Supplementary measurements to Eddy Covariance

LI-COR Ecosystem Gas Exchange

ChinaFlux

August 22, 2022

Dave Johnson

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Summarizing the past modules

- Module 1: The Importance of Measuring and Researching Carbon and Water Cycles and Their Impact on Climate Change
- Module 2: The Theory of Ecosystem Gas Exchange: The Eddy Covariance Method
- Module 3: Eddy Covariance Applications and Experimental Design
- Module 4: Instrumentation for Eddy Covariance
- Module 5: Integration of an Eddy Covariance System
- Module 6: Data Processing with EddyPro

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This module 7…

- What other biological influences affect GHG fluxes at our research sites?
  - Leaf-level drivers
  - Soil-level drivers
- How can we measure these additional influences?
- How can they be used to help explain and define our flux results?

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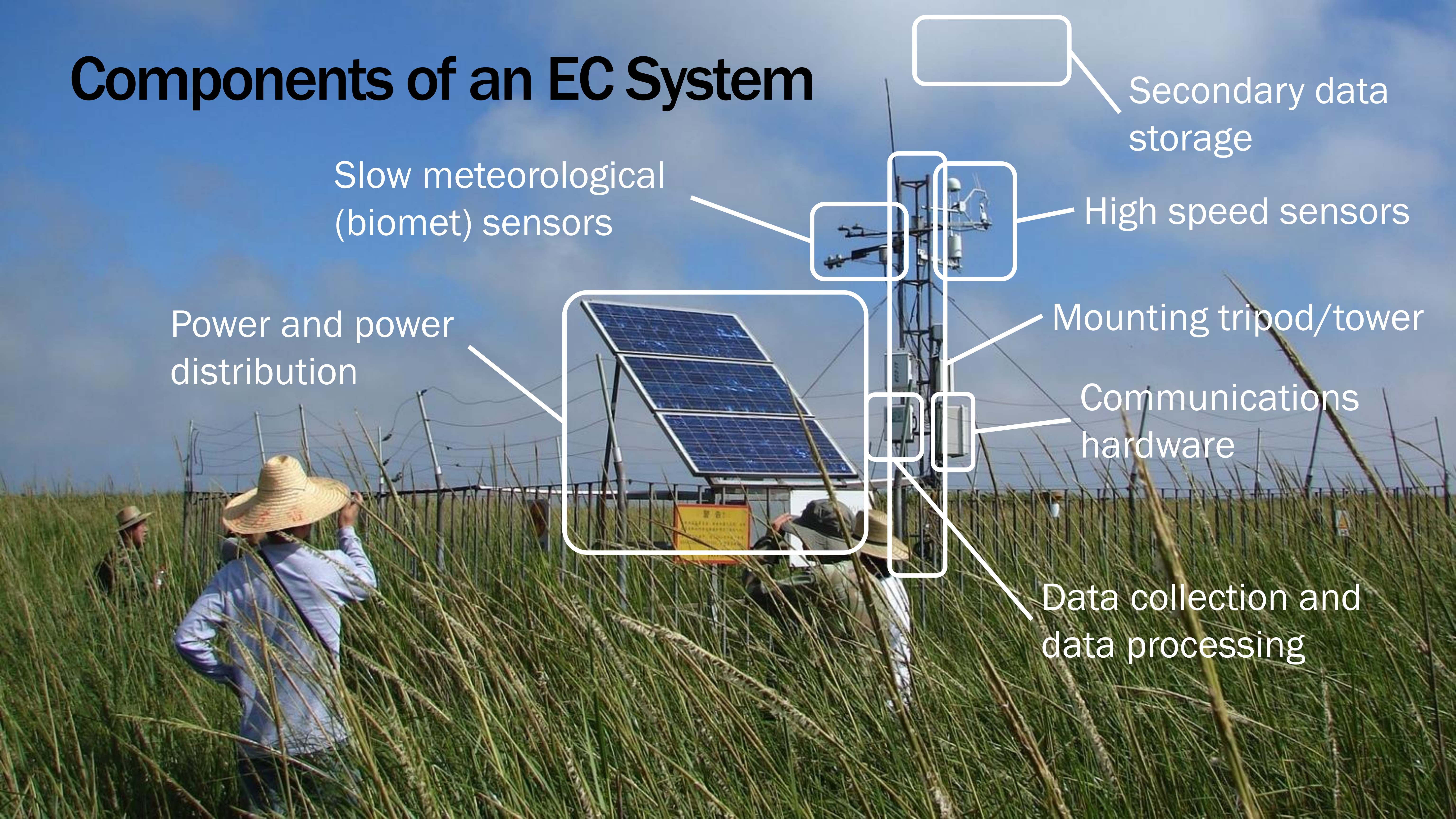
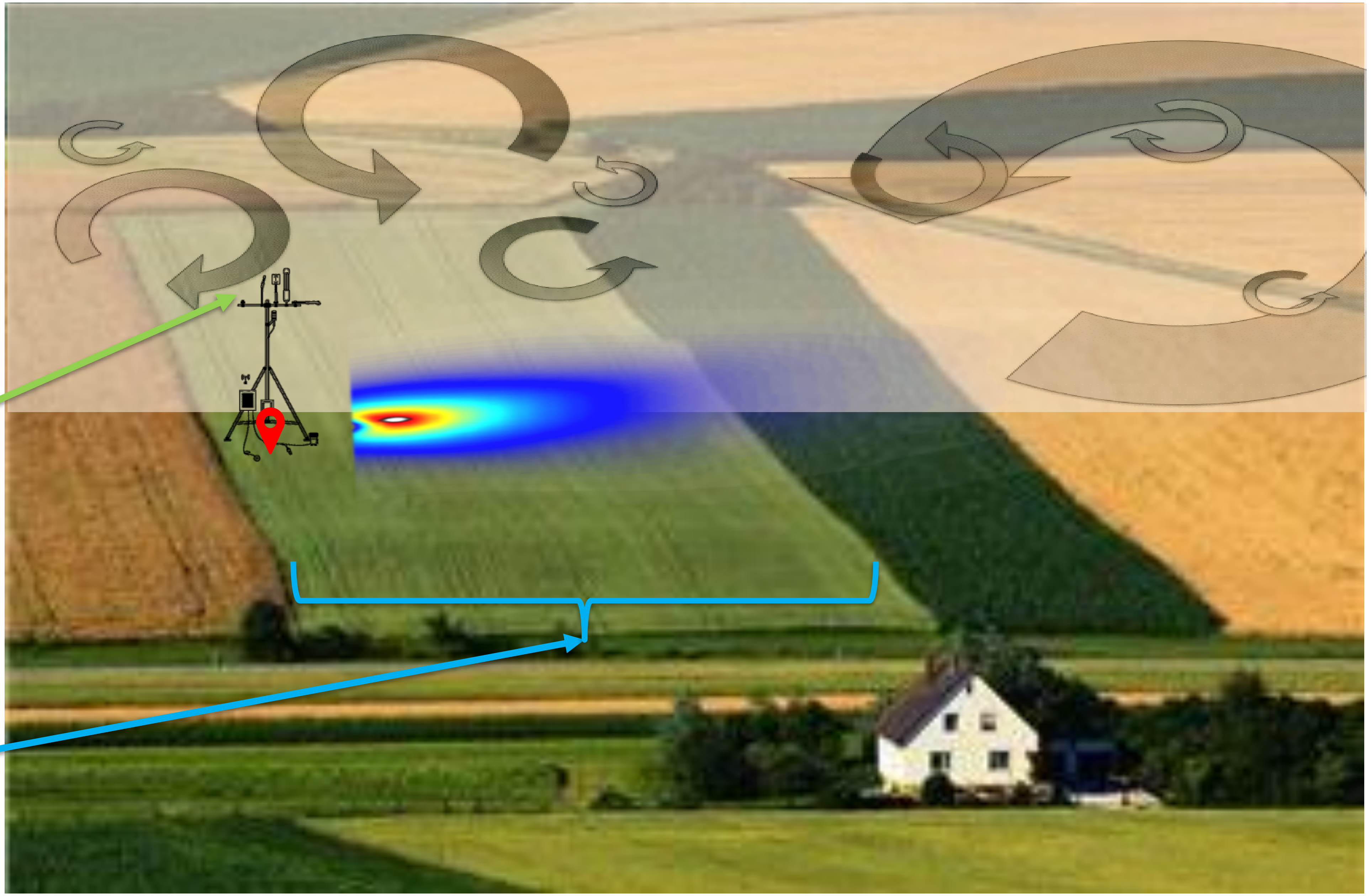
Components of an EC System



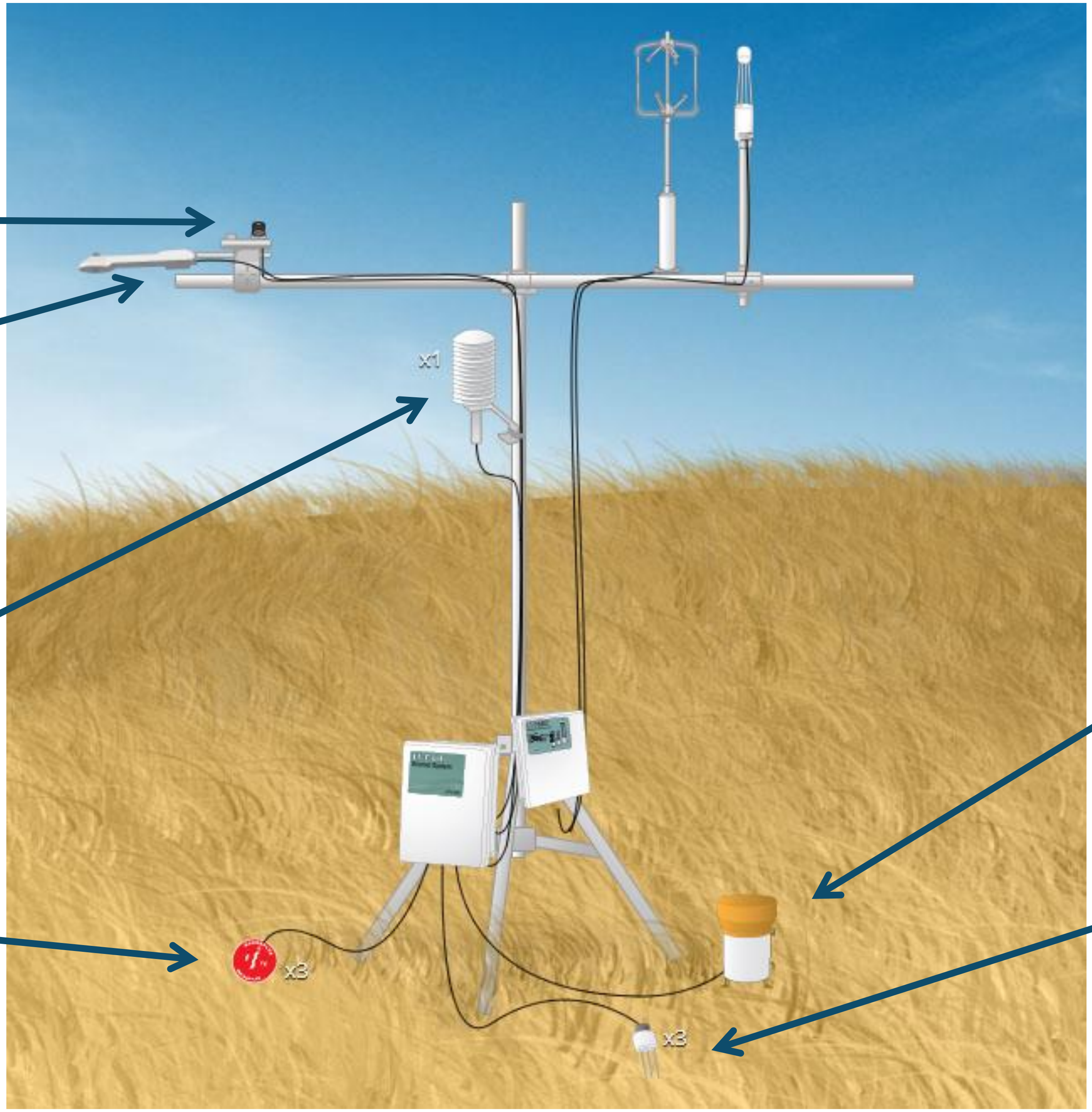
The big picture



Net measurements of CO_2, H_2O, CH_4, etc. fluxes

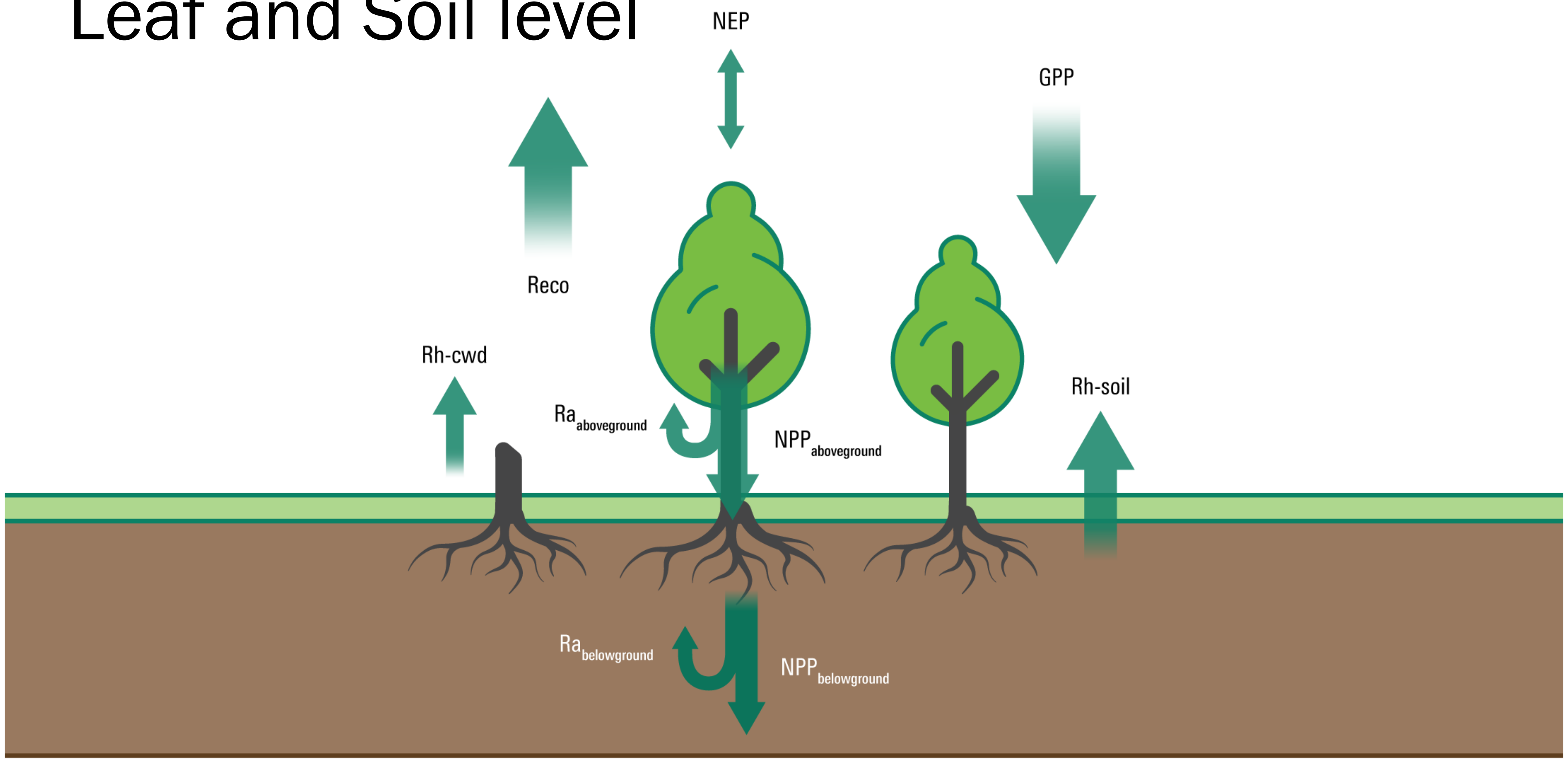
Field:
Area of Interest

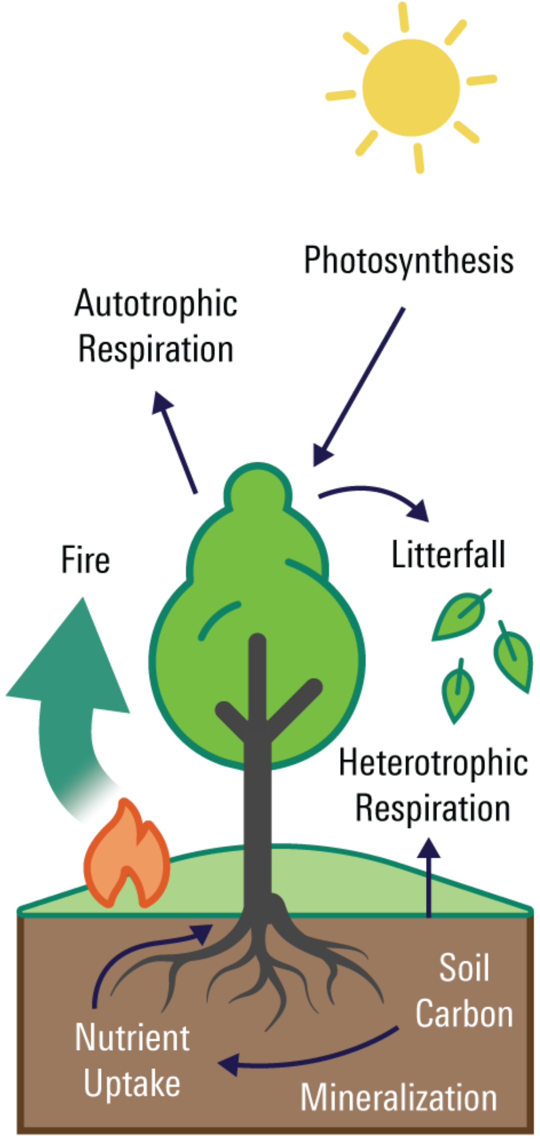
Biomet Measurements help identify some influences



What else influences or effects on our net fluxes?

Lots of processes;
Leaf and Soil level

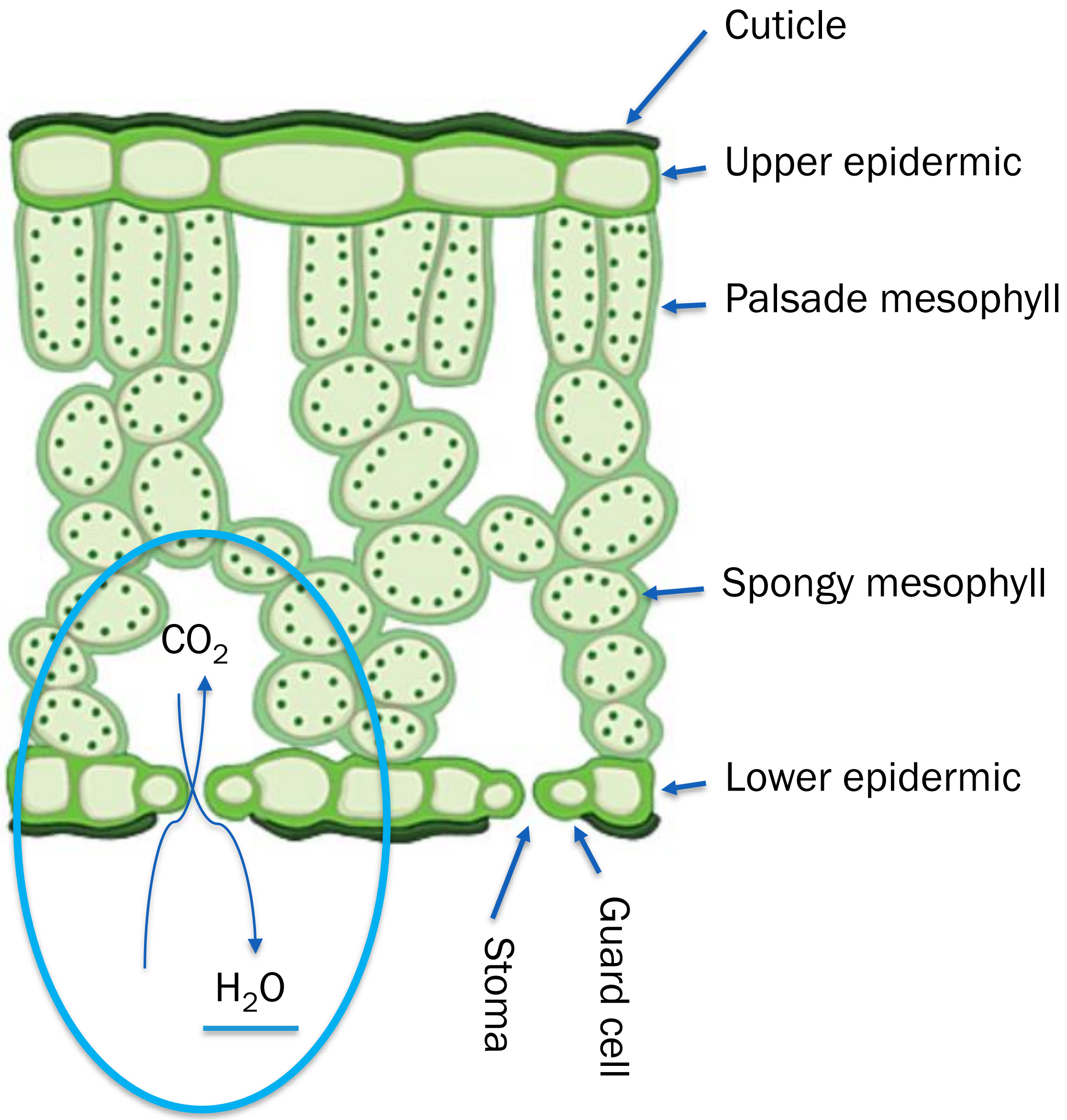




Carbon Cycle

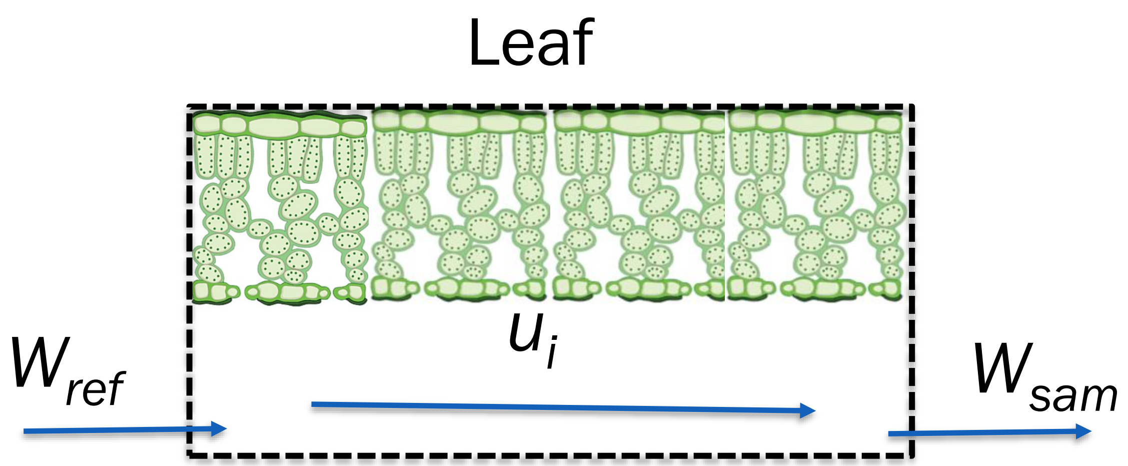
Let us start with the leaf-level influences

How do these tiny stomates have an affect on fluxes?



Stomatal Size: 20-50 mm
Stomatal Density: 10-80/mm^2 on upper surface, 25-330/mm^2 on lower surface

First, we can measure the transpiration



$$E = \frac{u_i(W_{sam} - W_{ref})}{s(1 - W_{sam})}$$

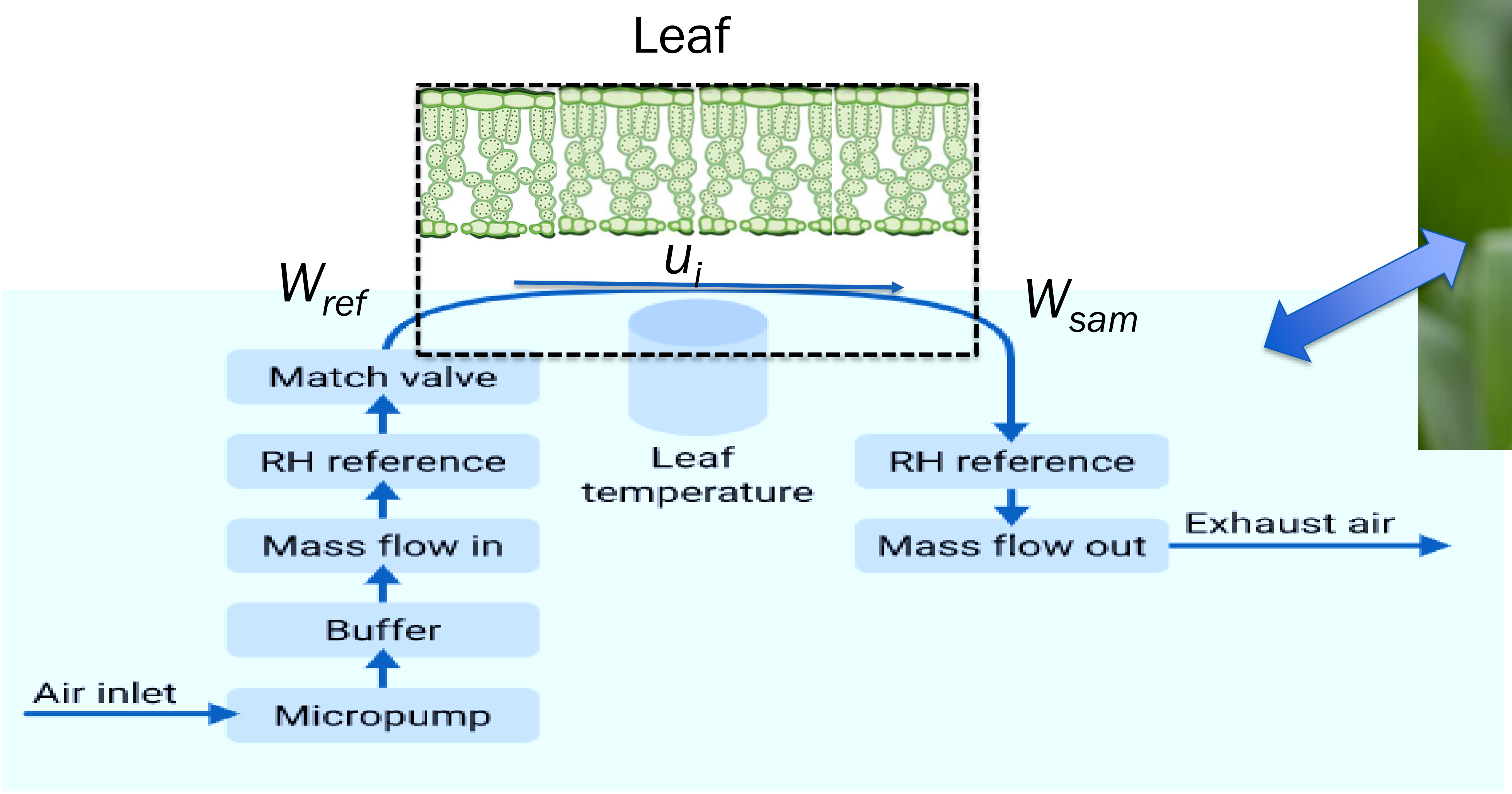
E transpiration (mmol $m^{-2}s^{-1}$)

u flow (mol s^{-1})

W water mole fraction (mmol mol^{-1})

s leaf area (m^2)

First, we can measure the transpiration



LI-600 Porometer

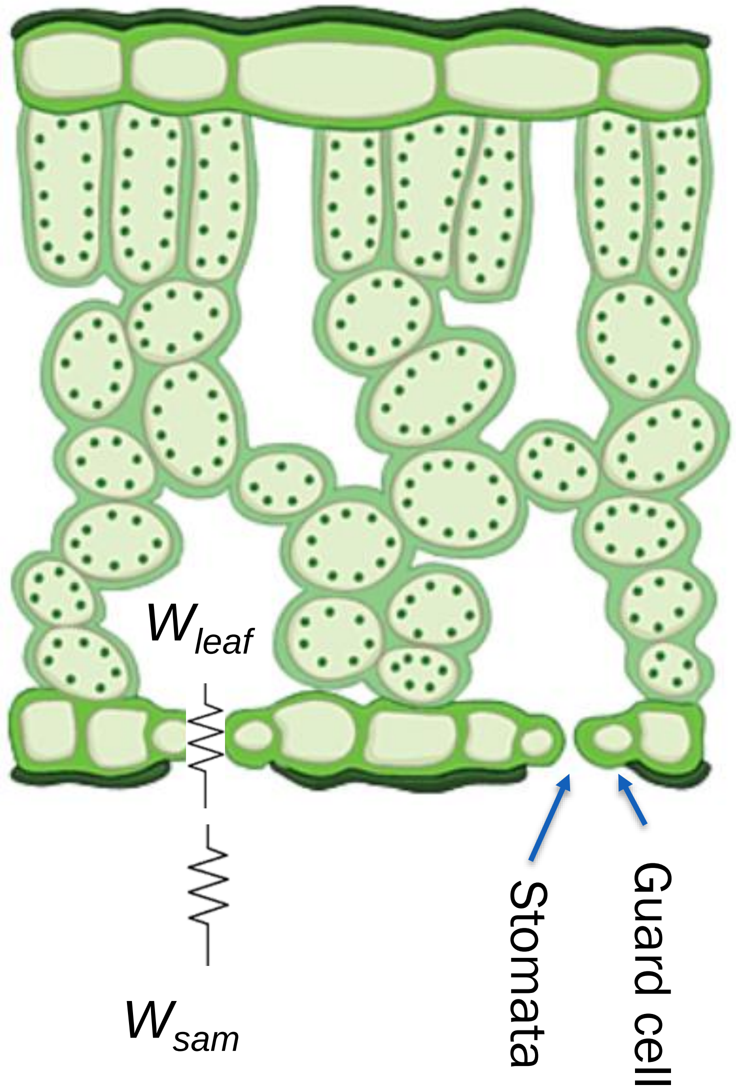
Then we can compute the conductance's that control the flow of H_2O (and CO_2) molecules

Total Conductance (g_{tw}) and stomatal conductance (g_{sw})

$$E = g_{tw}(W_{leaf} - W_{sam})$$

$$g_{tw} = \frac{E}{W_{leaf} - W_{sam}}$$

$$g_{sw} = \frac{1}{\frac{1}{g_{tw}} - \frac{1}{g_{bw}}}$$



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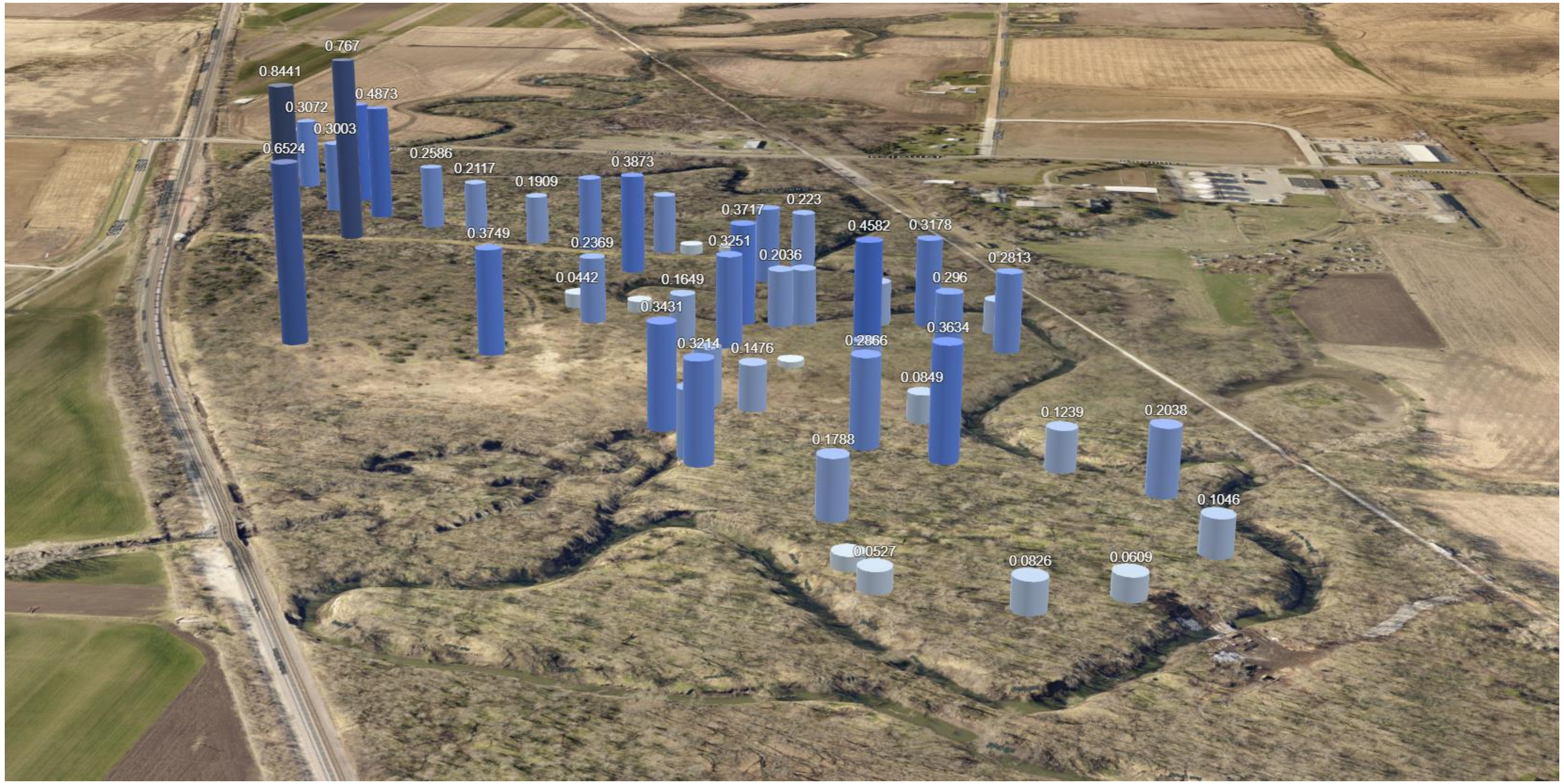
Measuring stomal conductance over an area of interest



Stomatal conductance (g_{sw}) measured with a GPS-enabled LI-600. Georeferenced measurements from the LI-600 are easily viewed in mapping applications including Google Earth™ and Esri® ArcGIS®.

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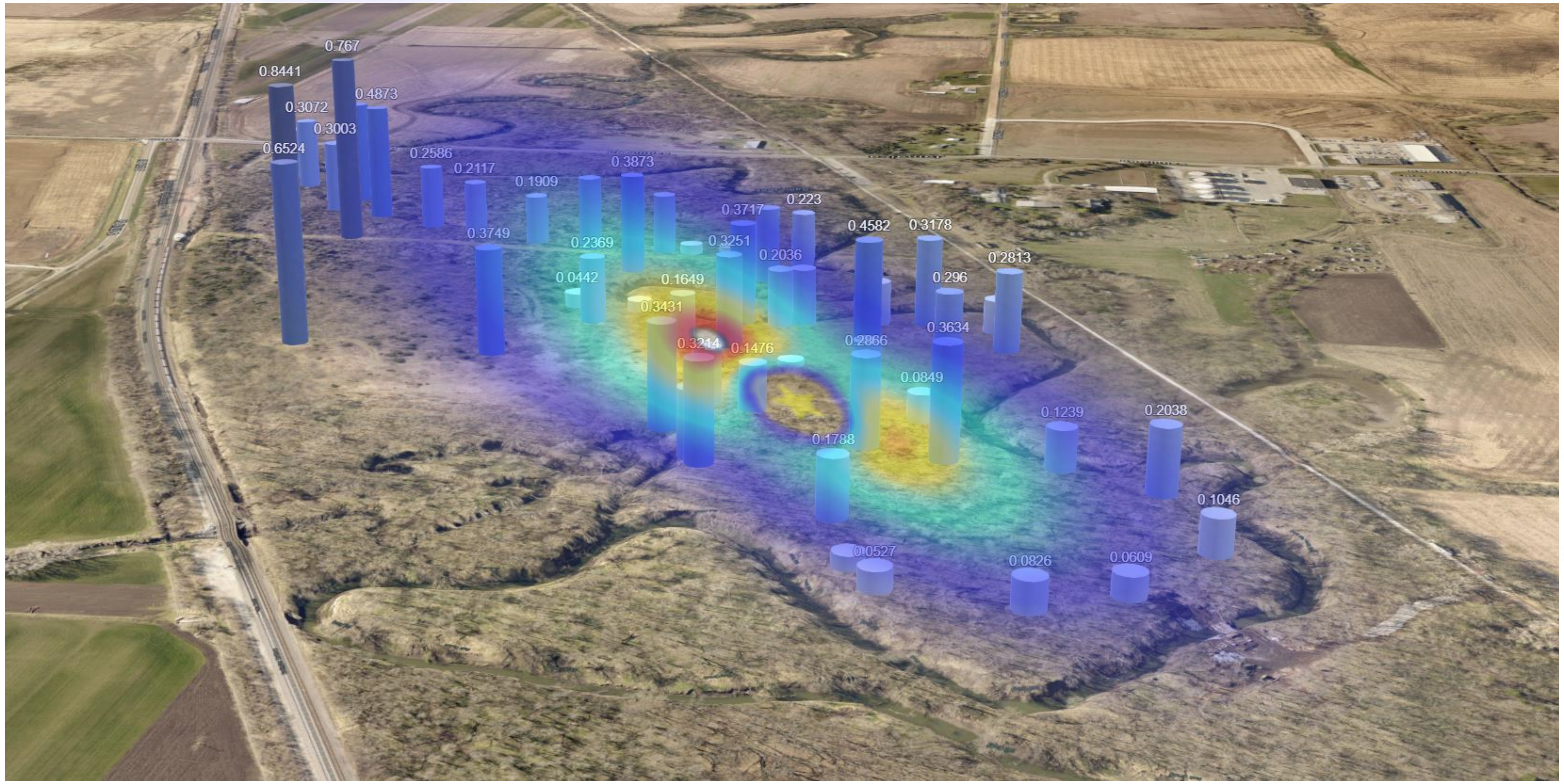
Integrating stomal conductance with EC fluxes



Stomatal conductance (g_{sw}) measured with a GPS-enabled LI-600. Georeferenced measurements from the LI-600 are easily viewed in mapping applications including Google Earth™ and Esri® ArcGIS®.

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Why its important to scaling up and down

Calculating canopy stomatal conductance from eddy covariance measurements, in light of the energy budget closure problem

Richard Wehr and Scott R. Saleska
Ecology and Evolutionary Biology, University of Arizona, Tucson, 85721, USA

Abstract

Canopy stomatal conductance is commonly estimated from eddy covariance measurements of the latent heat flux (*LE*) by inverting the Penman–Monteith equation. That method ignores eddy covariance measurements of the sensible heat flux (*H*) and instead calculates *H* implicitly as the residual of all other terms in the site energy budget. Here we show that canopy stomatal conductance is more accurately calculated from eddy covariance (EC) measurements of both *H* and *LE* using the flux–gradient equations that define conductance and underlie the Penman–Monteith equation, especially when the site energy budget fails to close due to pervasive biases in the eddy fluxes and/or the available energy. The flux–gradient formulation dispenses with unnecessary assumptions, is conceptually simpler, and is as or more accurate in all plausible scenarios. The inverted Penman–Monteith equation, on the other hand, contributes substantial biases and erroneous spatial and temporal patterns to canopy stomatal conductance, skewing its relationships with drivers such as light and vapor pressure deficit.

…the inverted Penman–Monteith equation is an inaccurate and unnecessary approximation to the flux–gradient equations for sensible heat and water vapor.

Incomplete measurement of the energy budget at EC sites causes substantial bias and misleading spatial and temporal patterns in canopy stomatal conductance, even after attempted eddy flux corrections.

The biases in stomatal conductance vary between 0 % and ~ 30 % depending on the time of day and the site characteristics, resulting in erroneous relationships between stomatal conductance and driving variables such as light and vapor pressure deficit.

Wehr, R. and Saleska, S. R.: Calculating canopy stomatal conductance from eddy covariance measurements, in light of the energy budget closure problem, Biogeosciences, 18, 13–24, https://doi.org/10.5194/bg-18-13-2021, 2021.

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Why its important to scaling up and down

ELSEVIER

Agricultural and Forest Meteorology
Volume 280, 15 January 2020, 107786

Partitioning evapotranspiration with concurrent eddy covariance measurements in a mixed forest

Eugénie Paul-Limoges [a], Sebastian Wolf [b], Fabian D. Schneider [c], Marcos Longo [c], Paul Moorcroft [d], Mana Gharun [e], Alexander Damm [a, f]

Both NPP and transpiration rates are limited by stomatal conductance.

Stomatal conductance is down-regulated depending on the amount of plant available soil moisture

Stomatal regulation was also found during summer afternoons in response to enhanced atmospheric evaporative demand in order to mitigate water-stress related damage (i.e. cavitation).

Even with nighttime stomatal conductance up to 90% of daytime conductance, transpiration rates at night tend to be lower than during daytime due to a (1) lack of photosynthesis and (2) considerably lower nighttime VPD

Paul-Limoges, Eugénie, et al. "Partitioning evapotranspiration with concurrent eddy covariance measurements in a mixed forest." *Agricultural and Forest Meteorology* 280 (2020): 107786.

Why its important to scaling up and down

Hydrol. Earth Syst. Sci., 23, 2877–2895, 2019
https://doi.org/10.5194/hess-23-2877-2019

Hydrology and Earth System Sciences
Open Access
EGU

Bayesian performance evaluation of evapotranspiration models based on eddy covariance systems in an arid region

Guoxiao Wei[1,2], Xiaoying Zhang[3], Ming Ye[4], Ning Yue[1,2], and Fei Kan[1,2]

[1]Key Laboratory of Western China's Environmental System (Ministry of Education), Lanzhou University, Lanzhou, 730000, China
[2]School of Earth and Environmental Sciences, Lanzhou University, Lanzhou, 730000, China
[3]College of Construction Engineering, Jilin University, Changchun, 130400, China
[4]Department of Earth, Ocean, and Atmospheric Science, Florida State University, Tallahassee, FL 32306, USA

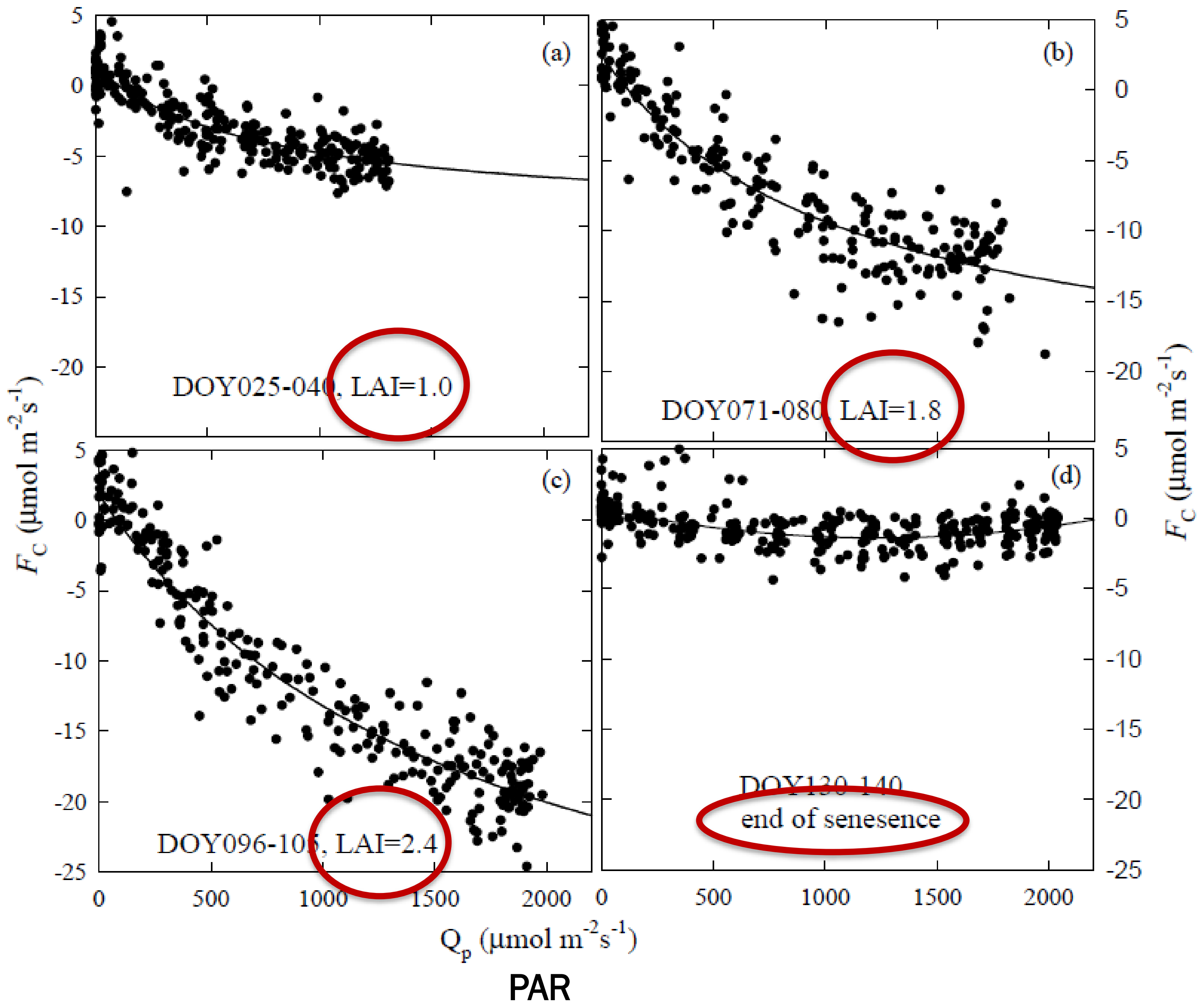
Correspondence: Xiaoying Zhang (xiaoyingzh@jlu.edu.cn)

The absence of a mechanistic representation of the physiological response to plant hydrodynamics makes it difficult for the available ET models to resolve the dynamics of intradaily hysteresis, producing patterns of diurnal error, while the imbalance or lack of between-leaf water demand and soil water supply imposes hydrodynamic limitations on stomatal conductance.

Wei, G., Zhang, X., Ye, M., Yue, N., and Kan, F.: Bayesian performance evaluation of evapotranspiration models based on eddy covariance systems in an arid region, Hydrol. Earth Syst. Sci., 23, 2877–2895, https://doi.org/10.5194/hess-23-2877-2019, 2019.

We can see that CO_2 fluxes are affected by the amount of Leaf Area

Seasonal relationships between *PAR* and CO_2 *flux*



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

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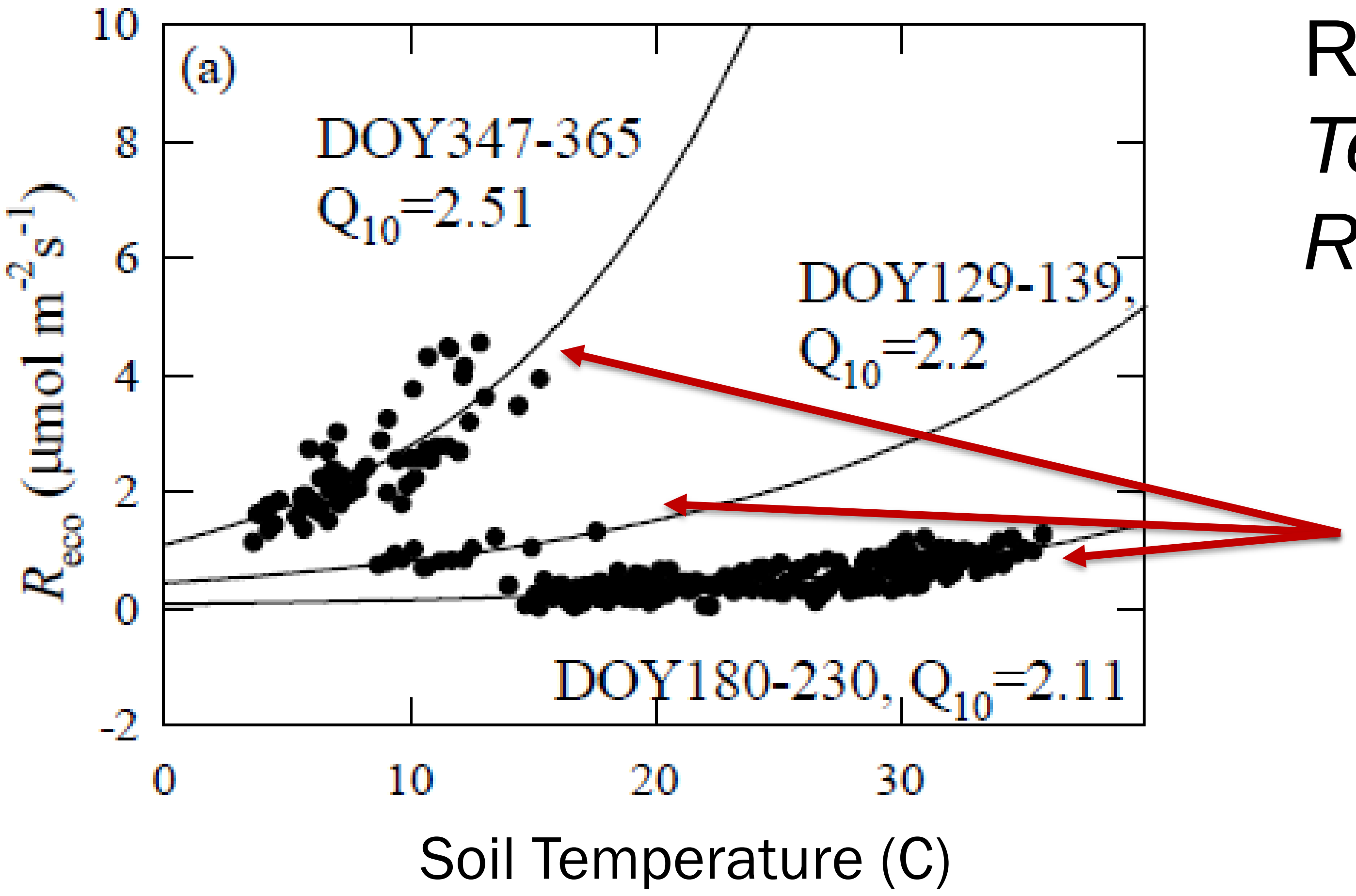
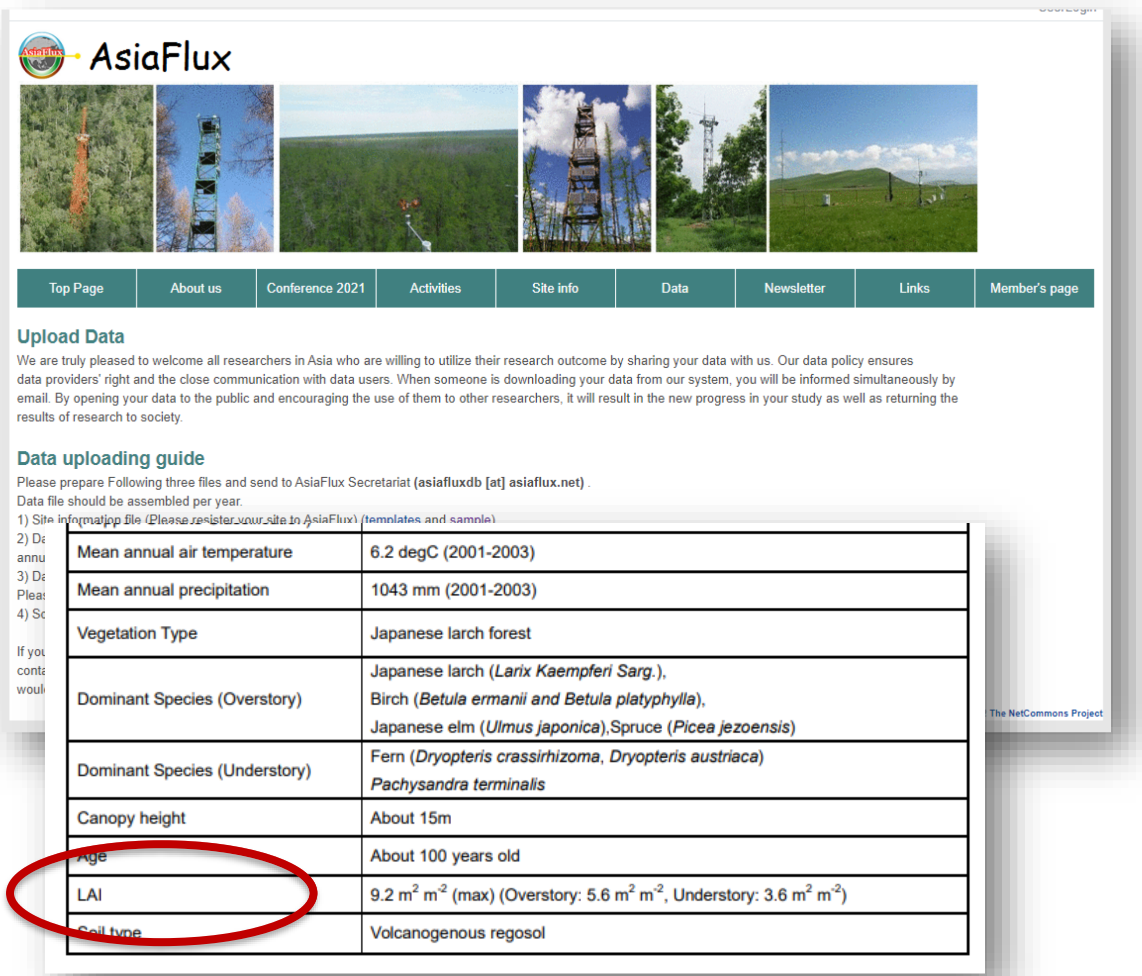
We also know ecosystem respiration fluxes are affected by the amount of Leaf Area

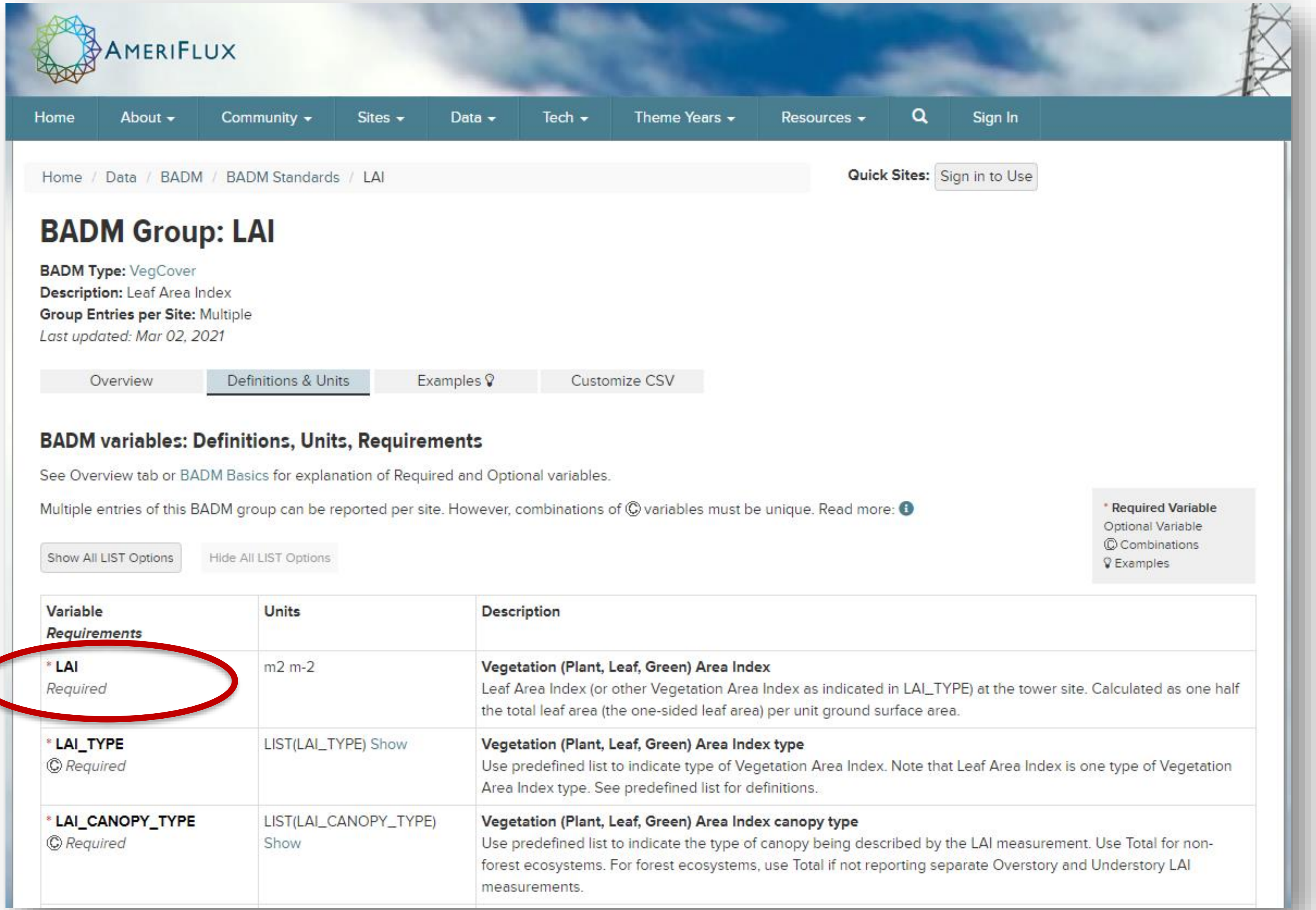


Relationships between *Soil Temperature* and *Ecosystem Respiration*

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

Leaf Area Index (LAI) is often required for submission to both the Flux Networks and with publications





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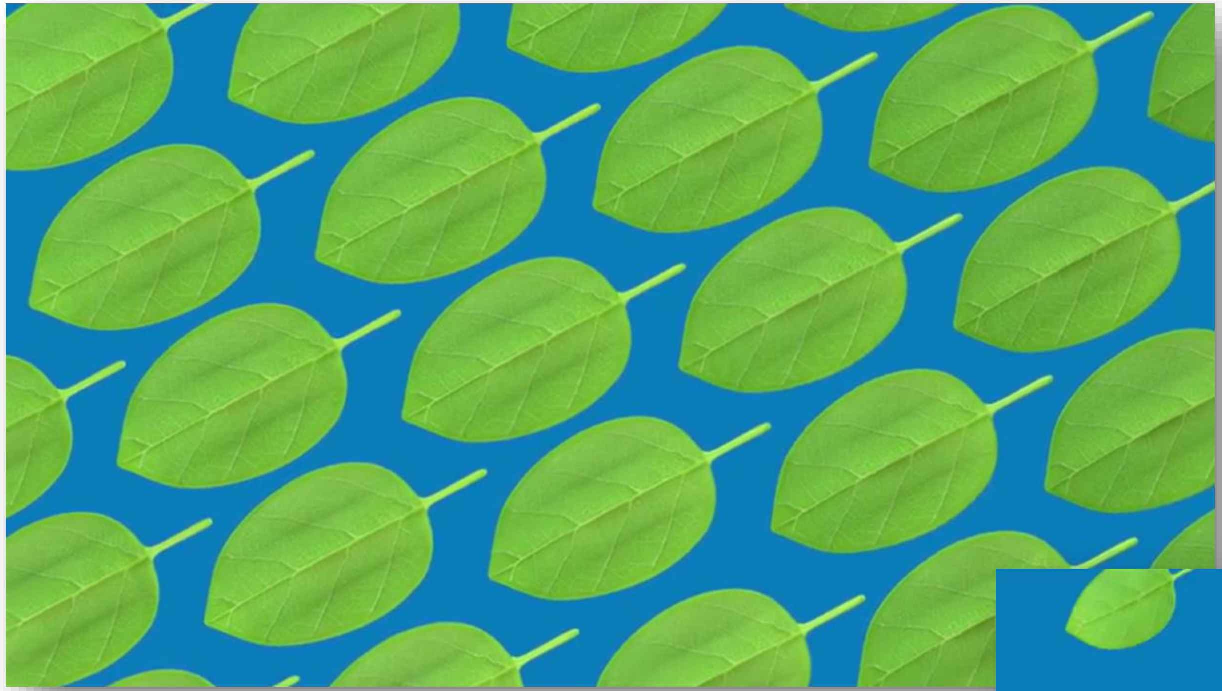
What to we mean by Leaf Area Index (LAI)?

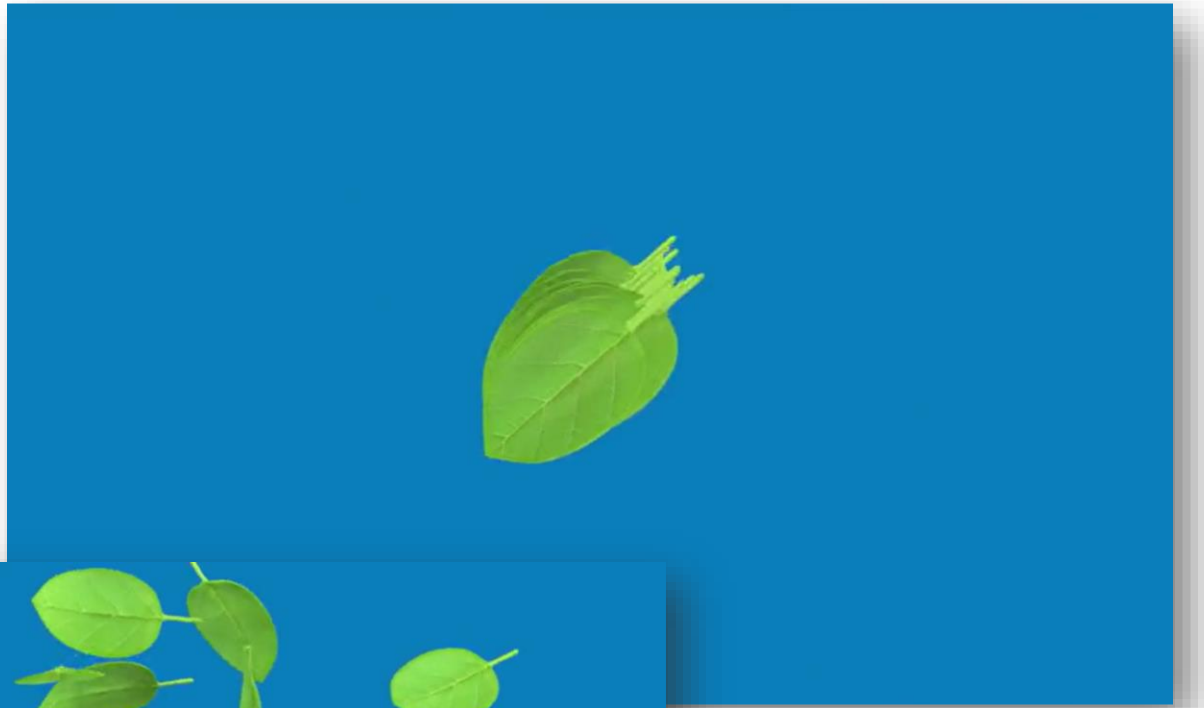
Simply, Leaf Area Index (LAI) is the ratio of
‘Leaf Area’ to the ‘Ground Area’

LAI = Leaf Area / Ground Area

And it can be used to describe an ecosystem’s dynamic canopy.

These three example have the same LAI!





The area of the leaves are the same in each example, over the same (blue) ground area

The LAI-2200C Plant Canopy Analyzer

- The LAI-2200C is a standalone instrument for manual, non-destructive LAI measurements.

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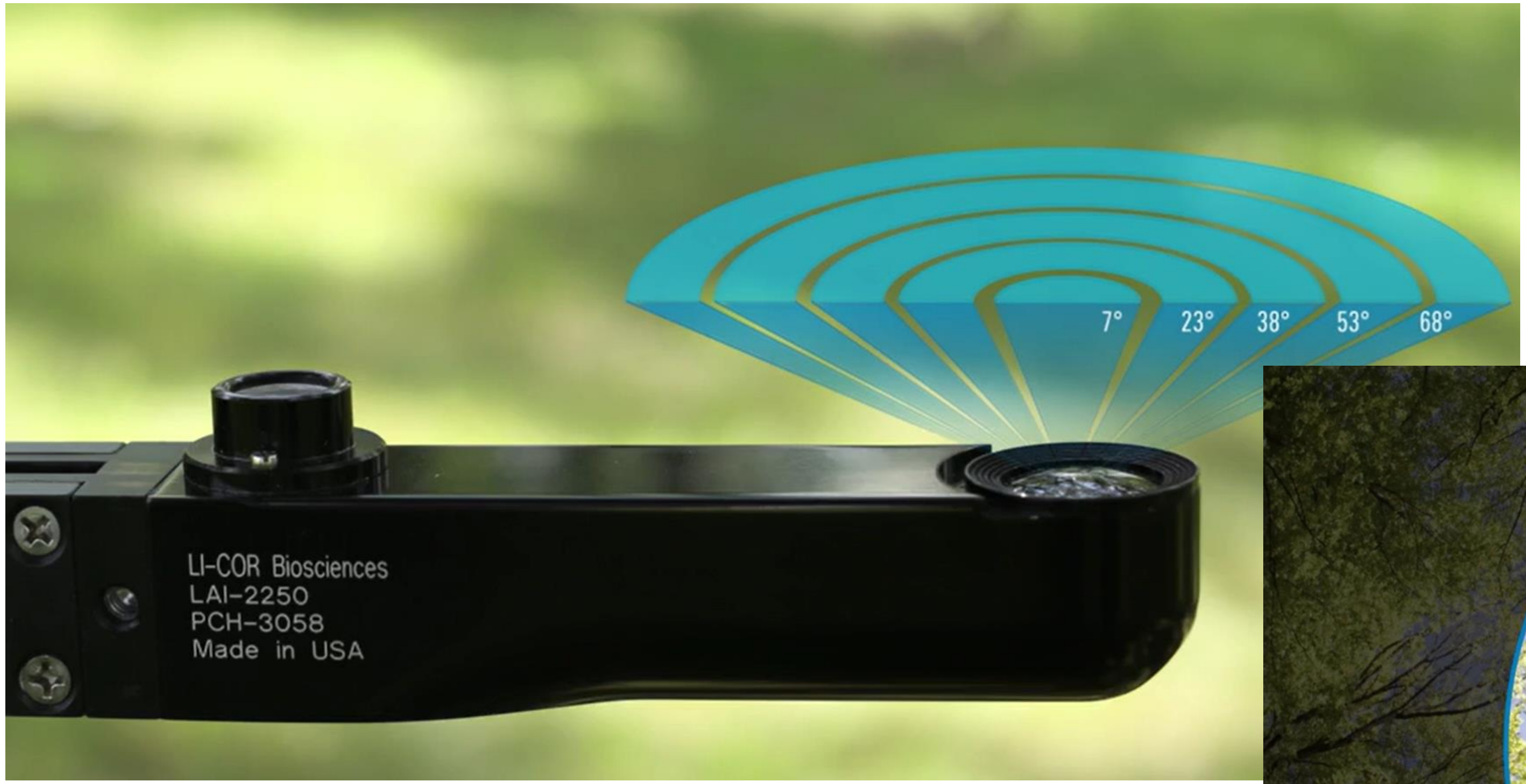
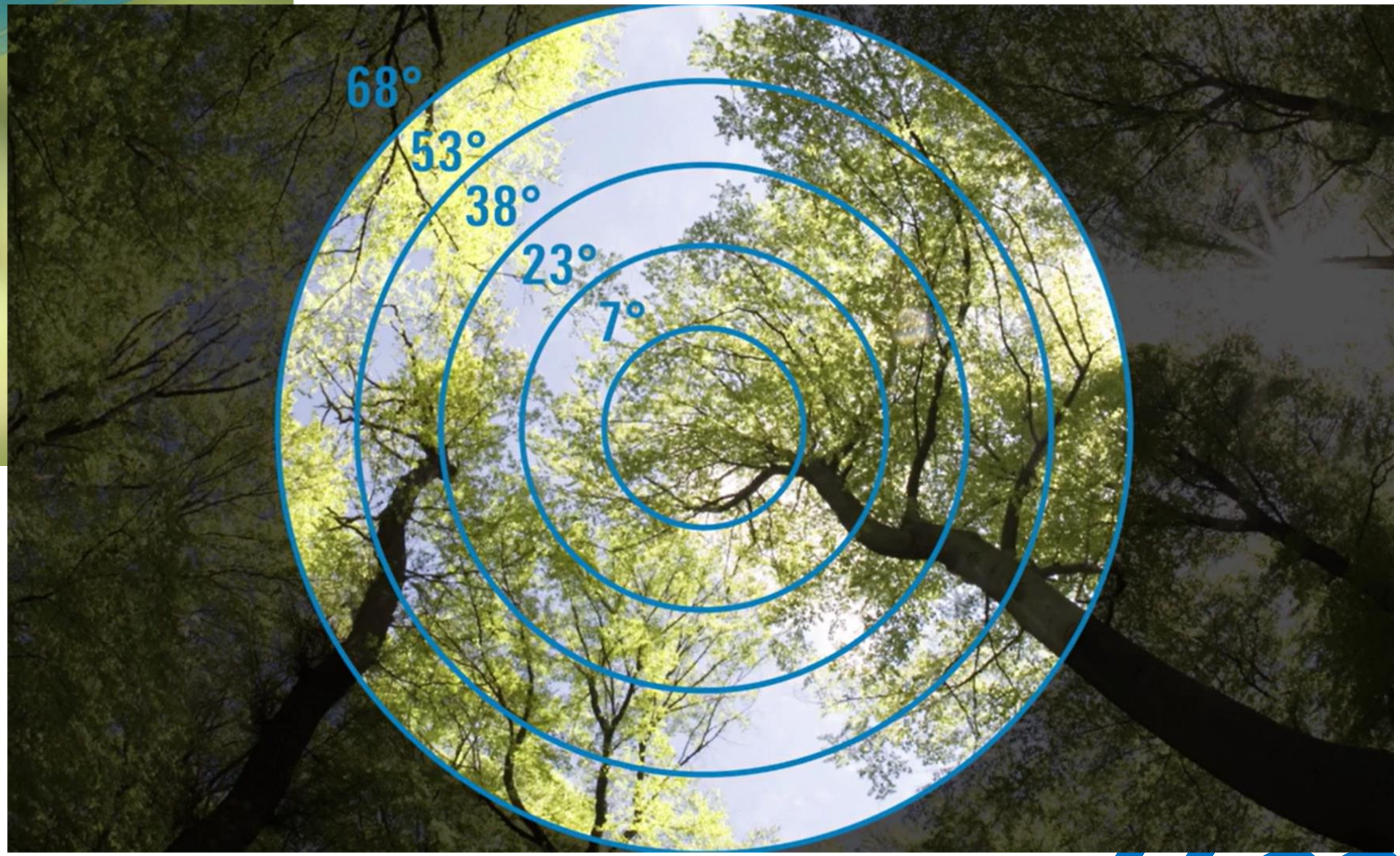
How it measures Leaf Area Index (LAI)





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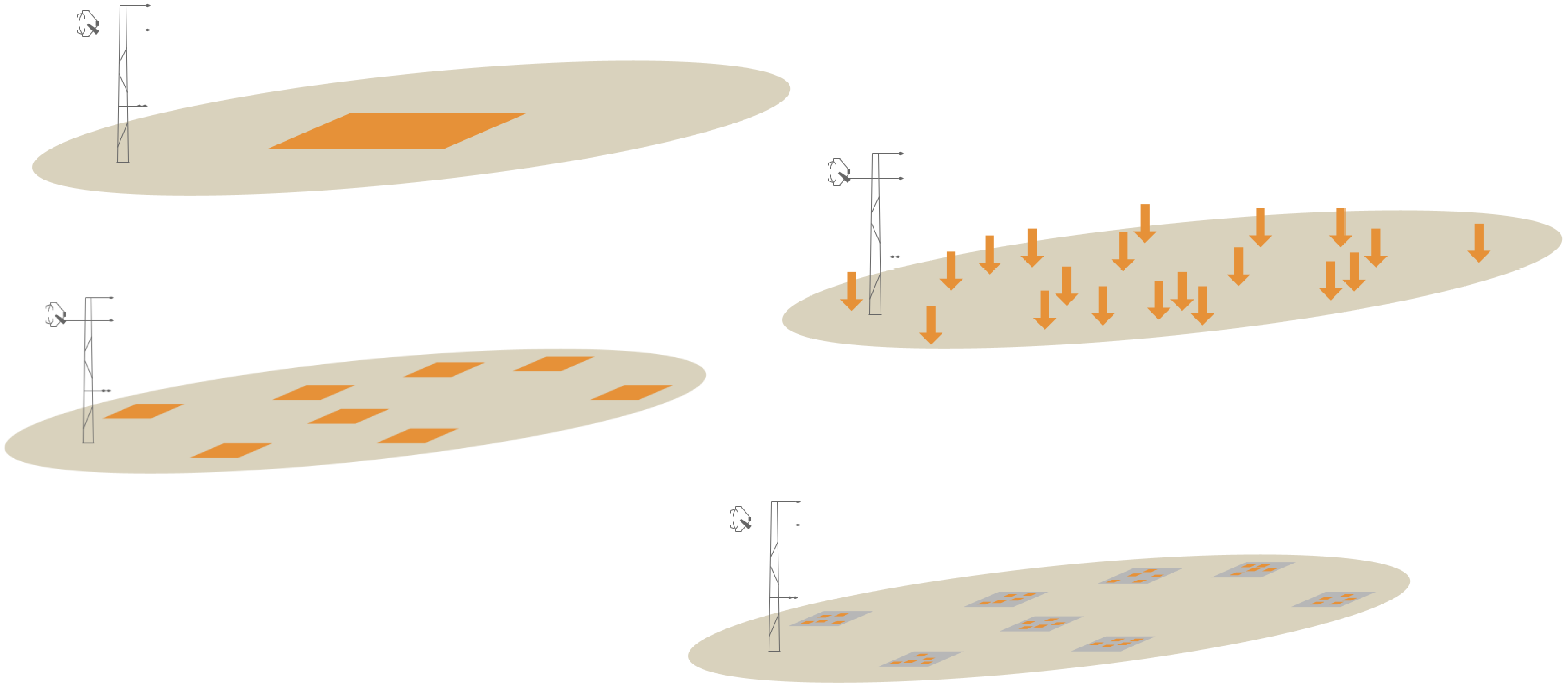
Example LAI measurement routines for EC fetches



https://ameriflux.lbl.gov/data/badm/badm-standards/LAI

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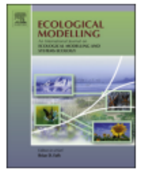
Integrating LAI with Eddy Covariance fluxes

Ecological Modelling 303 (2015) 30–41

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel



The effects of constraining variables on parameter optimization in carbon and water flux modeling over different forest ecosystems

Min Liu[a,b], Honglin He[a,*], Xiaoli Ren[a,c], Xiaomin Sun[a], Guirui Yu[a], Shijie Han[d], Huimin Wang[a], Guoyi Zhou[e]

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[b] Shanghai Key Laboratory for Urban Ecological Processes and Eco-Restoration, School of Ecological and Environmental Sciences, East China Normal University, Shanghai 200062, China
[c] University of Chinese Academy of Sciences, Beijing 100049, China
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Forest ecosystems
SIPNET

ABSTRACT

The ability of terrestrial biogeochemical models in predicting land-atmospheric carbon and water exchanges is largely hampered by the insufficient characterization of model parameters. The direct observations of carbon/water fluxes and the associated environmental variables from eddy covariance (EC) flux towers provide a notable opportunity to examine the underlying processes controlling carbon and water exchanges between terrestrial ecosystems and the atmosphere. In this study, we applied the Metropolis simulated annealing technique to conduct parameter optimization analyses of a process-based biogeochemical model, simplified PnET (SIPNET), using a variety of constraining variables from EC observations and leaf area index (LAI) from MODIS at three ChinaFLUX forest sites: a temperate mixed forest (CBS), a subtropical evergreen coniferous plantation (QYZ) and a subtropical evergreen broad-leaved forest (DHS). Our analyses focused on (1) identifying the key model parameters influencing the simulation of carbon and water fluxes with SIPNET; (2) evaluating how different combinations of constraining variables influence parameter estimations and associated uncertainties; and (3) assessing the model performance with the optimized parameterization in predicting carbon and water fluxes in the three forest ecosystems. Our sensitivity analysis indicated that, among three different forest ecosystems, the prediction of carbon and water fluxes was mostly affected by photosynthesis-related parameters. The performances of the model simulations depended on different parameterization schemes, especially the combinations of constraining variables. The parameterization scheme using both net ecosystem exchange (NEE) and evapotranspiration (ET) as constraining variables performed best with most well-constrained parameters. When LAI was added to the optimization, the number of well-constrained model parameters was increased. In addition, we found that the model cannot be well-parameterized with only growing-season observations, especially for those forest ecosystems with distinct seasonal variation. With the optimized parameterization scheme using both NEE and ET observations all year round, the SIPNET were able to simulate the seasonal and inter-annual variations of carbon and water exchanges in three forest ecosystems.

Disentangling Climate and LAI Effects on Seasonal Variability in Water Use Efficiency Across Terrestrial Ecosystems in China

Yue Li[1,2], Hao Shi[3], Lei Zhou[4], Derek Eamus[5,6], Alfredo Huete[5], Longhui Li[5], James Cleverly[5,6], Zhongmin Hu[7], Mahrita Harahap[5], Qiang Yu[3,5], Liang He[8], and Shaoqiang Wang[1,2]

[1]Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China, [2]College of Resources and Environment, University of Chinese Academy of Sciences, Beijing, China, [3]State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Northwest A & F University, Yangling, China, [4]College of Geography and Environmental Sciences, Zhejiang Normal University, Jinhua, China, [5]School of Life Sciences, University of Technology Sydney, Sydney, New South Wales, Australia, [6]Australian Supersite Network, Terrestrial Ecosystem Research Network, University of Technology Sydney, Sydney, New South Wales, Australia, [7]School of Geography, South China Normal University, Guangzhou, China, [8]Agro-meteorological Center, National Meteorological Center of China Meteorological Administration, Beijing, China

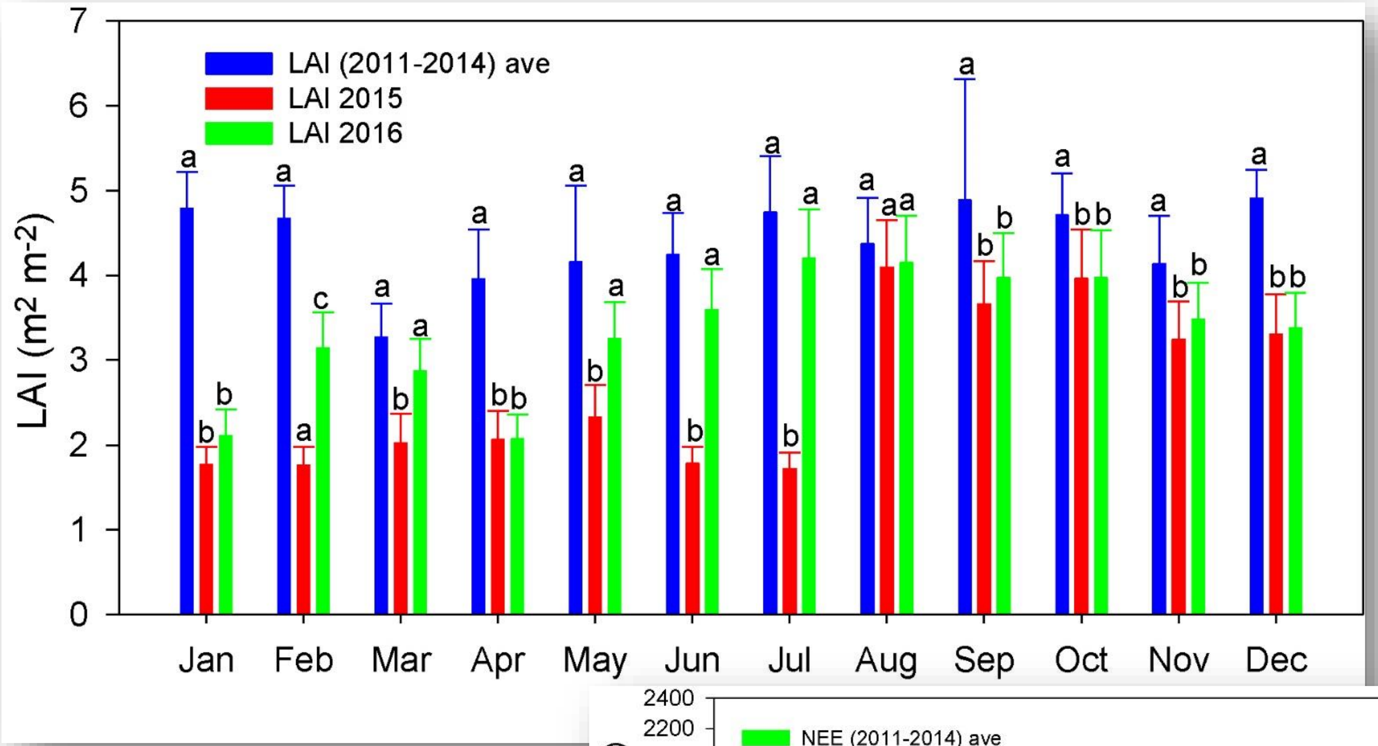
Abstract Water use efficiency (WUE), the ratio of gross primary productivity (GPP) over evapotranspiration (ET), is a critical ecosystem function. However, it is difficult to distinguish the individual effects of climatic variables and leaf area index (LAI) on WUE, mainly due to the high collinearity among these factors. Here we proposed a partial least squares regression-based sensitivity algorithm to confront the issue, which was first verified at seven ChinaFlux sites and then applied across China. The results showed that across all biomes in China, monthly GPP (0.42–0.65), ET (0.33–0.56), and WUE (0.01–0.31) showed positive sensitivities to air temperature, particularly in croplands in northeast China and forests in southwest China. Radiation exerted stronger effects on ET (0.55–0.78) than GPP (0.19–0.65), resulting in negative responses (−0.44 to 0.04) of WUE to increased radiation among most biomes. Increasing precipitation stimulated both GPP (0.06–0.17) and ET (0.05–0.12) at the biome level, but spatially negative effects of excessive precipitation were also found in some grasslands. Both monthly GPP (−0.01 to 0.29) and ET (0.02–0.12) showed weak or moderate responses to vapor pressure deficit among biomes, resulting in weak response of monthly WUE to vapor pressure deficit (−0.04 to 0.08). LAI showed positive effects on GPP (0.18–0.60), ET (0–0.23), and WUE (0.13–0.42) across biomes, particularly on WUE in grasslands (0.42 ± 0.30). Our results highlighted the importance of LAI in influencing WUE against climatic variables. Furthermore, the sensitivity algorithm can be used to inform the design of manipulative experiments and compare with factorial simulations for discerning effects of various variables on ecosystem functions.

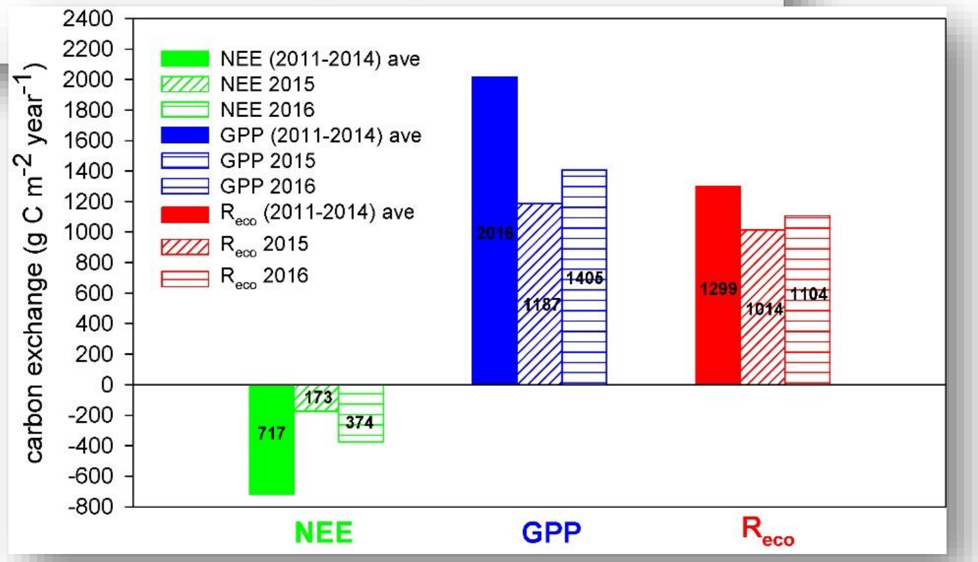
Effect of LAI on Net Ecosystem Exchange are clear

The study area is in the Xujiaba region of southwest China in the Ailaoshan National Nature Reserve

The forest has a mean canopy height was 20 m.

LAI in each month of 2015 was lower than the average value during 2011–2014 (significantly from Jan-Jul). The difference between the years were related to snowfall.





Annual variability of leaf area index (LAI) averaged over period of 'normal' years (2011–2014), 2015, and 2016. Bars indicate standard deviation. Different letters above bars indicate significant differences (one way ANOVA; $p < 0.05$).

Qing-Hai Song *et al* 2017 *Environ. Res. Lett.* **12** 104014 (https://doi.org/10.1088/1748-9326/aa82c4)

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?

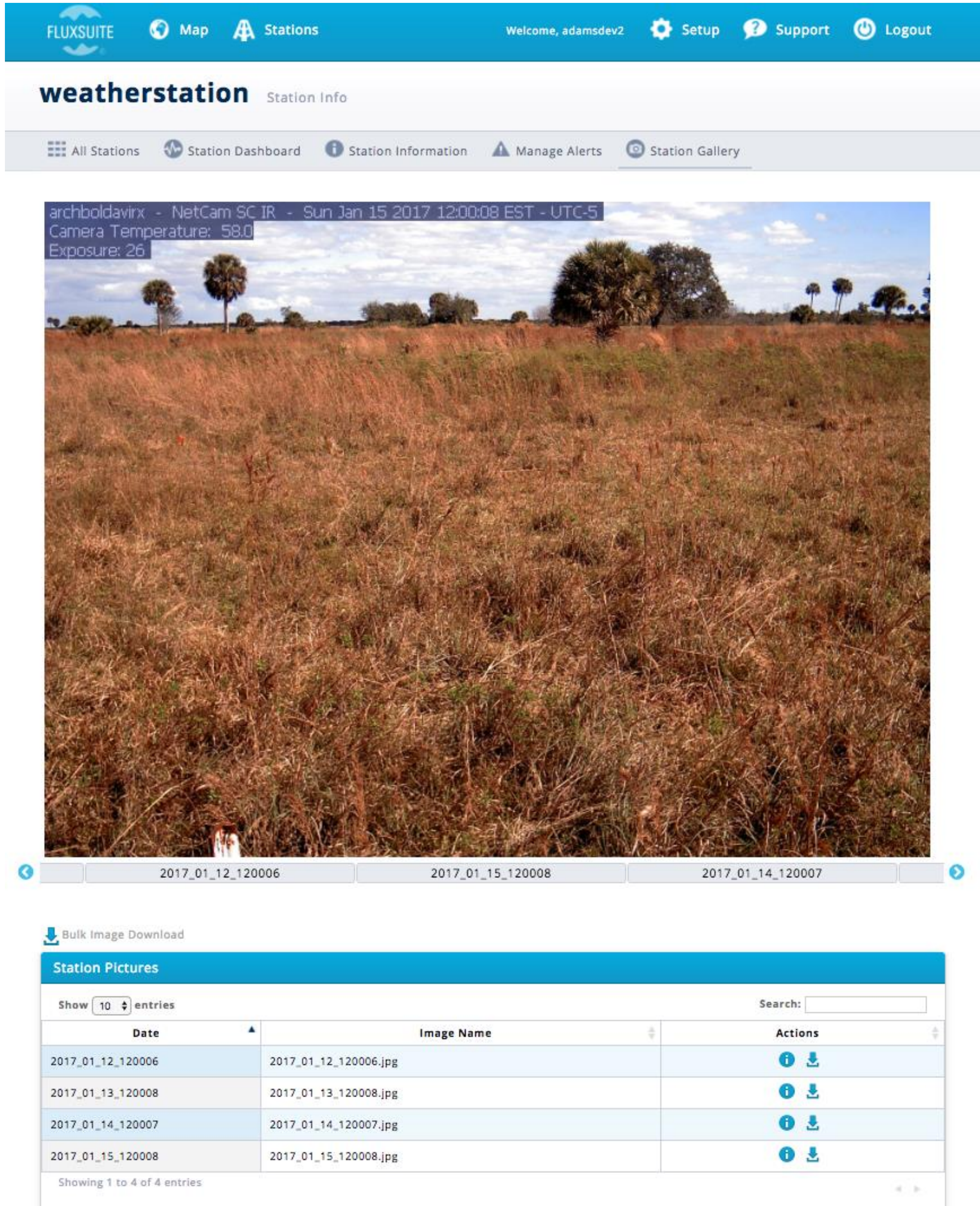
- Leafing, flowering, fruiting
- Leaf senescence
- Bird migration
- Insect infestation
- Plant disease
- Climate change
  - Springtime

PhenoCams

- Digital cameras used to monitor vegetation phenology
- Provide automated, near-surface remote sensing of canopy phenology
- Images uploaded to a server
- Techniques can be used to extract quantitative color information (i.e., greenness) from each picture.

Digital Camera (PhenoCam) Image Gallery

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



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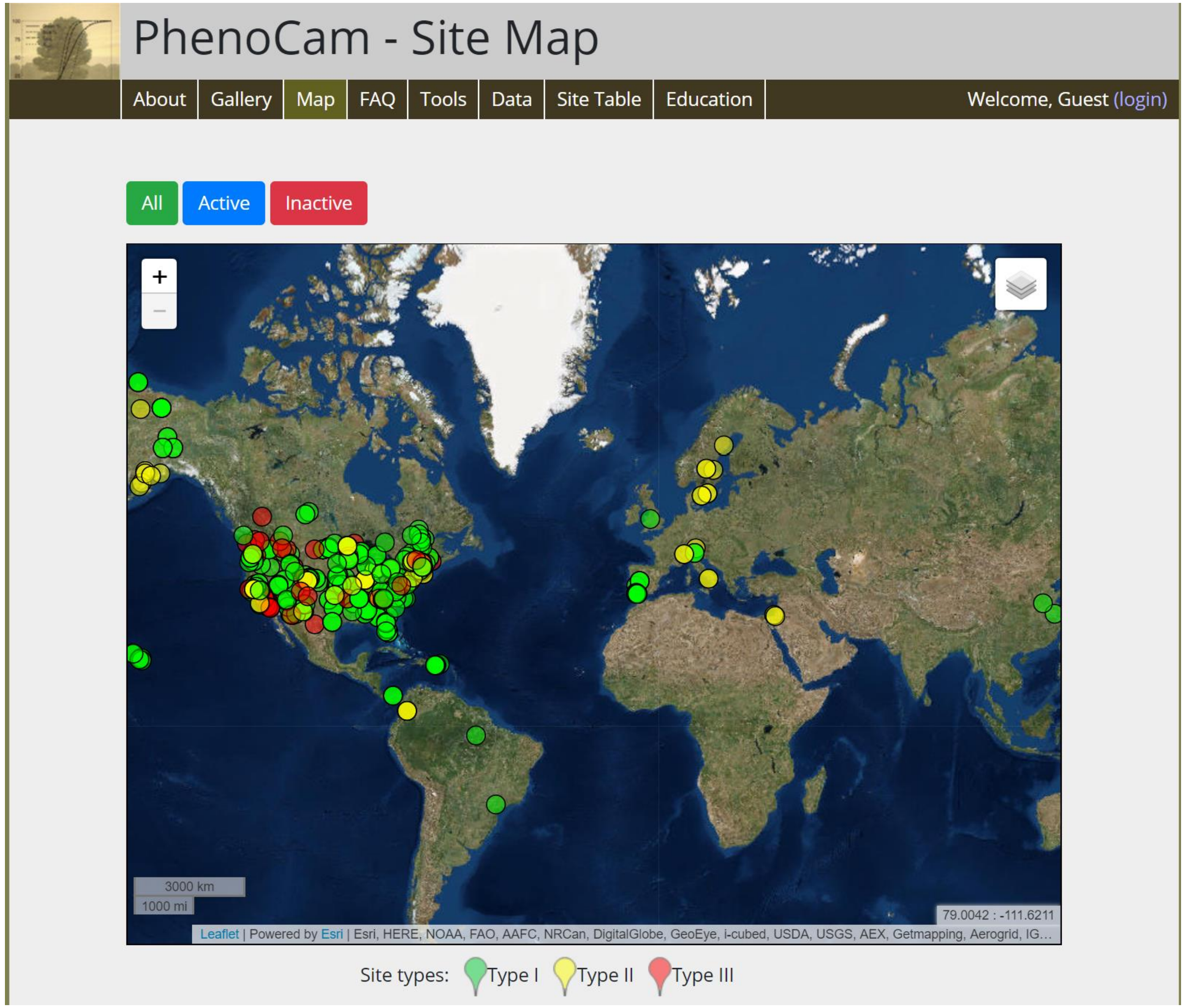
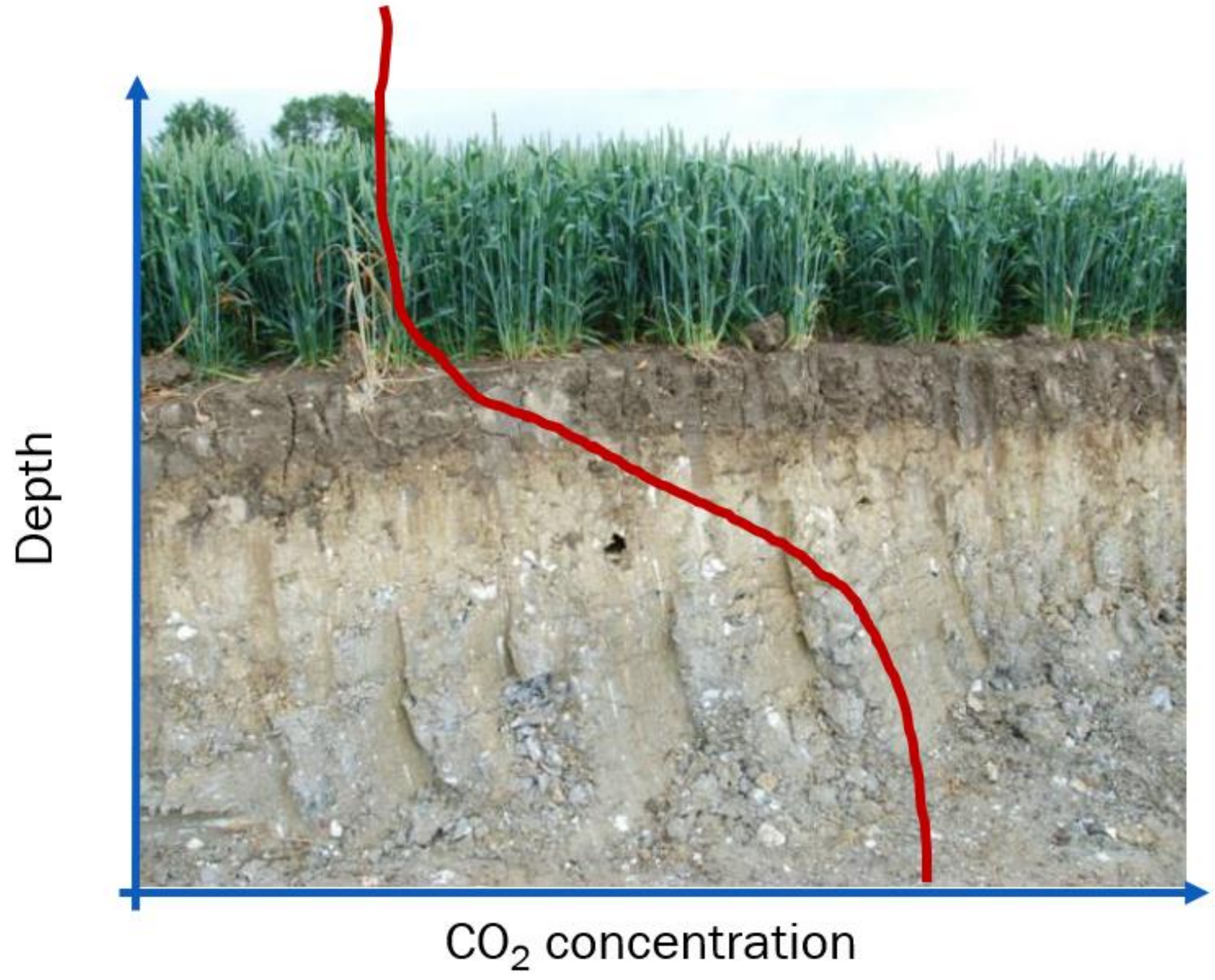
The PhenoCam Network

- https://phenocam.sr.unh.edu/webcam/
- Hosted by University of New Hampshire, but world-wide collaboration
- Recommend (and provide some support through hosted programs / instructions) for StarDot PhenoCams

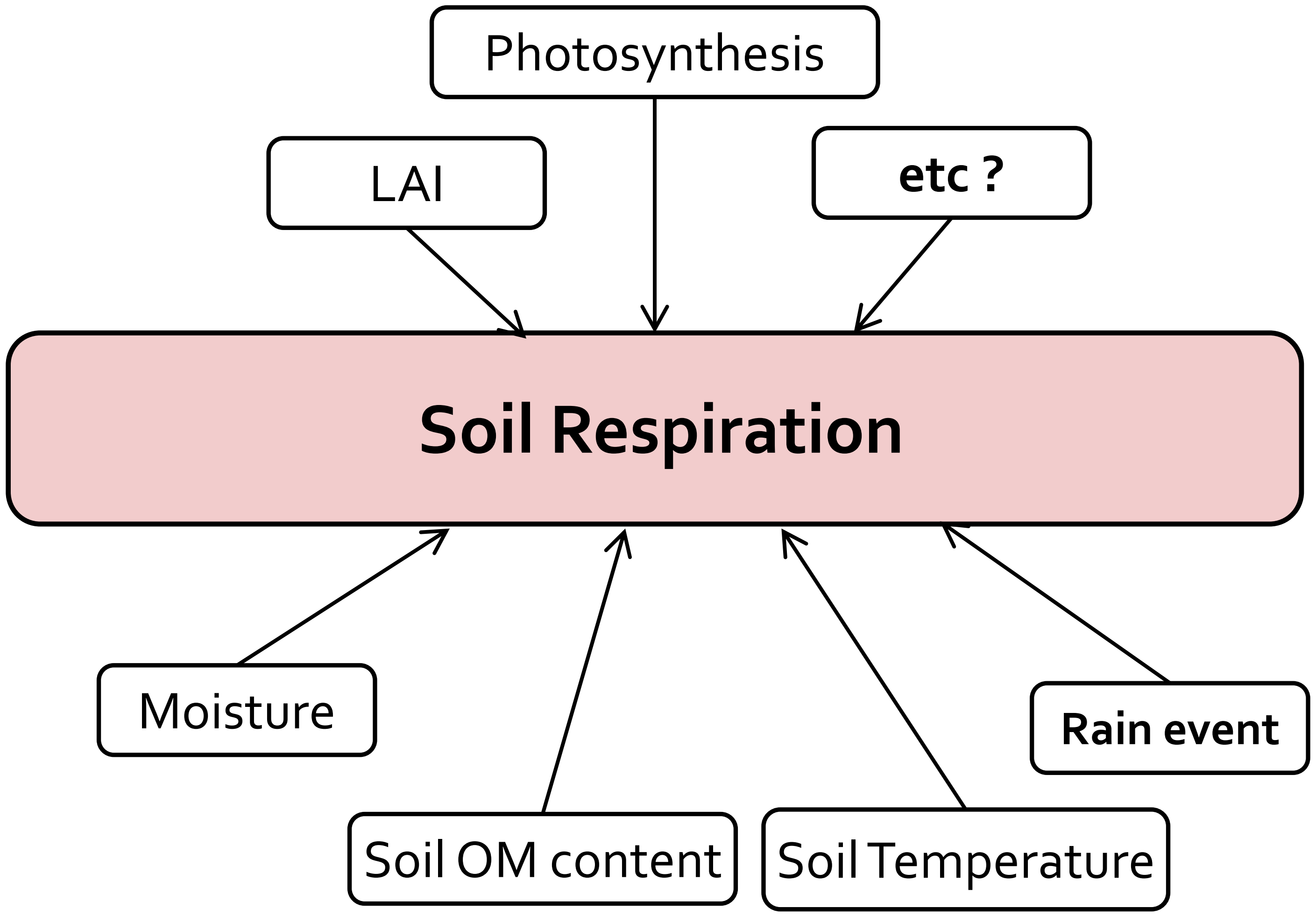


How does the soil (and what is in it) affect fluxes?

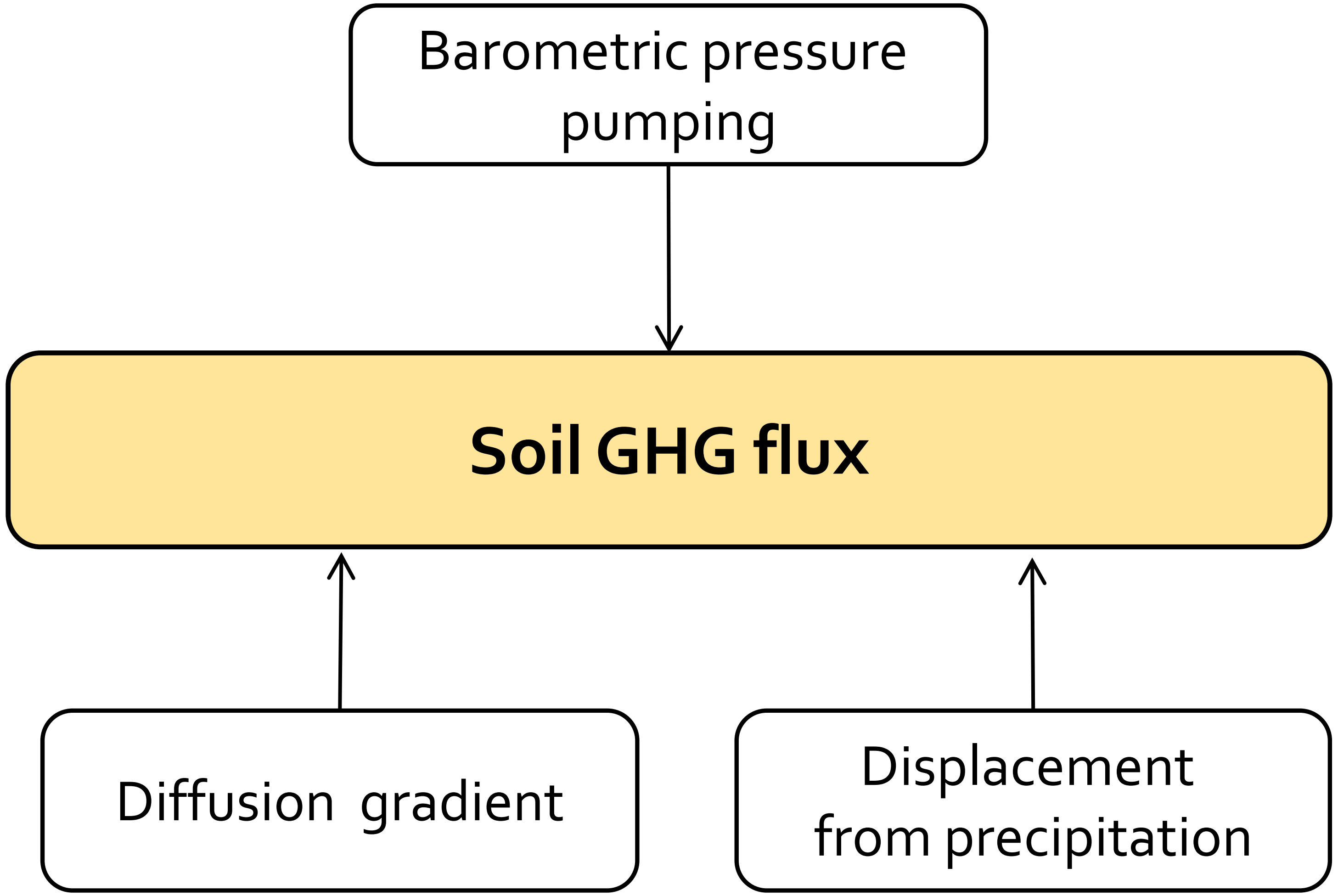
CO_2 profile in the soil



Understanding the drivers for Soil Respiration



What creates gas fluxes (in and out) of the soil?



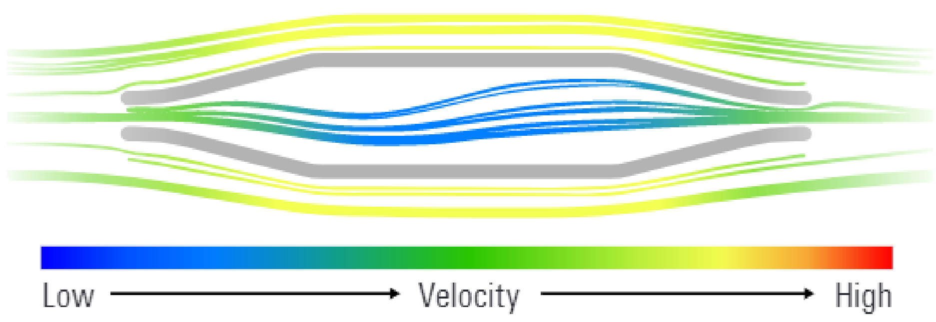
Using chambers to measure the fluxes from the soil

- Requirements and considerations for chamber-based soil GHG flux measurement
  - Measure amount of GHG from the soil accurately
  - Minimize the influence on soil GHG "Transport"
  - Minimize the influence on soil GHG "Production"
  - Deal with temporal and spatial variation

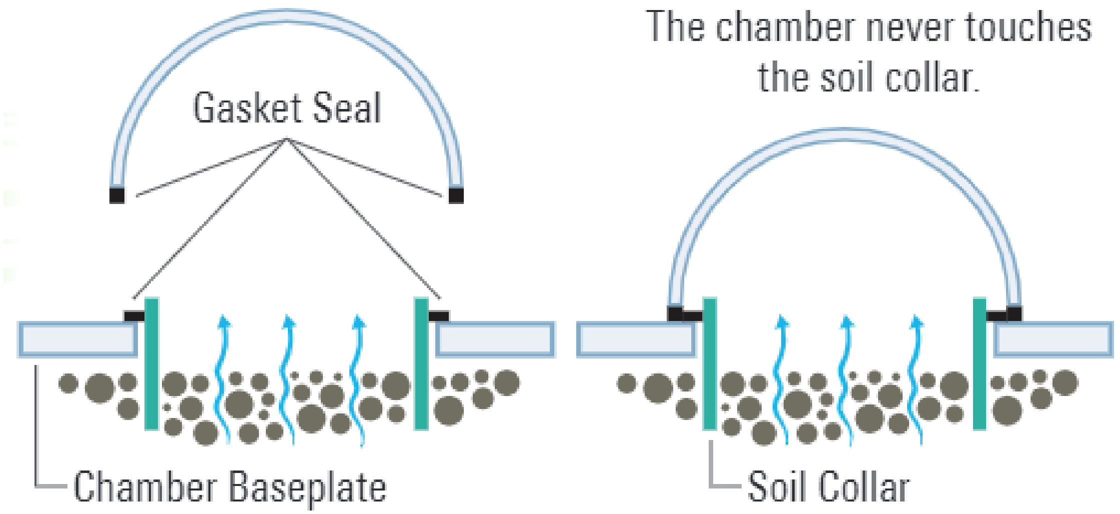
Requirement examples

Equalize chamber pressure

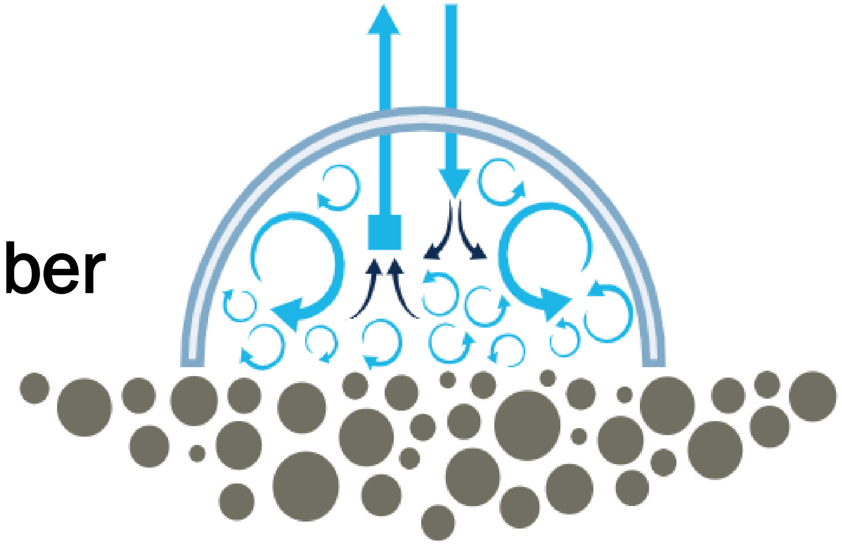
To maintain pressure equilibrium, all LI-COR soil chambers feature a patented pressure vent.



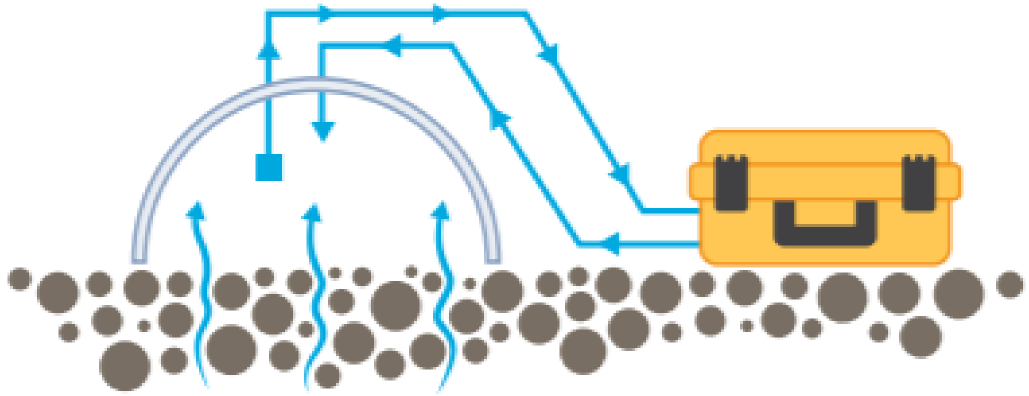
Minimize soil disturbance



Optimize chamber air mixing



Measuring fluxes with a chamber

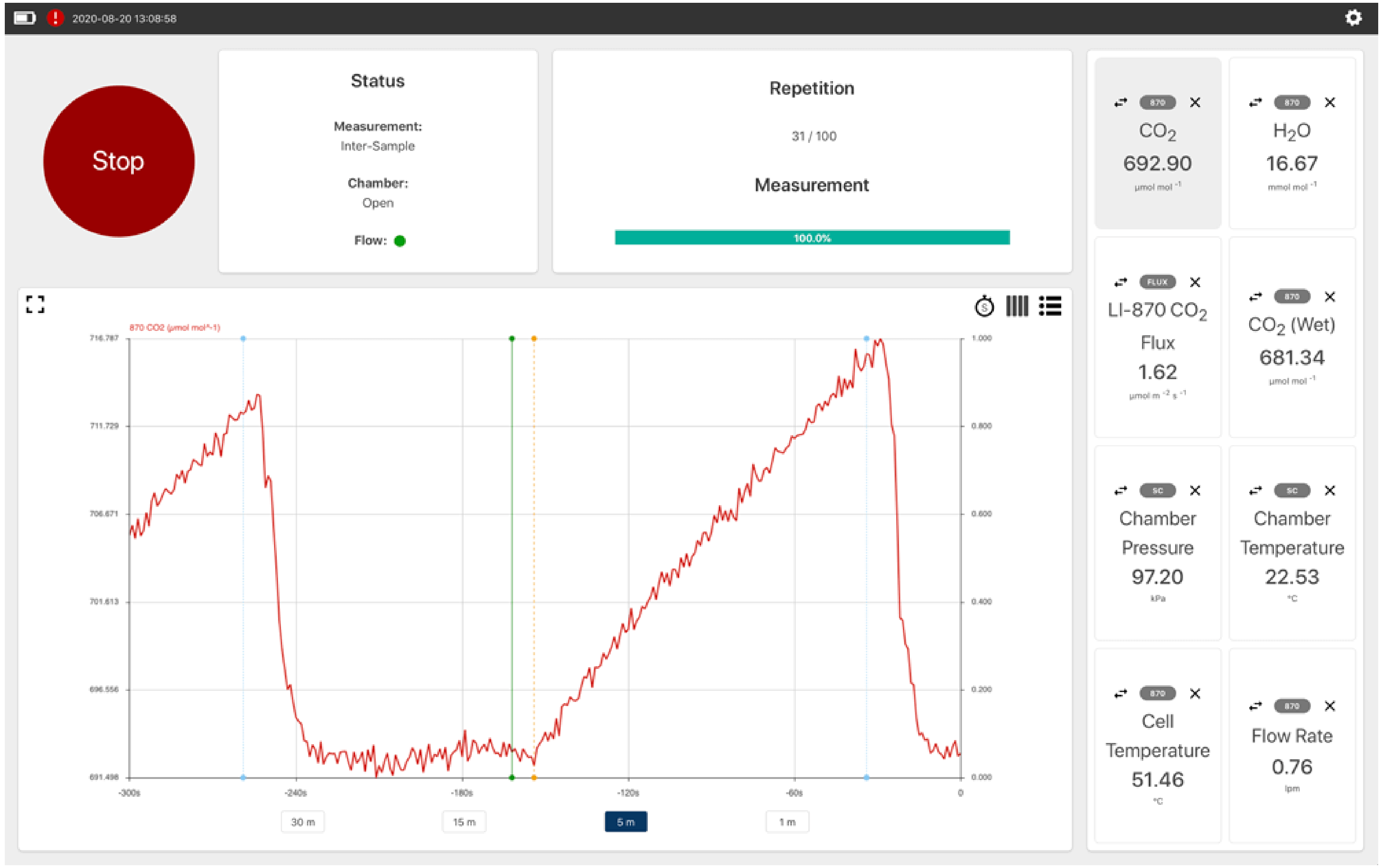


$$F_{CO2} = \frac{VP_o(1-W_o)}{RS(T_o+273.15)} \frac{dC'}{dt}$$

V: Chamber volume, m^3
P: Pressure, Pa
R: Gas constant, Pa m^3 $k^{-1}mol^{-1}$
S: Soil area, m^2
T: Temperature, K

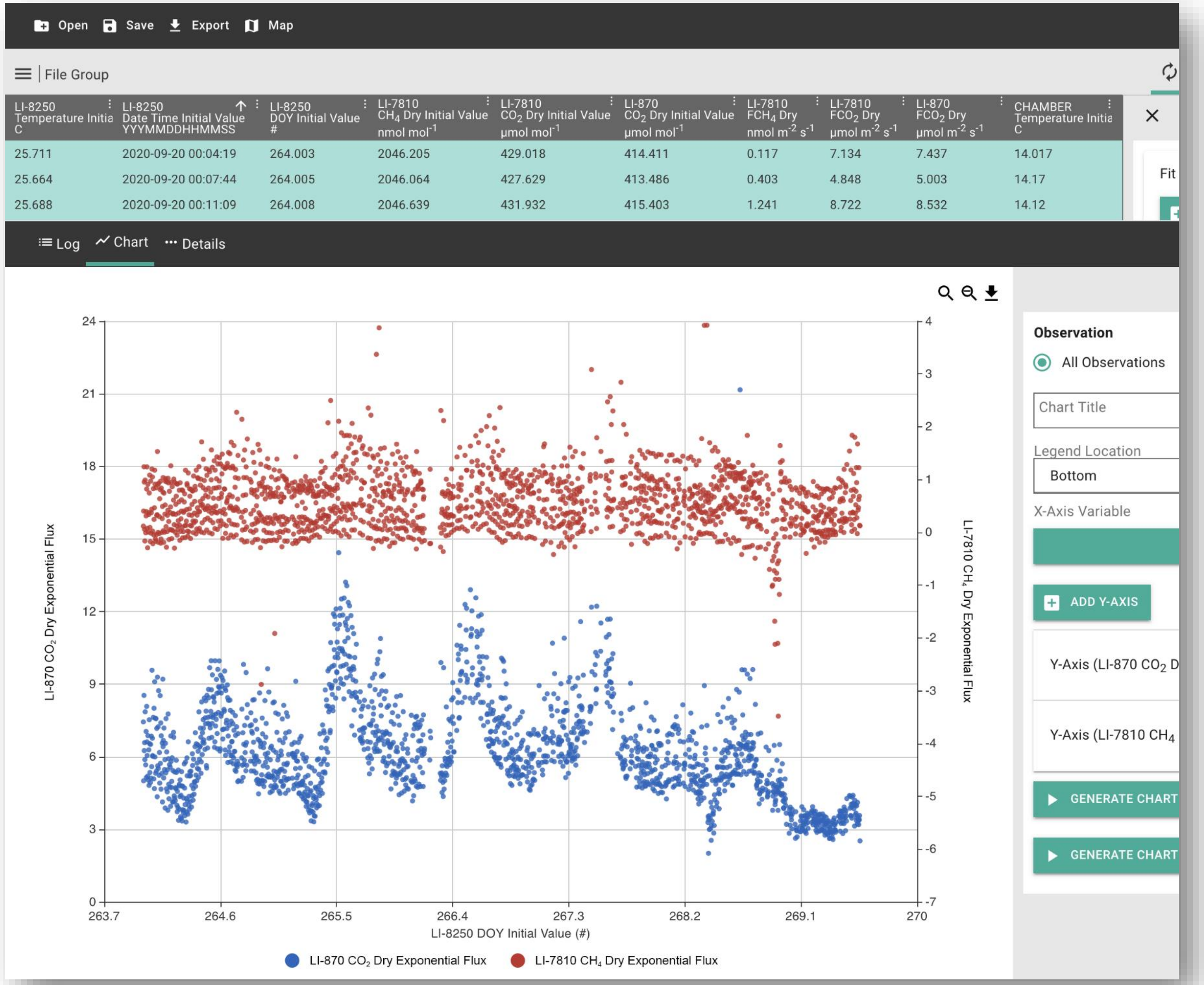
Slope, mmol $mol^{-1}s^{-1}$ $\frac{dC'}{dt}$

W_o H_2O,mol mol^{-1}
F_{CO2}: Flux, mmol $m^{-2}s^{-1}$



Measuring continuously to capture variations

Chambers are used to measure temporal variability of both CO_2 (blue) and CH_4 (red) soil fluxes.



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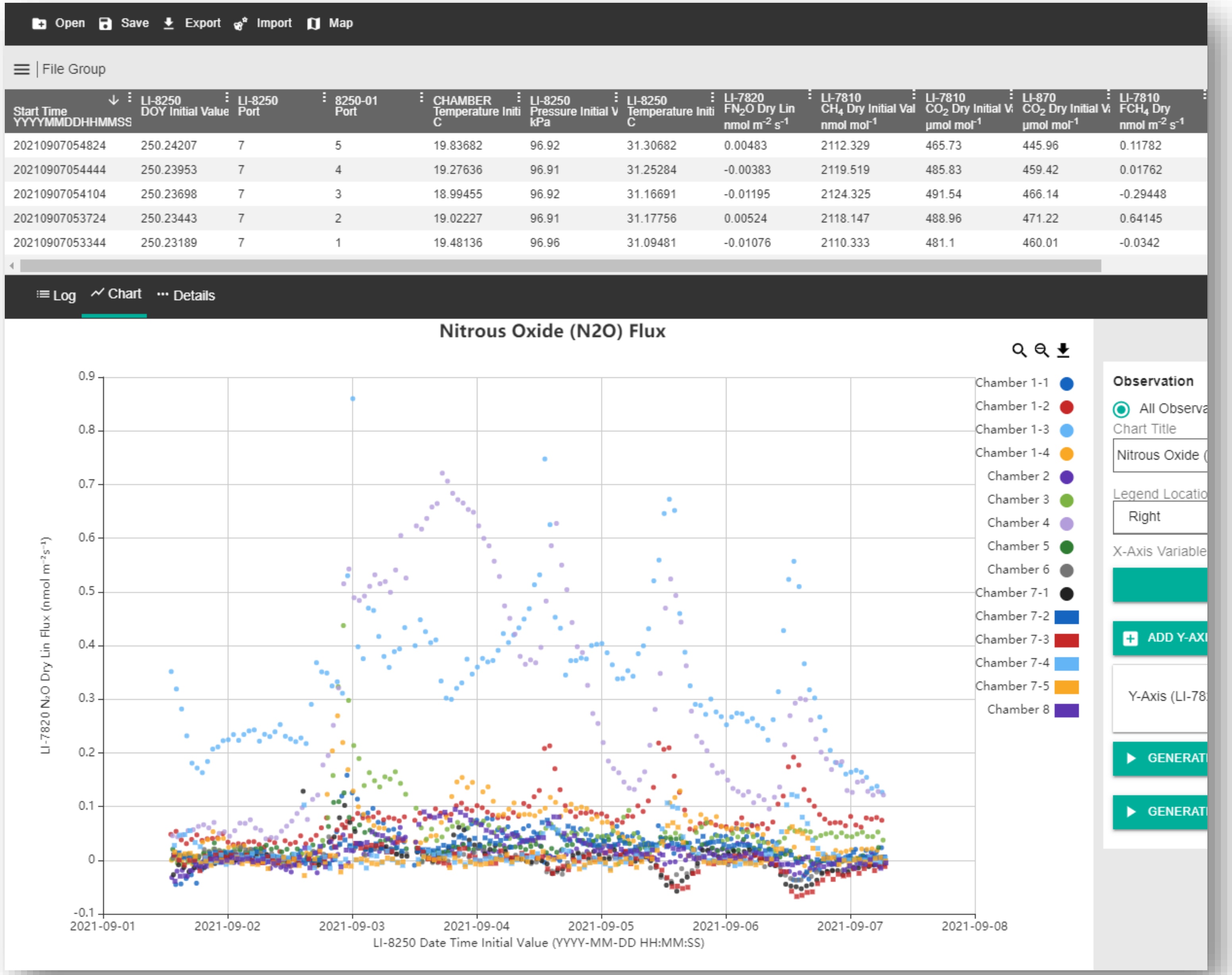
Measuring to capture spatial variations

Chambers can be used to measure spatial variability through multiplexed systems (1 - 36 chambers).

Trace gases, such as N_2O can be measured with the appropriate analyzer (precision) and chamber (technique).



Example of a long-term chamber system

Captures both temporal and spatial variations in soil fluxes

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Integrating Soil Flux with Eddy Covariance

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What can be learned from including soil flux measurements with your eddy covariance?

Processes

- Better understanding of components that go into the NEE.
- Partition Ecosystem Respiration into Soil/Plant(leaf/stem)/Litter/etc
- Get nighttime <u>and</u> daytime soil flux measurements
- The majority (2/3) of ecosystem respiration is from the soil
- Allows for better testing of ‘manipulative’ experiments (treatments, plot-scale)
- Process example; forest soils can transition between oxic and anoxic conditions depending on topographic position and environmental conditions, leading to significant variability in methane flux

What can be learned from including soil flux measurements with your eddy covariance?

Can measure Trace Gases

- Soil is primary source/sink for CH_4 and N_2O
- Fluxes of N_2O/CH_4 are much smaller so might not be detectable by Eddy Covariance
- In fact, no good solution for N_2O measured by Eddy Covariance yet.

What can be learned from including soil flux measurements with your eddy covariance?

Footprint Analysis

- Handles spatial heterogeneity in the footprint (i.e., upscaling CH_4)
- Soil variability within the footprint is a driver for differences in flux rates
- Eddy Covariance footprints and boundaries can change, while soil flux collars are static
- Higher % percent ground cover doesn't mean it dominates the flux. A small % land cover with a high flux rate could dominate a flux footprint
- Seasonal patterns and magnitudes of CH_4 flux can be due to fluxes from the different land types within the fetch

What can be learned from including soil flux measurements with your eddy covariance?

QA/QC

- Useful when EC measurements are unavailable (unstable conditions, QC cleaning, other interruptions (contamination, power, etc.)
- The ecosystem respiration (Re) calculation has several sources of uncertainty
- The short time step of the chamber method makes it ideal for gap-filling methane flux data (few alternatives are available).

Many EC sites (and publications) are now incorporating Soil Flux measurements

Many EC sites (and publications) are now incorporating Soil Flux measurements

Six years of ecosystem-atmosphere greenhouse gas fluxes measured in a sub-boreal forest

Andrew D. Richardson, David Y. Hollinger, Julie K. Shoemaker, Holly Hughes, Kathleen Savage & Eric A. Davidson

Scientific Data **6**, Article number: 117 (2019) | Cite this article

Application of eddy covariance measurements to the temperature dependence of soil organic matter mean residence time

Jonathan Sanderman, Ronald G. Amundson, Dennis D. Baldocchi

First published: 04 June 2003 | https://doi.org/10.1029/2001GB001833 | Citations: 80

Eddy covariance for quantifying trace gas fluxes from soils

W. Eugster and L. Merbold
ETH Zurich, Department of Environmental Systems Science, Institute of Agricultural Sciences, Universität-Strasse 2, 8092 Zurich, Switzerland

Rece… : 20 Feb 2015

Spatial and temporal variation of CO_2 efflux along a disturbance gradient in a *miombo* woodland in Western Zambia

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Received: 04 May 2010 – Discussion started: 29 Jul 2010 – Revised: 07 Dec 2010 – Accepted: 17 Dec 2010 – Published: 21 Jan 2011

Comparing ecosystem and soil respiration: Review and key challenges of tower-based and soil measurements

Josep Barba [a, 1], Alejandro Cueva [b, 1], Michael Bahn [c], Greg A. Barron-Gafford [d, e], Benjamin Bond-Lamberty [f], Paul J. Hanson [g], Aline Jaimes [a], Liisa Kulmala [h], Jukka Pumpanen [i], Russell L. Scott [j], Georg Wohlfahrt [c], Rodrigo Vargas [a]

Methane flux measurements in rice by static flux chamber and eddy covariance

Michele L. Reba, Bryant N. Fong, Ishara Rijal, M. Arlene Adviento-Borbe, Yin-Lin Chiu, Joseph H. Massey

First published: 16 November 2020 | https://doi.org/10.1002/agg2.20119 | Citations: 1

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Summary

- Measuring the following biological functions can help explain flux results and are often required for networks and publications:
  - Stomatal Conductance (LI-600)
  - Leaf Area Index (LAI-2200C)
  - Phenology (StarDot PhenoCam)
  - Soil fluxes (LI-COR Trace Gas Analyzers for CO_2, CH_4, N_2O integrated with multiplexed chambers)

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Thank You
Questions?