Biomet Measurements and Sensors

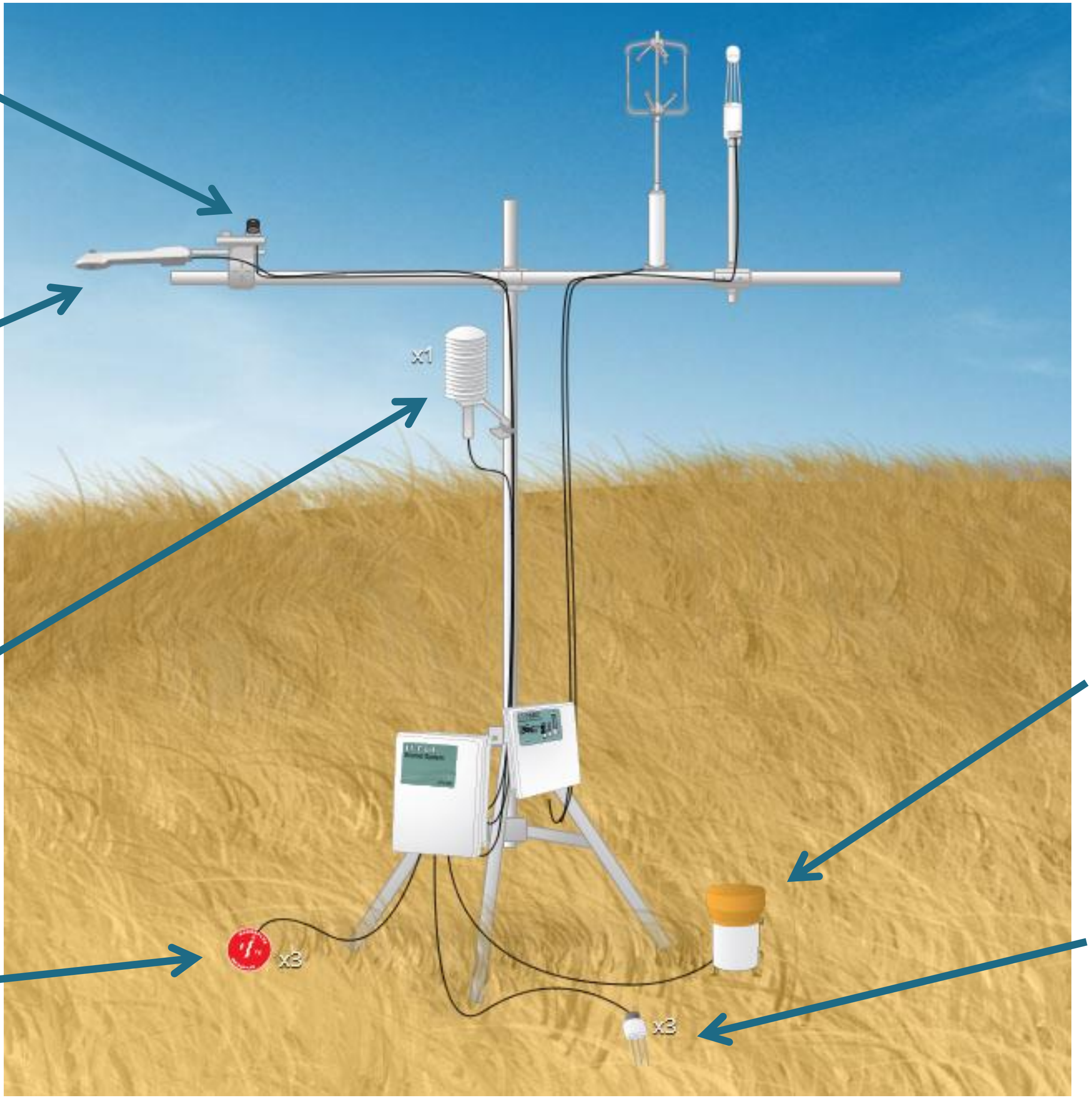
For Energy Balance Closure, Data Interpretation, Enhanced Flux Computations, and Gap Filling

LI-COR®

What are 'Biomet' Sensors?

- Sensors used for monitoring the environment (**bio**logical and **met**eorological).
- Typically measured once per second to once per minute.

Biomet Measurements

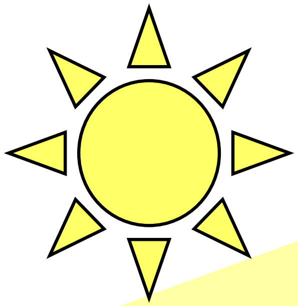


Biomet Sensors

- 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.
- Gap filling
  - When instrumentation or power fails.
- Improving Fluxes

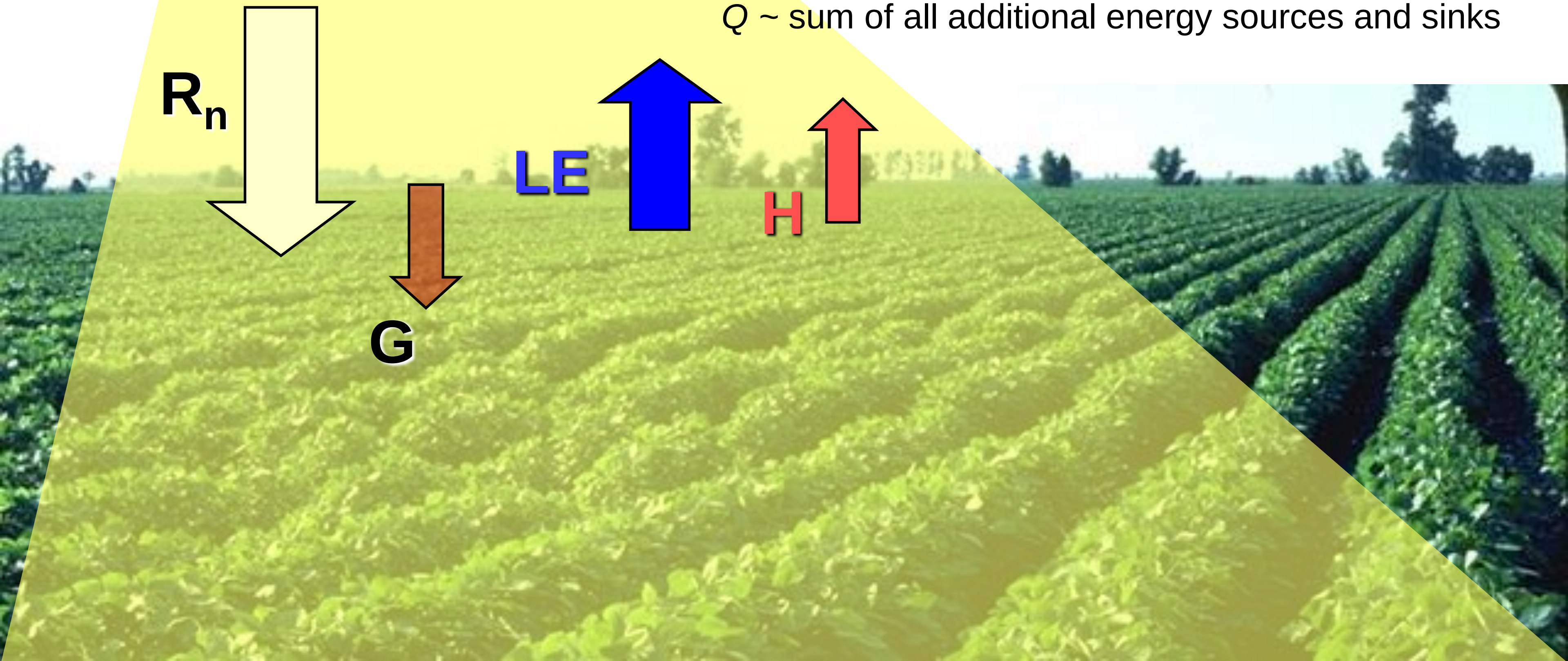


The Energy Budget (daytime)

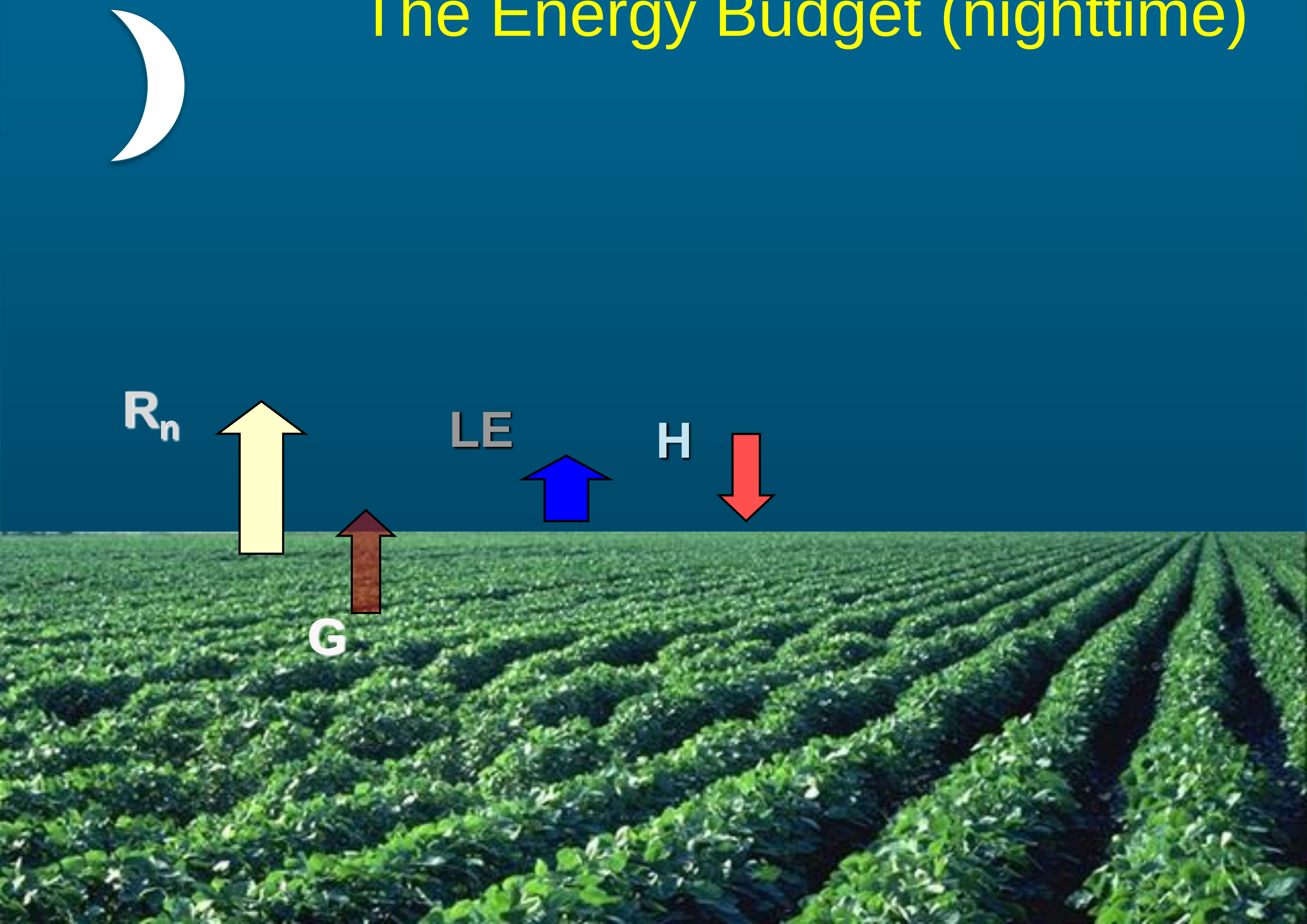
$$R_n = H + LE + G + S + Q$$

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)

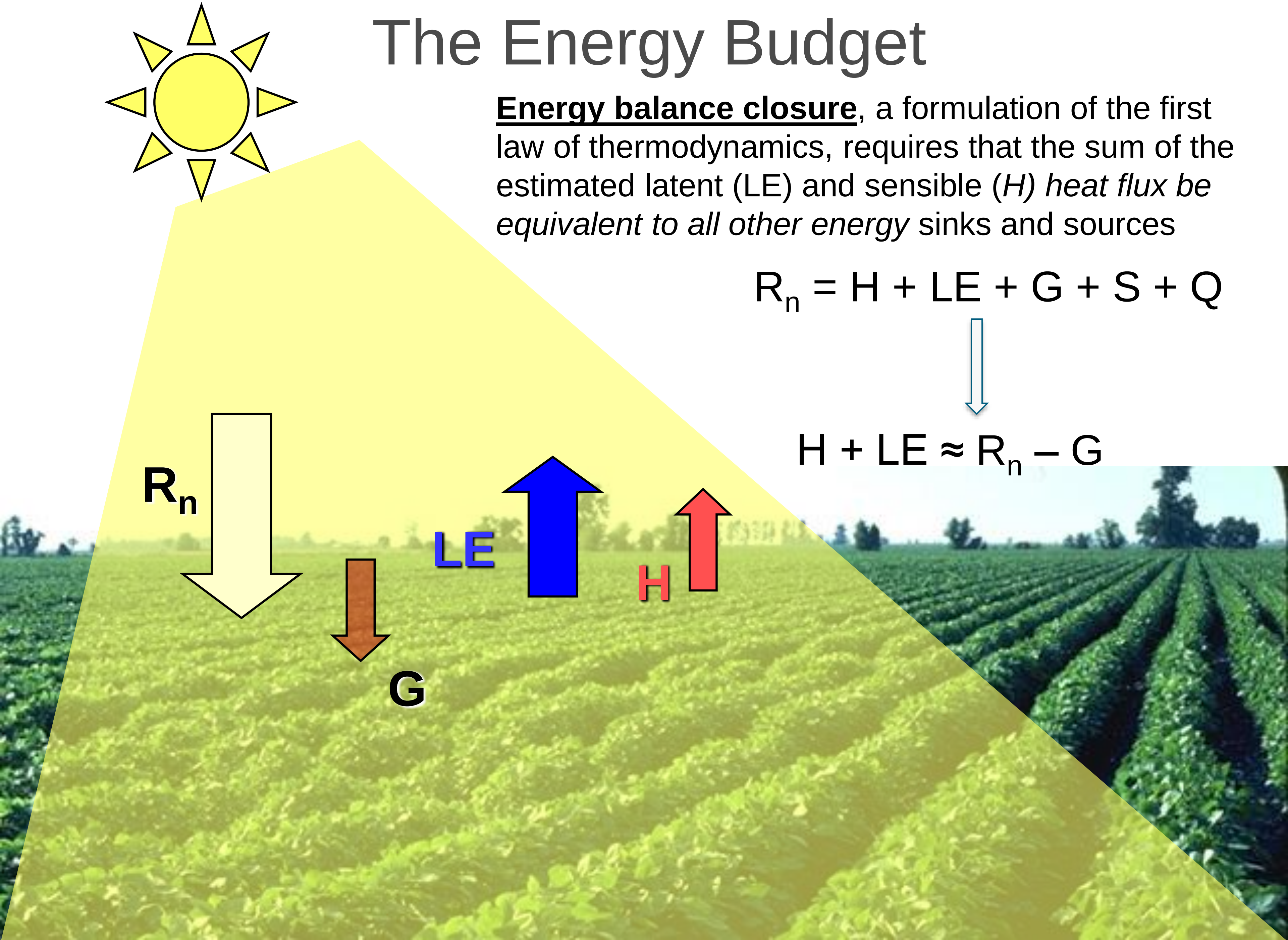


The Energy Budget

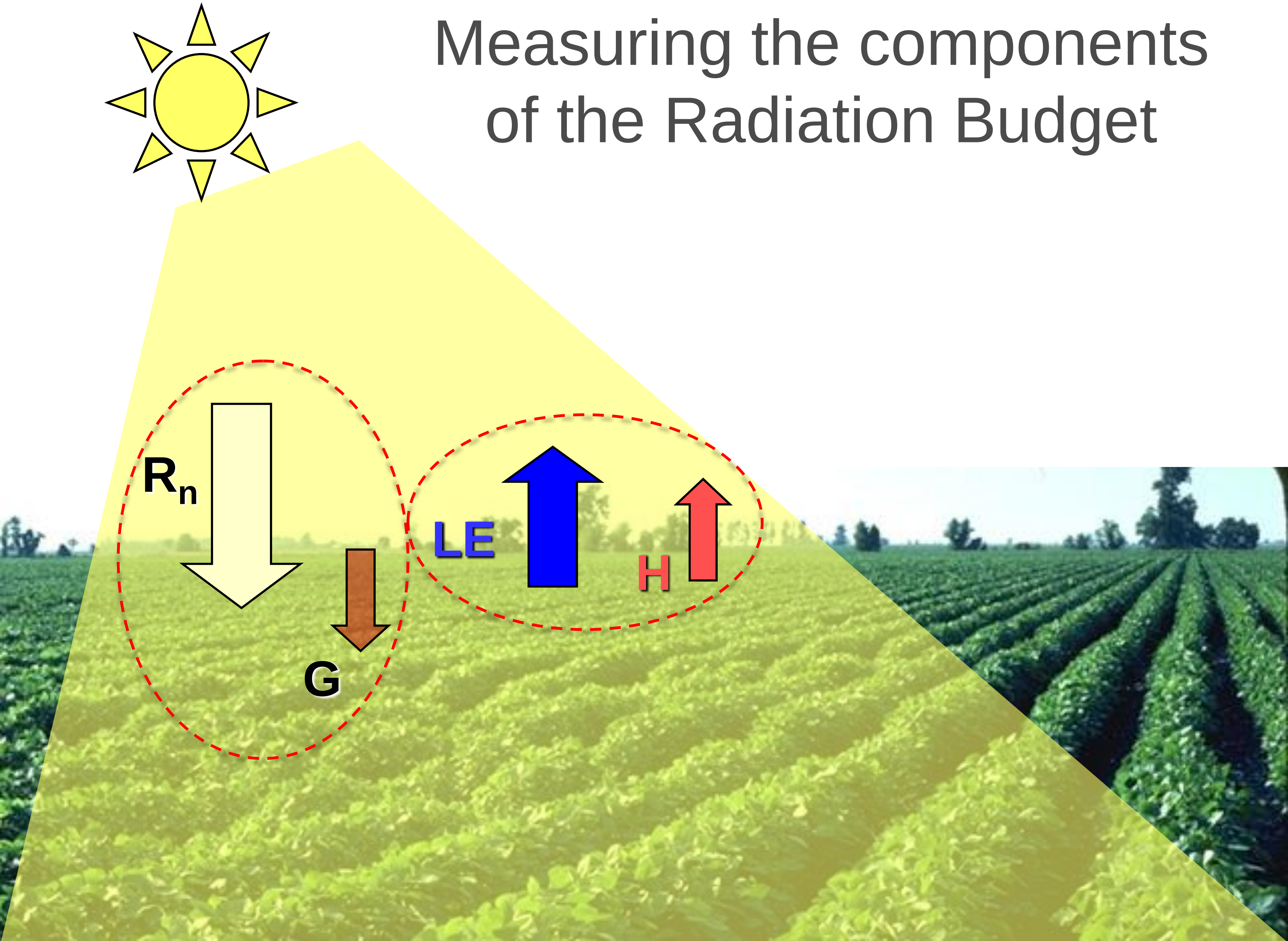
Energy balance closure, a formulation of the first law of thermodynamics, requires that the sum of the estimated latent (LE) and sensible (*H) heat flux be equivalent to all other energy* sinks and sources

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

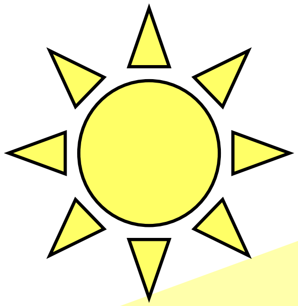
$$H + LE \approx R_n - G$$

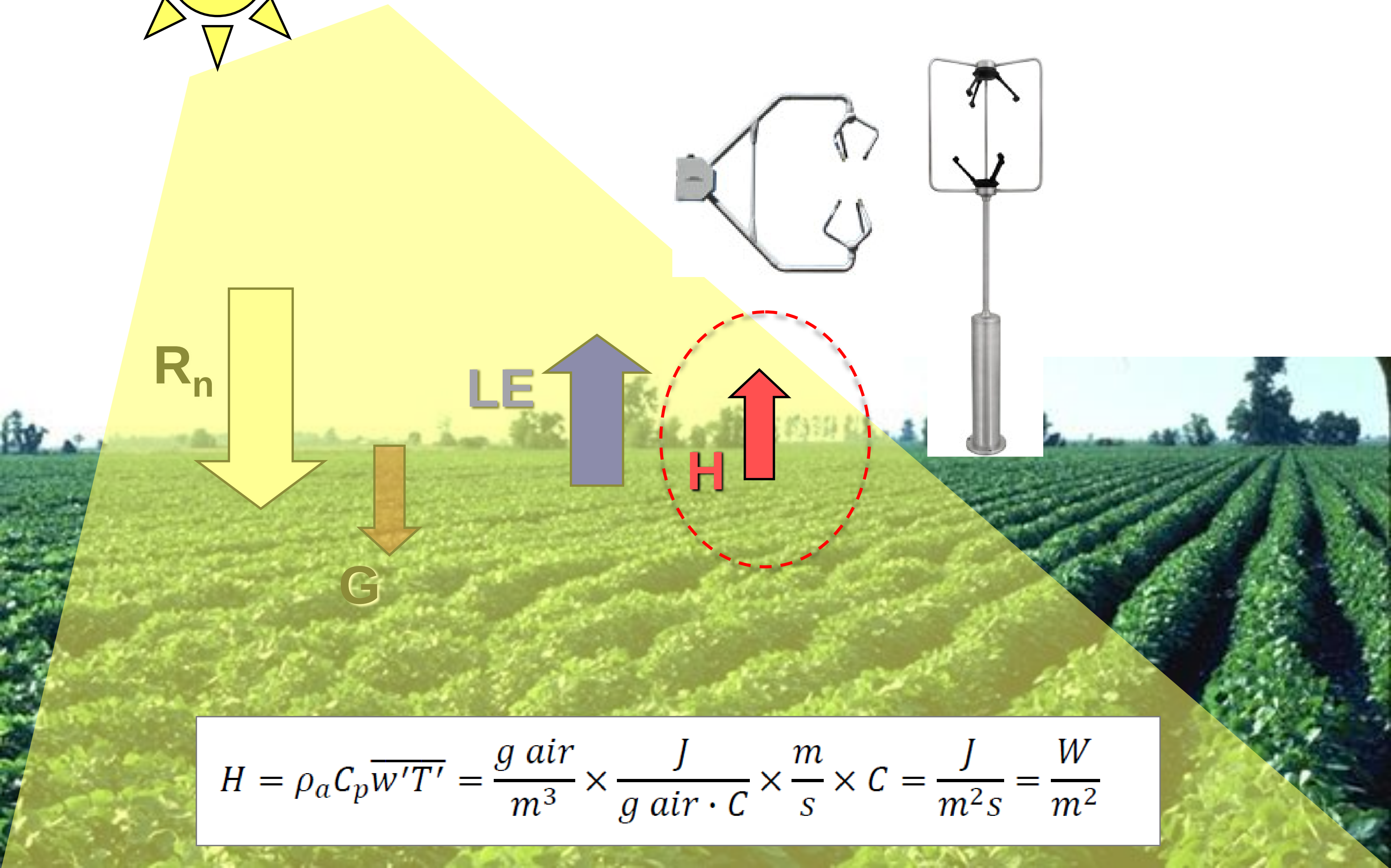


Measuring the components of the Radiation Budget



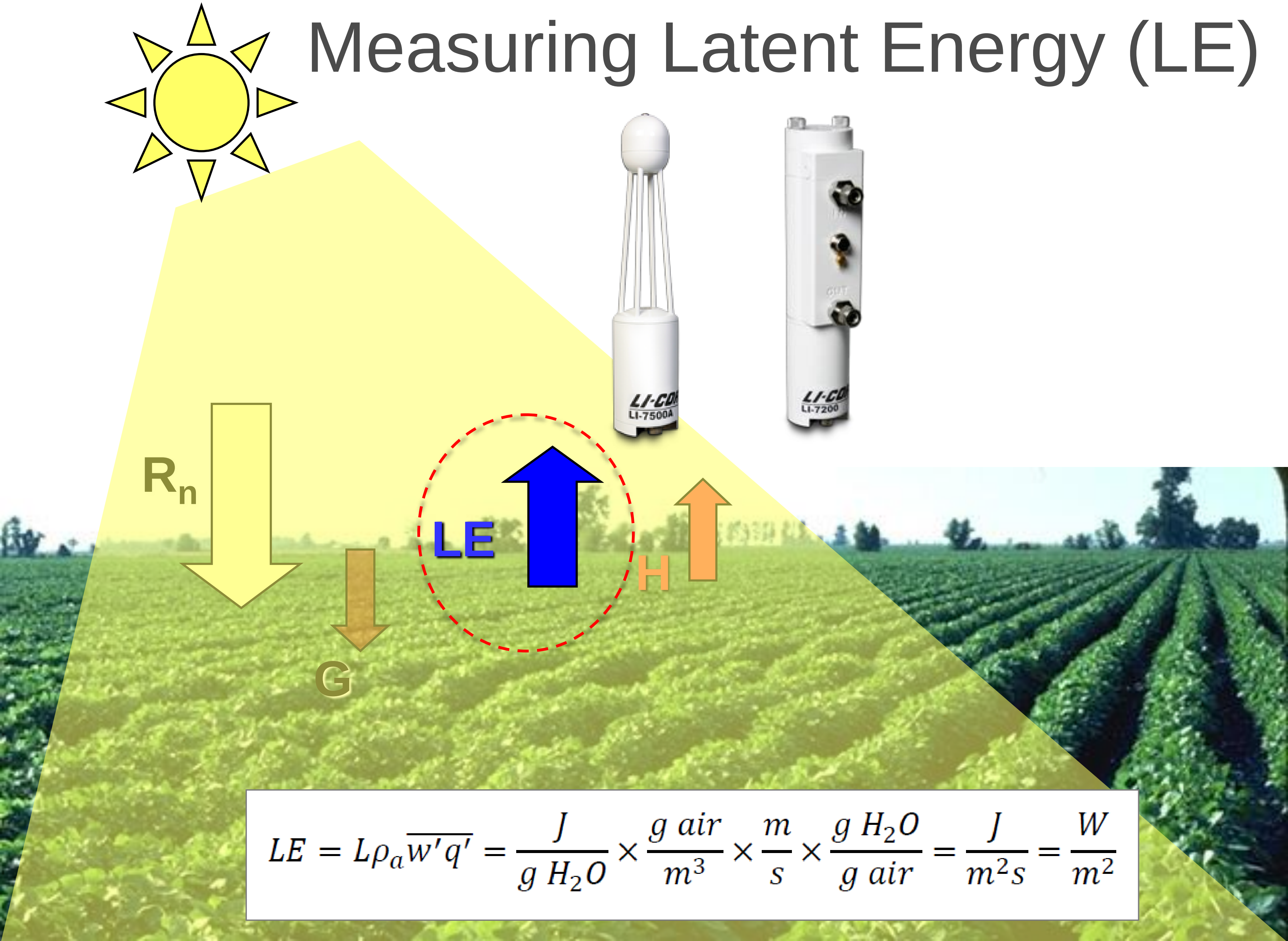
Measuring Sensible Heat (H)





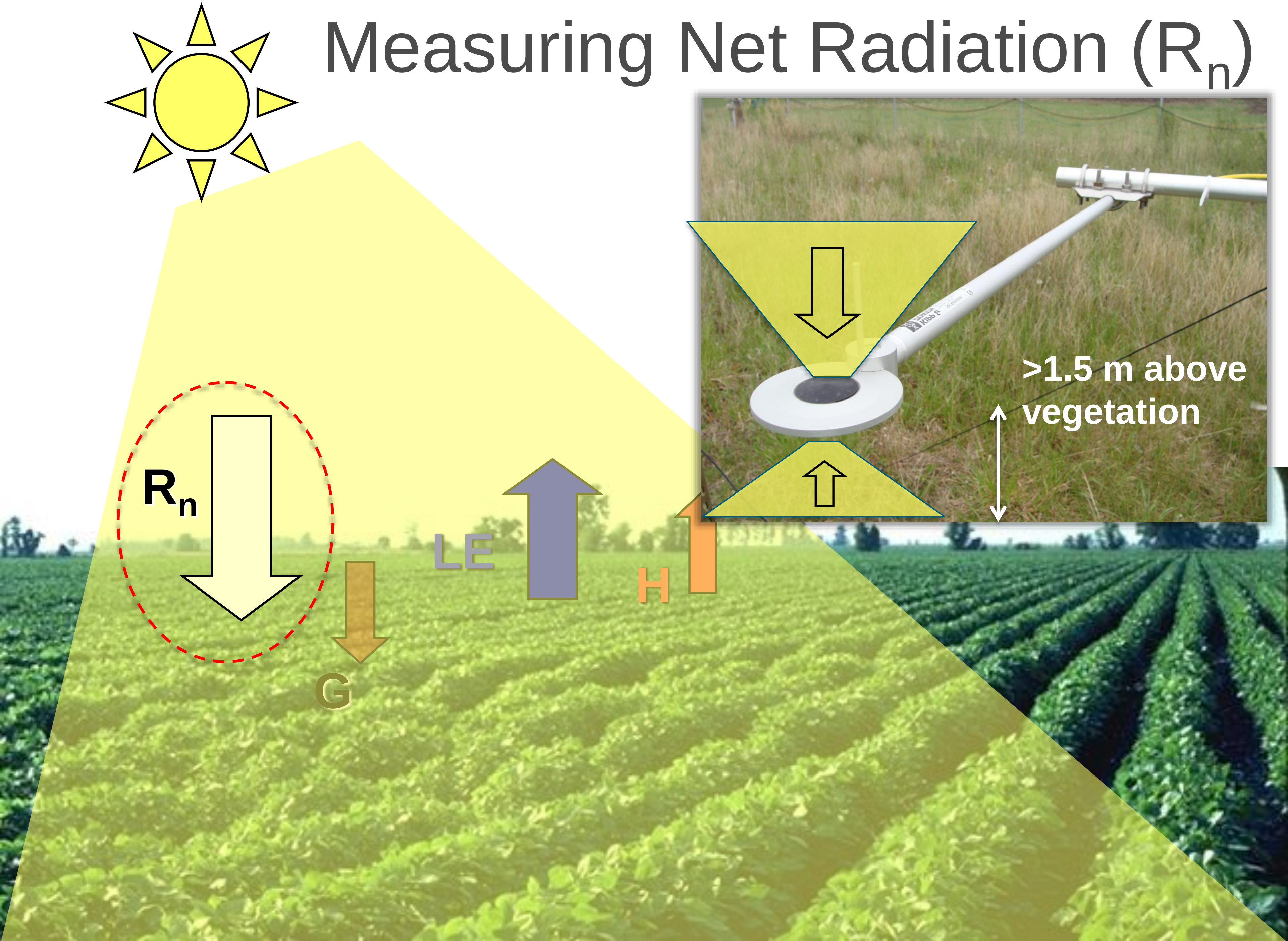
$$H = \rho_a C_p \overline{w'T'} = \frac{g\ air}{m^3} \times \frac{J}{g\ air \cdot C} \times \frac{m}{s} \times C = \frac{J}{m^2 s} = \frac{W}{m^2}$$

Measuring Latent Energy (LE)

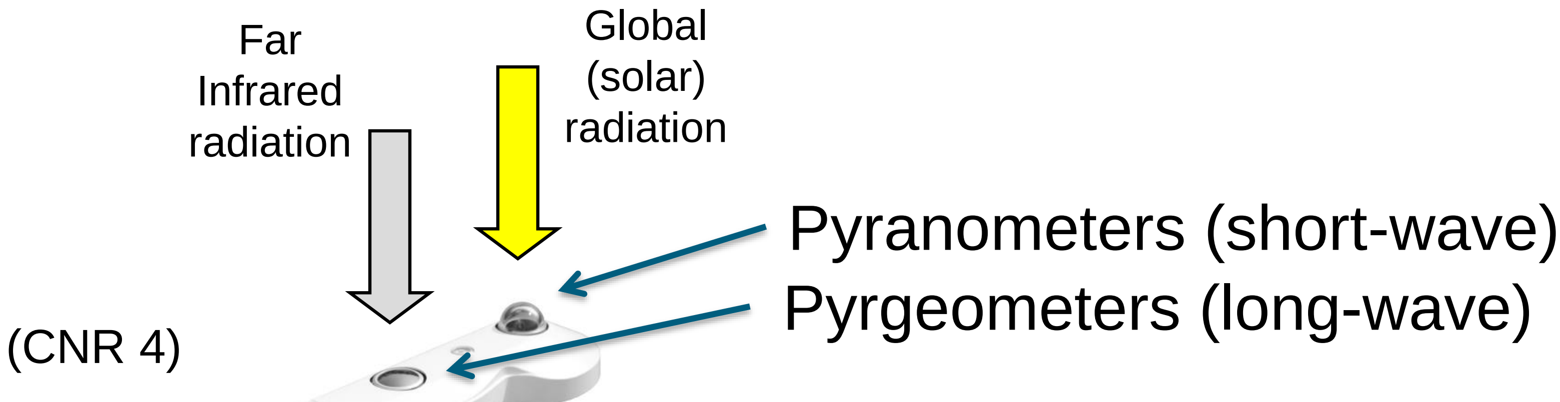


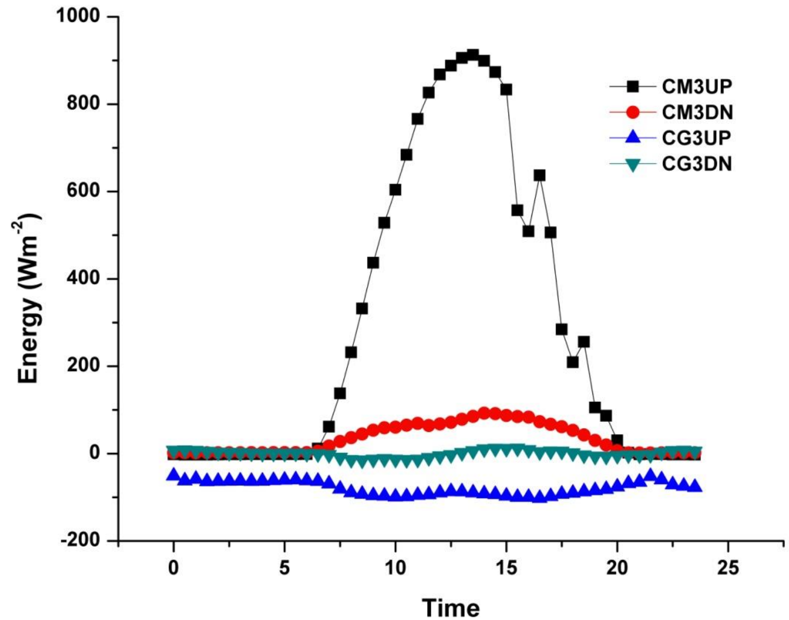
$$LE = L\rho_a\overline{w'q'} = \frac{J}{g\ H_2O} \times \frac{g\ air}{m^3} \times \frac{m}{s} \times \frac{g\ H_2O}{g\ air} = \frac{J}{m^2 s} = \frac{W}{m^2}$$

Measuring Net Radiation (R_n)



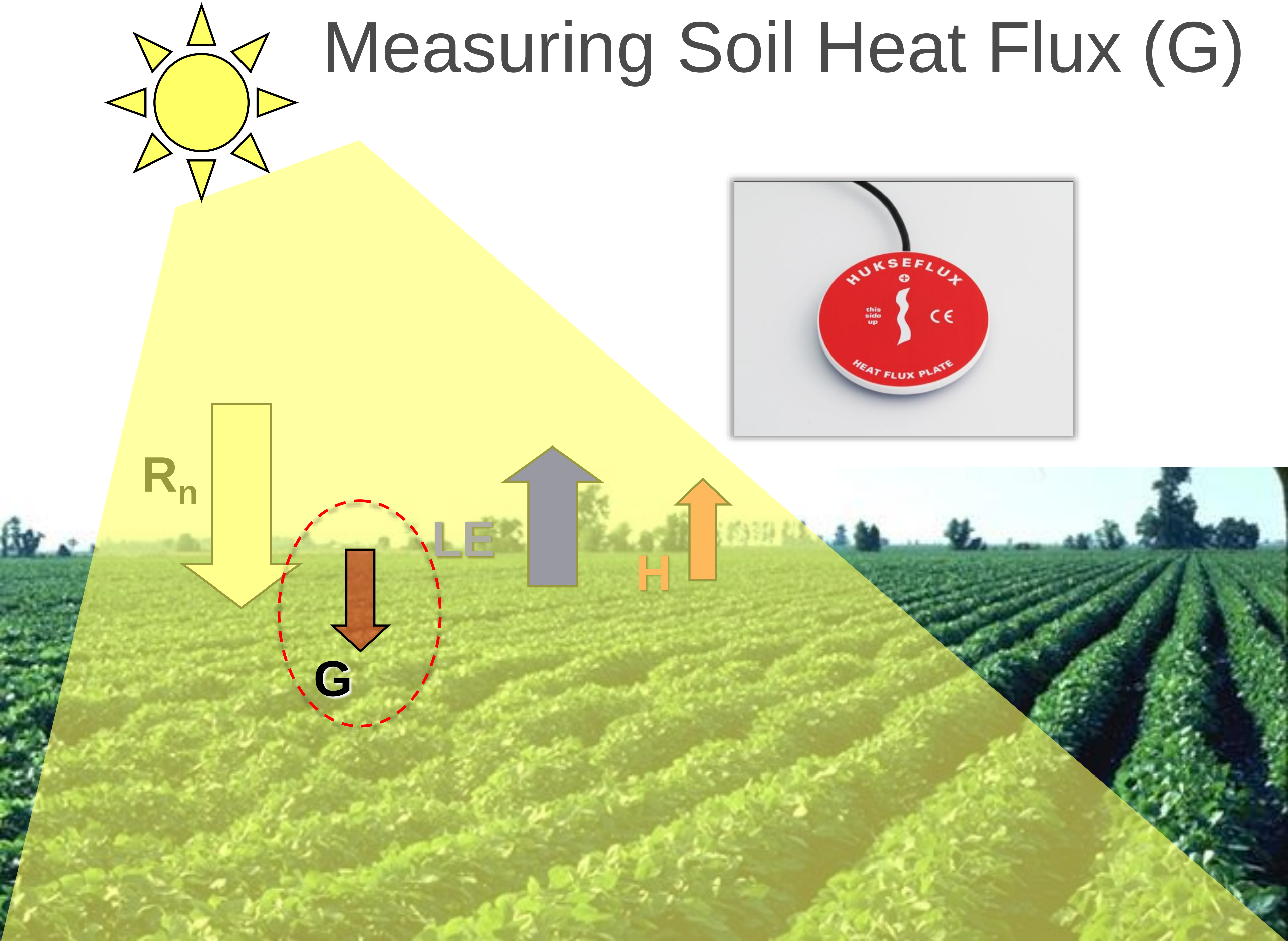
Four component ~ Incoming and Reflected Short-wave and Downward and Upward Long-wave





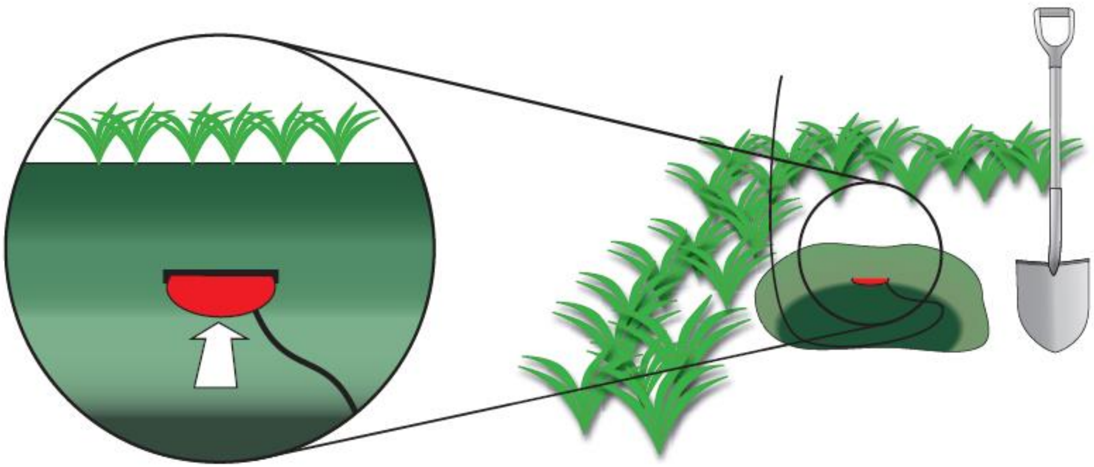
Pyrgeometer output is normally negative

Measuring Soil Heat Flux (G)



Deploying soil sensors

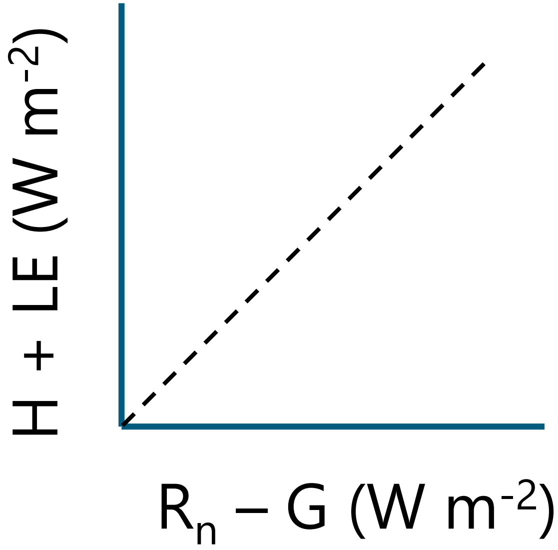
- Minimum of **3 each:**
  - Soil Variability
  - Sun vs. Shade
  - 5 m apart
- Depth:
  - At least 4 cm, typically 5 cm.
  - Bury with red side up
- Calibration:
  - Bi-annual.



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

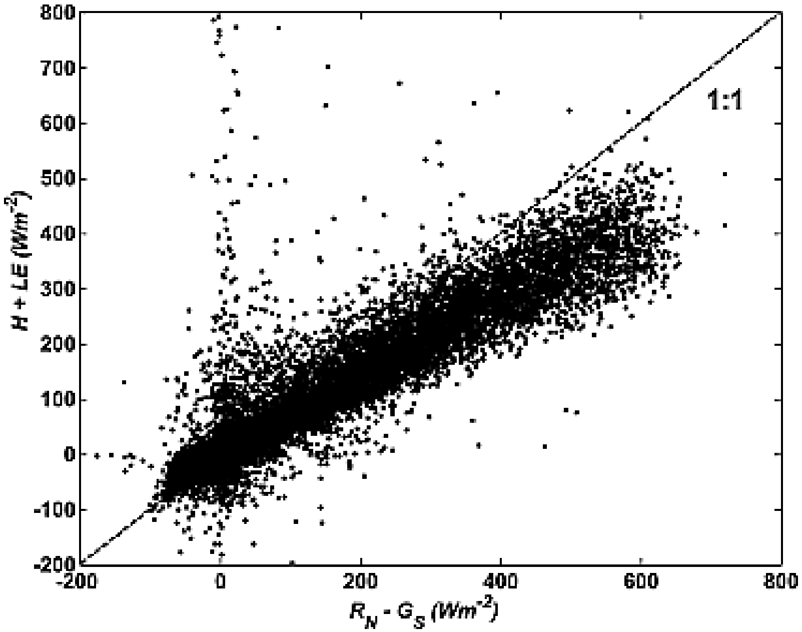
- A tool for verifying eddy covariance instrumentation (CO_2/H_2O/CH_4 analyzers and sonic anemometers) are working accurately and are installed properly.
  - In turn, this helps to verify that the final computed flux values are correct and accurate.

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



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

Realistic (measured) closure

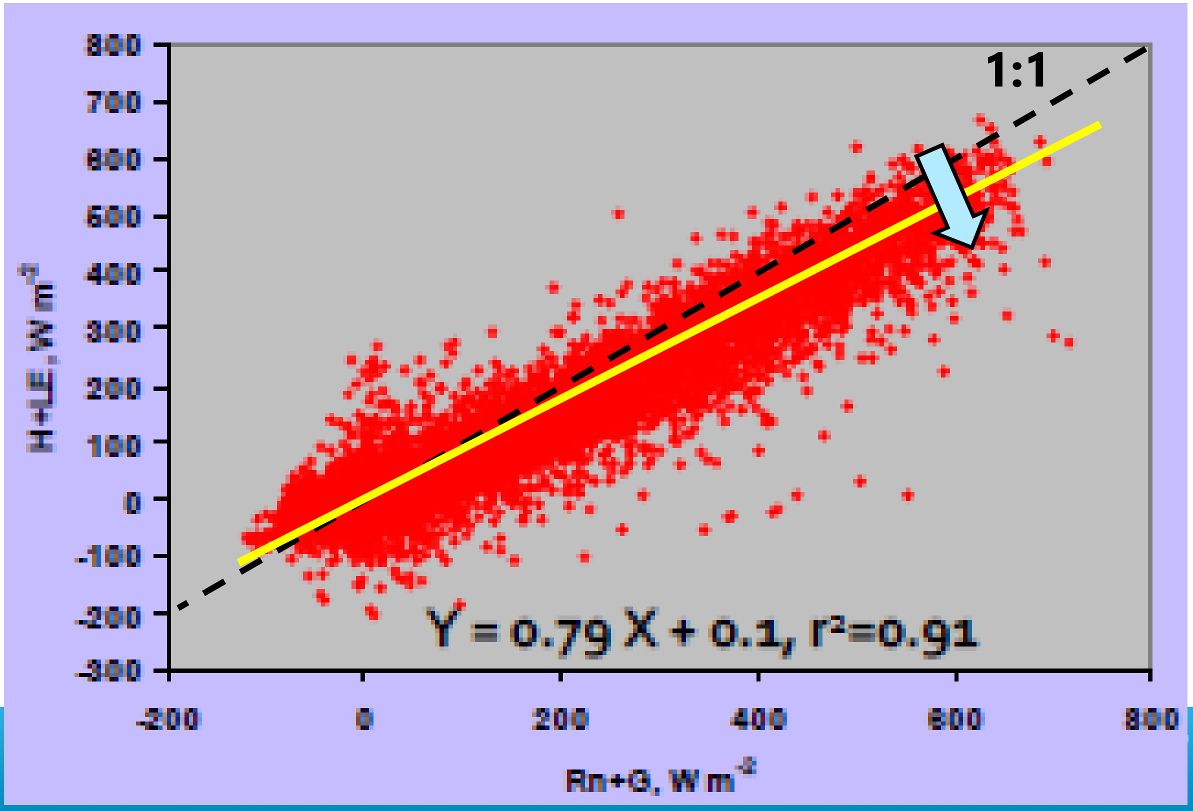


If not ideal:

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

Using Energy Balance Closure…

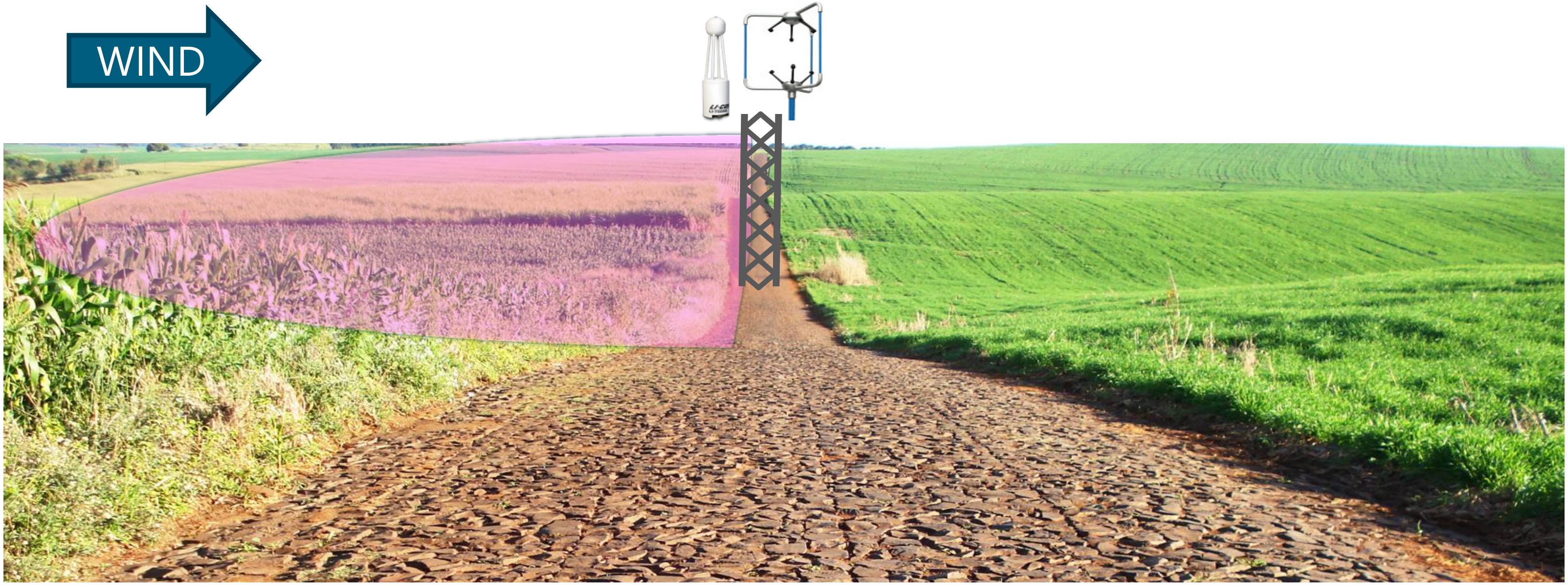
- Quality Assurance and Quality Checking (QA/QC)
  - From many studies (i.e., FLUXNET), a general concern has developed because surface energy fluxes *(LE + H) are frequently (but not always) underestimated* by about 10–30% relative to estimates of available energy flux *(Rn − G − S).*
  - *Why is this?*



What else could cause the 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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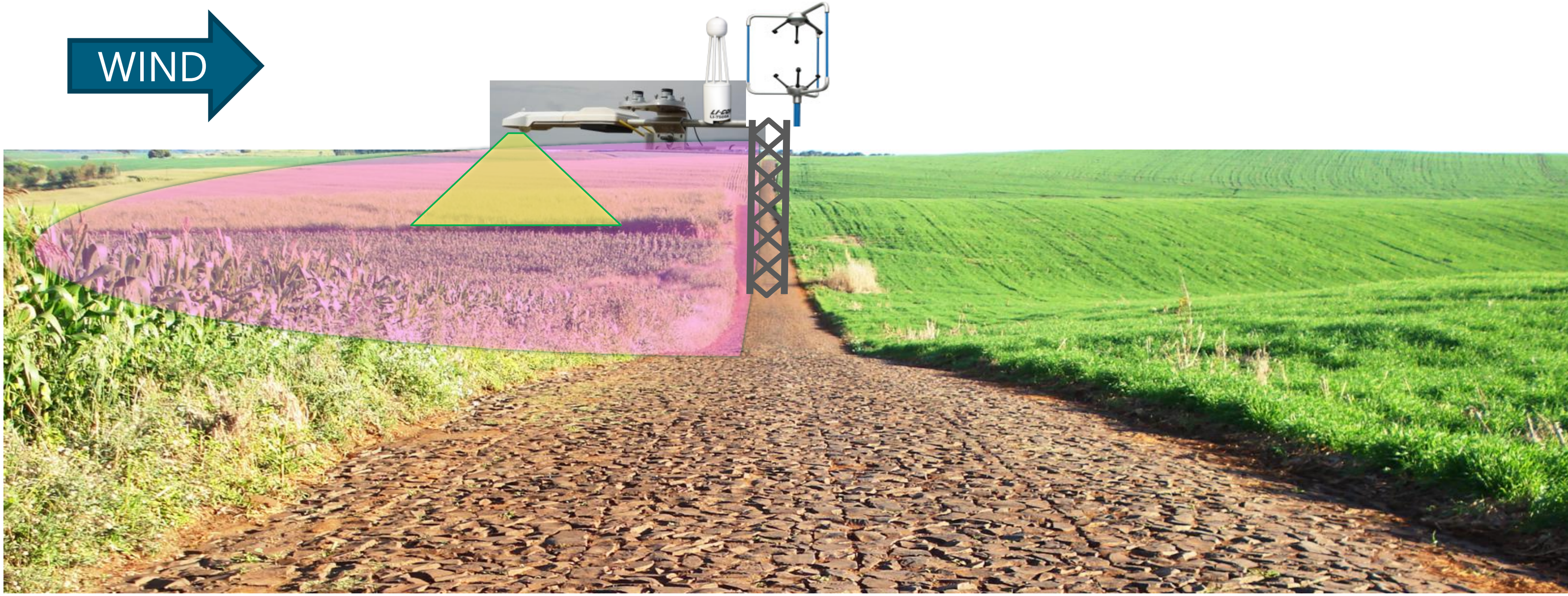
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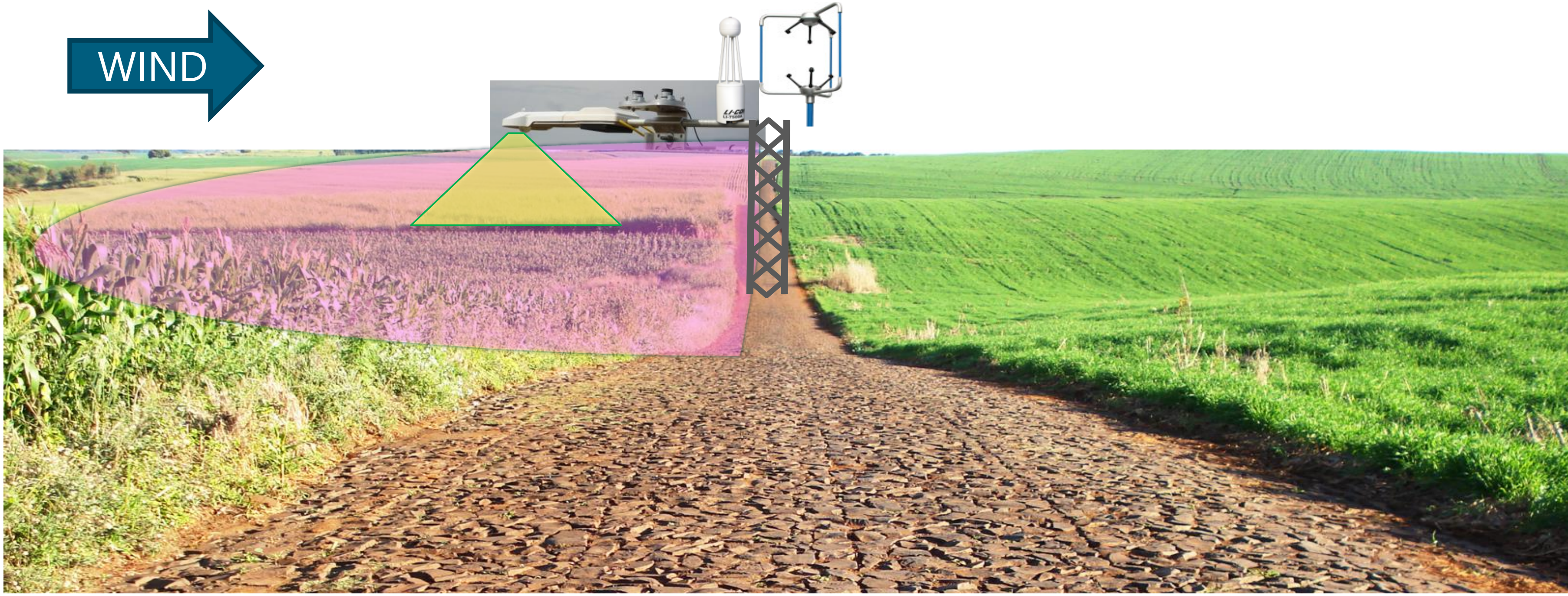
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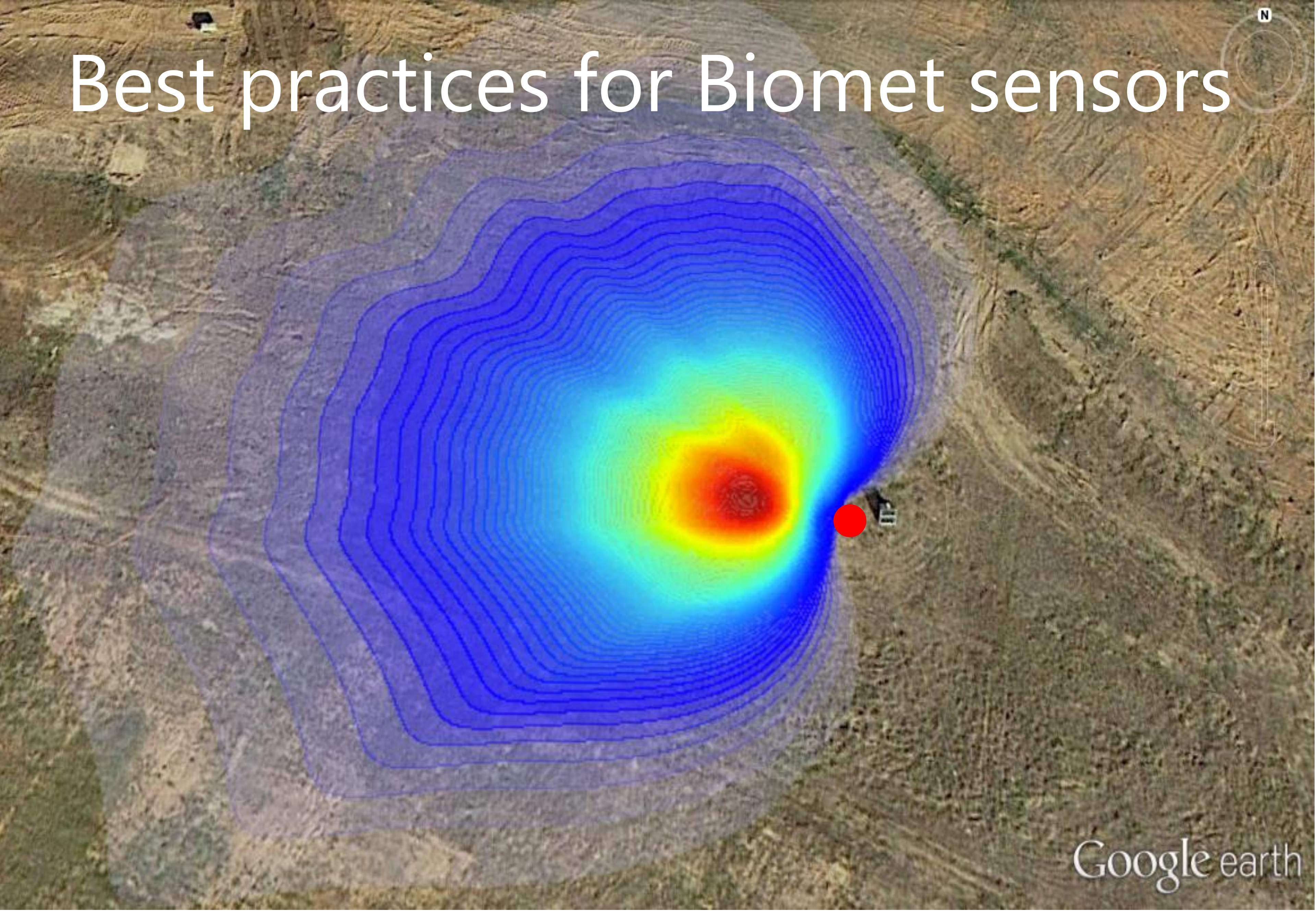
Best practices for Biomet sensors



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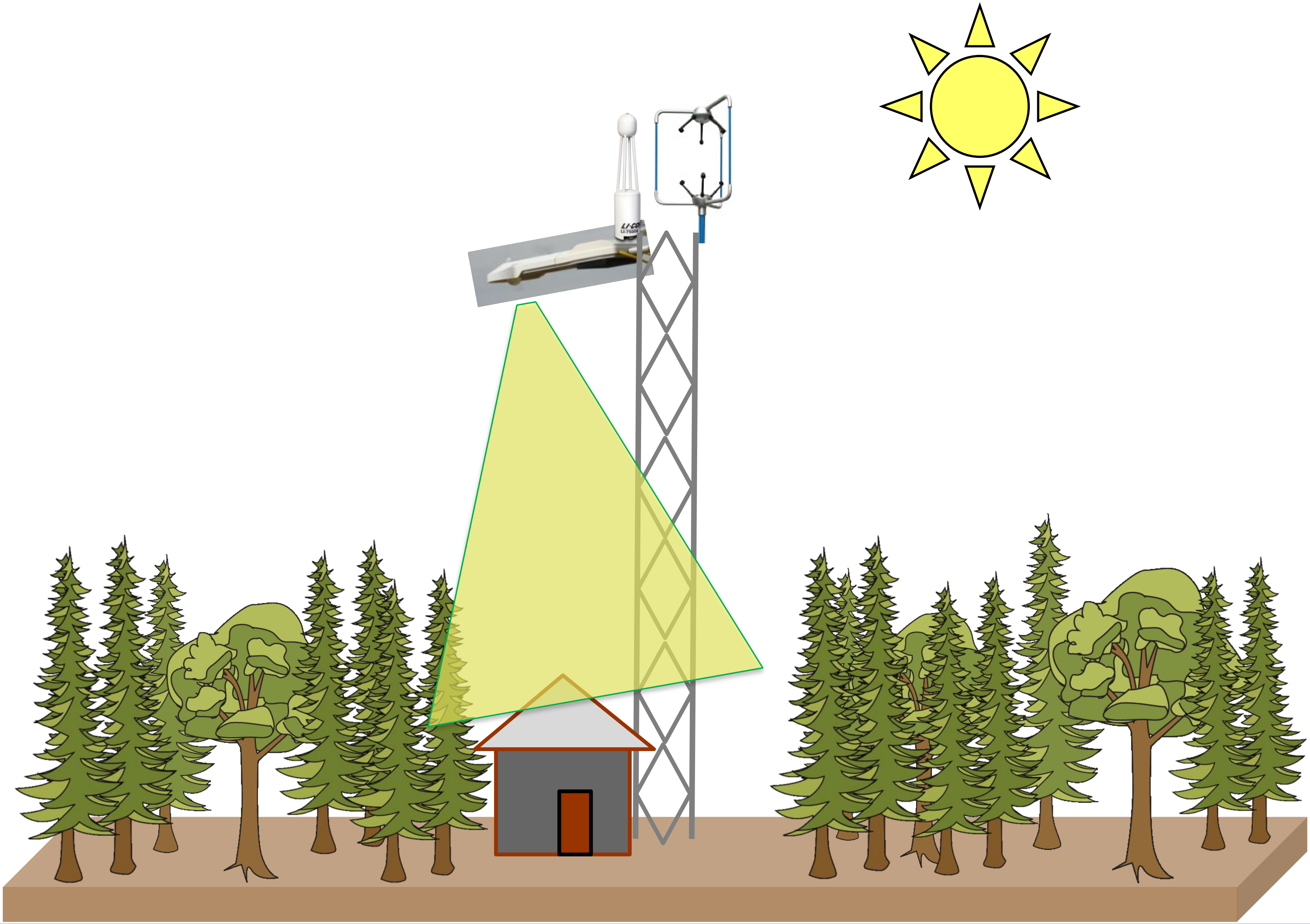

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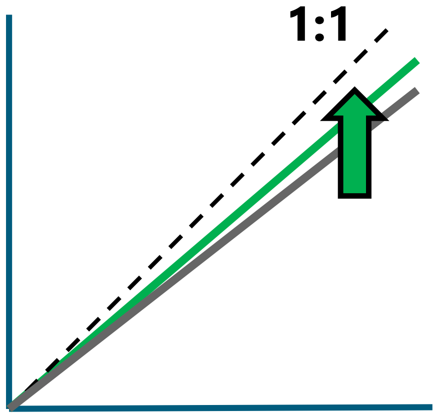
Role of canopy and ground heat storage…

- Tall vegetation sites *(h* > 8m*)* based on 26 site-years of data:
  - Including *S* in the regressions for these sites *increased* the slope by an average of 7%, which is why forested sites are required to report *S*.

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

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



- For grasslands, agricultural and chaparral sites
  - Soil heat flux (*G)* *increases* the average slope by about 20%. Soil heat flux has much less impact at the forested sites, where the average slope increased by only 3%.

What else could cause the imbalance?

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Energy Balance Closure summary

- Implications on CO_2 and H_2O Fluxes
  - 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 energy balance calculations can be independent of CO_2 flux estimates and vice versa.
  - If done properly, Energy Balance Closure can be a useful tool in verifying proper CO_2 and H_2O measurements and subsequent computed fluxes.

Why collect Biomet measurements?

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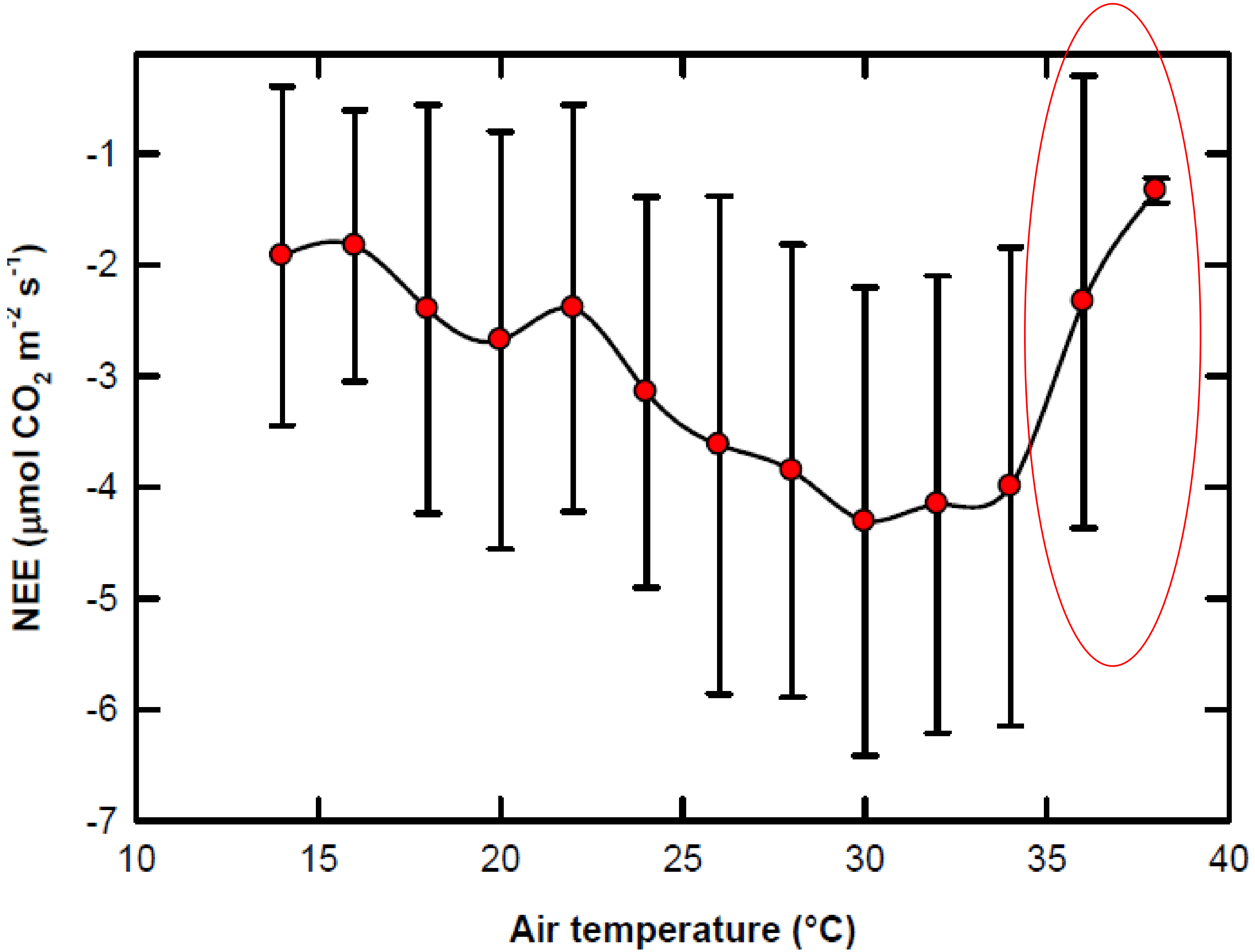
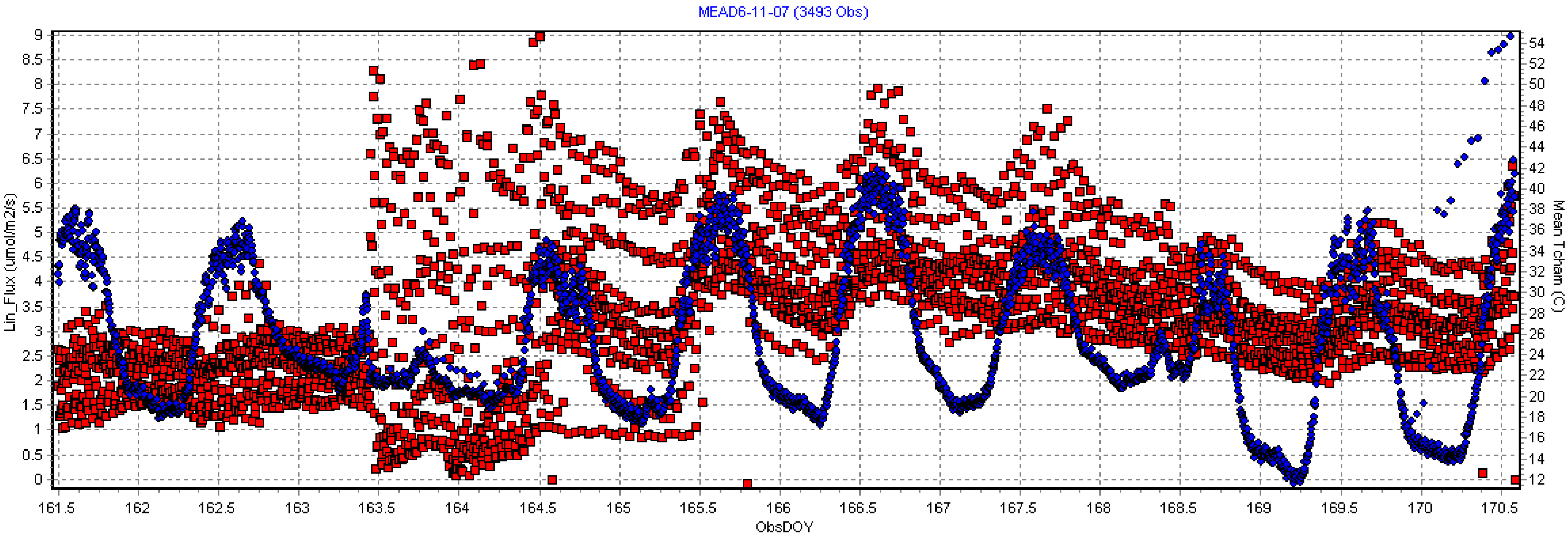
Air Temperature – F_{CO2} Relationship



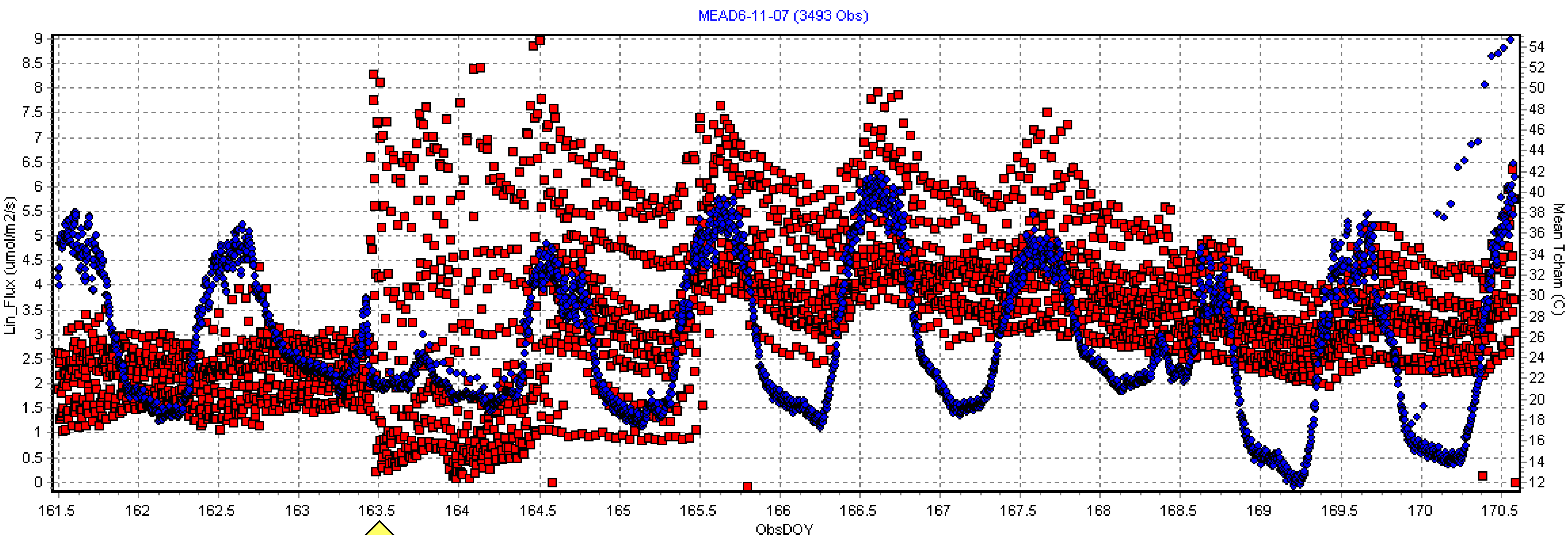
Measurements of CO_2 efflux from the soil…

…taken with a 16-Chamber, Multiplexed System.



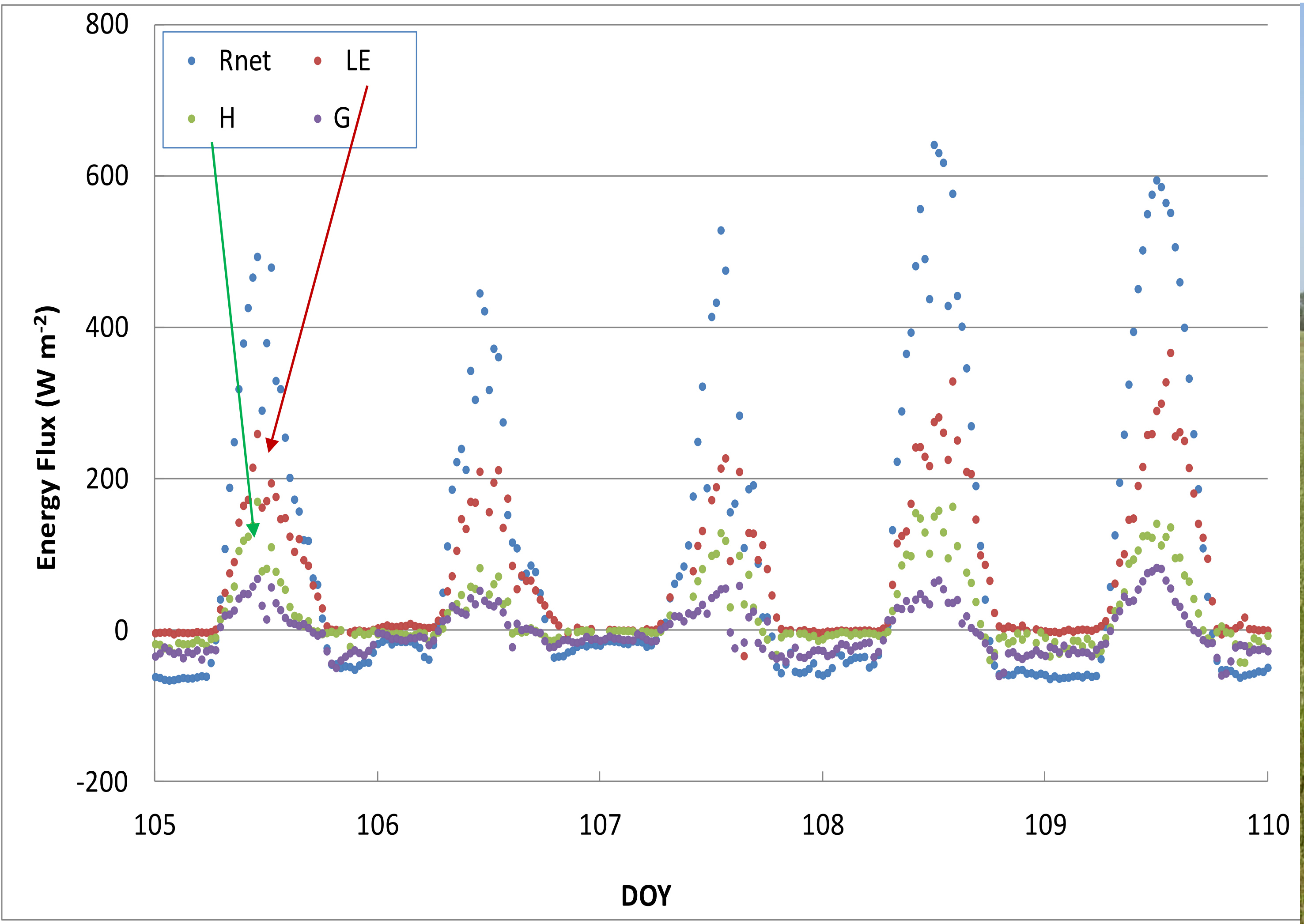
Weather events can effect fluxes

A rain event increases soil moisture and effects the CO_2 efflux from the soil…

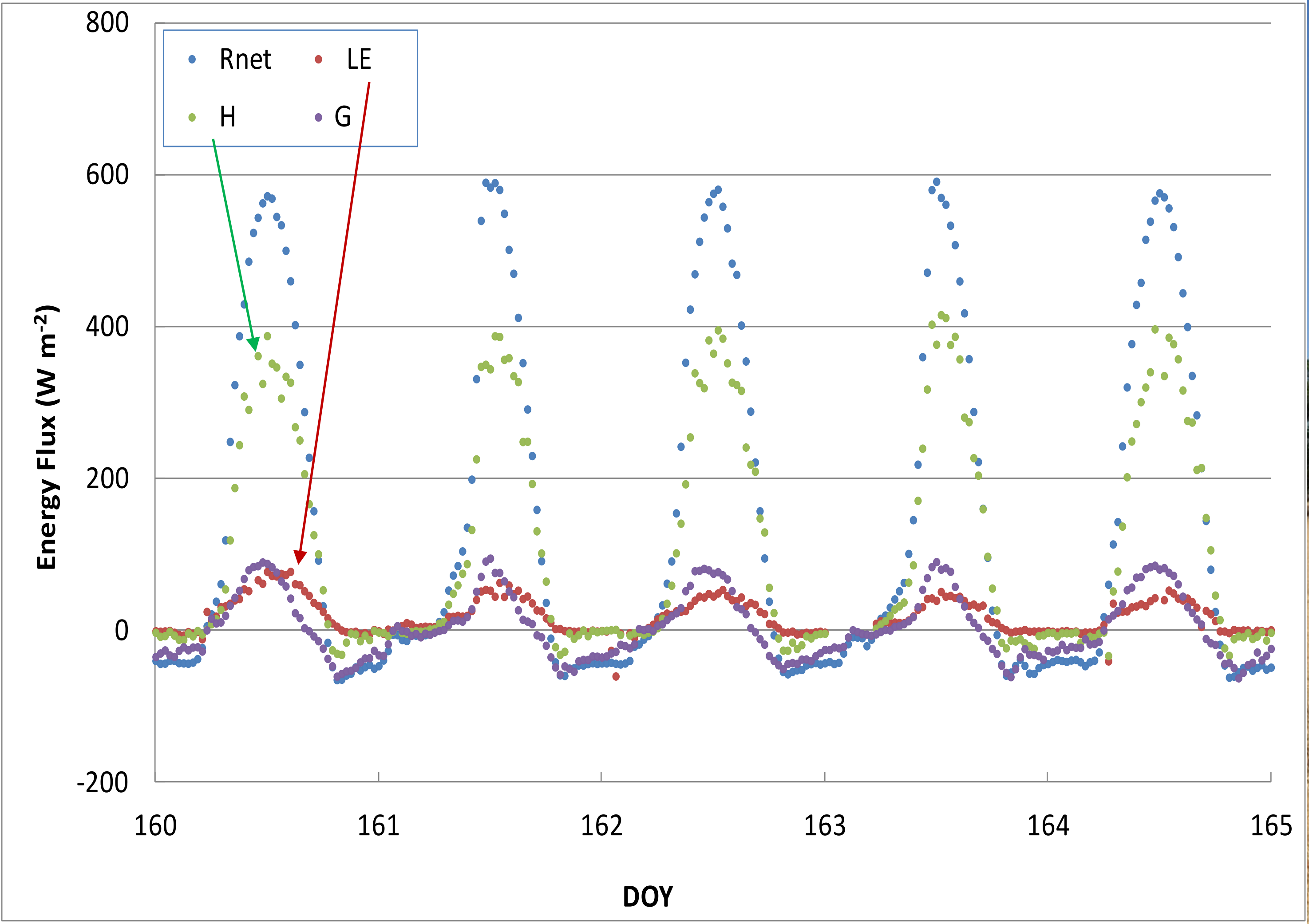


Rain event

Energy partitioning depends on availability of soil moisture



Energy partitioning depends on availability of soil moisture

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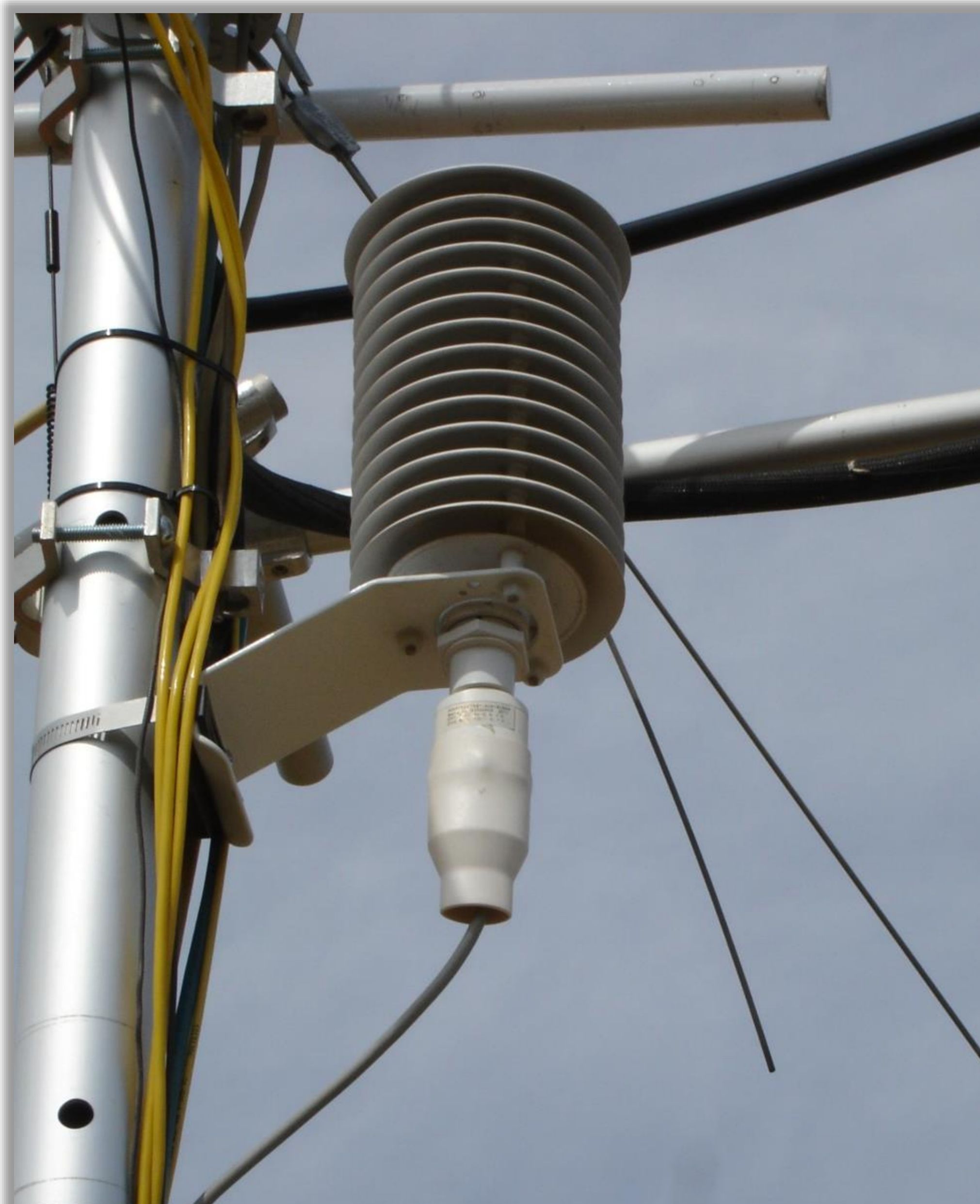
MODEL PYRANO
SR. NO. PY 1000


LI-COR®
MODEL QUANT
SR. NO. Q 1000



Phenology

The study of cyclic and seasonal natural phenomena, especially in relation to climate and plant and animal life

- Examples of plant phenological processes, include when leaves emerge in the spring and change color in the autumn.
- They are highly responsive to variation in weather as well as longer-term changes in climate

Why Phenology?

- Leafing, flowering, fruiting
- Leaf senescence
- Bird migration
- Insect infestation
- Plant disease
- Climate change
  - Springtime

PhenoCam's

- Digital cameras can be used to monitor vegetation phenology
- Provide automated, near-surface remote sensing of canopy phenology
- Images from these cameras are uploaded to a server
- Techniques can be used to extract quantitative color information from each picture.
    - Canopy greenness can provide information about the amount of foliage present.

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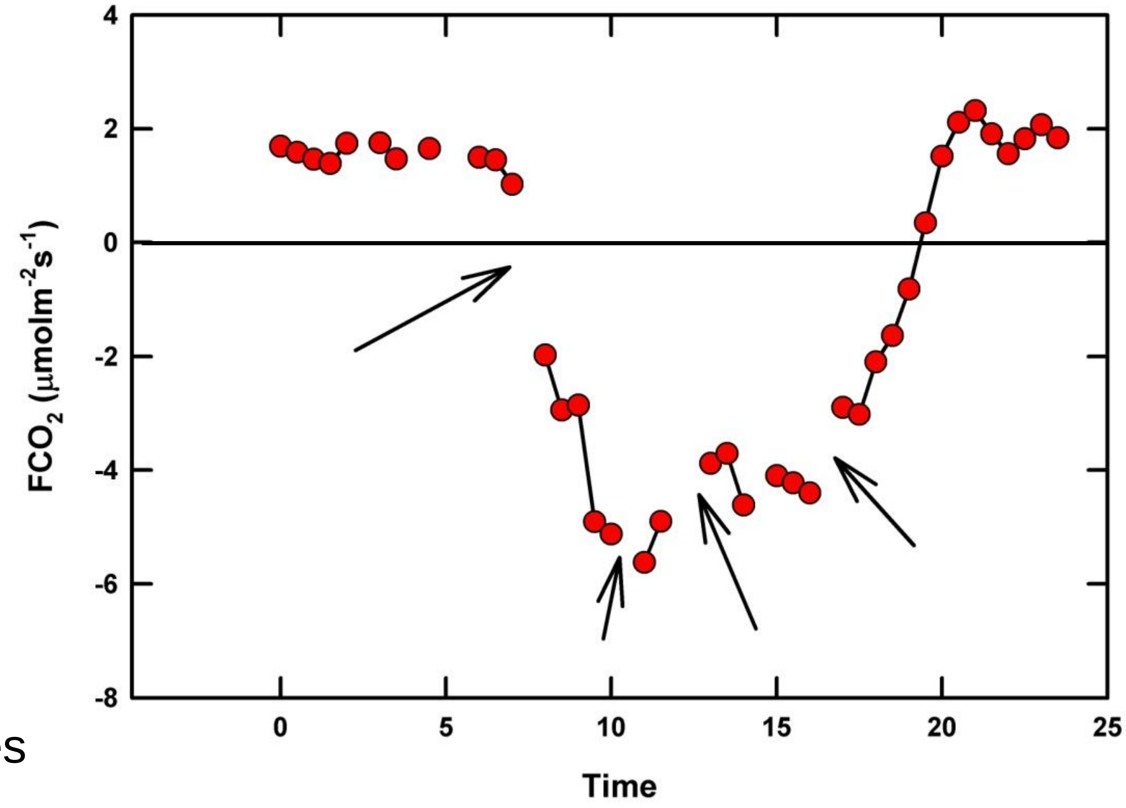
  - When instrumentation or power fails.
- Improving Fluxes

Gap Filling Flux Data

- Gaps occurs due to sensor failure
- Power supply issues
- Data flagged for bad quality
- Spikes in data due to rain events
- Data flagged for low U*

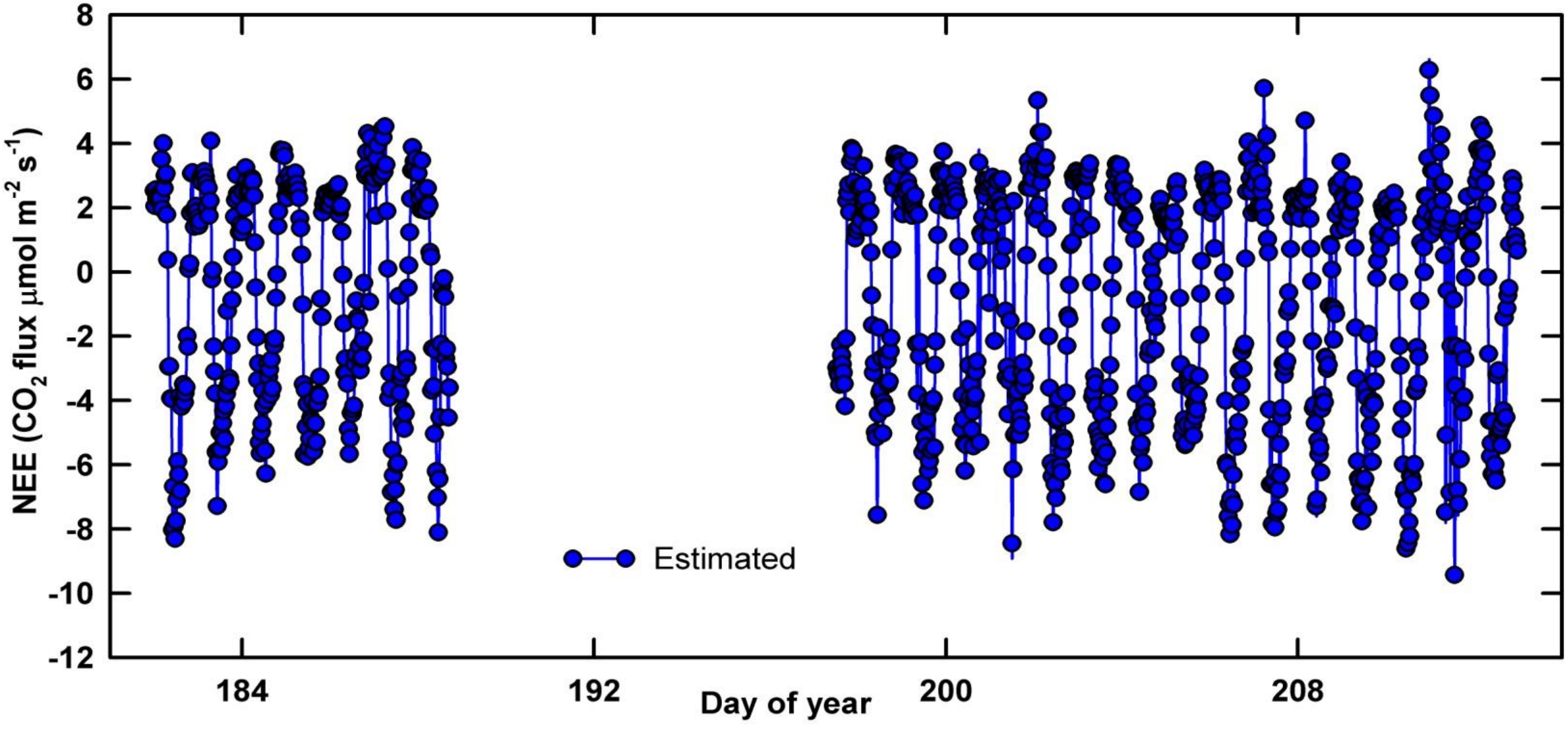
Smaller gaps



Smaller gaps can be filled using interpolation techniques

Gap Filling Flux Data

Larger gaps



Larger gaps are filled
with other techniques.

Gap Filling techniques

A) Mean Diurnal Variation: Use data from similar days for gap filling

B) Look-Up Tables: Multidimensional tables are created for gap filling

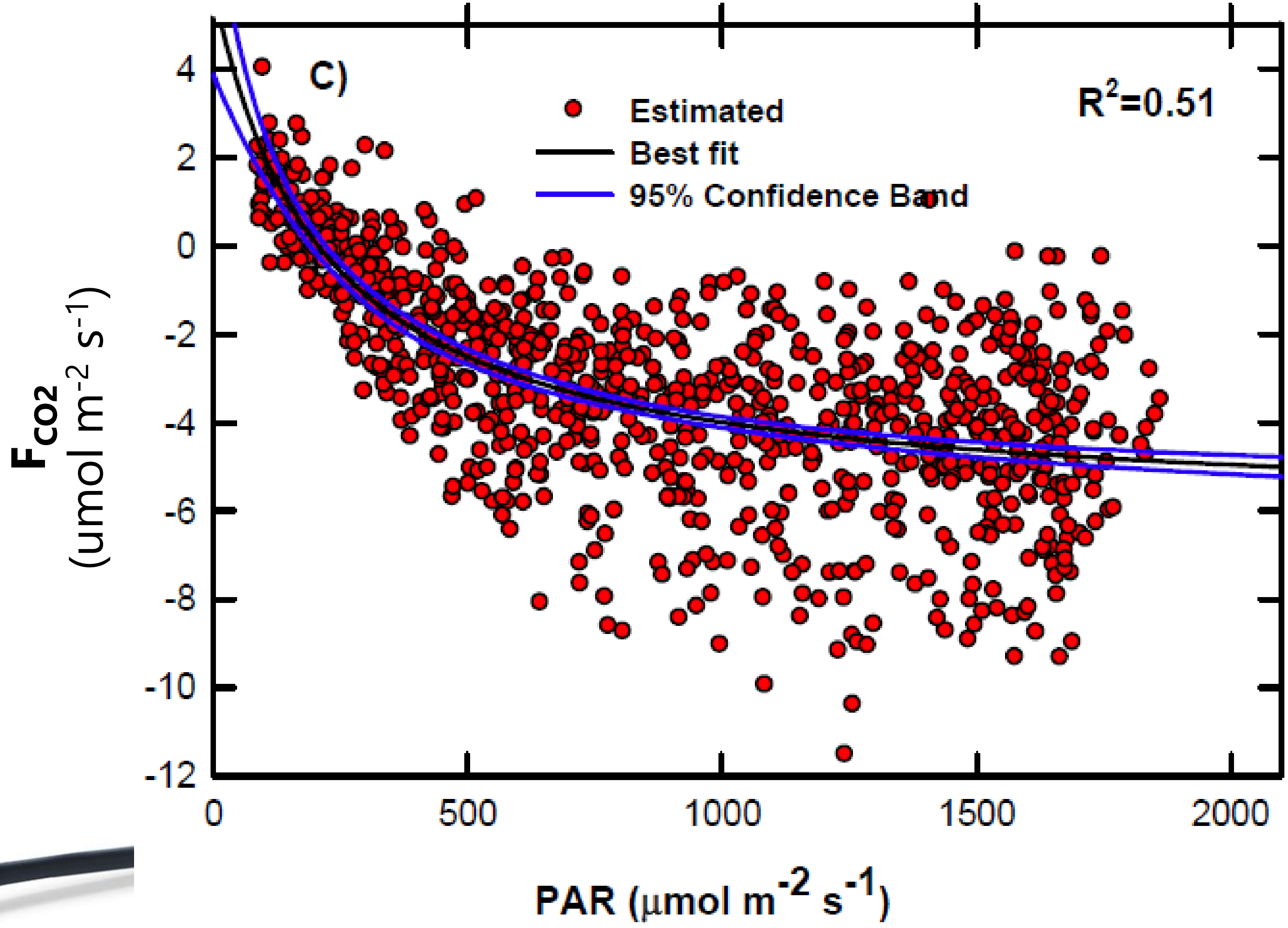
C) Artificial Neural Networks: Empirical non-linear regression models

D) Non-linear Regression: Models relating NEE to PAR and Respiration to Soil Temperature

$$NEE = \left[\frac{a \times PAR}{a / b + PAR} \right] + c \qquad R_e = R_{Tref} \exp\left[\left(\frac{E_a}{T_{ref} \times R} \right) \times \left(1 - \frac{T_{ref}}{T_{soil}} \right) \right]$$

E) Process Models : Complex models utilizing met data eg: CANOAK,

PAR and F_{CO2} Relationship



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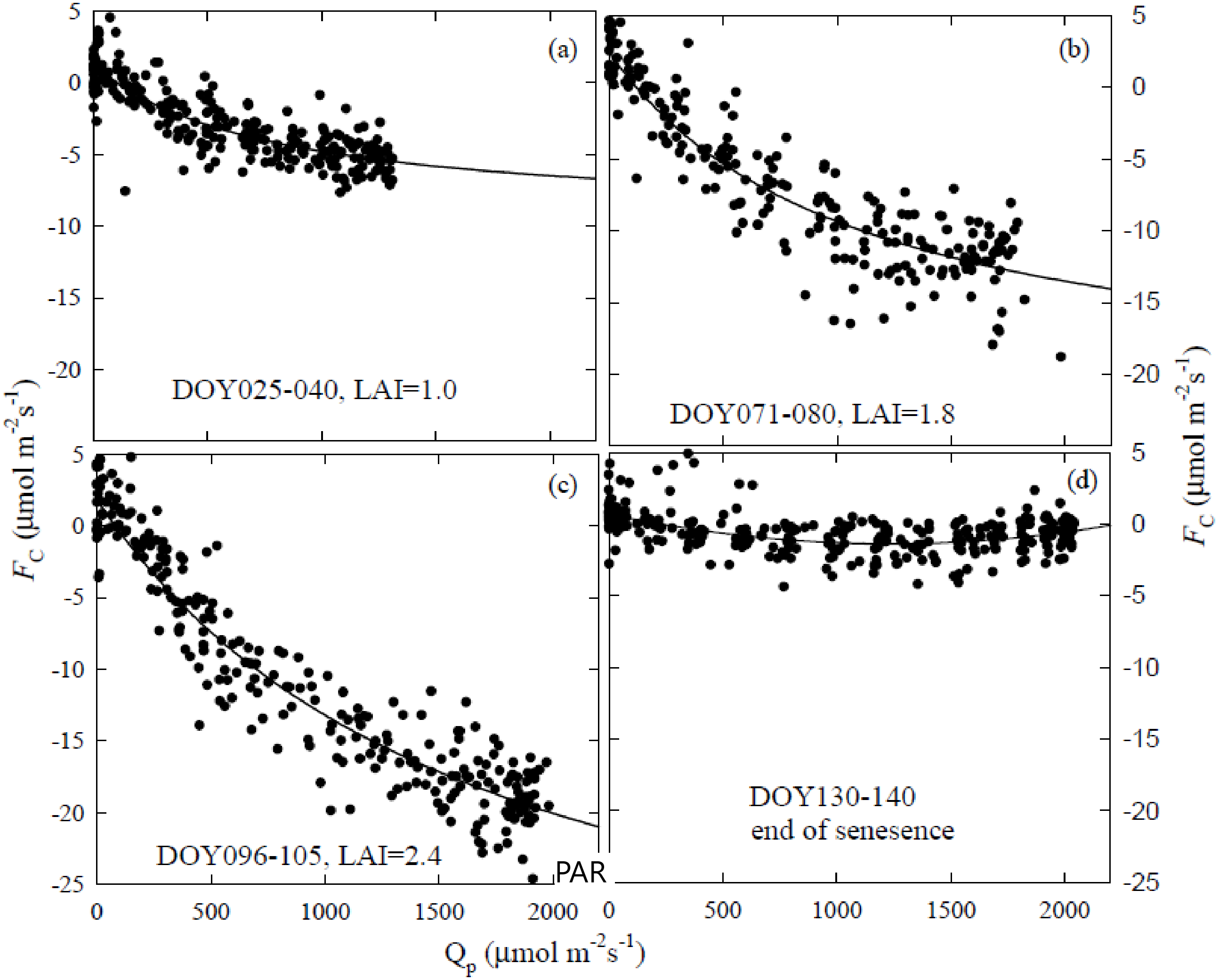
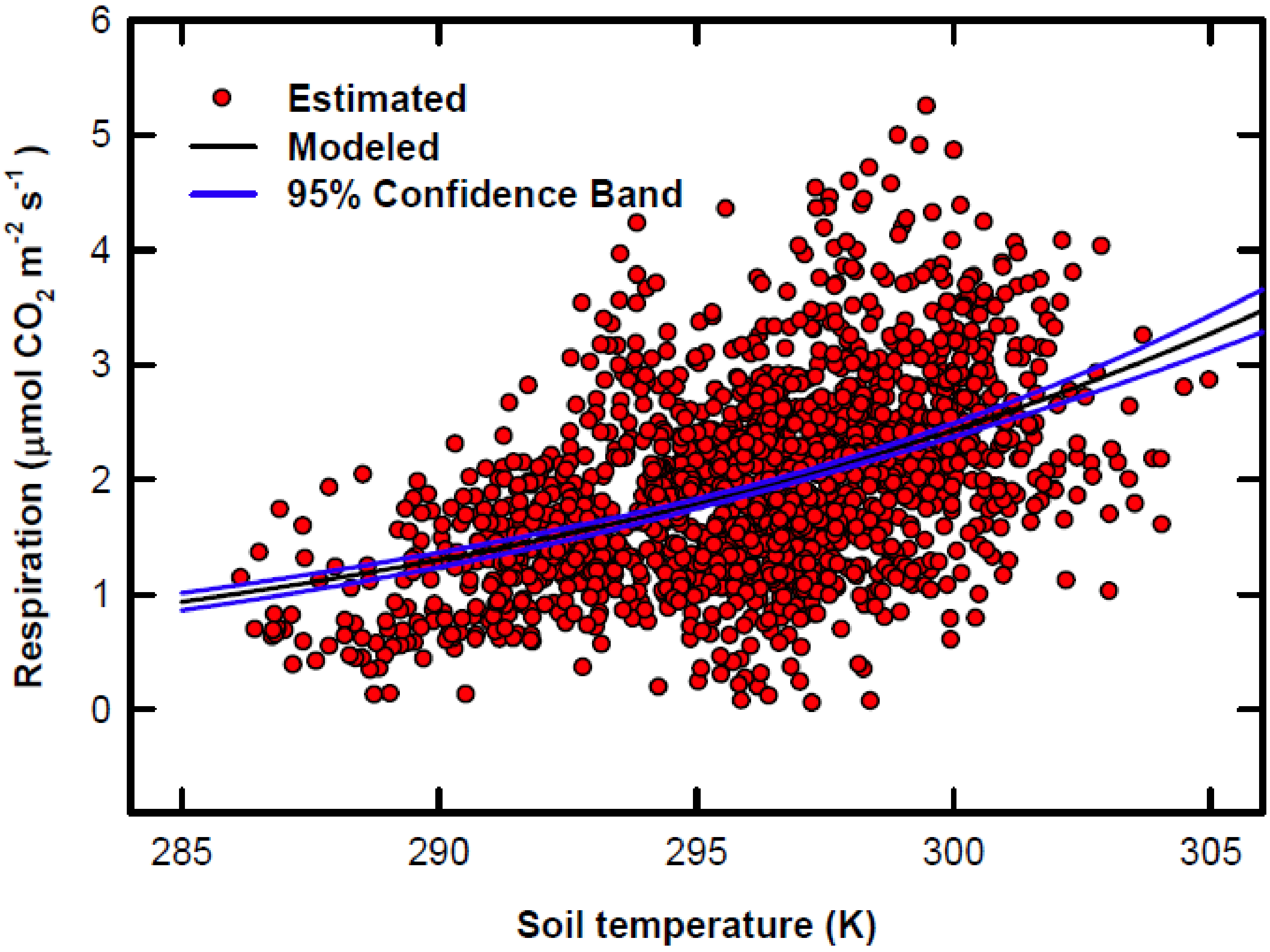
Seasonal relationships: PAR and CO_2 flux

L. Xu, D.D. Baldocchi / Agricultural and Forest Meteorology 1232 (2004) 79–96



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

Soil Temperature (Ts) & Respiration (R_{ECO}) Relationship



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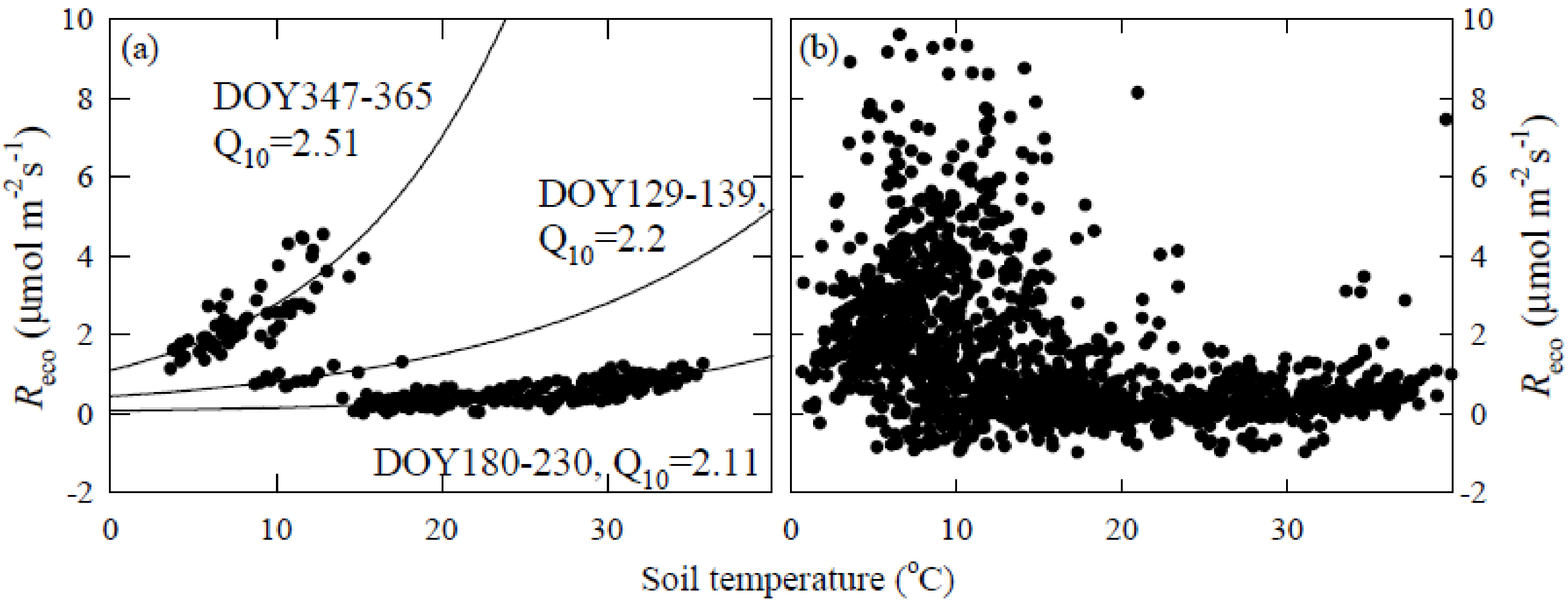
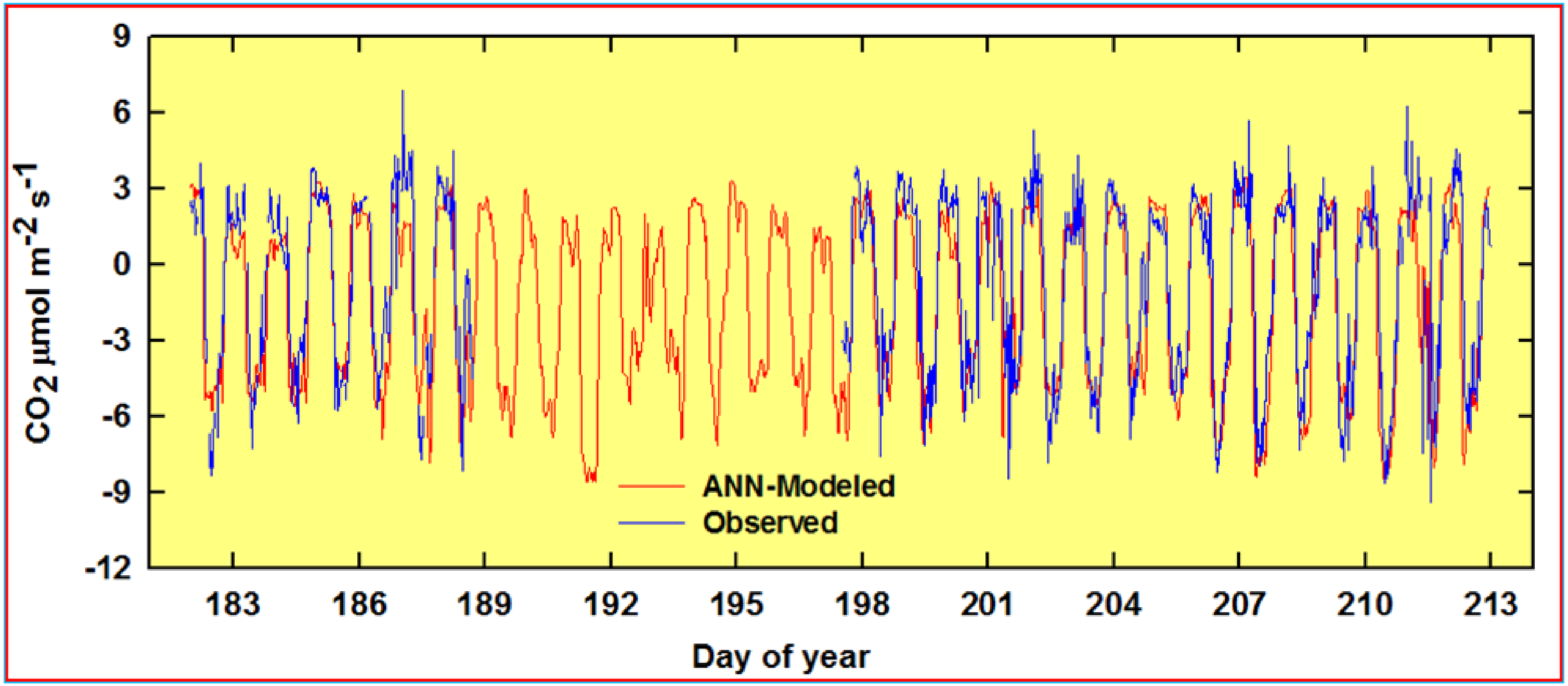


$$F_c = b_0 \exp(bT_{soil})$$

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

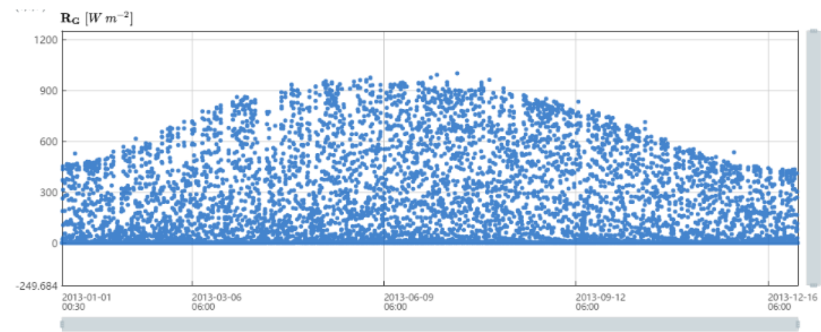
Neural Network example

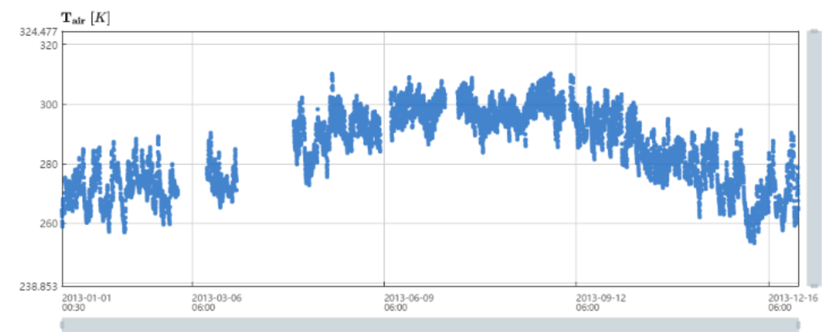
- *CO_2 Flux* modeled using PAR
- *Respiration* modeled using Ts

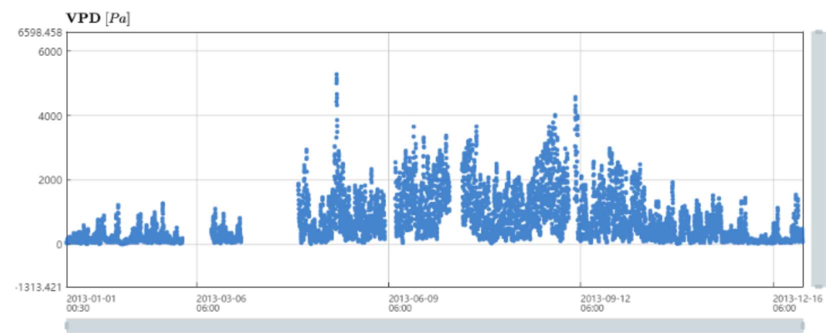


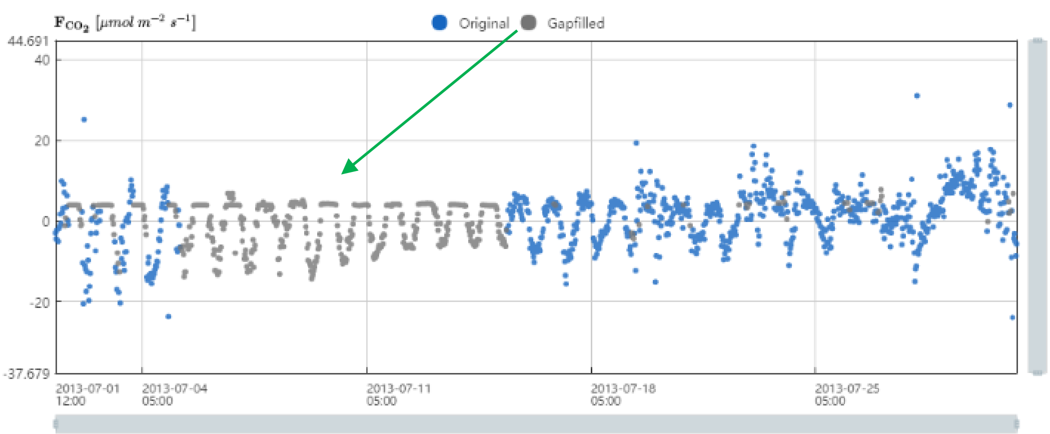
Marginal Distribution Sampling example

- *Used in Tovi*
- *Drivers:*
  - R_G, T_{AIR}, *VPD*



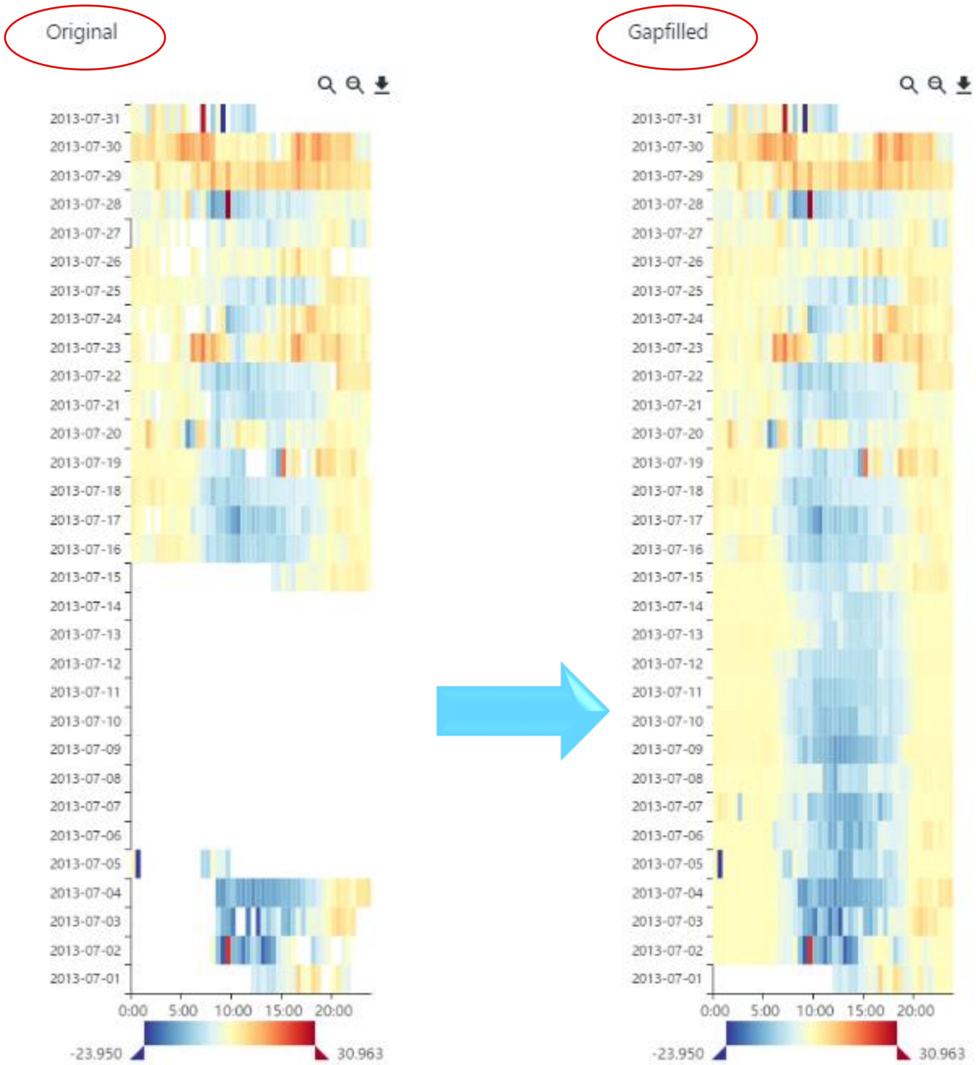






Marginal Distribution Sampling example

- *Used in Tovi*
- *Fingerprint visualization*

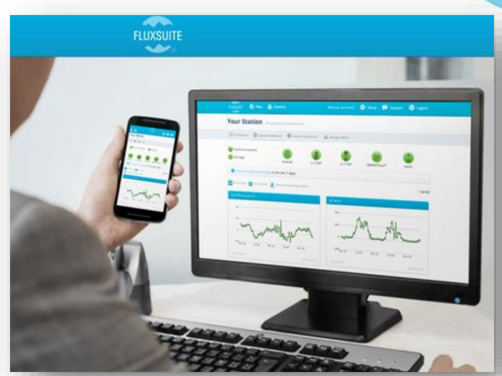


Bringing it all together…

SmartFlux® System

EDDYPRO™

FLUXSUITE®



Tovi™

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GHG Software Integration

- LI-7550 or SmartFlux polls datalogger for Biomet data every 30 seconds
- Data recorded once a minute
- GHG compressed file contains four files
  - High-frequency flux data, metadata, biomet data, and biomet metadata
- EddyPro processes files together

GHG Software Integration

- EddyPro can use a few variables for improving flux estimates
  - Measured air temperature, relative humidity, and pressure can replace the mean values of calculated variables (for example, sonic temperature)
  - Global radiation and long-wave incoming radiation can be used in the “multiple regression” version of the off-season uptake correction
  - PPFD can be used to assess day/night radiation load on the CO2/H2O analyzer

Resources

- Biomet System Instruction Manual
- Sutron Xlite Datalogger Manual
- Webinars
- LI-COR Science and Support Team (envsupport@licor.com)