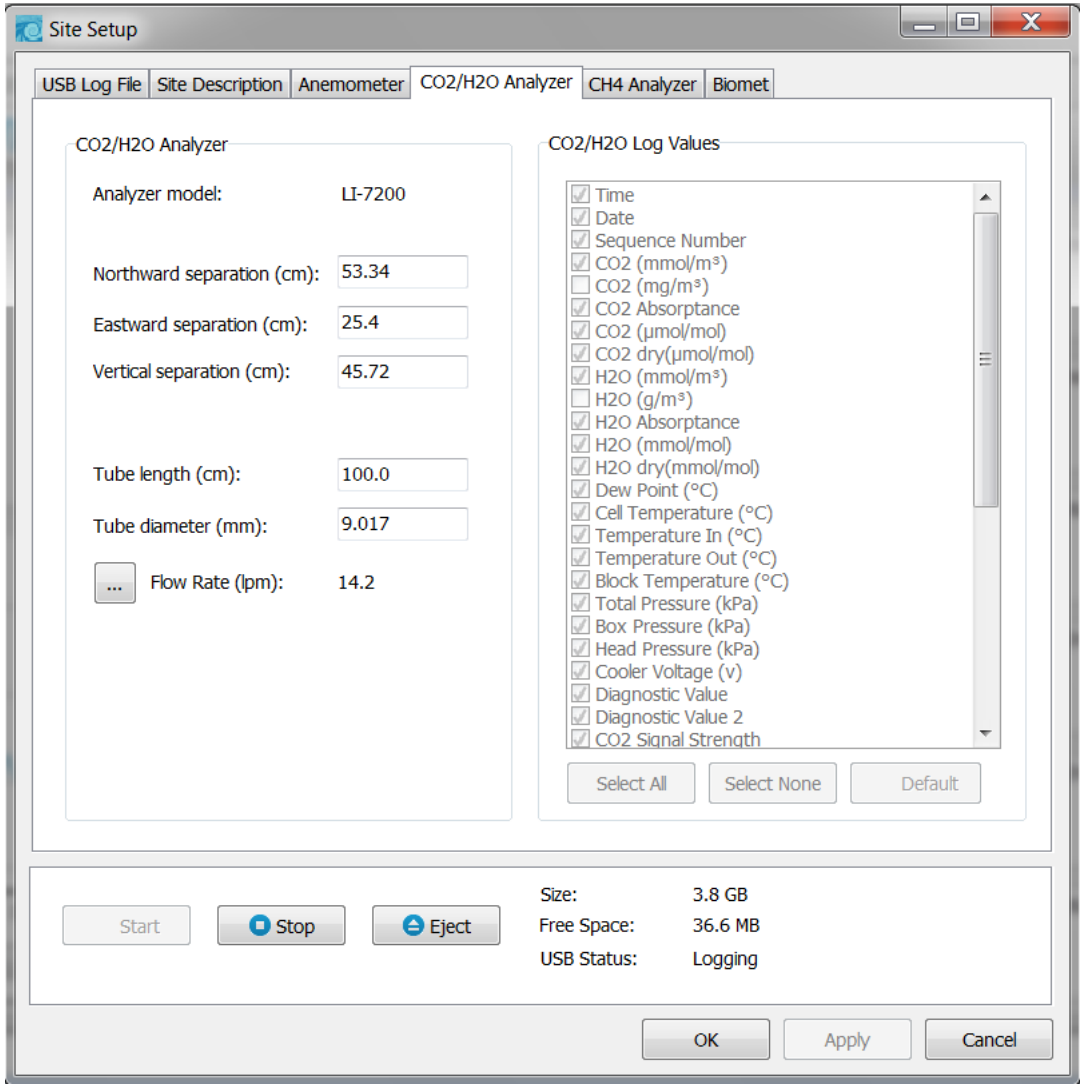


LI-7500A CO_2/H_2O Analyzer

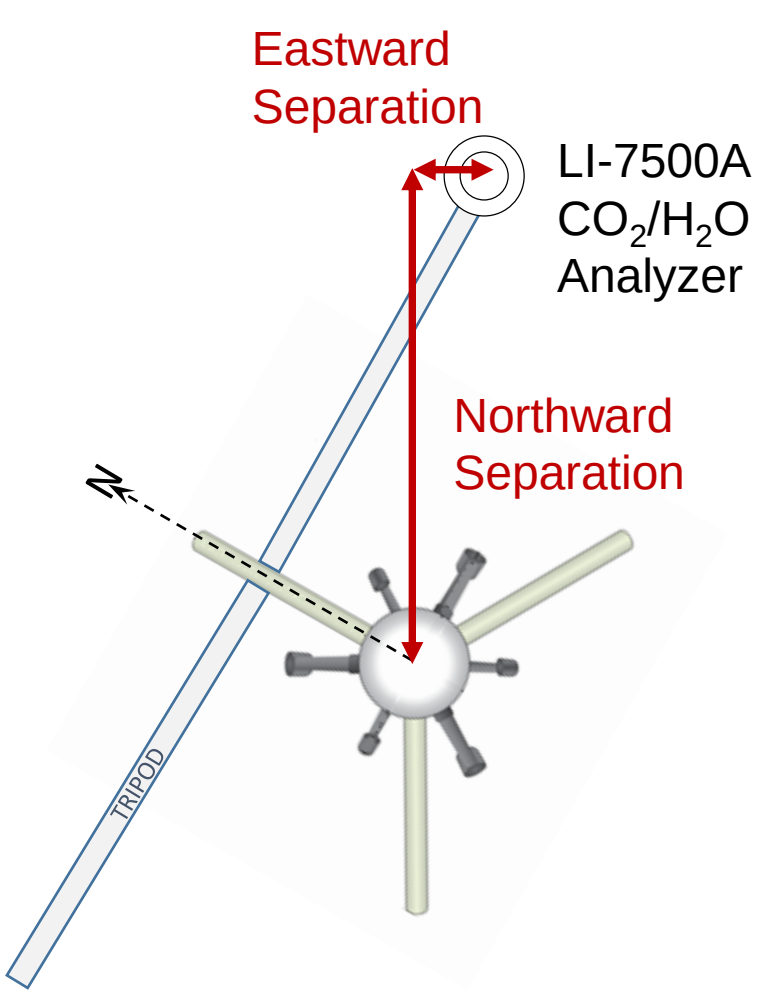


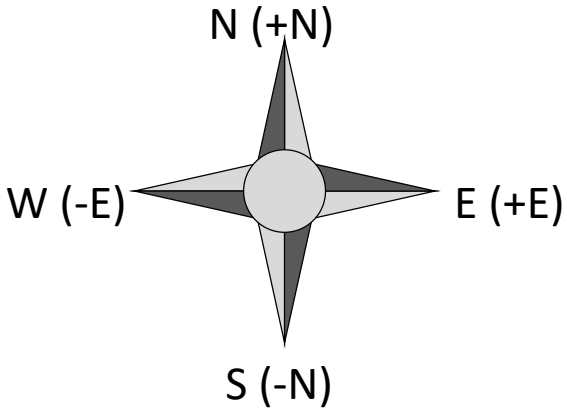
North offset: 0-359 degrees

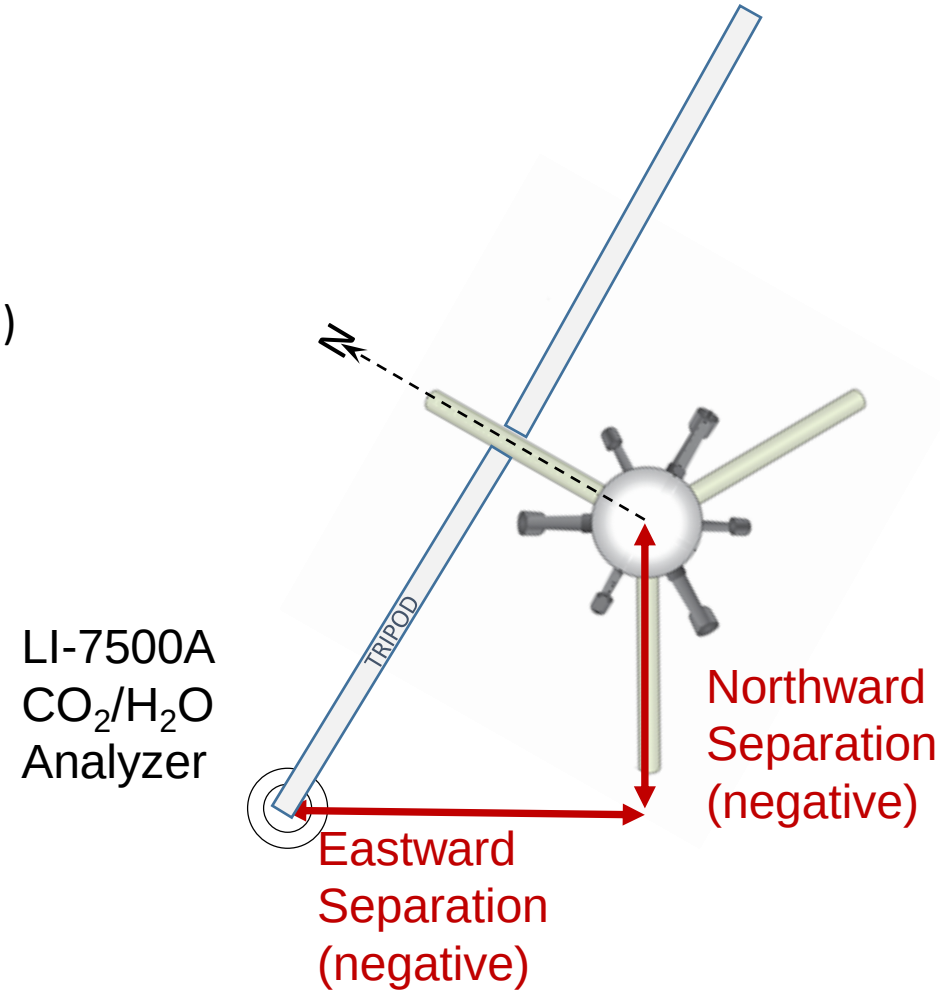
Recording metadata…



Horizontal Separation metadata (top view)

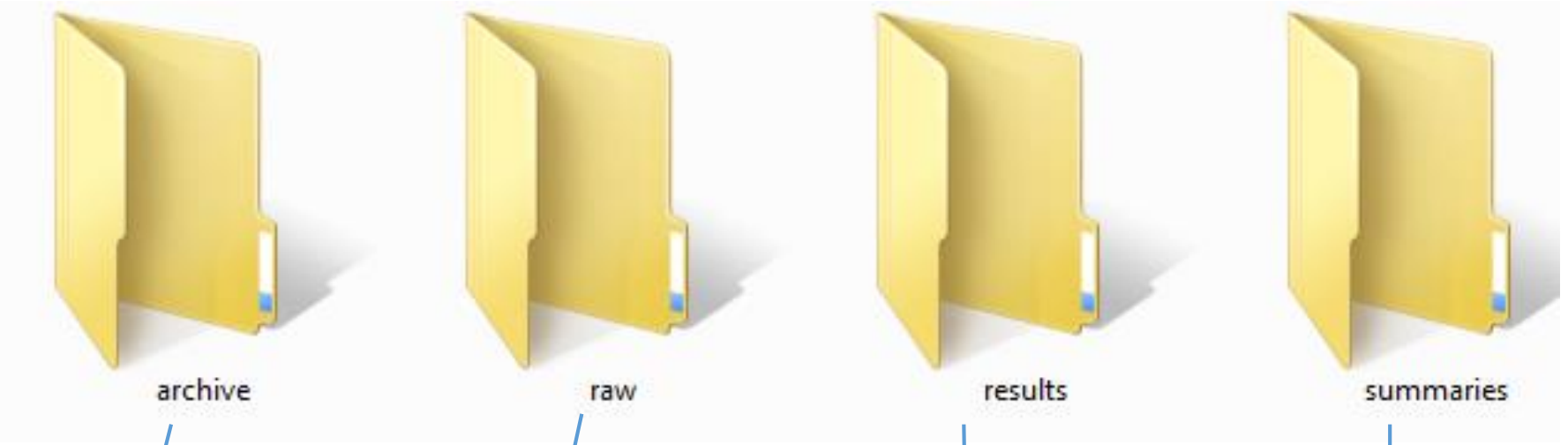






System Data Outputs

Files available through SMARTFlux™ equipped LI-7550



Archived Data

GHG Files

Zipped result output
for each EddyPro run

GHG and EddyPro®
daily summary files

Raw Data

EddyPro is optimized for LI-COR GHG data

“ . ghg” files
Raw archives containing four files

Flux data

1 High-frequency data
wind,
gas concentration, temperatures, etc

2 Flux metadata
Measurement height,
canopy height ,sensor seperation, etc

Biomet data

3 Low-frequency data
Radiation,
soil heat flux, air temperature, etc

4 Biomet metadata
Variable names,
units, sampling rates, etc

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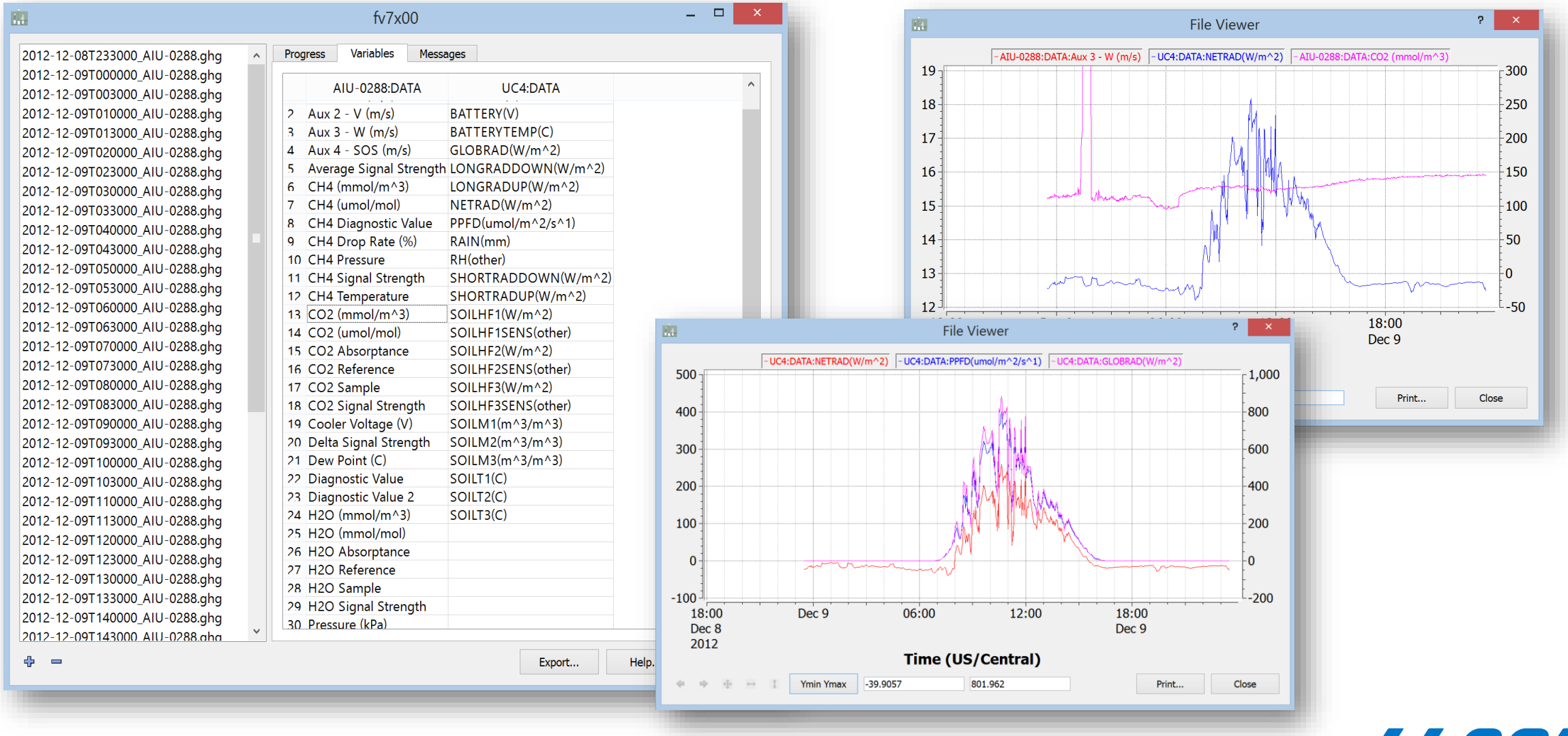
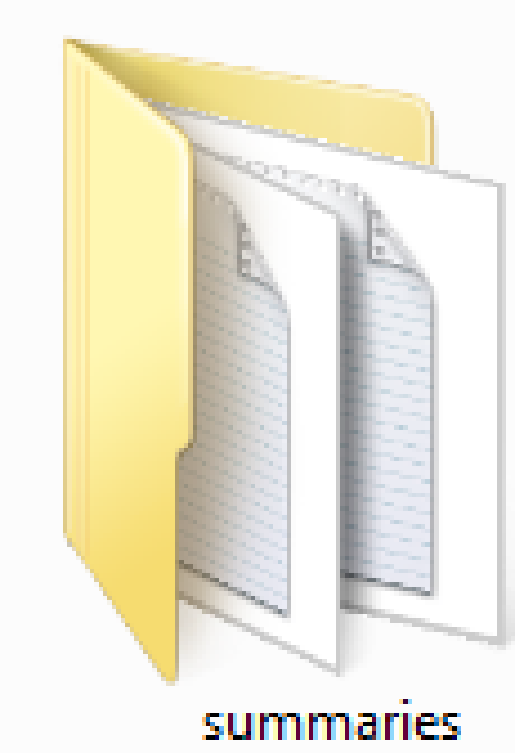
Raw Data Visualization – LI-7xx File Viewer

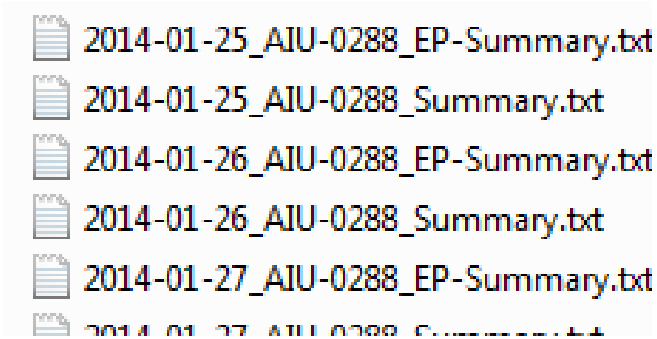


SmartFlux™ Outputs – Summaries Folder

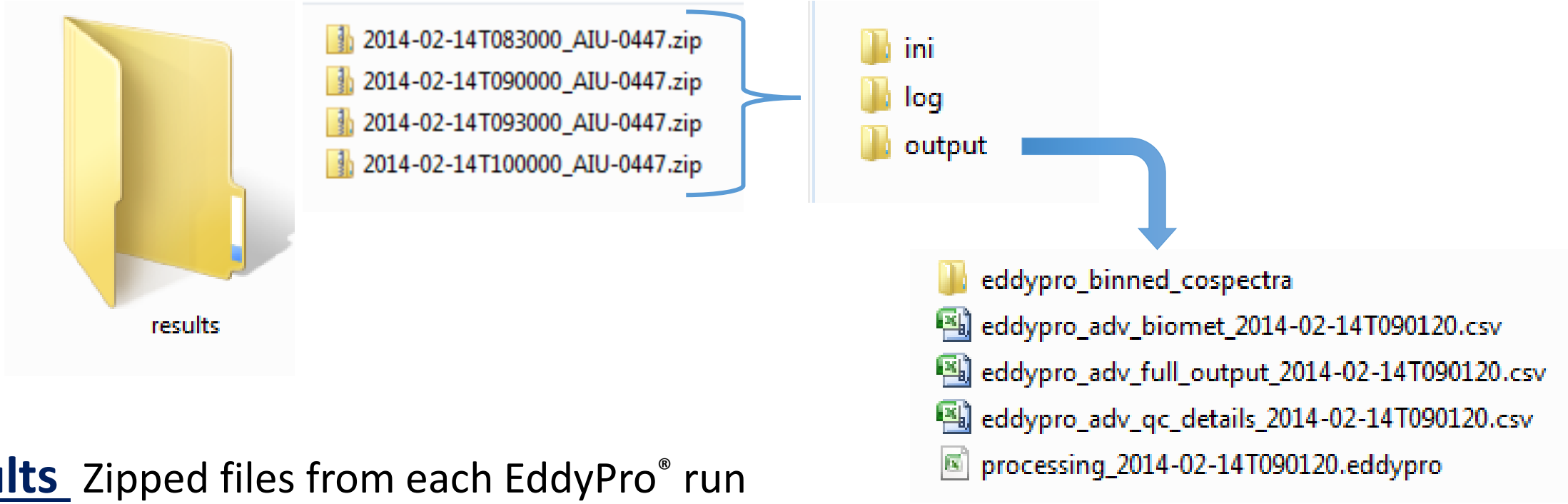


1. Final fluxes for each half hour of the day computed by SmartFlux™ (Flux Summary)

2. An average value for each half hour of the day for all variables measured by the gas analyzer (Diagnostic Summary)



SmartFlux™ Outputs – Results Folder



Results Zipped files from each EddyPro® run

ini folder – Project file used to process the data

log – the EddyPro® engine log for the run

output – contains all requested output files

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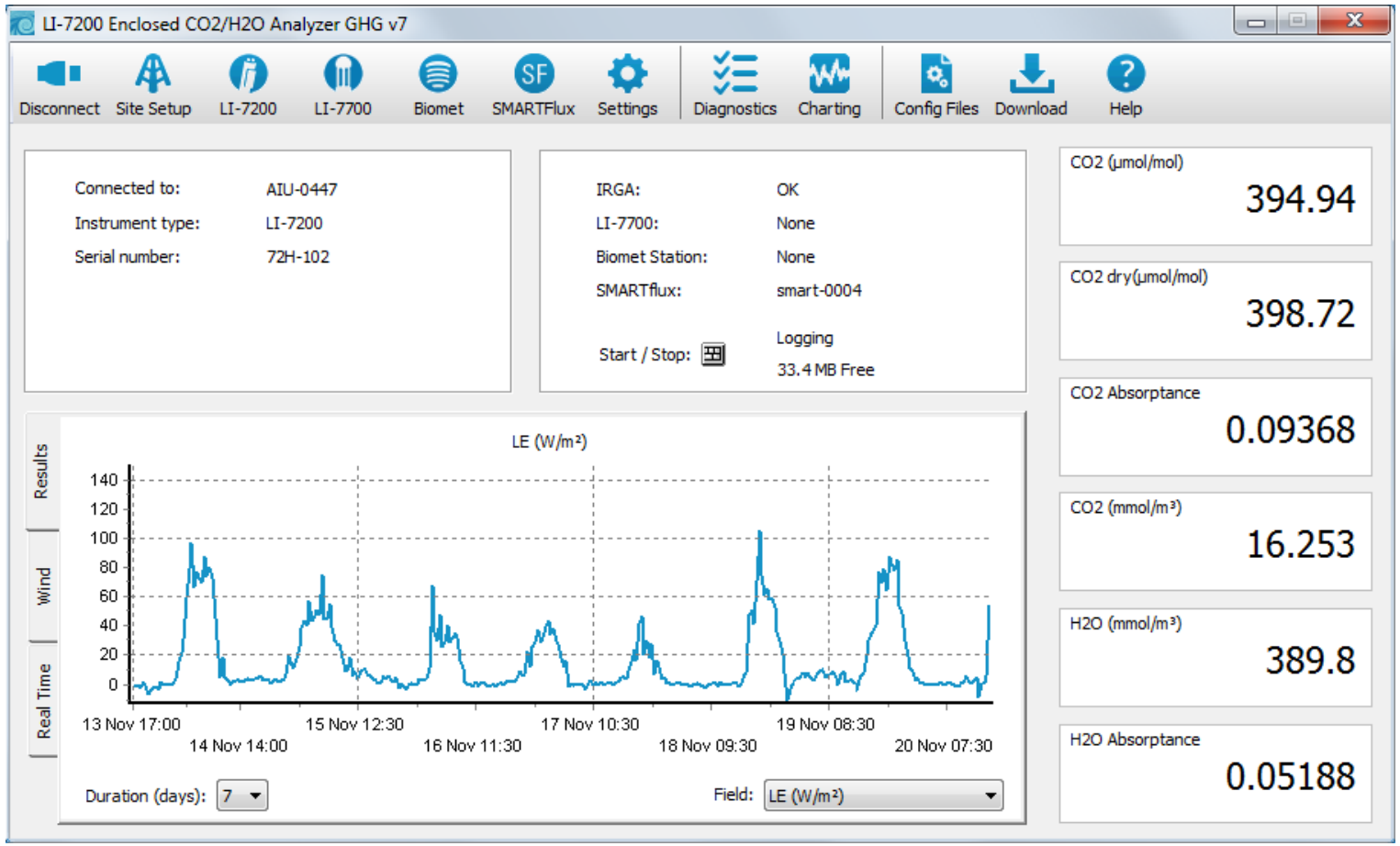
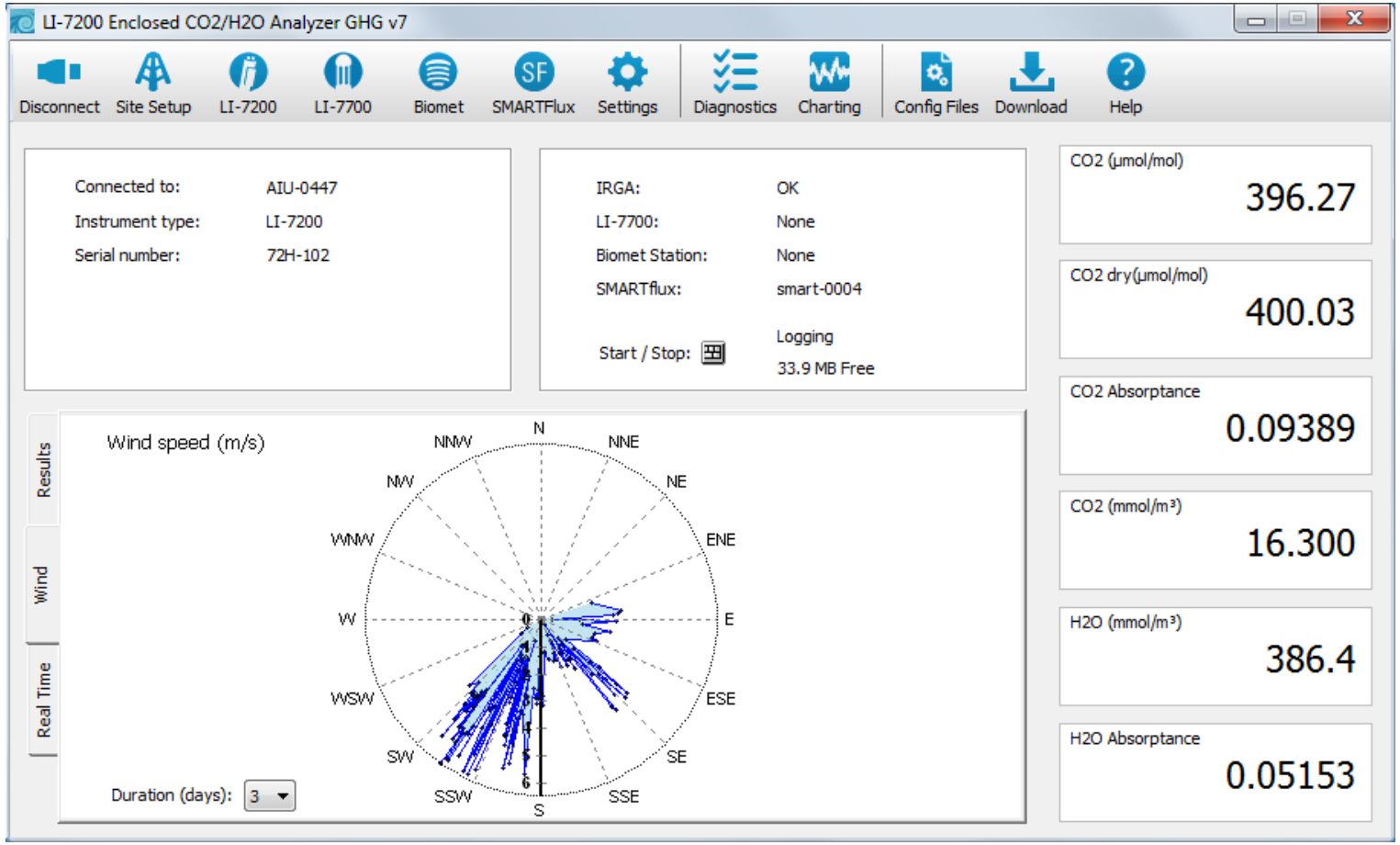
System Monitoring

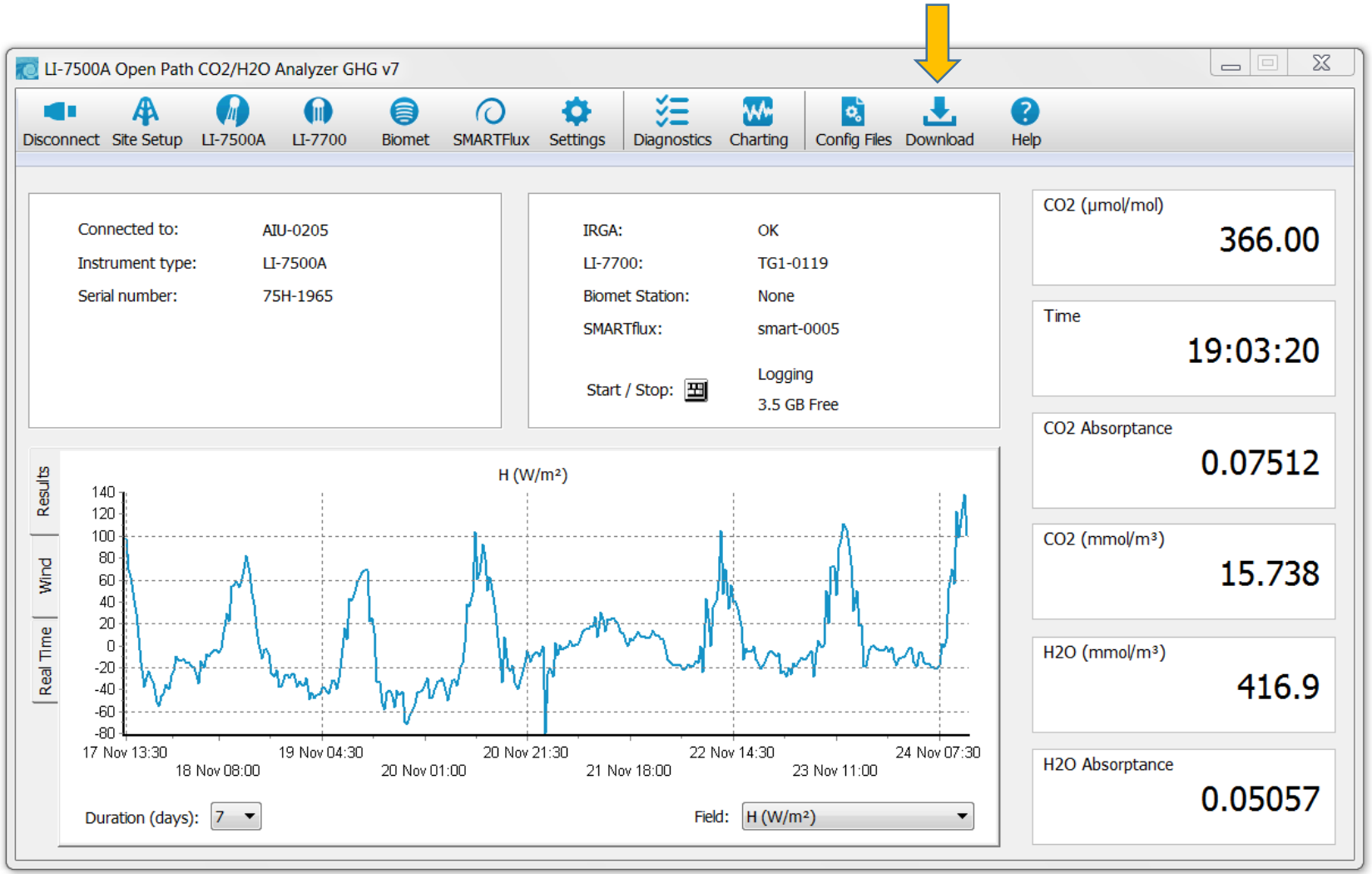
System Monitoring



System Monitoring



Set-up the automatic file transfer



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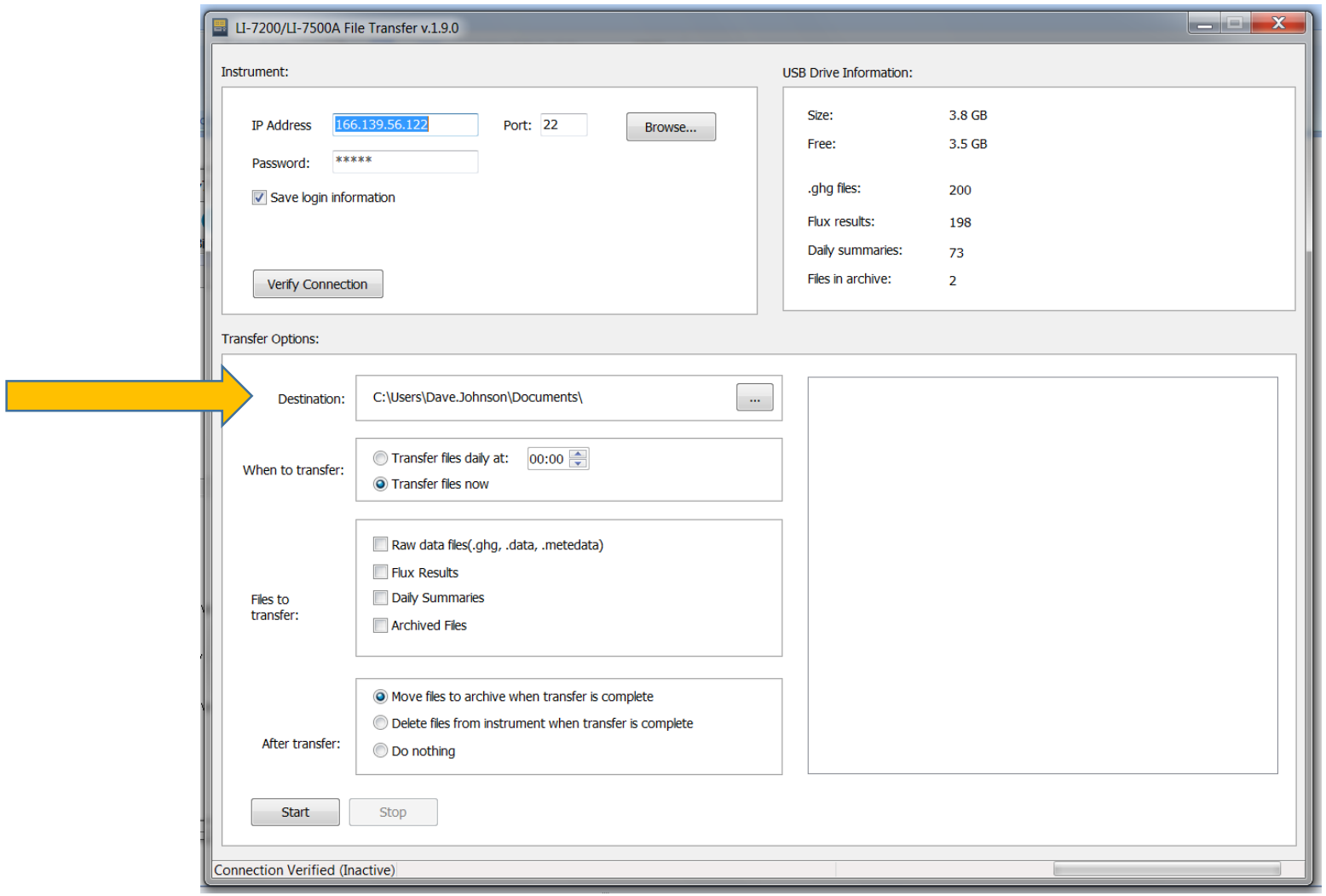
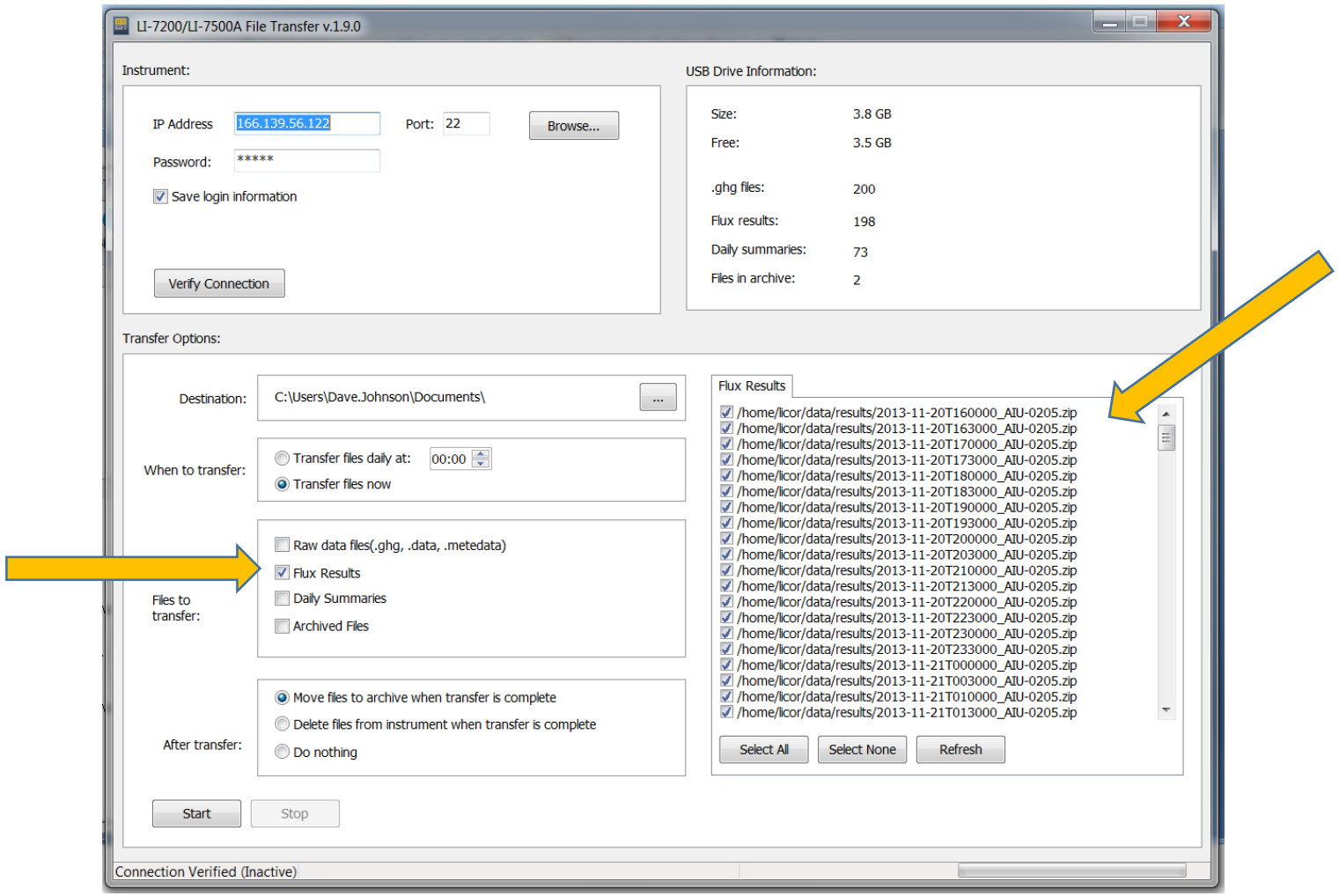


Data Transfer



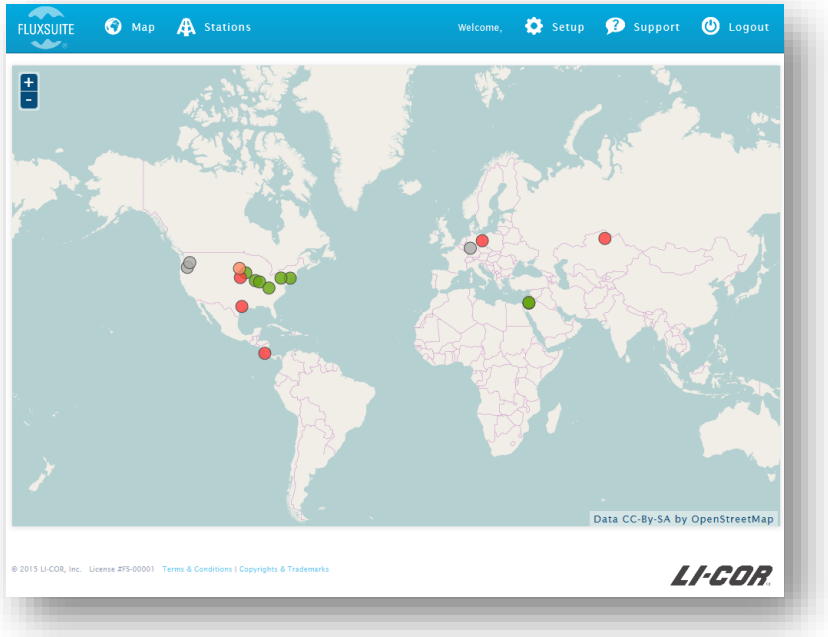
FLUXSUITE™

A NEW TOOL FOR ACTUAL AND VIRTUAL NETWORKS OF FLUX STATIONS

FluxSuite

- FluxSuite is a combination of hardware, software and web-service
- Modern, fast, and easy-to-use tool for station monitoring & management

FLUXSUITE®



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Thank You
Questions?