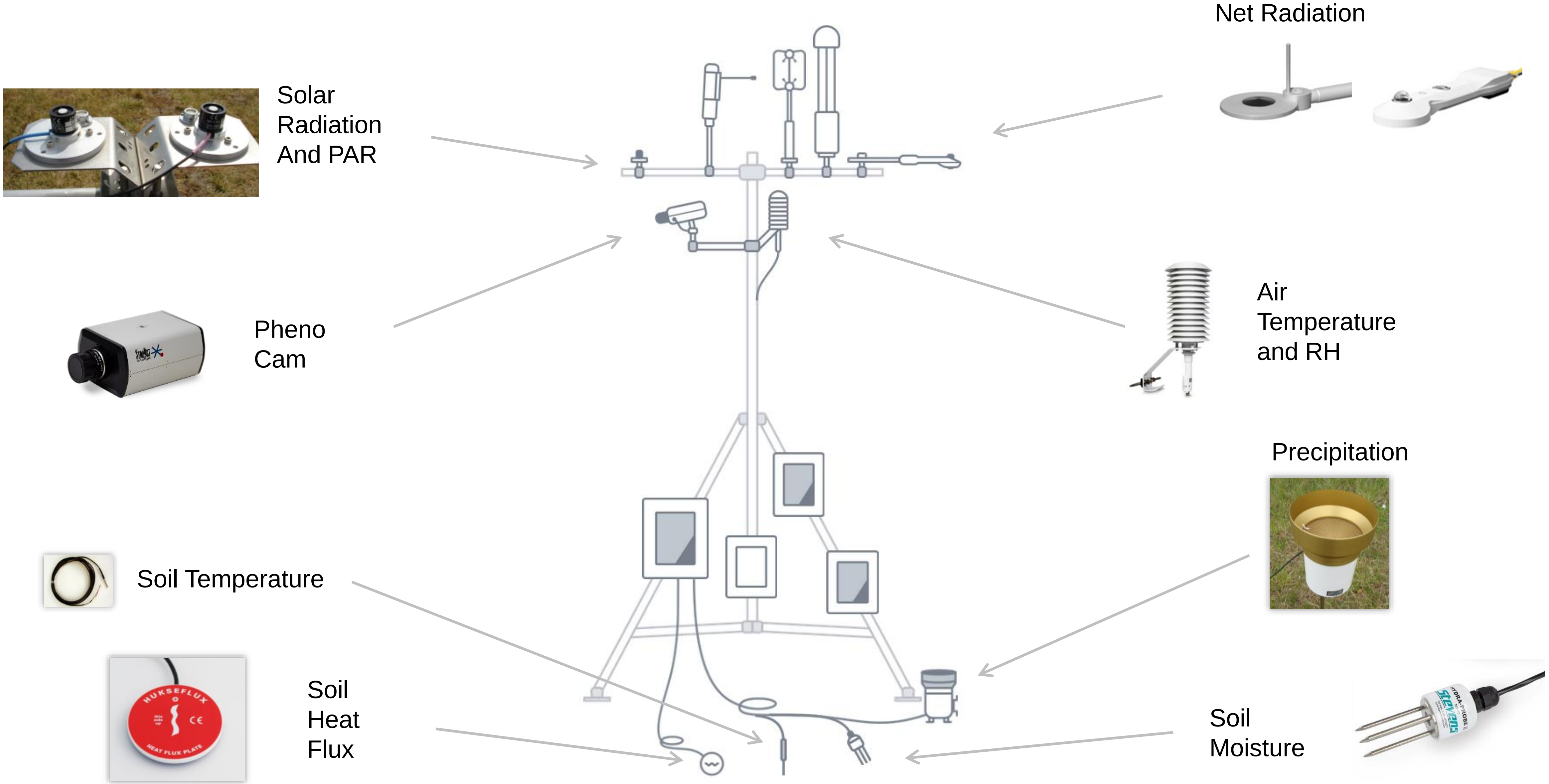
Biomet Sensors and Measurements

What are ‘Biomet’ Sensors?

- Sensors used for monitoring the environment (biological and meteorological).

- Typically measured once every 1-60 seconds

Biomet Measurements



Why collect Biomet measurements?

- Improved flux computation and corrections
  - Quantities estimated from EC replaced by mean values
- Quality Assurance and Quality Checking (QA/QC)
  - Energy Balance closure
- Gap filling, when instrumentation or power fails, low data quality
- Recording weather helps to explain site behavior
  - Physical/biological environment has profound effects on surface-atmosphere exchange

Improving fluxes

Fluxes (e.g. over 30 min intervals) are calculated and corrected based on:

- Covariances: calculated from fast measurement, acquired at f > 5 Hz
- Mean quantities: averaged over the 30 min interval, calculated starting either from fast or slow measurements

$$F = \overline{\rho_a} \cdot \overline{w'c'}$$

Improving fluxes

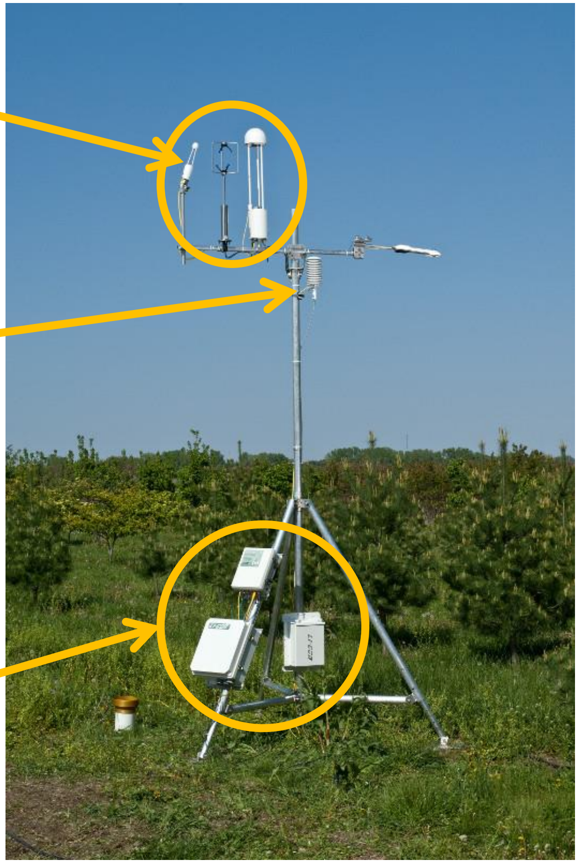
Average Ta and P are involved in various flux equations, for example:

- dry air density: $$\rho_d = \frac{P}{R_d T_a} - \rho_w \frac{m_d}{m_w}$$
- Gas flux: $$F = \overline{\rho_d}\,\overline{w's'}$$
- WPL term: $$F = F_o + \mu \frac{E}{\rho_d} \frac{\rho_c}{1 + \mu \frac{\rho_w}{\rho_d}} + \frac{H}{\rho_c C_p} \frac{\rho_c}{T_a} + P_{term}$$

Vaisala HMP155 Humidity and Temperature Probe with RM Young Radiation Shield

Improving fluxes

- Height where flux measurements are made.
- Measuring air temperature up here, and using this value in the flux calculations, can improve results.
- Height where the CO2/H2O analyzer measures temperature.



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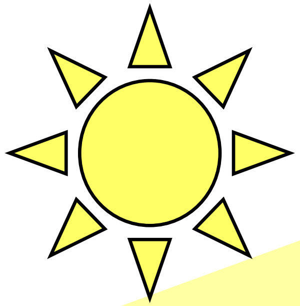
The Energy Budget (daytime)



$$R_n = H + LE + G + S + Q$$

All terms have units of (W m^2).

R_n ~ net radiation flux density

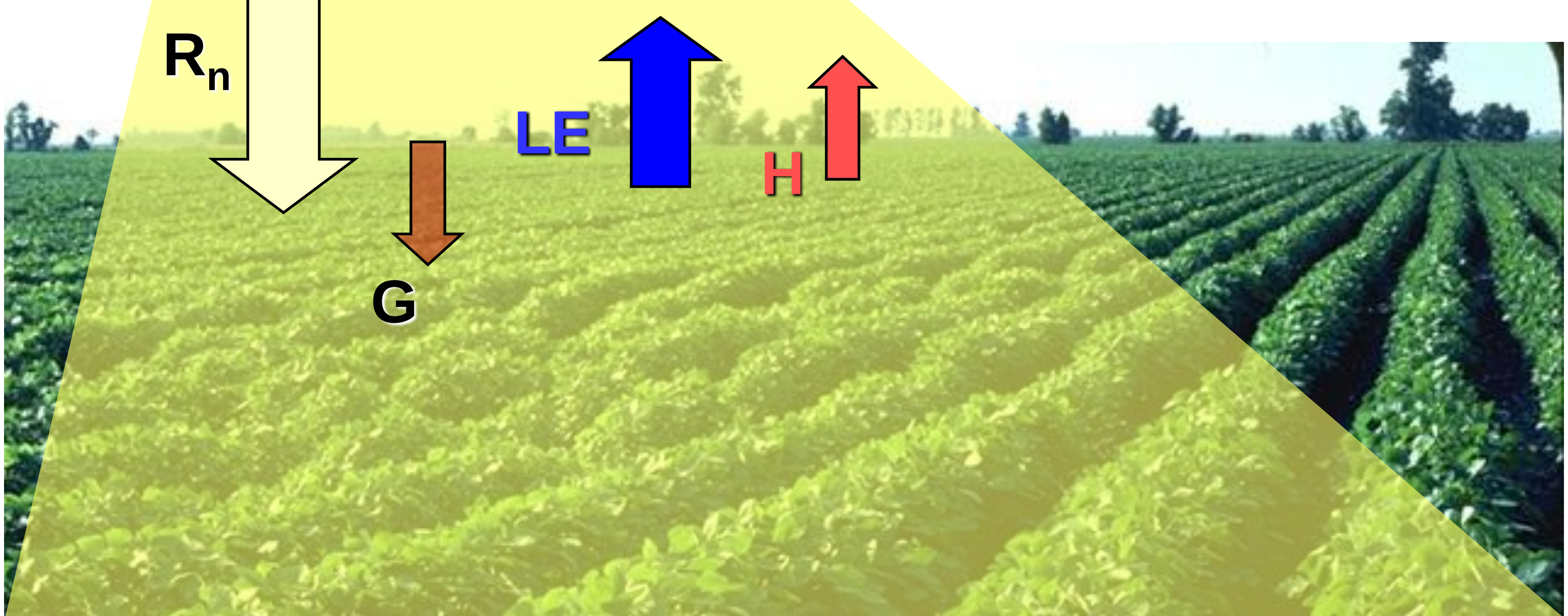
H ~ surface sensible heat flux density

LE ~ surface latent heat flux density

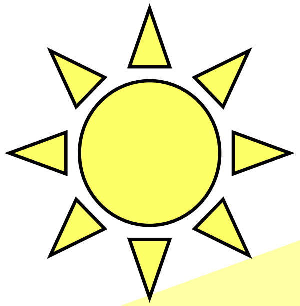
G ~ heat flux within the soil

S ~ rate of change of heat storage (air and biomass) between the soil surface and the level of the eddy covariance instrumentation

Q ~ sum of all additional energy sources and sinks



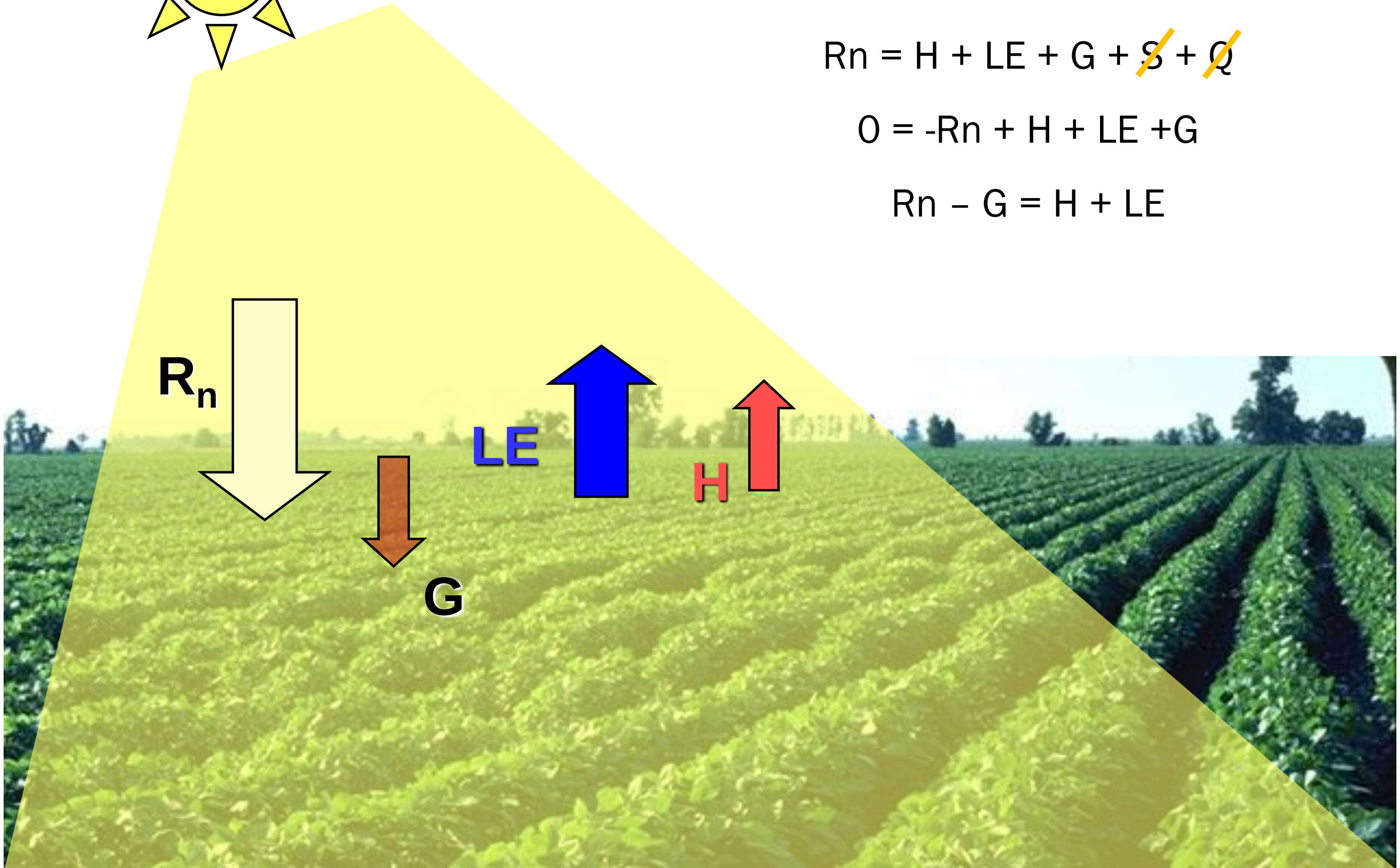
The Energy Budget



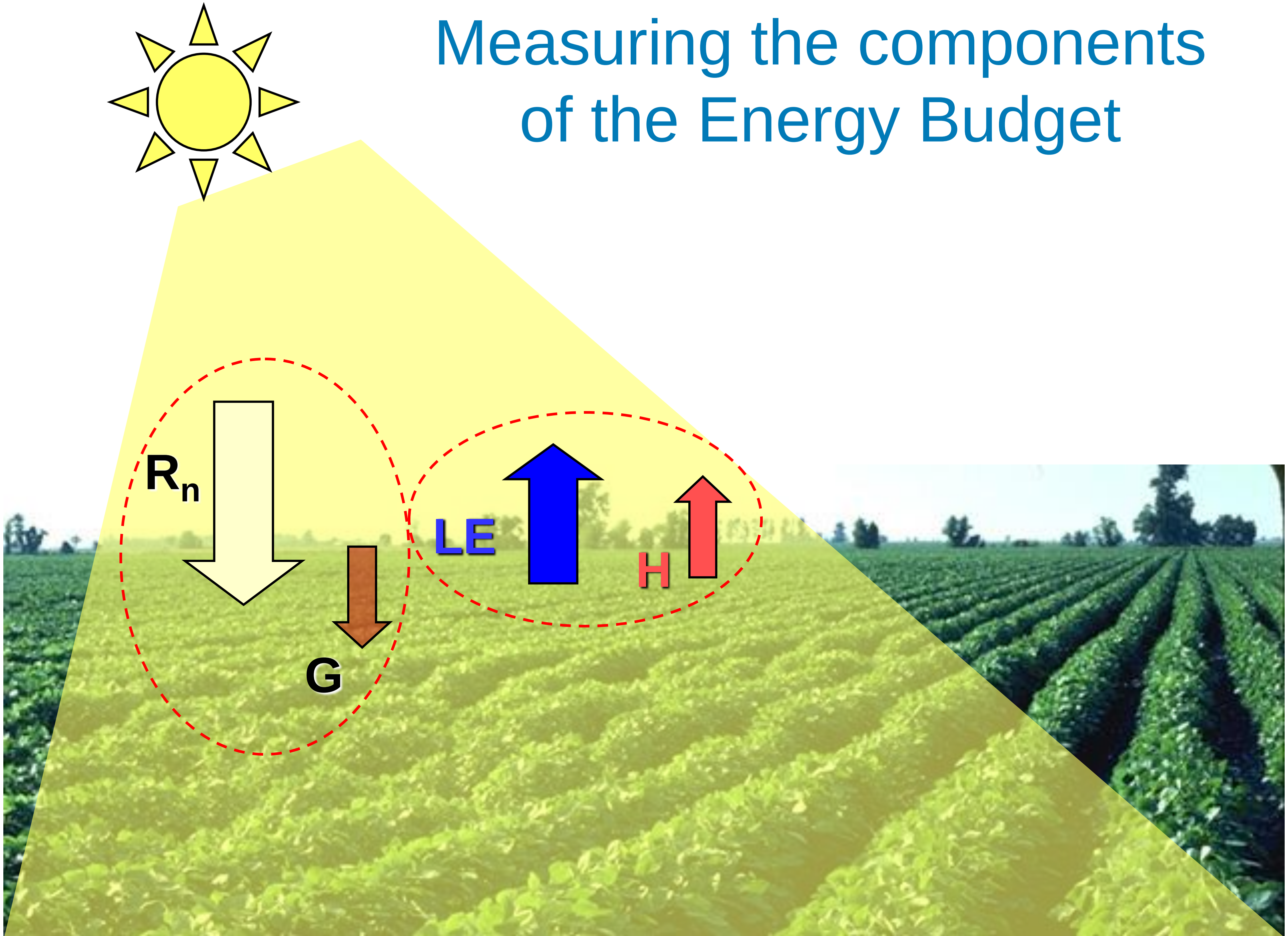
$$Rn = H + LE + G + \cancel{S} + \cancel{Q}$$

$$0 = -Rn + H + LE + G$$

$$Rn - G = H + LE$$

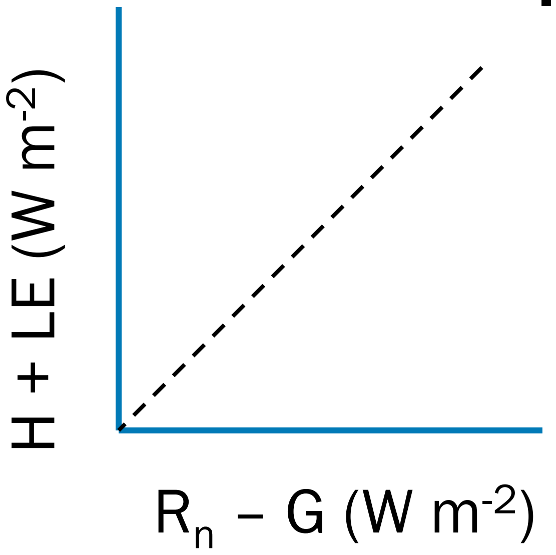


Measuring the components of the Energy Budget



Checking for energy balance closure

Measured by the **EC** System

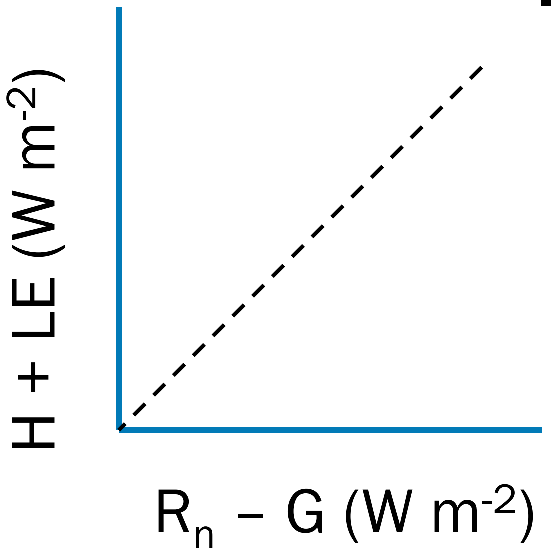


Measured by the **Biomet** System

Ideal closure is represented by a slope of 1 and an intercept of 0.

Checking for energy balance closure

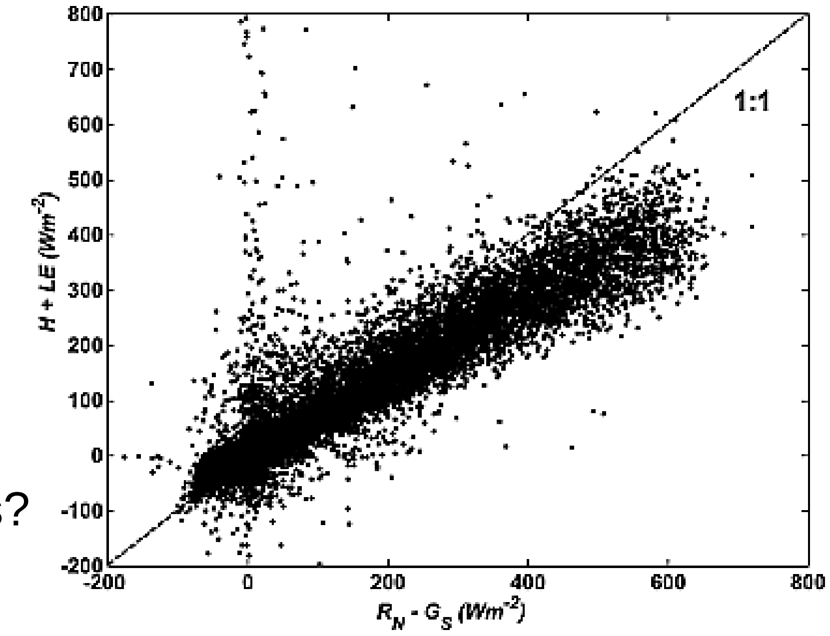
Measured by the **EC** System



Measured by the **Biomet** System

Ideal closure is represented by a slope of 1 and an intercept of 0.

Realistic (measured) closure



If not ideal:

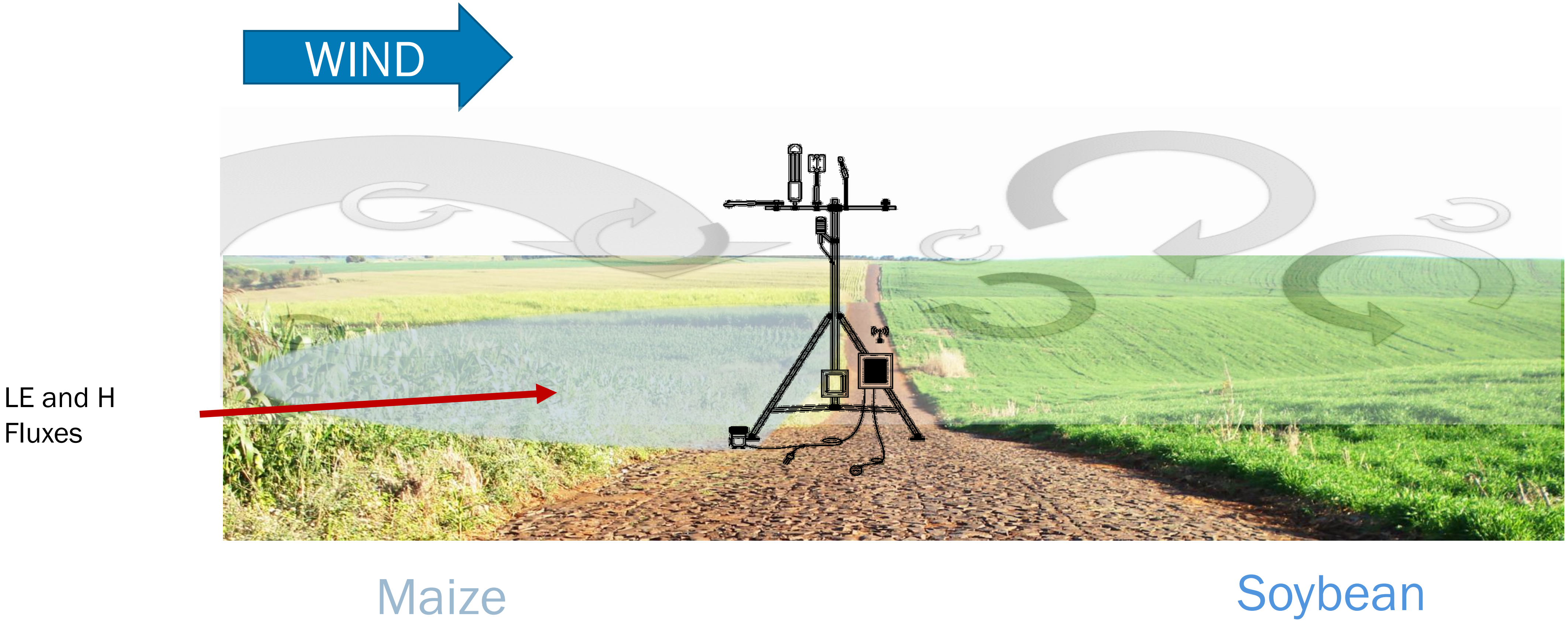
- Sampling errors?
- Systematic biases?
- Neglected energy sinks?
- Other?

How Sampling could cause an imbalance

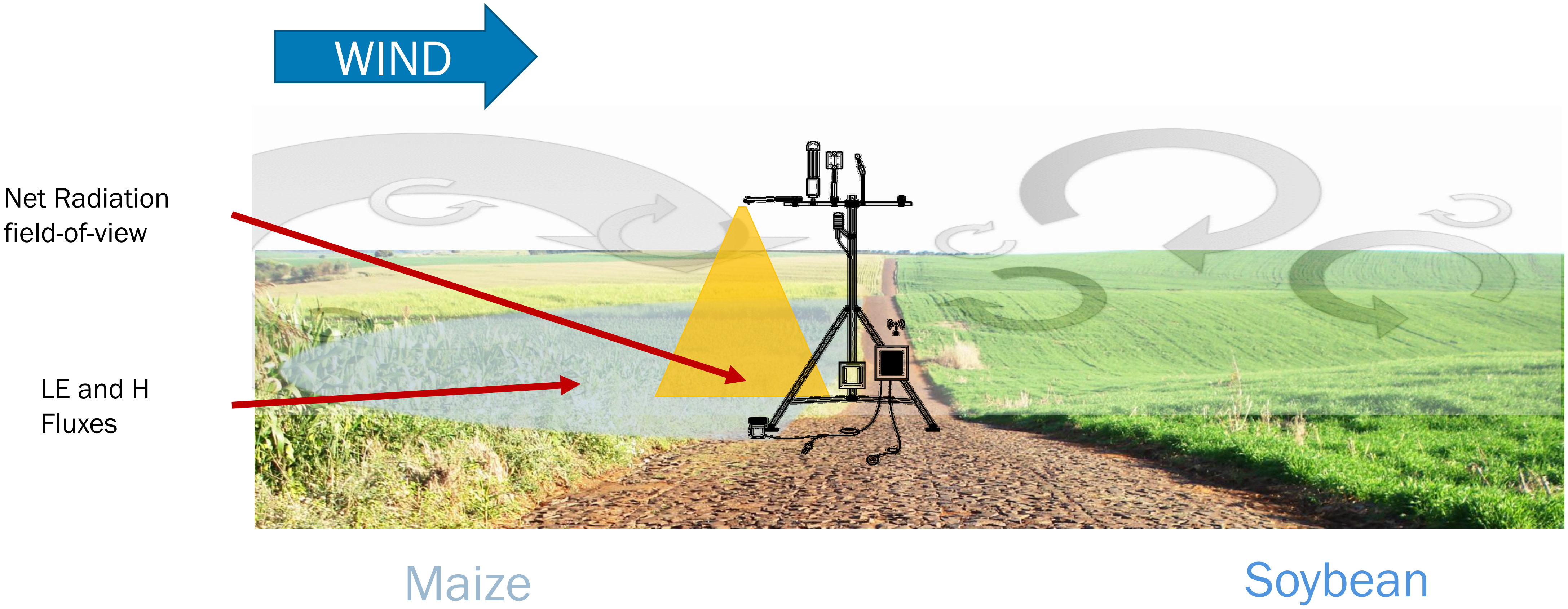
Cause of imbalance	Examples
Sampling	Source areas differ
Instrument bias	Net radiometer biased
Neglected energy sinks	Storage above soil heat plates
High/low frequency loss	Sensor separation/large eddies
Advection	Regional circulation

Wilson, K et al (2002). Energy balance closure at FLUXNET sites. Agricultural and Forest Meteorology

One EC System between two different plots

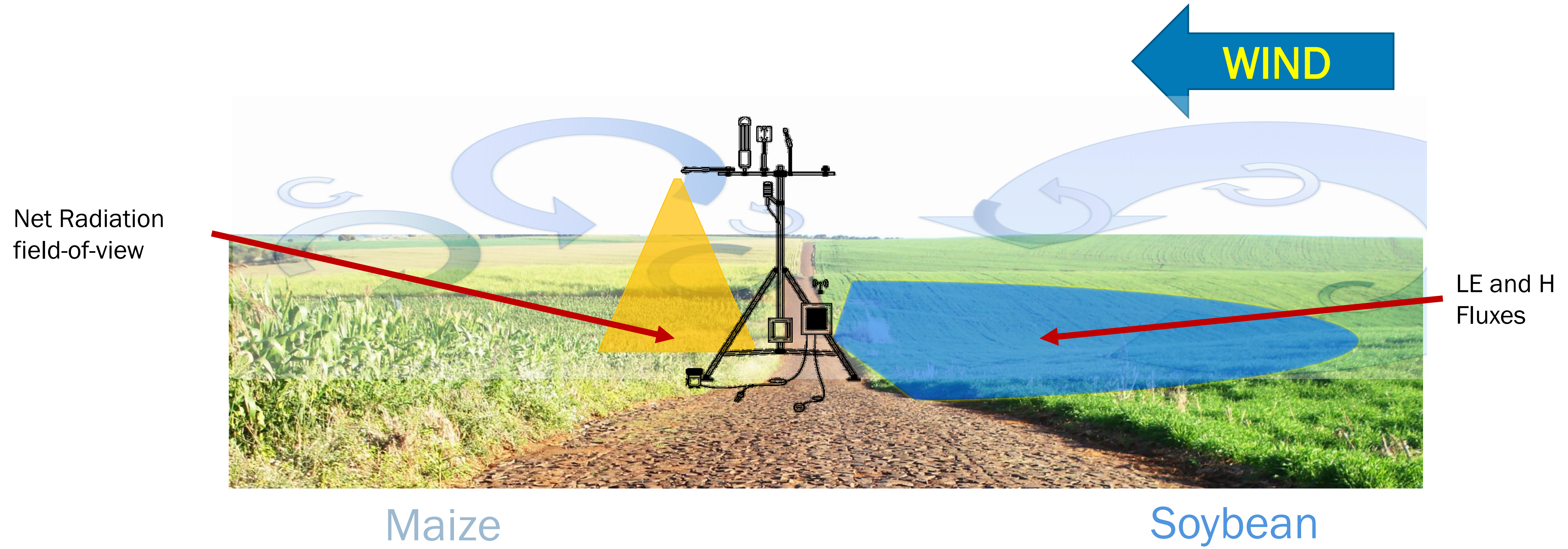


When Source Areas are the same...



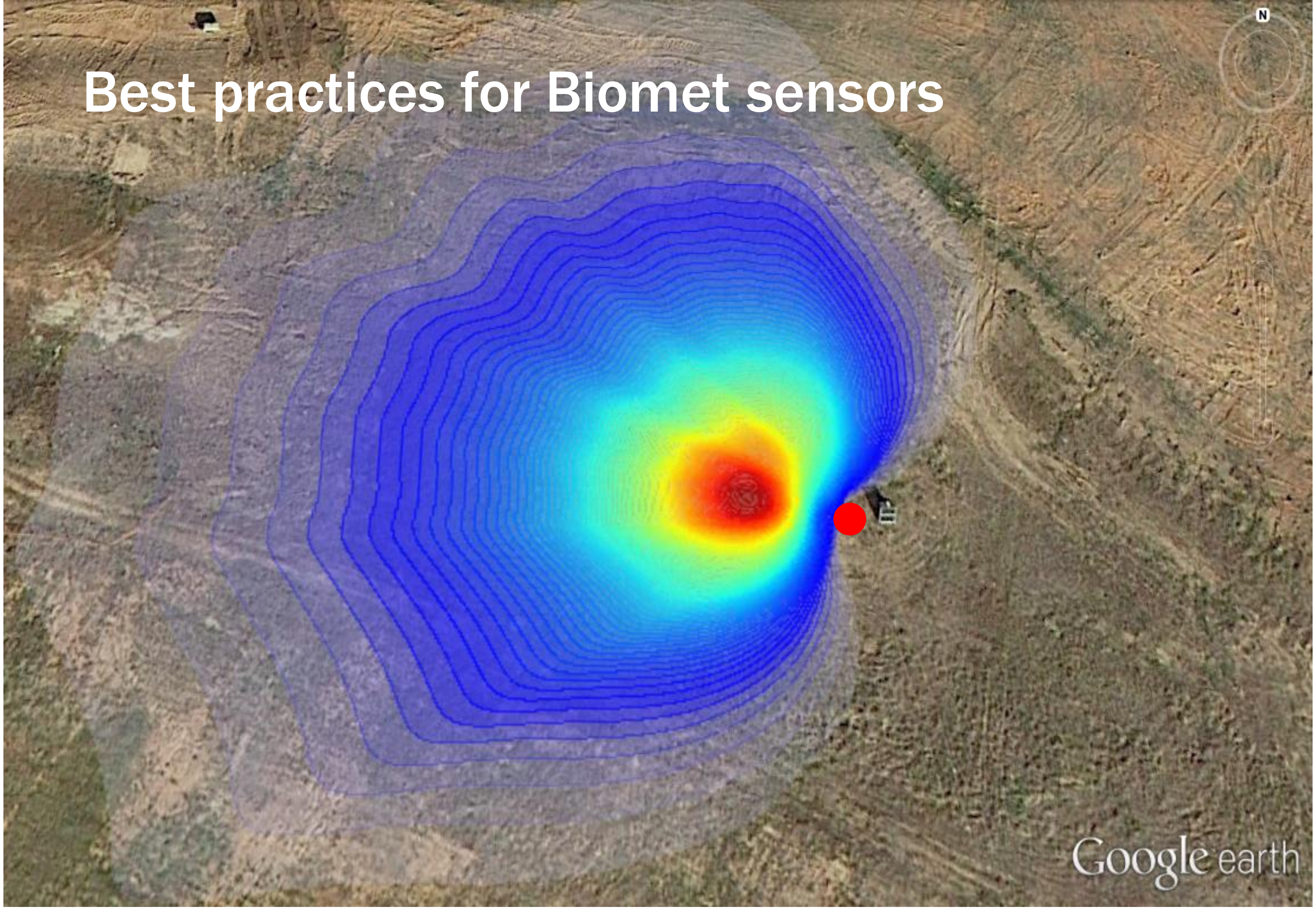
Energy measurements are from the same ecosystem

When Source Areas are different...



! Energy measurements are from the different ecosystems

Best practices for Biomet sensors

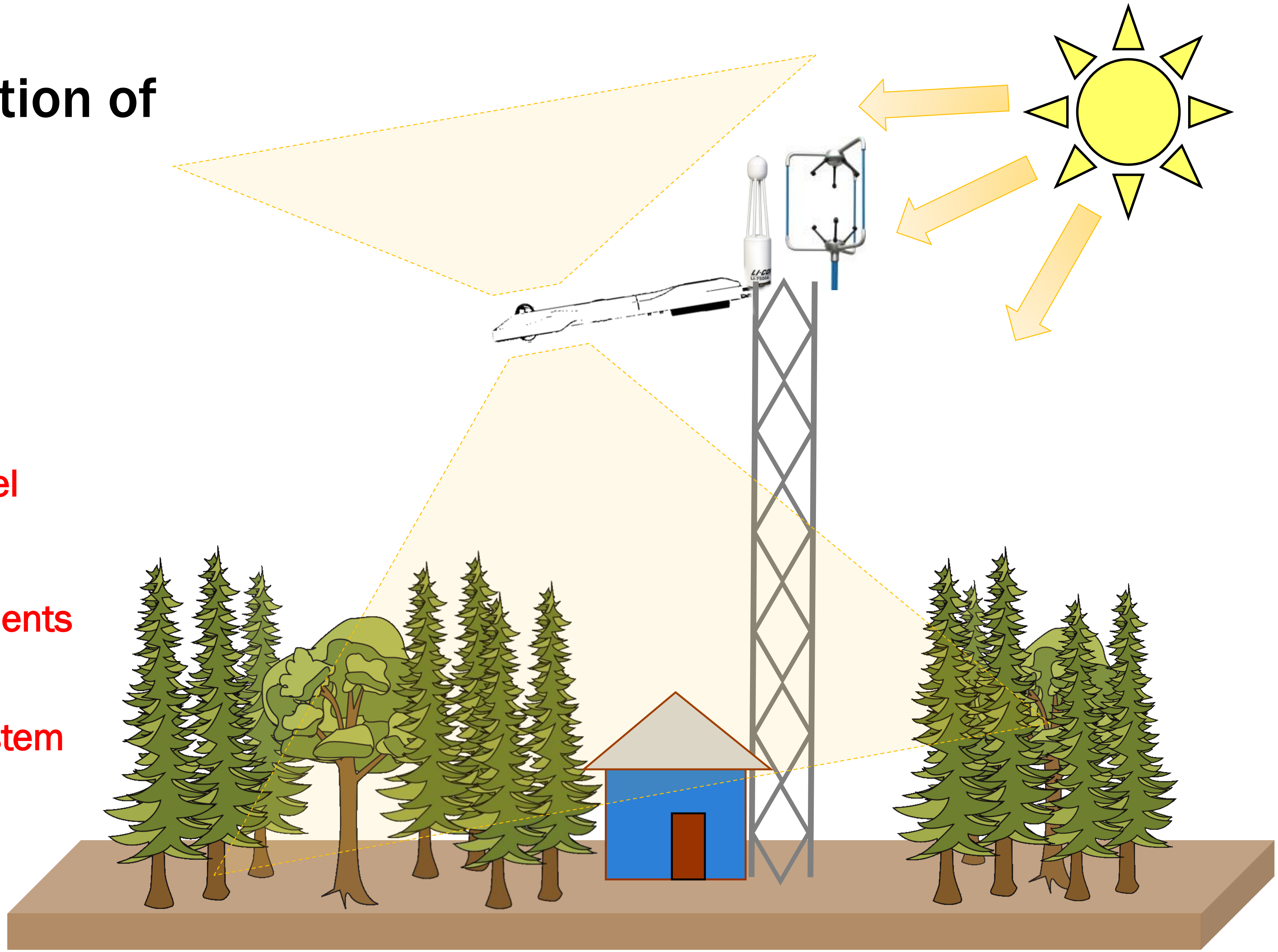


How Biases could cause an imbalance

Cause of imbalance	Examples
Sampling	Source areas differ
Instrument bias	Net radiometer biased
Neglected energy sinks	Storage above soil heat plates
High/low frequency loss	Sensor separation/large eddies
Advection	Regional circulation

Wilson, K et al (2002). Energy balance closure at FLUXNET sites. Agricultural and Forest Meteorology

Instrument bias; improper installation of Net Radiometer



- ! Radiometer is not level
- ! Radiometer can be shaded by EC instruments
- ! Radiometer is not measuring the ecosystem
- ! Radiometer is measuring the tower

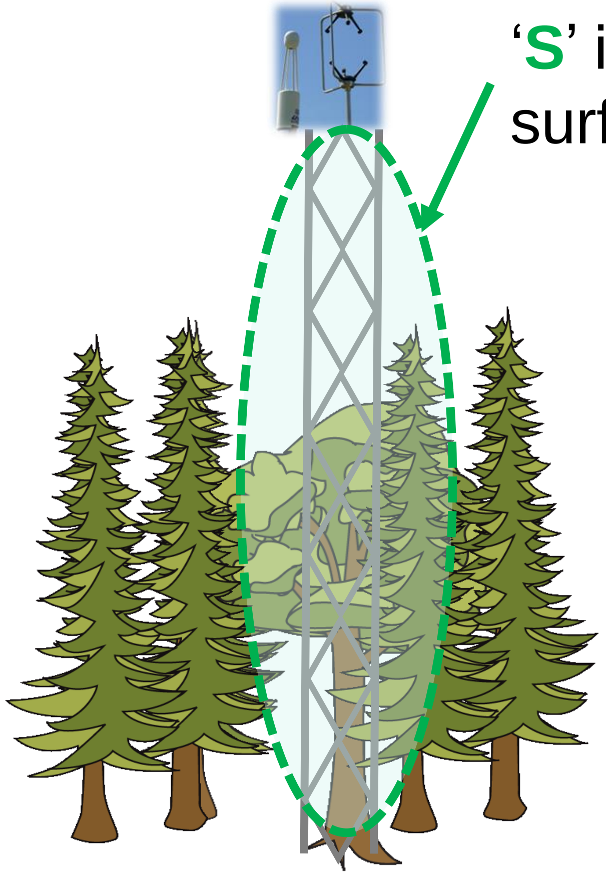
How neglecting energy sinks could cause an imbalance

Cause of imbalance	Examples
Sampling	Source areas differ
Instrument bias	Net radiometer biased
Neglected energy sinks	Storage above soil heat plates
High/low frequency loss	Sensor separation/large eddies
Advection	Regional circulation

Wilson, K et al (2002). Energy balance closure at FLUXNET sites. Agricultural and Forest Meteorology

Heat energy is stored in the (tall) canopy

For tall vegetation sites *(h* > 8m*)*



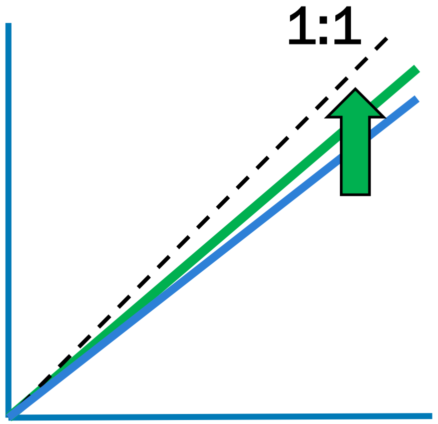
'**S**' is the rate of change of heat storage between the soil surface and the level of the eddy covariance instrumentation

*If we add '**S**' back into the Energy Balance Eqn:*

$$R_n = H + LE + G + S + Q$$

$$R_n - G - S \approx H + LE$$

Based on 26 site-years of data, including '**S**' for tall sites *increased* the slope by an average of **7%**



Tall forested sites should measure *S*.

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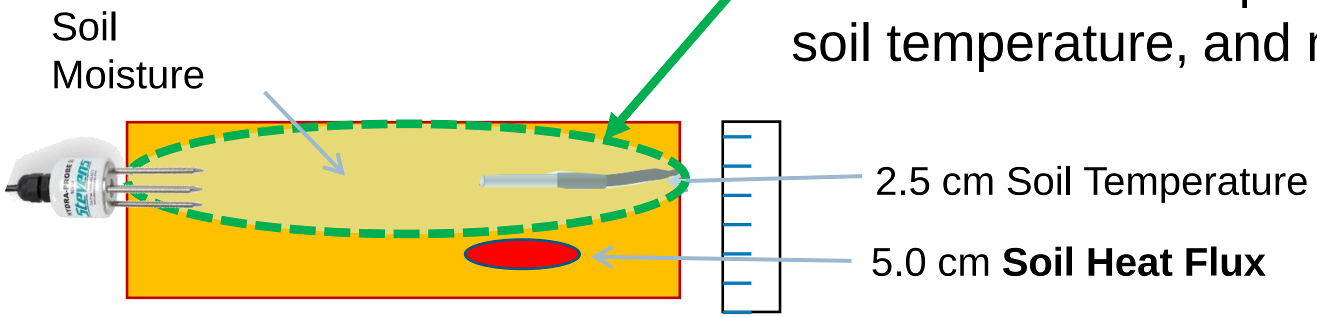
Heat Energy is also stored in the Soil

We can estimate Heat Storage in the Soil (between Heat flux plates and surface)

Heat stored '**S**' above heat flux plates can be estimated using information on soil properties, soil temperature, and moisture.



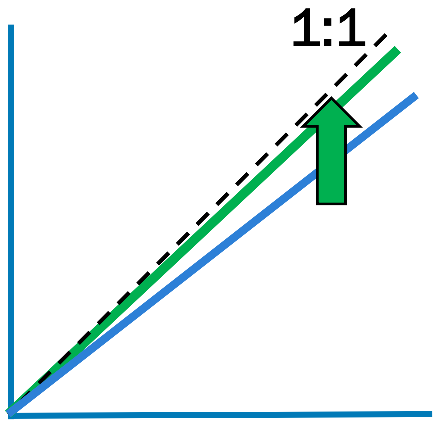
Soil Heat Flux at Surface = Measured Soil Heat Flux + Storage Term (S)

*If we add '**S**' back into the Energy Balance Eqn:*

$$R_n = H + LE + G + \mathbf{S} + Q$$

$$\Rightarrow R_n - G - \mathbf{S} \approx H + LE$$

Including the soil heat storage '***S***' *increases* the average slope by about **20%** for grasslands and agricultural sites



Short canopy sites should measure *S*.

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How losing high / low frequencies, and advection can cause an imbalance in the EB closure

Cause of imbalance	Examples
Sampling	Source areas differ
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Advection	Regional circulation

Wilson, K et al (2002). Energy balance closure at FLUXNET sites. Agricultural and Forest Meteorology

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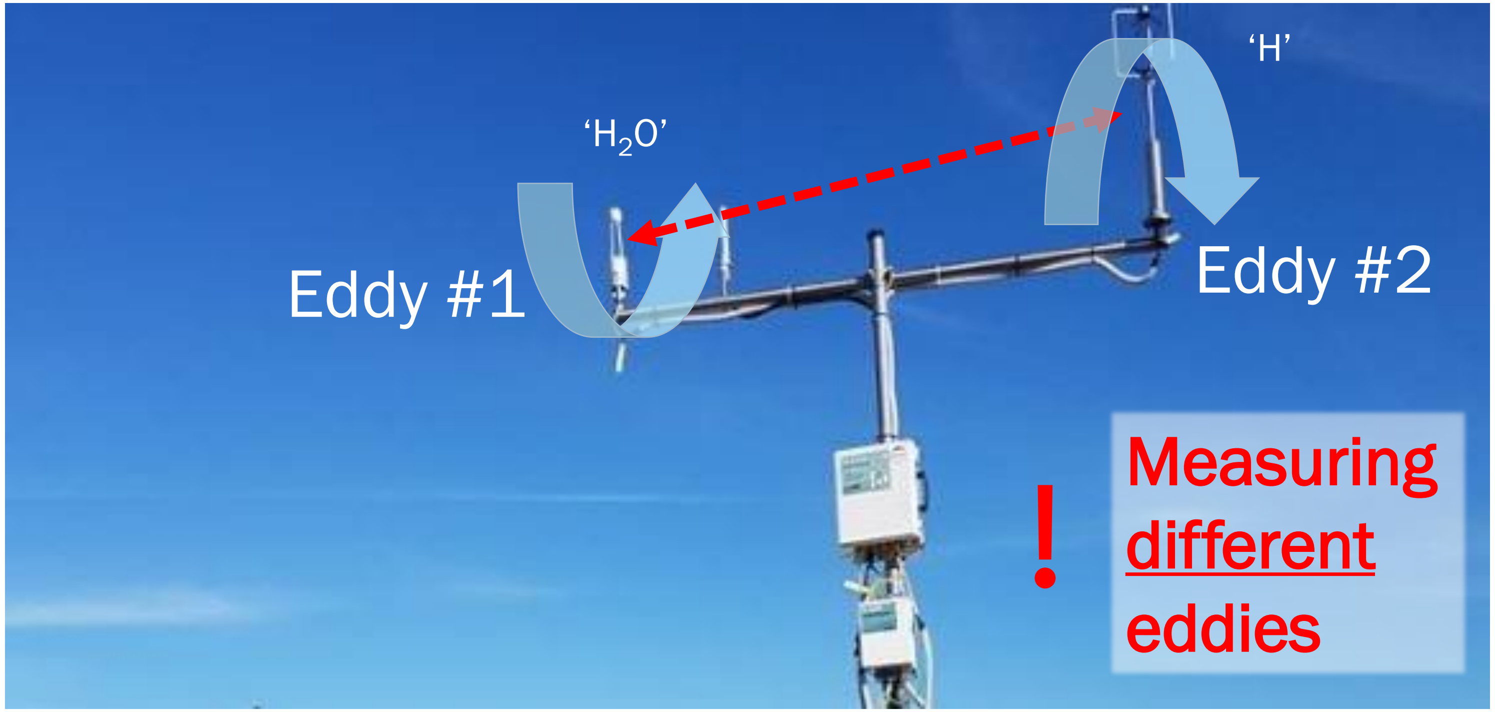
Improper sensor separation can cause the loss of high frequency energy measurements

- If separation is too big, H and H_2O are not from the same eddy and covariance is lost, creating an energy imbalance



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Summary Energy Balance closure

- **Good closure is not necessarily a validation, bad closure is a definite problem** *Burba 2013*

- Energy balance closures cannot be used as a quality criteria for turbulent fluxes (Aubinet et al. 2000). This is because the influencing factors are so greatly different, wrong conclusions are possible. In comparison with similar experiments, energy balance can give only a rough criterion about the accuracy of the fluxes. *Foken 2008*

Other Closure checks

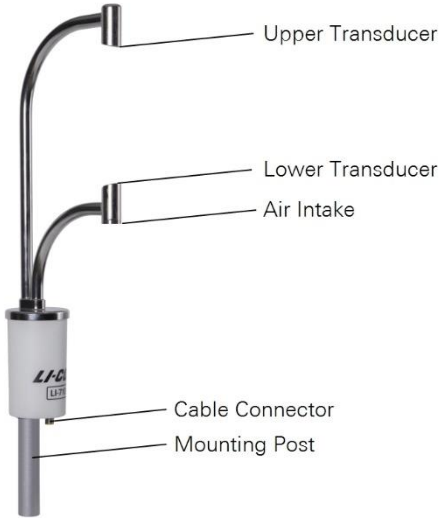
Carbon Closure

- Long-term biomass accumulation, compare to cumulated EC measurements

Other Closure checks

Hydrological balance

- Rain = **LE** + Runoff + Percolation + Storage



LI-710 Evapotranspiration Sensor

Water Node

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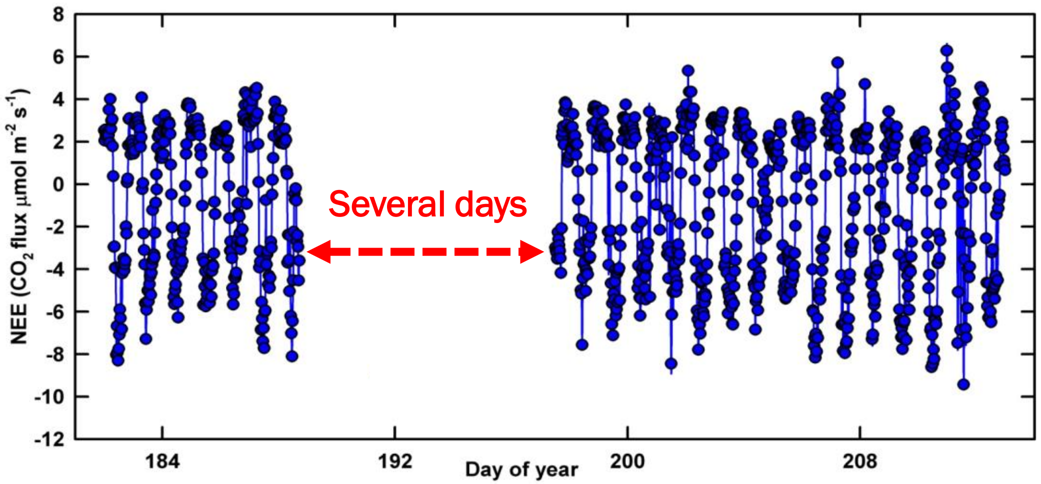
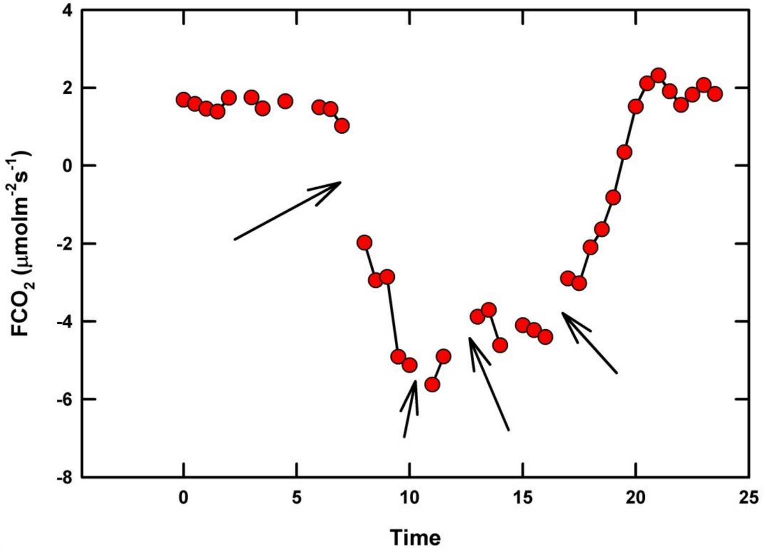
Gapfilling

Gaps occur due to:

- Power supply issues
- Sensor failures
- Data flagged
- Spikes in data due to rain events
- Data flagged for low U*

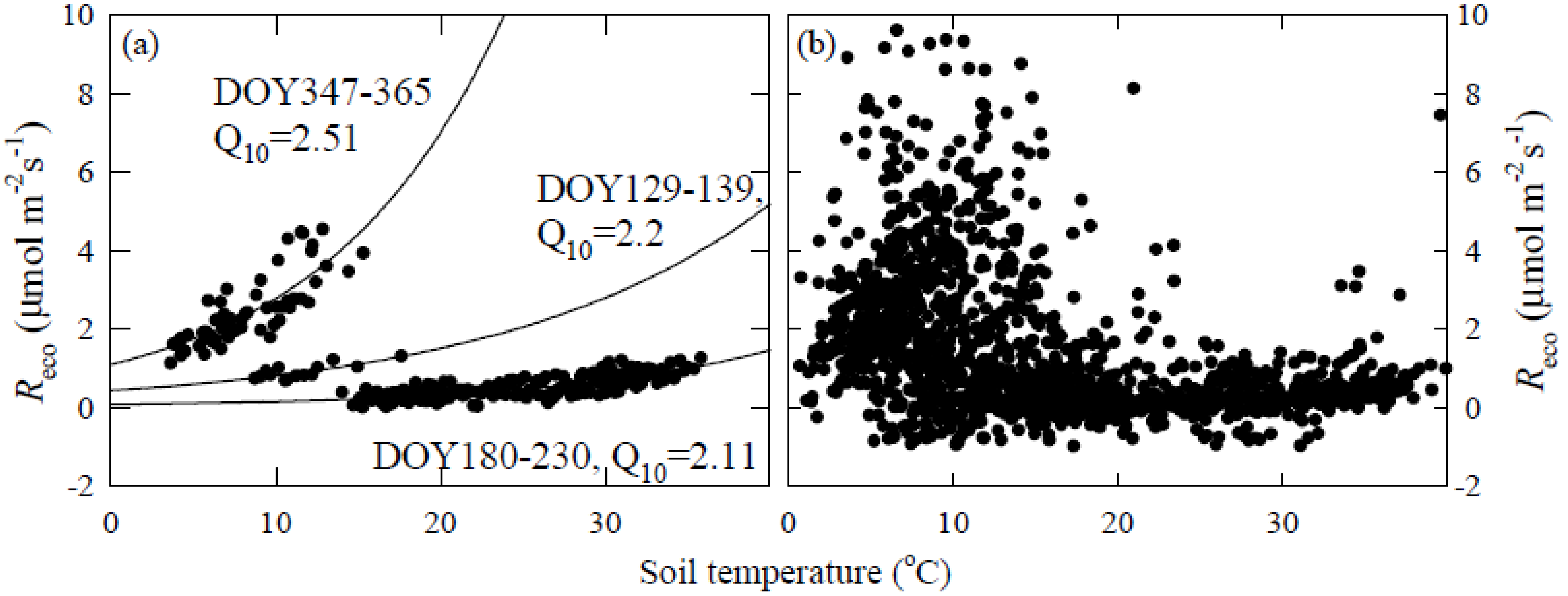




➢Small gaps: interpolation techniques

➢Large gaps: other techniques

Example, gap filling using Soil Temperature as a driver for Ecosystem Respiration

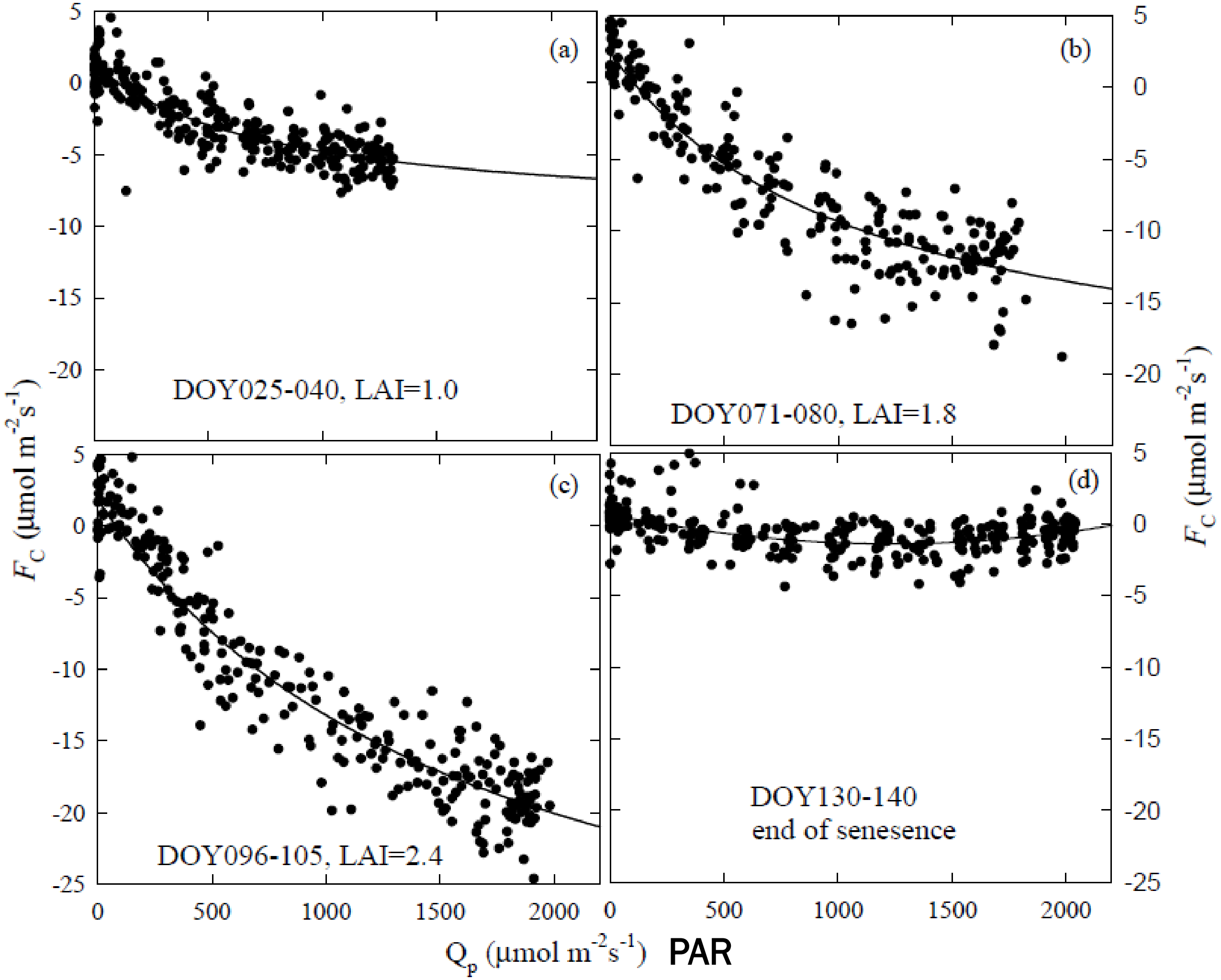


$$F_c = b_0 \exp(bT_{soil})$$

$$Q_{10} = \exp(10b)$$

Seasonal relationships between *Soil Temperature* and *Ecosystem Respiration*

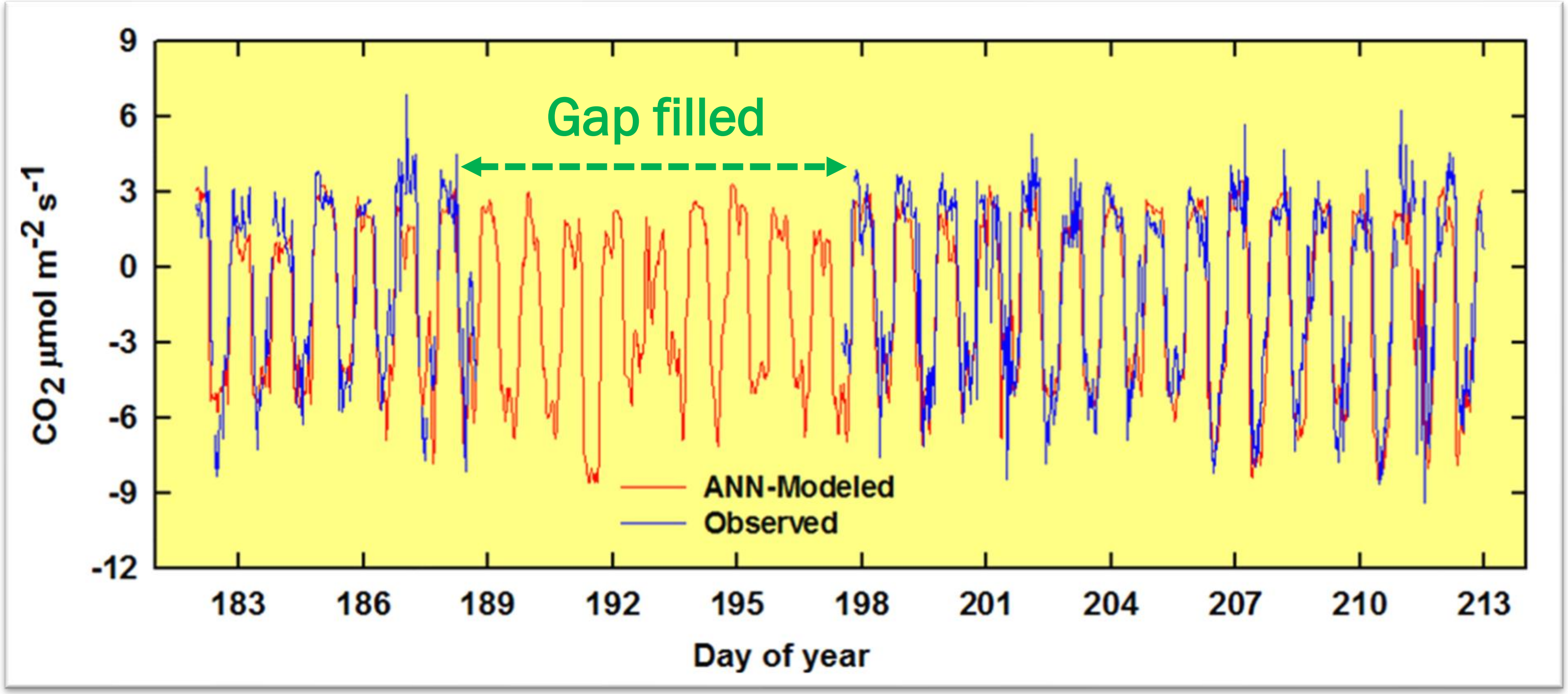
Example, gap filling using PAR as a driver for FCO_2



$$F_c = \frac{F_{max}\alpha PAR}{\alpha PAR + F_{max}} + R_{eco}$$

Seasonal relationships between *PAR* and *CO_2 flux*

Gapfilling – Artificial Neuronal Networks



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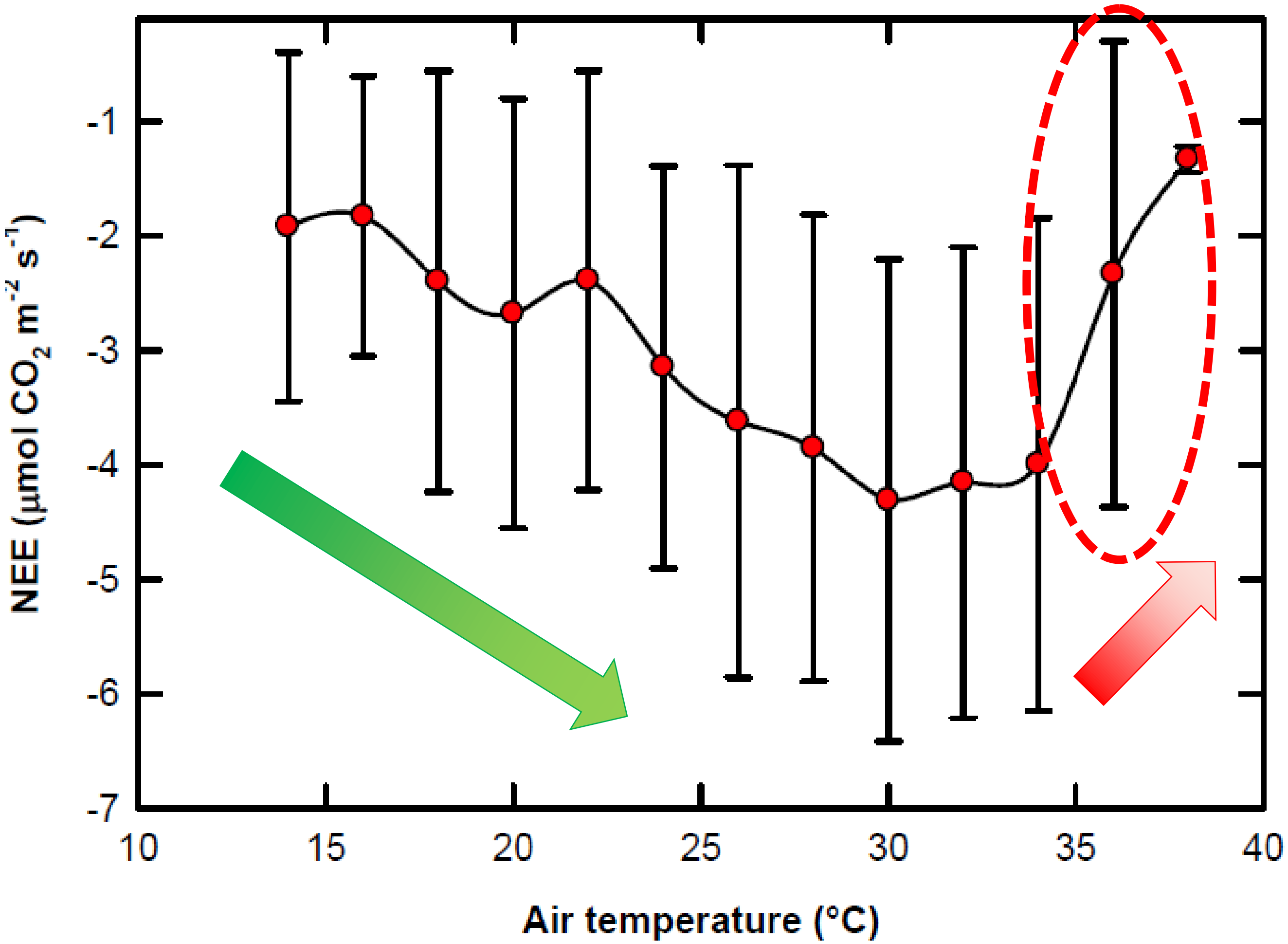
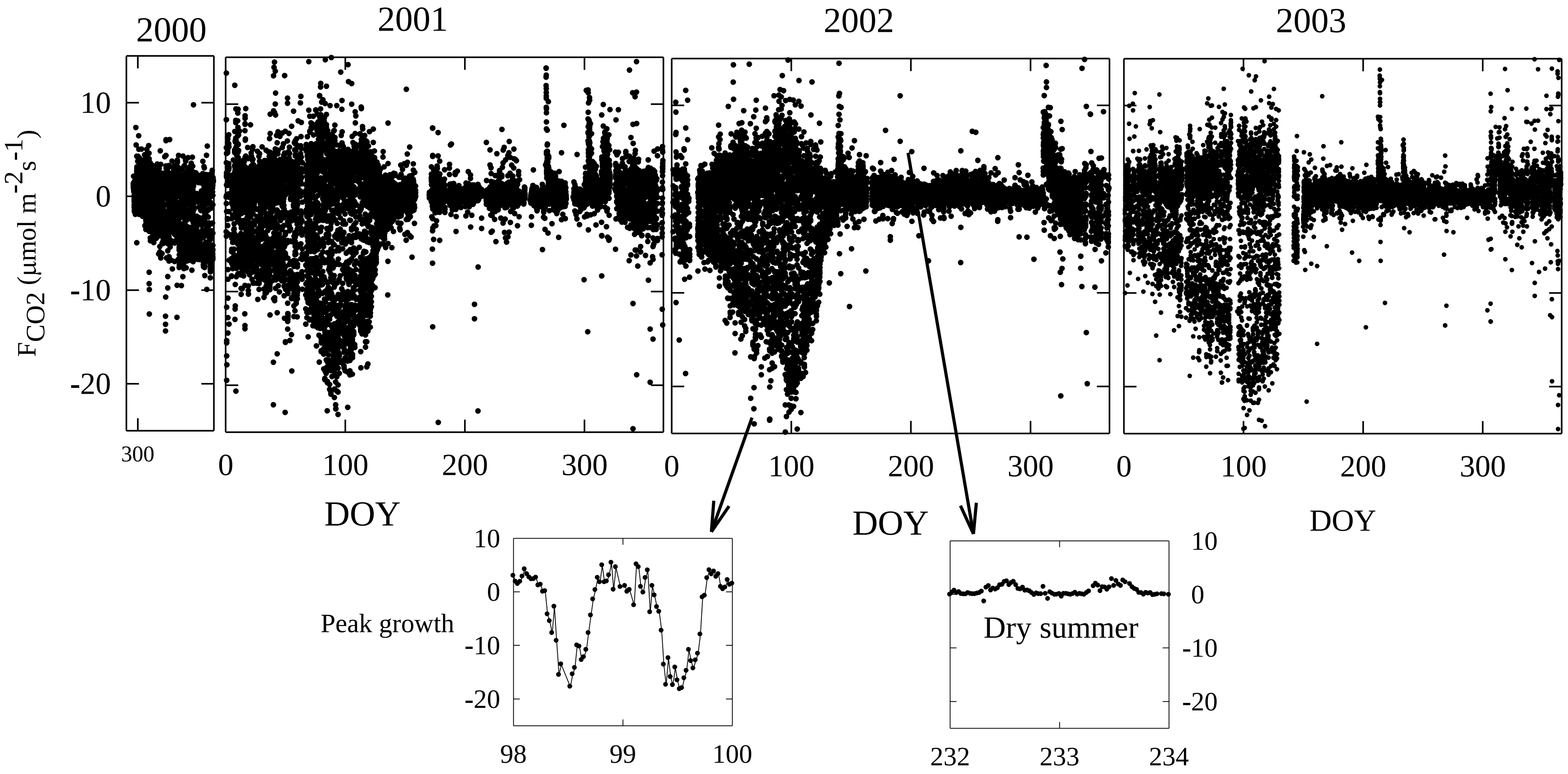
Example, how air temperature can affect fluxes

- We can see that air temperature can be a driver for fluxes

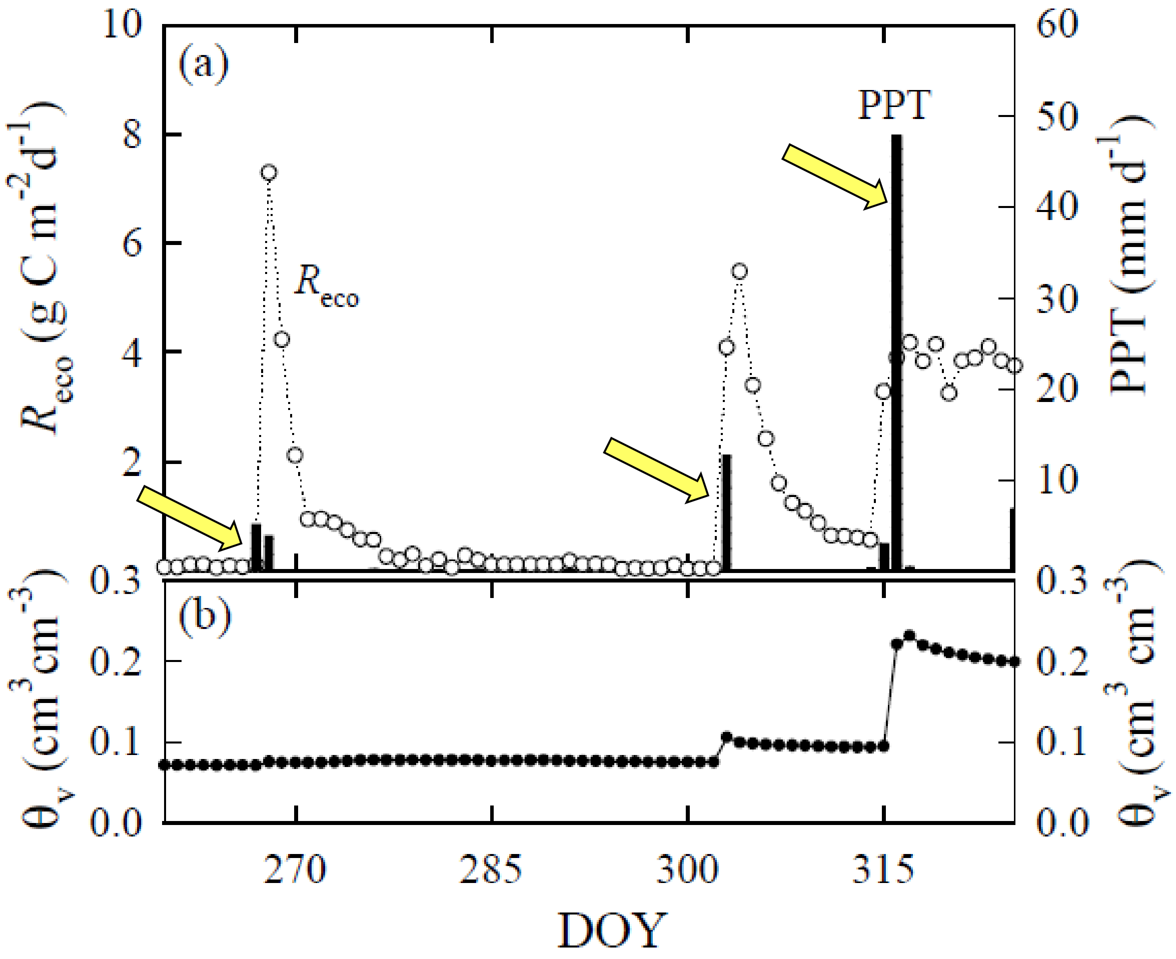


Example of long-term flux data - California grassland

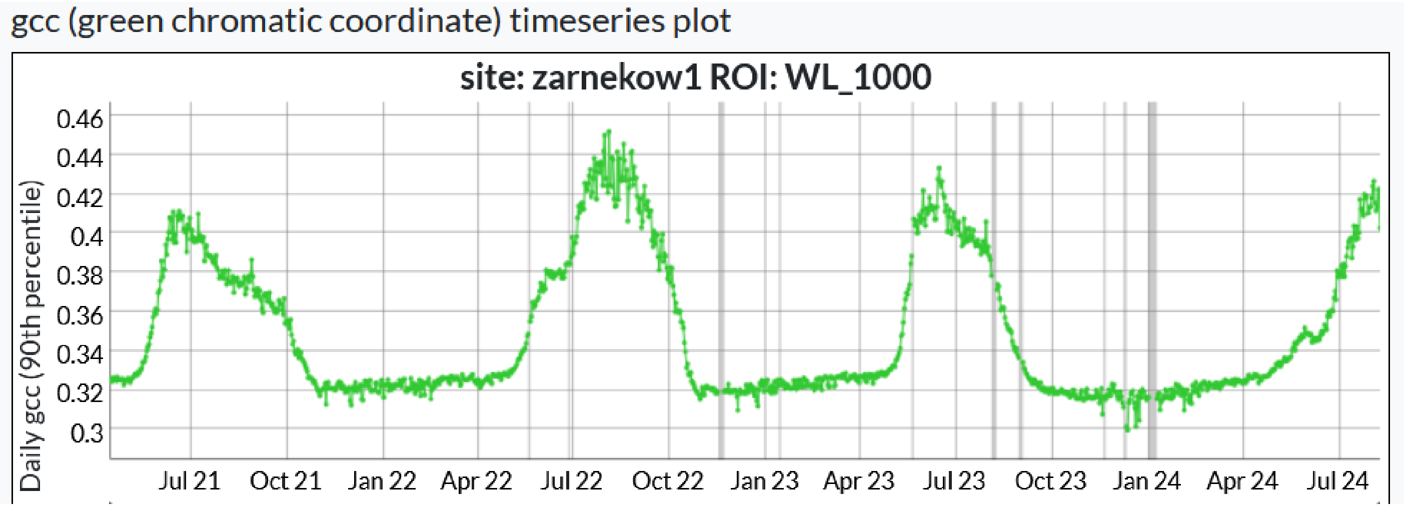


Example of long-term flux data - California grassland

Rain events affect Soil Moisture and Ecosystem Respiration rates



Phenocam – Network

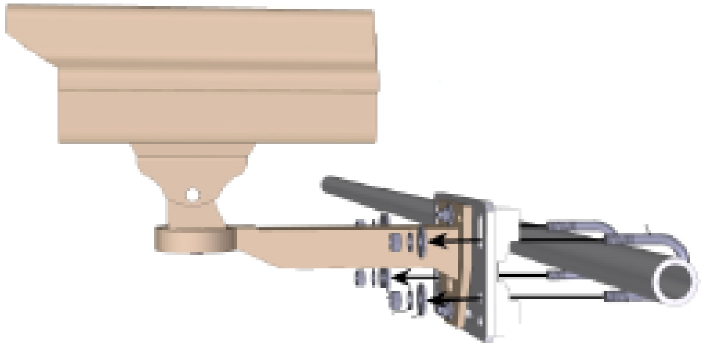


StarDot:
- NetCam SC
- StarDot Live2 (new!)

Interface: Ethernet
Power requirements: 12 VDC

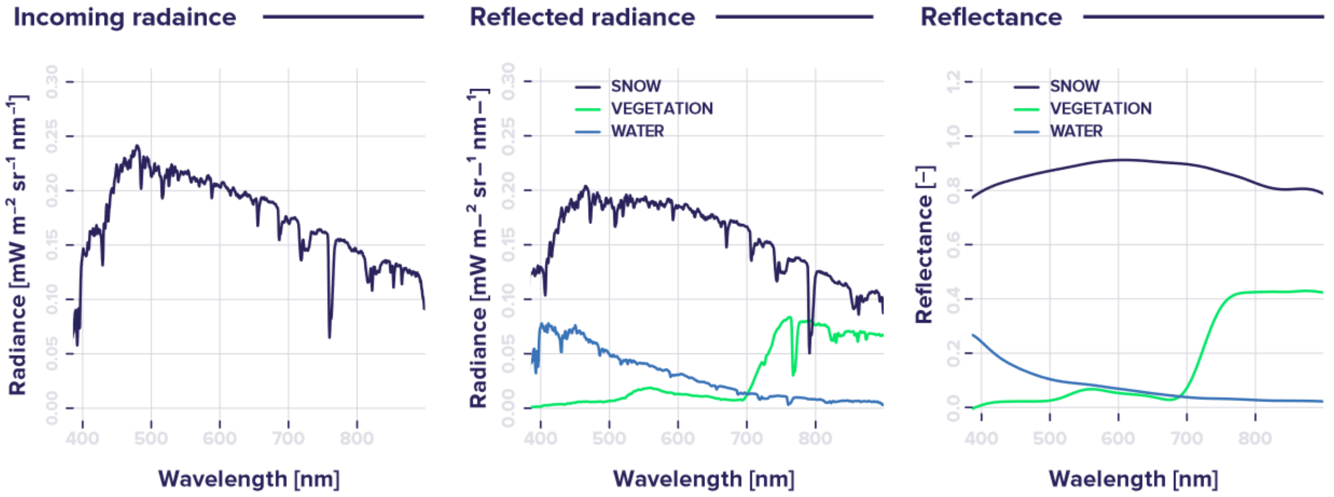
Phenocam –Installation

- Direct the camera to the North (on northern hemisphere) to avoid lens flare and shadowing.
- Mount the camera at a height of 5 to 10 meters above the canopy.
- The image should capture about 20% sky and 80% canopy. Be sure to include the horizon in the image.
- Mount the camera securely to prevent movement.



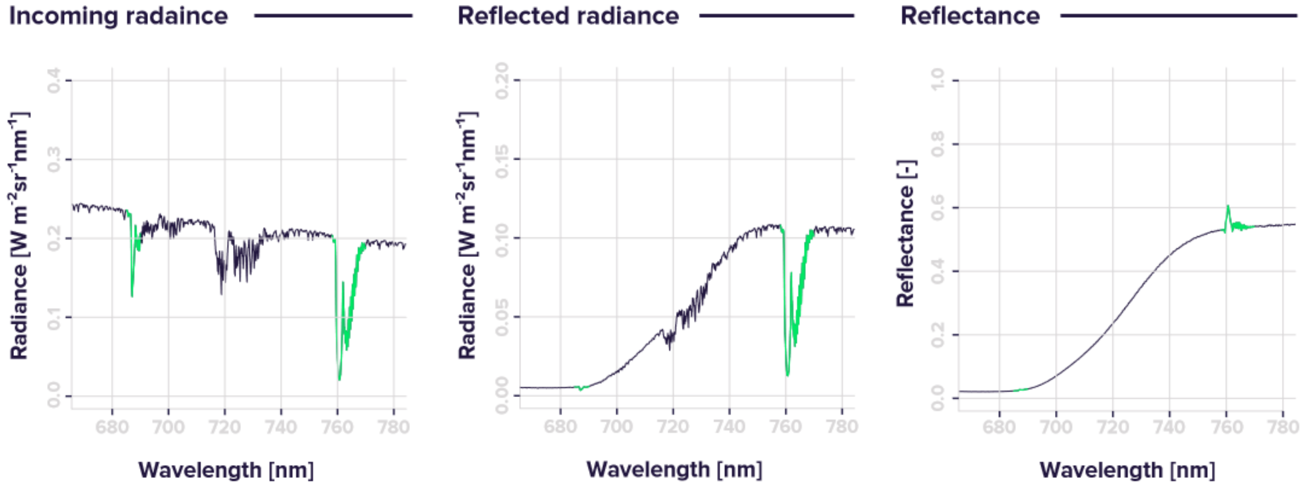
RoX and FloX

RoX – The Reflectance Box



Spec: 400-950 nm, SSI 0.65 nm, FWHM 1.5 nm, in 180°, refl. 25°

FloX – The Fluorescence Box



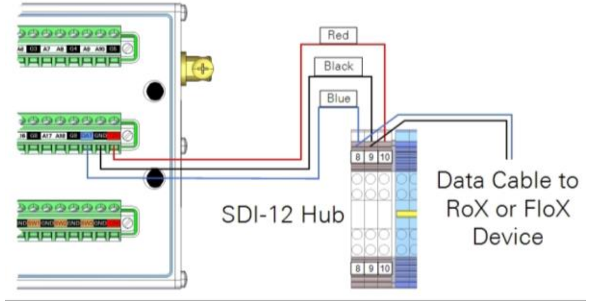
Spec1: 650-800 nm, SSI 0.17 nm, FWHM 0.3 nm, in 180°, refl. 25°
Spec2: 400-950 nm, SSI 0.65 nm, FWHM 1.5 nm, in 180°, refl. 25°

JB-Hyperspectral Devices Integration

DAQM Integration via SDI-12

SDI-12 integration

DAqM

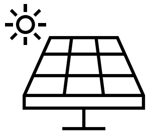


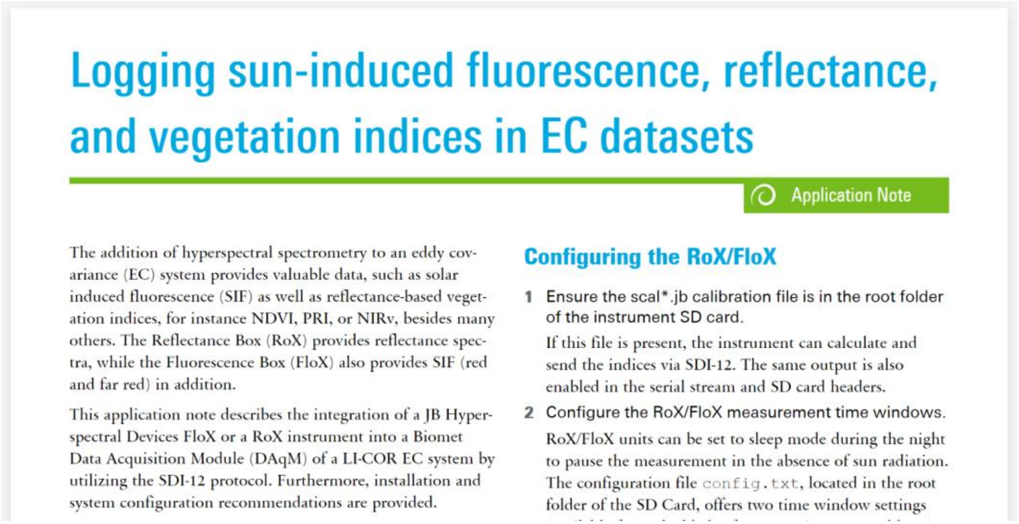
FloX

RoX

Table 1. RoX and FloX specifications[3].

	RoX	FloX
Power Requirements	10 to 14 VDC, 15 W	10 to 14 VDC, 60 W[1]
Weight	3 kg	18 kg
Fiber Length[2]	1x/1x, 7 meters	2x/2x, 7 meters
Internal Memory	32 GB SD card (24 months of raw data)	32 GB SD card (12 months of raw data)





Logging sun-induced fluorescence, reflectance, and vegetation indices in EC datasets

Application Note

The addition of hyperspectral spectrometry to an eddy covariance (EC) system provides valuable data, such as solar induced fluorescence (SIF) as well as reflectance-based vegetation indices, for instance NDVI, PRI, or NIRv, besides many others. The Reflectance Box (RoX) provides reflectance spectra, while the Fluorescence Box (FloX) also provides SIF (red and far red) in addition.

This application note describes the integration of a JB Hyperspectral Devices FloX or a RoX instrument into a Biomet Data Acquisition Module (DAqM) of a LI-COR EC system by utilizing the SDI-12 protocol. Furthermore, installation and system configuration recommendations are provided.

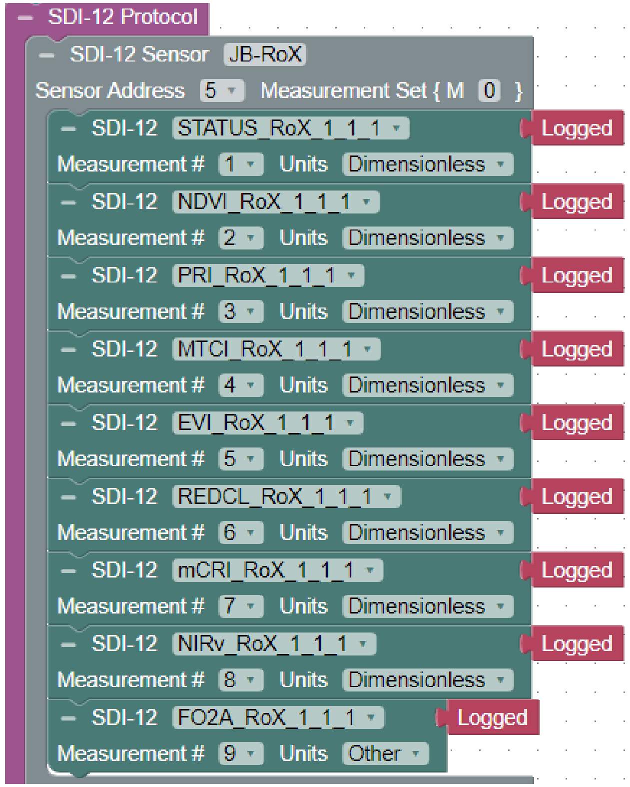
Configuring the RoX/FloX

1 Ensure the scal*.jb calibration file is in the root folder of the instrument SD card.
If this file is present, the instrument can calculate and send the indices via SDI-12. The same output is also enabled in the serial stream and SD card headers.

2 Configure the RoX/FloX measurement time windows.
RoX/FloX units can be set to sleep mode during the night to pause the measurement in the absence of sun radiation. The configuration file `config.txt`, located in the root folder of the SD Card, offers two time window settings

RoX and FloX output via SDI-12

DAQM Code



SDI-12	Name	Wavelengths	FWHM	Formula
1	STATUS	n/a	n/a	temperature+humidity+errors+voltage
2	NDVI	800;670	10;10	(a-b)/(a+b)
3	PRI	531;570	2;2	(a-b)/(a+b)
4	MTCI	754;709;681	7;10;7	(a-b)/(b+c)
5	EVI	800;670;480	10;10;10	2.5*(a-b)/(a+6*b-7.5*c+1)
6	RedCL	785;725	15;5	a/b-1
7	mCRI	510;725;785	5;5;15	c/(a-b)
8	NRIv	L800	40	NDVI * L800
9	FO2A	O2A	n/a	3FLD

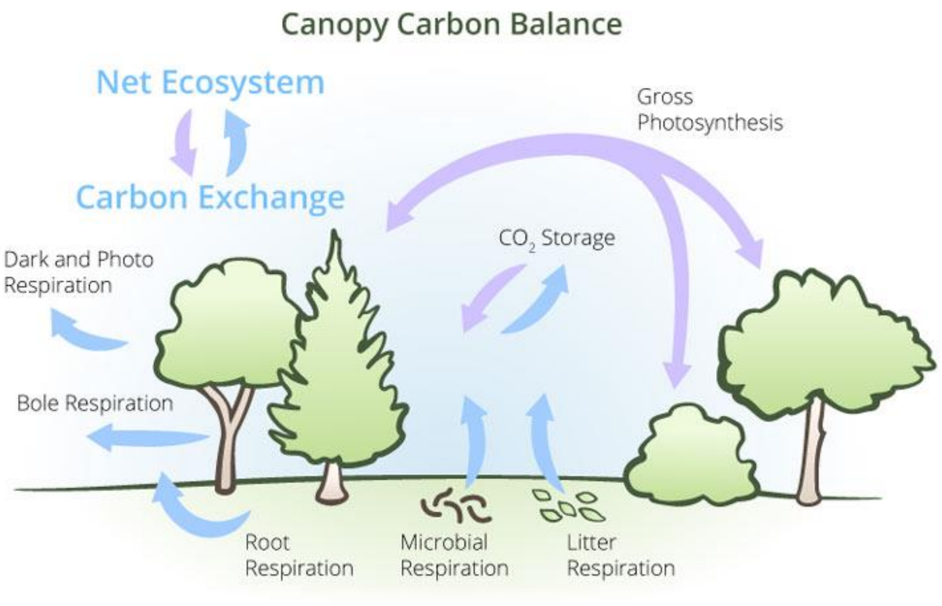
FO2A (SIF) only available from FloX; FWHM: full width at half maximum
Requires reprocessing for publication grade results

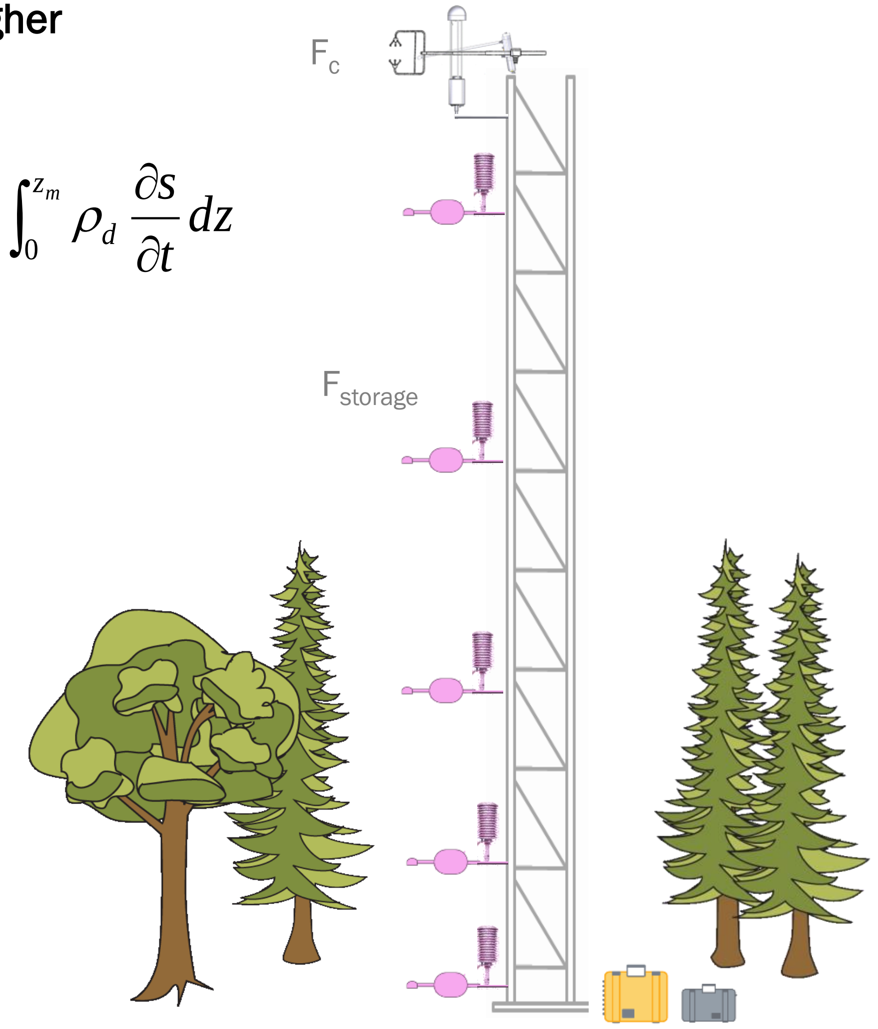
Atmospheric Profiling System with LI-8250 Multiplexer

Storage Flux - CO_2 / CH_4 / N_2O

ICOS: Atmospheric storage flux measurements are mandatory for **EC systems higher than 4 m above ground.**

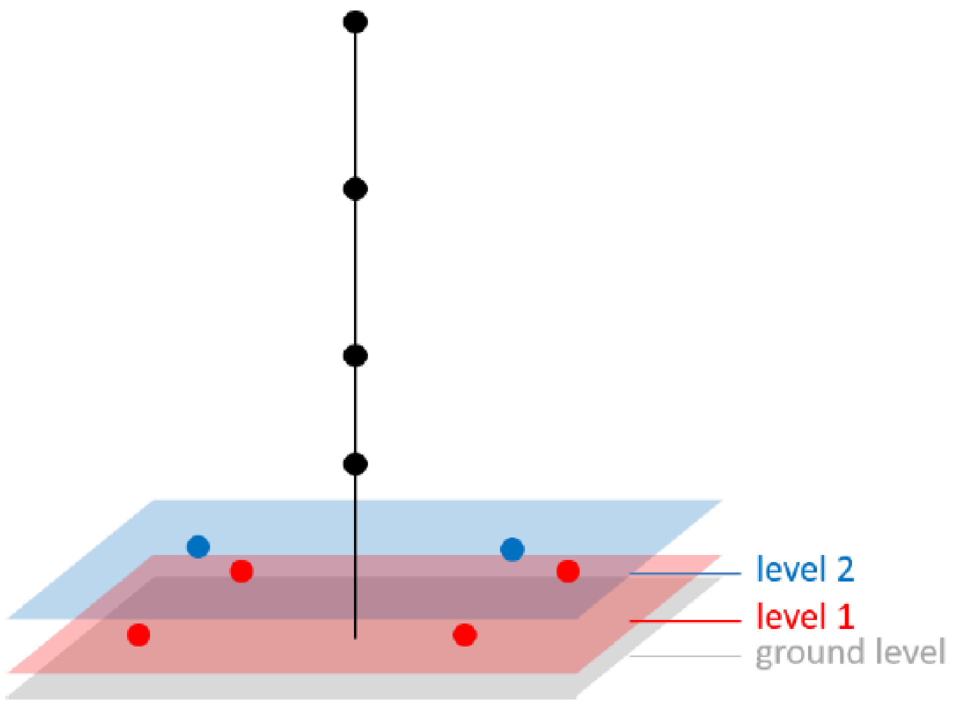
$$F_{ecosys} = F_c + F_{storage} = F_c + \int_0^{z_m} \rho_d \frac{\partial s}{\partial t} dz$$





Distribution of profile sampling points

ICOS Ecosystem Thematic Centre



Horizontal: 5 m distance, larger than the average canopy radius of dominant trees

Vertical: Non-linear distribution, with the greatest density of sampling points closest to the ground

$$n = h_m{}^a$$

N: number or levels
hm: max sampling height, parallel the EC system [m]
a: 2/3, or up to ¾ for complicated canopies

	Number of profile levels	
hm [m]	a=2/3	a=3/4
50	14	19
40	12	16
30	10	13
20	8	10
10	5	6

ICOS Instruction on eddy covariance storage fluxes (icos-etc.eu)

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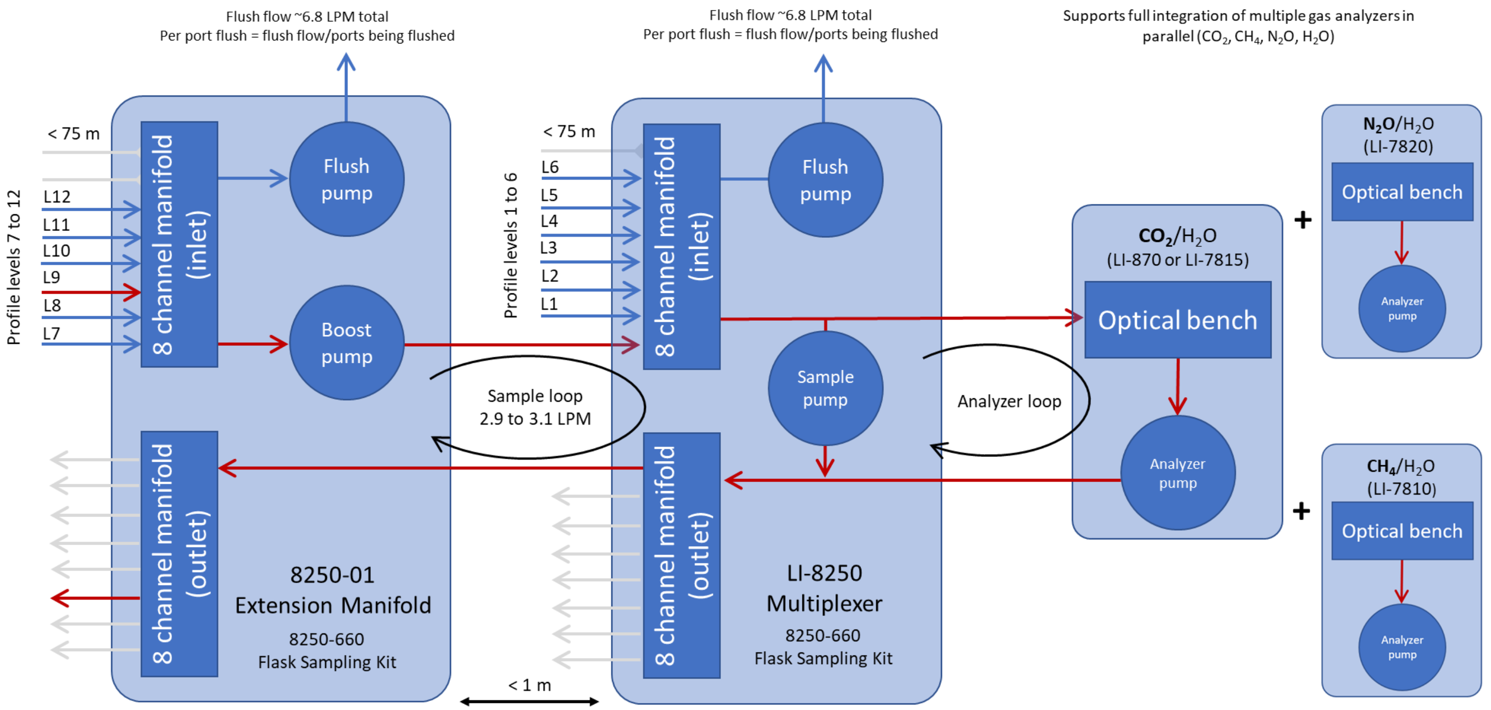
Atmospheric Profiling System with LI-8250 Multiplexer

12 Level Atmospheric Profile



ICOS compliant profile system: 1 lpm flow rate per sample line

Mixed System – Profile and Soil Flux in one System

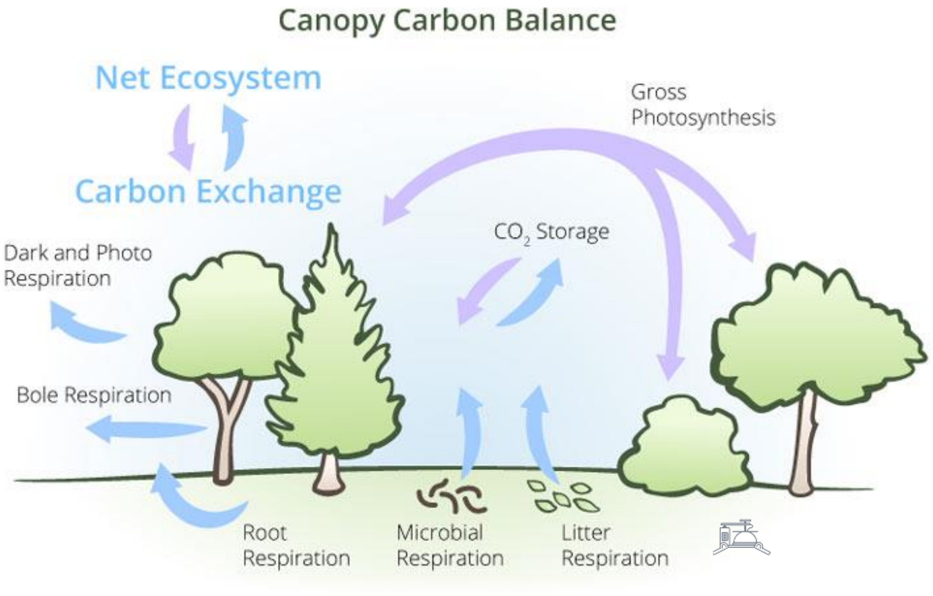
Add Soil Flux Measurement to Profile Measurement

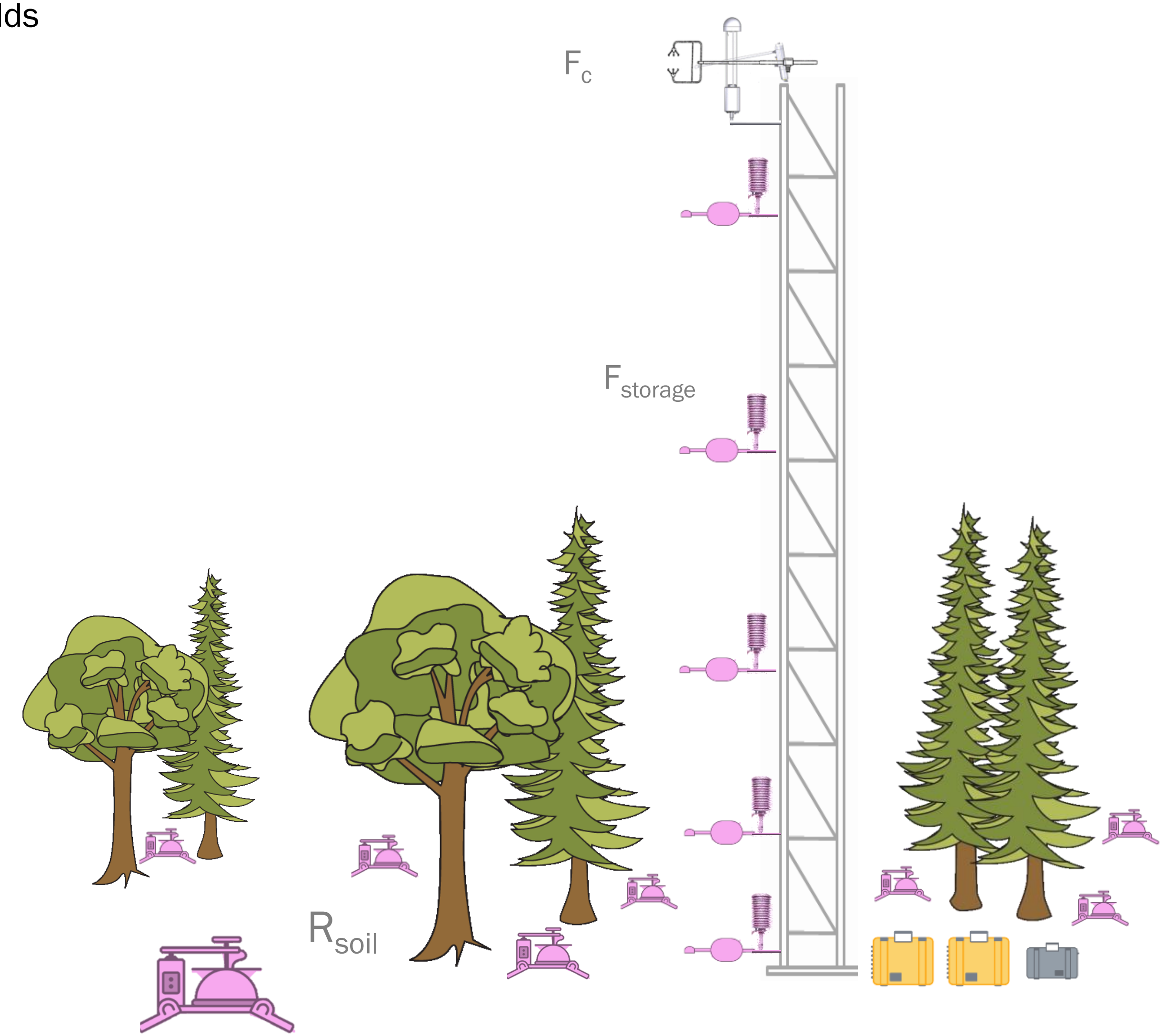
$$F_{ecosys} = F_c + F_{storage}$$

Recommended to connect **chambers** and **profile** tubes on different manifolds (multiplexer + extension manifold/s)

Example of a 30 min measurement schedule (1x mux + 2x ext. manifold):

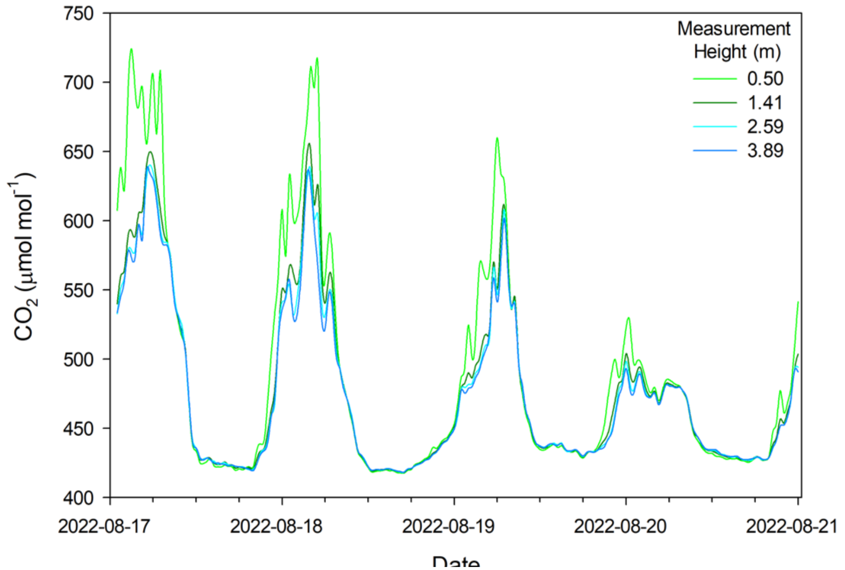
EC flux interval (30 min)
12x profile level -> 3 min
8x Long term chamber, each 3 min -> 24 min

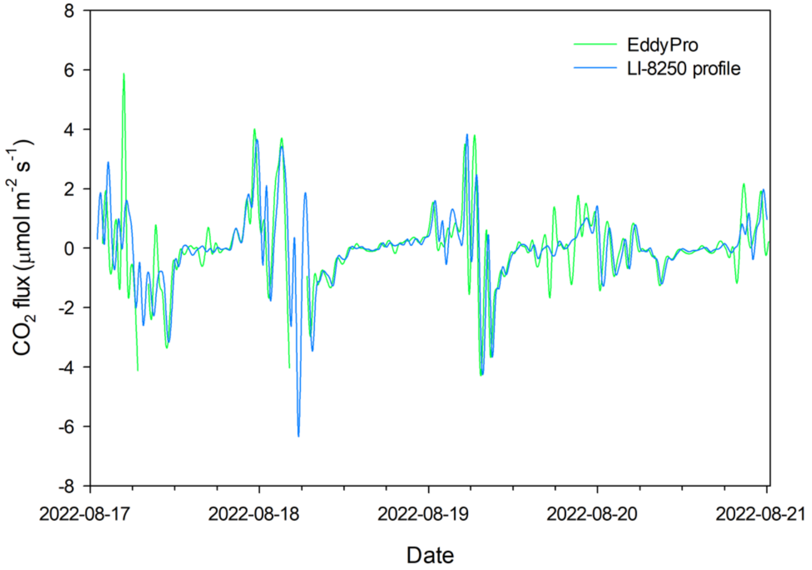




Atmospheric Profiling System with LI-8250 Multiplexer

CO_2 Storage Flux - Example setup at LI-COR experimental station, Lincoln NE





Buffered intake, rain cap and 3l buffer volume

Atmospheric profile measurements with the LI-8250 multiplexer system

Application Note

Contents

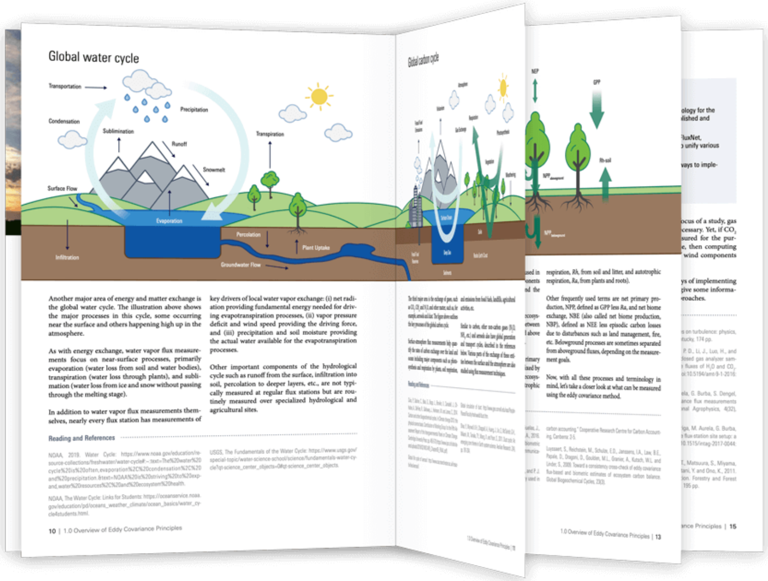
fall between 1.5 and 2 times the height of the plant canopy that the system is deployed in.

$$n = h_m{}^a \quad (1)$$

The parameter a has a recommended default value of 2/3, but may be adjusted depending on canopy characteristics. For canopies where vegetation density is highly uniform with respect to height this value may be reduced to as little as 0.5. For more complicated, less uniform canopies values up to 0.75 may be used.

Basic reading for non-micrometeorologists and beginners:

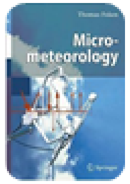
New book: 2022
Free PDF
Paperback
Simple - for everyone
Yet detailed - for experts



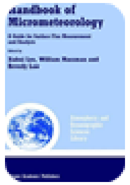
LI-COR

A more advanced reading for both non- and micrometeorologists:

EC: A Practical Guide to Measurement and Data Analysis, 2012. By M. Aubinet, T. Vesala, D. Papale *et al.* (Eds.)



Micrometeorology, 2008. By T. Foken. Springer-Verlag.



Handbook of Micrometeorology: A Guide for Surface Flux Measurement and Analysis, 2008. By X. Lee; W. Massman; B. Law (Eds.). Springer-Verlag.

Thank you