The importance of Biomet information to interpret Eddy Covariance data

LI-COR Eddy Covariance Training - ChinaFlux

August 22, 2022

Dave Johnson

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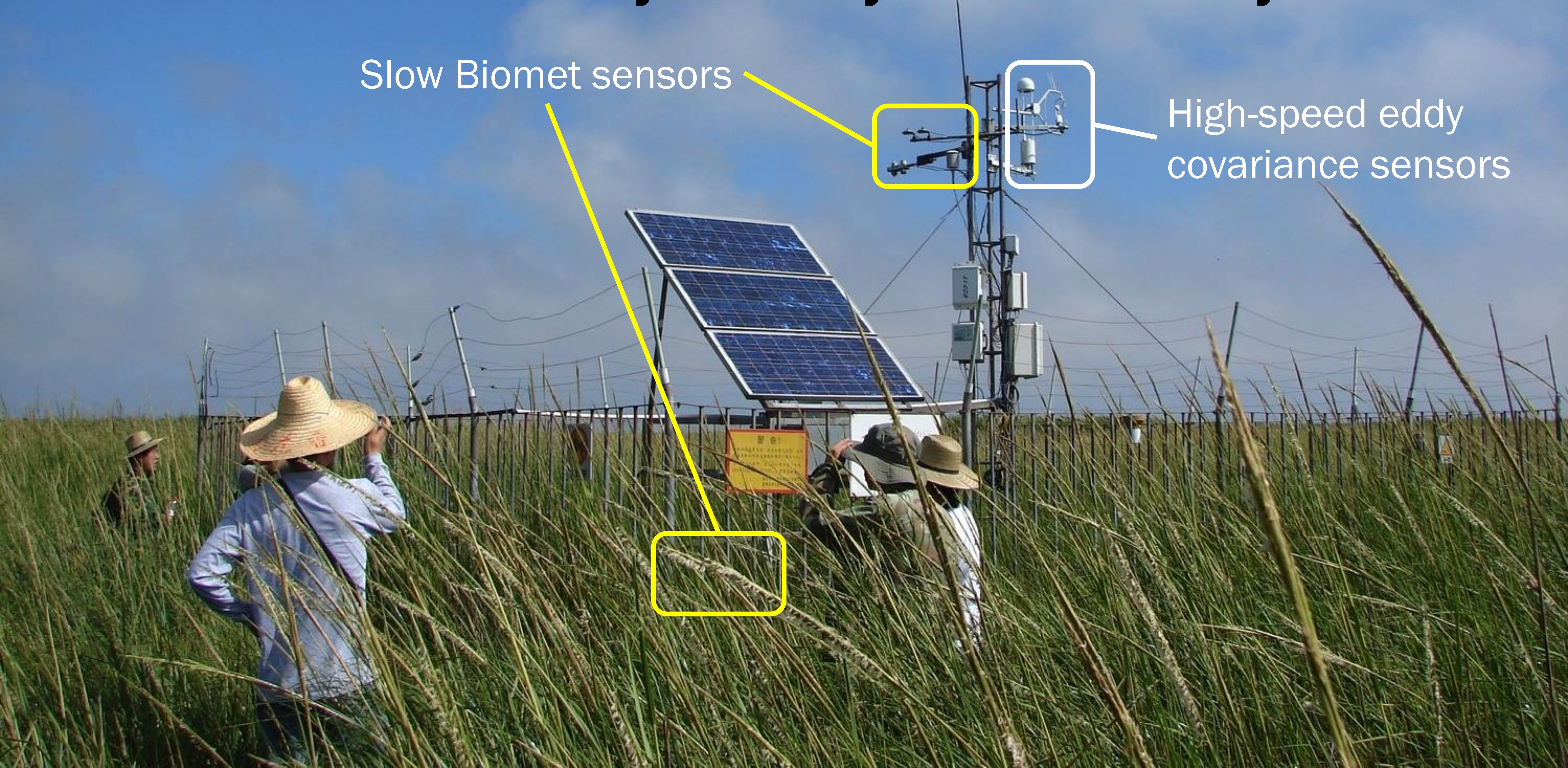
Data sets collected by an Eddy Covariance System



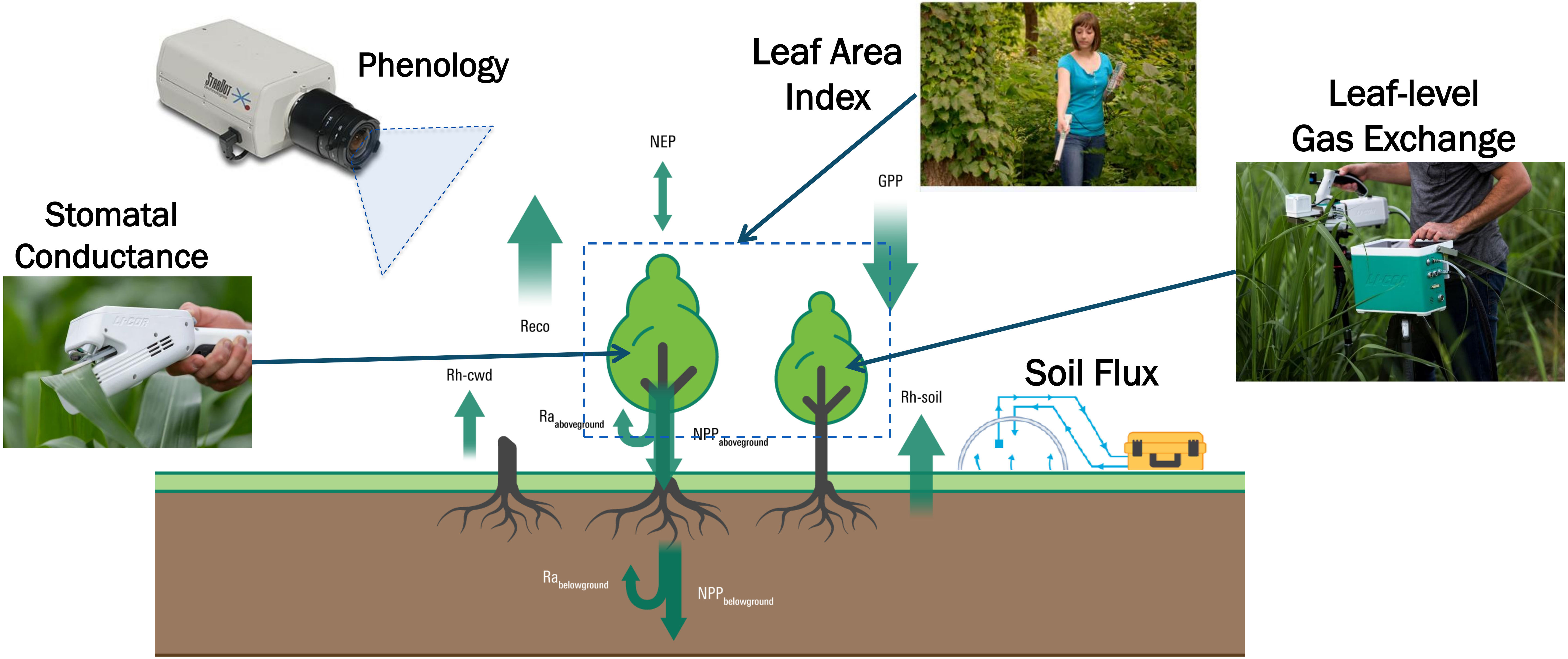
What are ‘Biomet’ Sensors?

- Sensors used for monitoring the environment (**bio**logical and **met**eorological).

- Biological sensors are typically used periodically to measure biological functions.

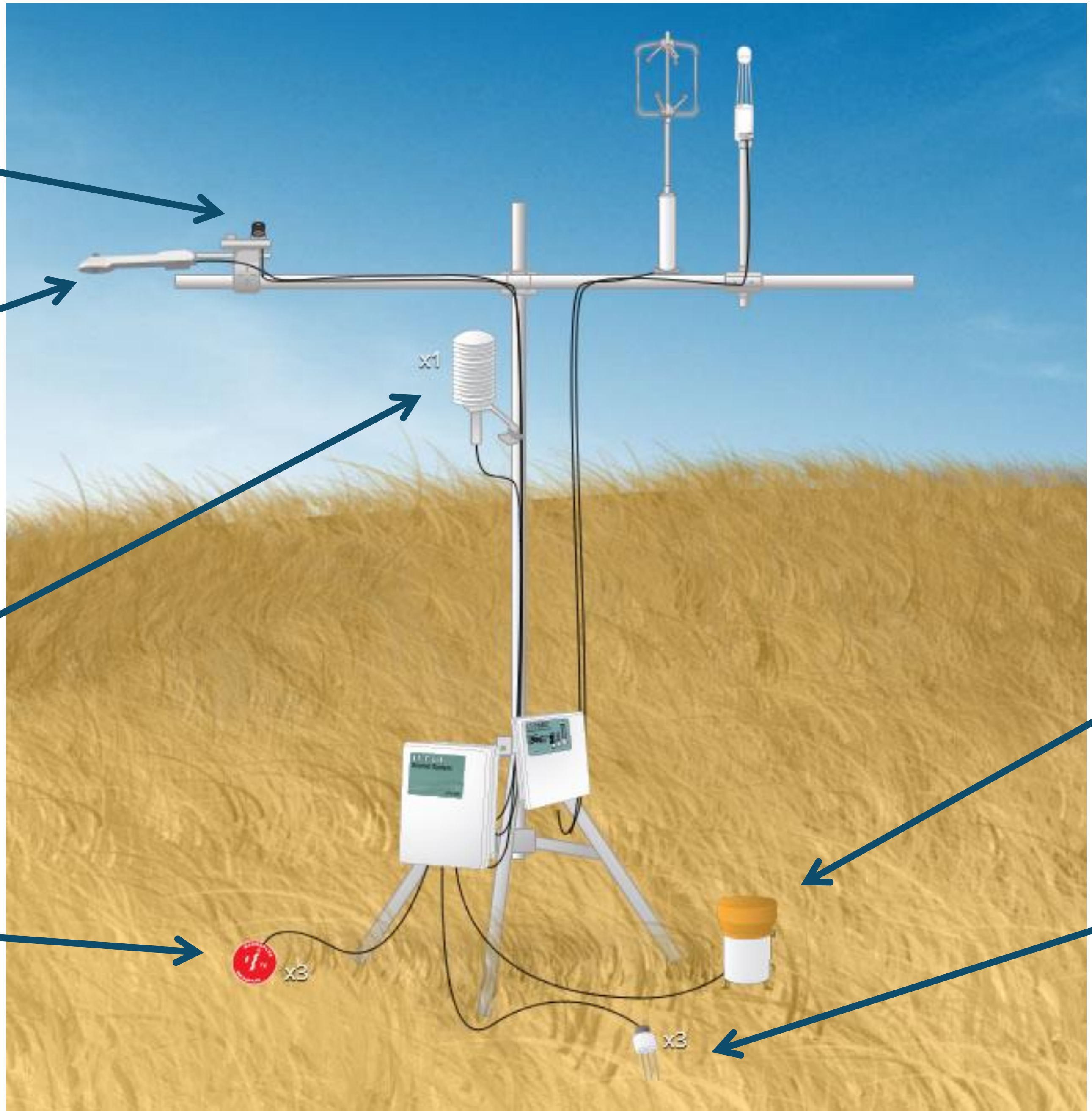
- Meteorological sensors typically measure once per second to once per minute.

Biomet Measurements: Biological variables



Lots of processes; Leaf and Soil level

Biomet Measurements: Meteorological variables



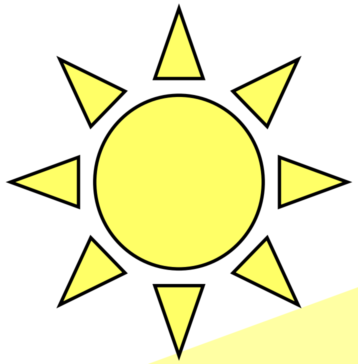
Biomet Sensors

- Why do we need additional Biomet measurements?

    - We can already calculate flux measurements from the *sonic anemometer* and *gas analyzer* data…

Why collect Biomet measurements?

- Quality Assurance and Quality Checking (QA/QC)
  - Energy Balance closure.
- Recording weather helps to explain site behavior
  - The physical environment has profound effects on the biology as well as on the surface-atmosphere exchange.
- For Data Analysis
  - Gap filling – When instrumentation or power fails.
  - Partitioning – separating NEE into GPP and R_{ECO}
- Improving Fluxes

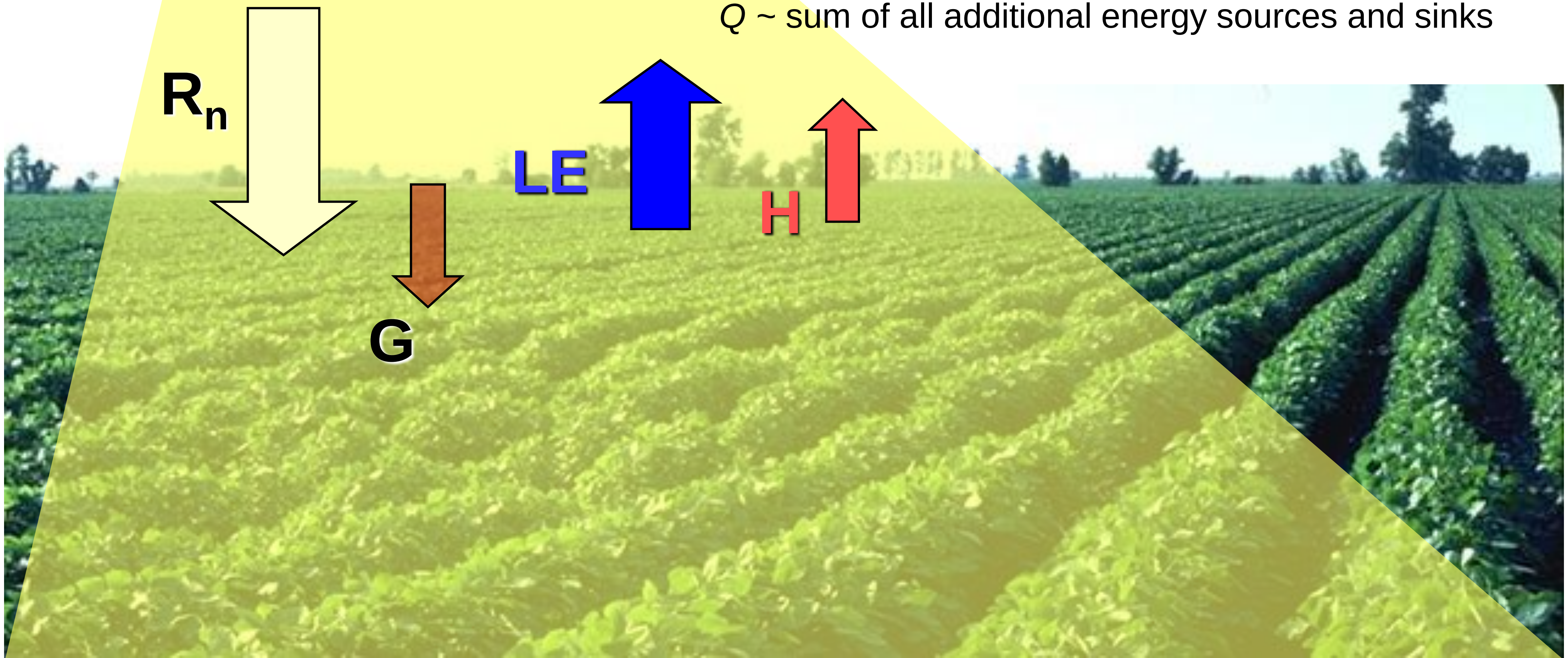


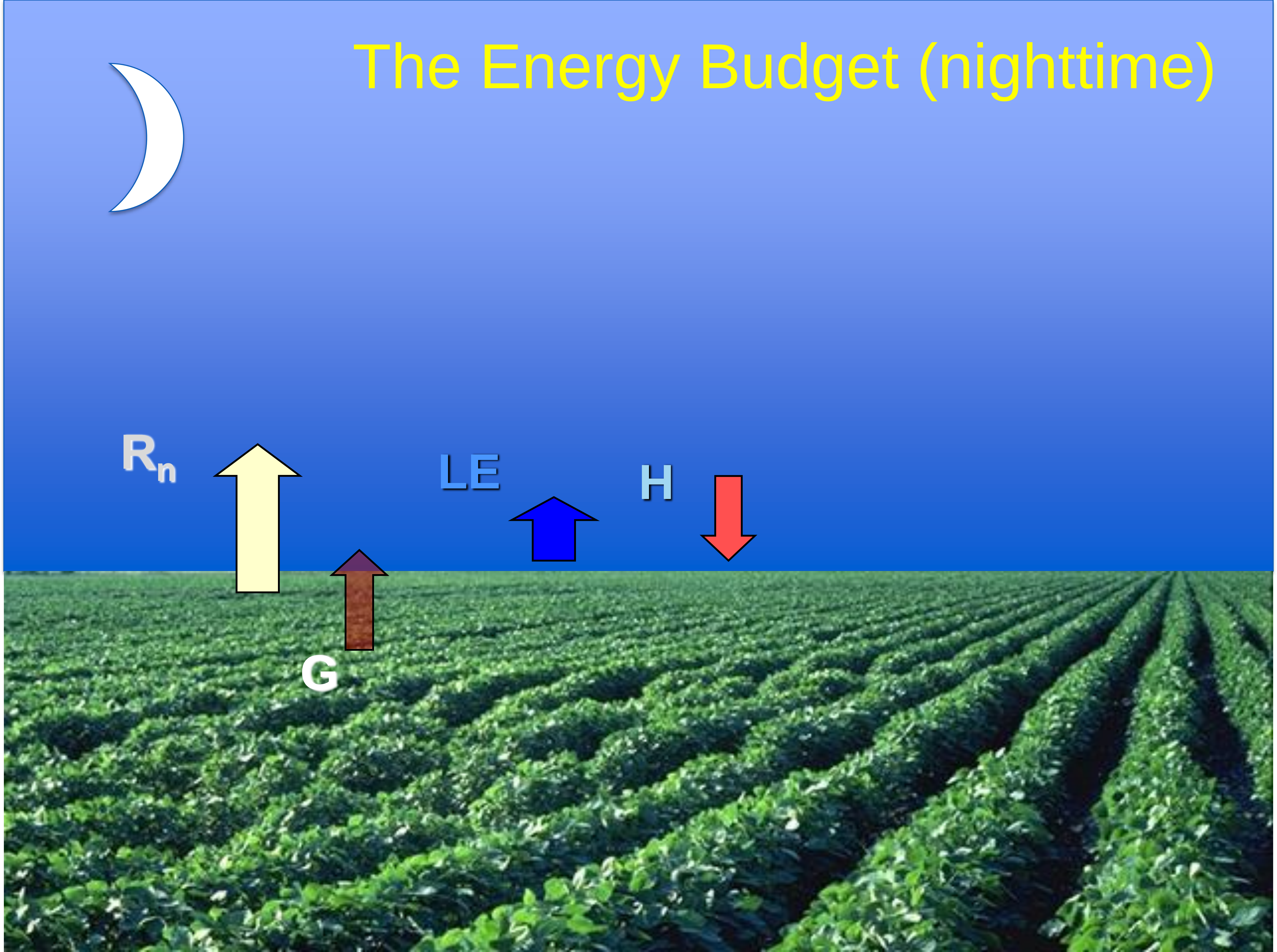
The Energy Budget (daytime)

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

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



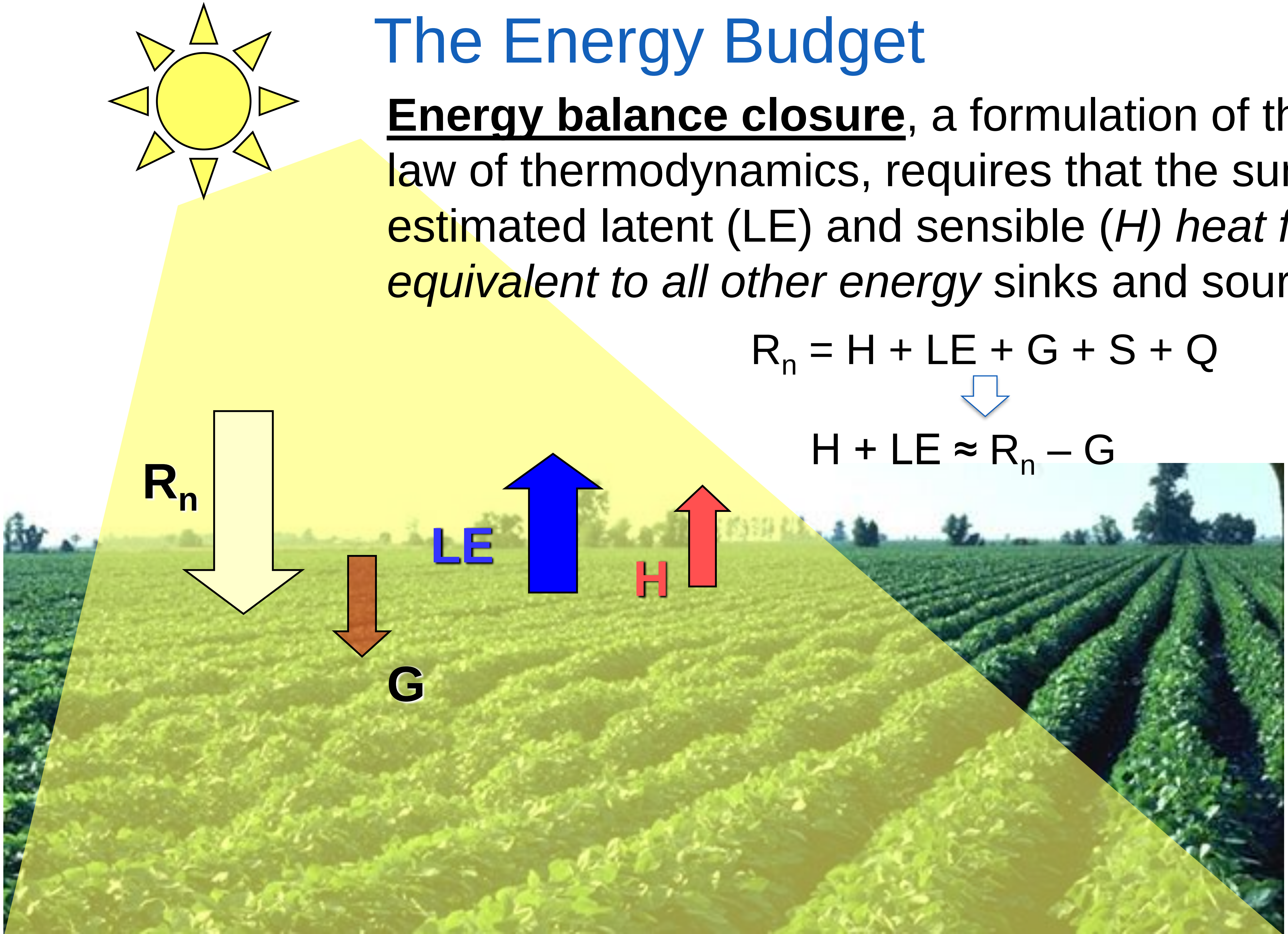

The Energy Budget (nighttime)
R
n
LE
H
G

The Energy Budget

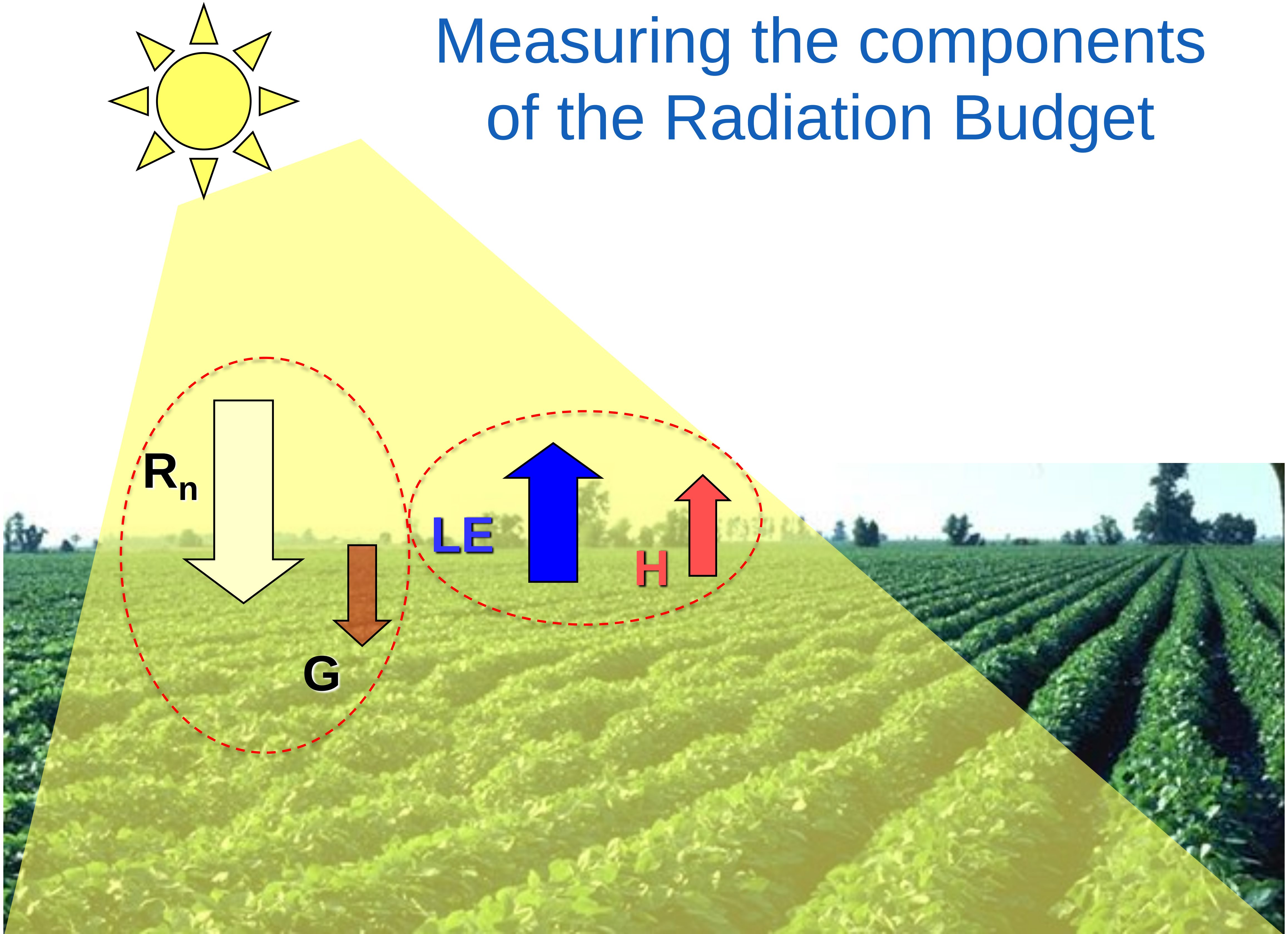
Energy balance closure, a formulation of the first law of thermodynamics, requires that the sum of the estimated latent (LE) and sensible (*H) heat flux be equivalent to all other energy* sinks and sources

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

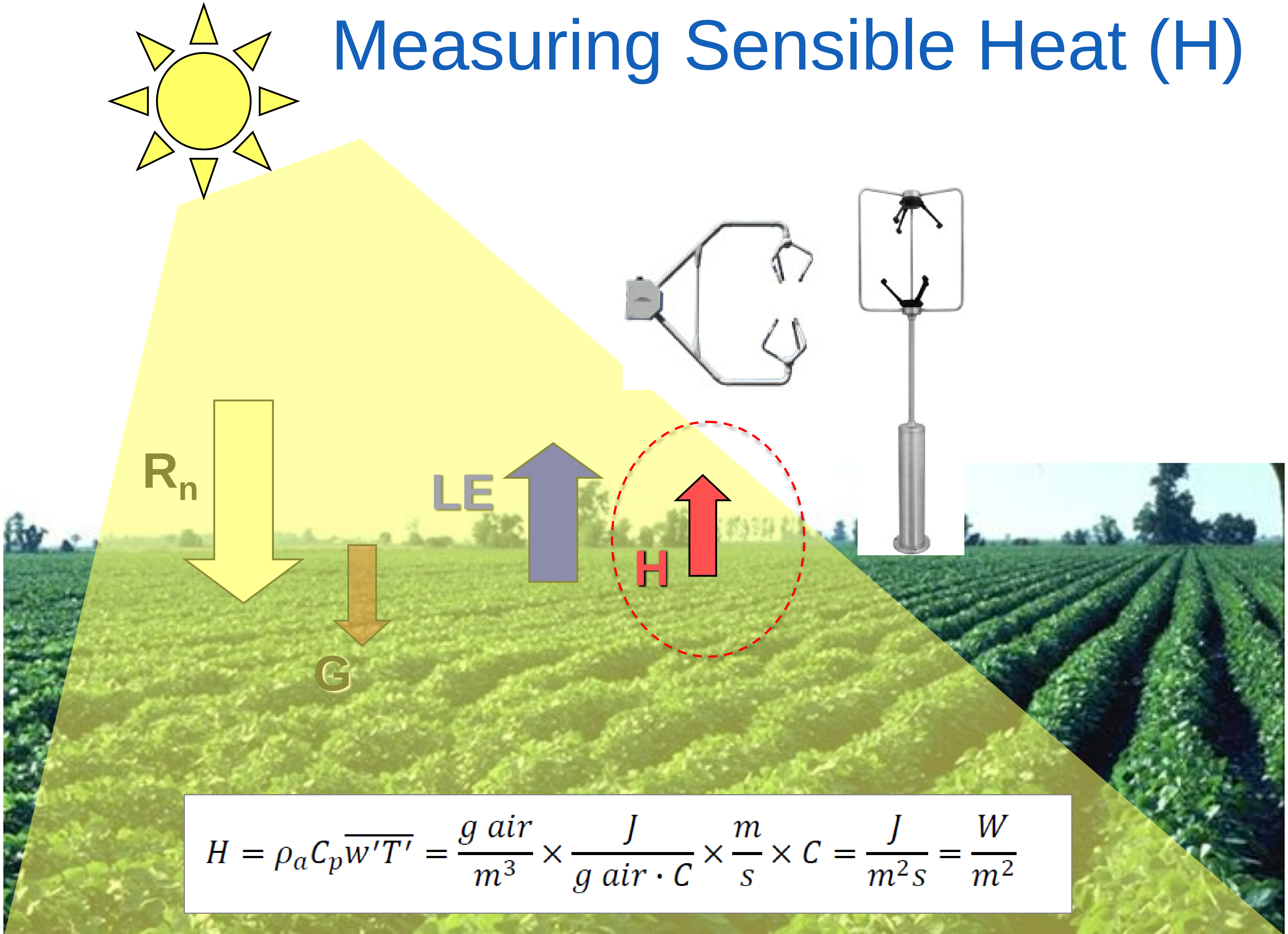
$$H + LE \approx R_n - G$$



Measuring the components of the Radiation Budget

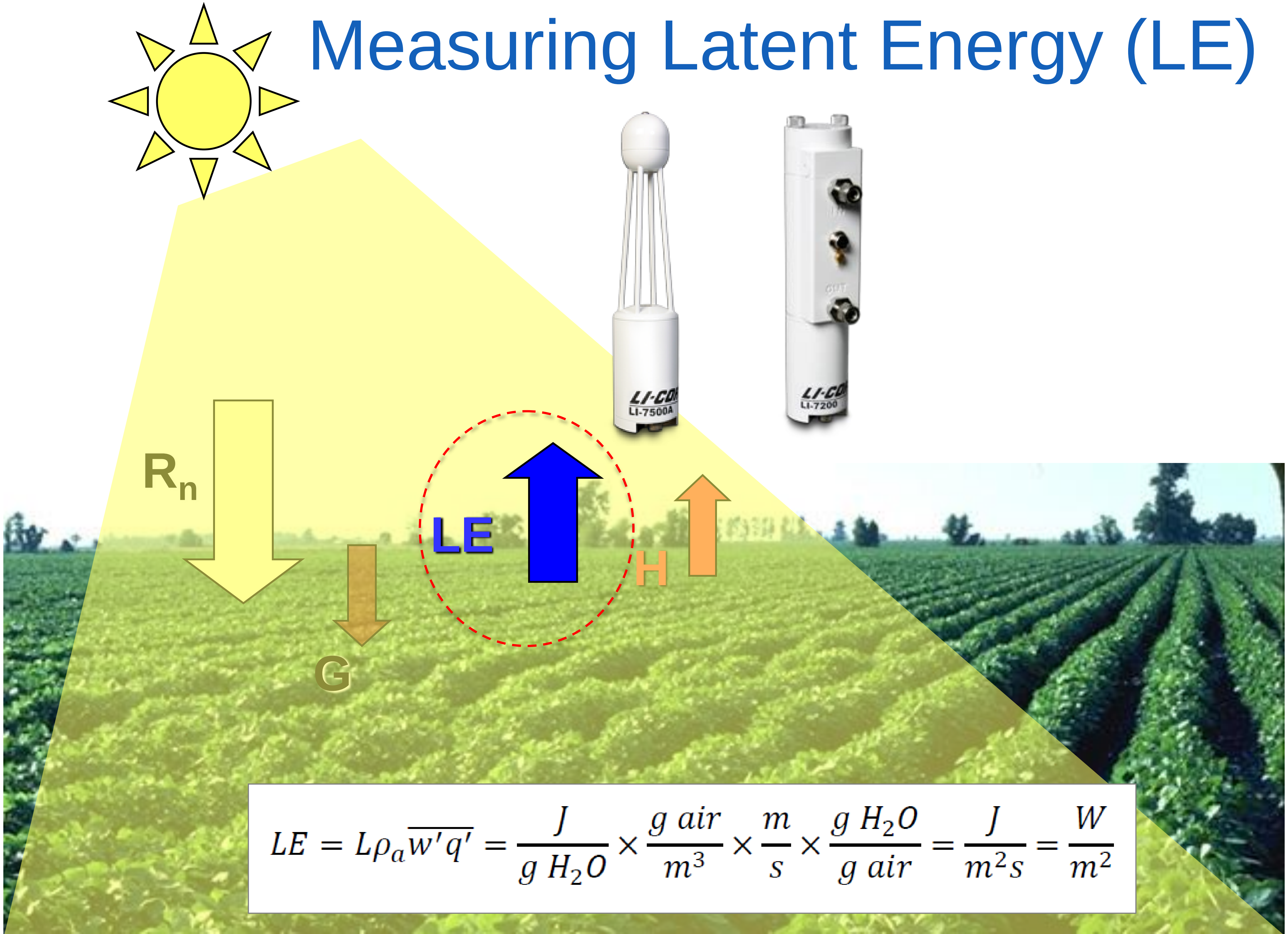


Measuring Sensible Heat (H)



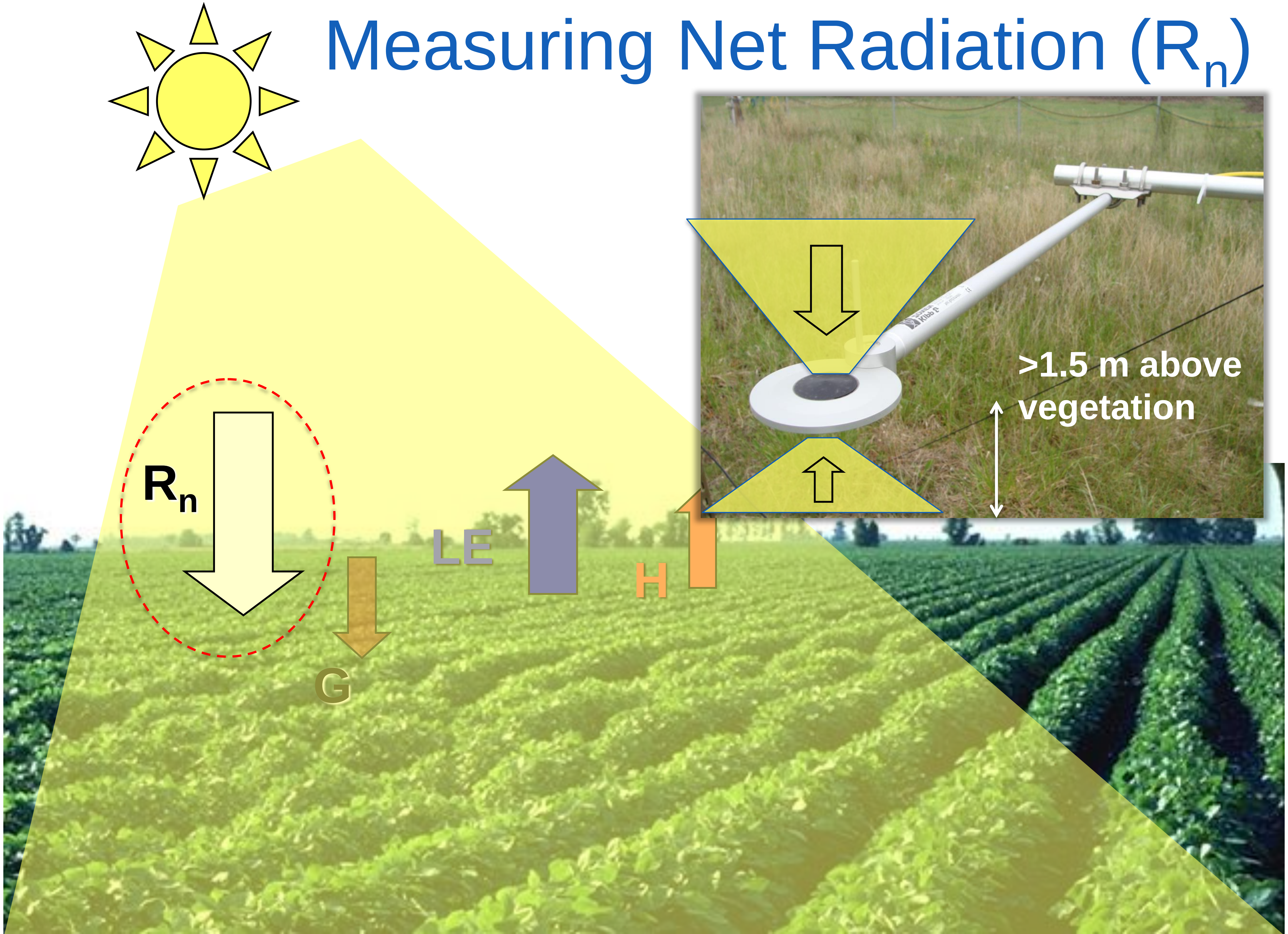
$$H = \rho_a C_p \overline{w'T'} = \frac{g\ air}{m^3} \times \frac{J}{g\ air \cdot C} \times \frac{m}{s} \times C = \frac{J}{m^2 s} = \frac{W}{m^2}$$

Measuring Latent Energy (LE)



$$LE = L\rho_a\overline{w'q'} = \frac{J}{g\ H_2O} \times \frac{g\ air}{m^3} \times \frac{m}{s} \times \frac{g\ H_2O}{g\ air} = \frac{J}{m^2 s} = \frac{W}{m^2}$$

Measuring Net Radiation (R_n)



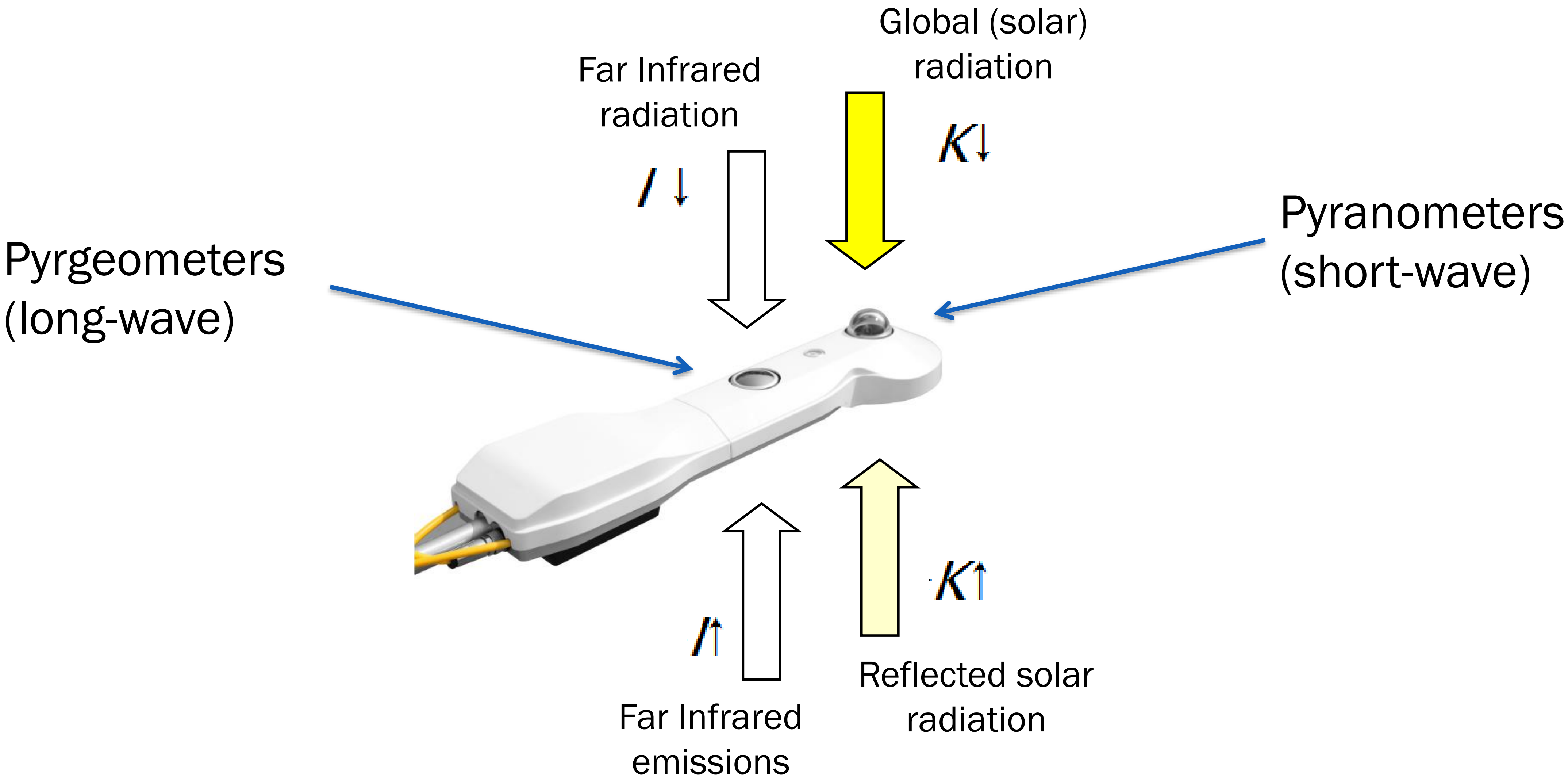
Typical Net Radiation Sensors

Kipp & Zonen
NR Lite2
Single component

Hukseflux
NR01
Four component

Kipp & Zonen
CNR 4
Four component

The four-component radiometer give more detailed information of the various radiation components



Heating and Ventilation can help with the continuous collection of good data

Heating:

- recommended to activate when there is a risk of dew deposition
  - NR01: 1.5 W at 12 VDC
  - CNR4: 10 W at 12 VDC

Ventilation:

- CNF4 ventilation unit
  - CNR4: 5 W at 12 VDC

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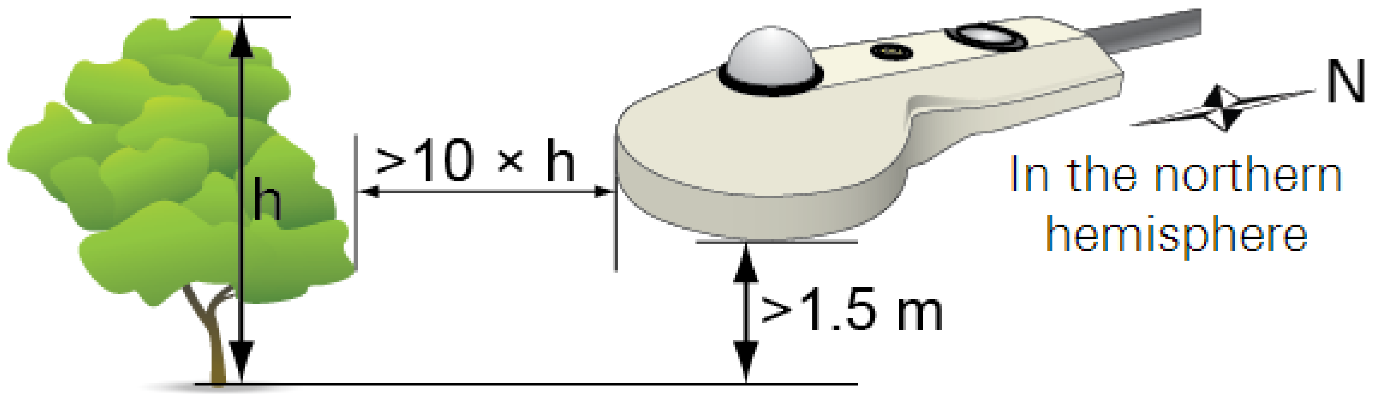
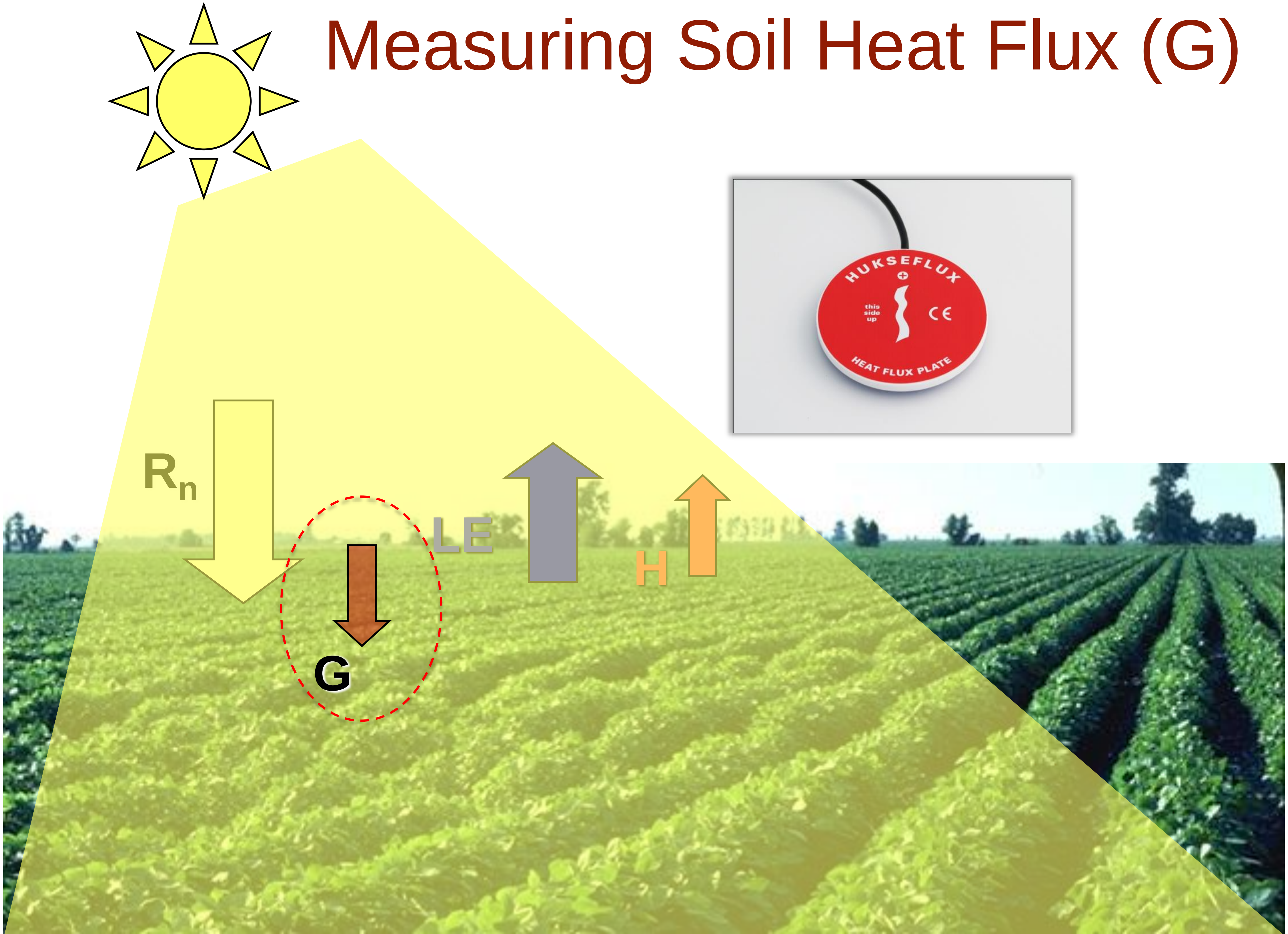
Net Radiation - Installation

- No obstruction and shadows of up/downwards view
- Away from heat source or reflected surfaced
- Orient towards south (northern hemisphere)
- Mount at least 1.5 m above plant canopy
- Mount at least 10xh away from high vegetation



Measuring Soil Heat Flux (G)

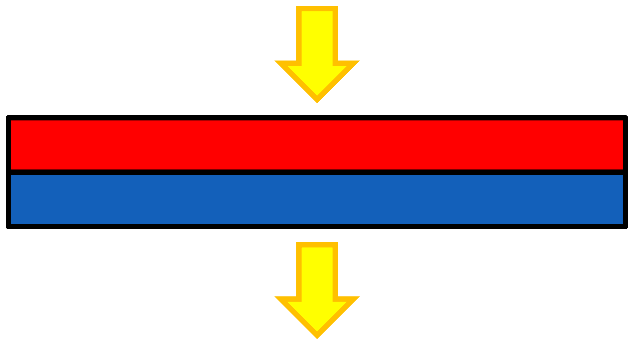


Soil Heat Flux: Measure the heat transfer in the soil

Hukselflux

HFP01

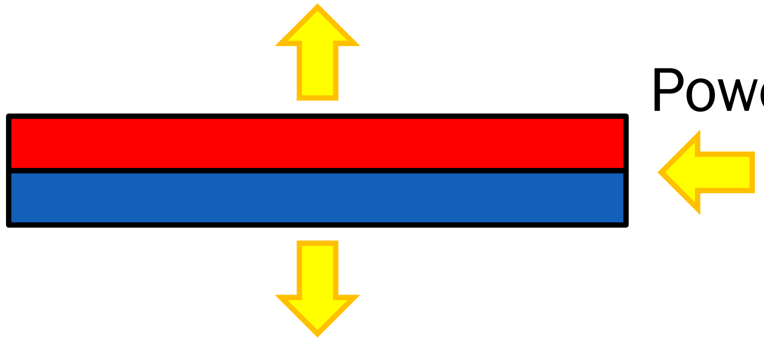
Normal Operation



Hukselfux

HFP01SC

Self-Calibrating



φ = heat flux

X = deflection error

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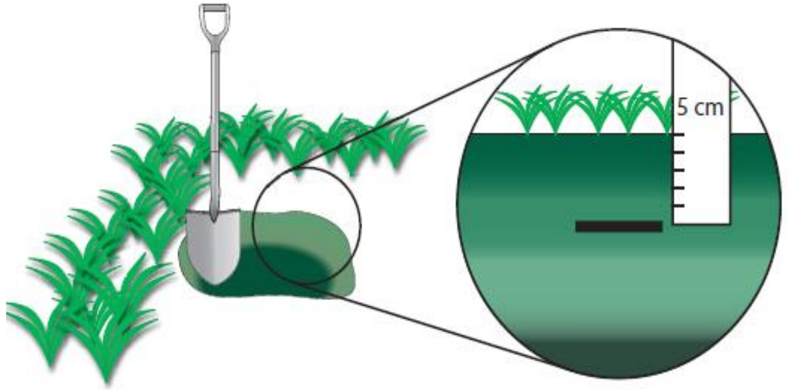
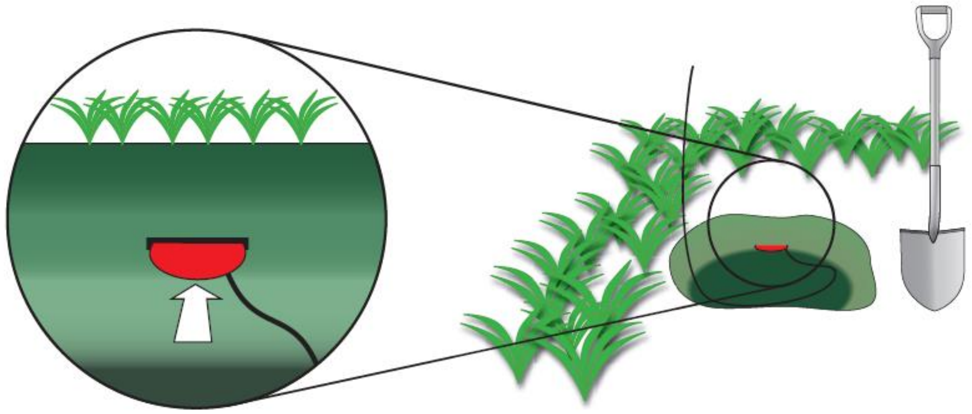
Soil heat flux plates - Installation

Minimum of 3 each:

- Soil variability
- Sun vs. Shade
- 5 m apart





Installation:

- Typically, 5 cm
- Bury with red side up
- Be sure each sensor is completely covered with soil, no air pockets
- Bury a short length of the cable to prevent thermal conduction through wires
- Fill the hole with excavates soil

How can the Energy Budget and Energy Balance Closure help us?

- A tool for verifying eddy covariance instrumentation ($CO_2/H_2O/CH_4$ analyzers and sonic anemometers) are working accurately and are installed properly.
  - Helps verify that final computed flux values are correct and accurate.

- Quality Assurance and Quality Checking (QA/QC).
  - Investigate relationships between half-hourly estimates of dependent flux variables $(LE + H)$ against independently derived available energy $(R_n - G)$.

Remember … $H + LE \approx R_n - G$

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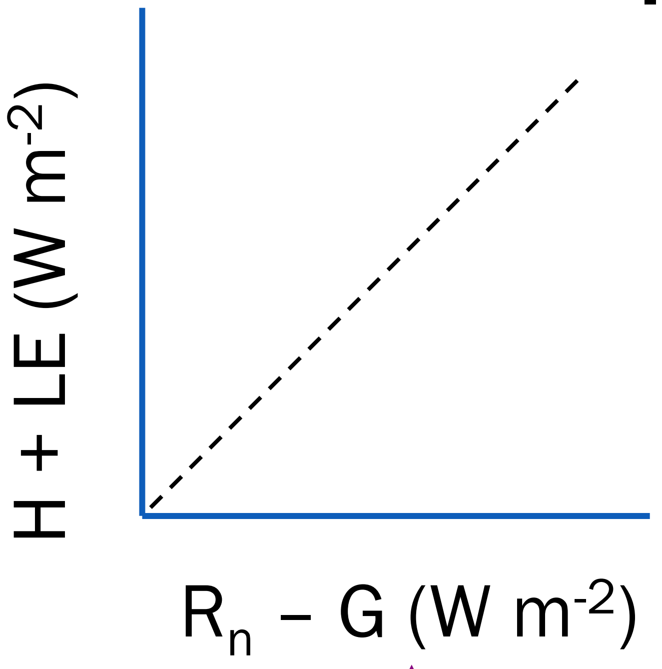
Checking for energy balance closure

Measured by the **EC** System

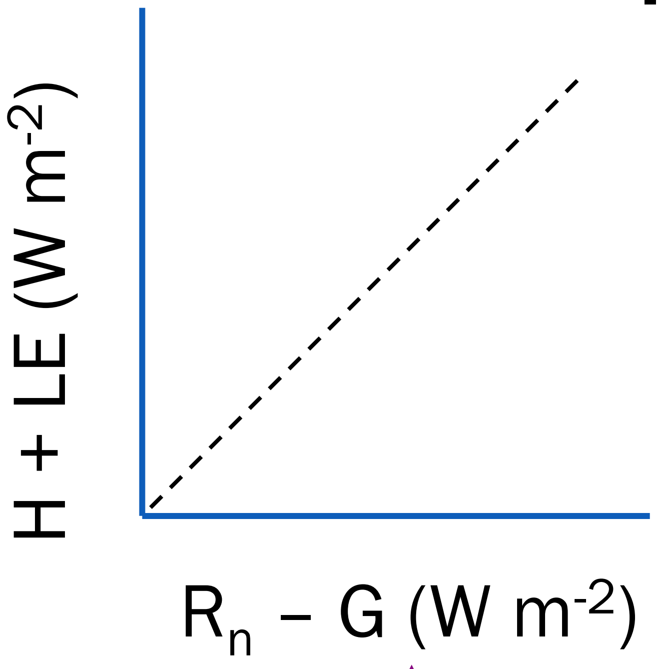


Ideal closure is represented by a slope of 1 and an intercept of 0.

Measured by the **Biomet** System

Checking for energy balance closure

Measured by the **EC** System



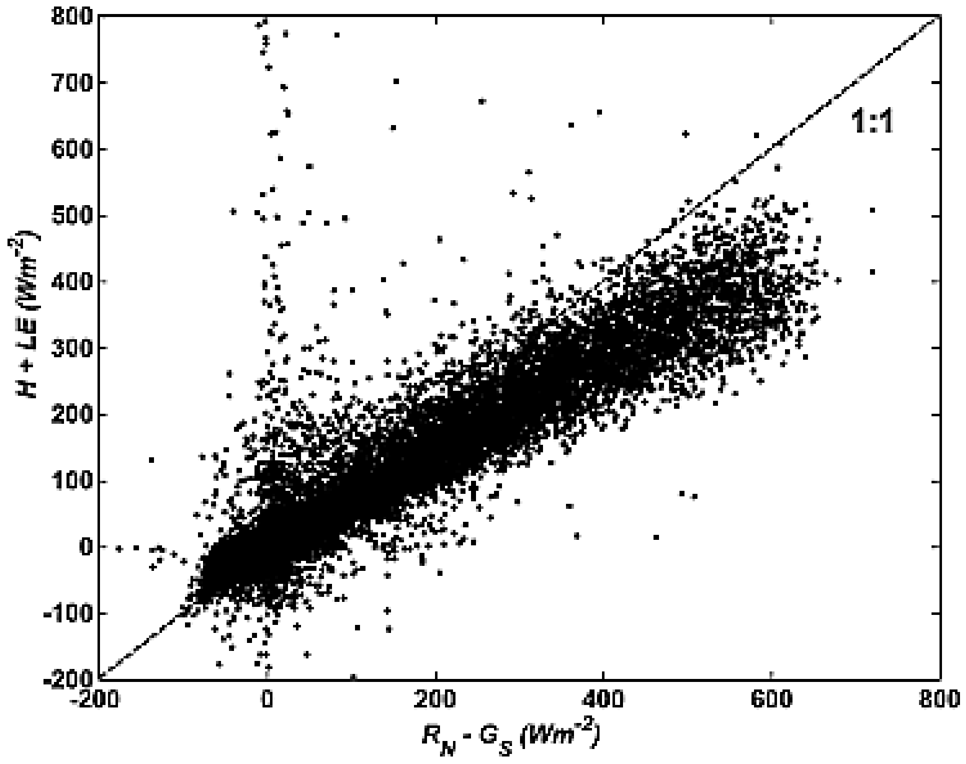
Measured by the **Biomet** System

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

If not ideal:

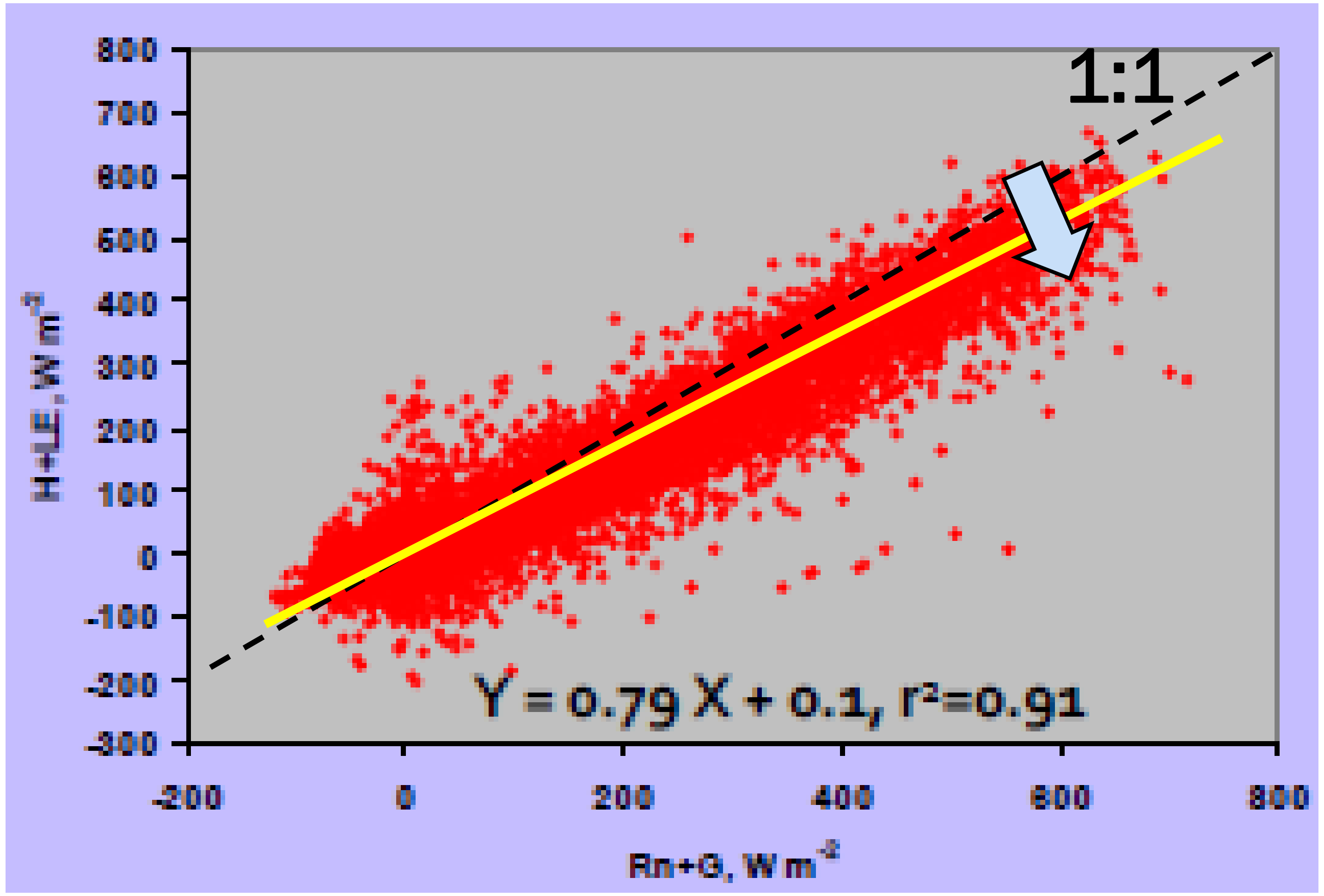
- Sampling errors?
- Systematic biases?
- Neglected energy sinks?
- Other?

Realistic (measured) closure



What are typical closure results for Eddy Covariance sites?

- From many studies (i.e., FLUXNET), surface energy fluxes (**LE + H**) are frequently underestimated by about 10-to-30% relative to estimates of available energy flux (***Rn − G − S***).
- *Why is this?*



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Probably causes for this imbalance

Energy component	Cause of imbalance	Examples
Rn, G, H, LE	Sampling	Source areas differ
Rn, G	Instrument bias	Net radiometer biased
	Neglected energy sinks	Storage above soil heat plates
H, LE	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

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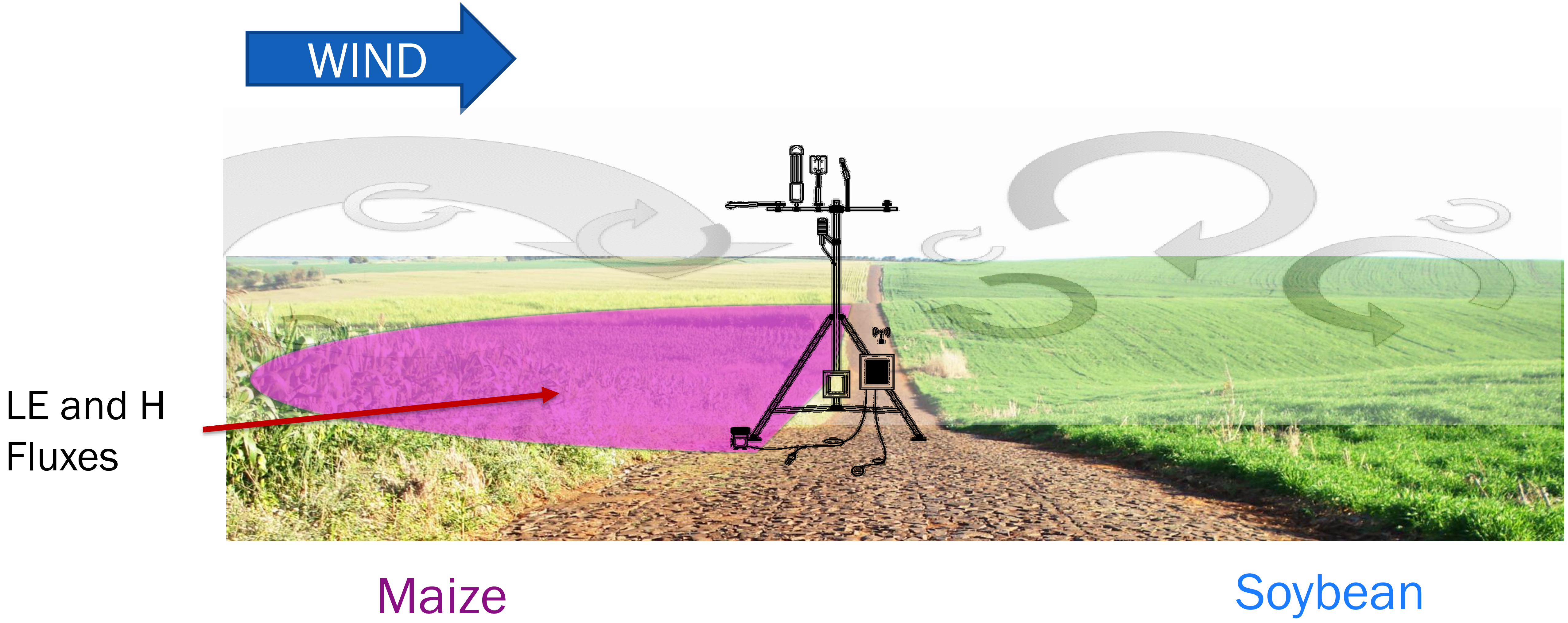
Wilson, K et al (2002). Energy balance closure at FLUXNET sites. Agricultural and Forest Meteorology

One EC System between two different plots



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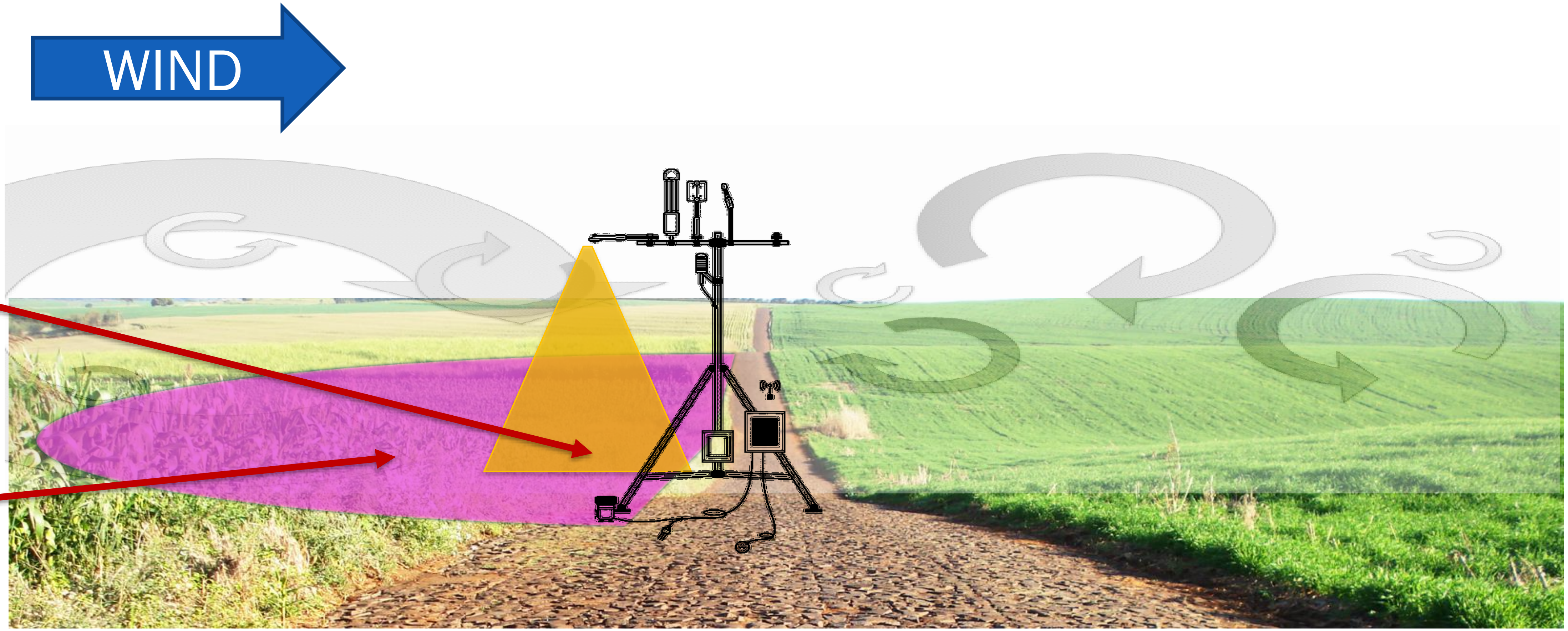
When Source Areas are the same…

Net Radiation field-of-view

LE and H Fluxes

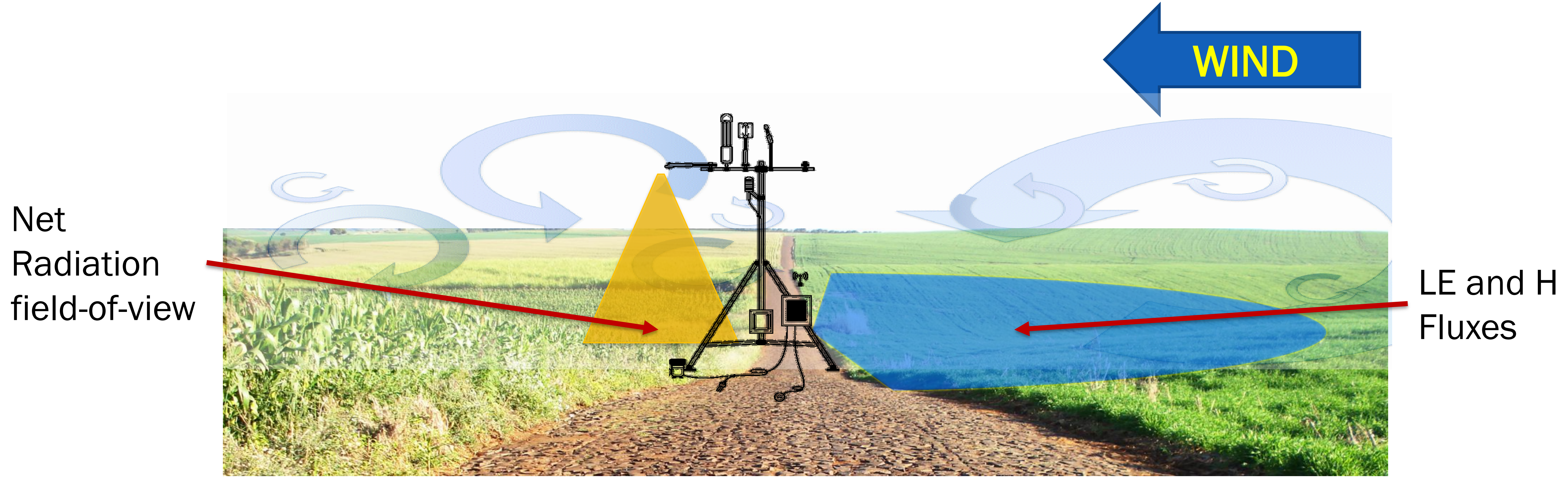


Maize

Soybean

✓ Energy measurements are from the same ecosystem

When Source Areas are different…

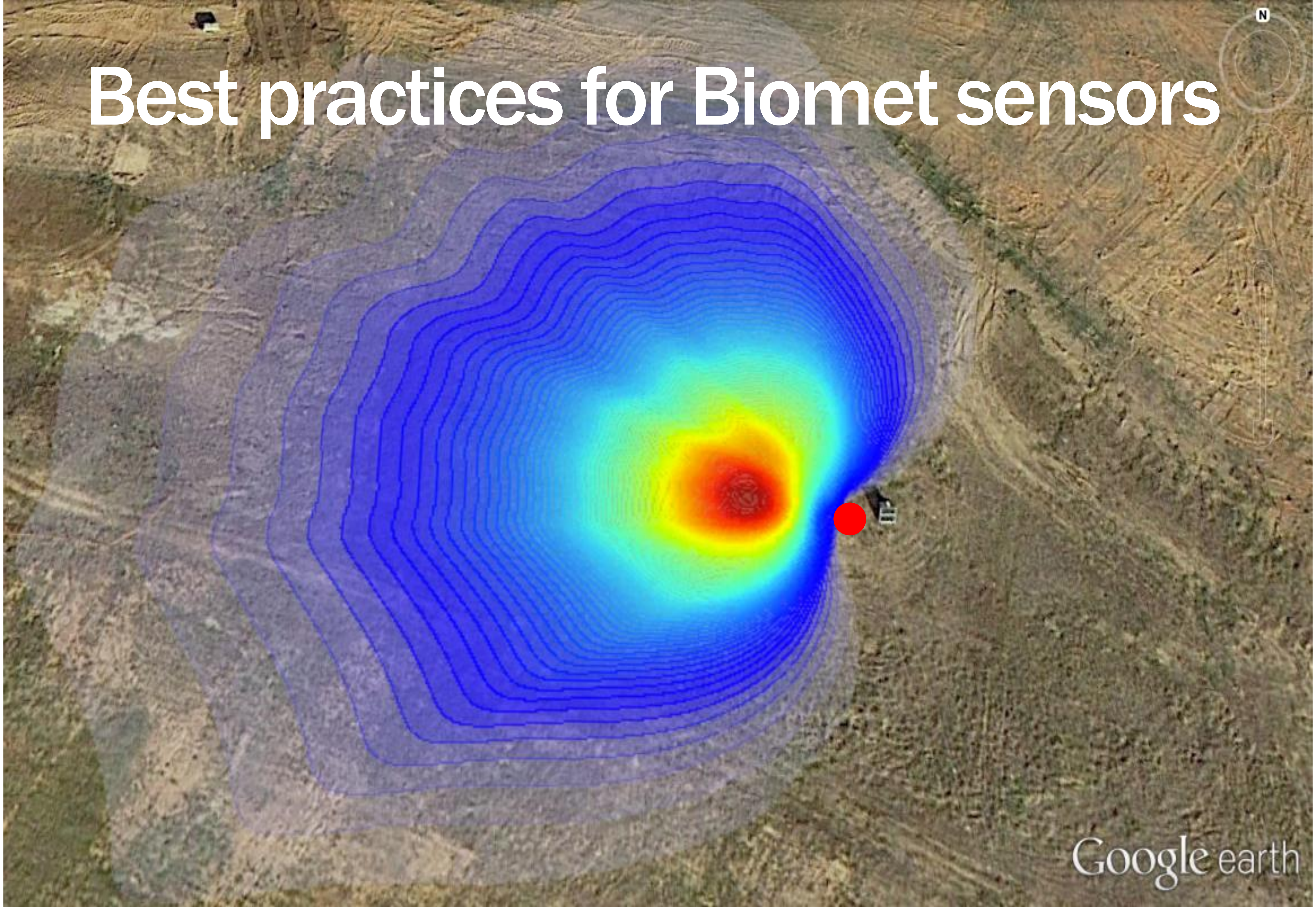


Maize

Soybean

! Energy measurements are from the <u>different</u> ecosystems

Best practices for Biomet sensors



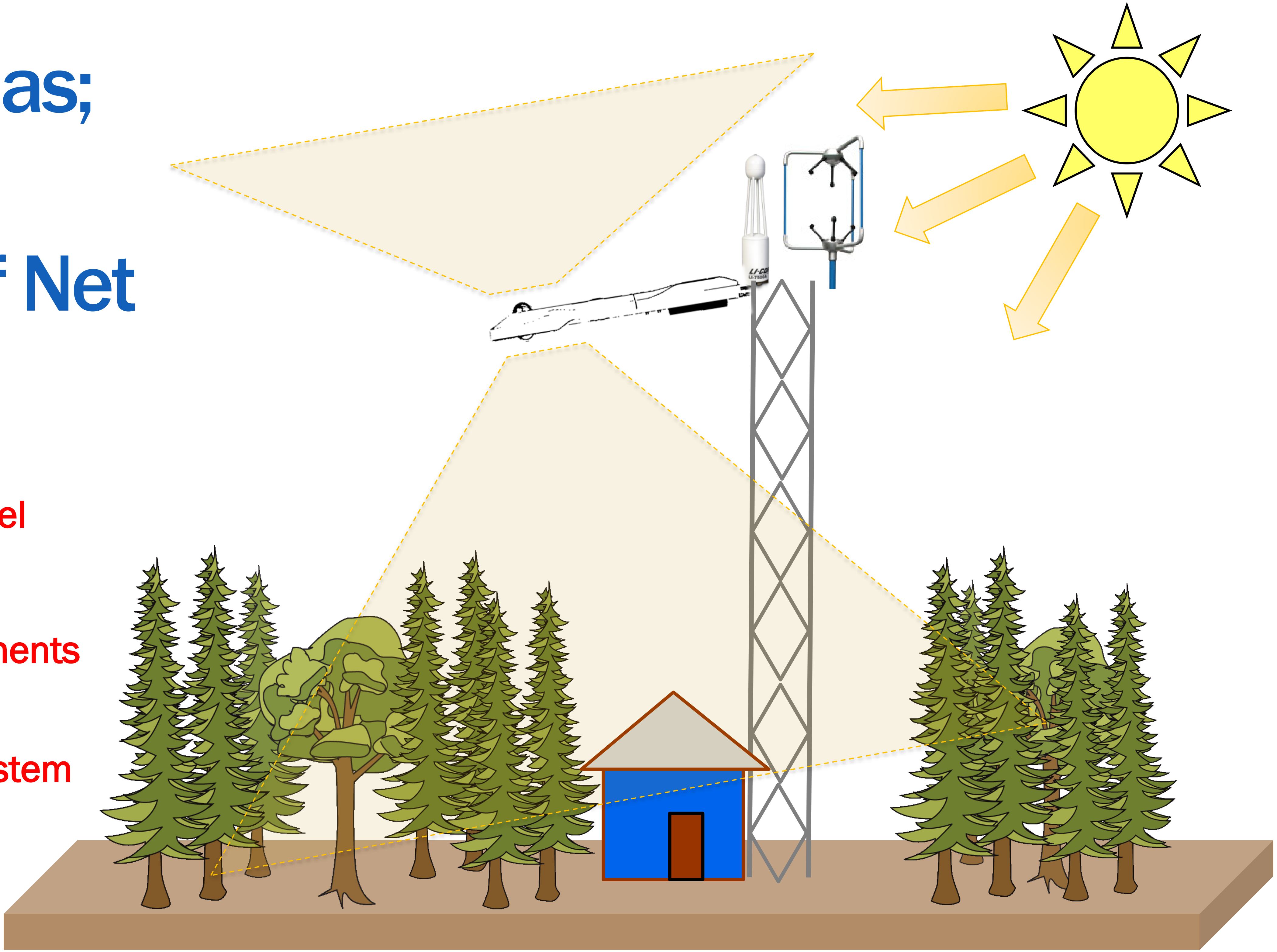
How Biases could cause an imbalance

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



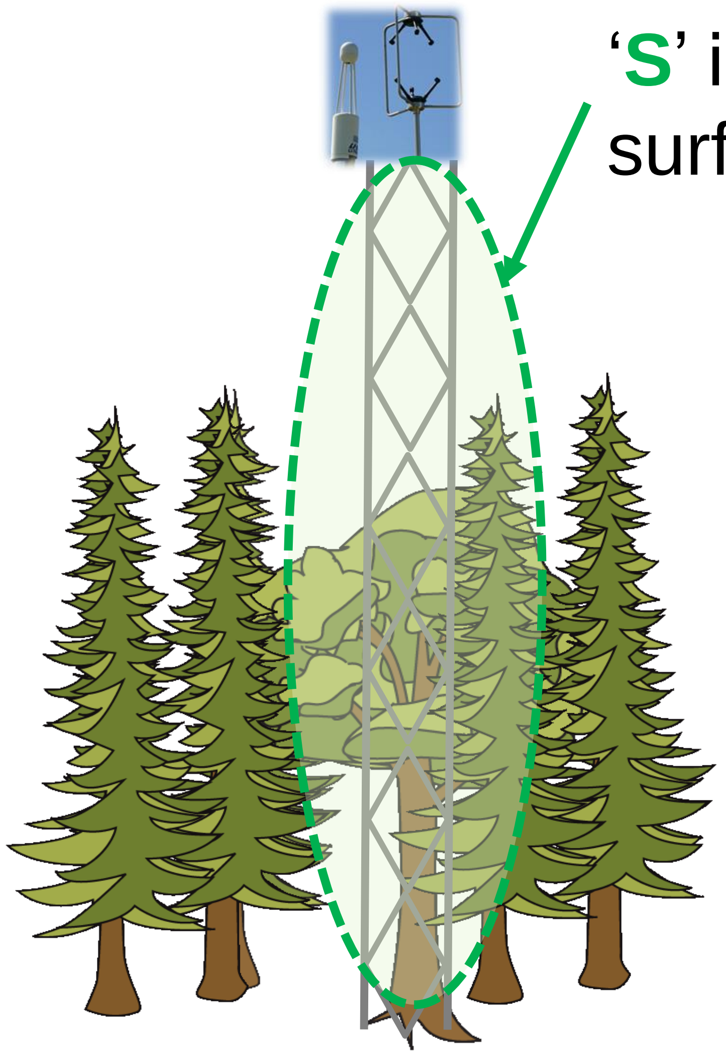
How neglecting energy sinks could cause an imbalance

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)*



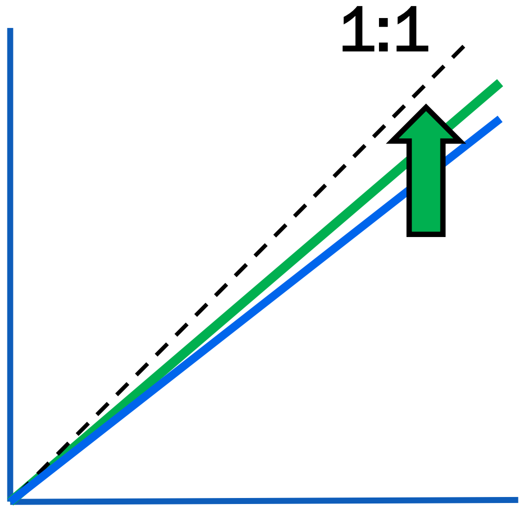
'**S**' is the rate of change of heat storage between the soil surface and the level of the eddy covariance instrumentation

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

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

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

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

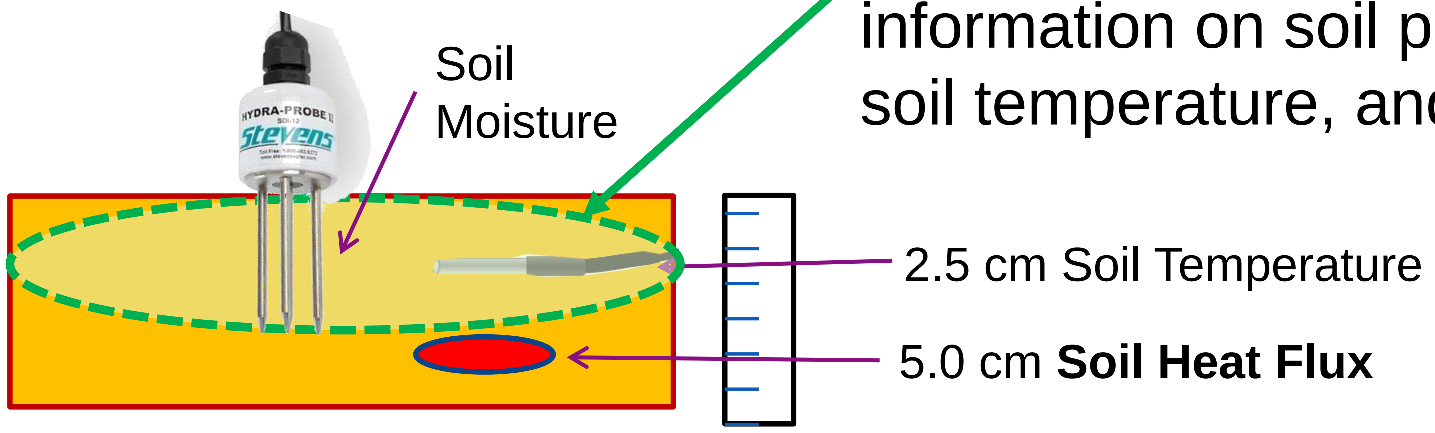


✓ Tall forested sites should measure *S*.

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.



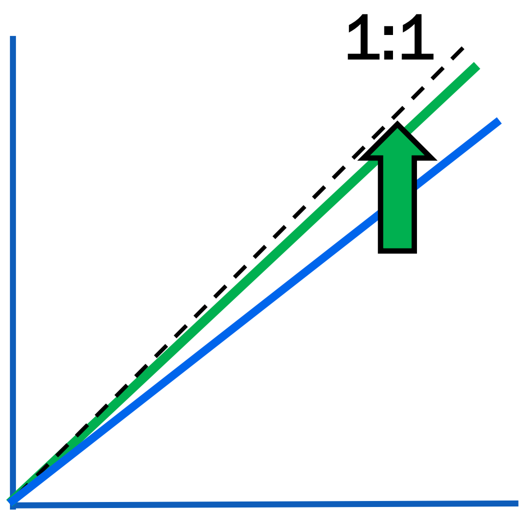
Soil Heat Flux at Surface = Measured Soil Heat Flux + Storage Term (S)

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

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

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

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



Short canopy sites should measure S.

Soil temperature sensors - Soil thermistor

LI-COR
7900-180
Soil Thermistor

Soil thermistor - Installation

Minimum of 3 each:

- Soil variability
- Sun vs. Shade
- 5 m apart

Installation:

- Typically, 5 cm
- Be sure each sensor is completely covered with soil, no air pockets
- Bury a short length of the cable to prevent thermal conduction trough wires
- Fill the hole with excavates soil

Thermistor

Heat Flux Plate

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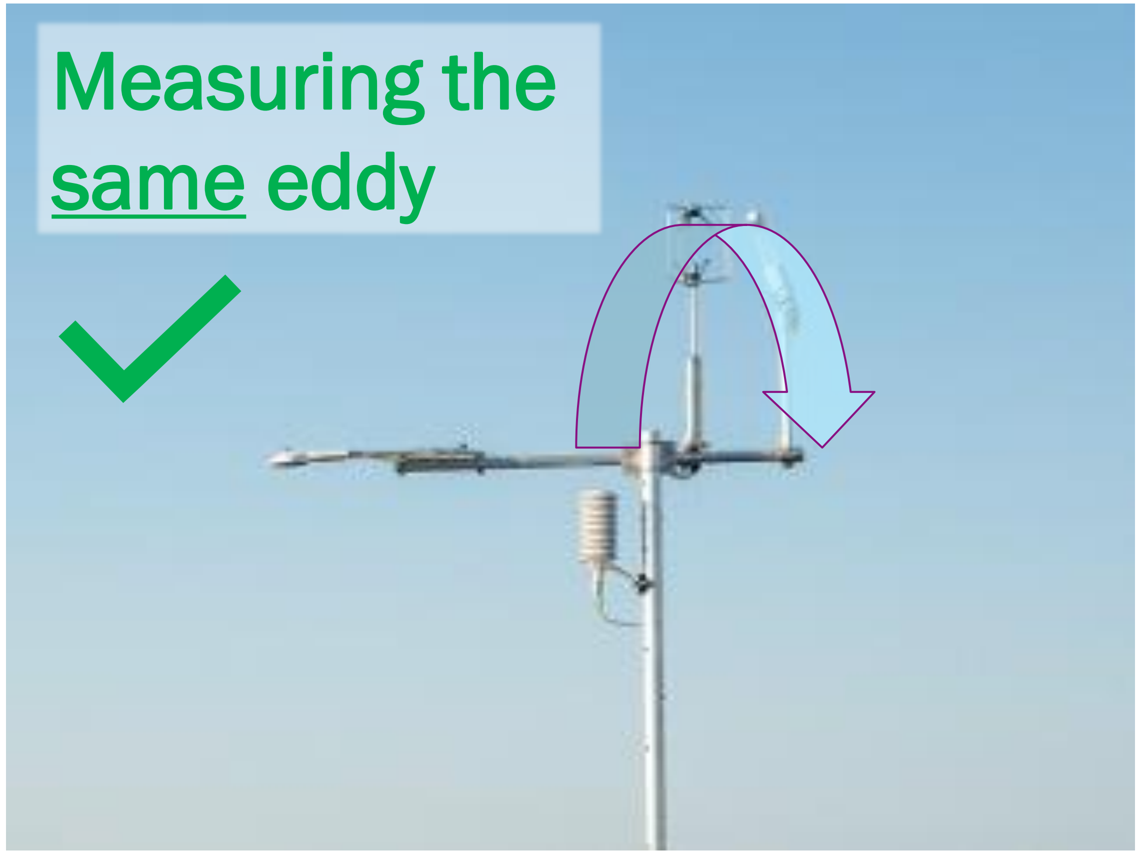
How losing high / low frequencies, and advection can cause an imbalance in the EB closure

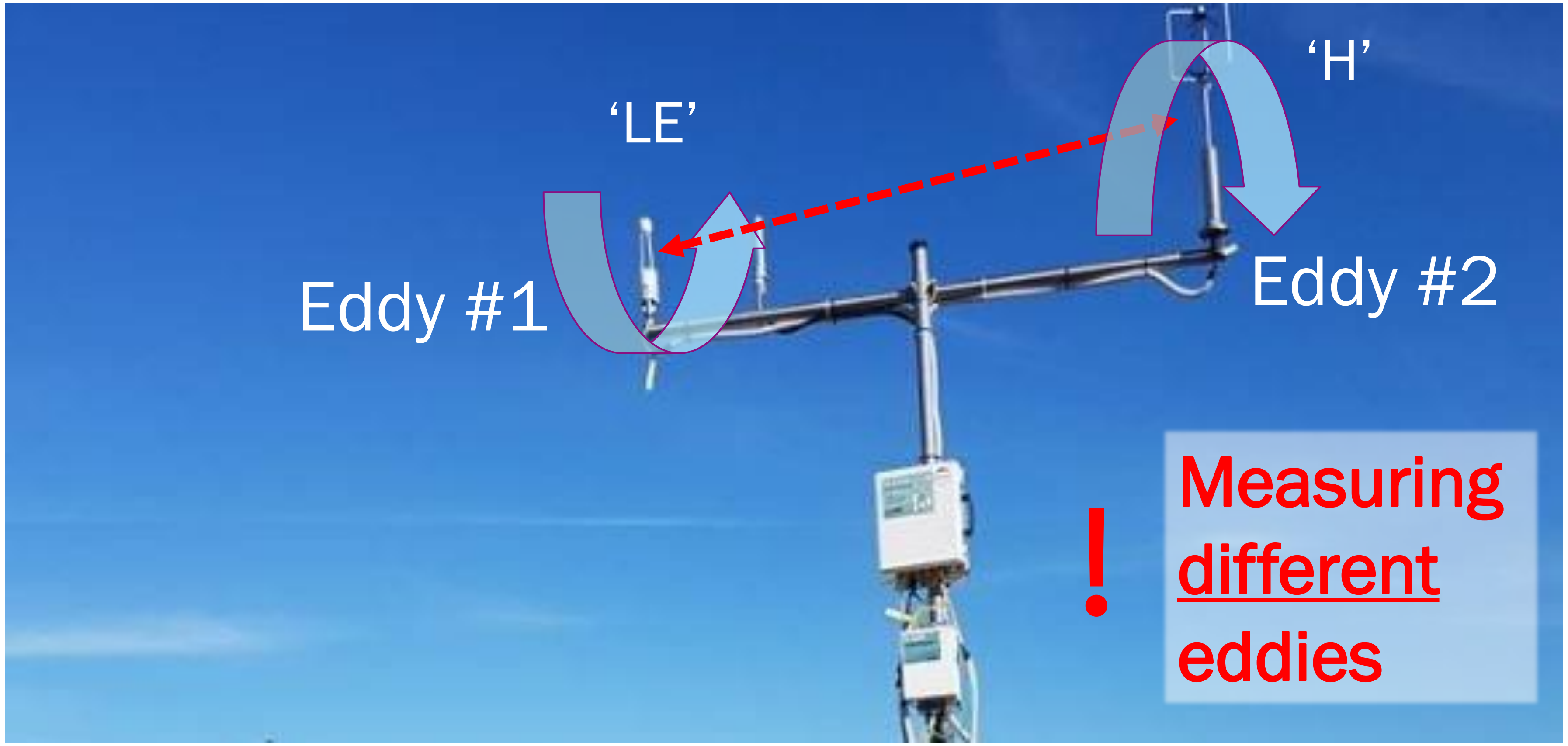
Cause of imbalance	Examples
Sampling	Source areas differ
Instrument bias	Net radiometer biased
Neglected energy sinks	Storage above soil heat plates
High/low frequency loss	Sensor separation/large eddies
Advection	Regional circulation

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

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

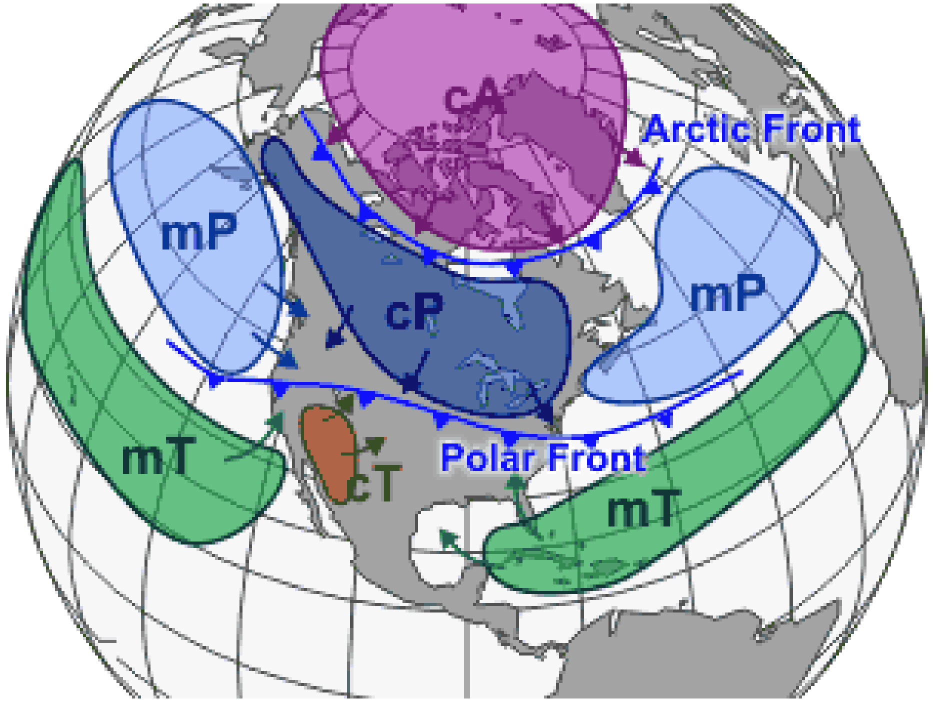
- If separation is too big, H and LE are not from the same eddy and covariance is lost, creating an energy imbalance

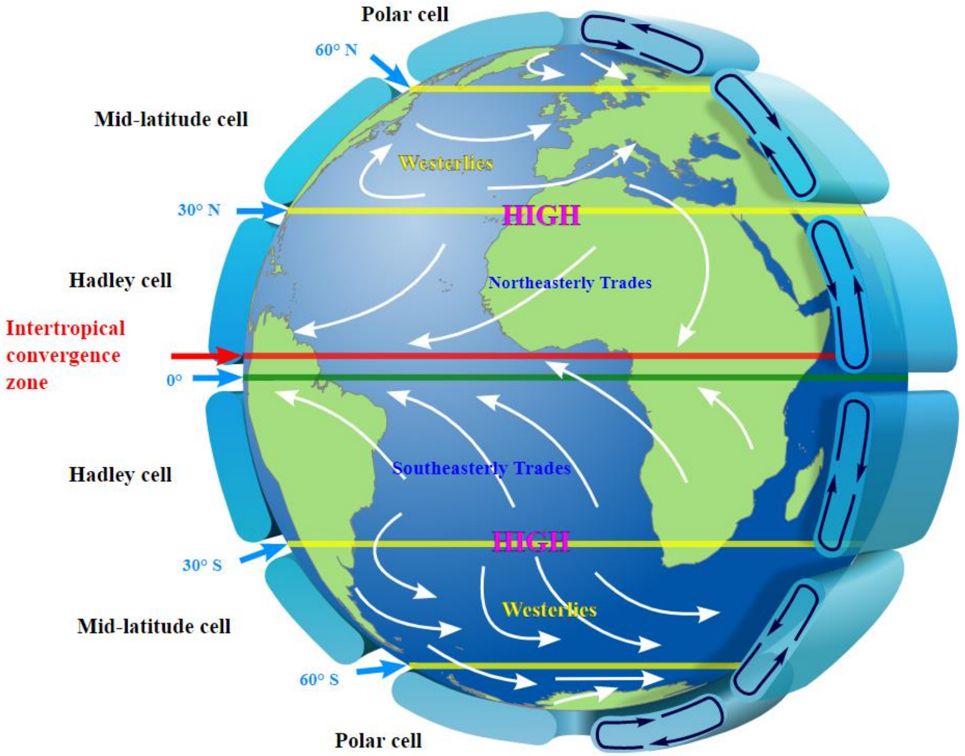




Large, slow-moving structures can cause the loss of low frequency energy terms

- Large (synoptic) Scale, slow-moving structures transport portions of H and LE on scales longer than 30 minutes, creating residual energy terms





This can be corrected in post-processing of the data

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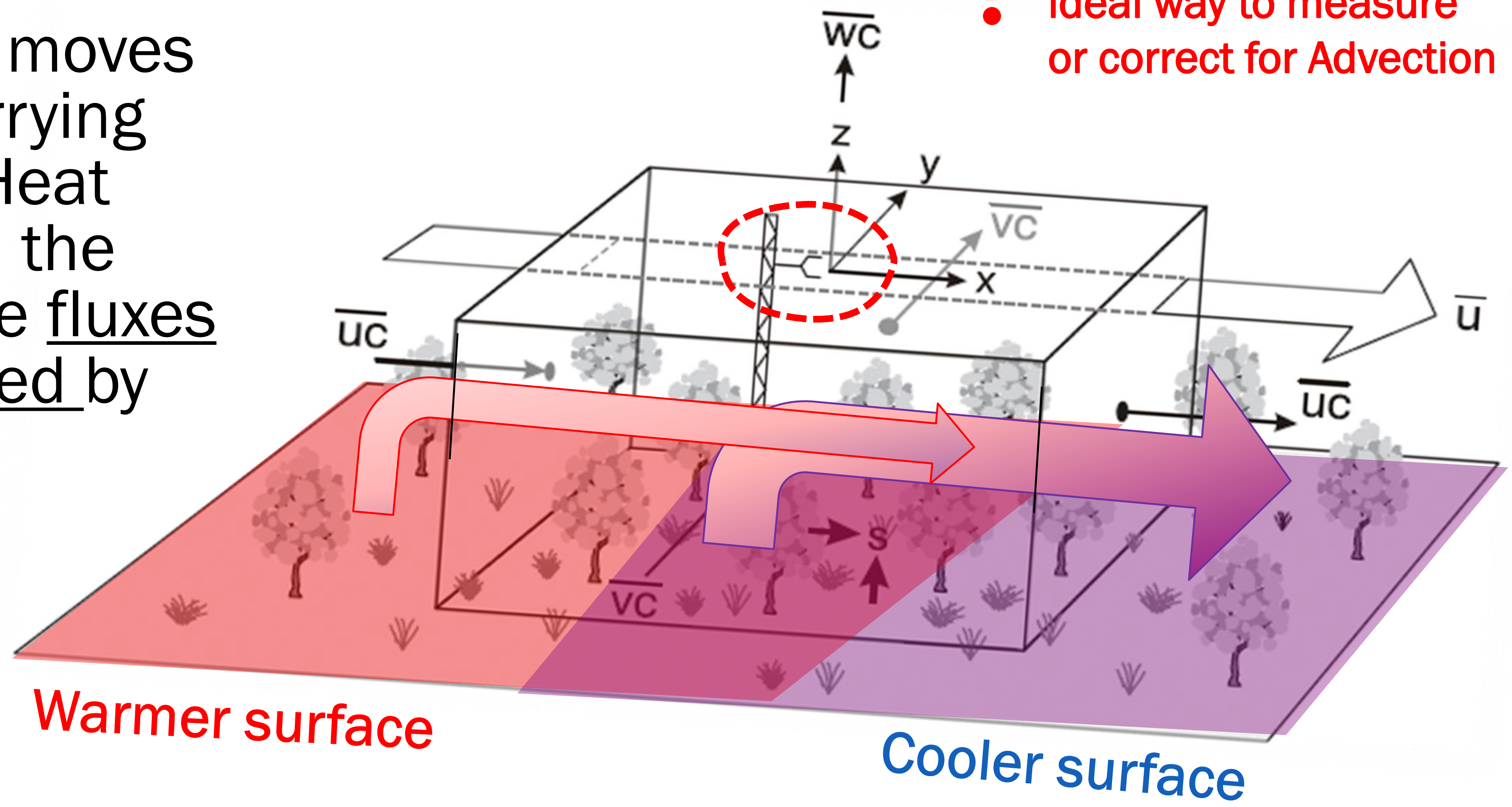
How Advection can cause an imbalance in the energy balance closure

- Air mass slowly moves horizontally, carrying CO_2, H_2O, and Heat Energy beneath the tower, and these fluxes are not measured by the EC System

! There is still not an ideal way to measure or correct for Advection



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Summary – how can we obtain better Energy Balance closure for flux verification?

- Biomet Sensors can collect Energy Balance terms
- A lack of energy balance closure may indicate that CO_2 and H_2O flux estimates may be in error; however, it is not conclusive.
  - Errors in the Biomet measurements can give false errors of flux estimates.
  - Additional measurements (storage) may be needed
  - Biomet Sensors need to be installed correctly
- In general, Biomet variables and eddy covariance variables (H and LE) together can be a used to verify CO_2 and H_2O measurements and subsequent computed fluxes.

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Why collect Biomet measurements?

- Quality Assurance and Quality Checking (QA/QC)
  - Energy Balance closure.
- Recording weather helps to explain site behavior
  - The physical environment has profound effects on the biology as well as on the surface-atmosphere exchange.
- For Data Analysis
  - Gap filling – When instrumentation or power fails.
  - Partitioning – separating NEE into GPP and R_{ECO}
- Improving Fluxes

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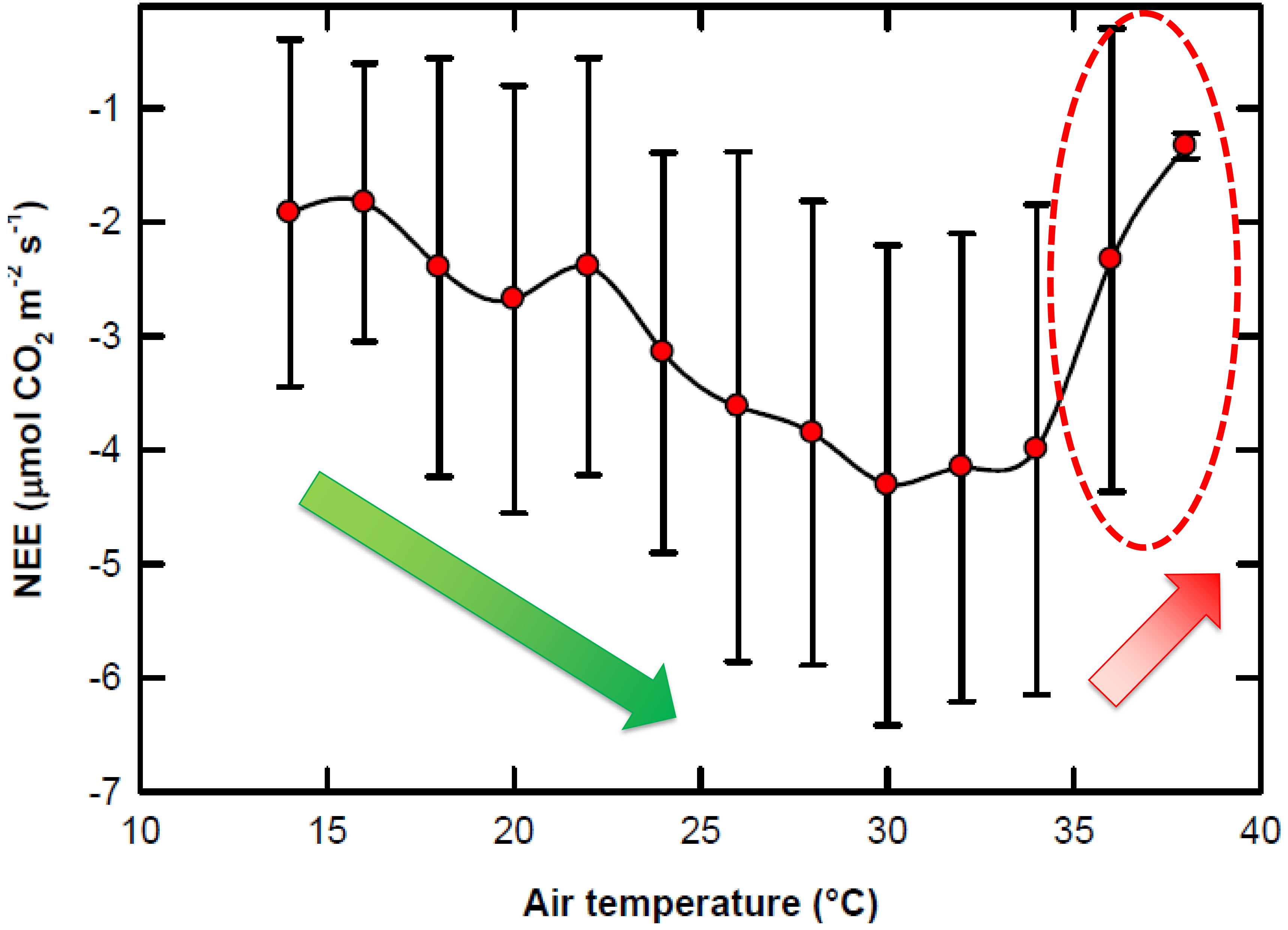
Example; how air temperature can affect fluxes

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



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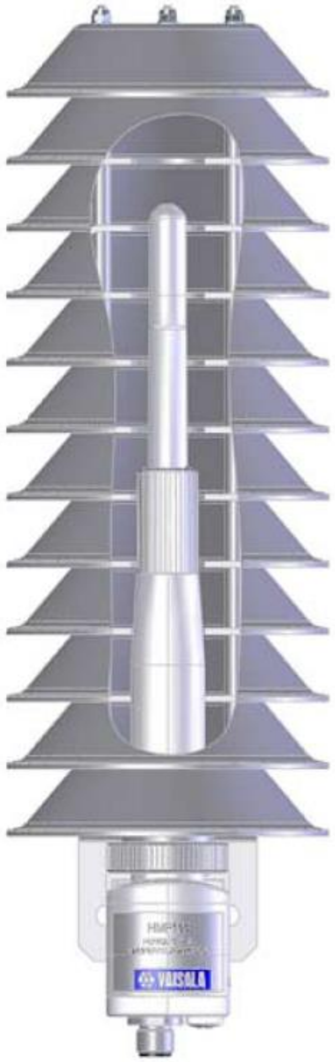
Measuring Air Temperature

Humidity and Temperature Probe
Vaisala HMP155 with RM Young Radiation Shield



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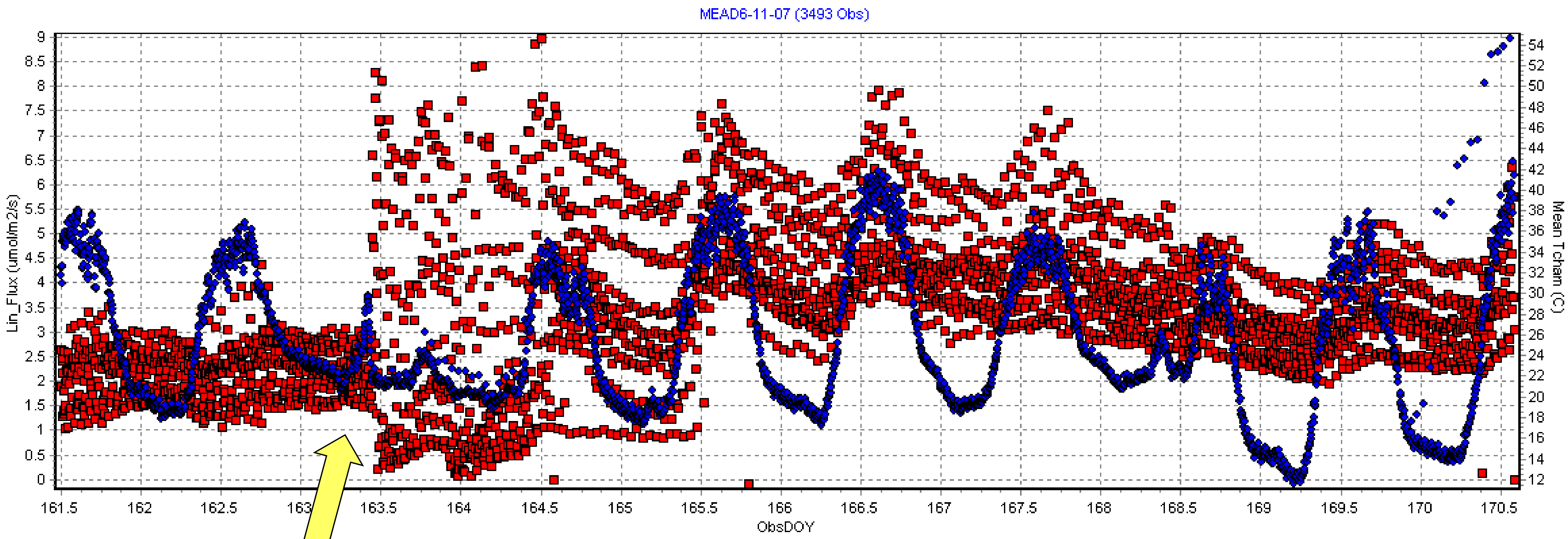
Example; how rainfall can affect fluxes

- We can see that CO_2 Soil efflux from the soil is dramatically altered after a rain event



Rain event

Soil Flux measurements taken with a 16-Chamber, Multiplexed System.

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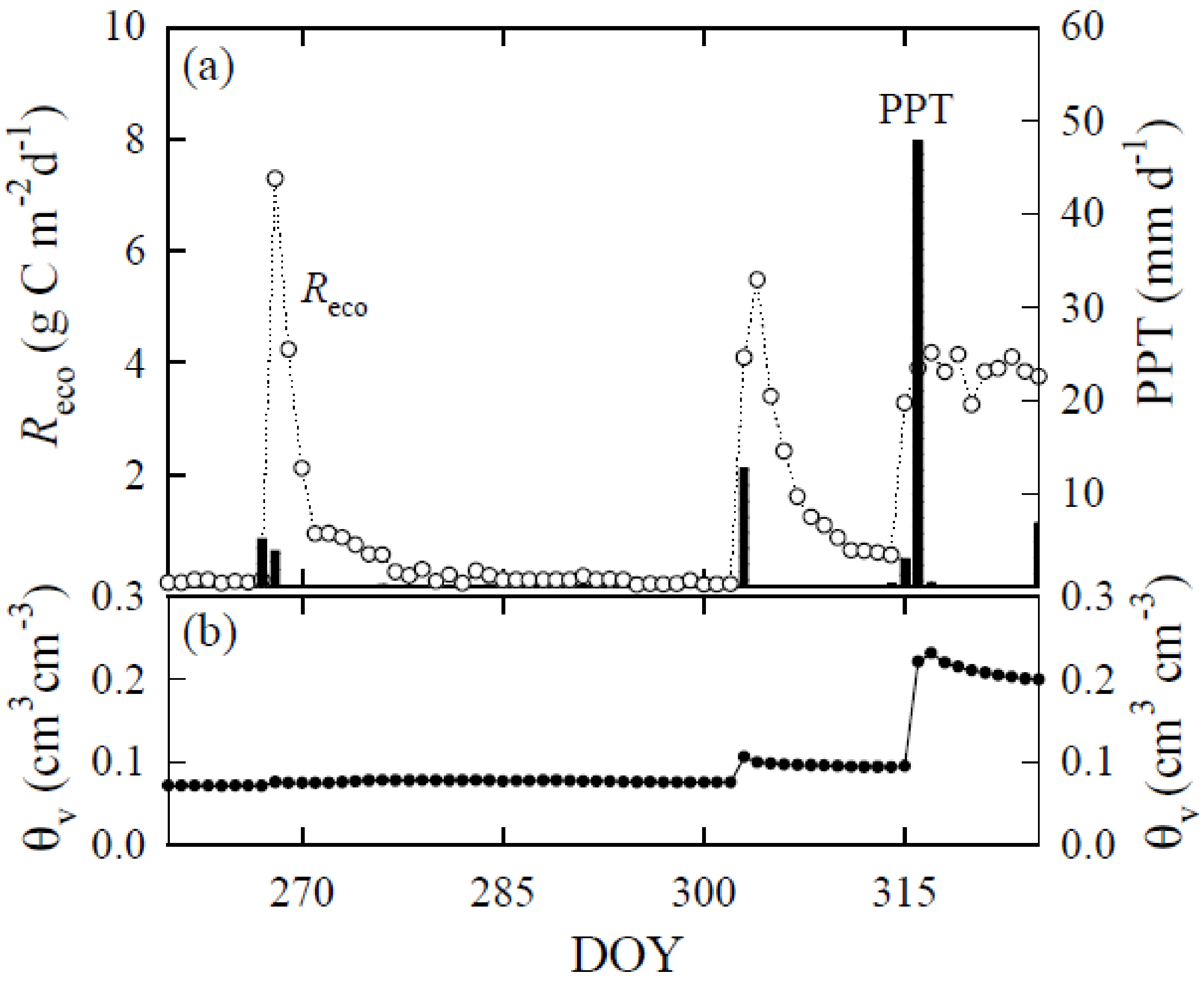
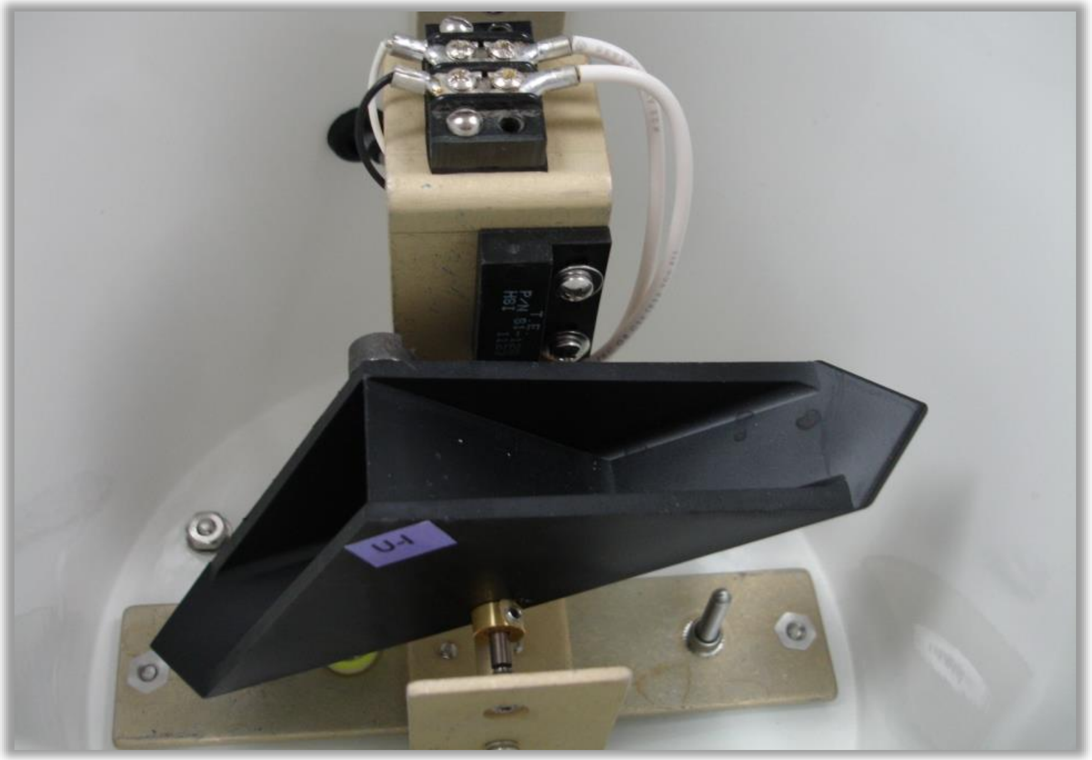
Example of long-term flux data - California grassland



Xu and Baldocchi, 2004

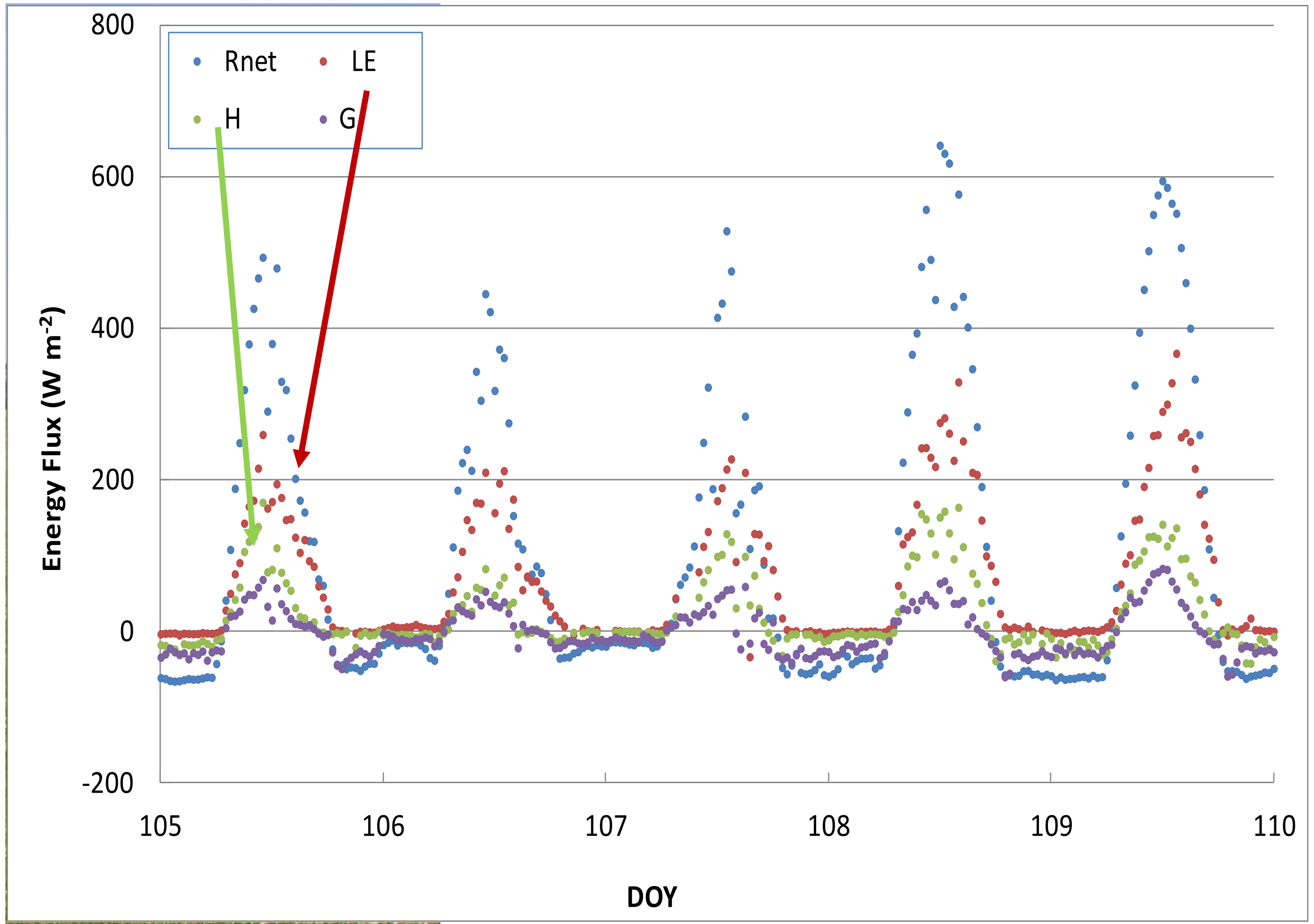
Precipitation Gauges measure rain and/or snowfall

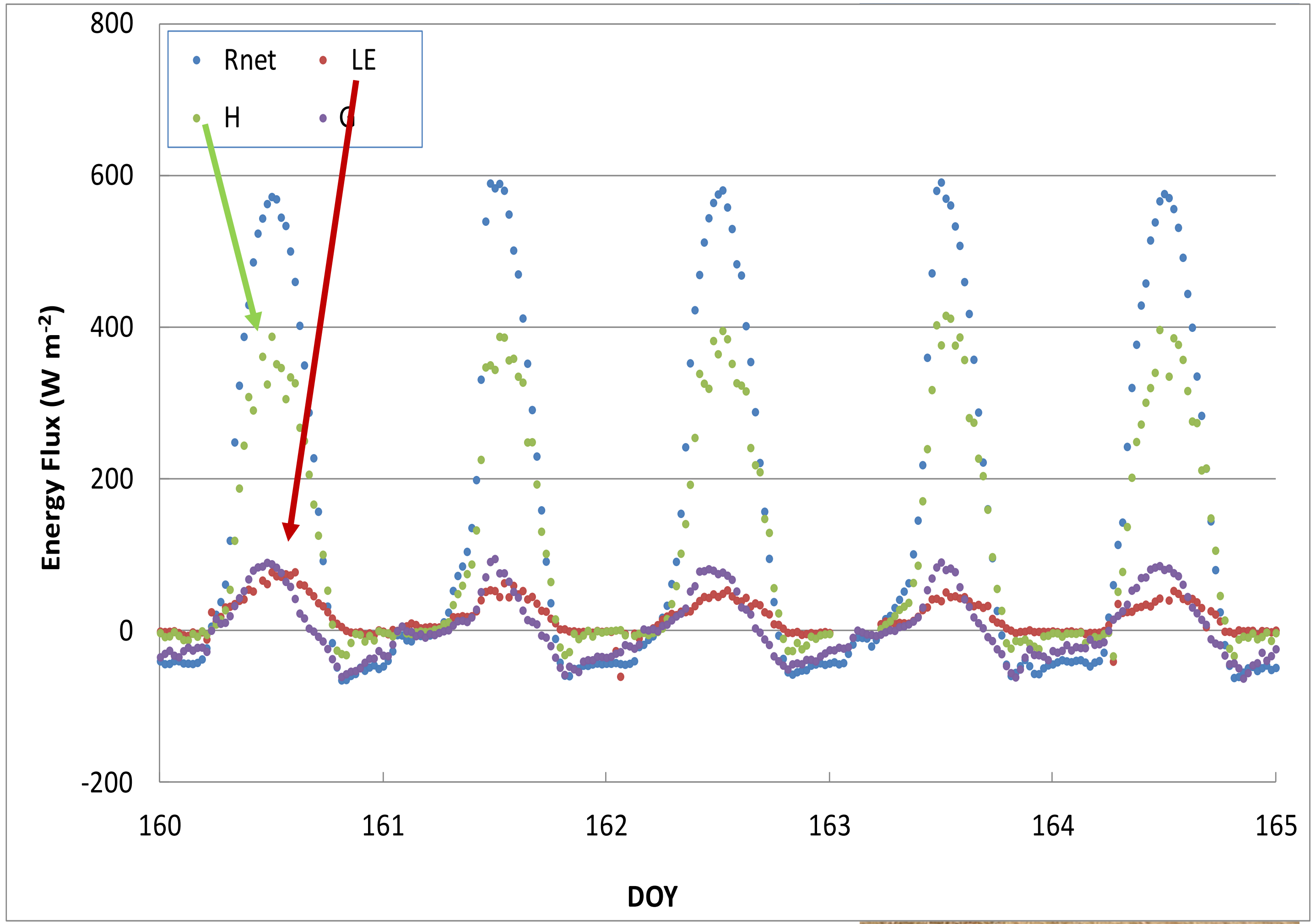
Texas Electronics
TRM25
Tipping Bucket Rain Gauge



Precipitation Gauge TR-525M Specifications:	
Resolution:	0.1 mm (0.004 in)
Accuracy:	1.0% up to 50 mm/hr (2 in/hr)
Collector diameter:	245 mm (9.66 in)
Operating Temperature Range:	0 to 50° C
Switch:	Momentary potted reed
Switch Rating:	30 VDC @ 2A
Switch Closure Time:	135 ms

Example, how soil moisture can affect fluxes





Spring

Energy partitioning depends on availability of soil moisture

Summer

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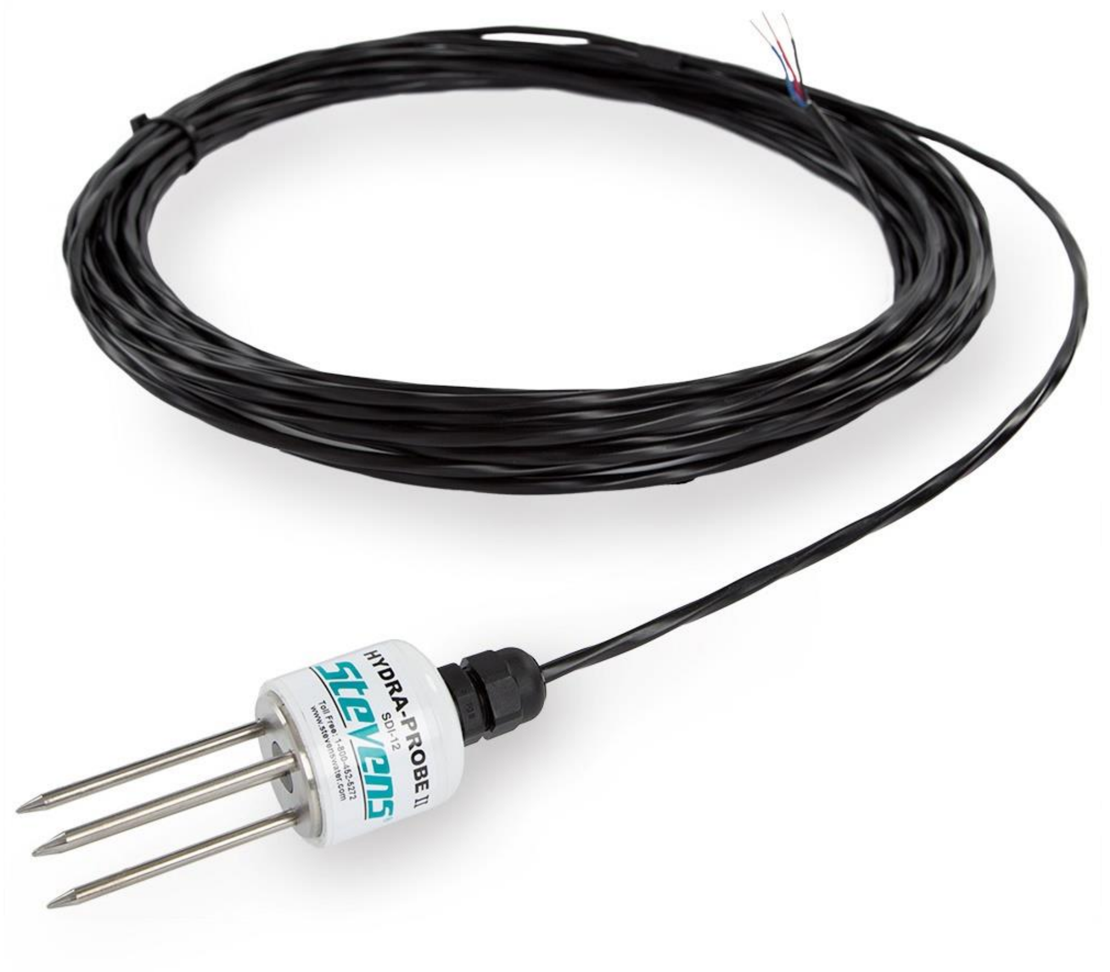
Soil moisture sensors

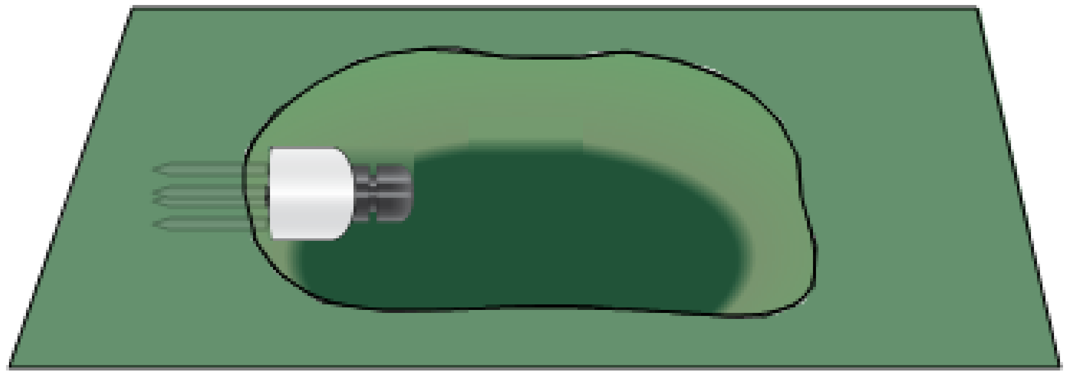
Steven’s Hydra Probe II

- Soil Moisture
- Soil Temperature
- Soil Conductivity
- Salinity



Soil moisture sensor - Installation

- Due to spatial variations in soil, a minimum of 3 Probes are needed, more are better
- Press the probe into the soil until the rods are completely under the soil surface
- Air pockets around the rods will reduce the accuracy
- Be especially careful to avoid creating air pockets when re-inserting the probe into previously used holes



Why collect Biomet measurements?

- Quality Assurance and Quality Checking (QA/QC)
  - Energy Balance closure.
- Recording weather helps to explain site behavior
  - The physical environment has profound effects on the biology as well as on the surface-atmosphere exchange.
- For Data Analysis
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  - Partitioning – separating NEE into GPP and R_{ECO}
- Improving Fluxes

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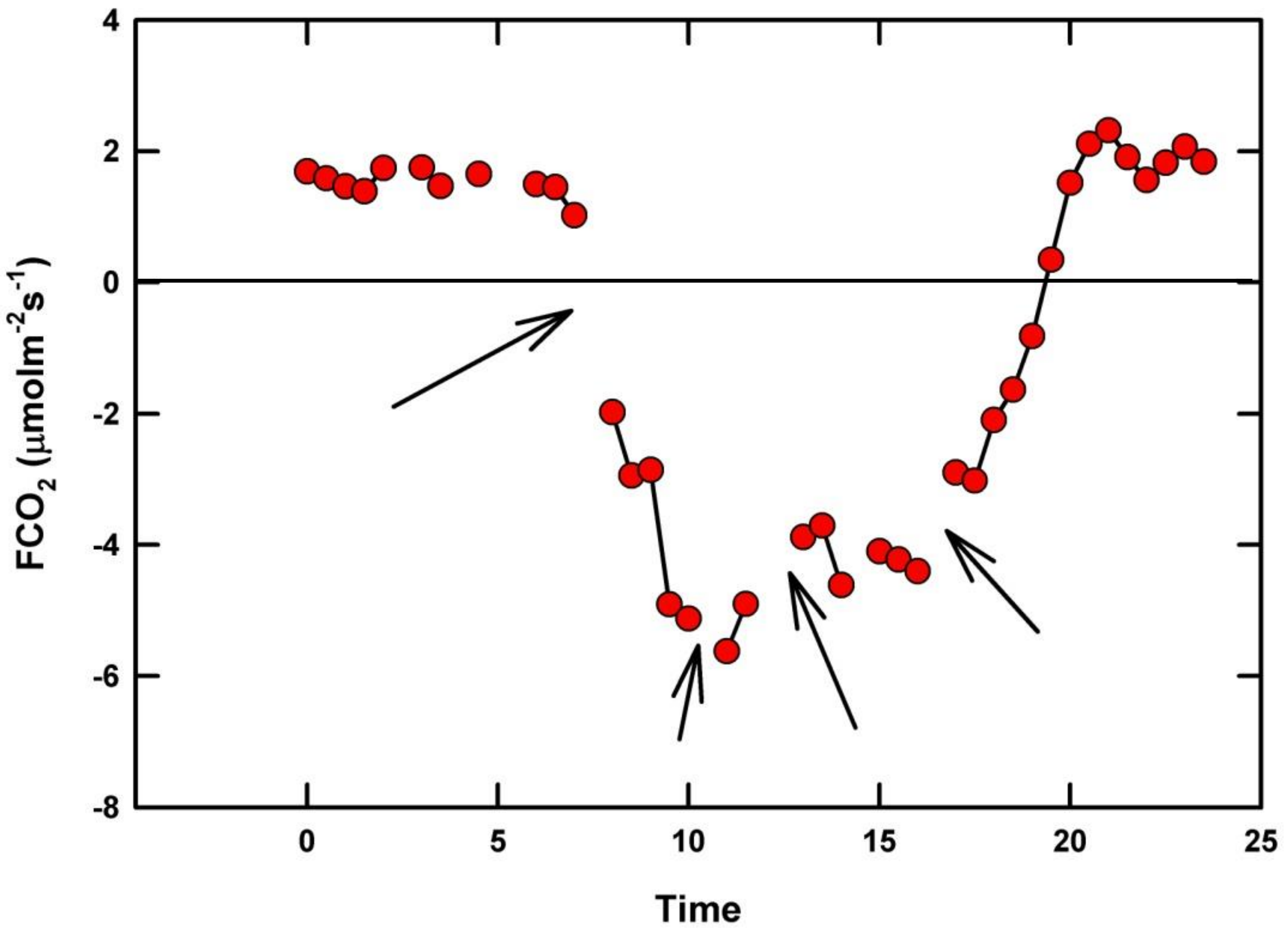
Filling data gaps in your flux measurements

Gaps in the flux data occur due to:

- Sensor failure
- Power supply issues
- Data flagged for bad quality
- Spikes due to rain events
- Data flagged for low windspeed or turbulence

Smaller gaps (0.5 - 1 hour) in a diurnal curve



✓ *Smaller gaps* can be filled using interpolation techniques

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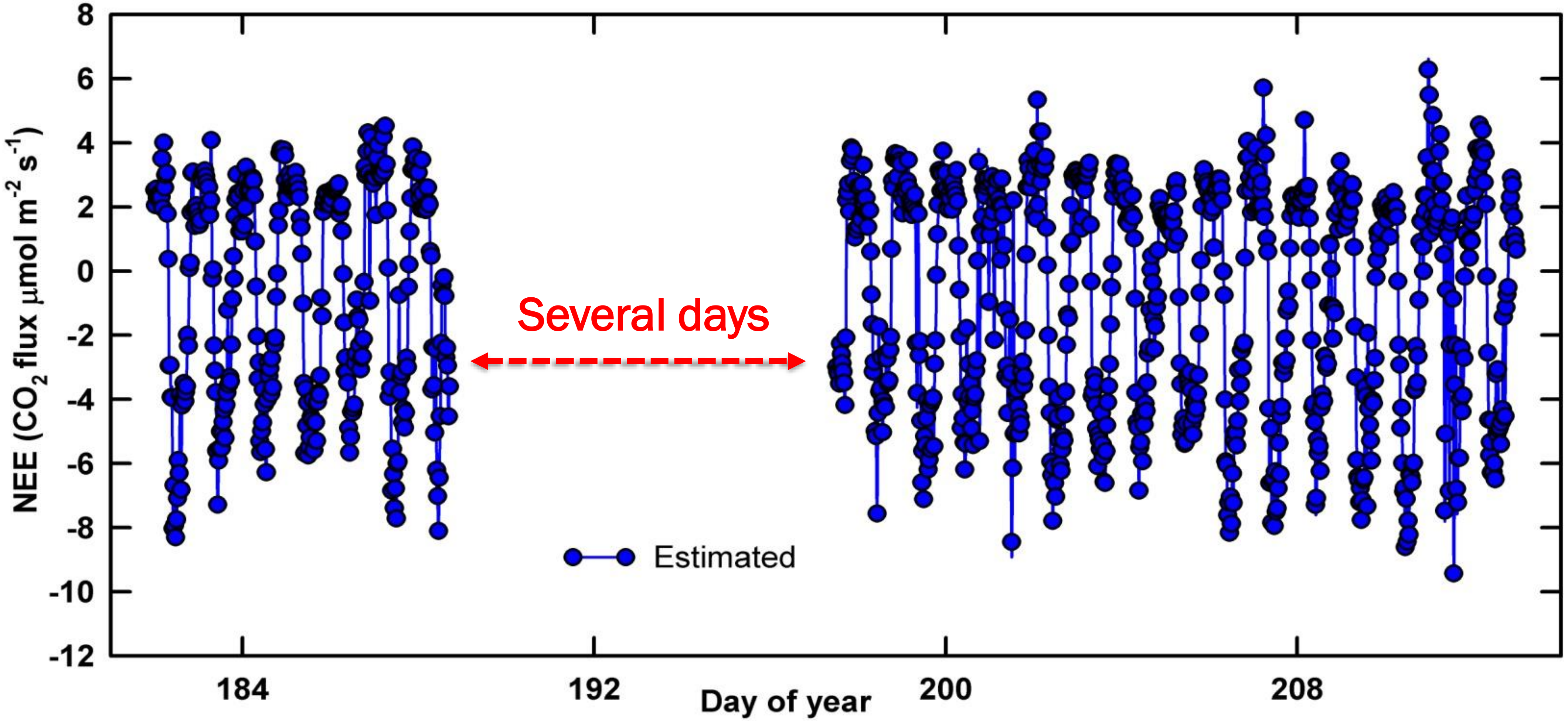
Filling data gaps in your flux measurements

Larger data gaps (days)



! Larger gaps cannot be filled using interpolation

✓ *Larger gaps* can be filled using other techniques

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A few Flux Gap Filling techniques

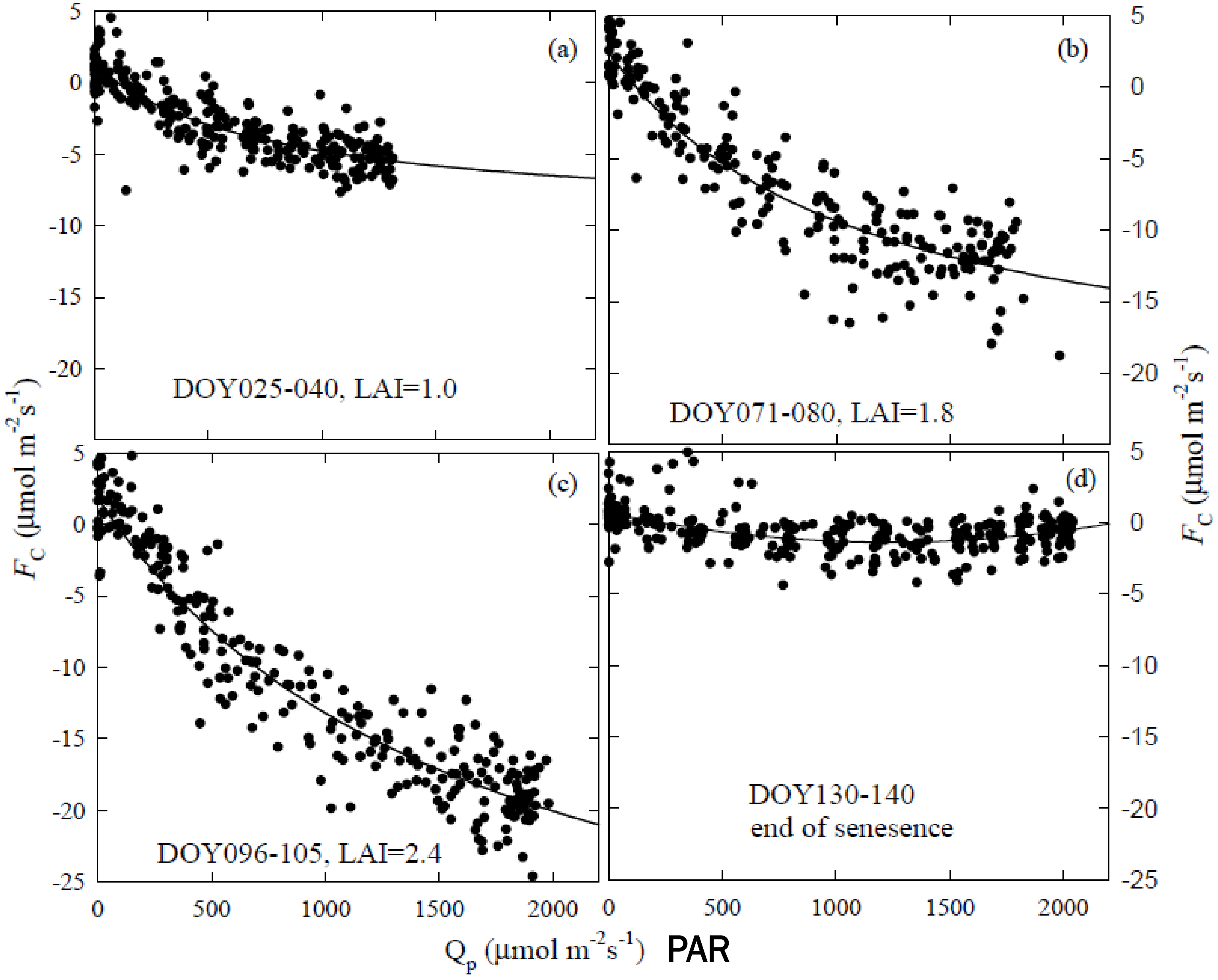
- Mean Diurnal Variation: Use data from similar days for gap filling
- Look-Up Tables: Multidimensional tables are created for gap filling
- Artificial Neural Networks: Empirical non-linear regression models
- Non-linear Regression: Models relating NEE to PAR and Respiration to Soil Temperature

Examples using ***Biomet*** *variables:*

$$NEE = \left[\frac{a \times PAR}{a / b + PAR} \right] + c$$

$$R_e = R_{Tref} \exp\left[\left(\frac{E_a}{T_{ref} \times R} \right) \times \left(1 - \frac{T_{ref}}{T_{soil}} \right) \right]$$

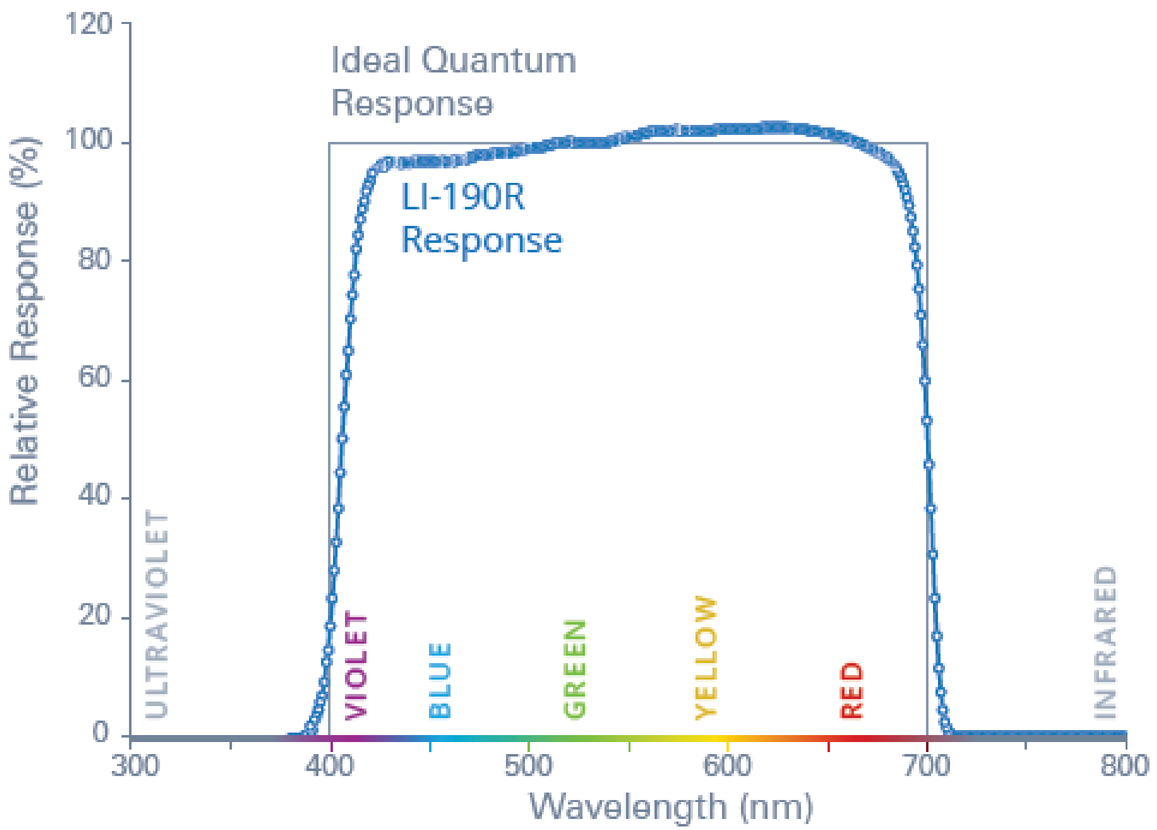
Example; gap filling using PAR as a driver for FCO_2



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

✓ Seasonal relationships between *PAR* and CO_2 *flux*

PAR - Quantum Sensor LI-190R



Typical values: 0 – 2000 µmol m-2 s-1

PAR - Quantum Sensor LI-190R

Installation

- Never under a shadow, either from the surrounding landscape elements or from the tower
- Mount the sensor on the tower to minimize reflected radiation that is visible to the sensor
- Mount leveled

Maintenance

- Keep domes, windows, and absorbers clean.
- Keep level.
- Recalibrate every two years.

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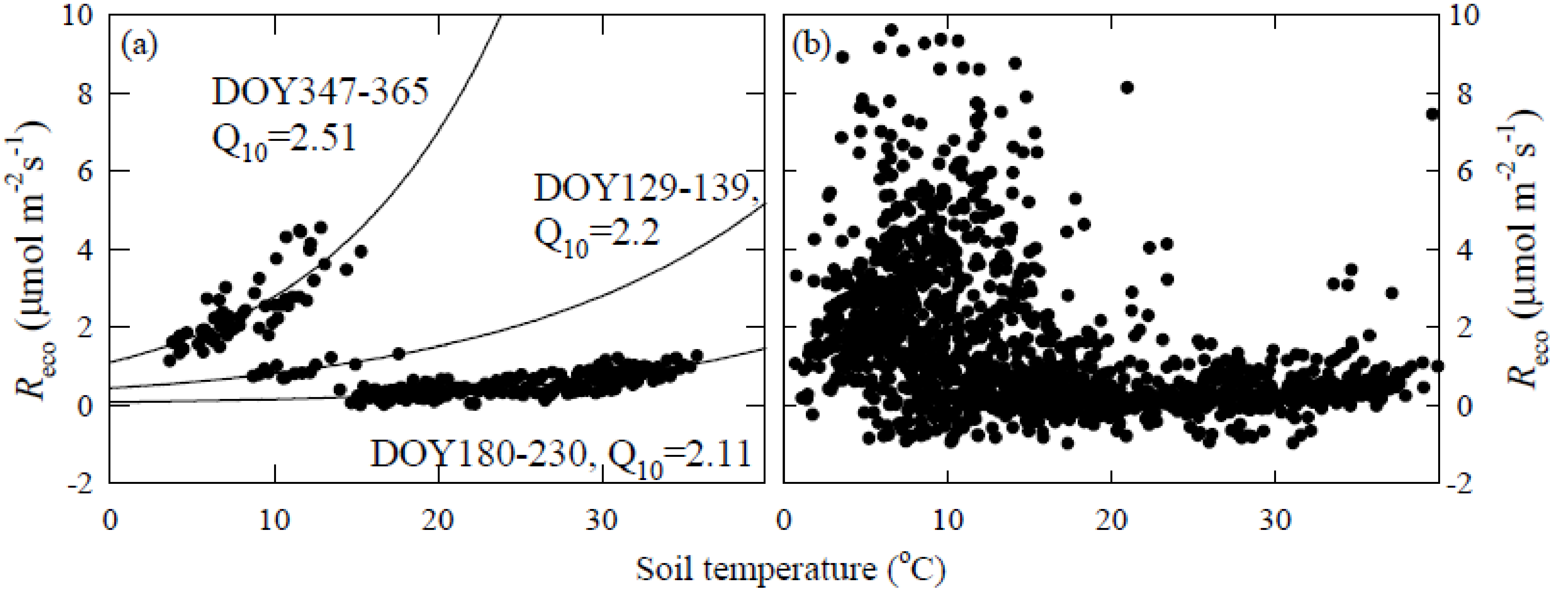
Example; gap filling using Soil Temperature as a driver for Ecosystem Respiration



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

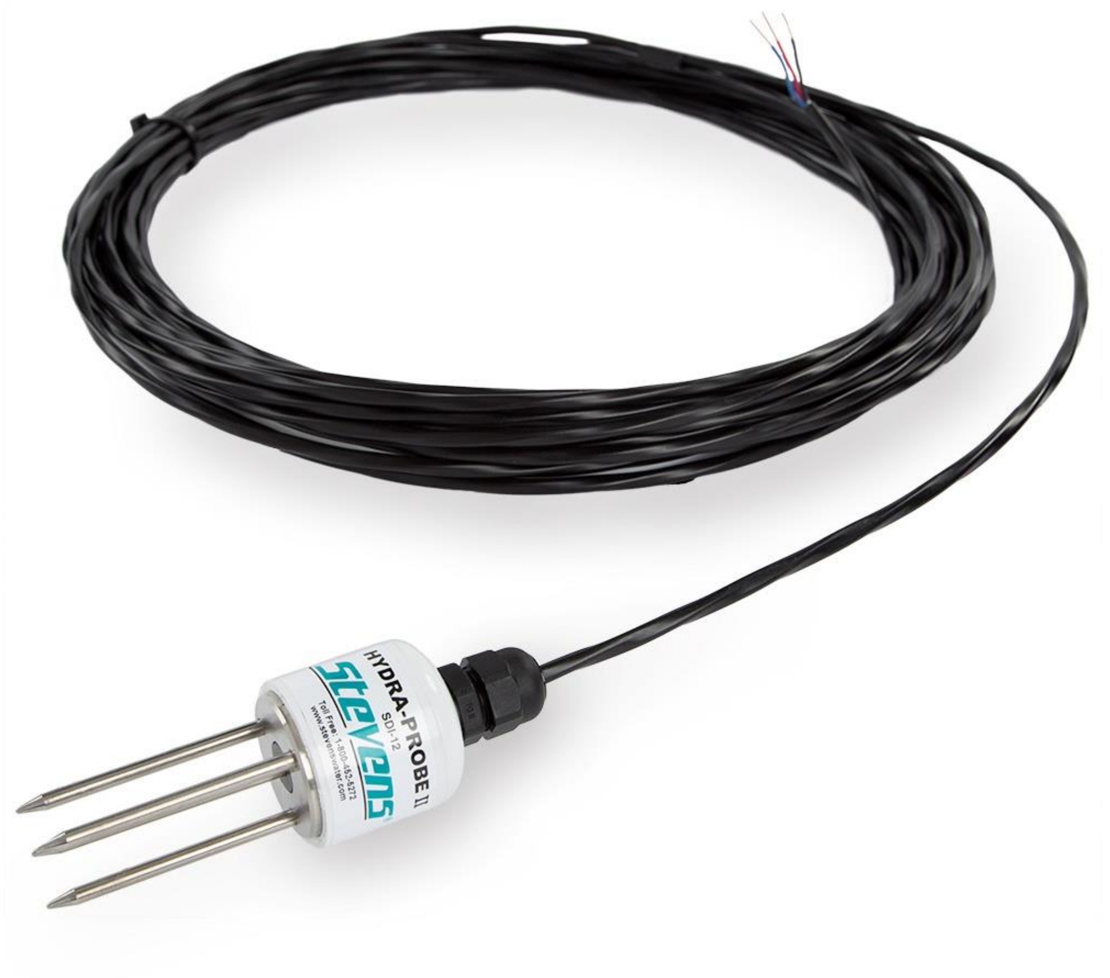
$$Q_{10} = \exp(10b)$$

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

Soil moisture sensors

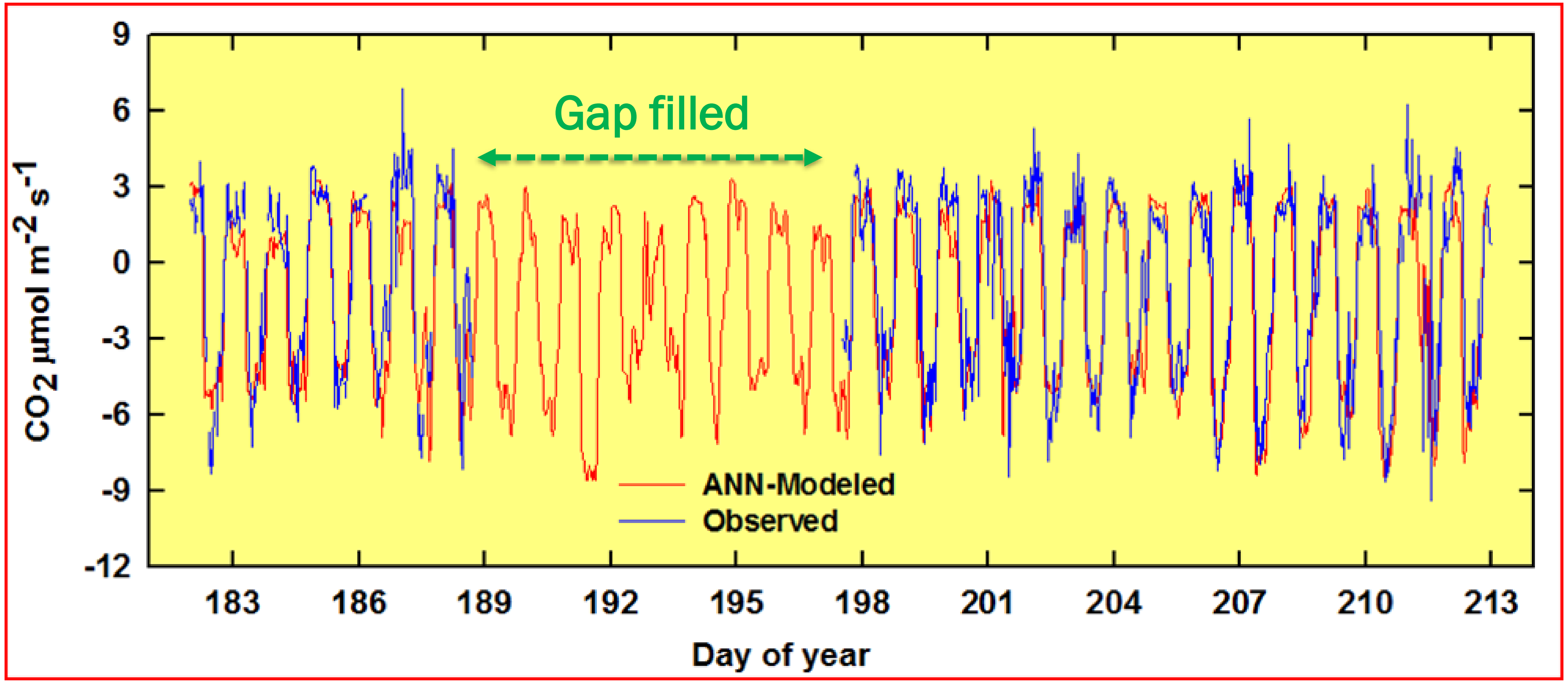
Steven's Hydra Probe II

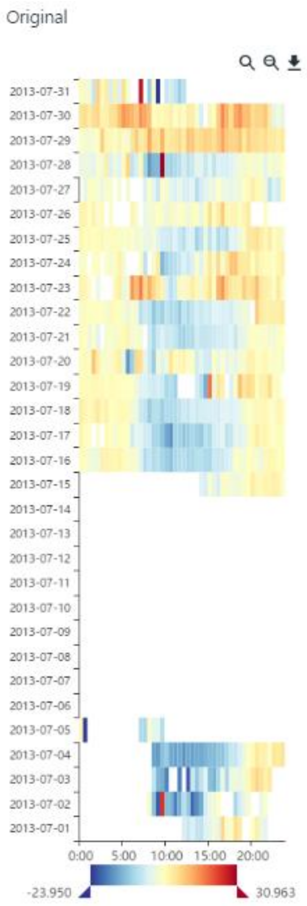
- Soil Moisture
- Soil Temperature
- Soil Conductivity
- Salinity

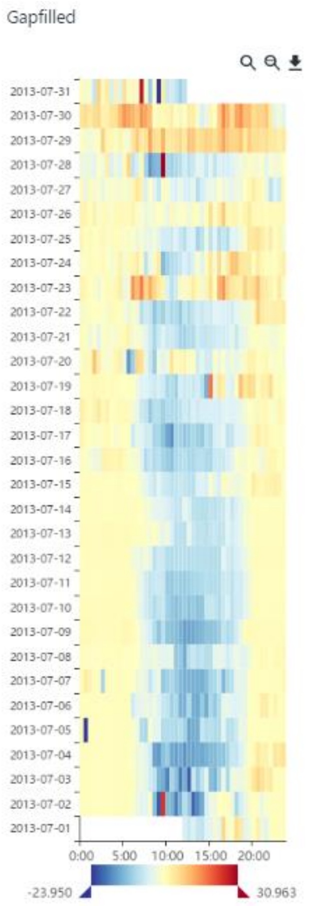


Example, large gap (days) in fluxes filled using Biomet variables

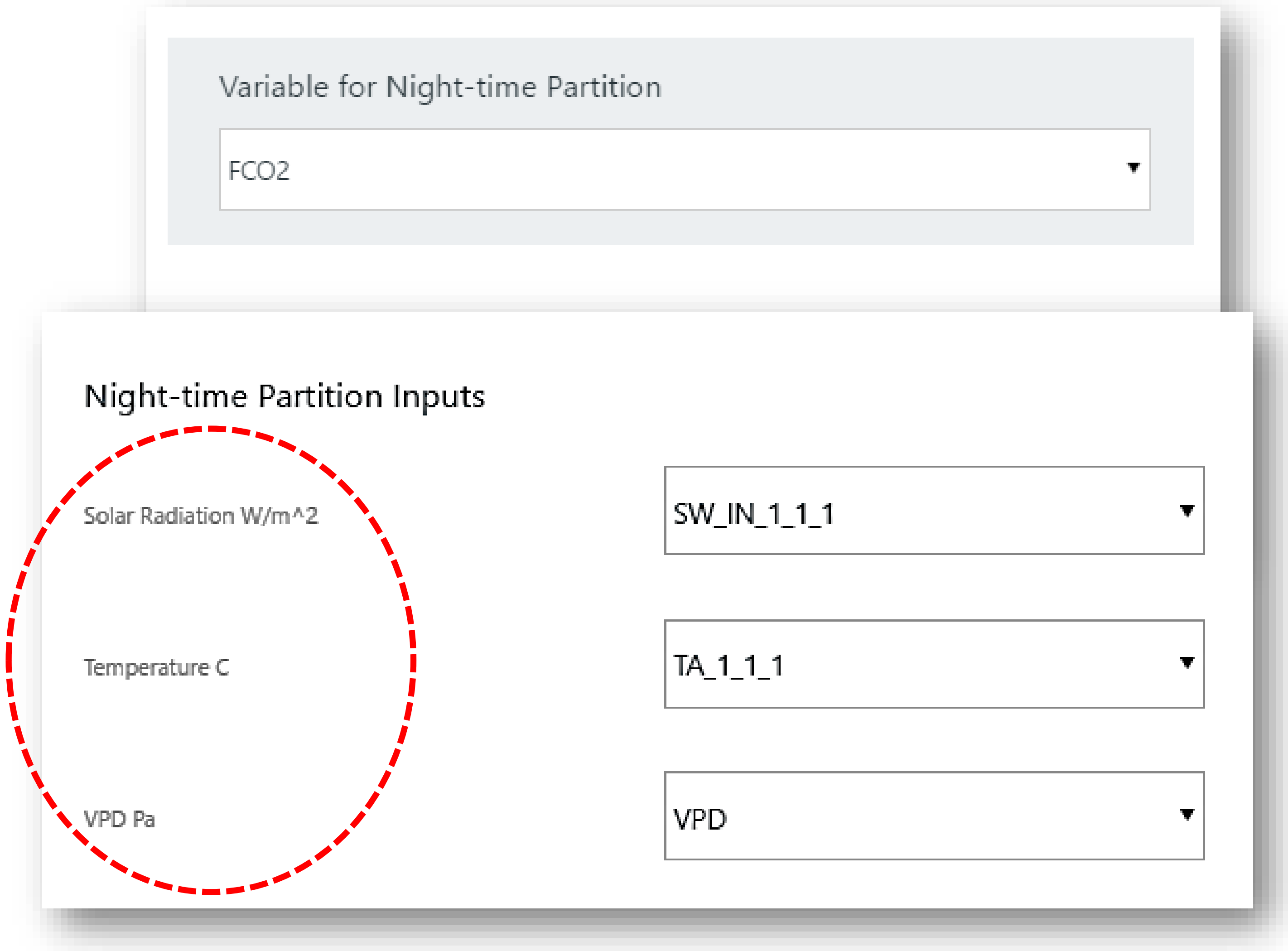
- *CO_2 Flux* modeled using PAR
- *Respiration* modeled using Ts

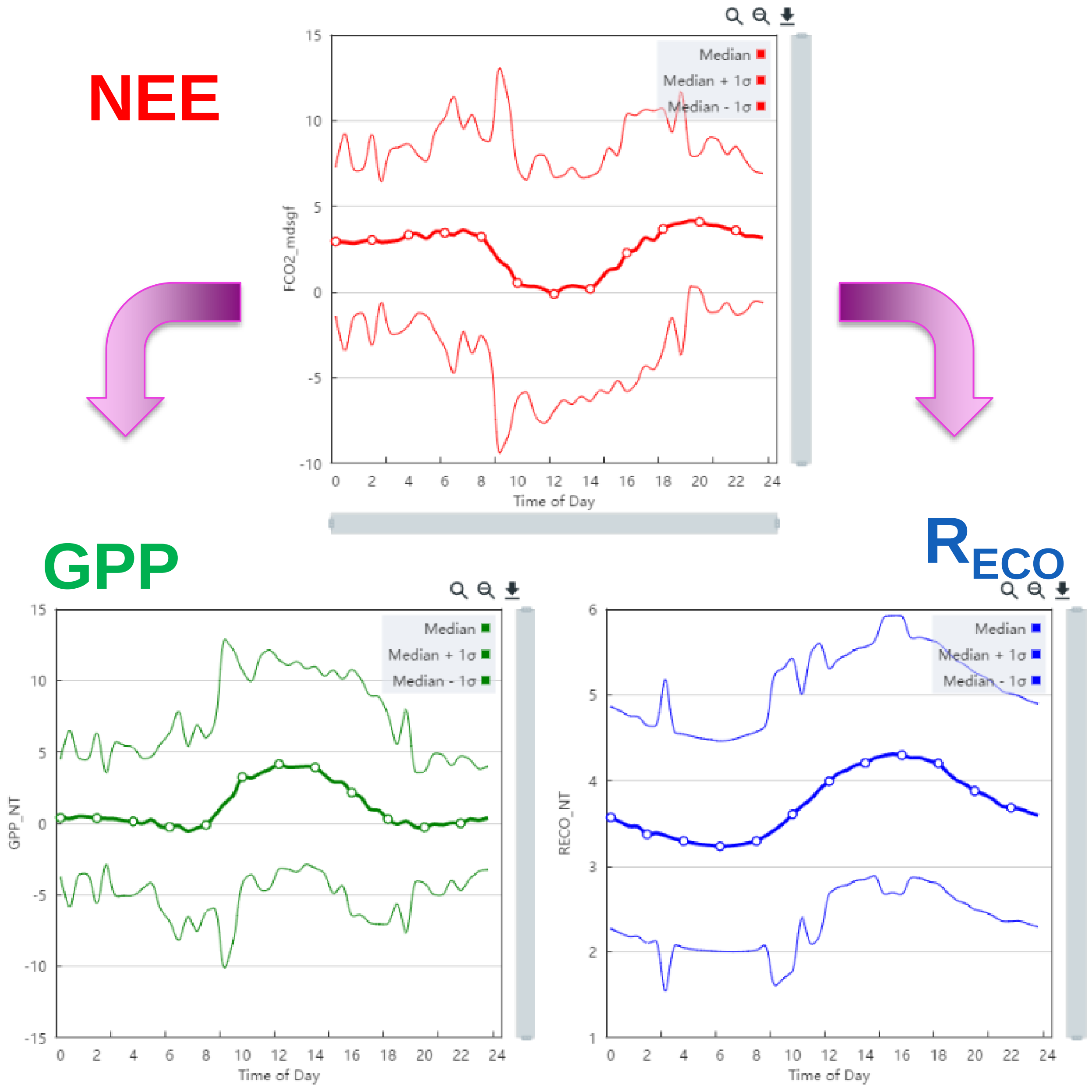






Biomet used for Partitioning...





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GHG Software Integration

- Some Biomet variables can improve flux estimates
  - Measured T_{AIR}, RH, and P can replace the mean calculated variables (for example, T_{SONIC})
  - Global radiation and long-wave incoming radiation can be used for off-season uptake correction
  - PAR can be used to assess day/night radiation load on the CO_2/H_2O analyzer

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Improving fluxes

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

- **Covariances**: calculated from fast measurement, acquired at frequencies > 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: $$F = F_o + \mu \frac{E}{\rho_d} \frac{\rho_c}{1 + \mu \frac{\rho_w}{\rho_d}} + \frac{H}{\rho_a C_p} \frac{\rho_c}{T_a} + P_{term}$$

Improving fluxes

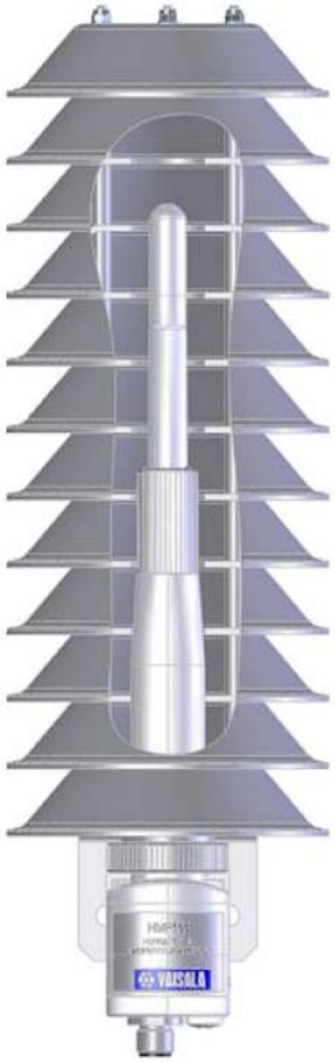
- Global (R_g), longwave incoming (R_l) radiations or PAR are needed in the off-season uptake correction of the LI-7500(A), Burba et al. 2008:

	Parameters for multiple regression* between T_s–T_a and T_a, R_g, R_l, U				
	Offset	Parameter 1 (for T_a)	Parameter 2 (for R_g)	Parameter 3 (for R_l)	Parameter 4 (for U)
Daytime					
T_s^{bot}–T_a	2.8	−0.0681	0.0021	–	−0.334
T_s^{top}–T_a	−0.1	−0.0044	0.0011	–	−0.022
T_s^{spar}–T_a	0.3	−0.0007	0.0006	–	−0.044
Night-time					
T_s^{bot}–T_a	0.5	−0.1160	–	0.0087	−0.206
T_s^{top}–T_a	−1.7	−0.0160	–	0.0051	−0.029
T_s^{spar}–T_a	−2.1	−0.0200	–	0.0070	0.026

*Multiple regression: daytime T_s–T_a = offset + parameter 1 × T_a + parameter 2 × R_g + parameter 4 × U; night-time T_s–T_a = offset + parameter 1 × T_a + parameter 3 × R_l + parameter 4 × U. All temperatures are in °C.

Improving fluxes

Humidity and Temperature Probe
Vaisala HMP155 with RM Young Radiation Shield



Thank You

Questions?