

An aerial photograph showing a vast green forest under a blue sky with scattered clouds. In the foreground, the dark wing of a research aircraft is visible, extending from the bottom left towards the center. A tall, thin tower stands in the distance, rising above the tree line. The overall scene is bright and clear.

***Energetic Ecosystems Emit Enchanting Emissions***

**Ankur Desai, UW-Madison**

**UIUC NRES**

**Mar 26, 2020**

**Pandemic edition**

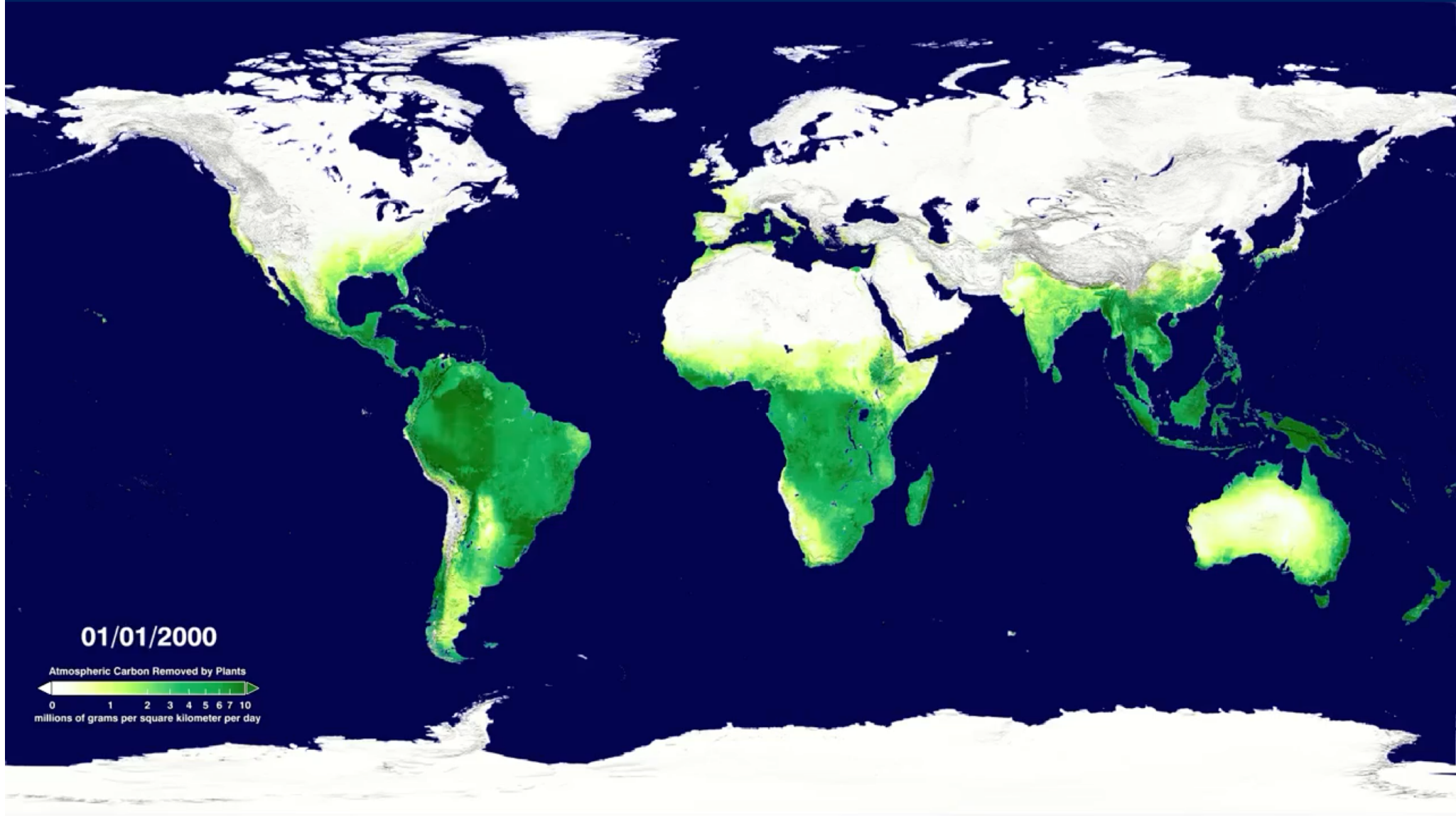
**Photo: B. Butterworth**





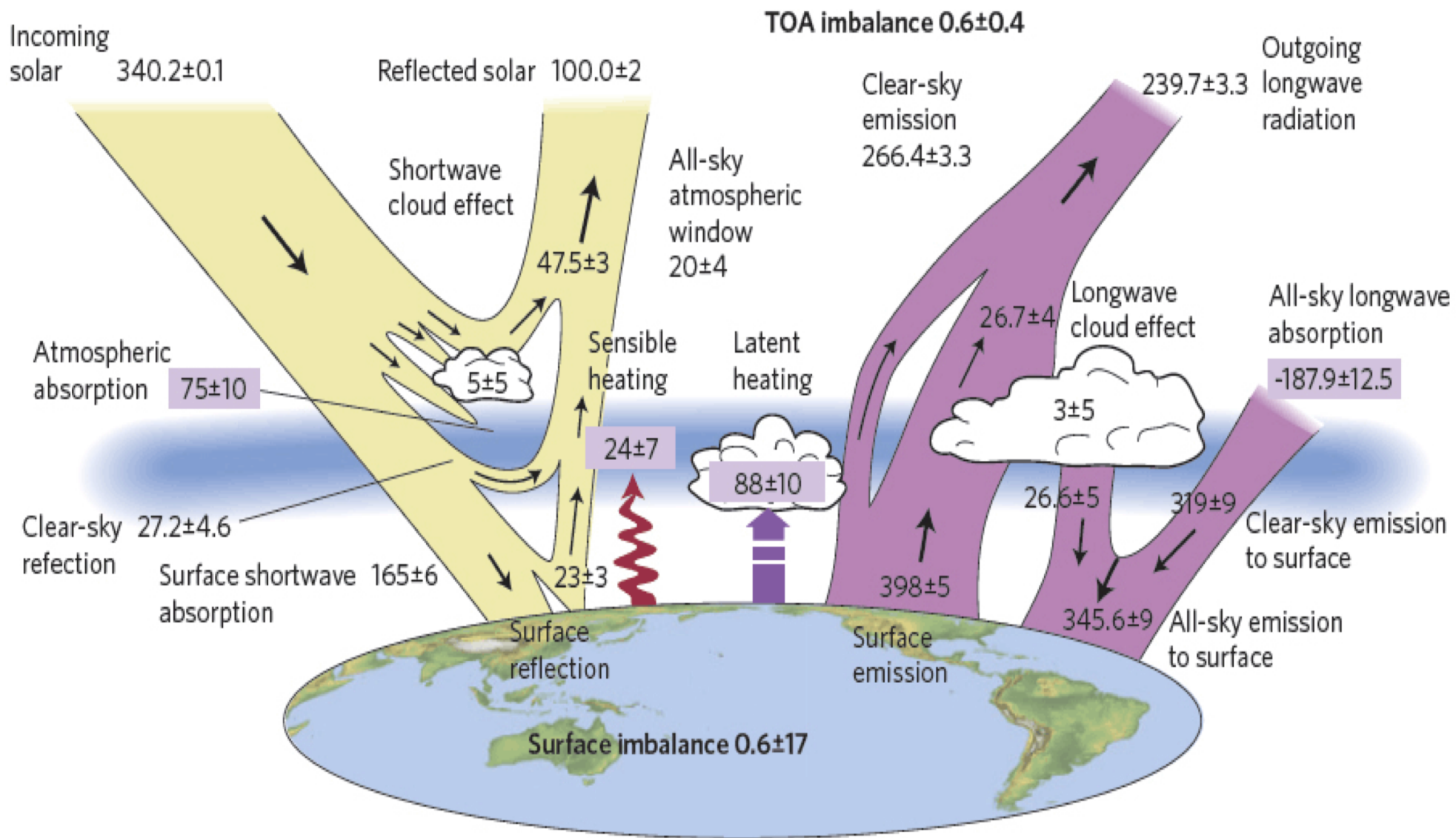


GPP = Gross Primary Productivity = photosynthesis



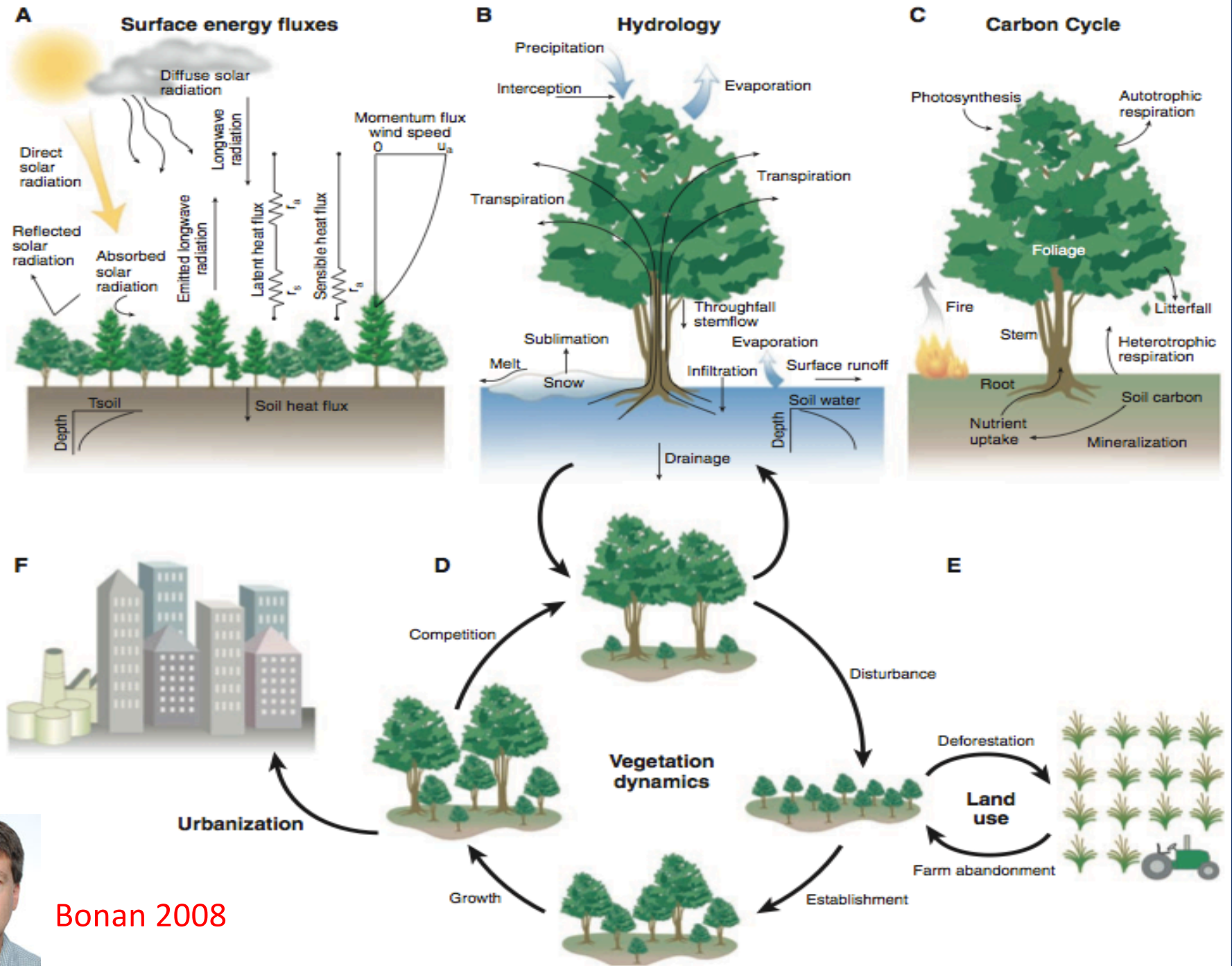
MODIS GPP (NASA)







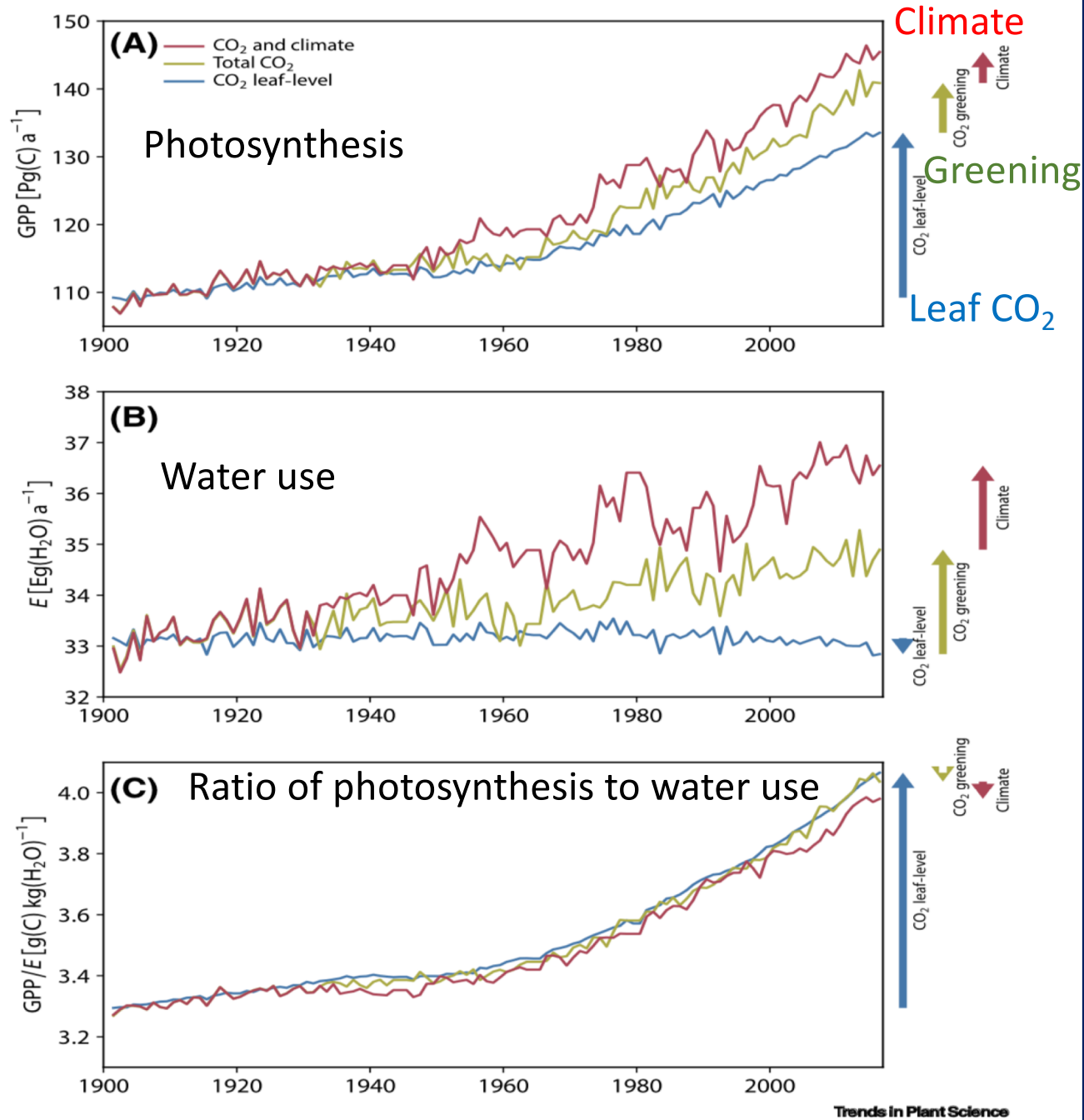
# Forests in Flux



Bonan 2008











<https://www.nytimes.com/2020/01/10/world/australia/australia-wildfires-photos.html>









Peter Bakwin  
NOAA (Colorado)



Ken Davis  
Penn State



Arlyn Andrews  
NOAA (Colorado)



Jon Kofler  
NOAA (Colorado)



Bruce Cook  
NASA Goddard



Ankur Desai  
UW-Madison  
AOS



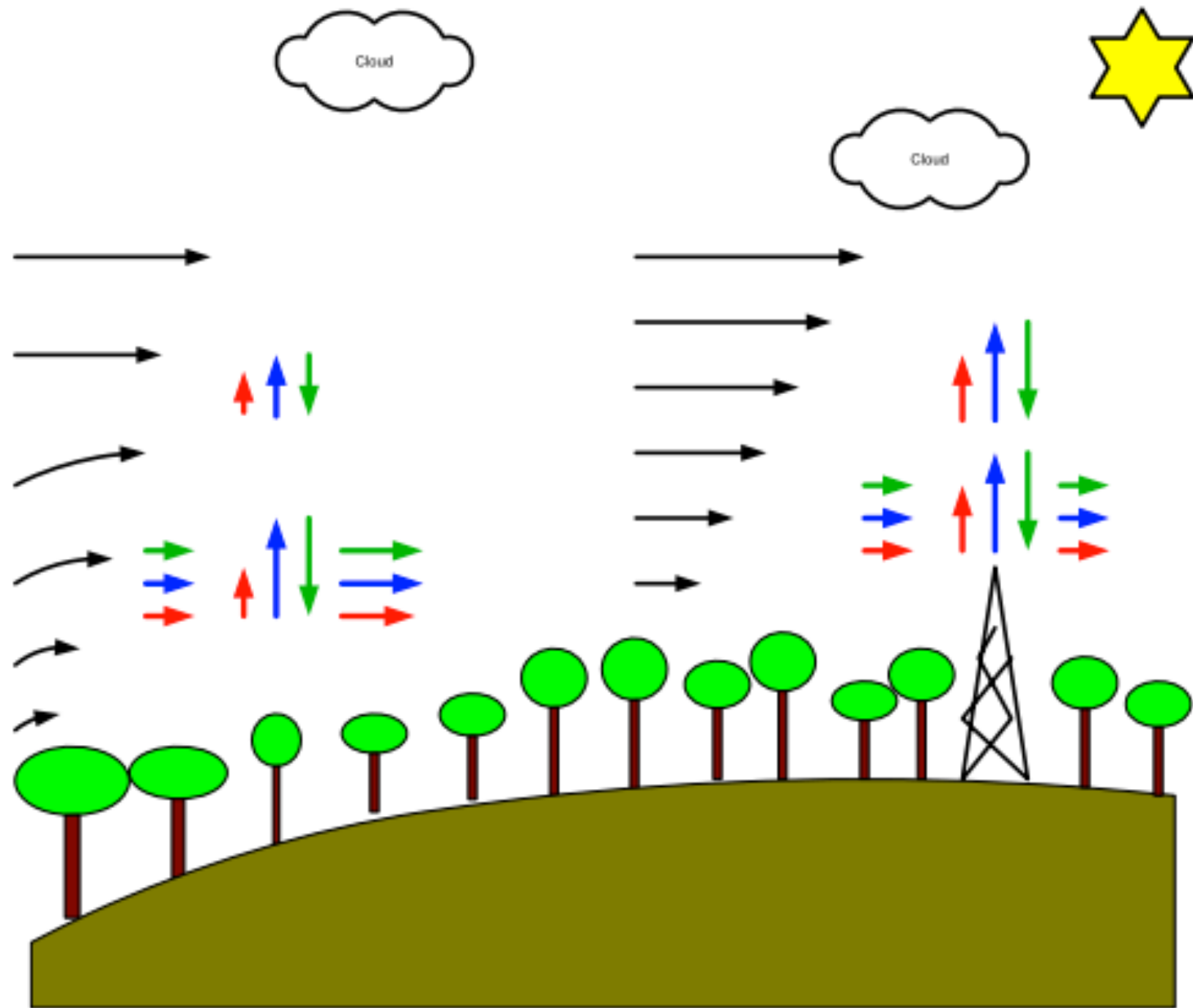
Jonathan Thom  
UW-Madison  
SSEC

The true journey of discovery is not in seeing  
new landscapes but in developing new eyes  
-Marcel Proust

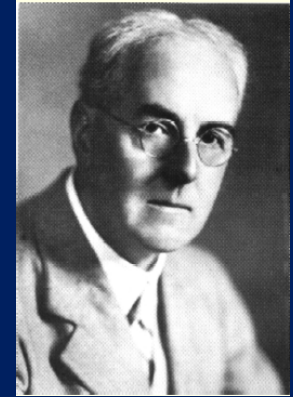
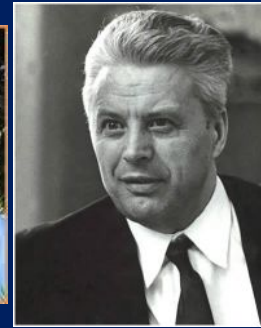












- 1880-1920s Turbulence theory (Reynolds, Prandtl, Richardson, Taylor)
- 1940s-1950s Surface-layer theory (Monin-Obukhov, Kolmogorov), development of fast sensors for anemometry
- 1960s early measurements (Inoue, Wyngaard, Kaimal)
- 1970s forest fluxes (Raupach, Lenschow, Denmead)
- 1970s CO<sub>2</sub> fluxes (Desjardins, Leuning)
- 1980s Infrared gas analyzers (Verma, Anderson, Valentini)
- 1990s First long-term regional CO<sub>2</sub> flux networks (Wofsy, Baldocchi, Goulden, Law, Aubinet, Torn)
- 2000s Global syntheses (FLUXNET, Falge, Papale, Reichstein, Moffat, Novick)
- 2010s Model-data integration, development of operational measurements (NEON, ICOS, you?)





# Huge Ecology!





Settings

Citation: source  
[https://due.esrin.esa.int/page\\_globcover.php](https://due.esrin.esa.int/page_globcover.php)

Forests  
Wetlands  
Lakes

Farms

Urban  
Lakes

US-PFa  
US-Los  
US-Syv  
US-WCr  
US-Alq  
US-CS1  
US-CS2  
US-CS3  
US-DFC  
US-DFK  
US-PnP  
US-Men  
  
US-PFb  
to  
Us-PFt

AMERIFLUX

Map created at [ameriflux.lbl.gov](http://ameriflux.lbl.gov)



# ChEAS core site cluster

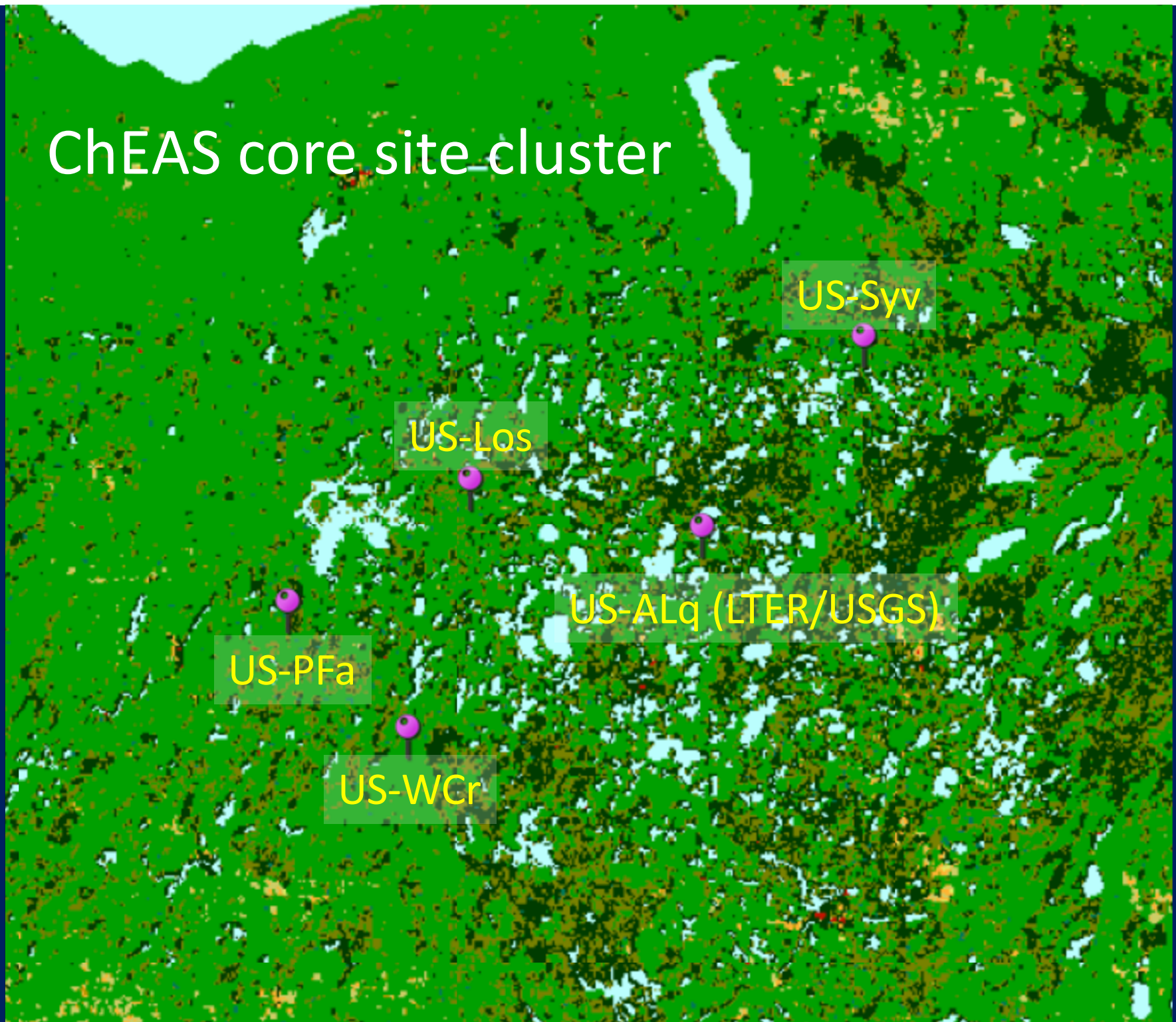
US-Syv

US-Los

US-PFa

US-ALq (LTER/USGS)

US-WCr









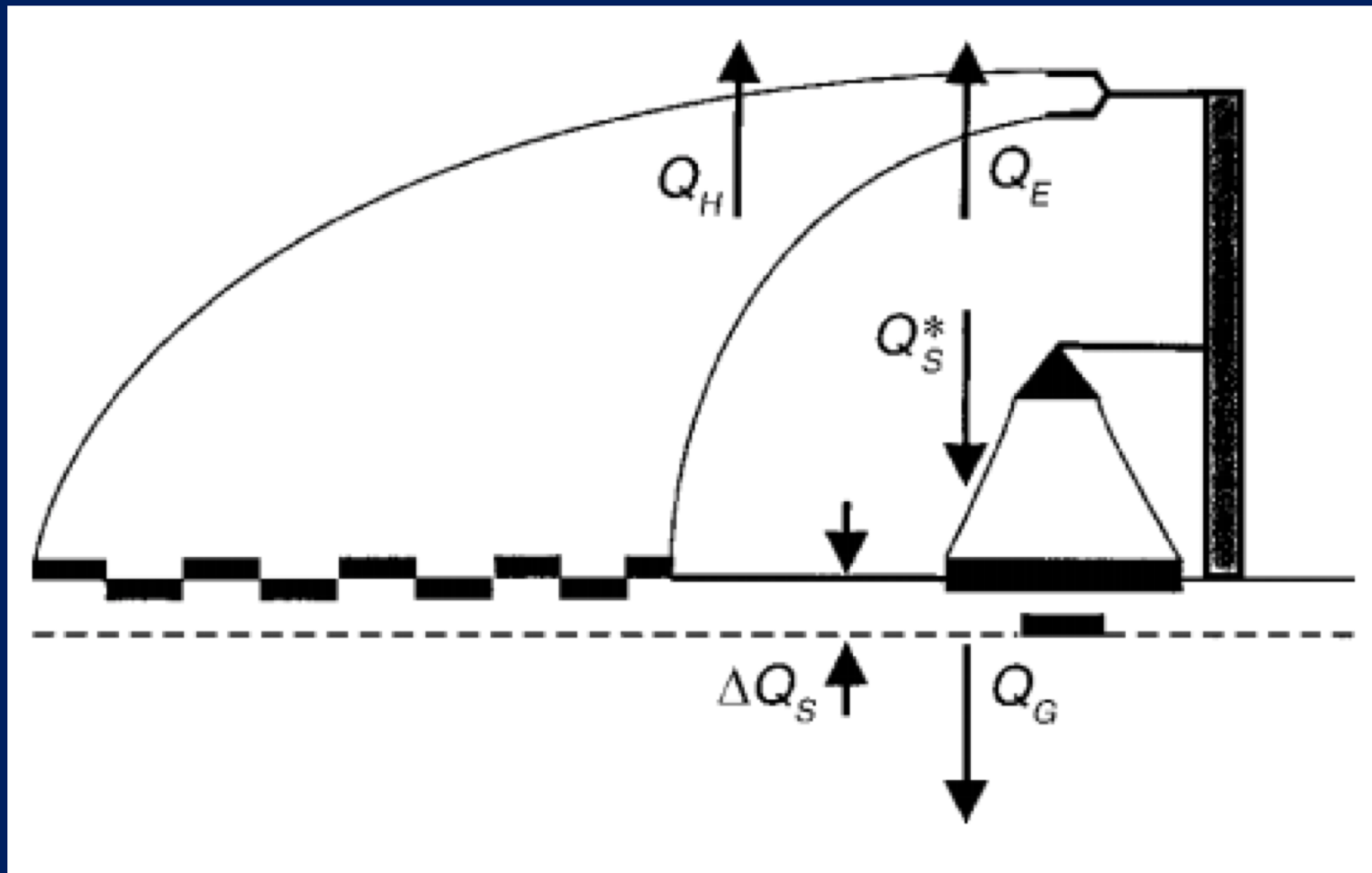




*Ecological Applications*, 18(6), 2008, pp. 1351–1367  
© 2008 by the Ecological Society of America

## THE ENERGY BALANCE CLOSURE PROBLEM: AN OVERVIEW

THOMAS FOKEN<sup>1</sup>

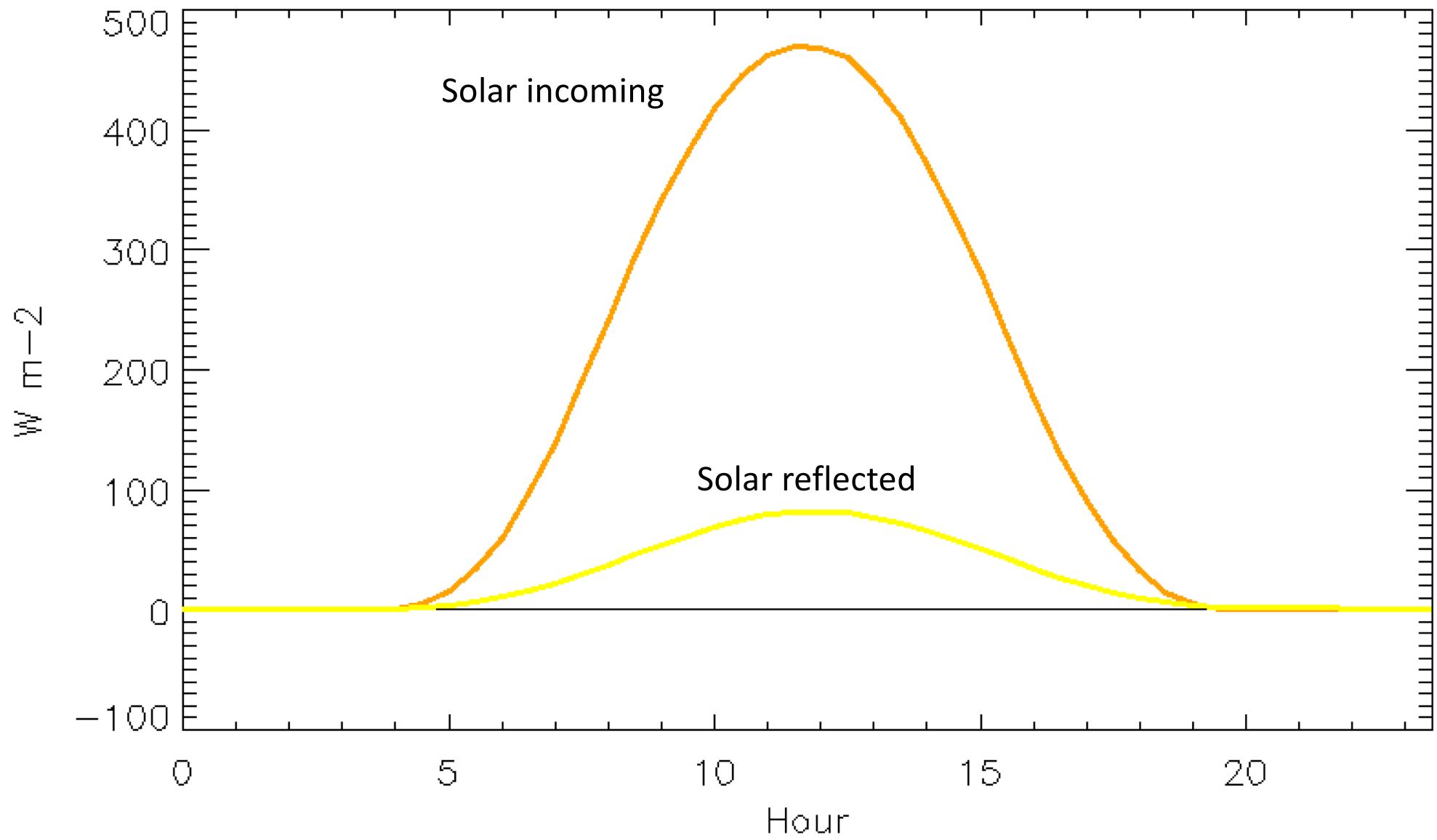


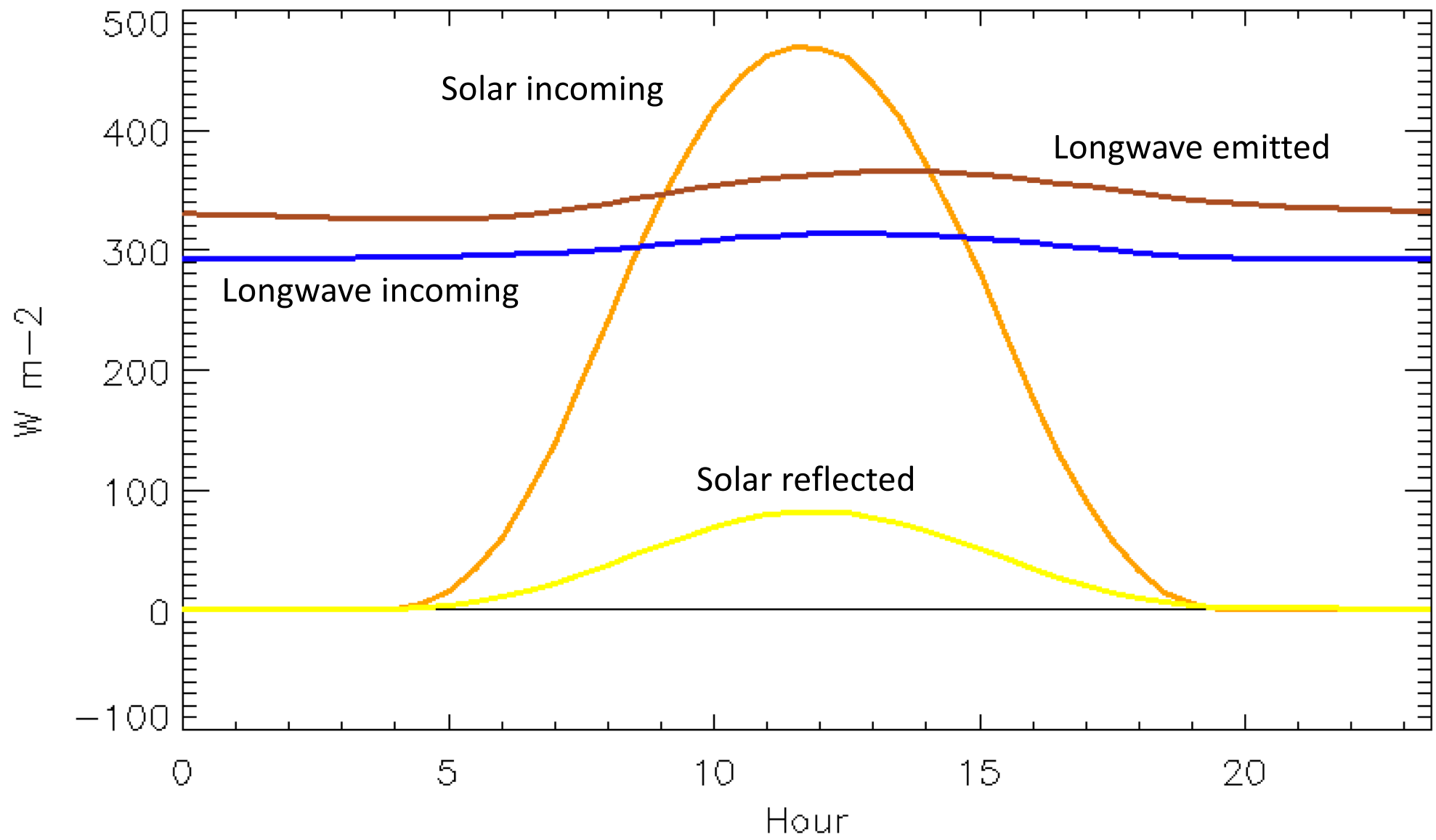
US-Syv (Sylvania)

Desai et al., 2005, Ag For Met

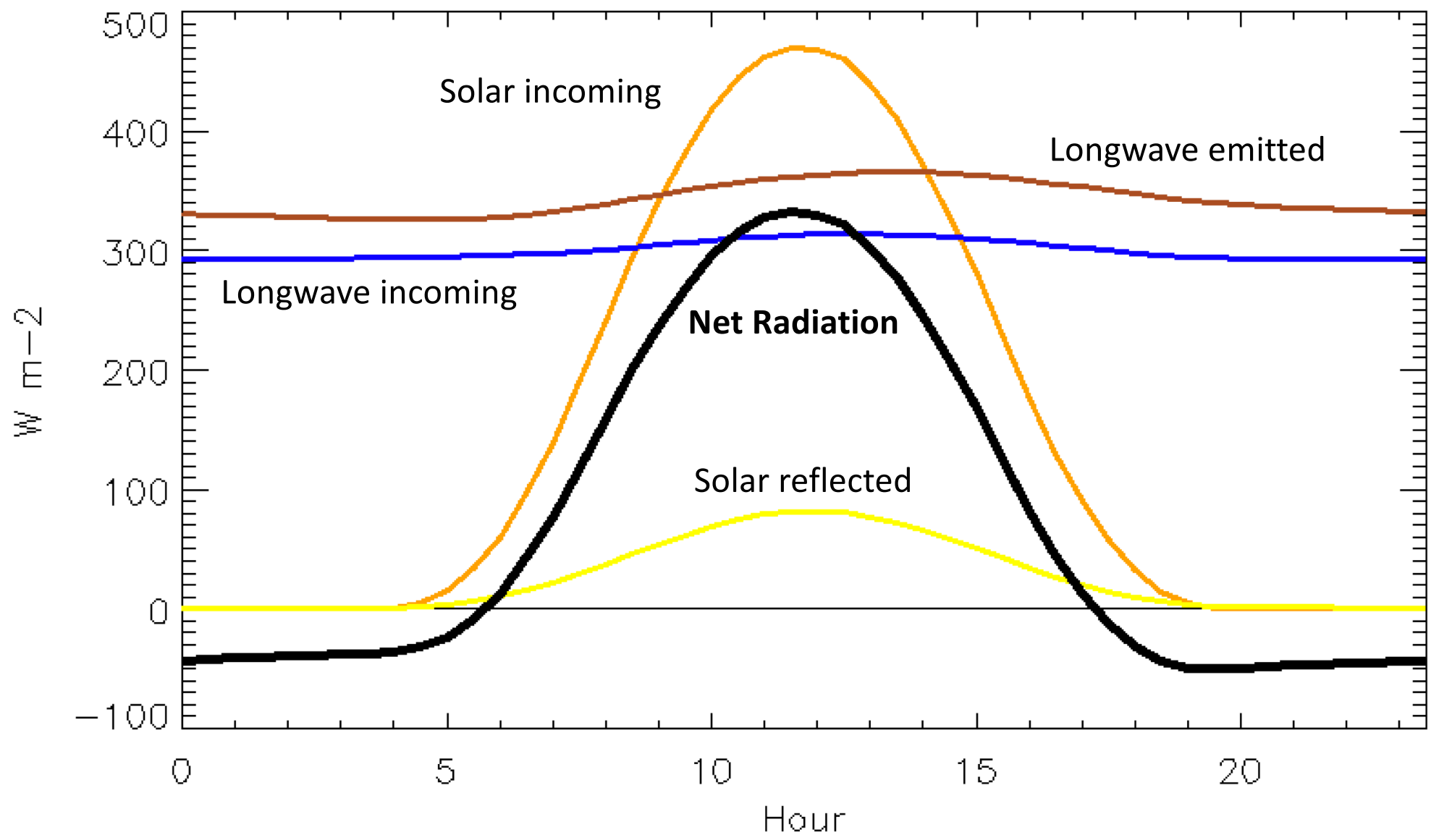




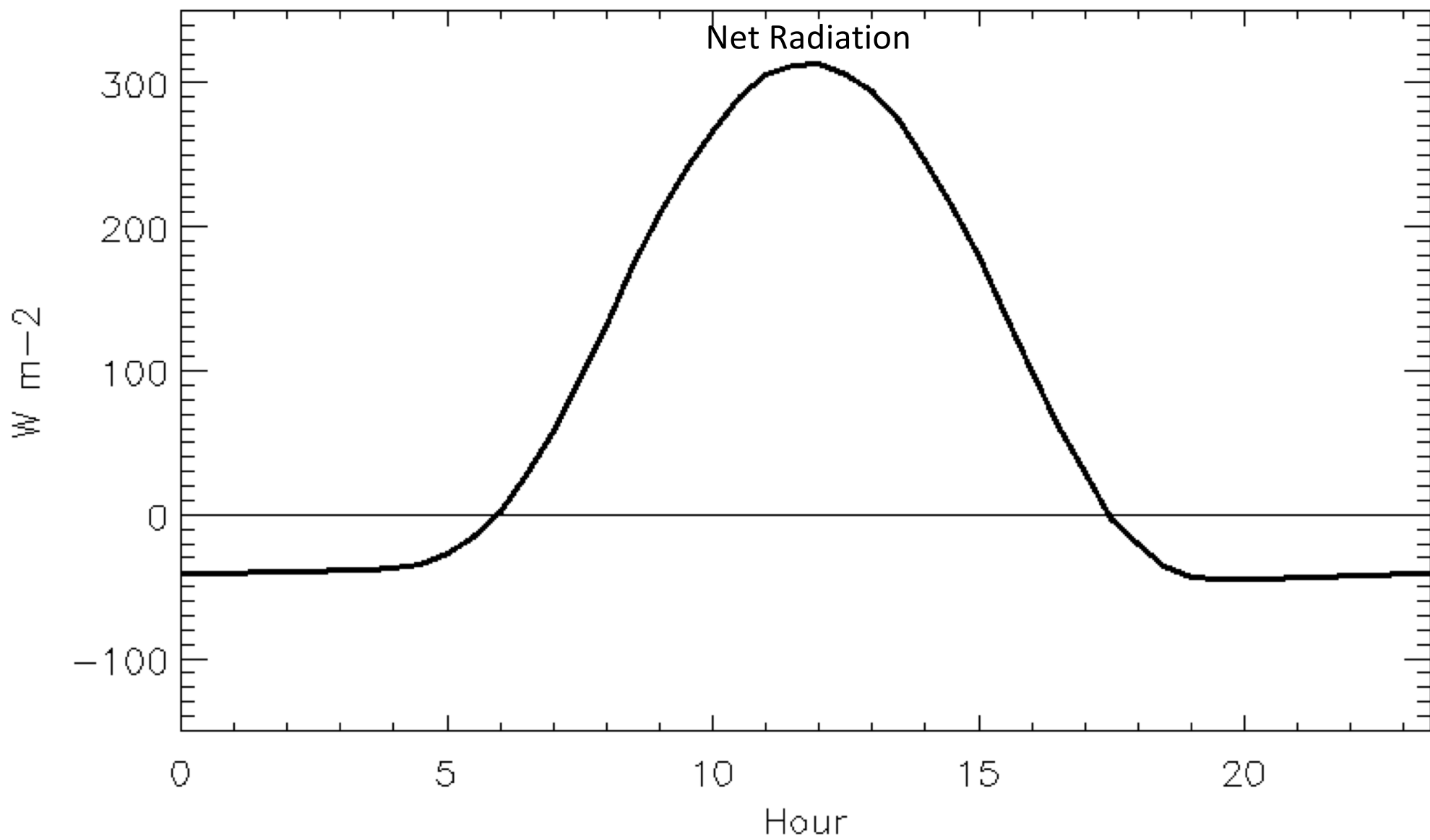


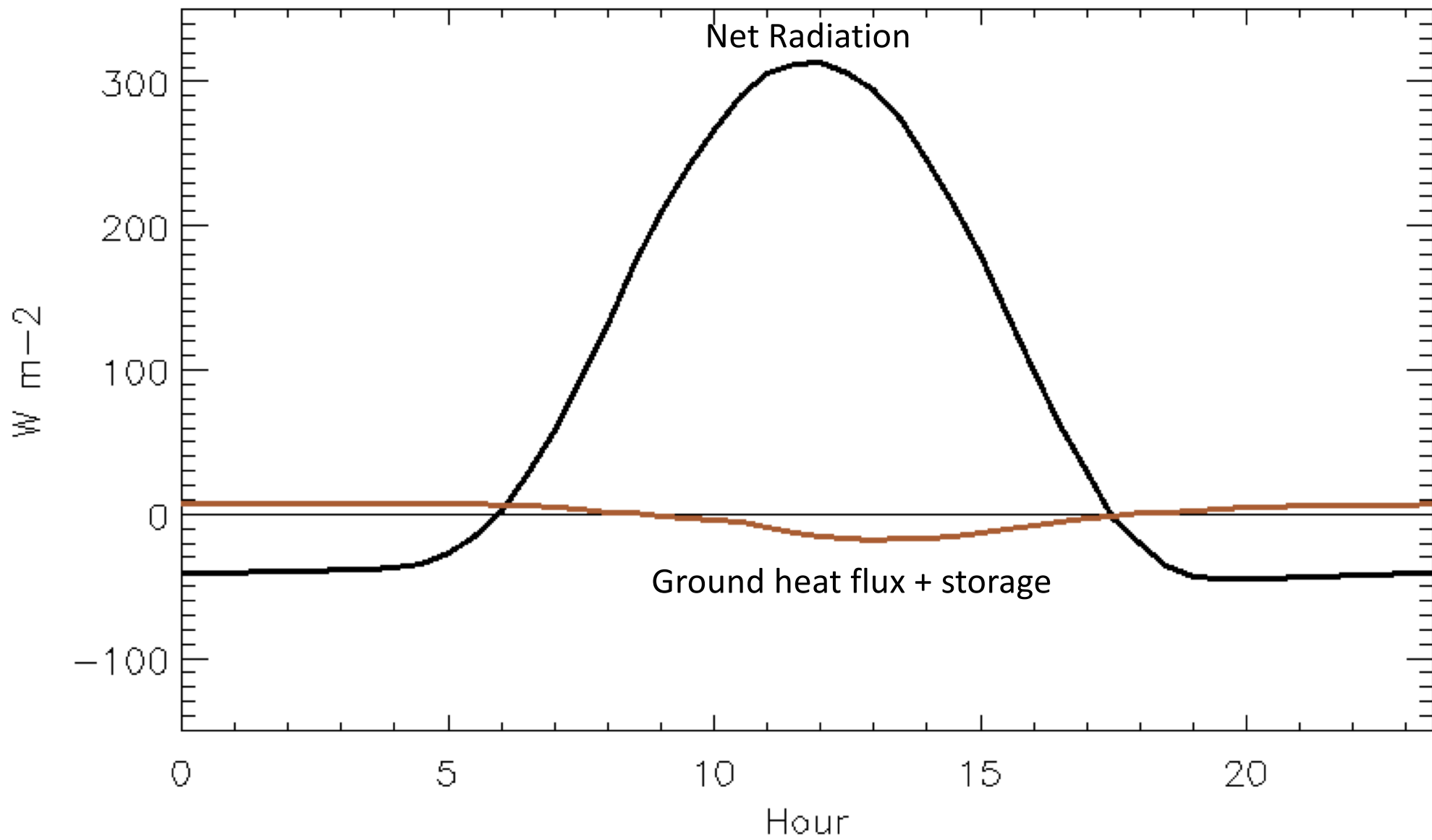




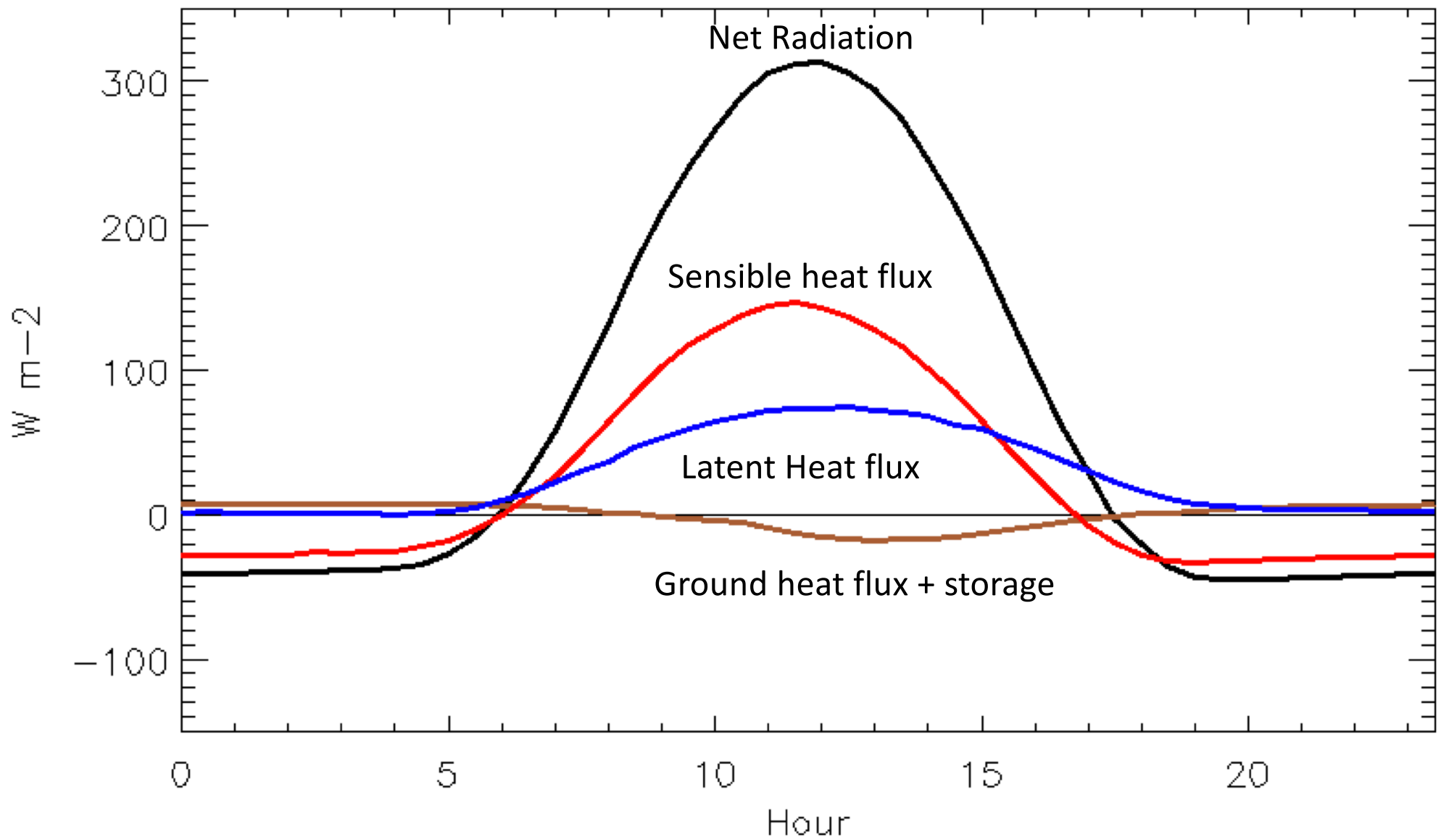


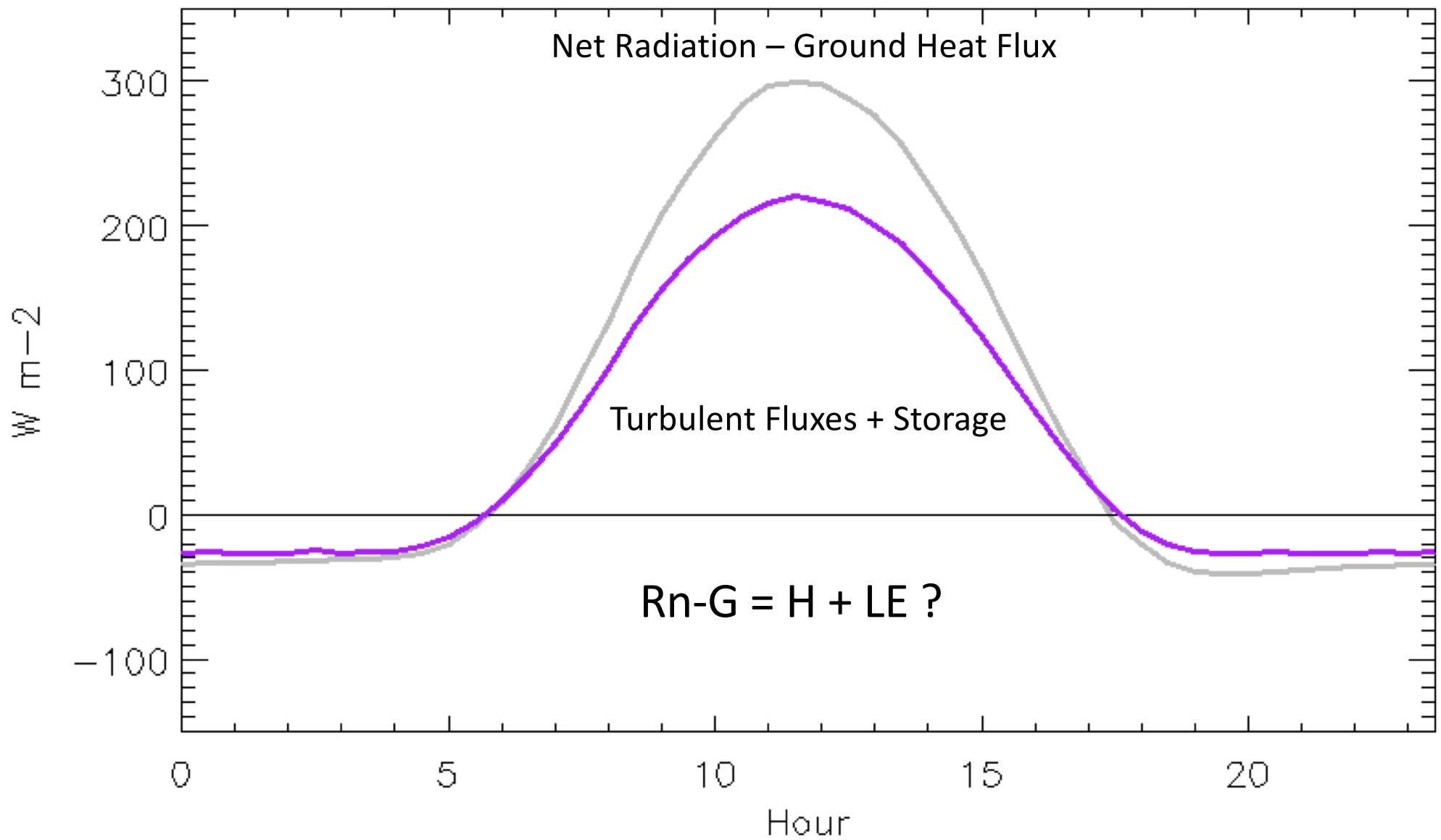




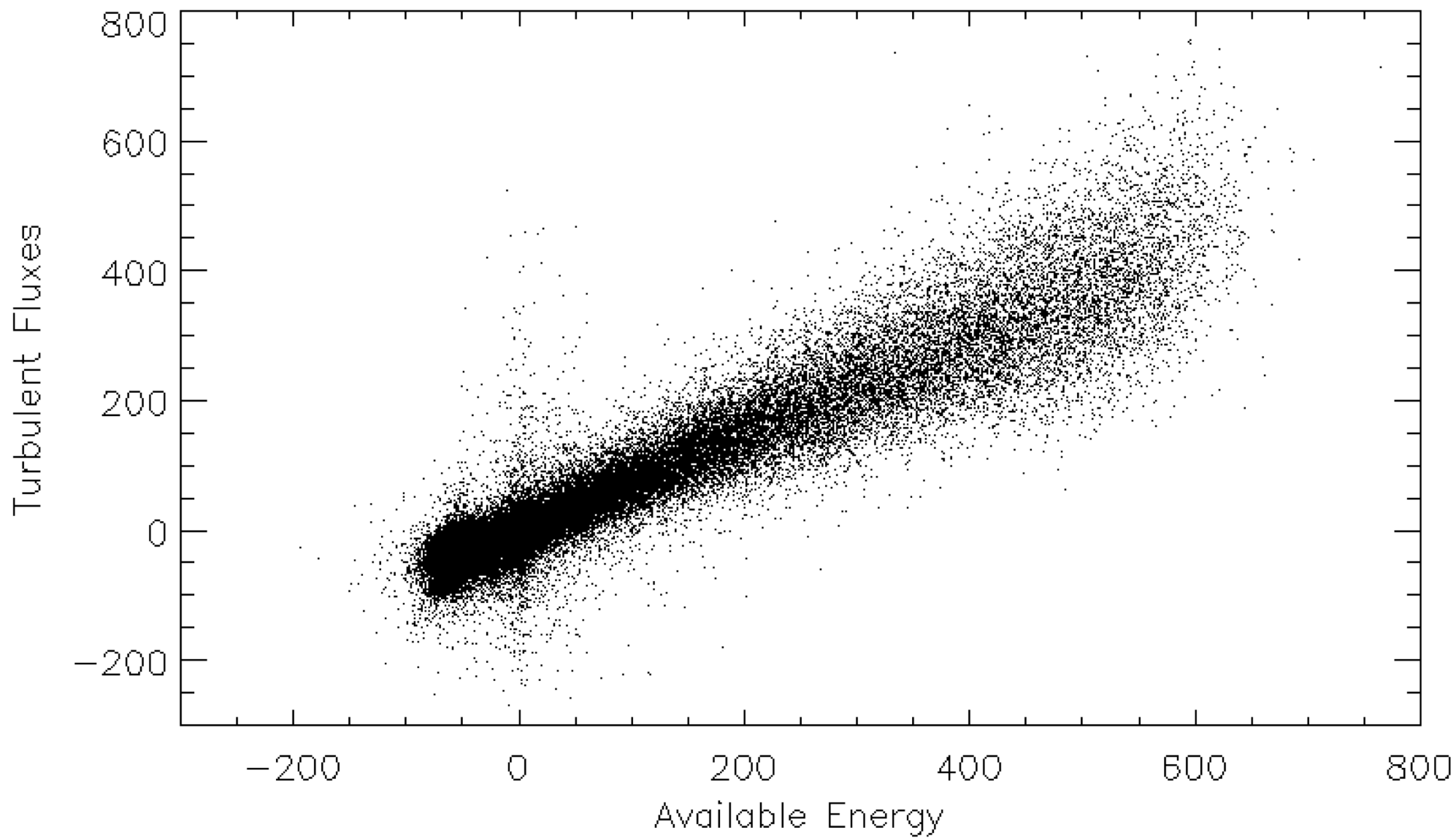


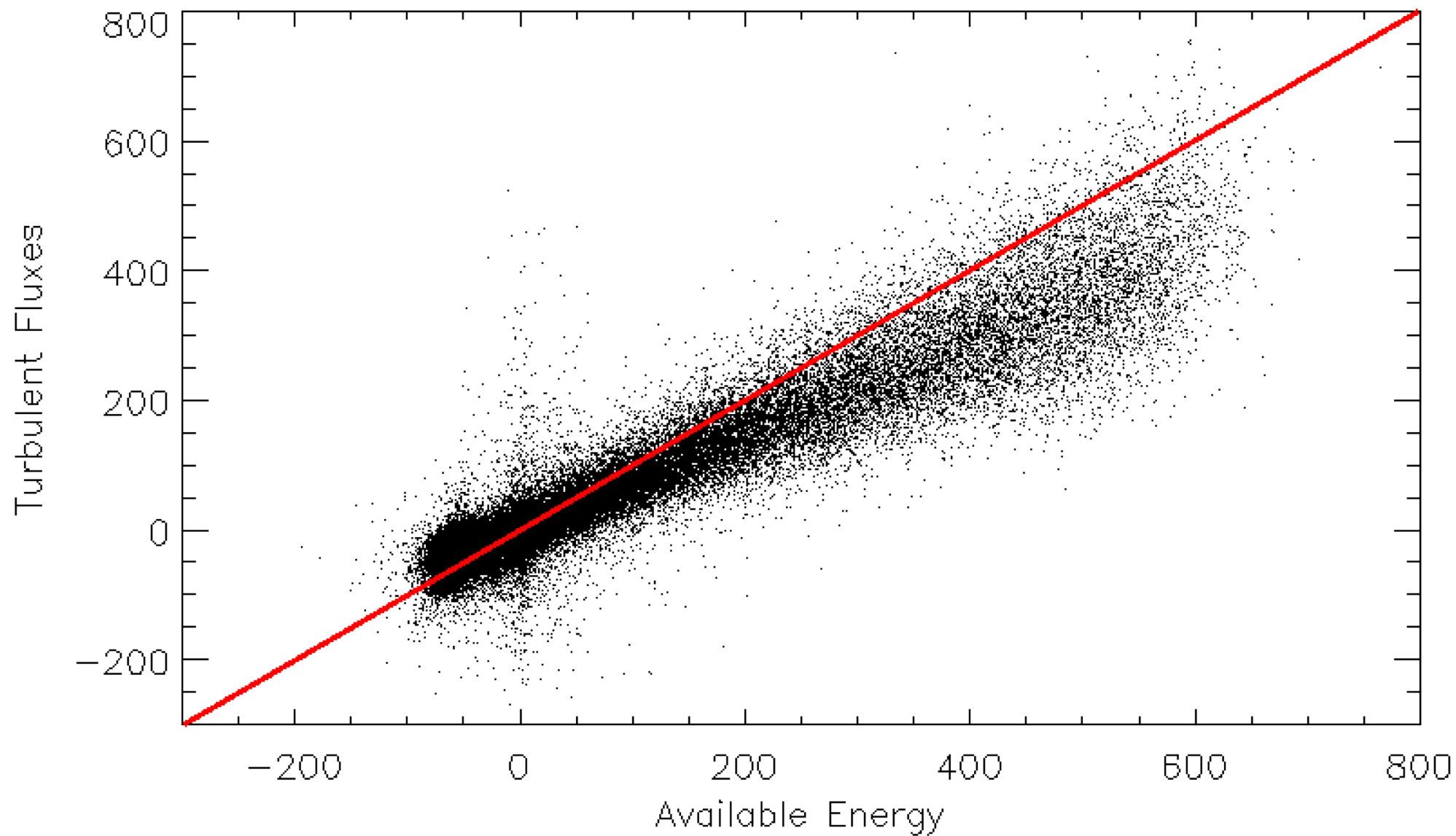




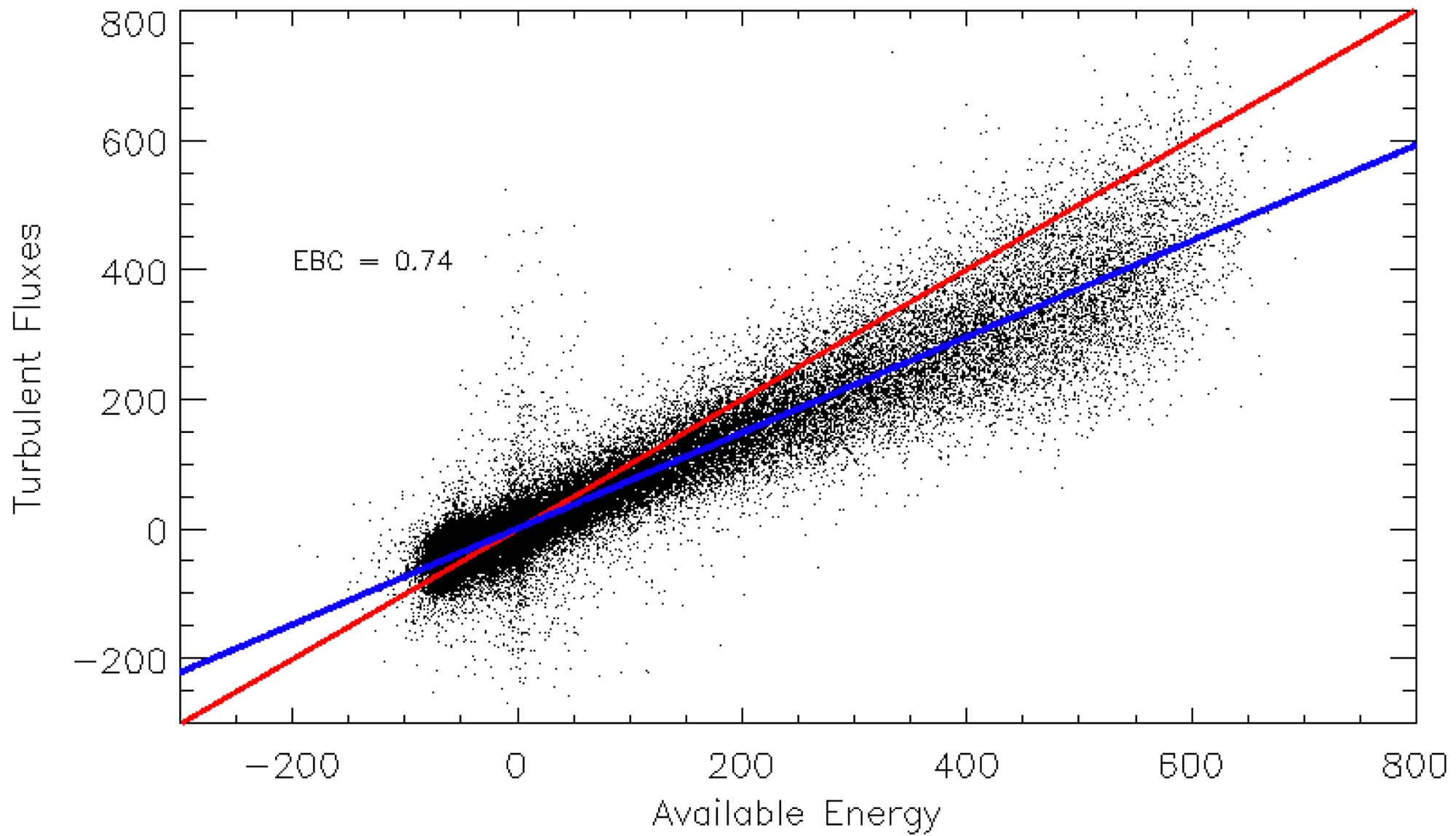












# Energy Imbalance is Common But Variable in Space and Time

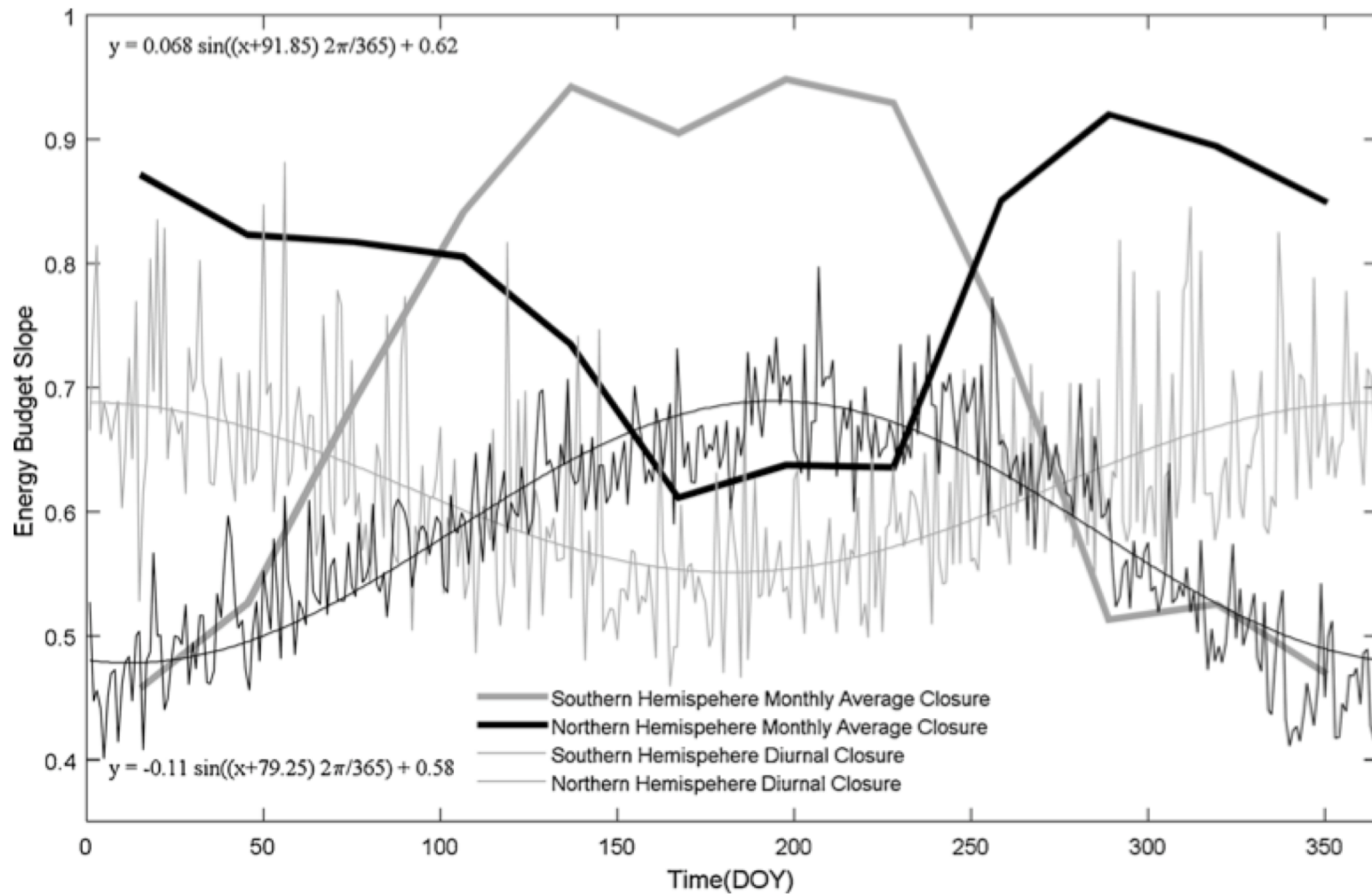
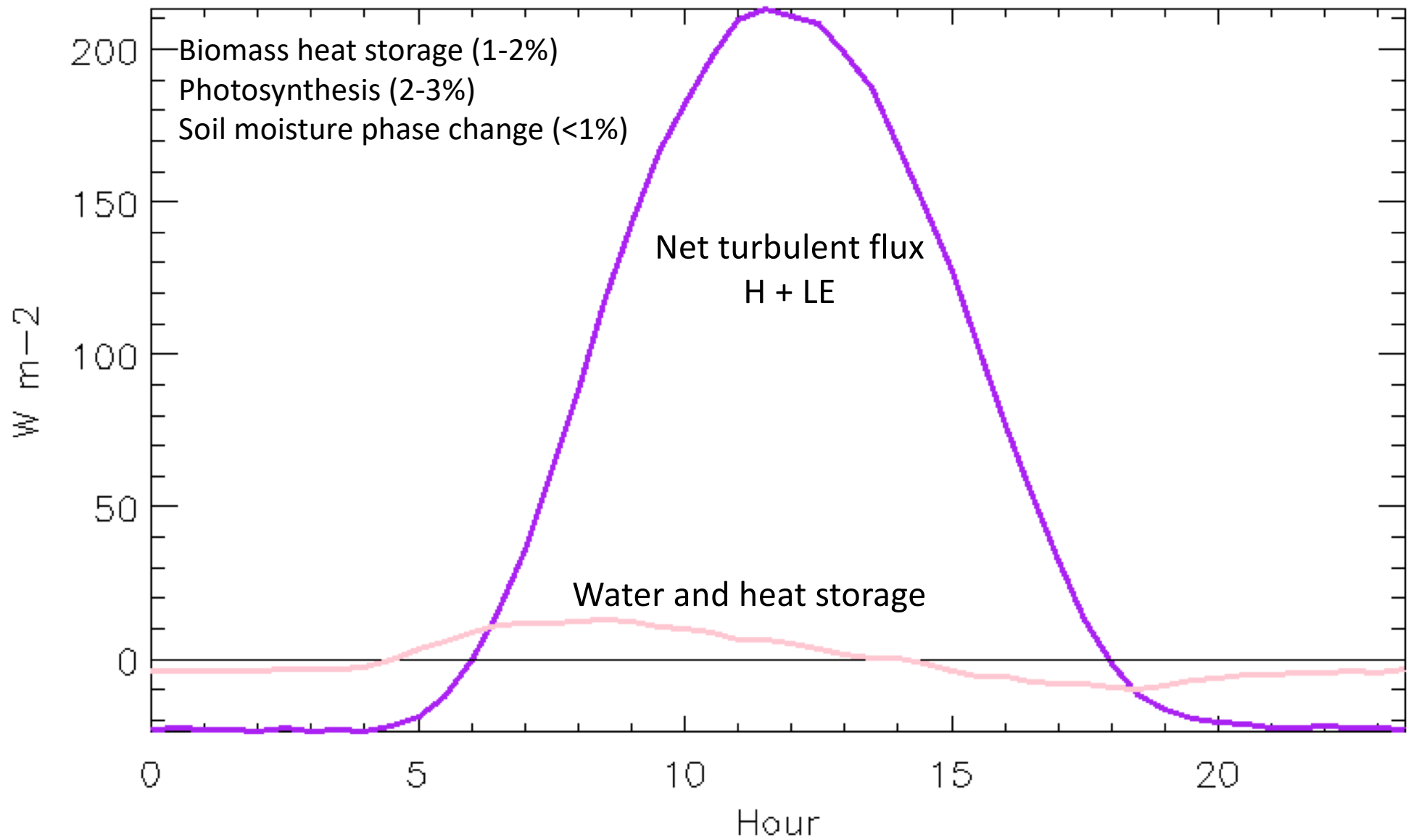


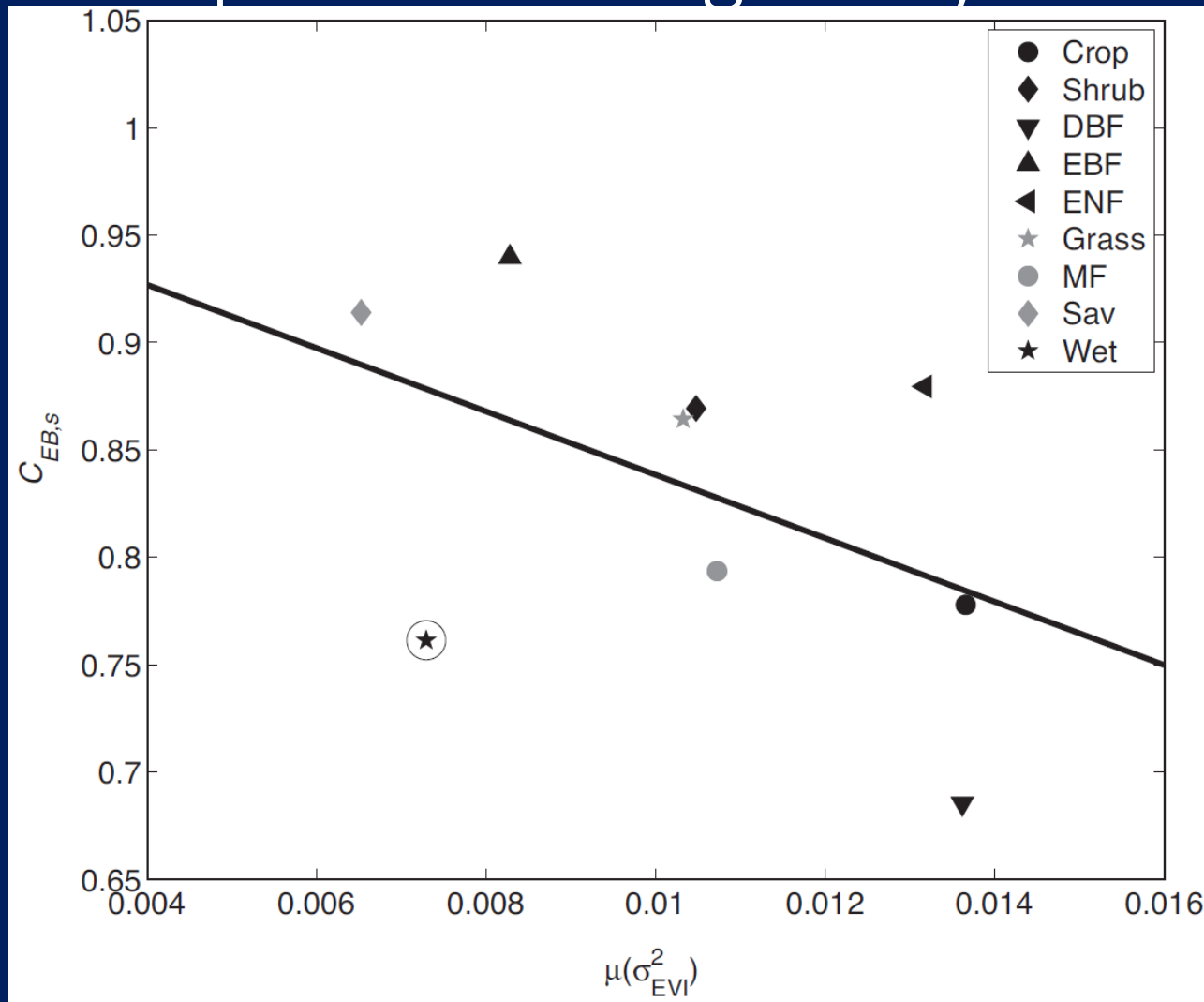
Fig. 7. Variation over an average year in FLUXNET2015 site energy closure, based on regression slope. Site separated by northern hemisphere (black, n=132) and southern hemisphere (grey, n=27). Bold lines shows monthly average regression energy closure at northern (bold black) and southern (bold grey) hemisphere sites.





# Energy imbalance worsens with increased regional spatial heterogeneity

EBC=  
H+Le  
-----  
Rnet-G

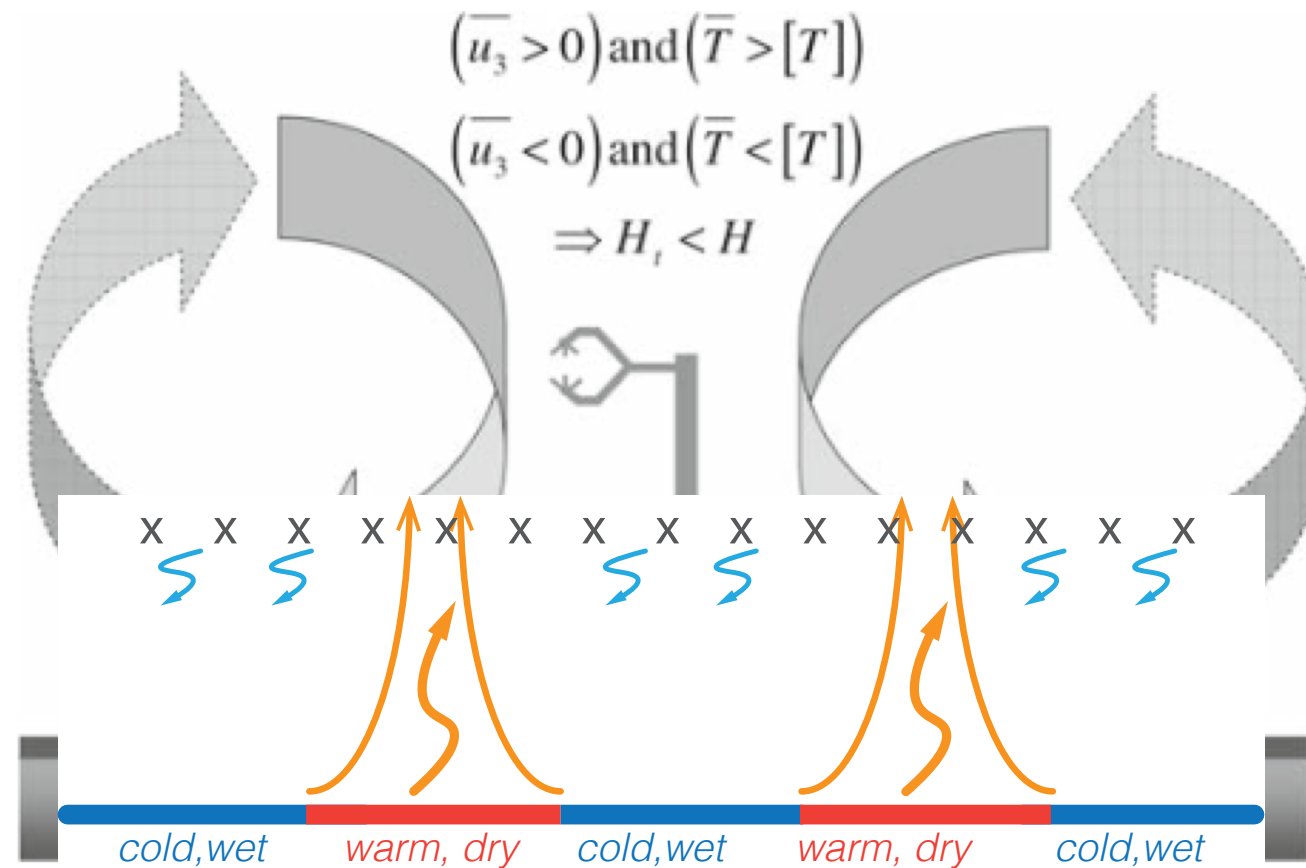


Greenness spatial variance

Stoy et al., 2013, AFM

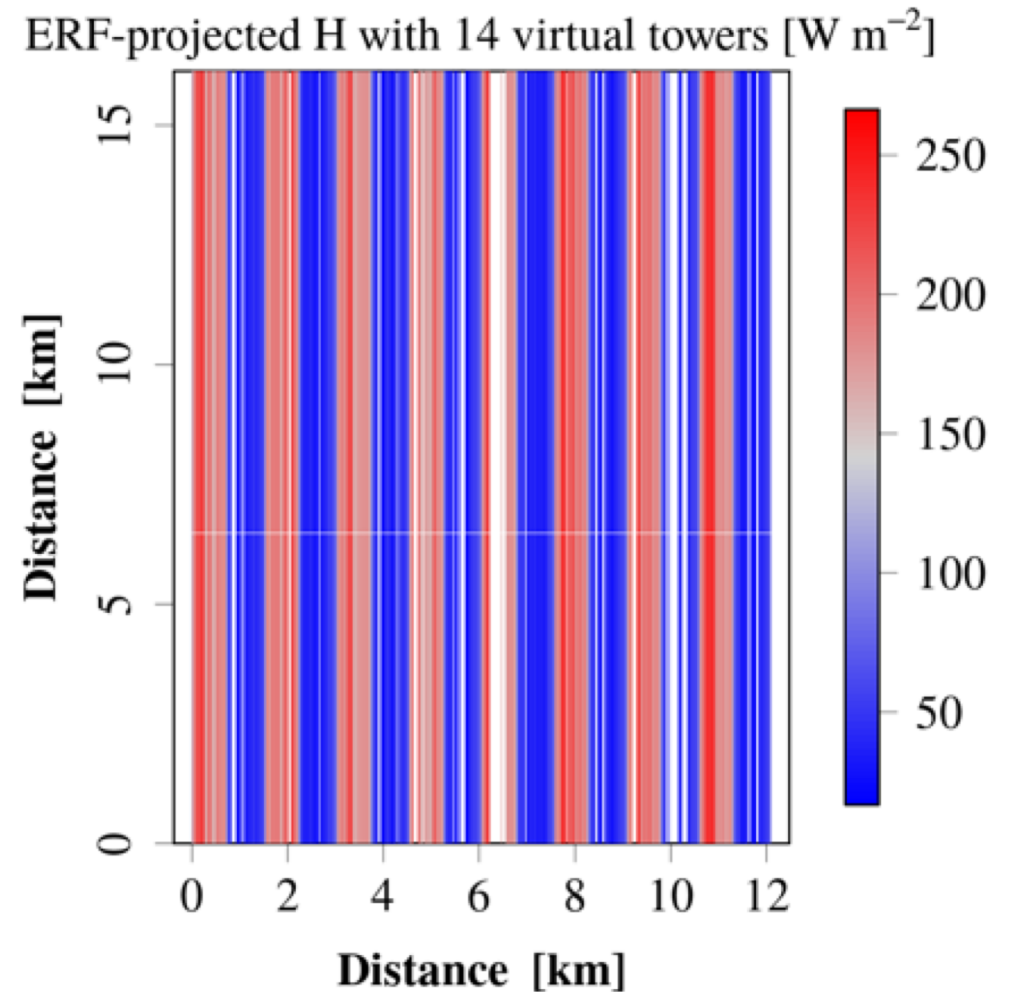
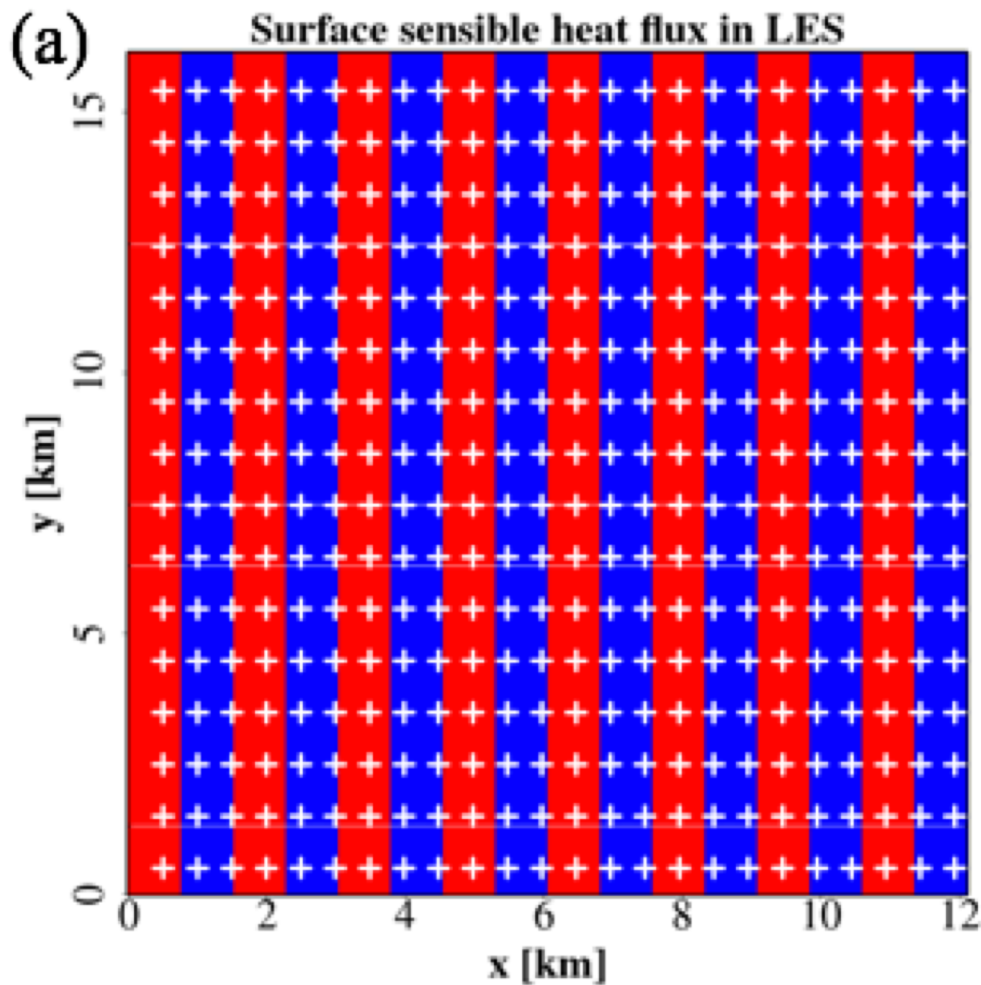


# Landscape variance potentially drives stationary eddies



**Fig. 1** Schematic showing how quasi-stationary eddies cause an underestimation of the total sensible heat flux  $H$  when using the temporal EC method to calculate  $H_t$ . The single-point sonic measurement in the centre is not able to resolve quasi-stationary eddies

With 14 towers, we can recover highly heterogeneous fluxes in LES with ERF



Original

Xu et al, 2020, BLM

Retrieved



So how does that lead to this?



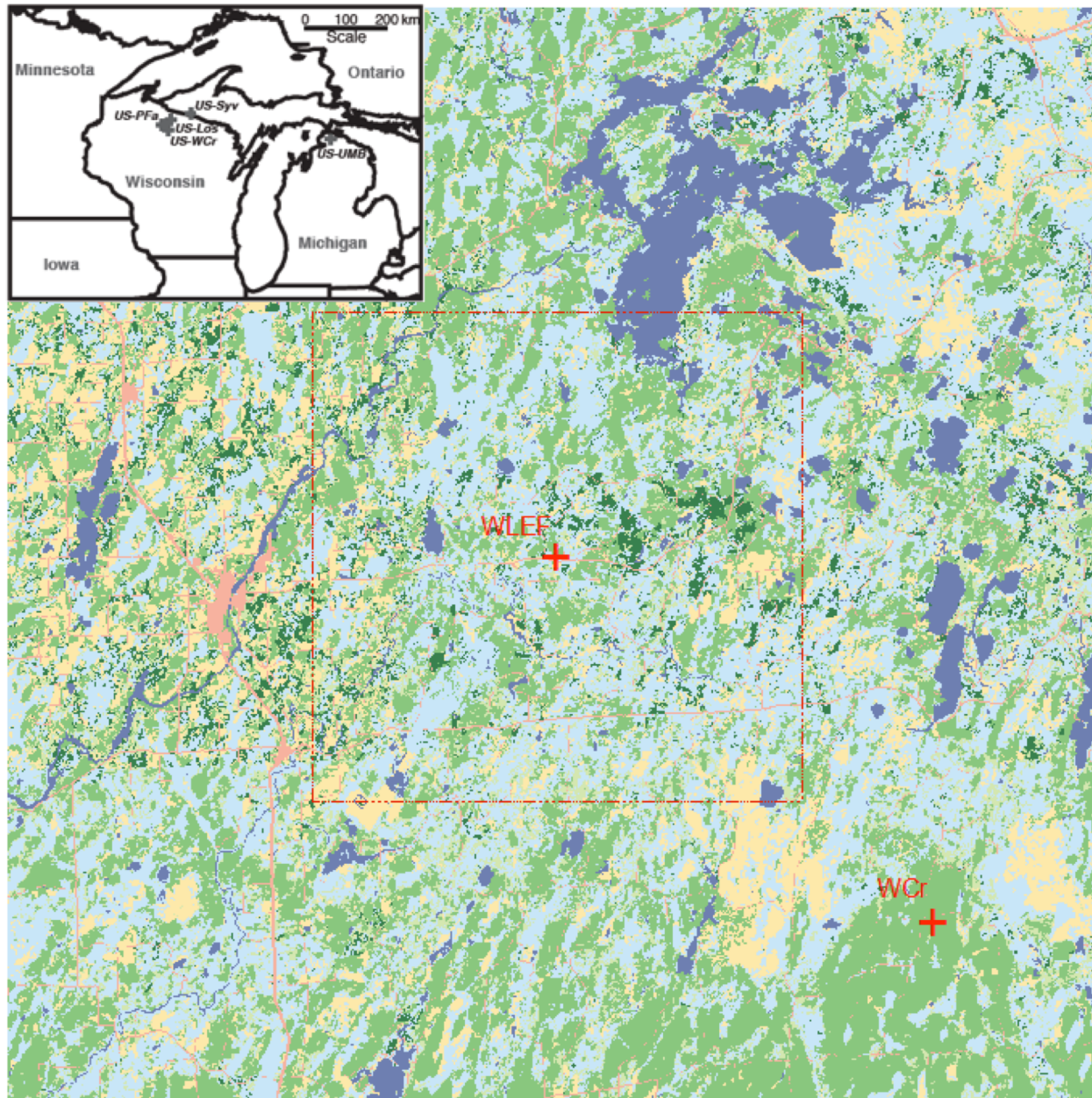


# CHEESEHEAD 2019

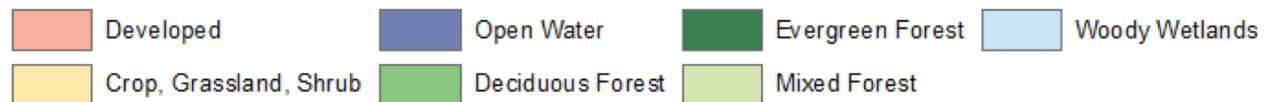
*Chequamegon Heterogeneous Ecosystem  
Energy-balance Study Enabled by a High-  
density Extensive Array of Detectors*



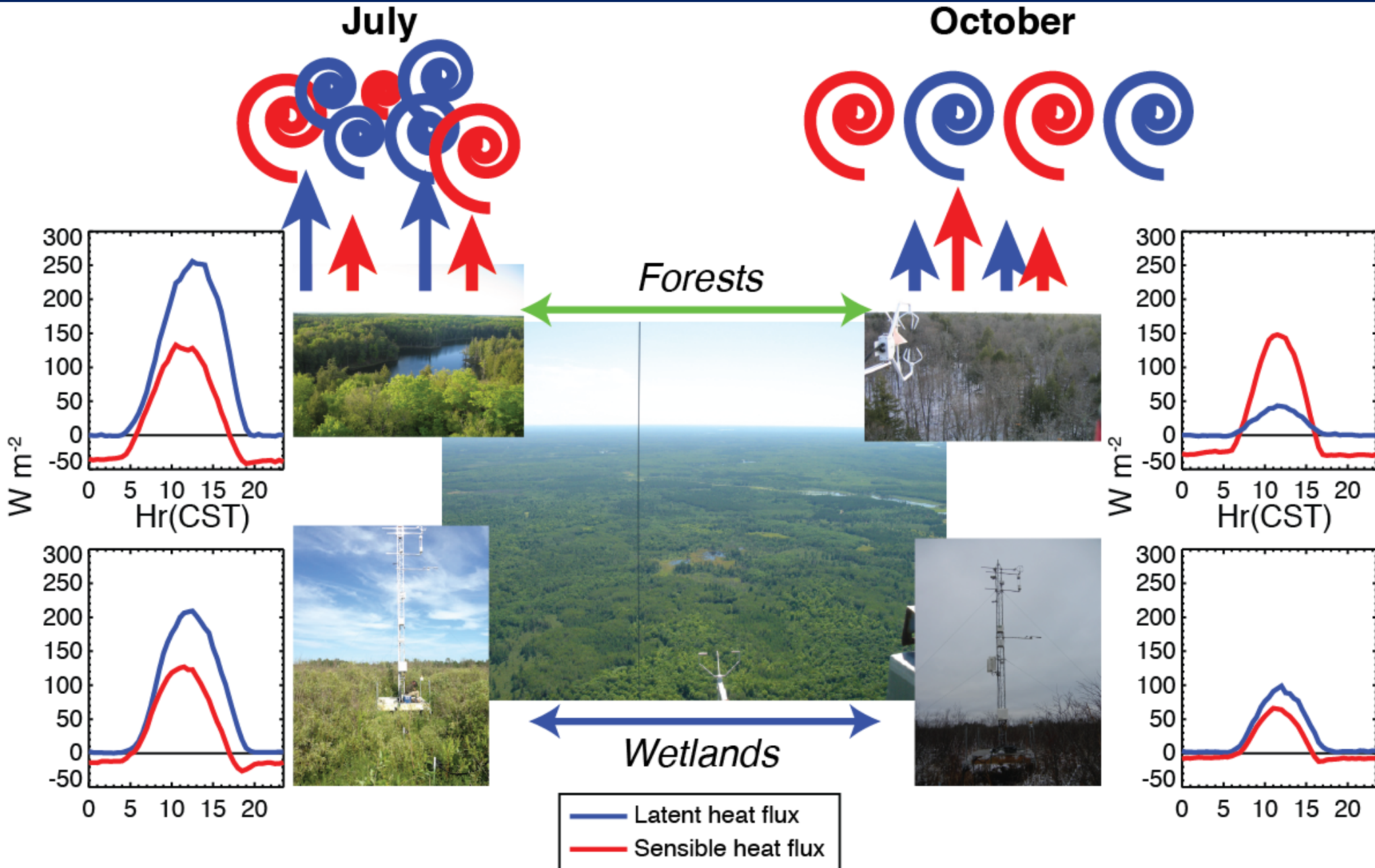




0 2 4 8 km



Experiment ran from July to October 2019, to take advantage of the natural changes in vegetation that occur over the season







Chequamegon High School









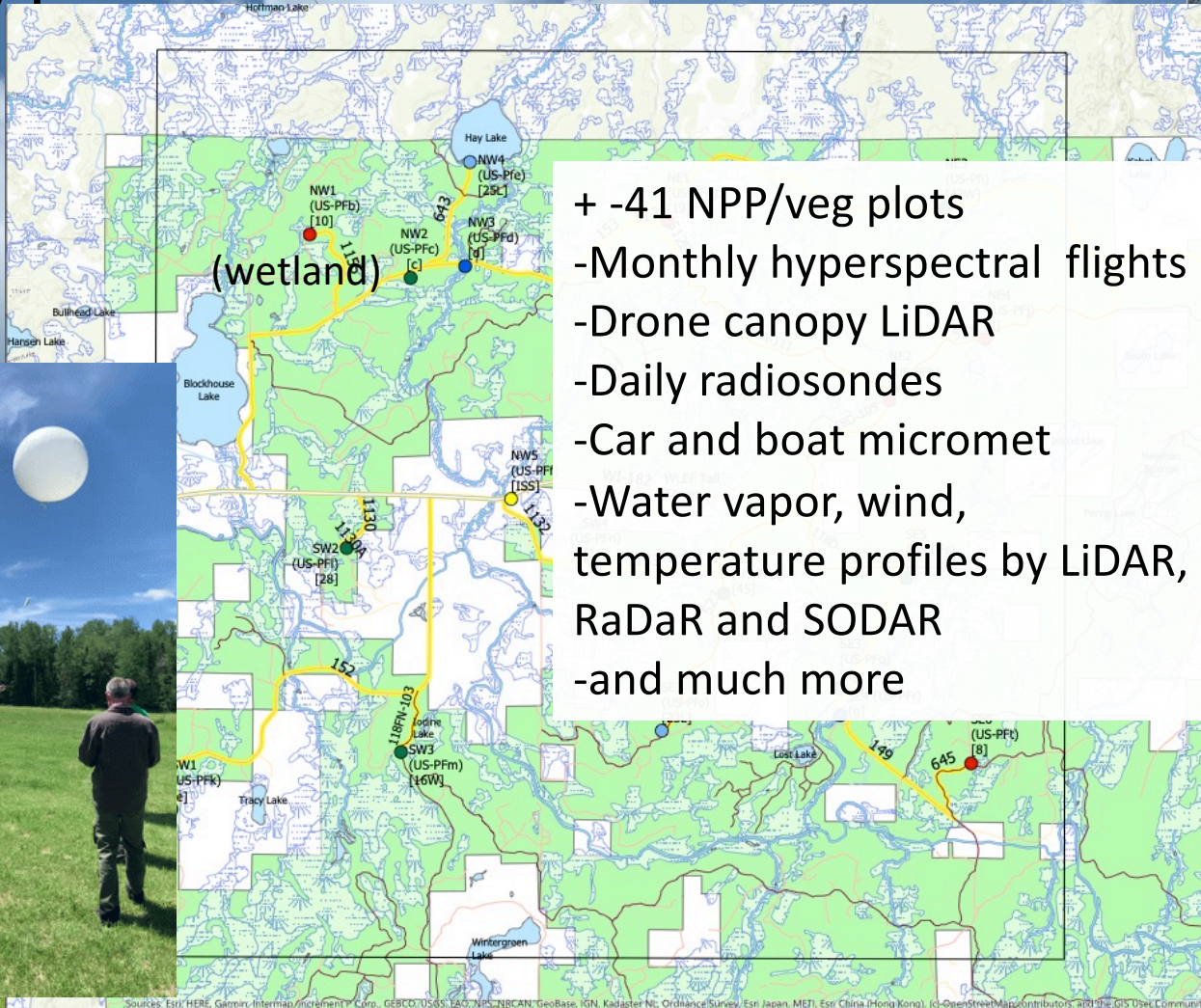








# 19 towers allowed us to have replicates across all major vegetation types in one 10x10 km area!



### CHEESEHEAD 2019

**Legend**

**Type**

- Conifer
- Grass
- Hardwood Deciduous
- Lake
- Tussock
- ★ Tall Tower
- Lake
- River
- ▨ Wetland
- NON-FS
- ▨ USDA FOREST SERVICE

**JURISDICTION**

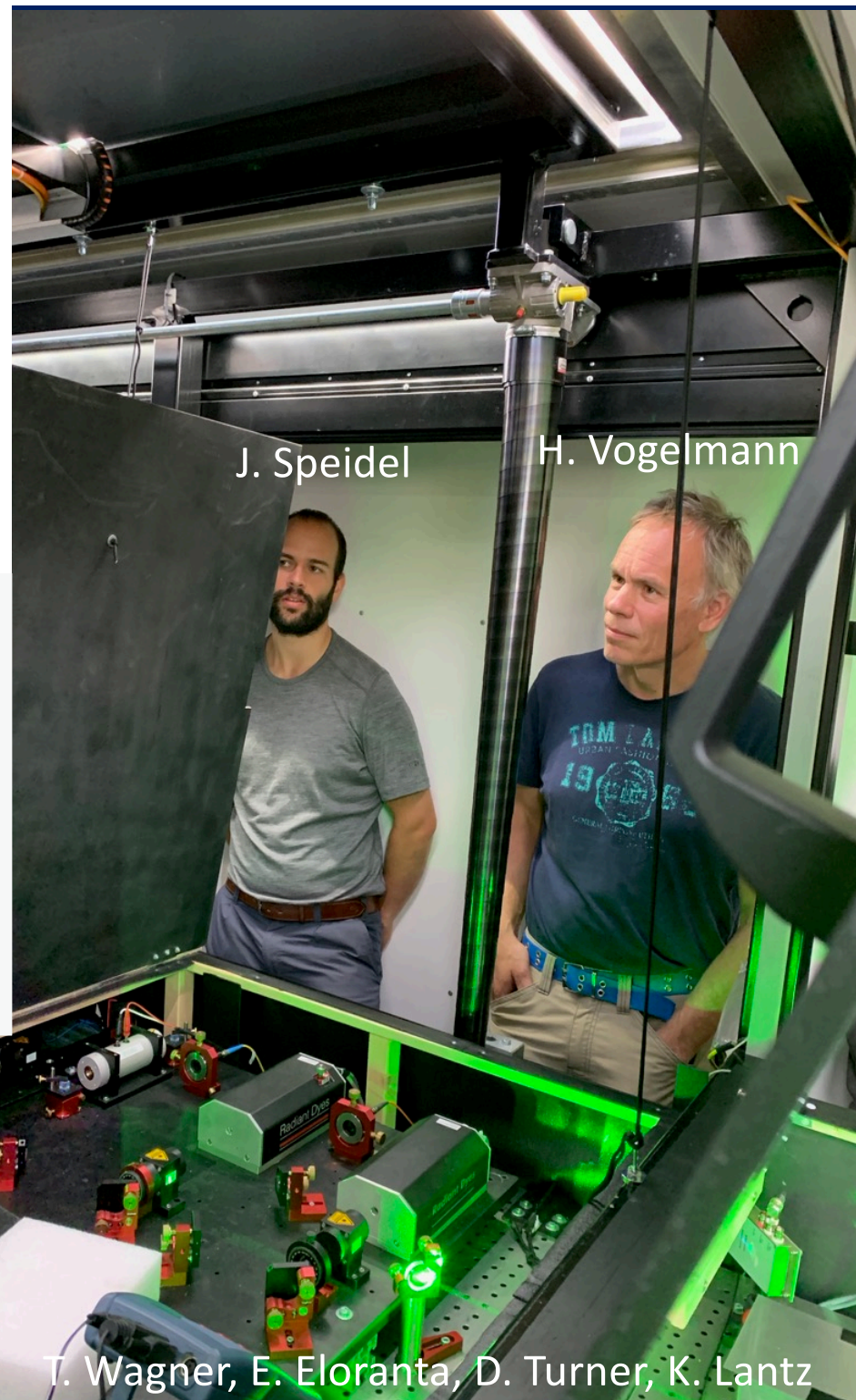
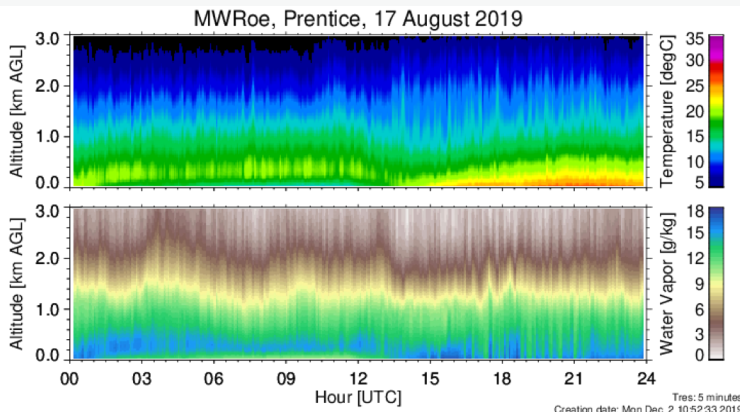
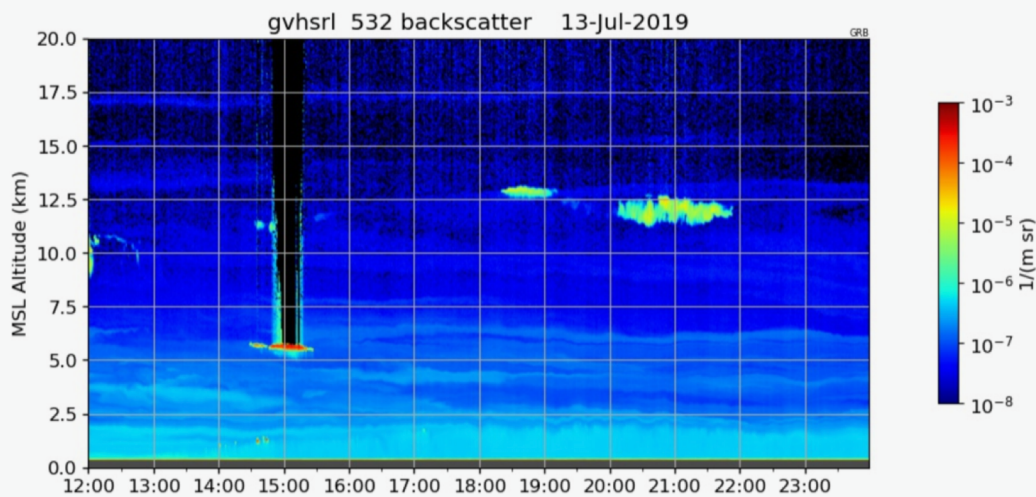
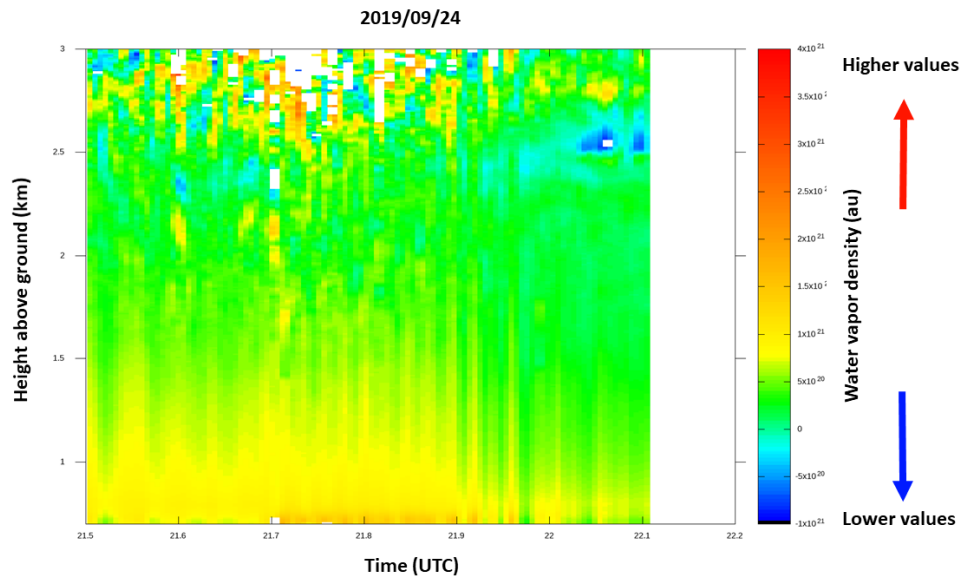
- FOREST SERVICE
- STATE
- LOCAL
- PRIVATE
- Trails
- Lead to Sites

0 0.3 0.6 1.2 1.8 2.4 Kilometers

James Mineau  
23 May 2019

[https://www.eol.ucar.edu/field\\_projects/cheesehead](https://www.eol.ucar.edu/field_projects/cheesehead)

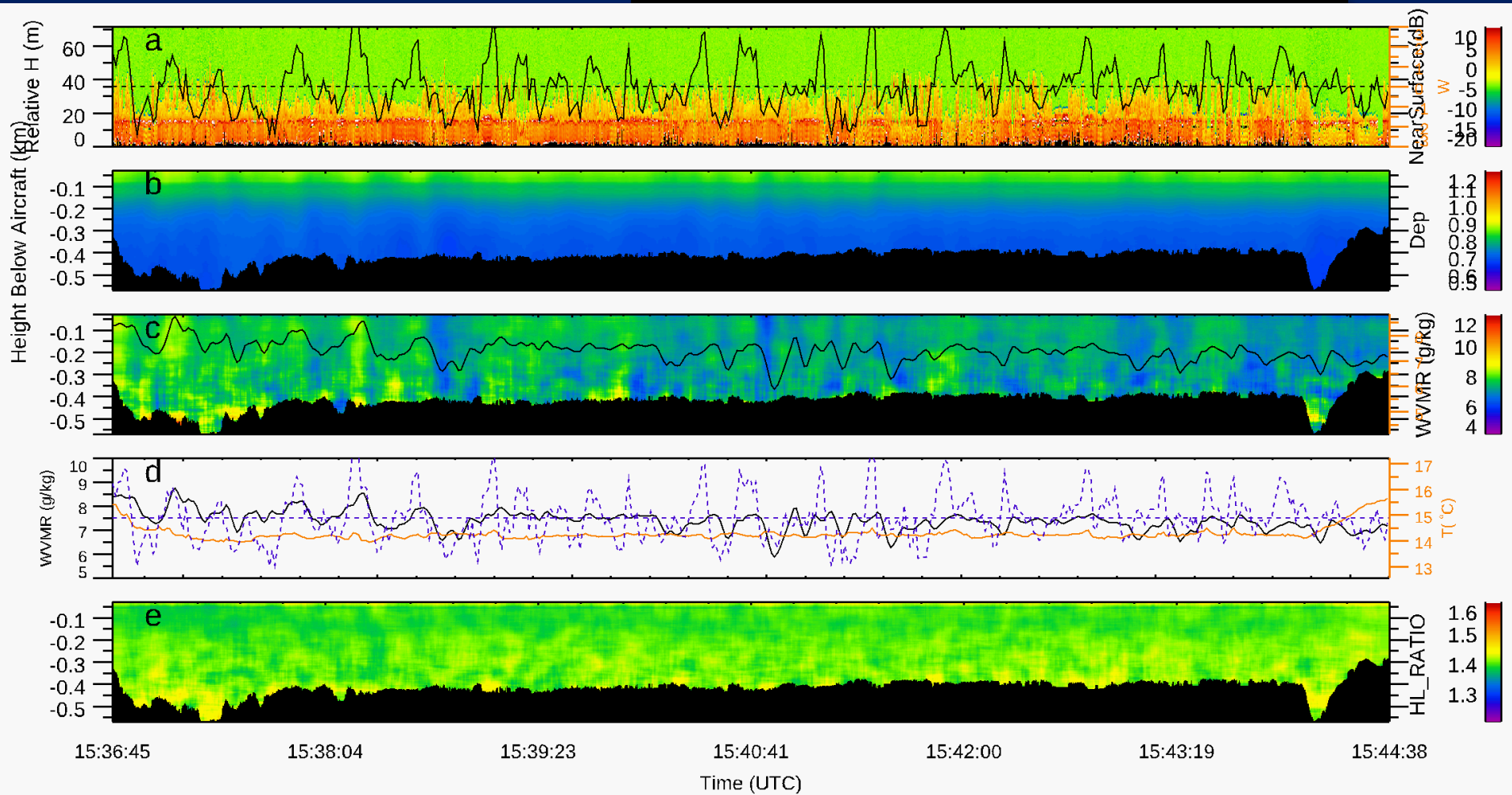






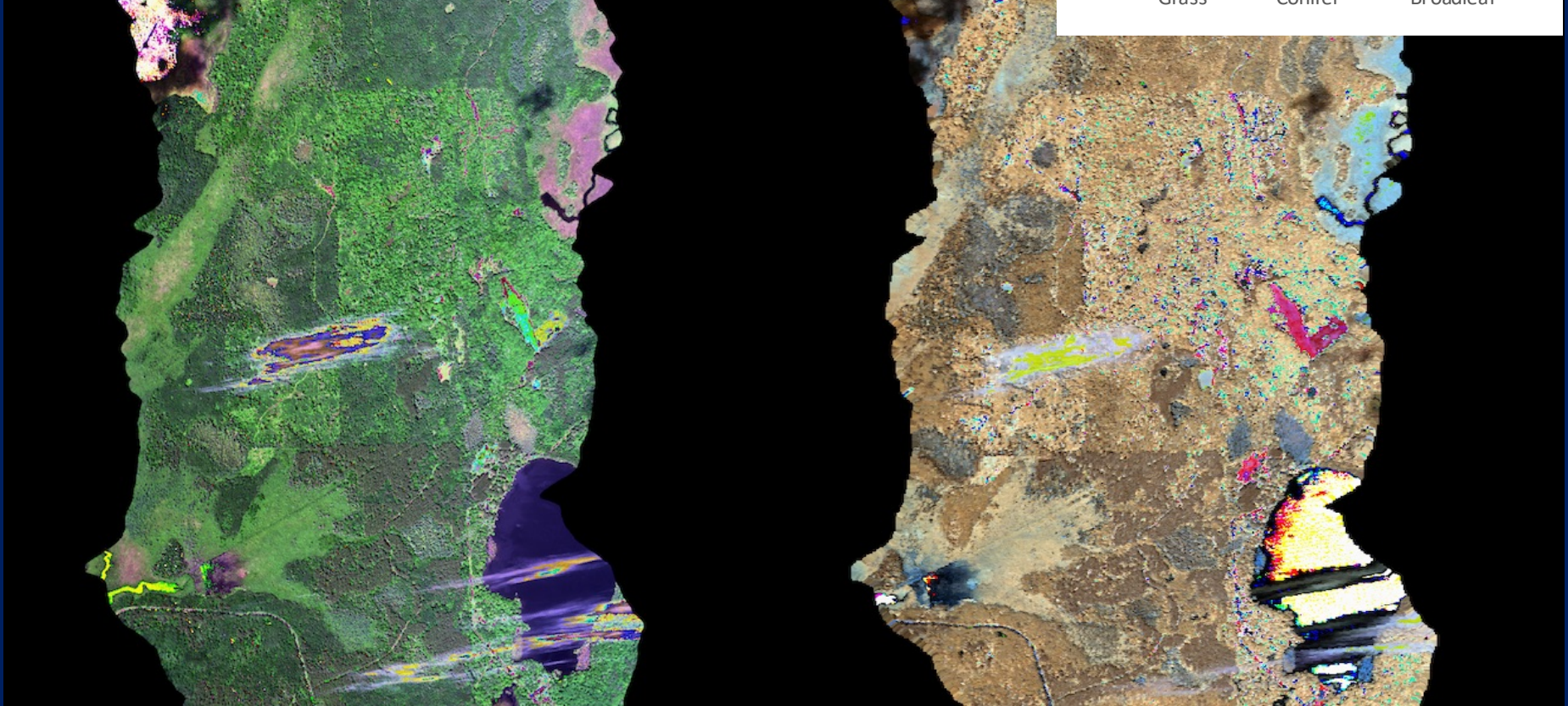
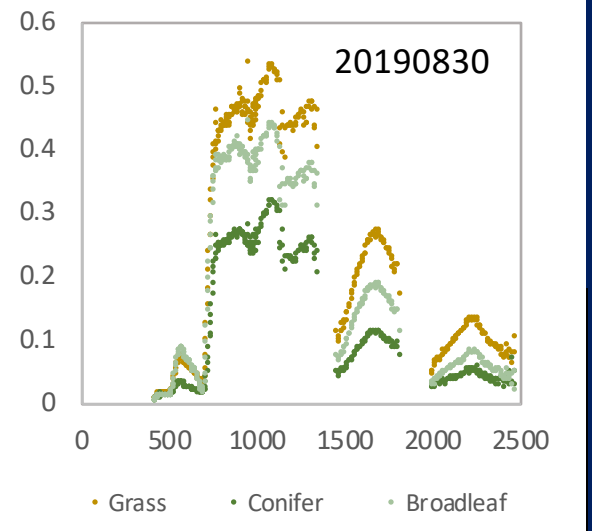
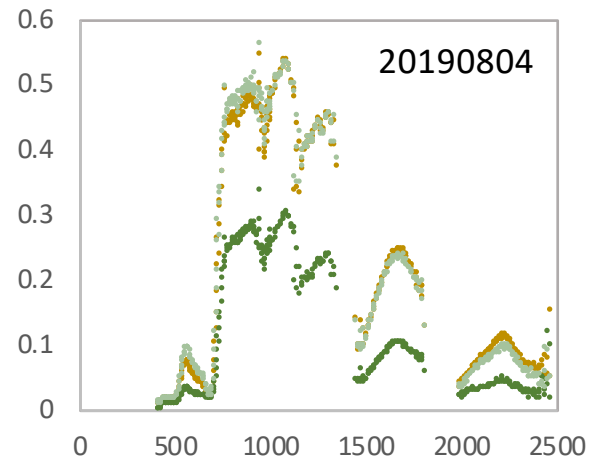
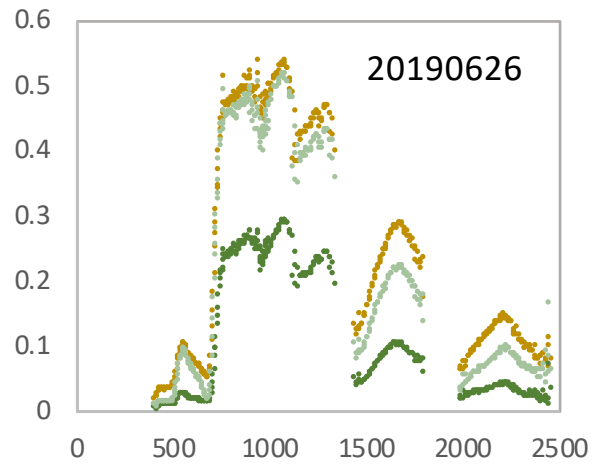


# Three intensives with airborne sampling of surface fluxes



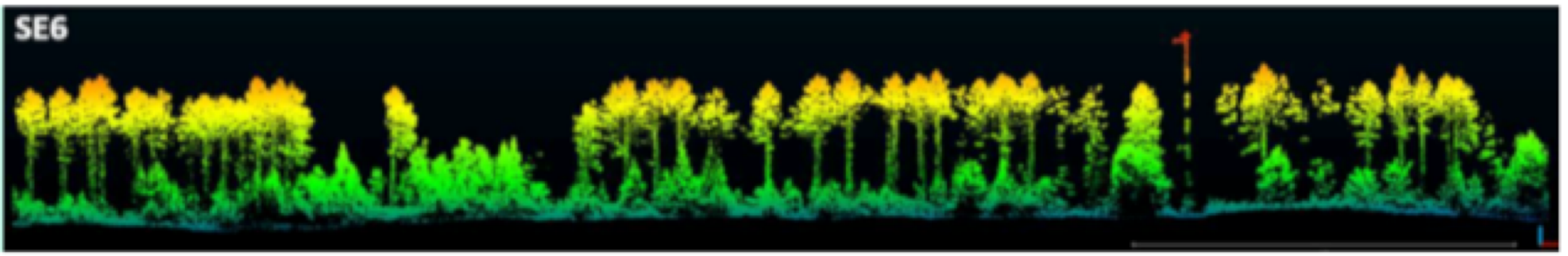
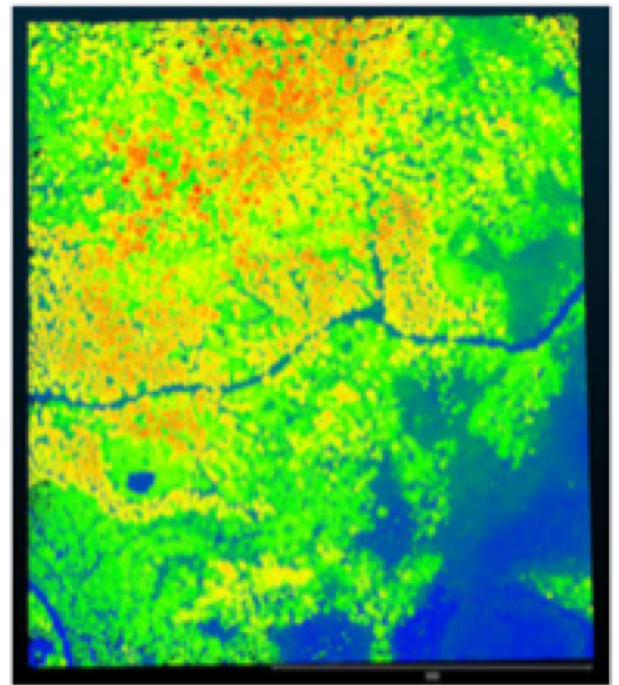
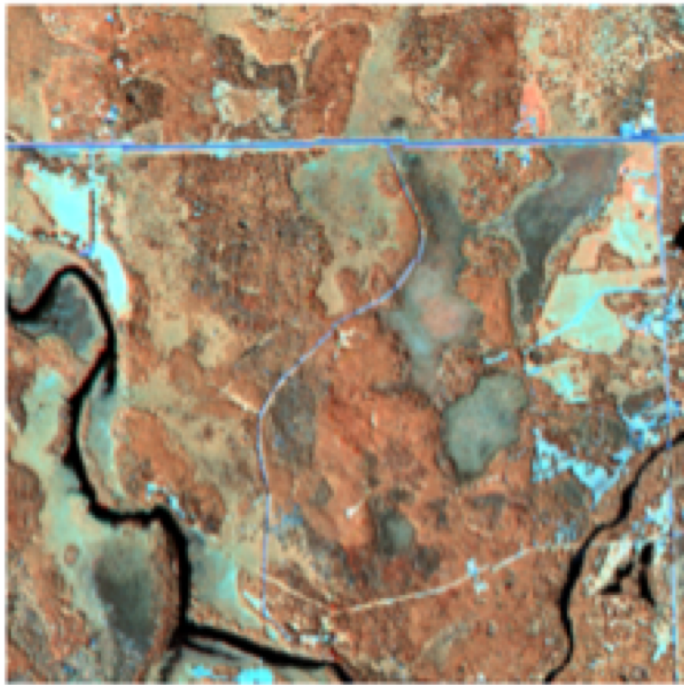
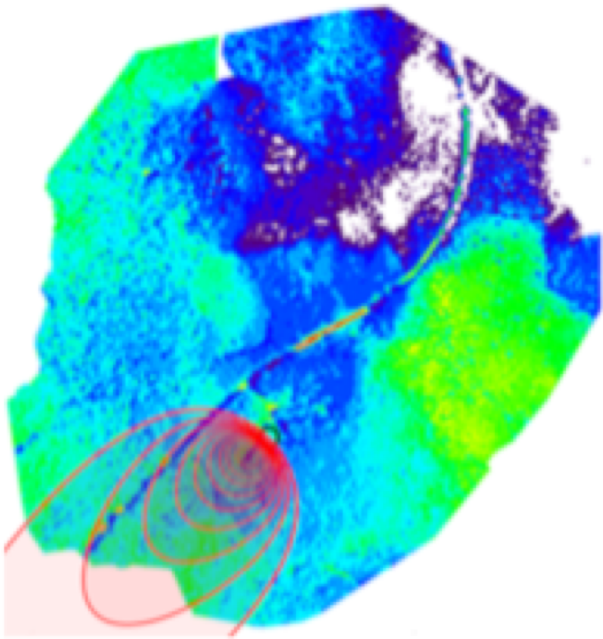
lon (degree)







# Comprehensive surface sampling



C. Andreson, M. Buban, T. Lee, E. Dumas





# CHEESEHEAD19

## Research Sites

- Conifer
- Grass
- Hardwood Deciduous
- Lake
- Tussock
- ★ Tall Tower

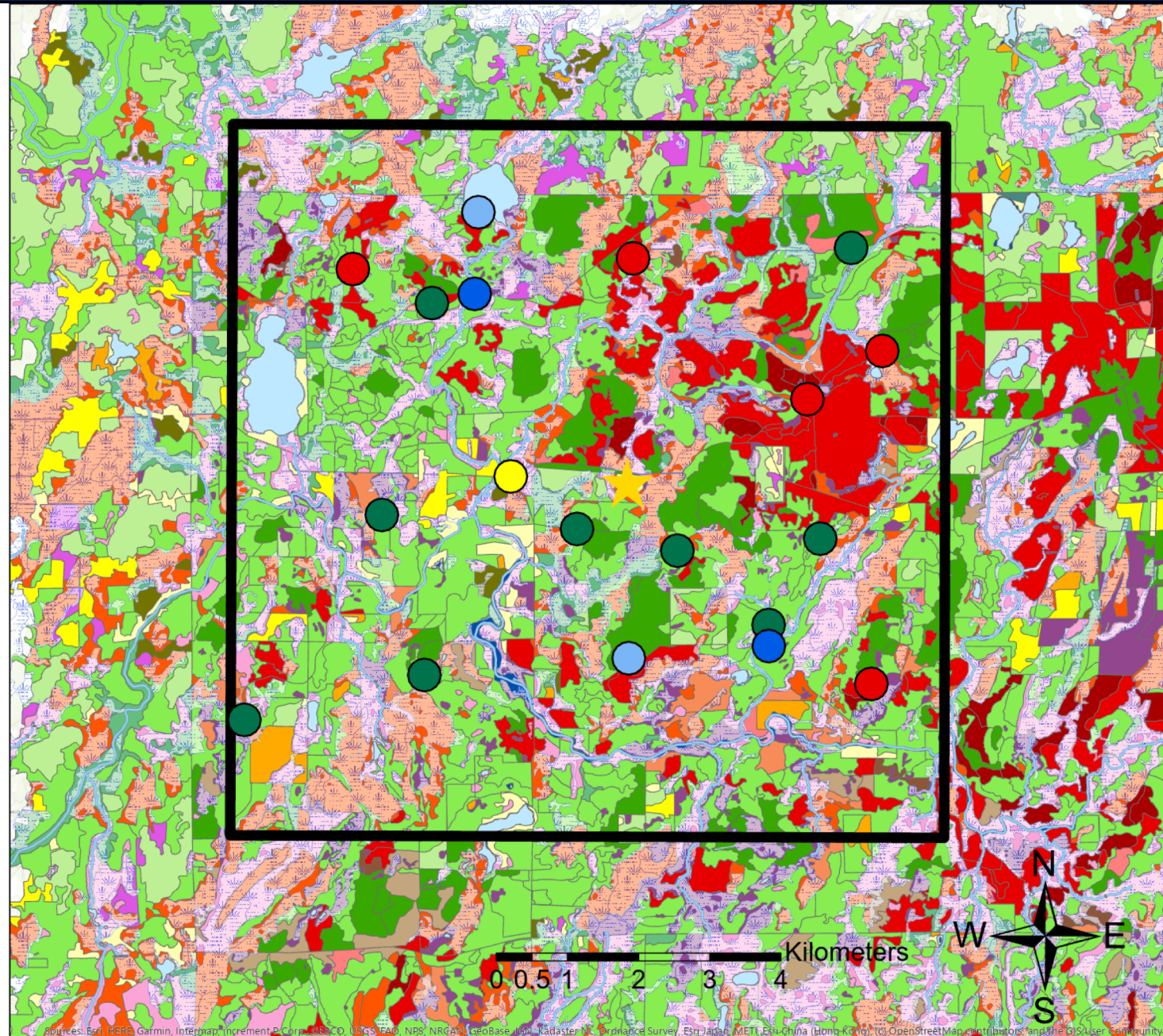
## Hydrology

- ▭ Lake
- River
- ▭ Wetland

## Vegetation

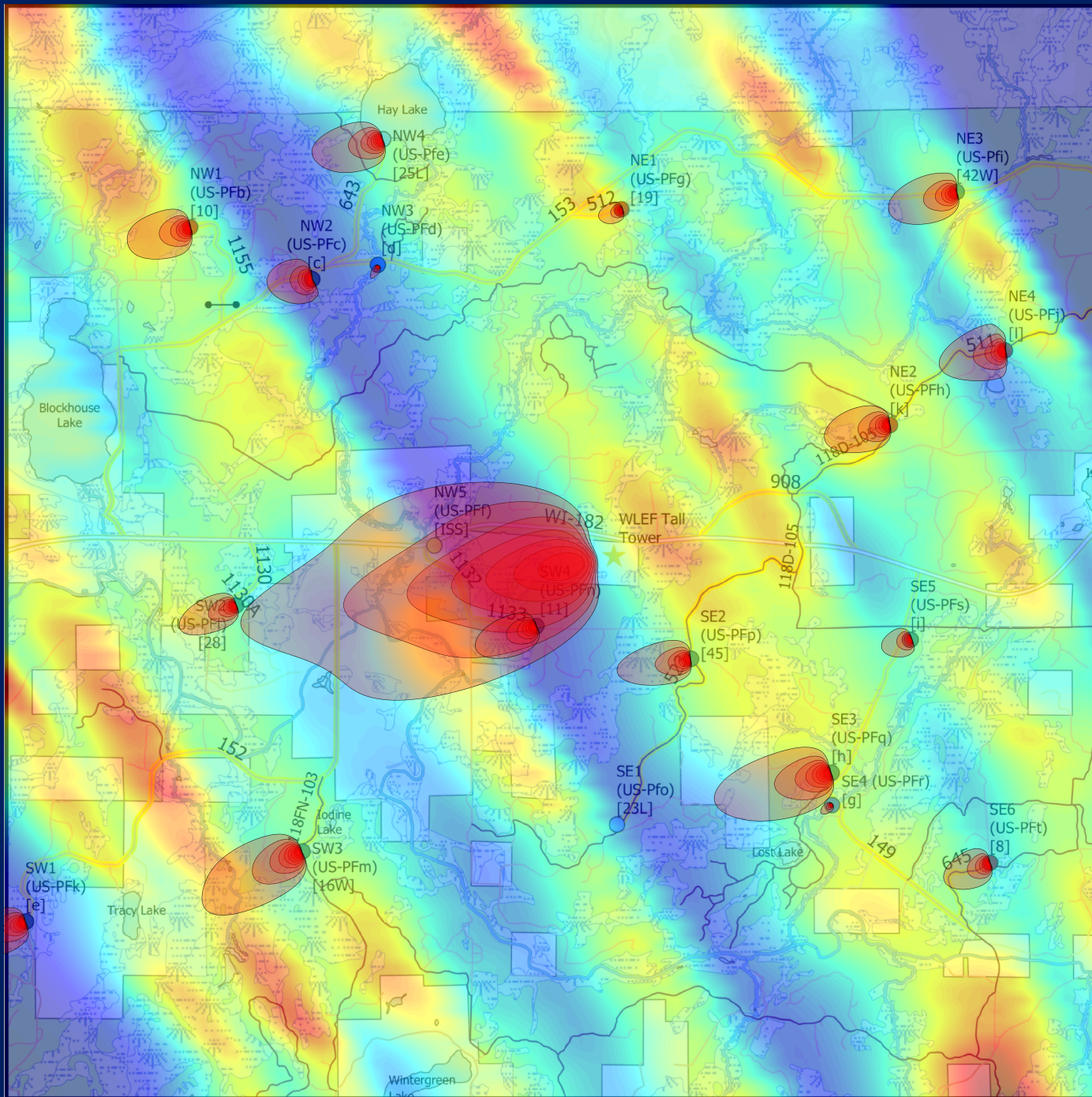
- ▭ Agriculture
- ▭ Aspen
- ▭ Balsam Fir
- ▭ Clearcut
- ▭ Hardwoods
- ▭ Hemlock
- ▭ Jack Pine
- ▭ Lowland Conifers
- ▭ Lowland Hardwoods
- ▭ Lowland Opening
- ▭ Oak
- ▭ Paper Birch
- ▭ Pine
- ▭ Red Pine
- ▭ Spruce
- ▭ Spruce/Fir
- ▭ Upland Hardwoods
- ▭ Upland Opening
- ▭ Urban
- ▭ Water
- ▭ White Pine

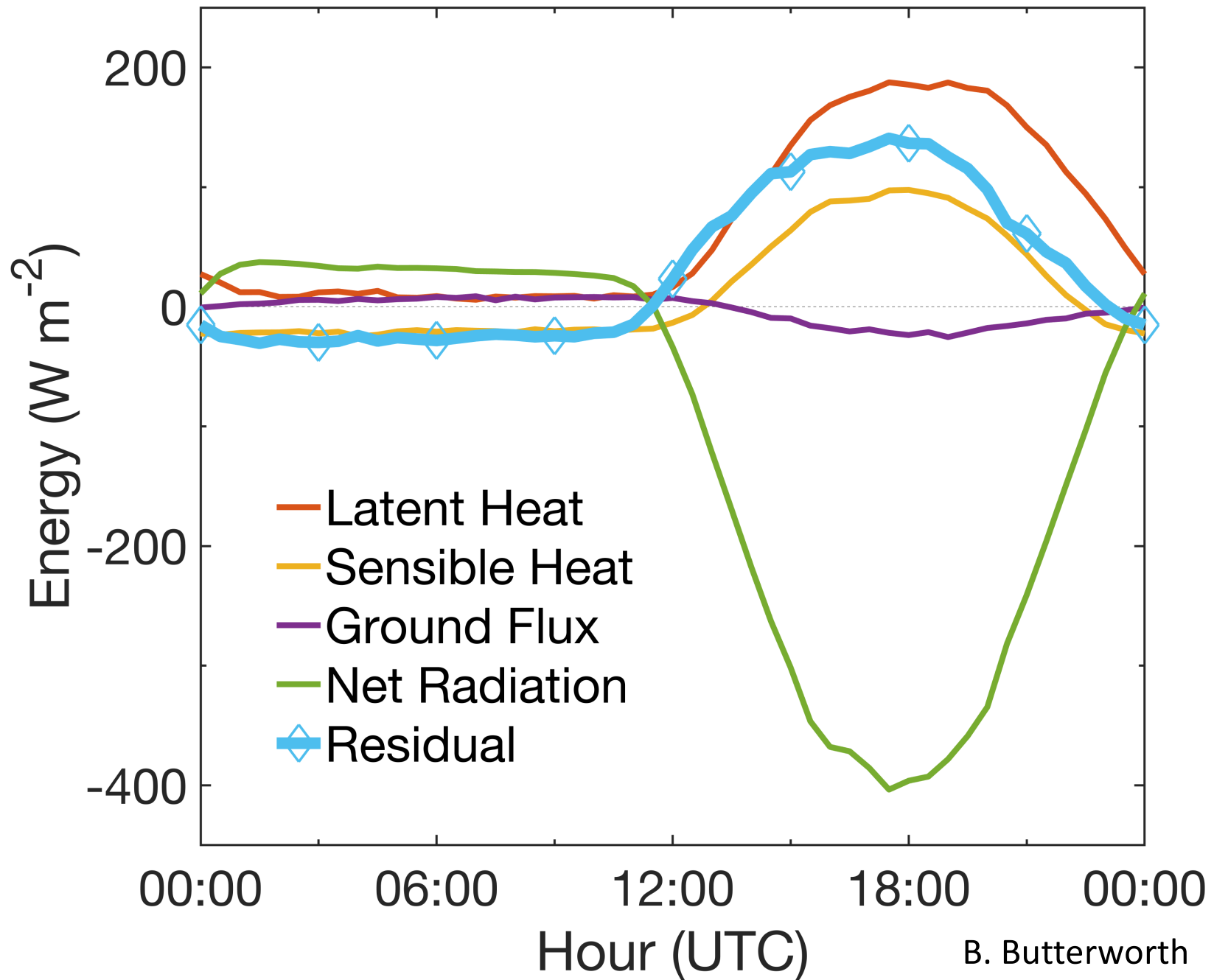
James Mineau  
12 Sep 2019



Desai et al., 2007, 2008; Xu et al., 2017, 2018; Sühning et al., 2019

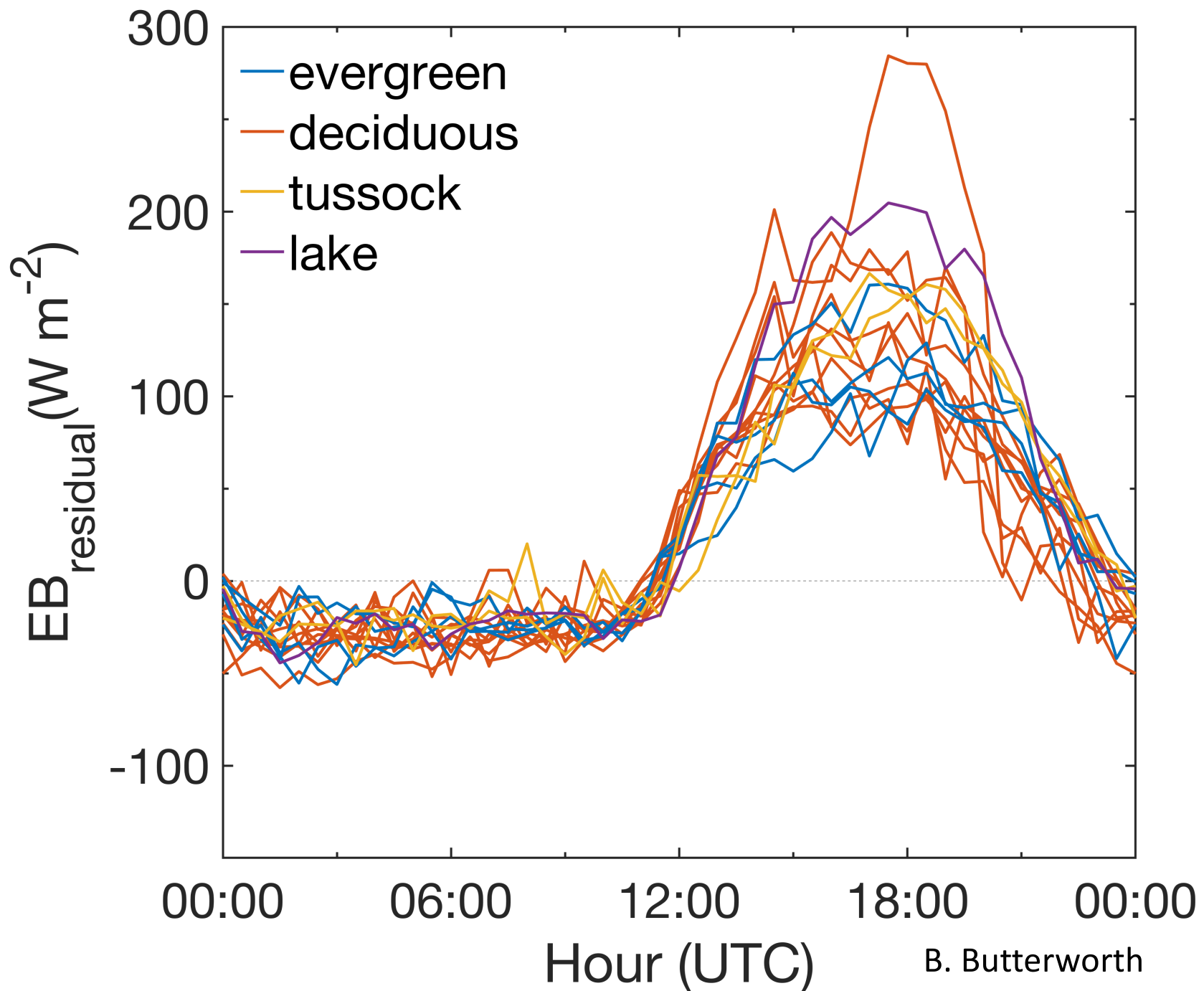






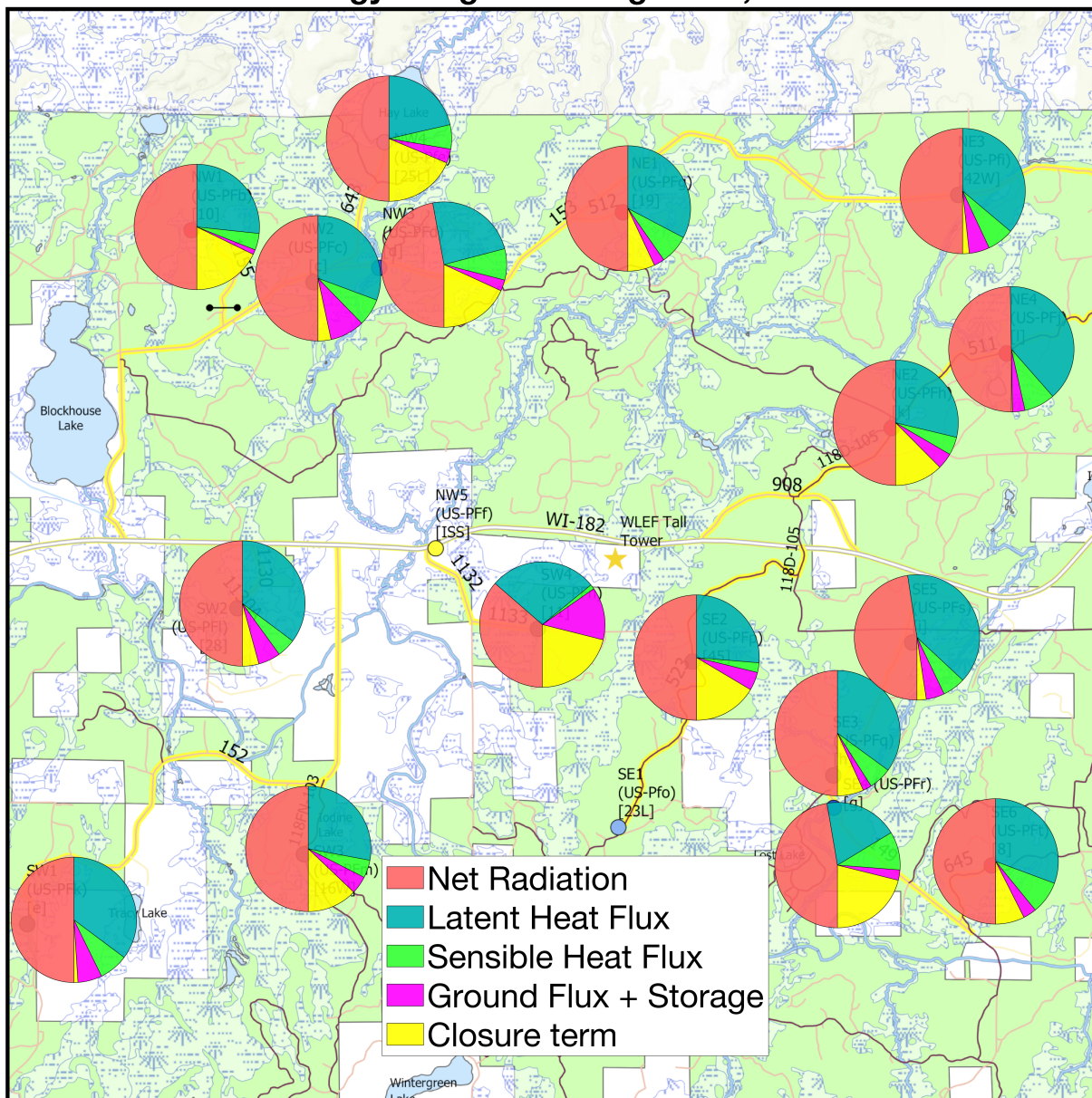
B. Butterworth





B. Butterworth

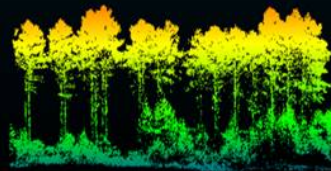
# Energy Budgets on August 22, 2019



B. Butterworth



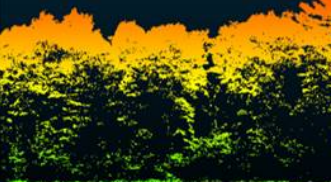
SE6



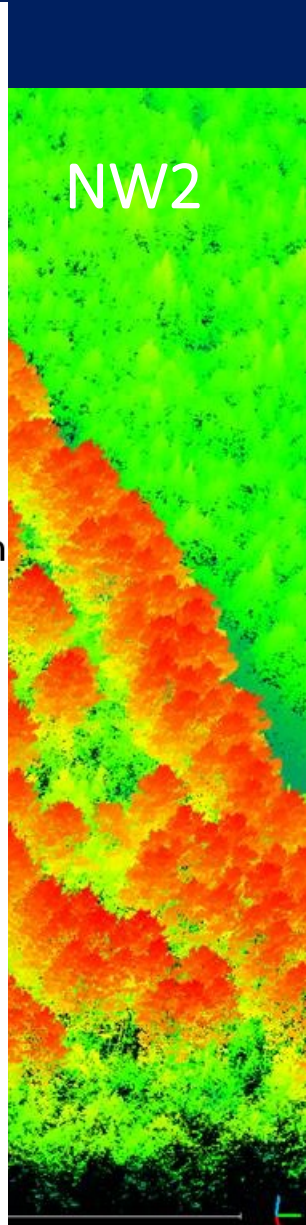
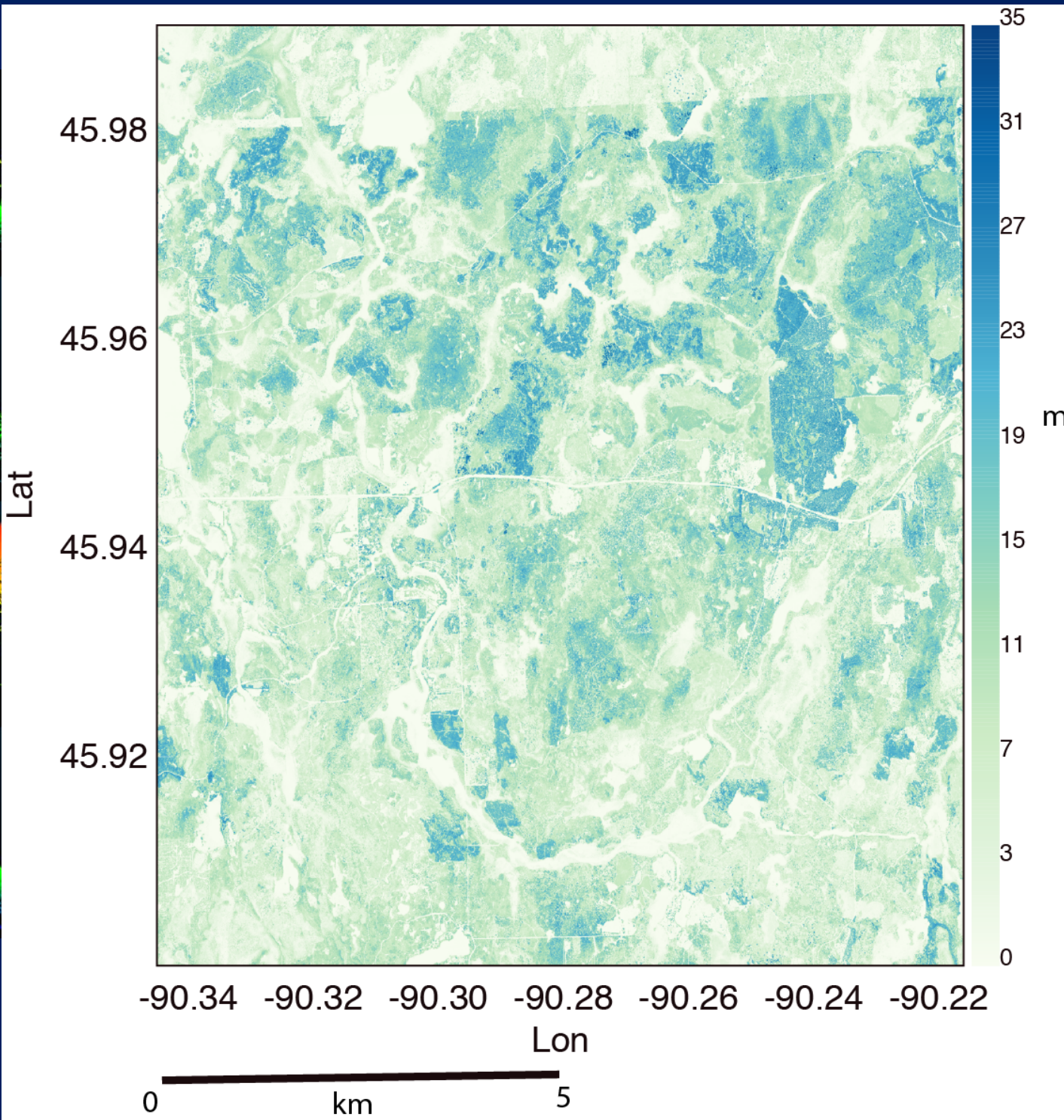
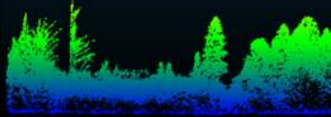
NE2



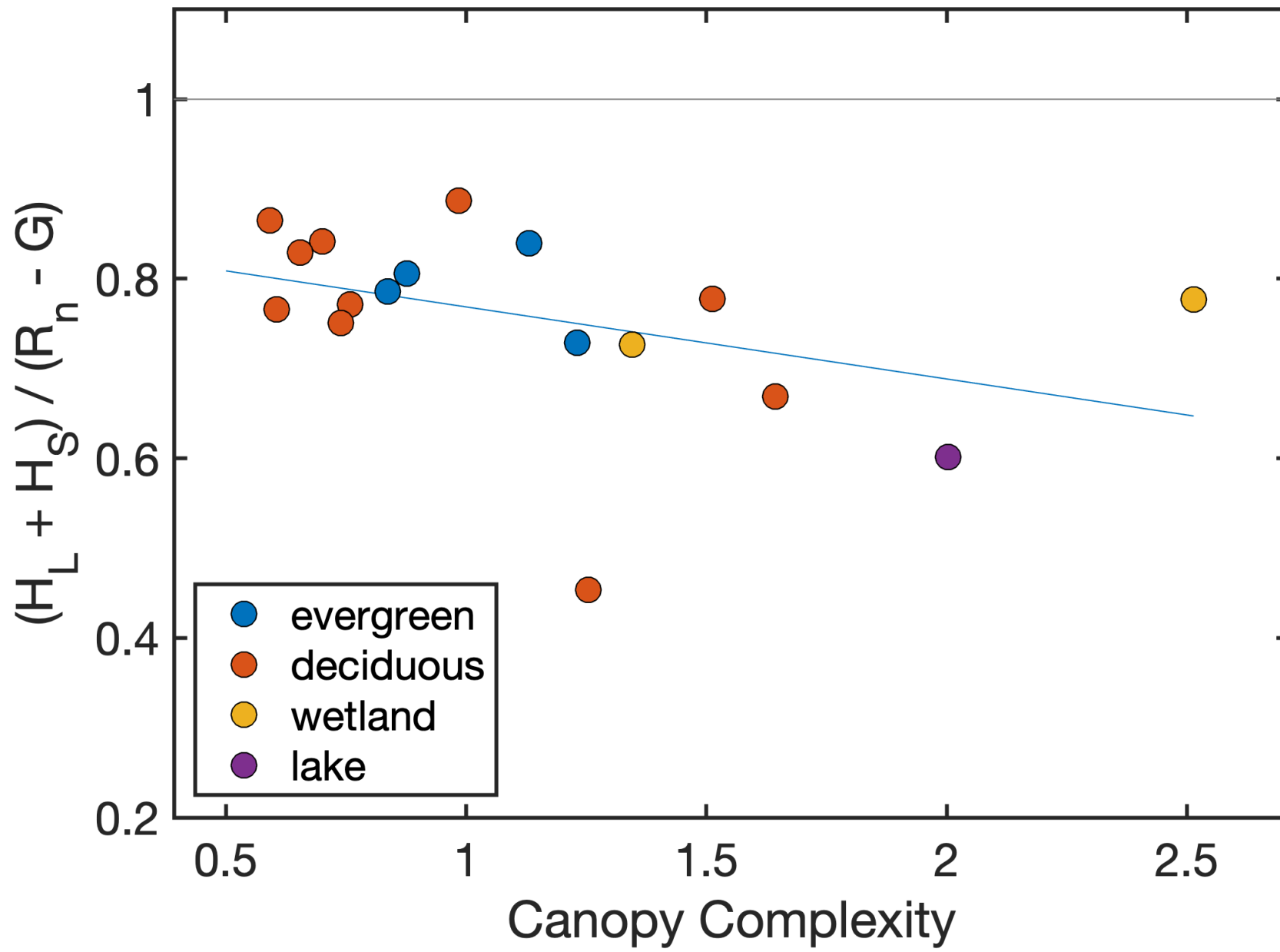
NE3



NE4



T. Zheng



( $\sigma$  of vegetation height in meters)

B. Butterworth





# CHEESEHEAD 2019

## Low-altitude (100m) airborne fluxes and PBL

by J. Mineau, King Air connects the dots

### Legend

#### Research :

- Conifer
- Grass
- Hardwo
- Lake
- Tussock

★ Tall Tow

□ Resear

#### Water Fea

- Lake
- River
- Wetland

#### Land Own

- Private
- USDA FO

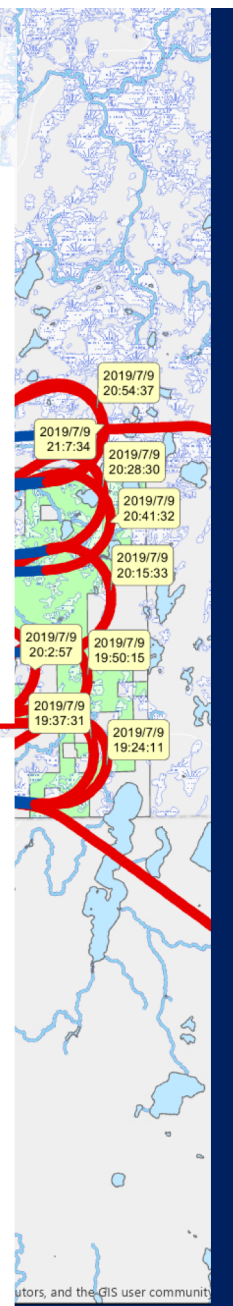
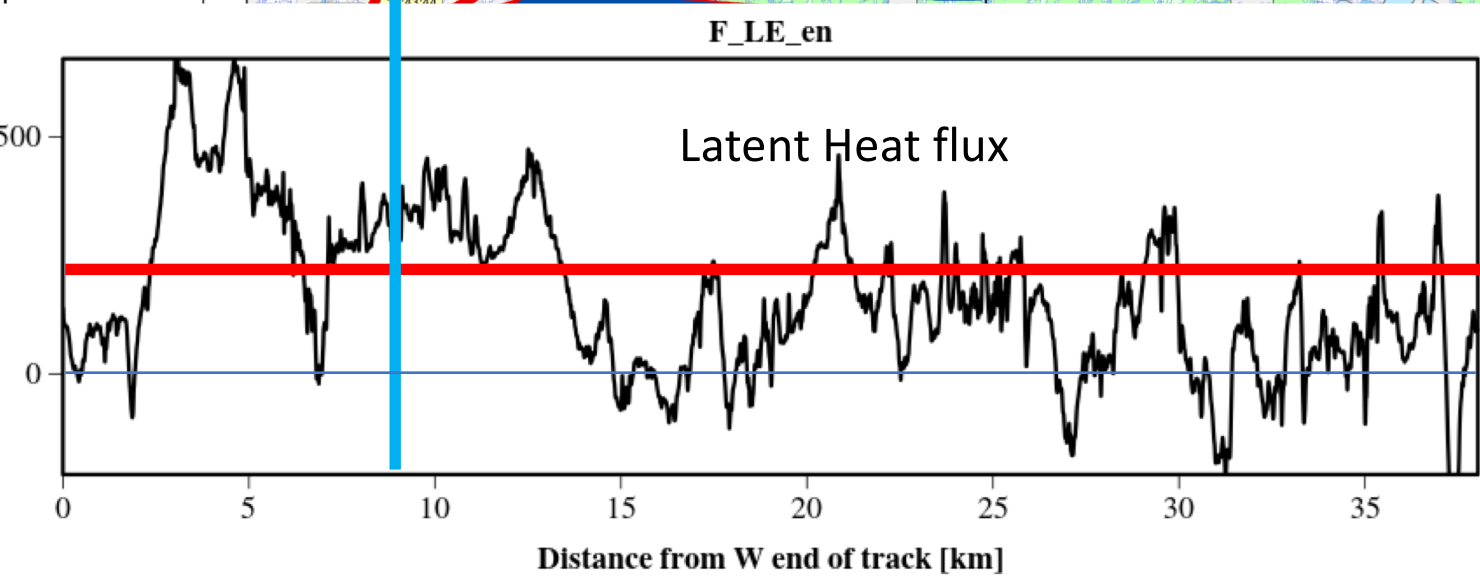
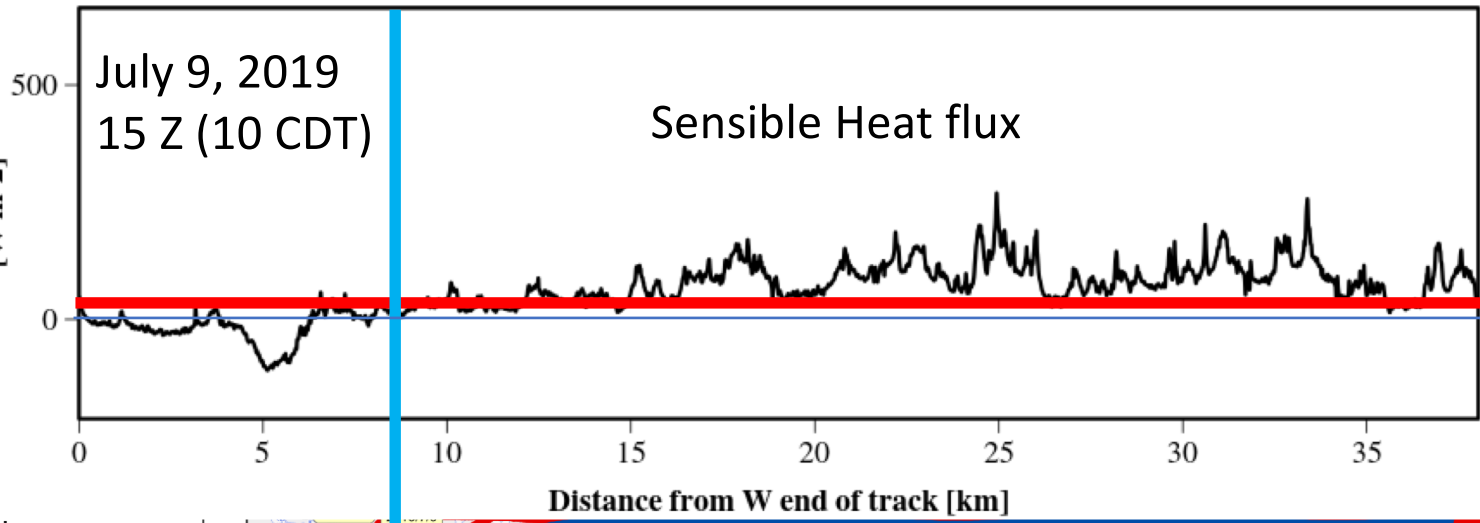
#### King Air Flight

##### Alt

- ≤600 M
- ≤1300
- ≤3000



James Mineau  
12 Sep 2019



Map: J. Mineau  
Photo: B. Butterworth  
Figure: D. Durden + A. Desai



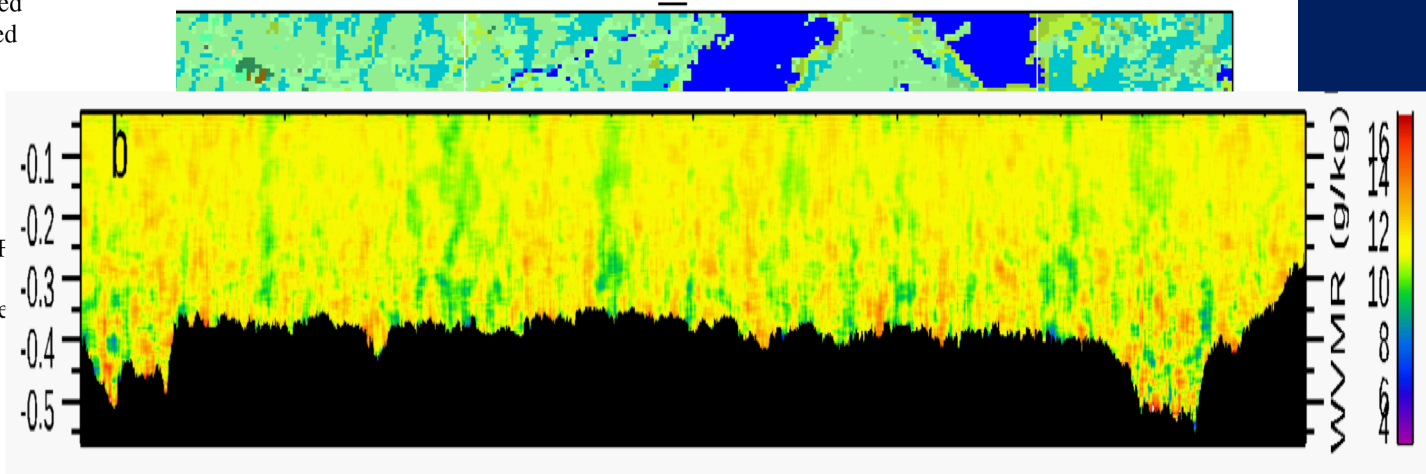
Photo: B. Butterworth



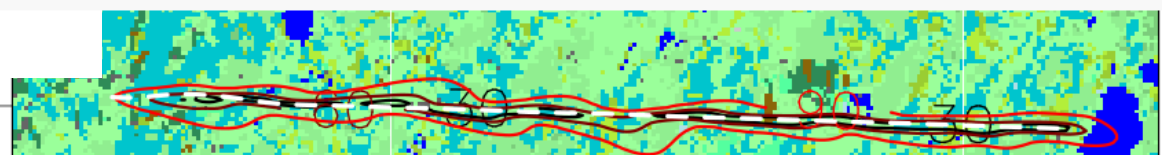
landcover\_wisland

- High Intensity Urban/Developed
- Low Intensity Urban/Developed
- Crop Rotation
- Cranberries
- Foraged Grass
- Idle Grass
- Coniferous
- Broad-leaved Deciduous
- Mixed Deciduous/Coniferous F
- Open Water
- Aquatic Bed (Floating Herbace
- Emergent/Wet Meadow
- Scrub/Shrub Wetland
- Forested Wetland
- Barren
- Shrubland

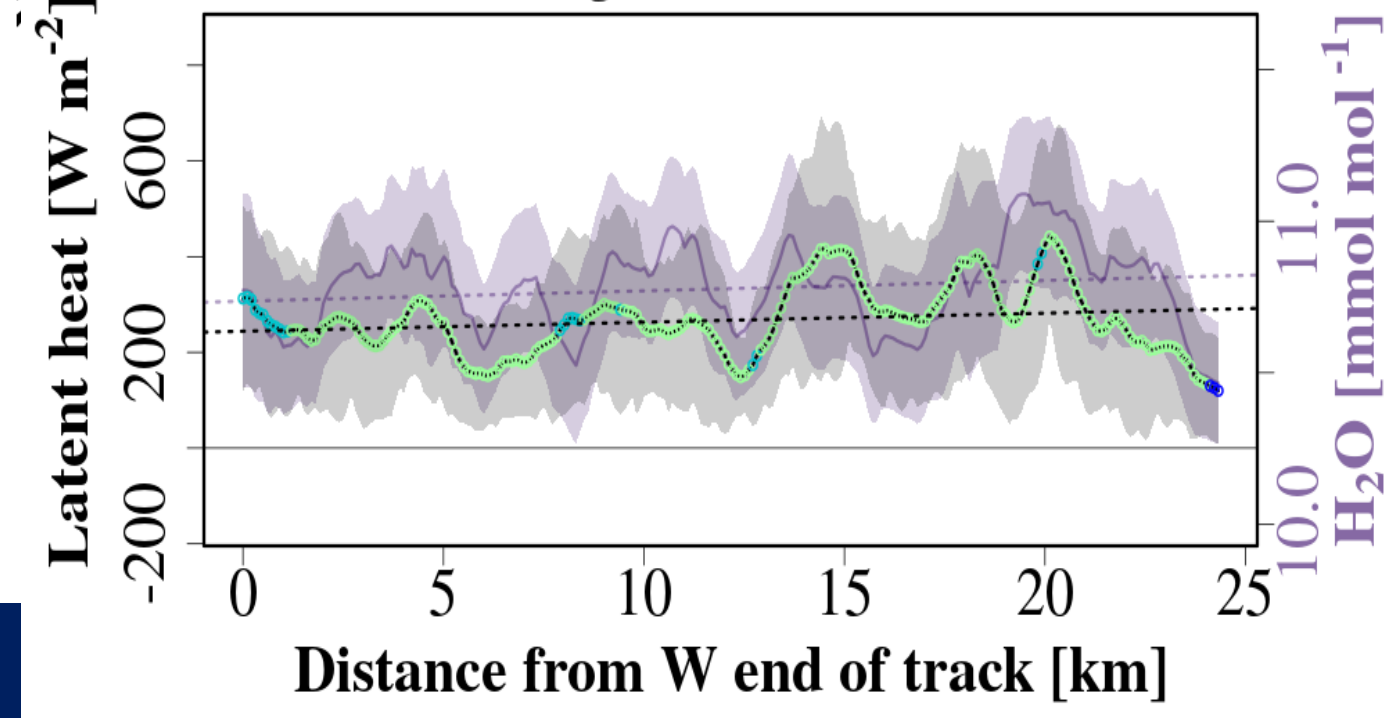
landcover\_wisland



hin  
900



RF16\_leg08\_landcover\_wisland



S. Paleri  
S. Metzger  
Z. Wang

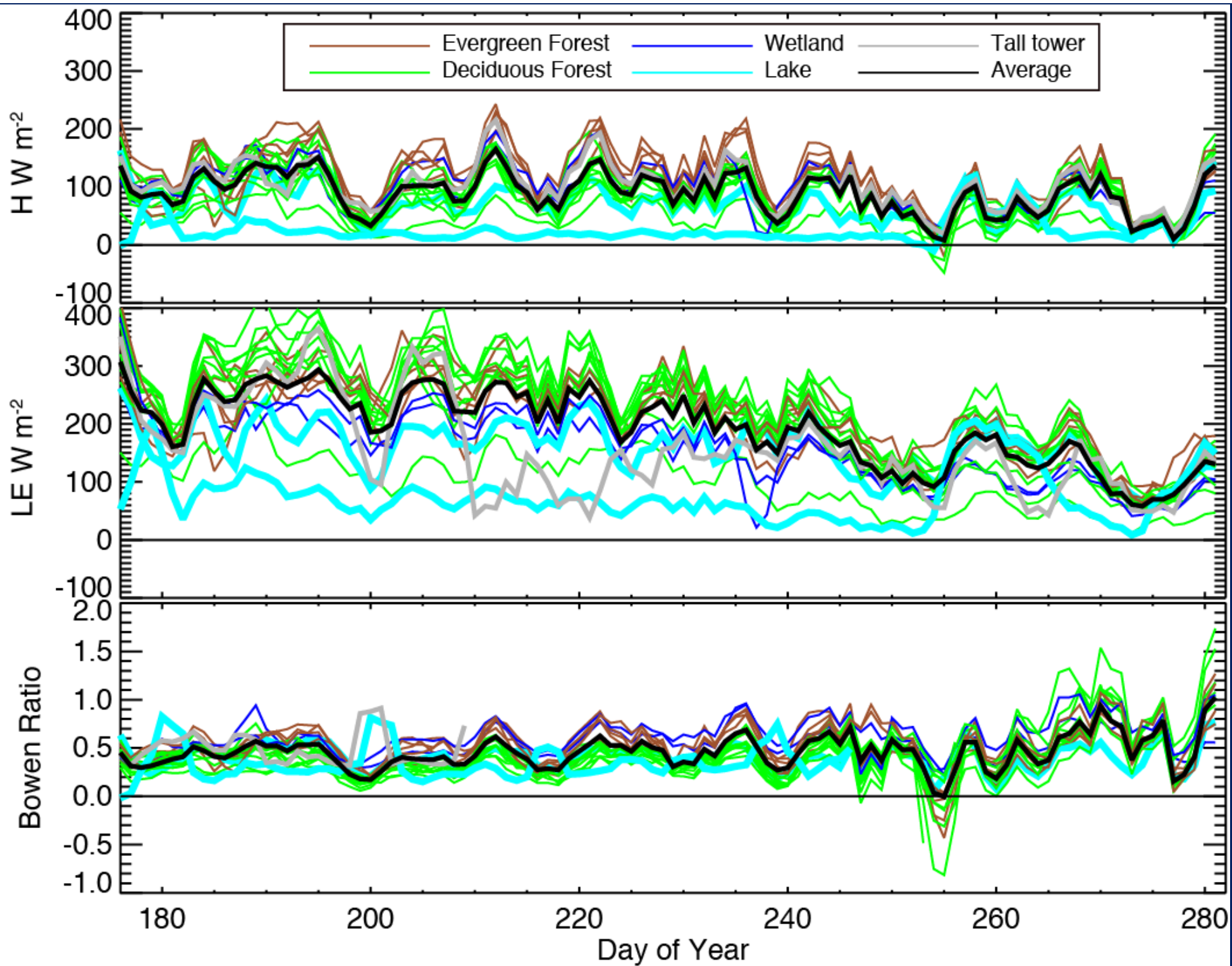


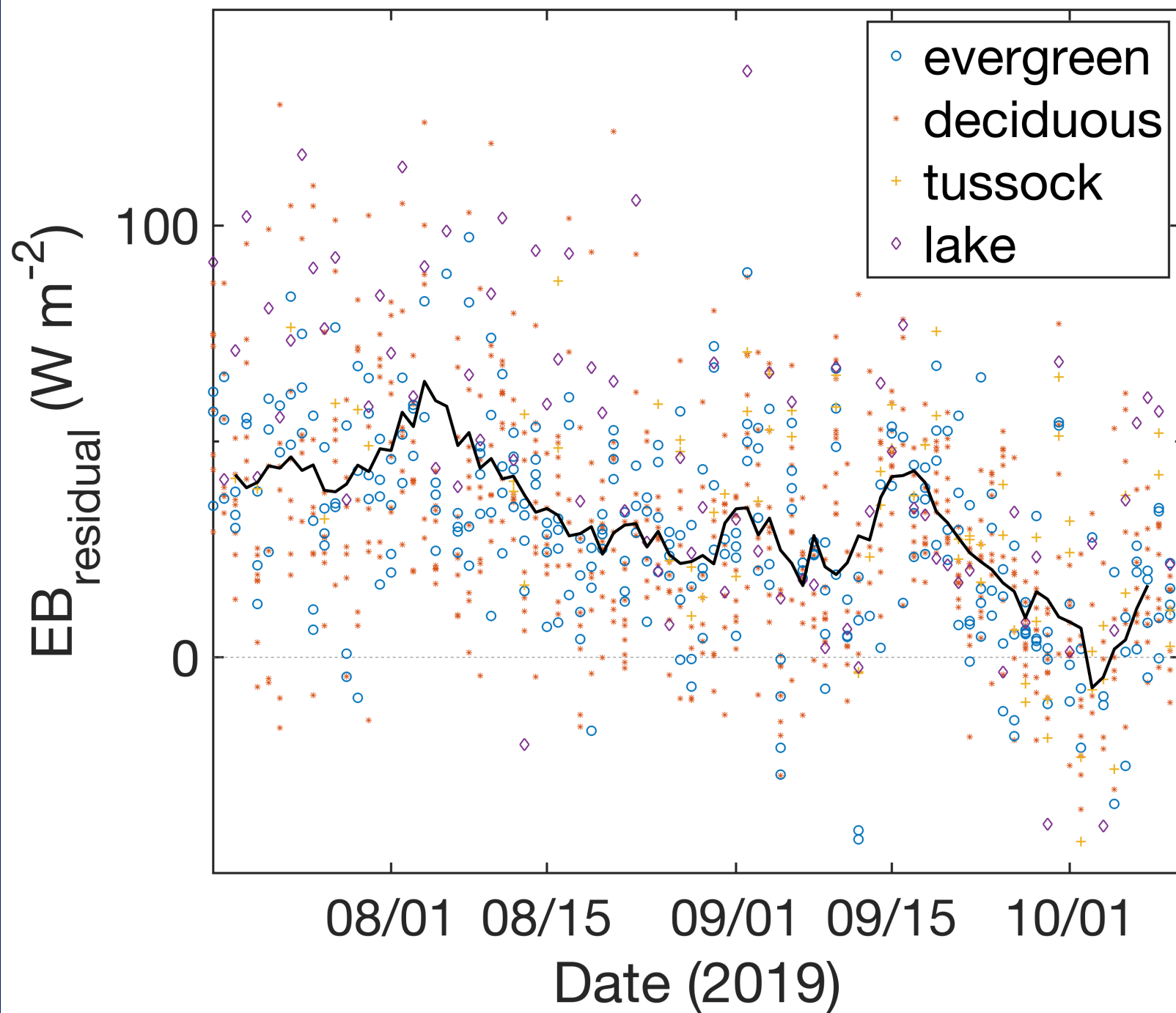


Tower: P. Stoy, B. Butterworth, J. Thom, N. Lottig, P. Schramm

Photo: A. Desai

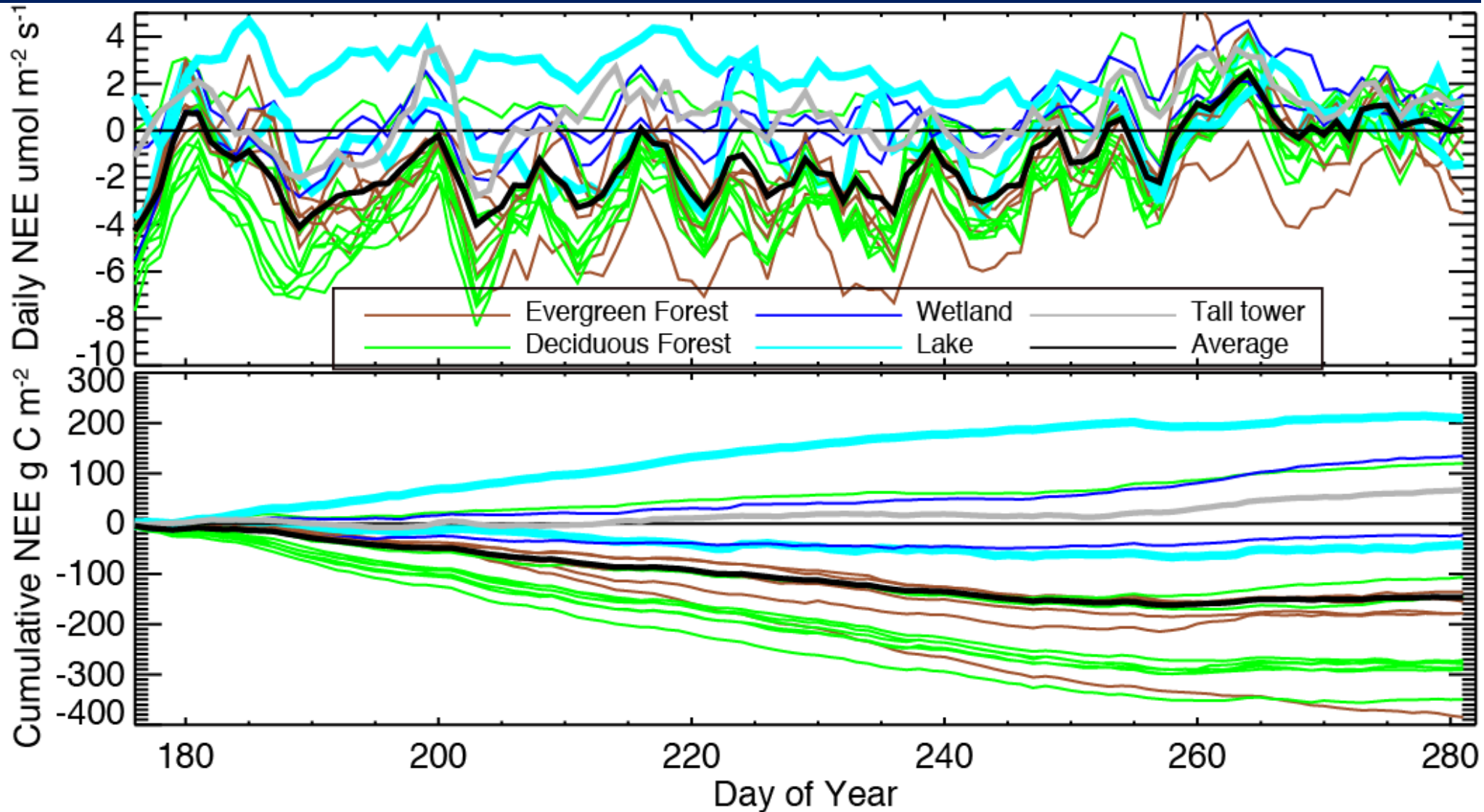






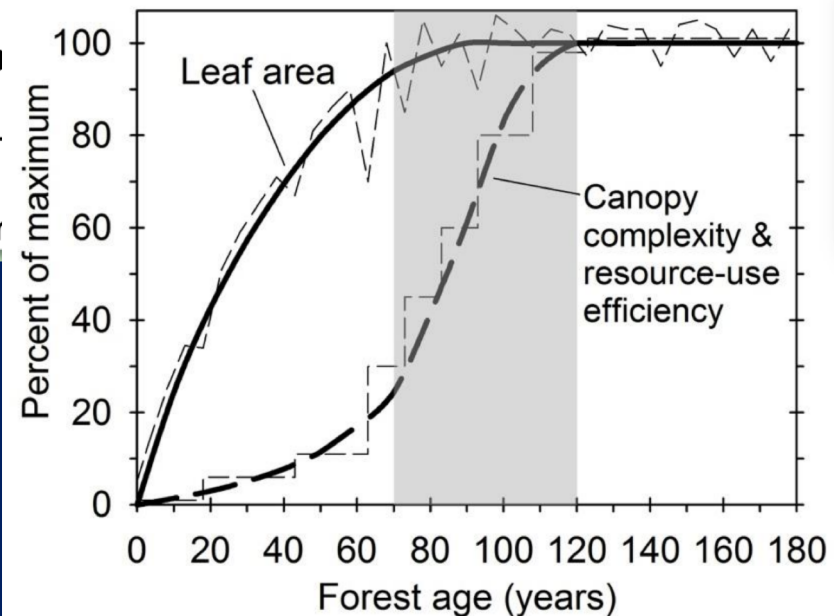
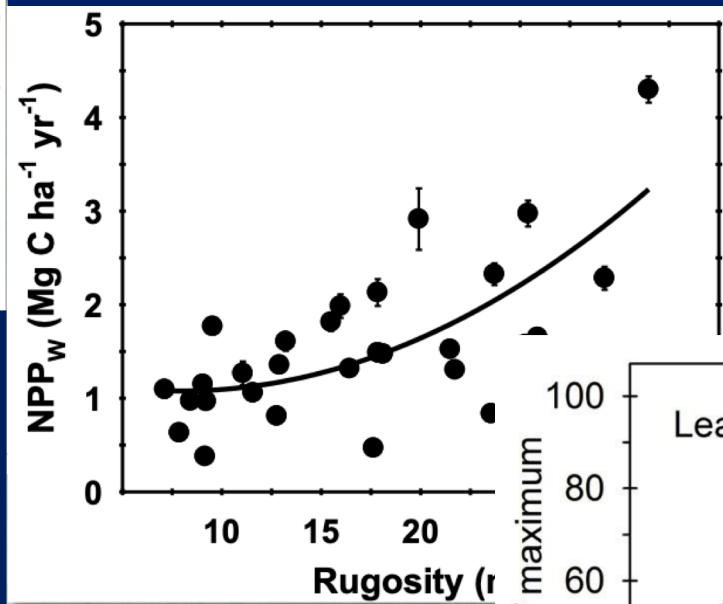
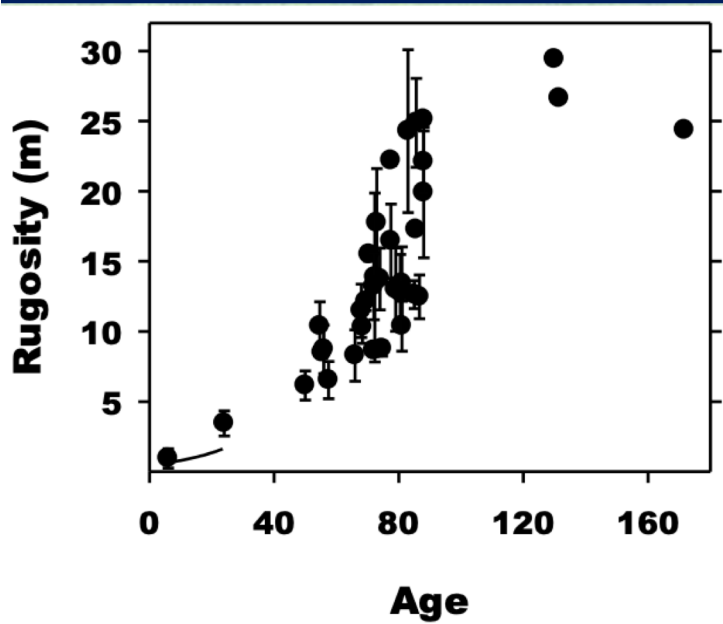


# What about the carbon cycle?

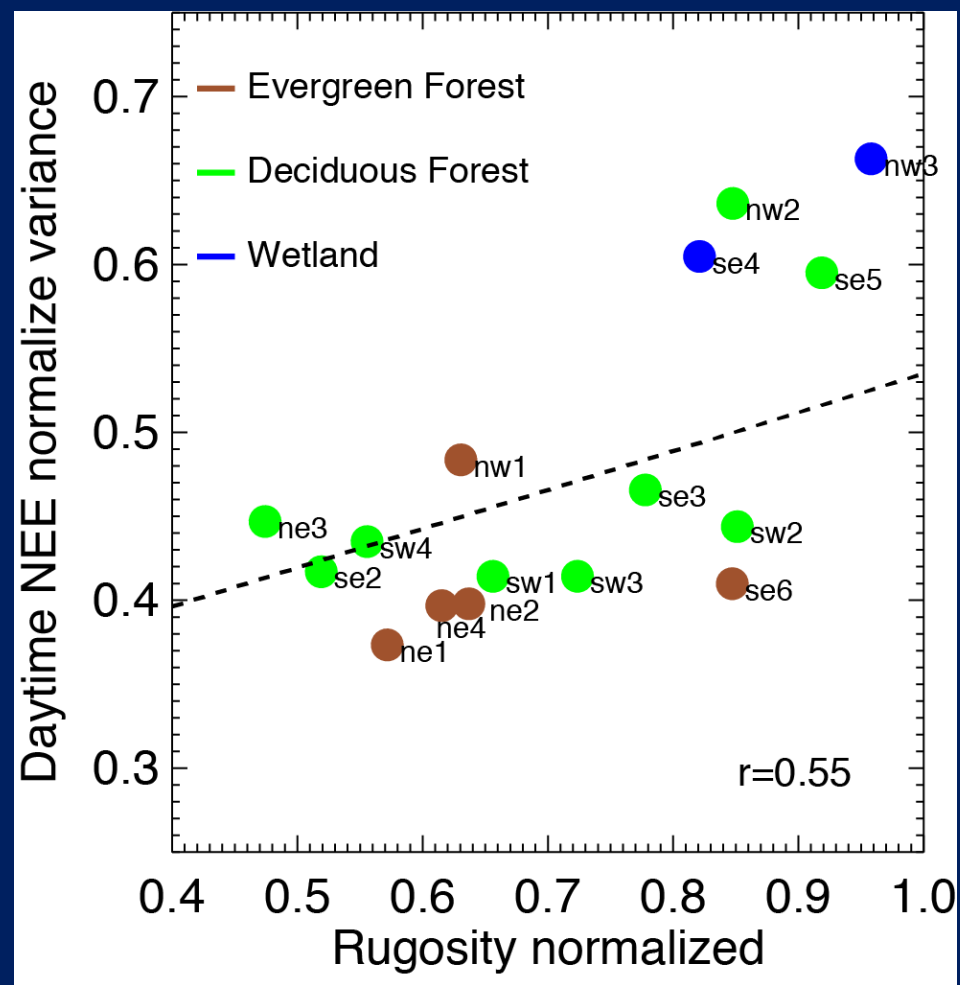
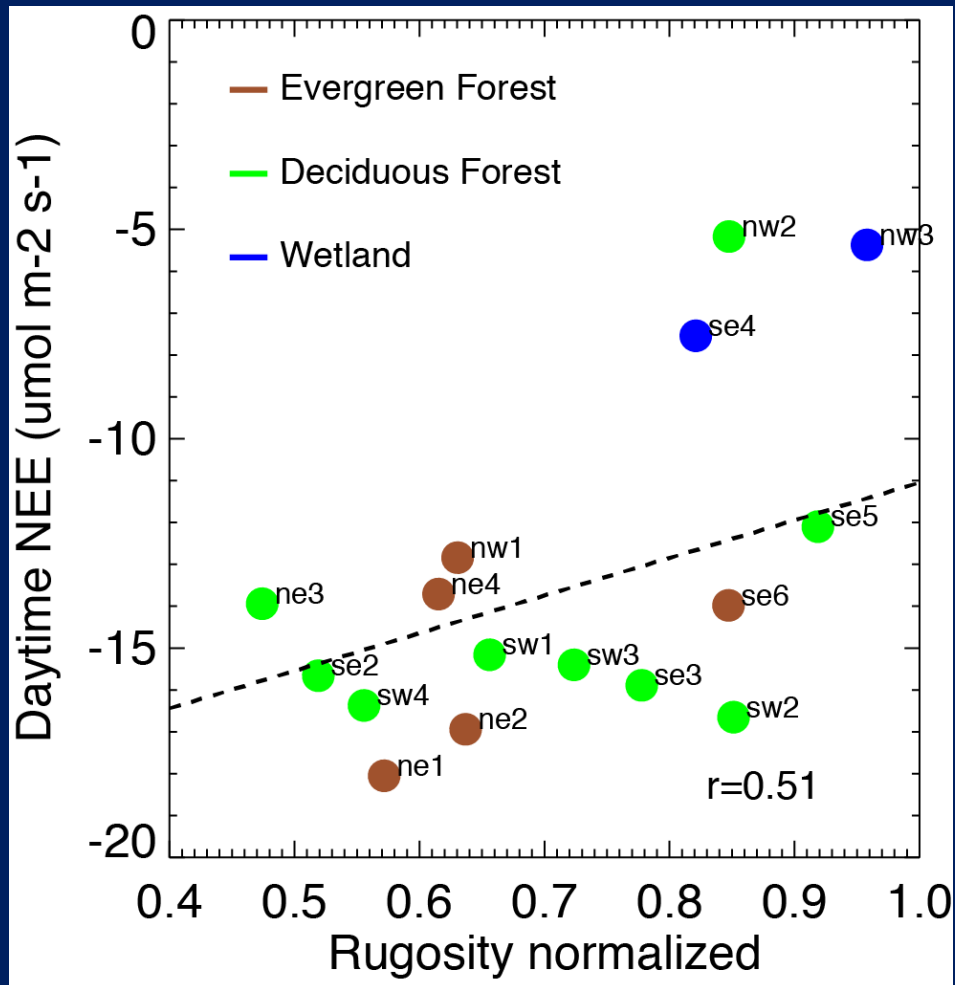


# High rates of primary production in structurally complex forests

CHRISTOPHER M. GOUGH,<sup>1,4</sup> JEFF W. ATKINS,<sup>1</sup> ROBERT T. FAHEY,<sup>2</sup> AND BRADY S. HARDIMAN<sup>3</sup>







# Forest management plays a role

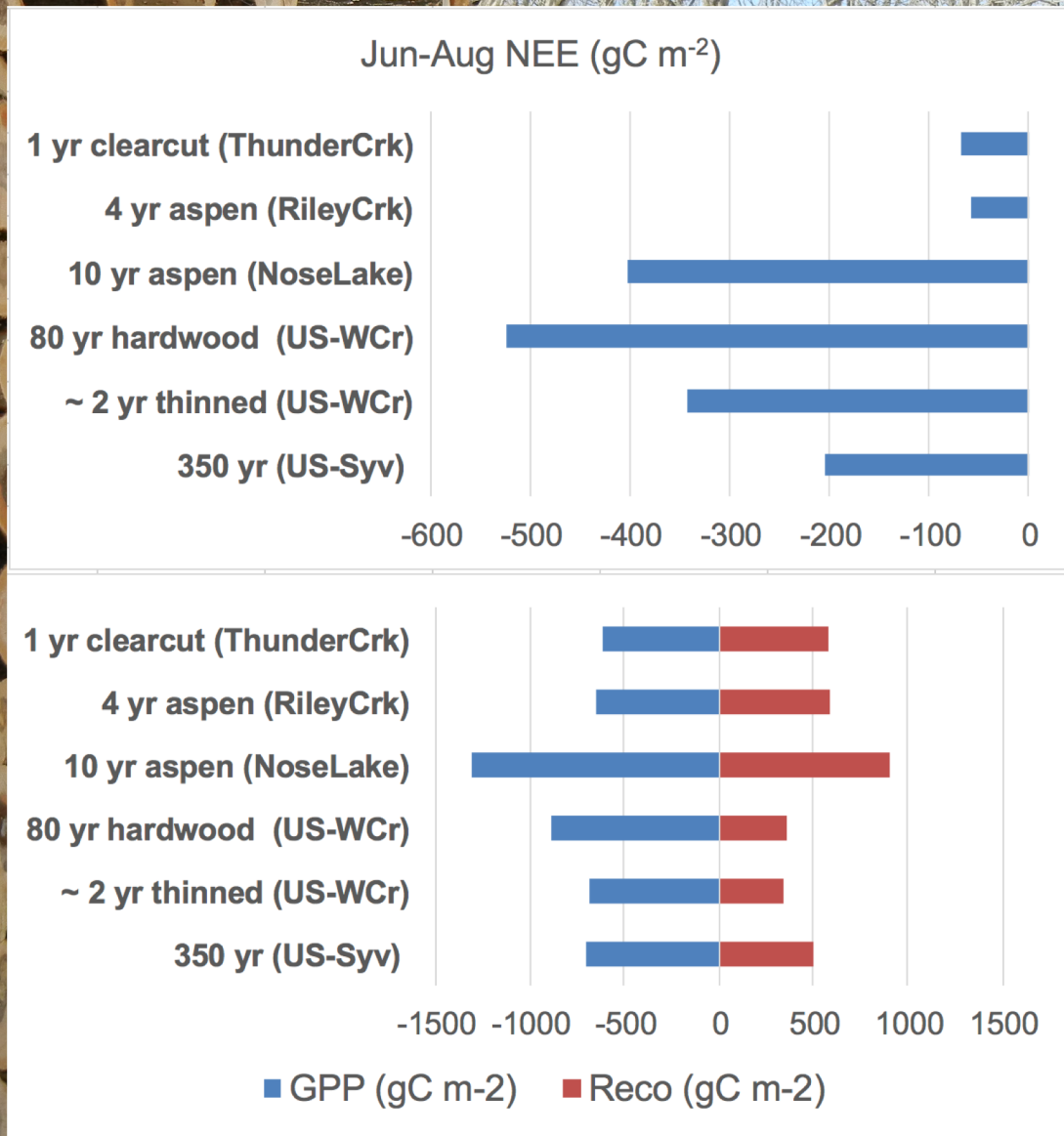
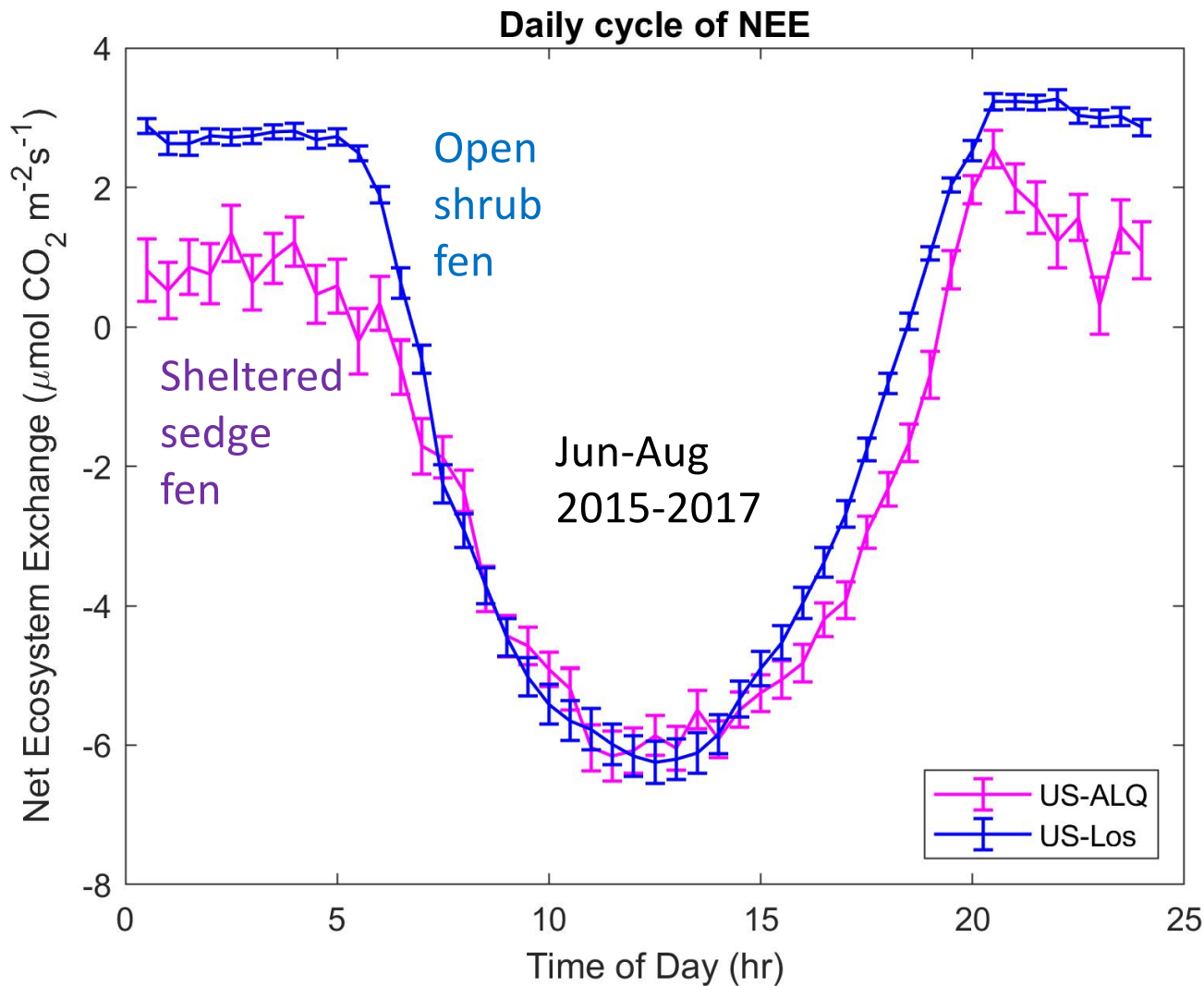


Photo: J Thom  
Figure:  
J McCarty  
A Desai



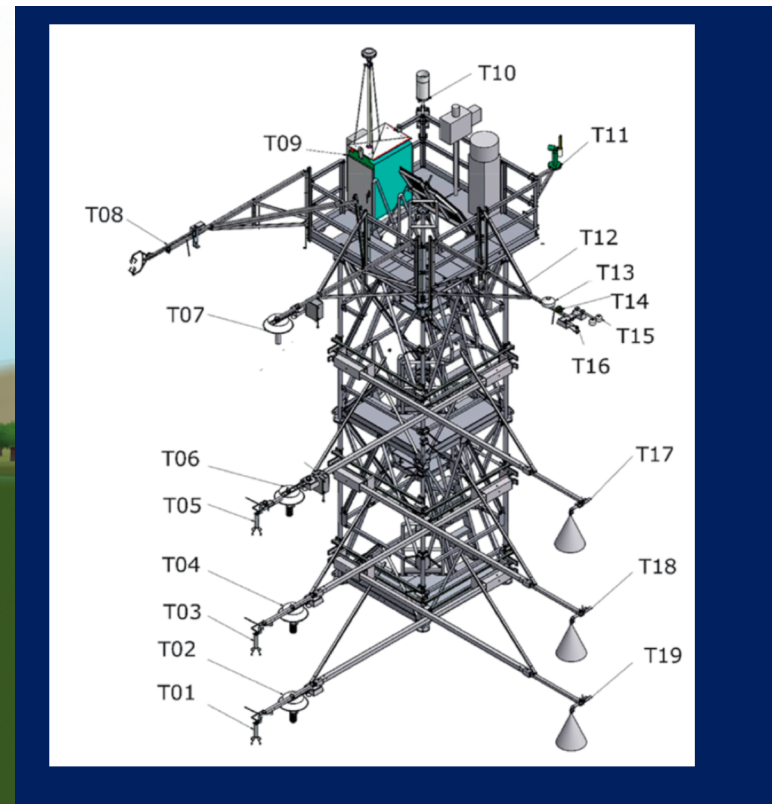
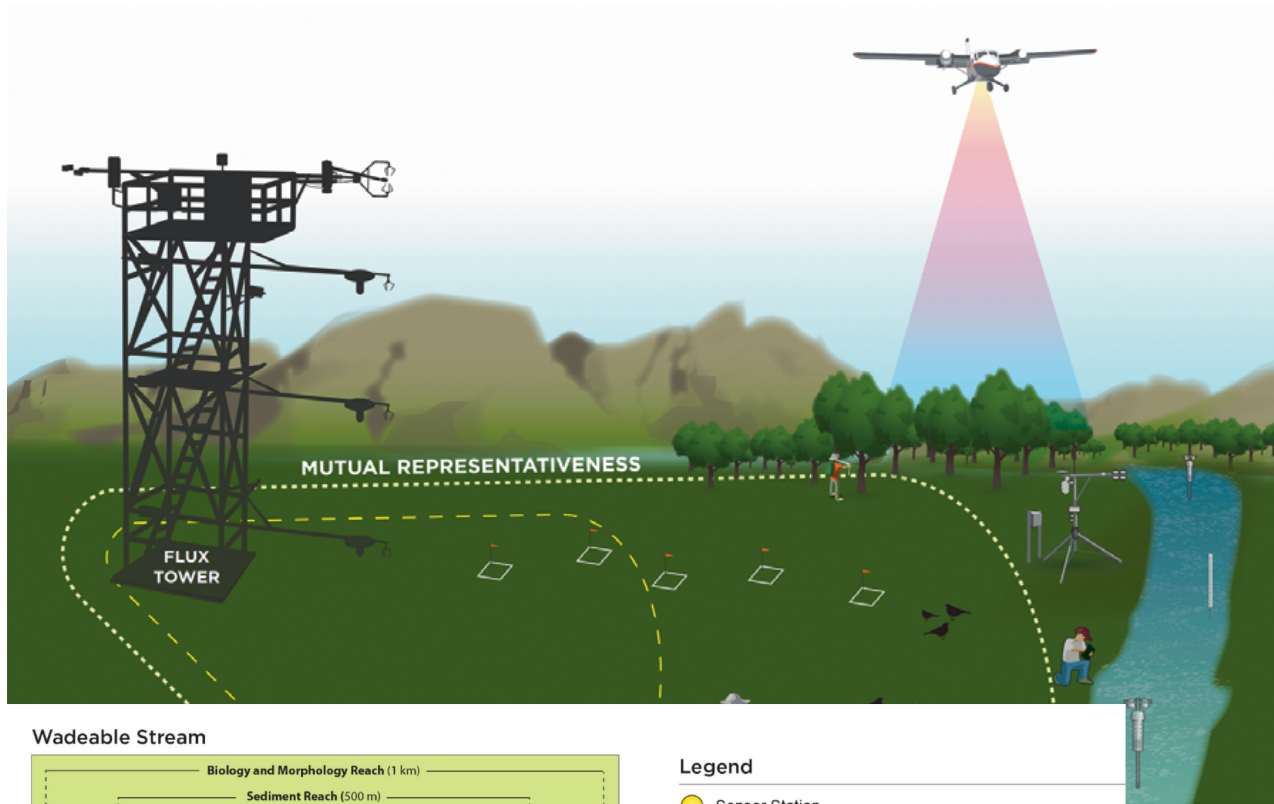
# Wetlands are another part of it



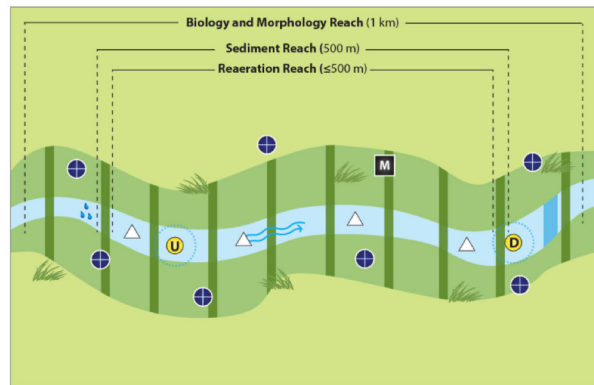
# What does it all mean?

- Energy balance closure is a symptom of eddy covariance assumptions and methods
  - It is ubiquitous
- However, it should be seen not just as a problem that needs correction, but as an opportunity to understand ecosystem and atmospheric responses
  - Wavelet based approaches and scaling can account for mesoscale dispersive fluxes and estimate true energy balance
  - Canopy complexity worsens energy balance, drives atmospheric circulations and also influences net carbon uptake, but perhaps counter to theory
- We are now using large eddy simulations and environmental response function scaling methods to develop rectified surface energy and carbon fluxes using CHEESEHEAD19 as a testbed (S. Paleri, M. Mauder, L. Wanner, S. Metzger)





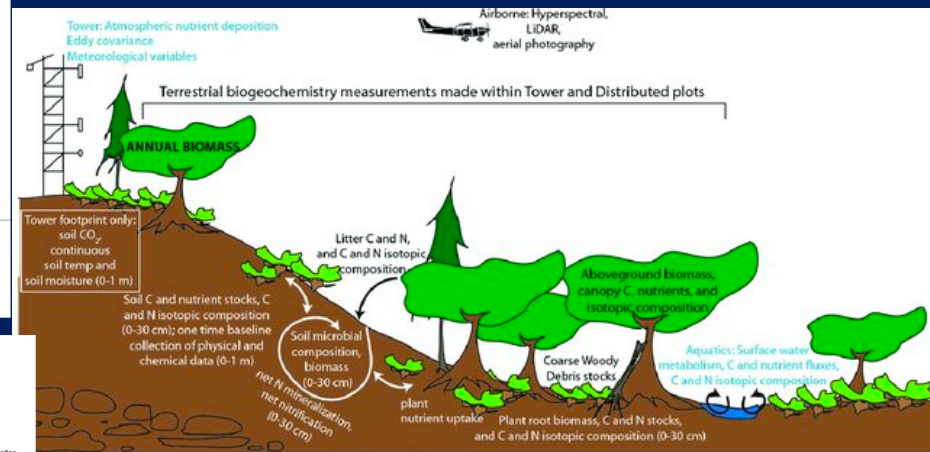
Wadeable Stream



Legend

- Sensor Station
- Water Chemistry Sampling
- ⊕ Groundwater Well
- M Meteorological Station
- Riparian Assessment
- 💧 Reaeration Drip
- △ Reaeration Sampling

Note: Fish, sediments, macroinvertebrates, plants, and macroalgae are sampled based on site-specific habitats and are not identified in the figures.



> 62,000 samples

> 400 taxa



Distribution of samples by collection type.



Distribution of samples by top 5 determined taxa.

A landscape photograph showing a wide view of a forested valley. The sky is filled with large, white, fluffy clouds. A faint rainbow is visible in the upper left portion of the sky. The foreground shows a dense forest of green trees, and the background features rolling hills under a bright blue sky.

# Thank you!

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Photo: A. Desai