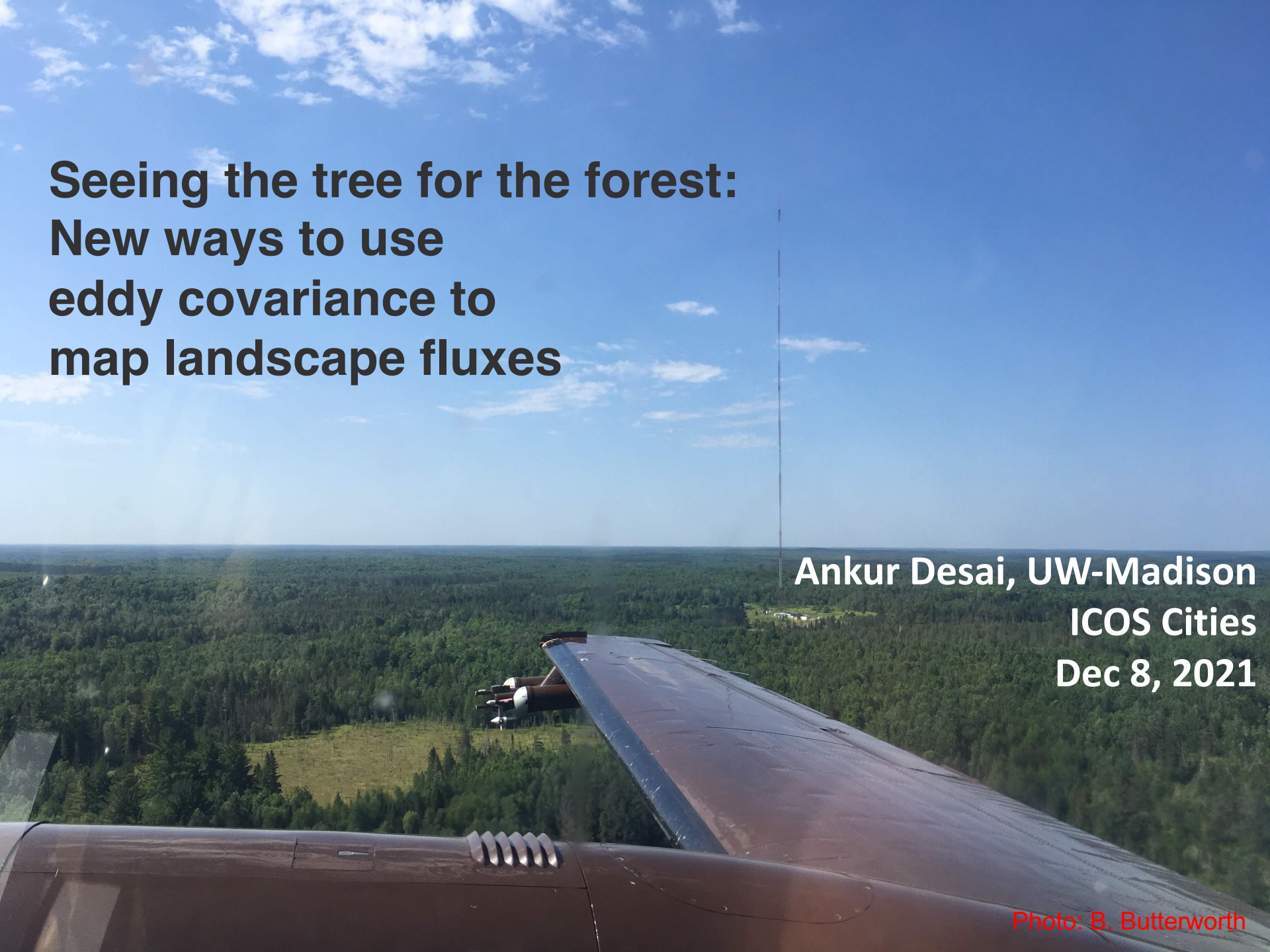


Seeing the tree for the forest: New ways to use eddy covariance to map landscape fluxes

Ankur Desai, UW-Madison

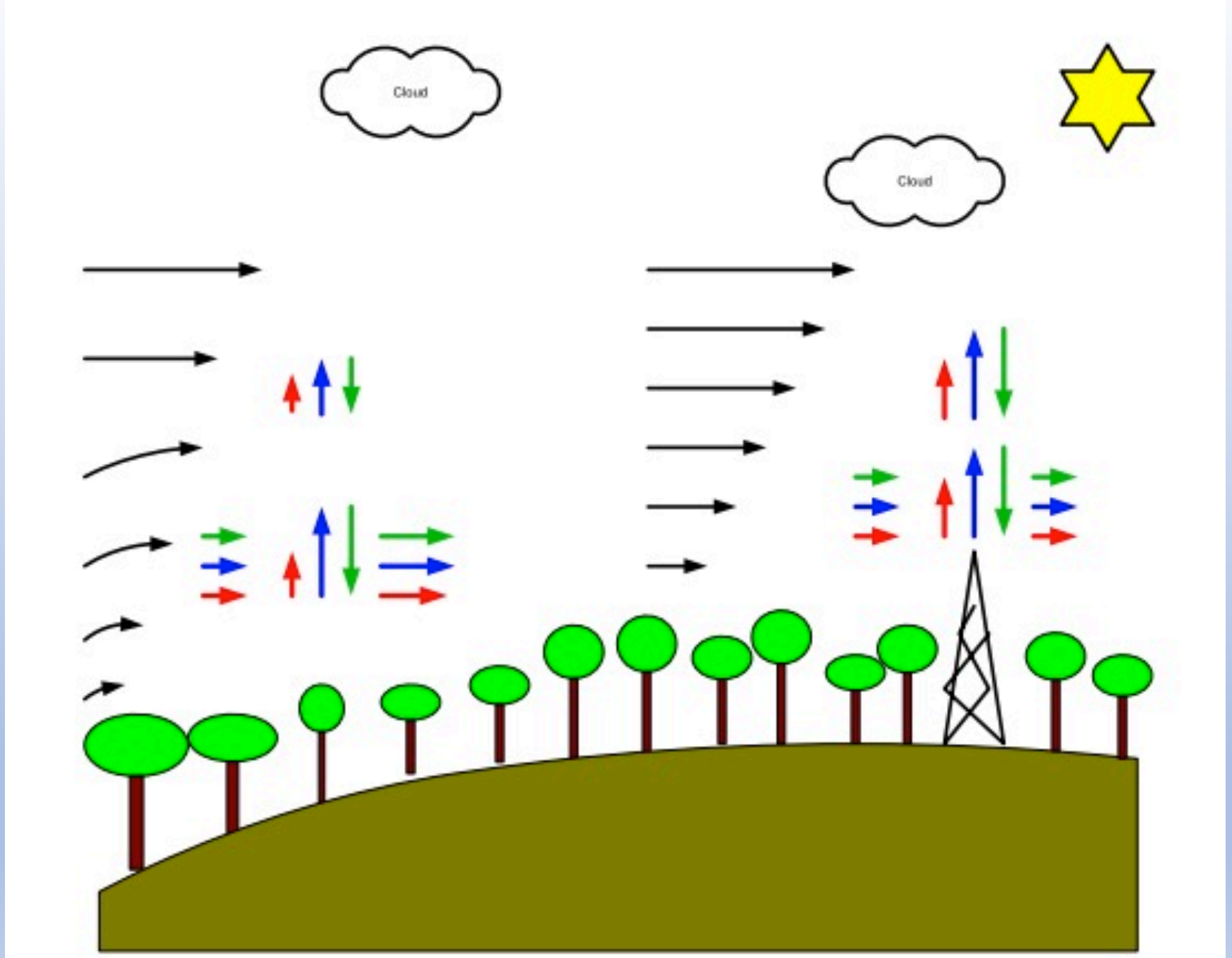
ICOS Cities

Dec 8, 2021

Photo: B. Butterworth

Take home messages

- I do not work in urban systems, but have operated very tall tower eddy covariance and atmospheric observations for a long-time
  - I'm also involved in providing science advice to ICOS and am invested in seeing it succeed in this area
- Co-location of boundary-layer, atmospheric mole fraction, and ecosystem flux measurements affords opportunities for robust estimation of greenhouse gas sources and sinks
- Landscape heterogeneity is a challenge for traditional eddy covariance but not impossible to solve
- Tall tower eddy covariance does require additional considerations for quality control



D. Baldocchi

Jeff Miller, UW

Jeff Miller, UW

A. Desai

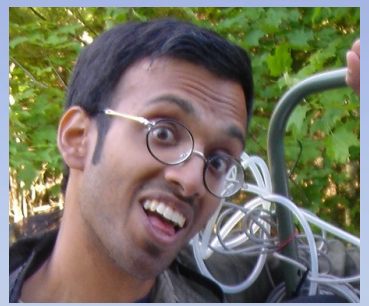
Peter Bakwin
NOAA (Colorado)

Ken Davis
Penn State

Arlyn Andrews
NOAA (Colorado)

Jon Kofler
NOAA (Colorado)

Bruce Cook
NASA Goddard



Ankur Desai
UW-Madison
AOS

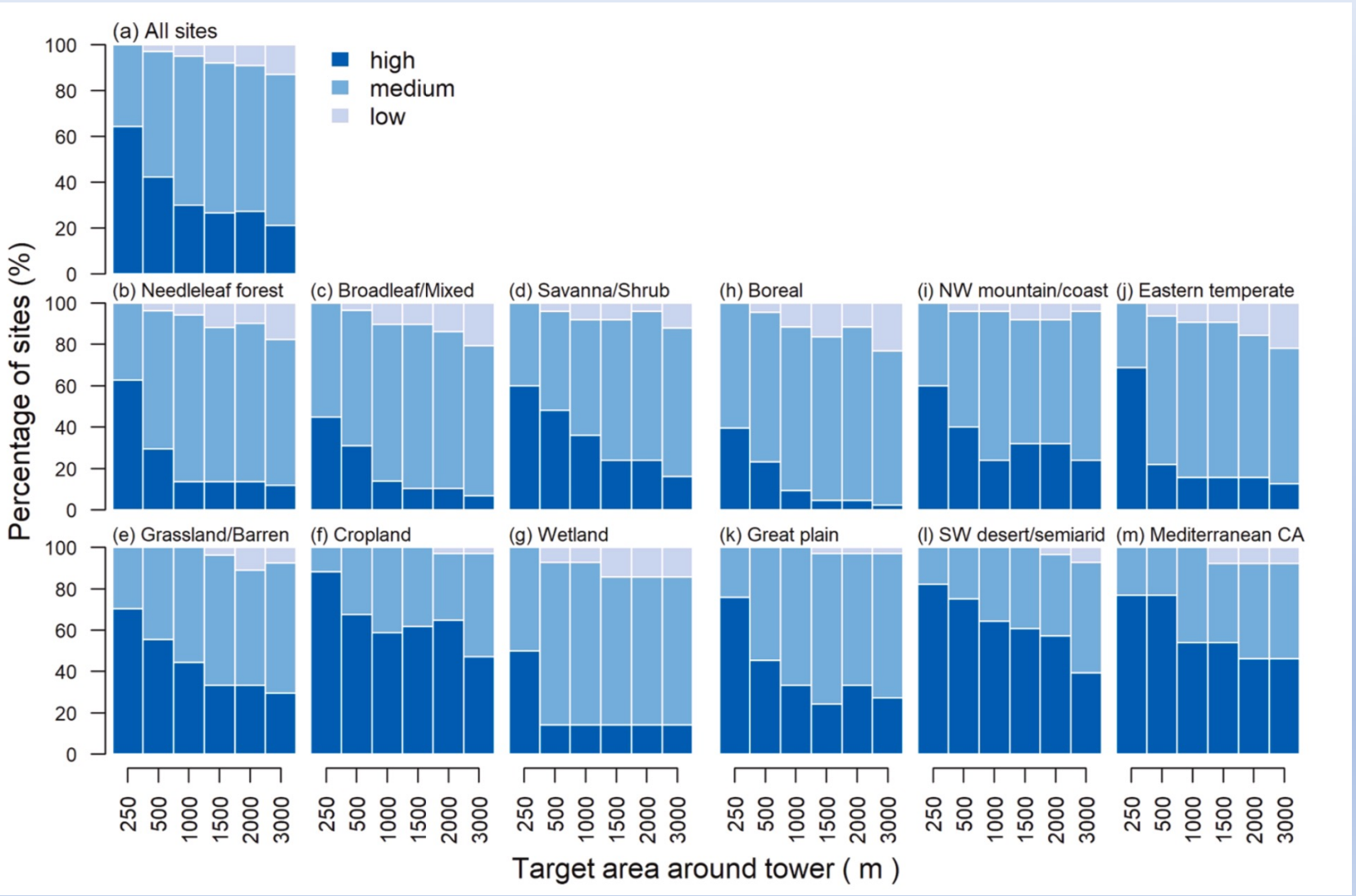
Jonathan Thom
UW-Madison
SSEC

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

-Marcel Proust

Representativeness of Eddy-Covariance flux footprints for areas surrounding AmeriFlux sites

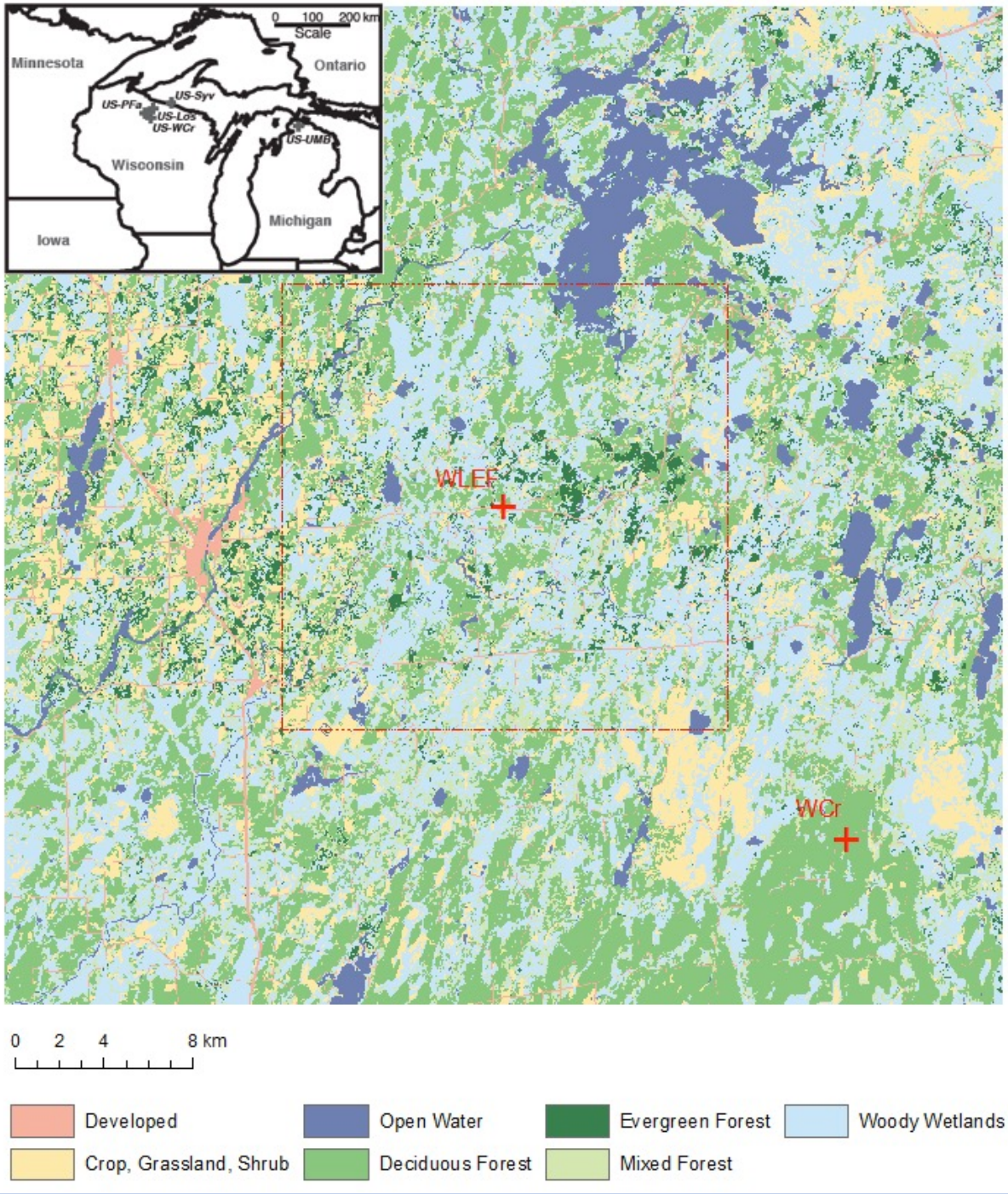
Chu et al., AgForMet, 2021



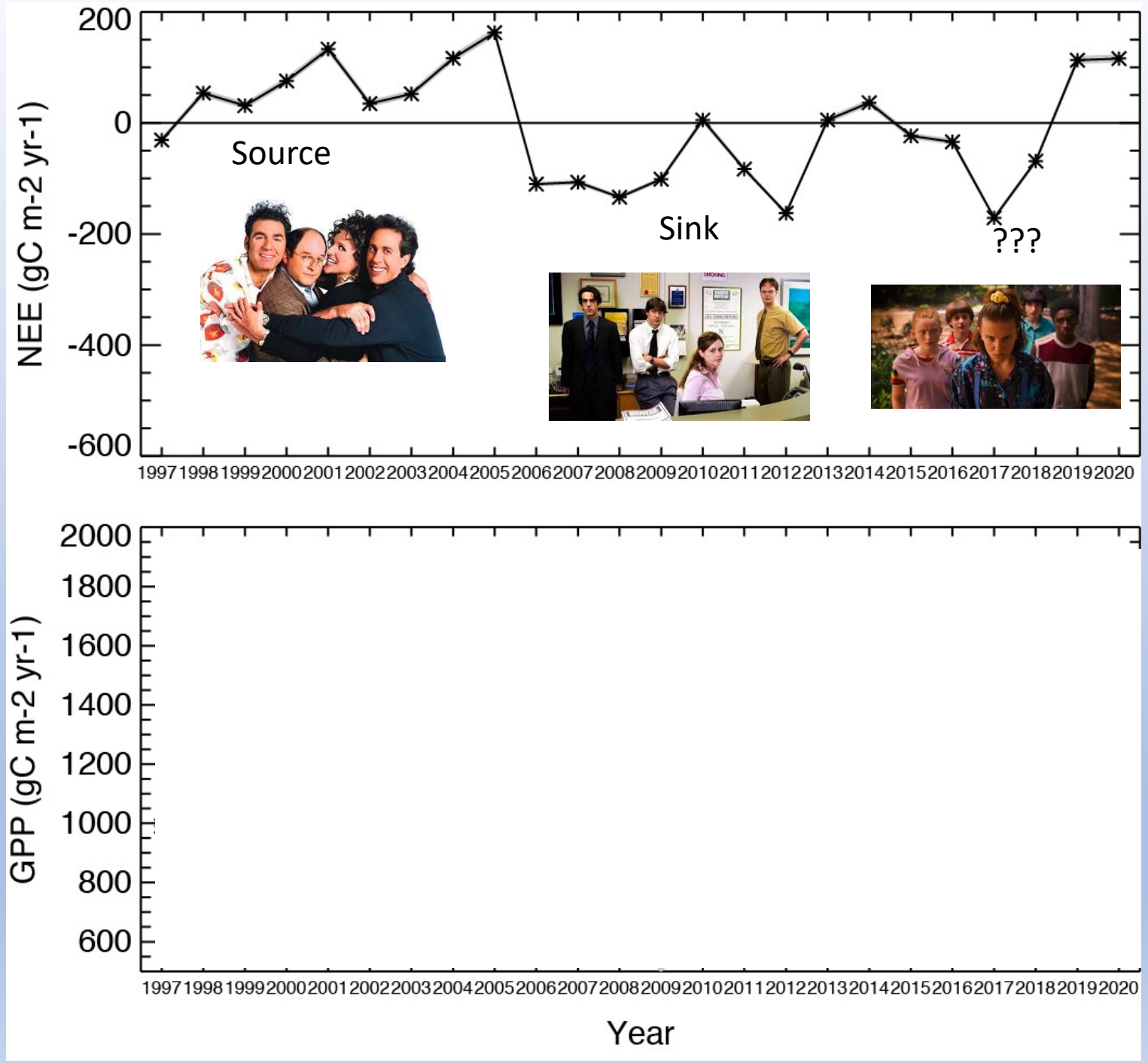
How do we deal with this?

- Ignore it
- Build a lot of towers
  - Combine with tall tower boundary-layer observations
- Do something different with flux towers
  - Spatial and temporal resolved fluxes
  - Environmental Response Functions
- Some challenges with very tall towers
  - Storage flux, energy balance, footprints
- Final thoughts

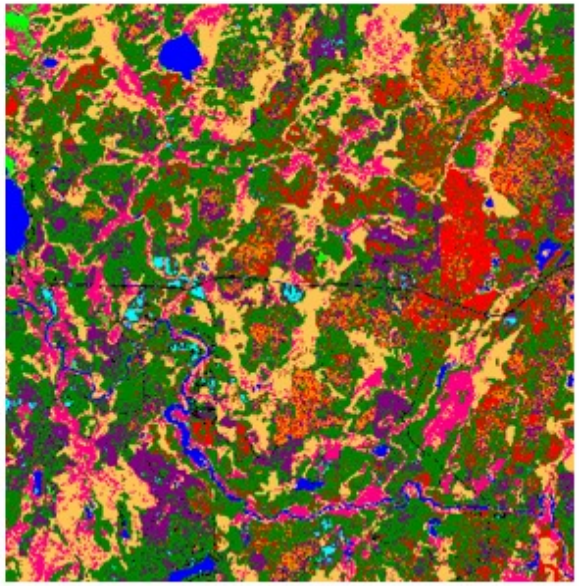
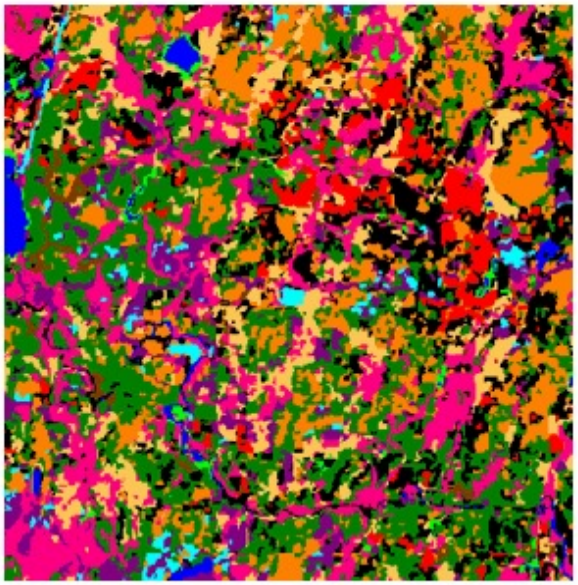
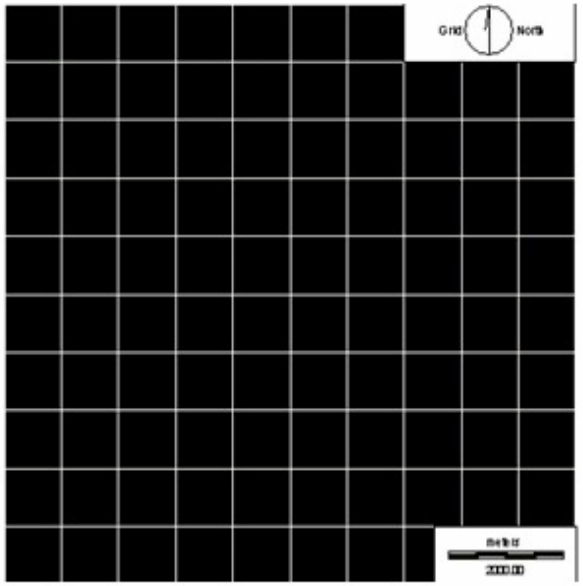
Ignore it!

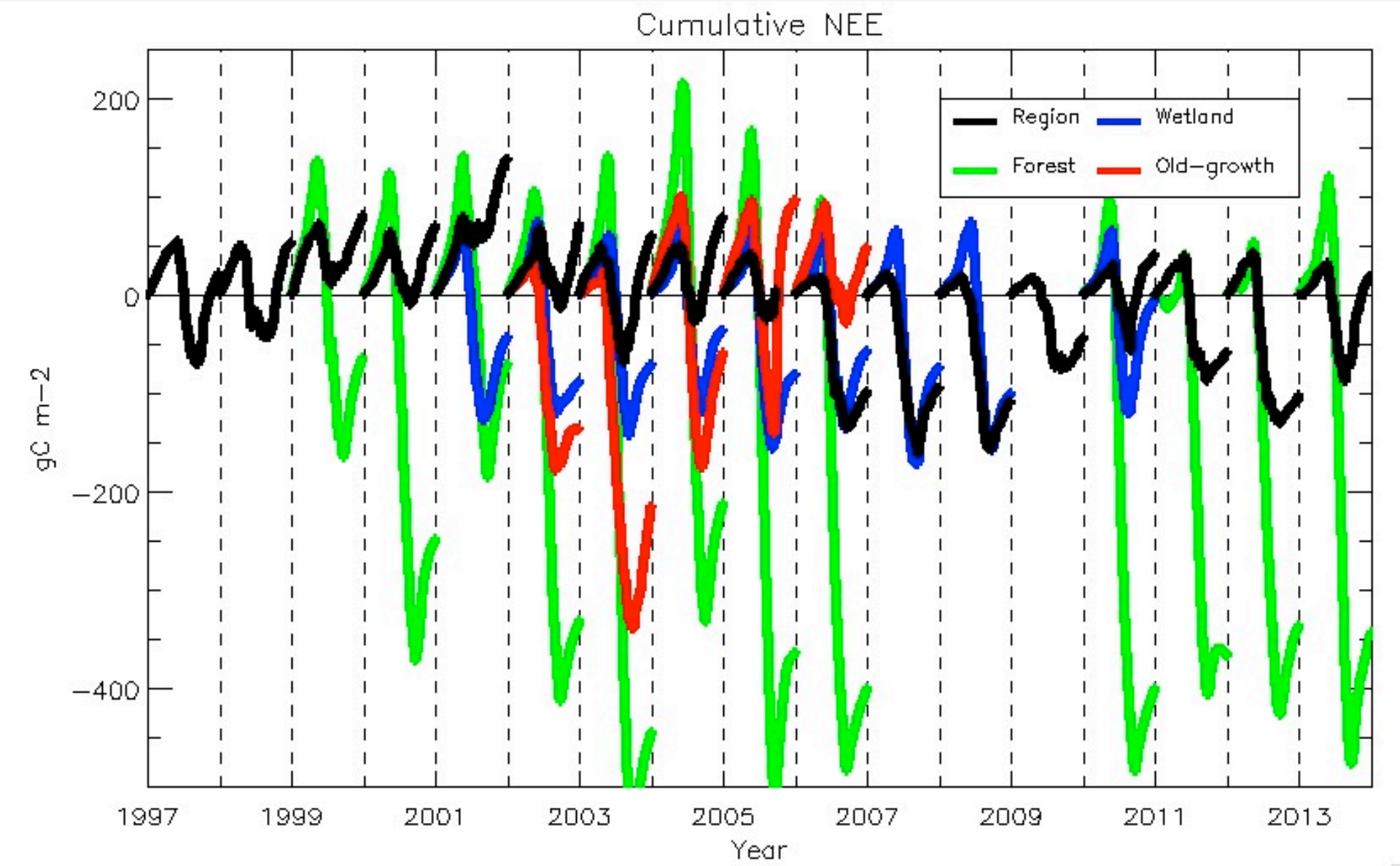

0 100 200 km
Scale
Minnesota
Ontario
US-Syv
US-PFa
US-Los
US-WCr
US-UMB
Wisconsin
Michigan
Iowa
WLEF
WCr
0 2 4 8 km
Developed
Open Water
Evergreen Forest
Woody Wetlands
Crop, Grassland, Shrub
Deciduous Forest
Mixed Forest

Ameriflux US-PFA
NOAA GHG Tall Towers (LEF)
TCCON (Park Falls)
447 m tall
Park Falls, Wisconsin

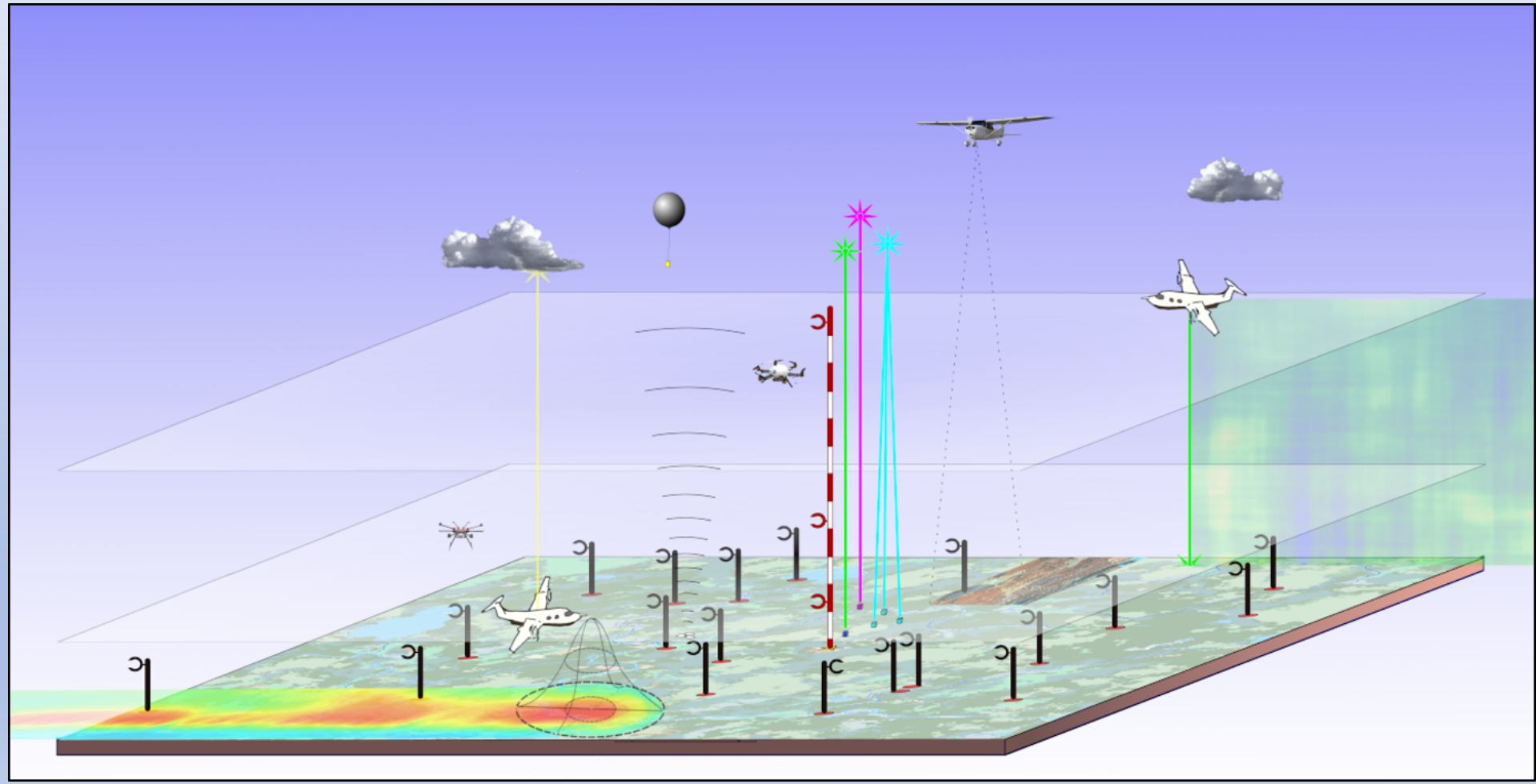

NEE (gC m-2 yr-1)
200
0
-200
-400
-600
Source
Sink
???
1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
GPP (gC m-2 yr-1)
2000
1800
1600
1400
1200
1000
800
600
Year

Complex Regions: 1+1≠2

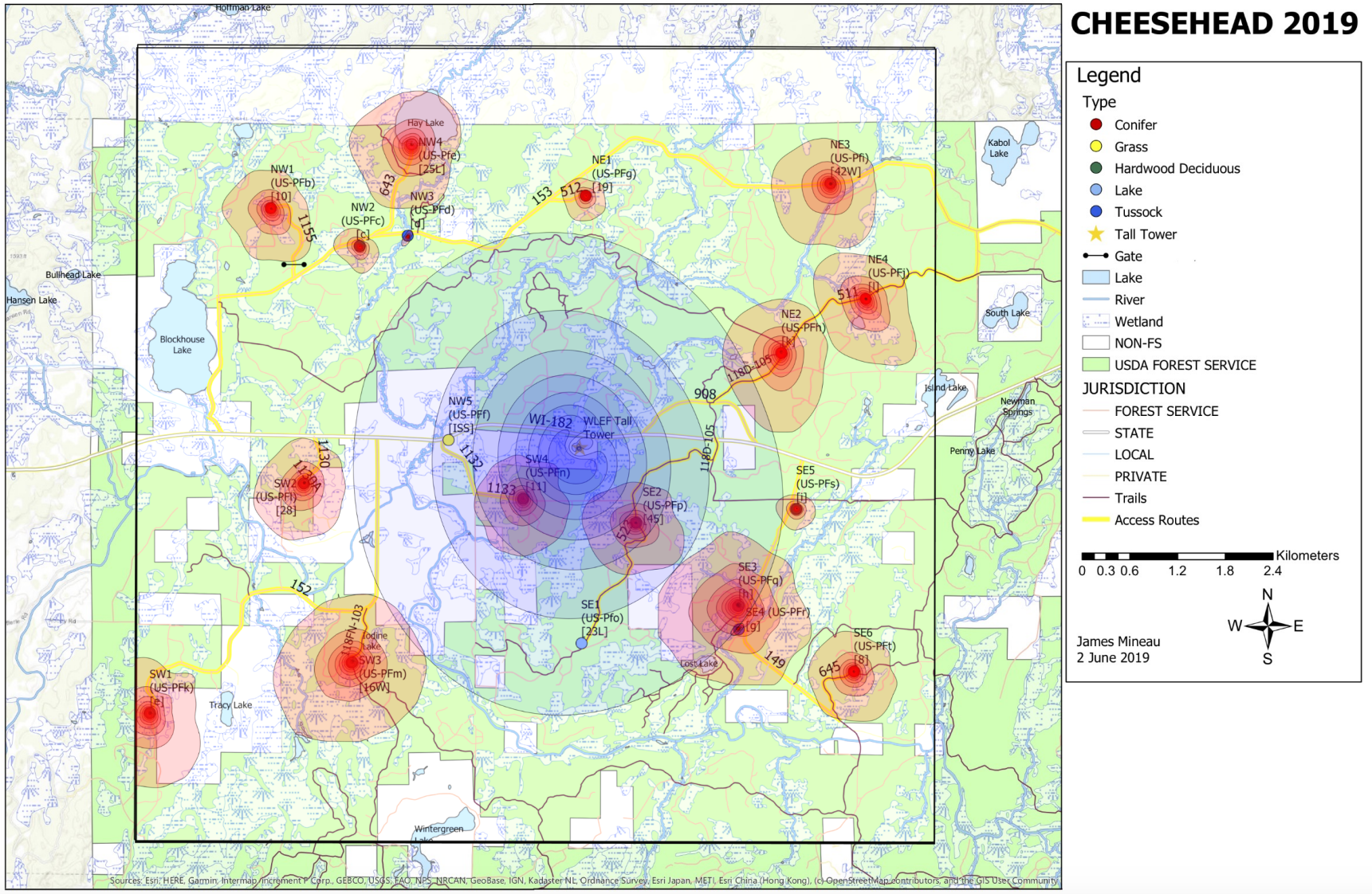
a) IKONOS.	b) WISCLAND.	c) MODIS-UMD and IGBP.
		
— Mixed Forest 13.3% Upland Conifer 34.8% Aspen-Birch 5.7% Upland Hardwood 12.0% Upland Opening/Shrub 0.9% Grassland 17.8% Lowland Conifer 0.7% Lowland Deciduous 10.6% Lowland Shrub 0.6% Wet Meadow 2.6% Open Water 1.0% Road	7.1% Mixed Forest 13.0% Upland Conifer 25.3% Aspen-Birch 14.6% Upland Hardwood 6.8% Upland Opening/Shrub 1.8% Grassland 10.7% Lowland Conifer 1.9% Lowland Deciduous 16.3% Lowland Shrub 1.0% Wet Meadow 1.6% Open Water — Road	100% Mixed Forest


Cumulative NEE
Region
Wetland
Forest
Old−growth
200
0
−200
−400
gC m−2
1997
1999
2001
2003
2005
2007
2009
2011
2013
Year

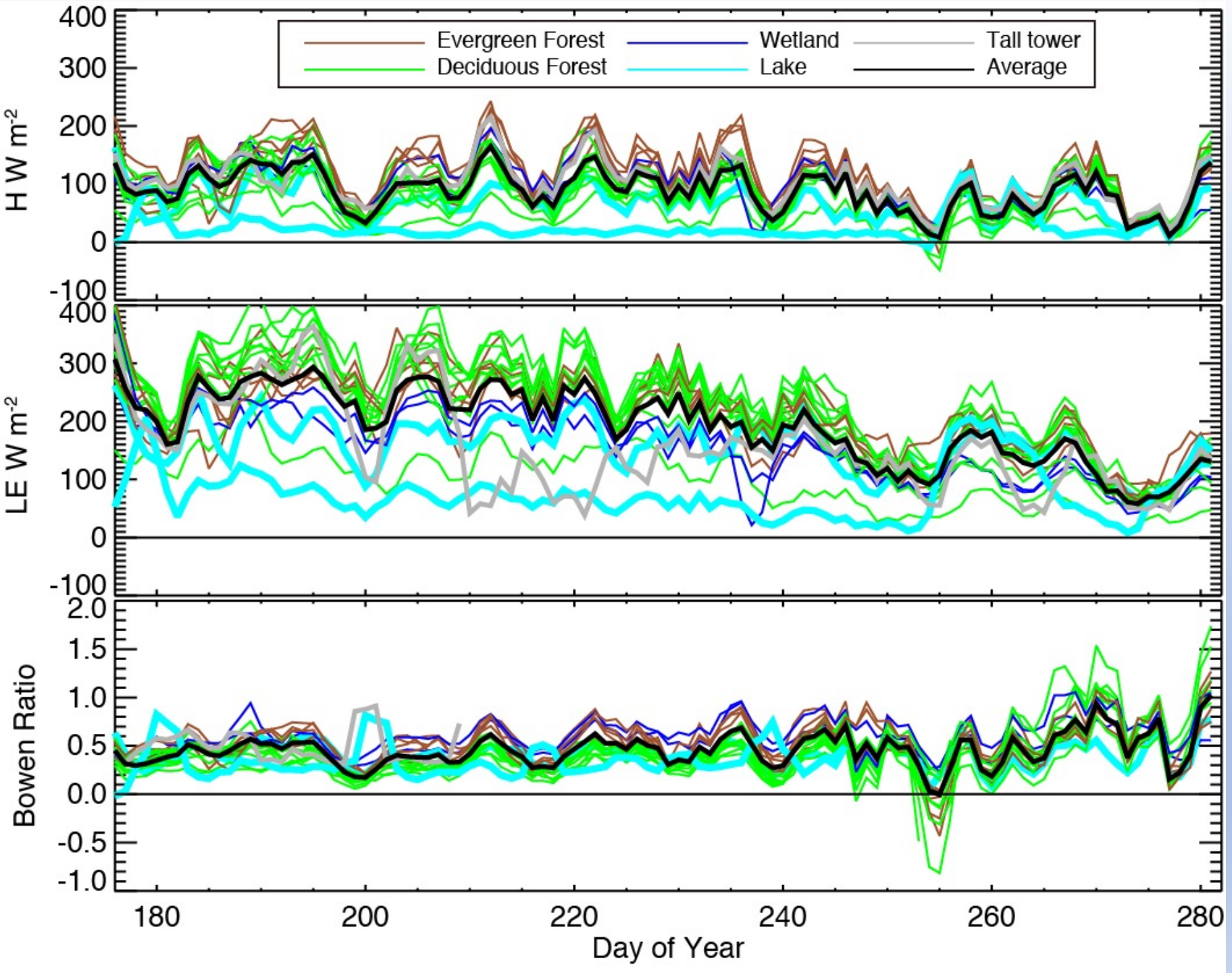
What if we build a lot of towers?

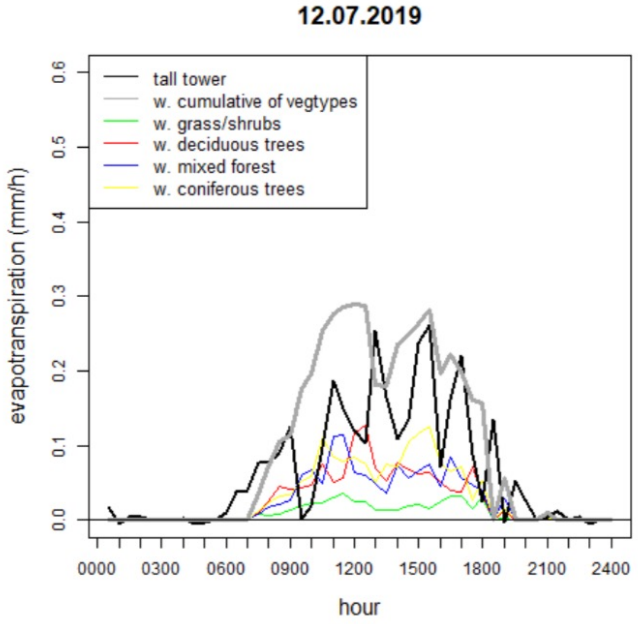


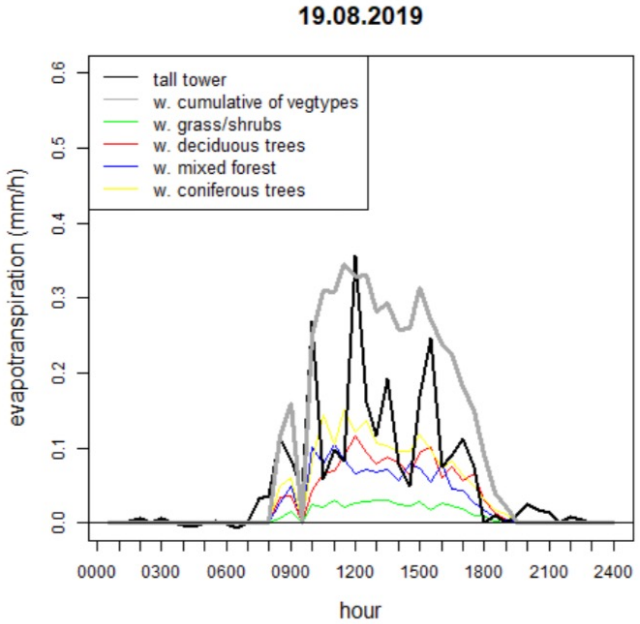
Butterworth *et al*., 2020, BAMS

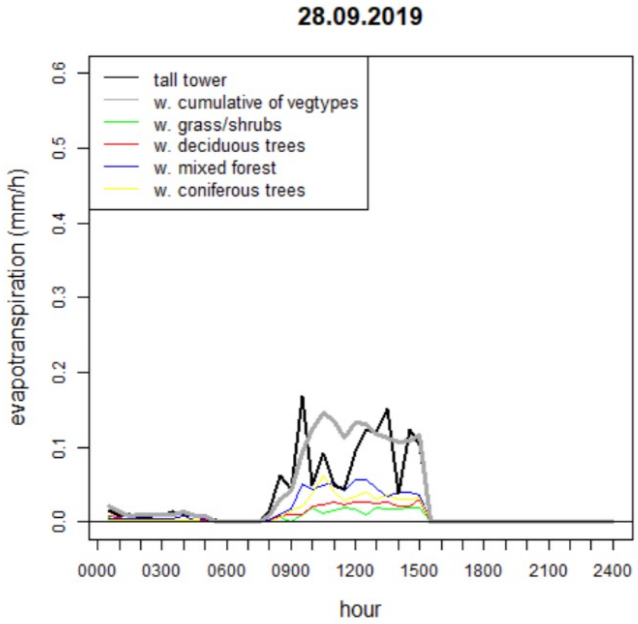


J. Mineau / B. Butterworth

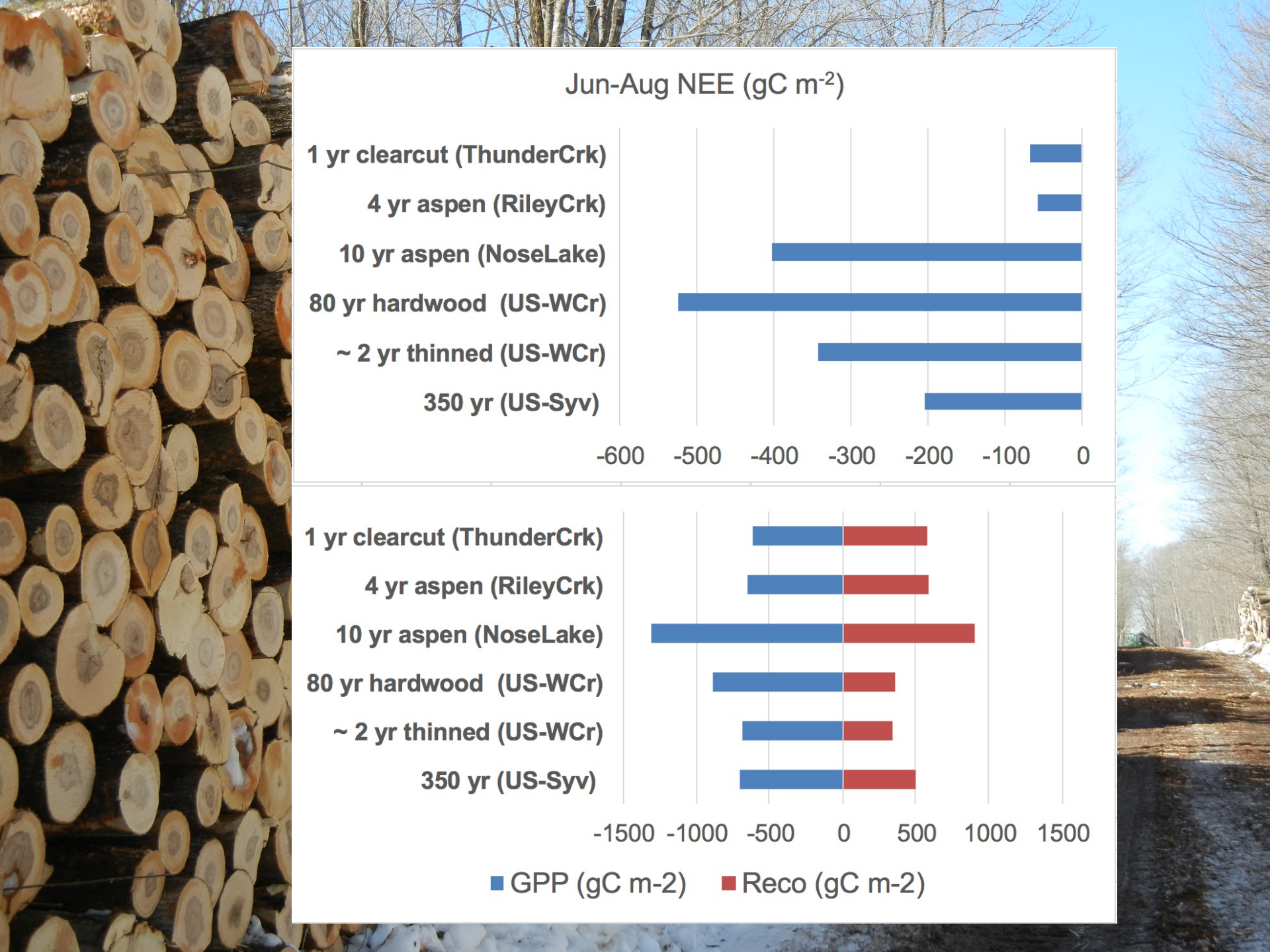

Evergreen Forest
Deciduous Forest
Wetland
Lake
Tall tower
Average
H W m-2
LE W m-2
Bowen Ratio
Day of Year
400
300
200
100
0
-100
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
180
200
220
240
260
280





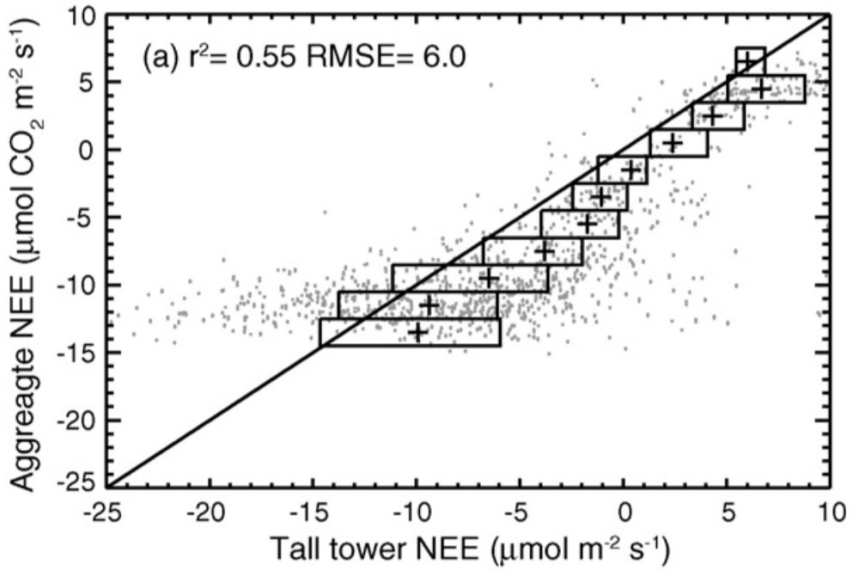


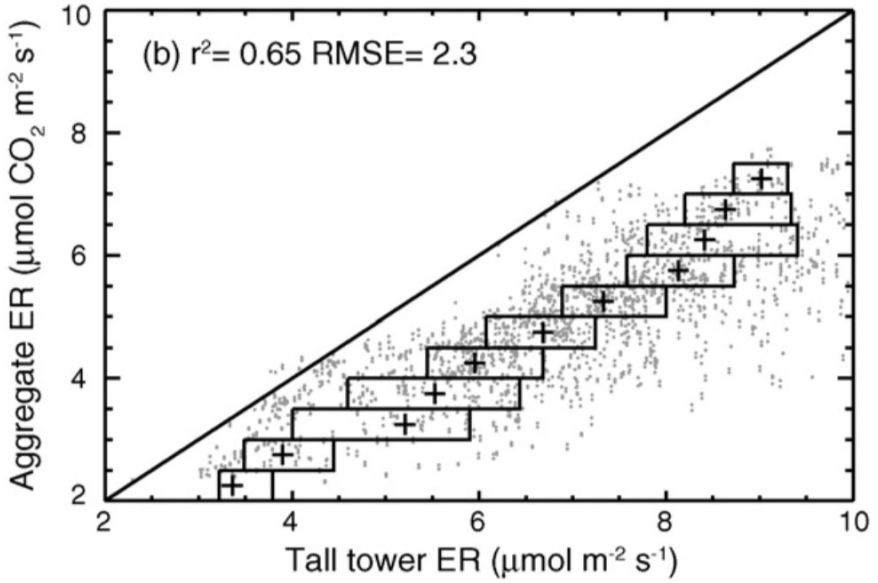
Christine Mihalyfi-Dean, Luise Wanner


Jun-Aug NEE (gC m-2)
1 yr clearcut (ThunderCrk)
4 yr aspen (RileyCrk)
10 yr aspen (NoseLake)
80 yr hardwood (US-WCr)
~ 2 yr thinned (US-WCr)
350 yr (US-Syv)
-600
-500
-400
-300
-200
-100
0
1 yr clearcut (ThunderCrk)
4 yr aspen (RileyCrk)
10 yr aspen (NoseLake)
80 yr hardwood (US-WCr)
~ 2 yr thinned (US-WCr)
350 yr (US-Syv)
-1500
-1000
-500
0
500
1000
1500
GPP (gC m-2)
Reco (gC m-2)

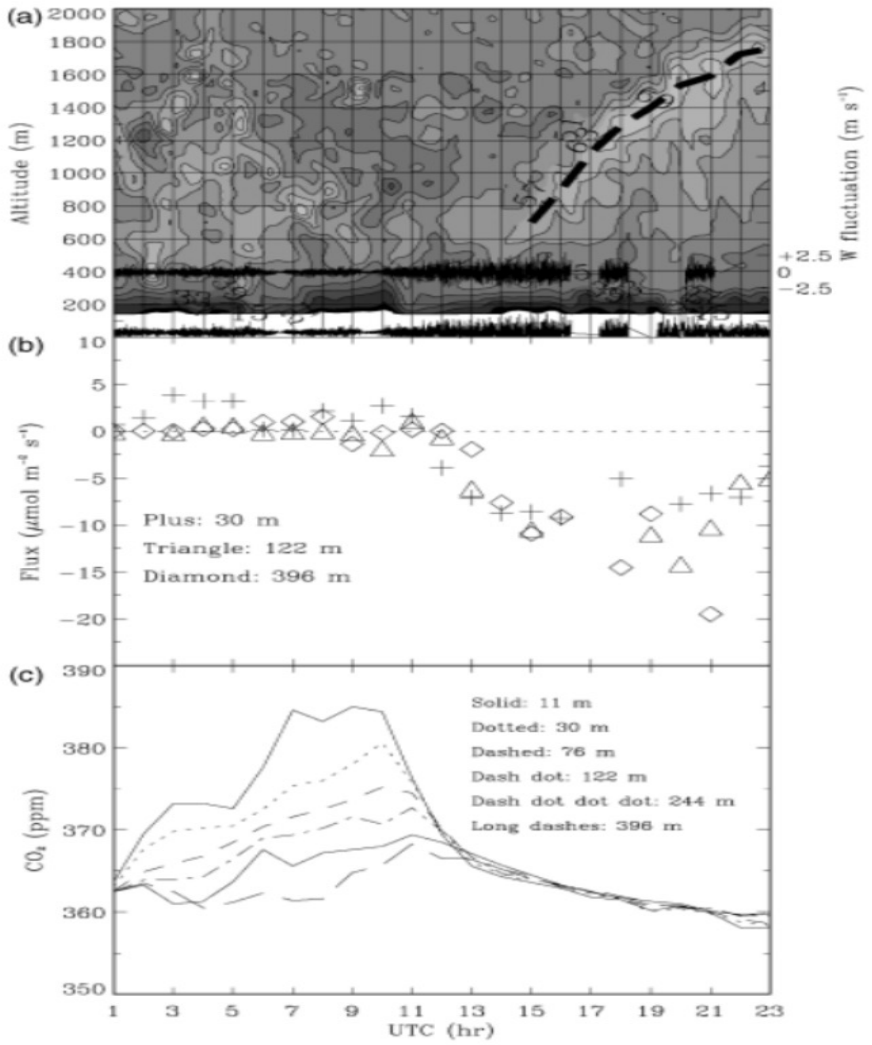
Influence of vegetation and seasonal forcing on carbon dioxide fluxes across the Upper Midwest, USA: Implications for regional scaling

Ankur R. Desai [a,*], *Asko Noormets* [b], *Paul V. Bolstad* [c], *Jiquan Chen* [d], *Bruce D. Cook* [c], *Kenneth J. Davis* [e], *Eugenie S. Euskirchen* [f], *Christopher Gough* [g], *Jonathan G. Martin* [h], *Daniel M. Ricciuto* [i], *Hans Peter Schmid* [j], *Jianwu Tang* [k], *Weiguo Wang* [l]





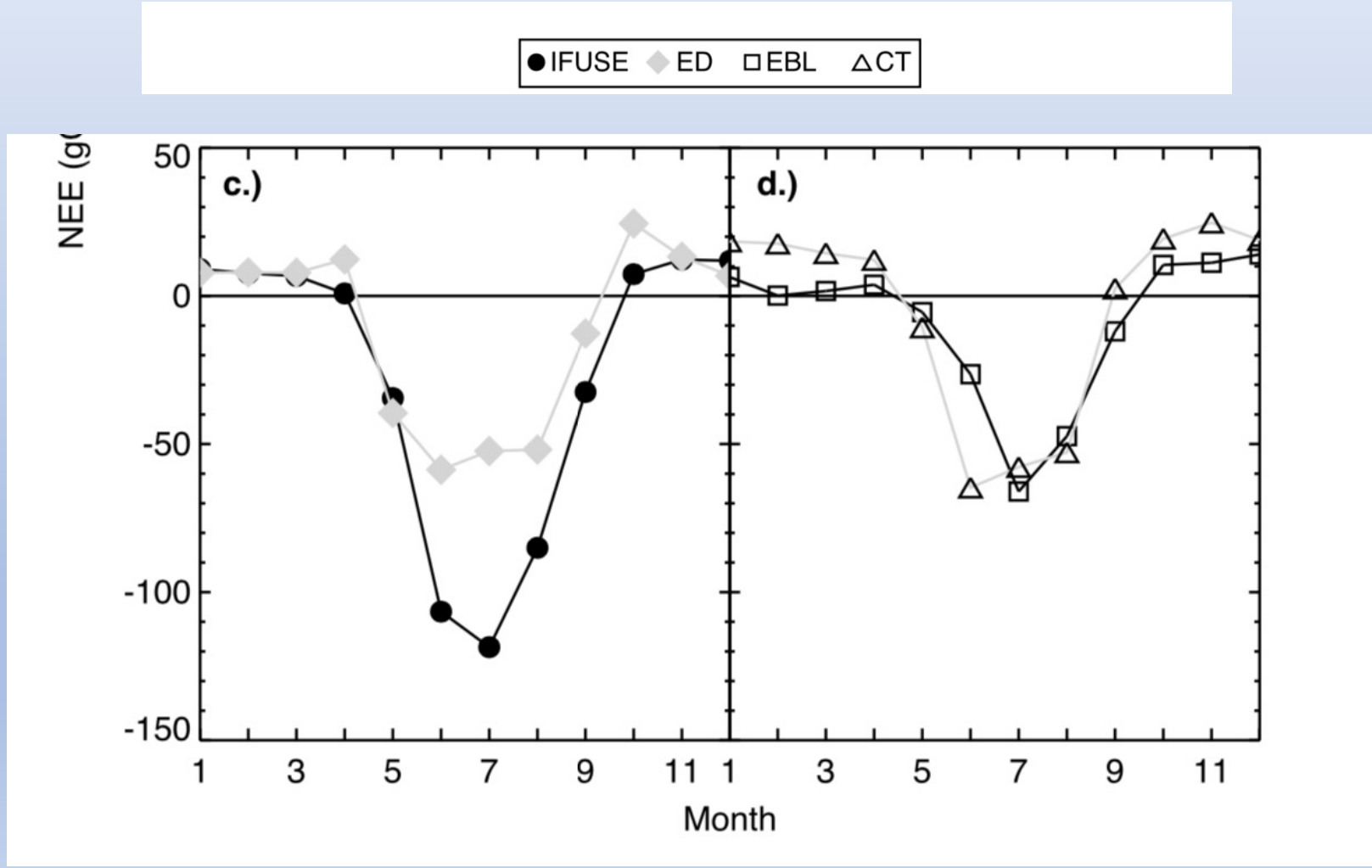
But tall towers can do more!

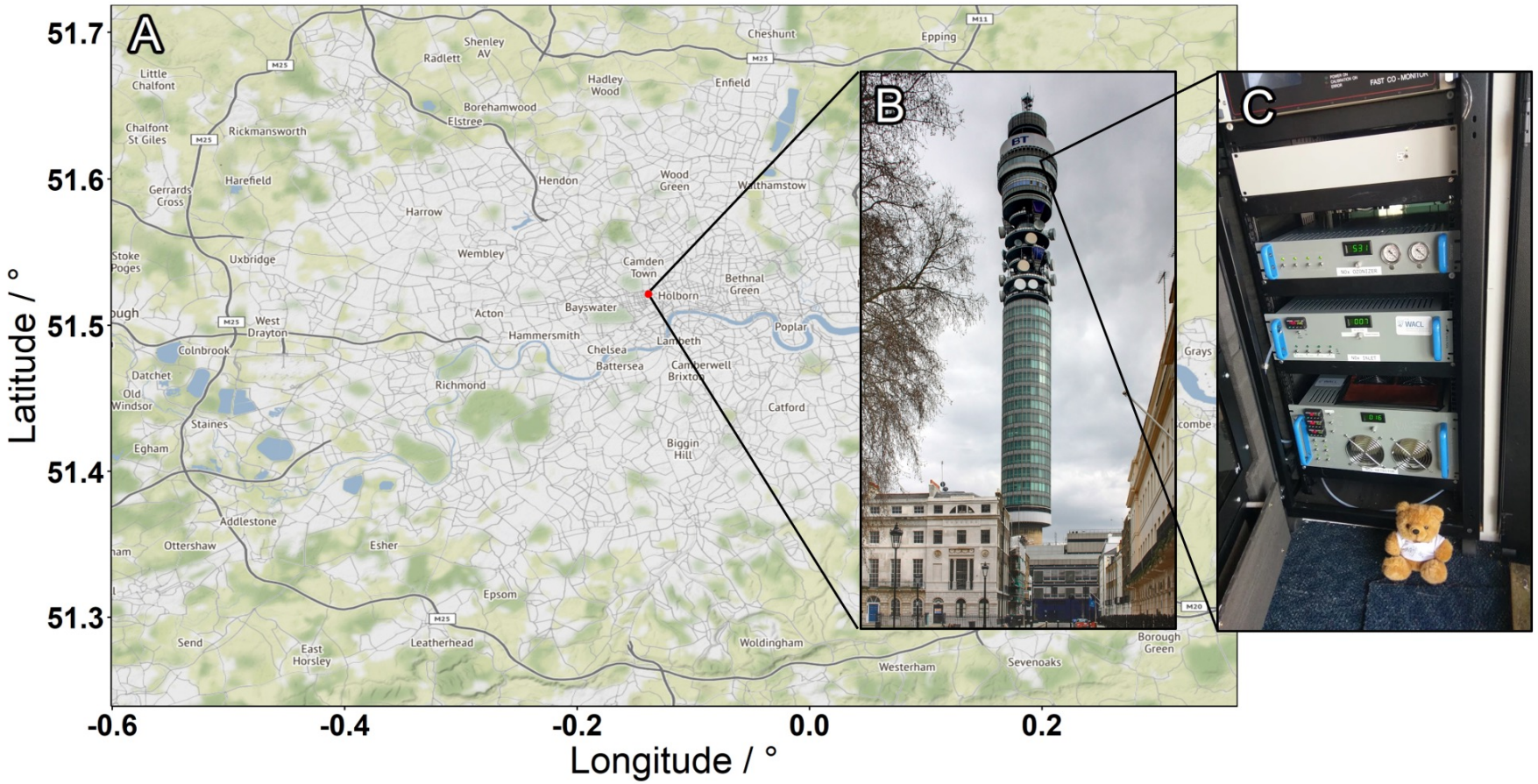


Davis et al., 2003

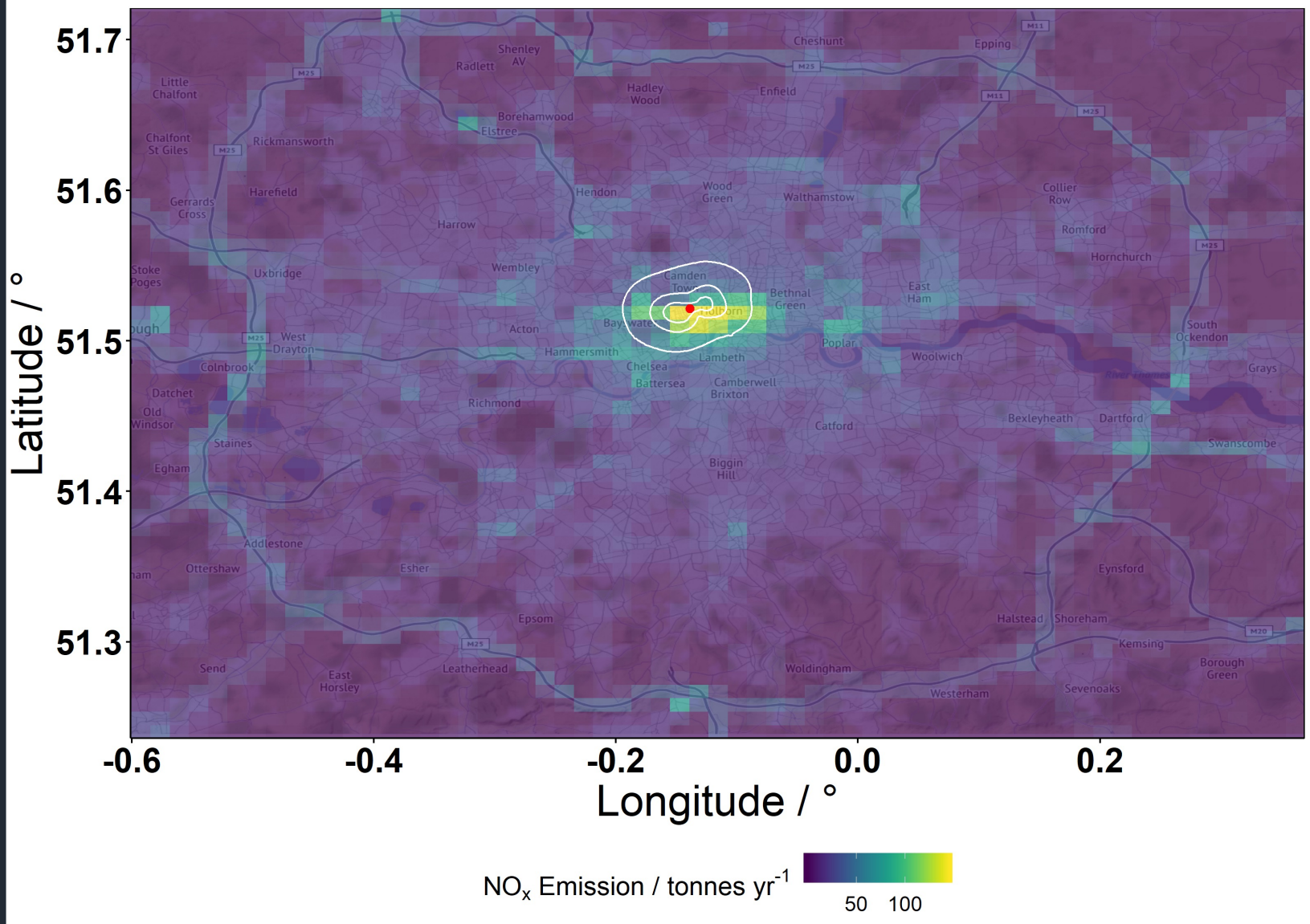
Climatic controls of interannual variability in regional carbon fluxes from top-down and bottom-up perspectives

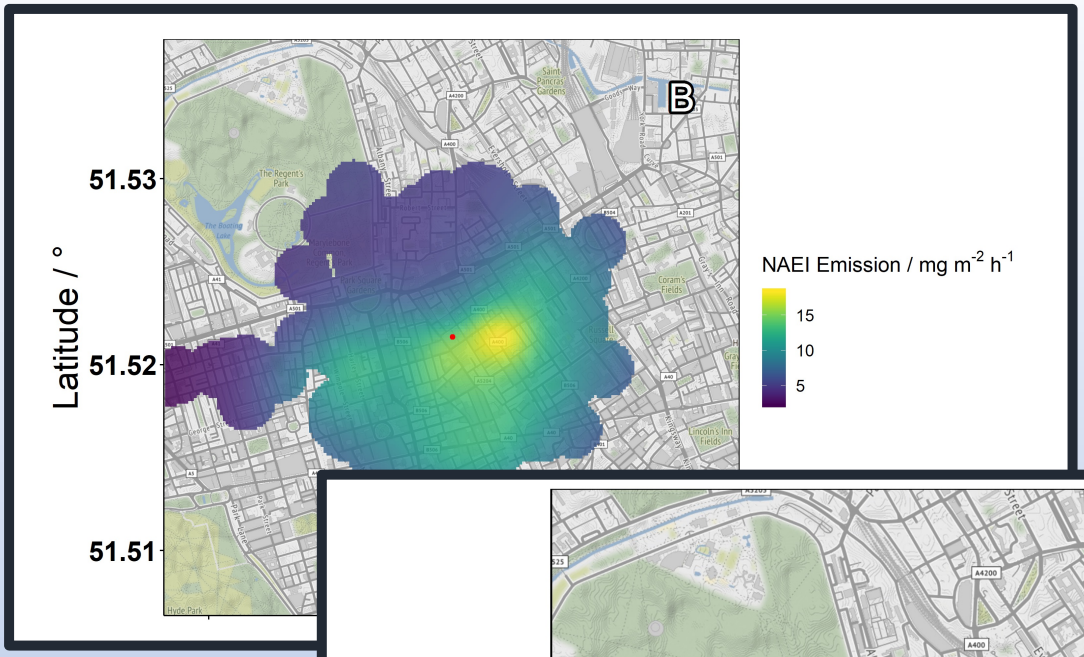
Ankur R. Desai,[1] Brent R. Helliker,[2] Paul R. Moorcroft,[3] Arlyn E. Andrews,[4] and Joseph A. Berry[5]

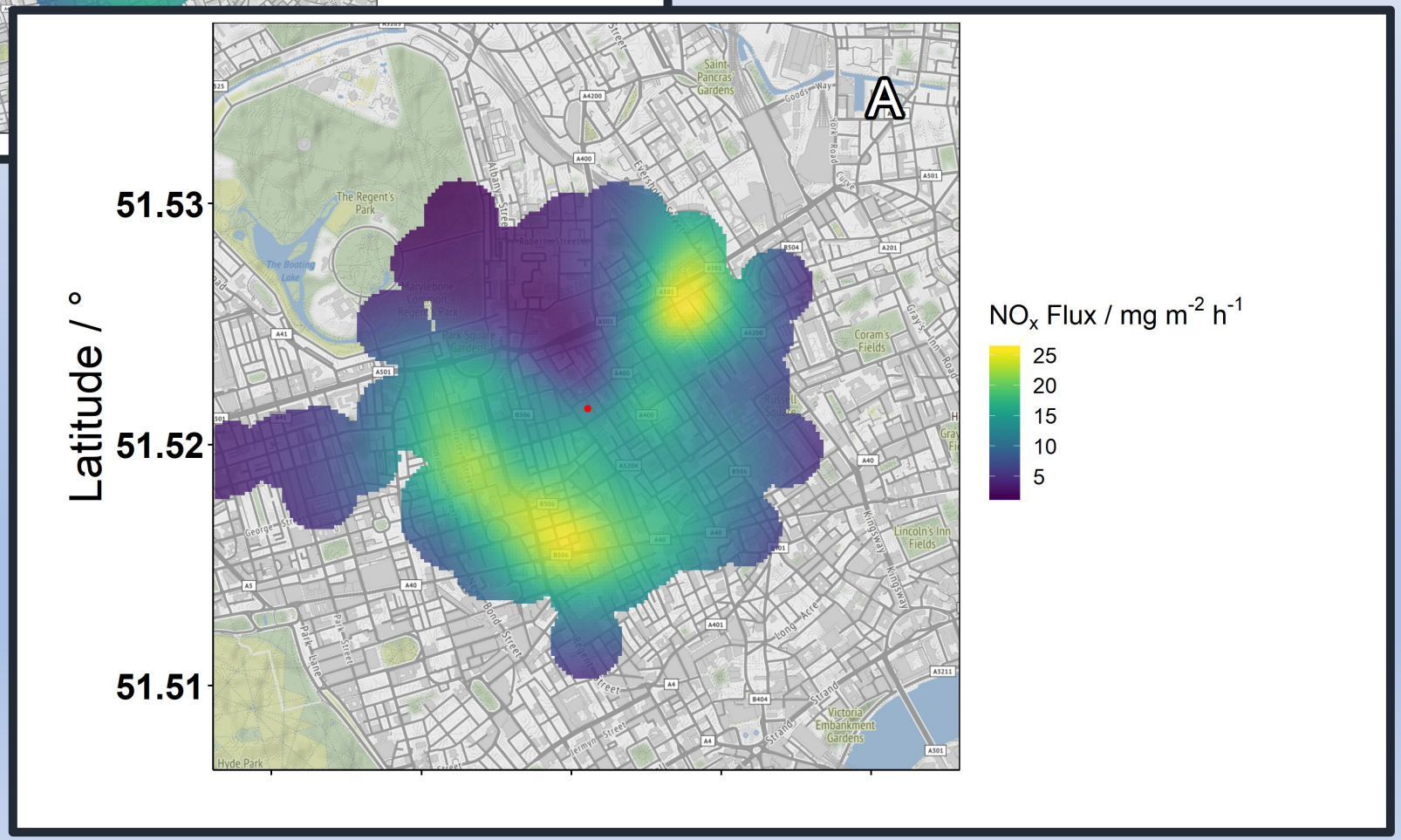


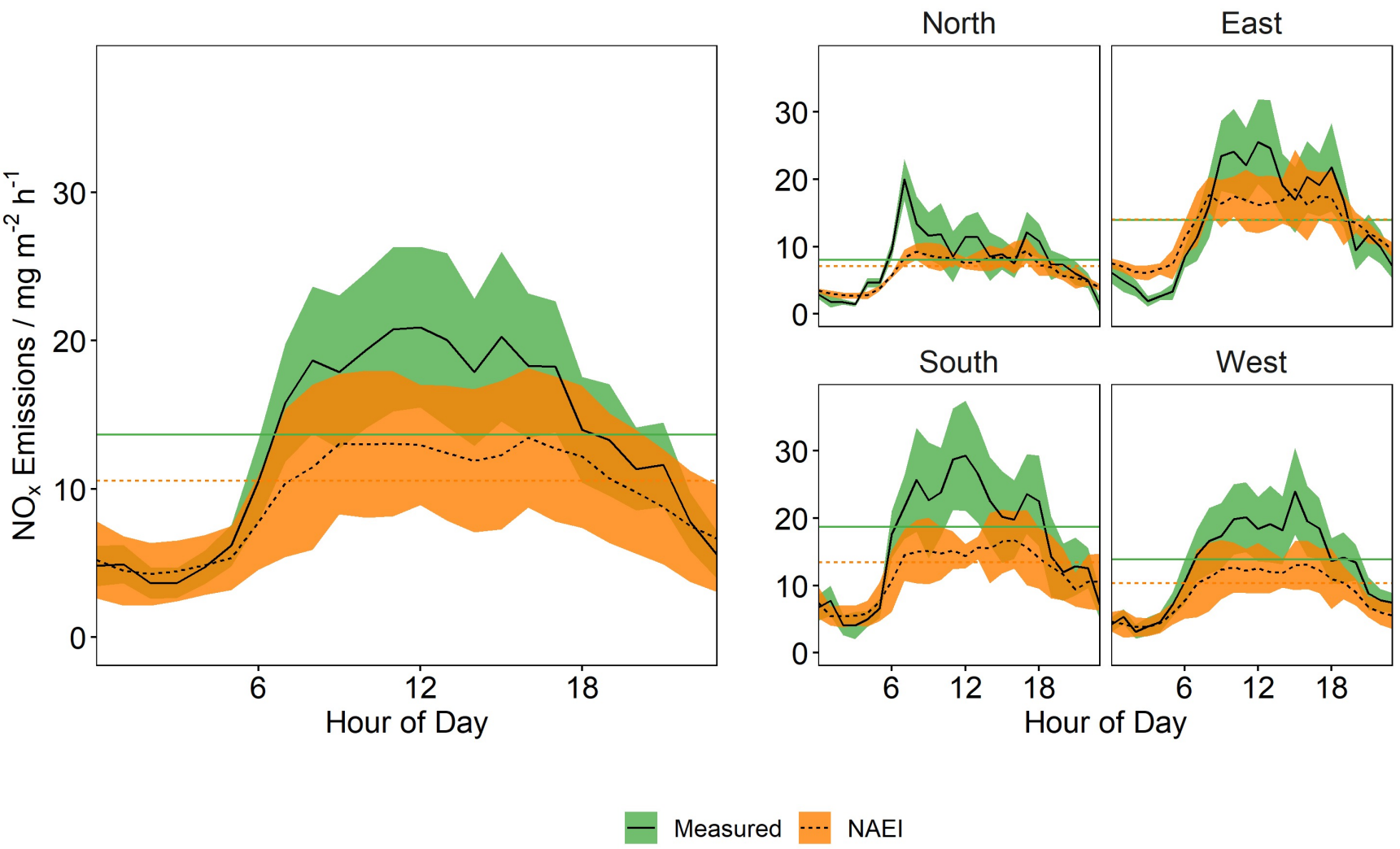


Will Drysdale (York U)
Adam Vaughan (UK)

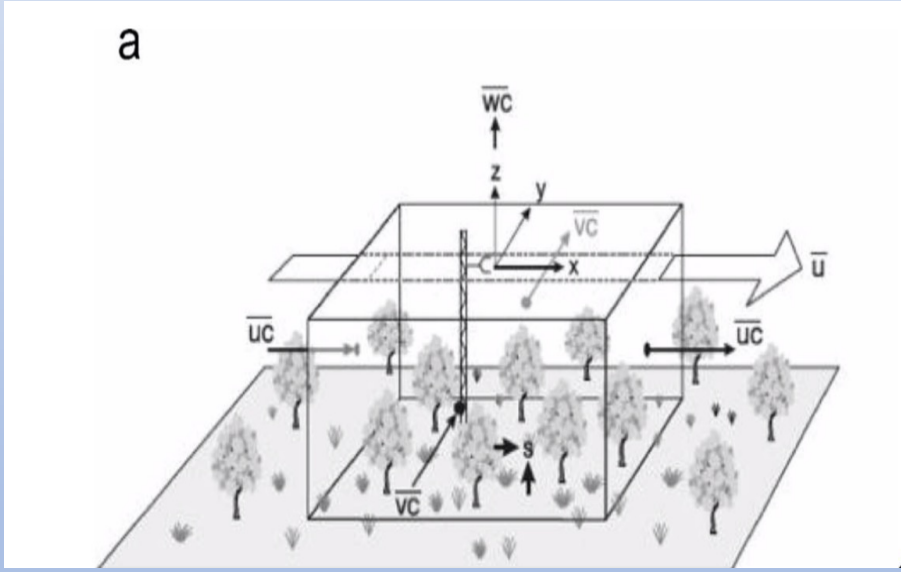

51.7
51.6
51.5
51.4
51.3
Latitude / °
-0.6
-0.4
-0.2
0.0
0.2
Longitude / °
Shenley AV
Radlett
Little Chalfont
Cheshunt
Epping
Hadley Wood
Enfield
Borehamwood
Elstree
Chalfont St Giles
Rickmansworth
Harefield
Gerrards Cross
Hendon
Wood Green
Walthamstow
Collier Row
Harrow
Romford
Hornchurch
Stoke Poges
Uxbridge
Wembley
Camden Town
Bethnal Green
East Ham
Acton
Bayswater
Poplar
South Ockendon
West Drayton
Hammersmith
Chelsea
Lambeth
Woolwich
Colnbrook
Battersea
Camberwell
Brixton
Grays
Datchet
Old Windsor
Richmond
Catford
Bexleyheath
Dartford
Staines
Swanscombe
Egham
Biggin Hill
Addlestone
Ottershaw
Esher
Eynsford
Epsom
Halstead
Shoreham
Kemsing
Send
East Horsley
Leatherhead
Woldingham
Borough Green
Westerham
Sevenoaks
M25
M11
M20
NOx Emission / tonnes yr-1
50
100

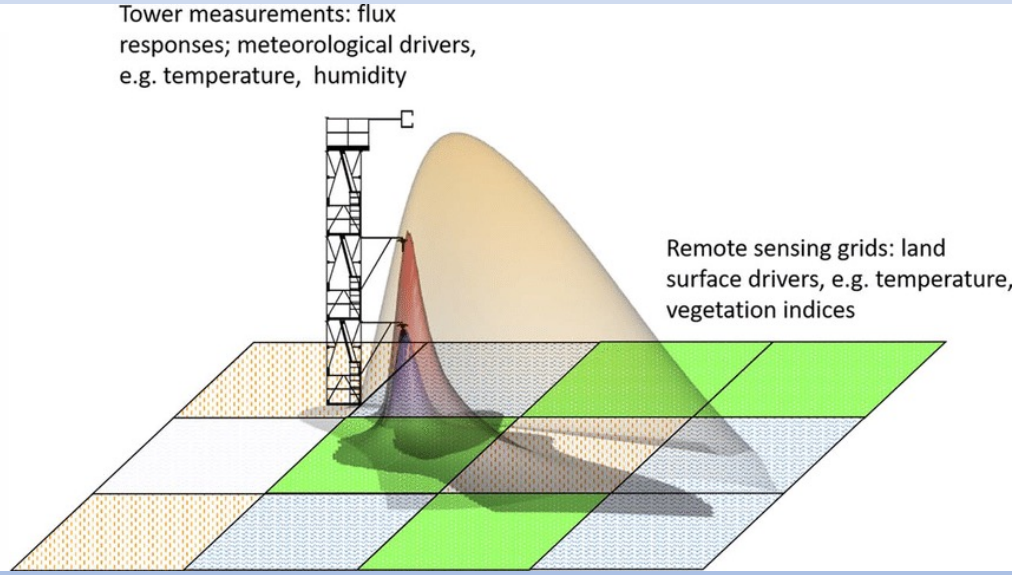

B
Latitude / °
51.53
51.52
51.51
NAEI Emission / mg m-2 h-1
15
10
5


A
Latitude / °
51.53
51.52
51.51
NOx Flux / mg m-2 h-1
25
20
15
10
5


North
East
South
West
NO_x Emissions / mg m^{-2} h^{-1}
0
10
20
30
6
12
18
Hour of Day
Measured
NAEI

Something different: Environmental Response Functions

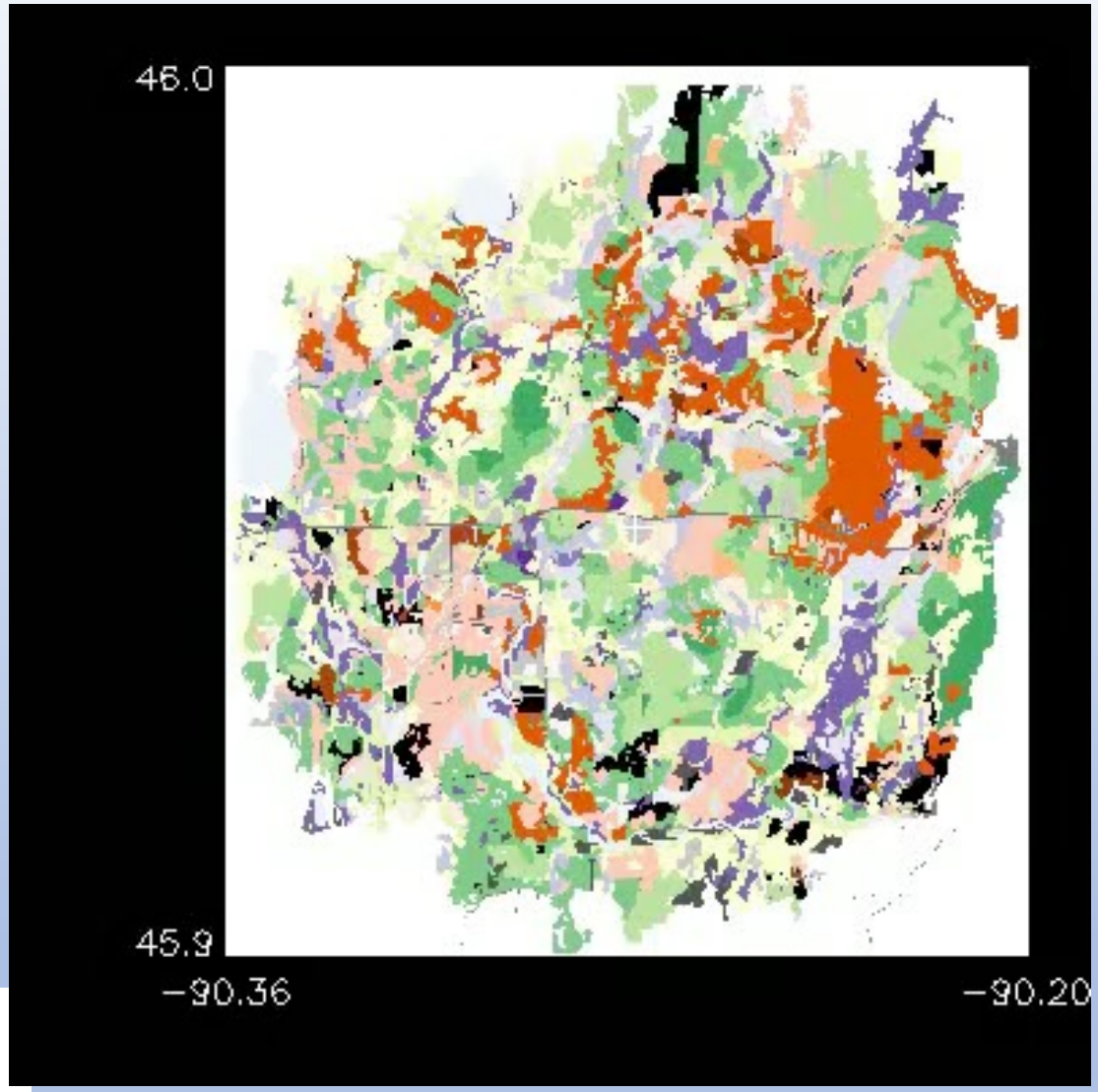




Xu et al (2018)
Adapted from Finnigan et al (2003)

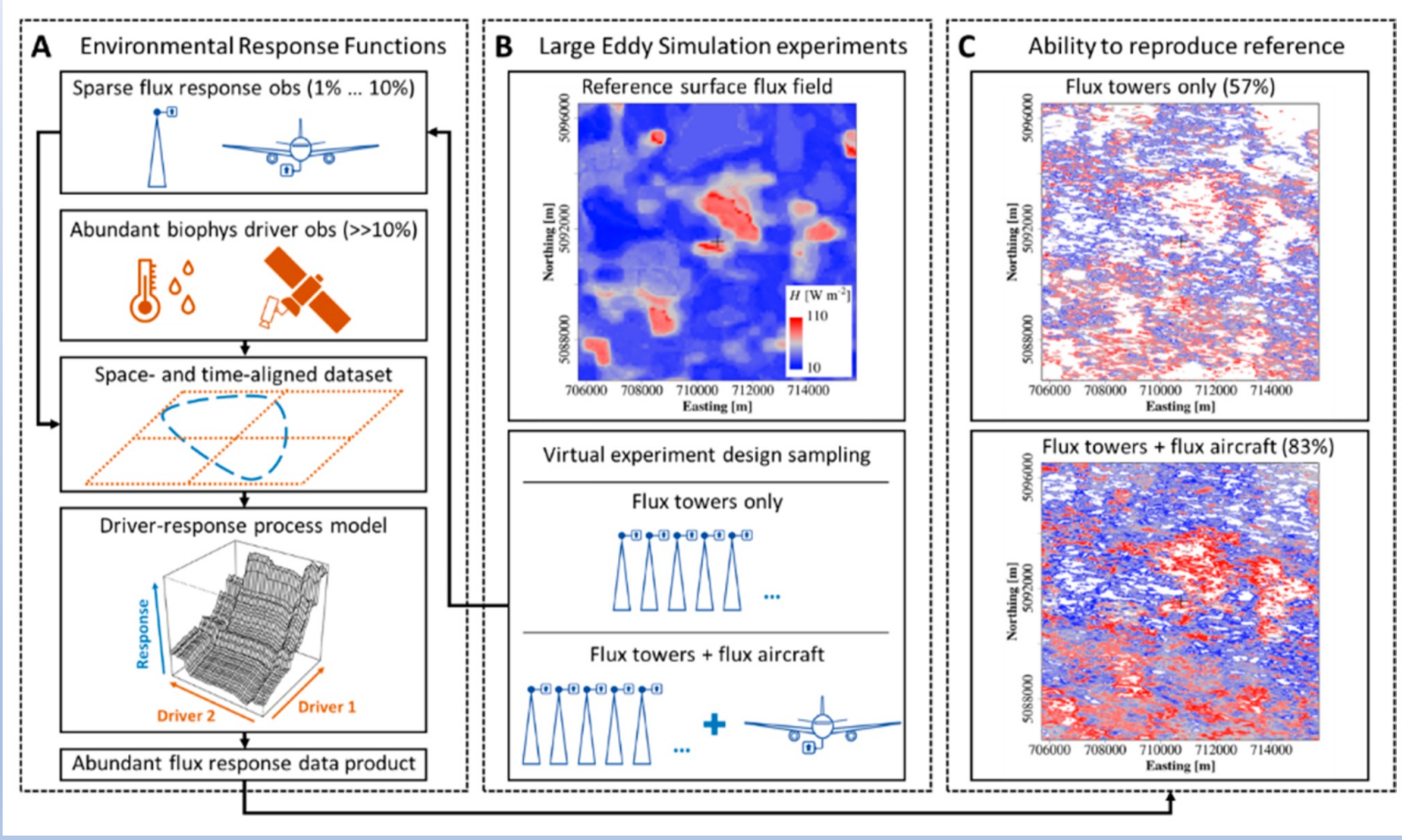
Metzger (2018)

Flux towers see the trees for the forest…

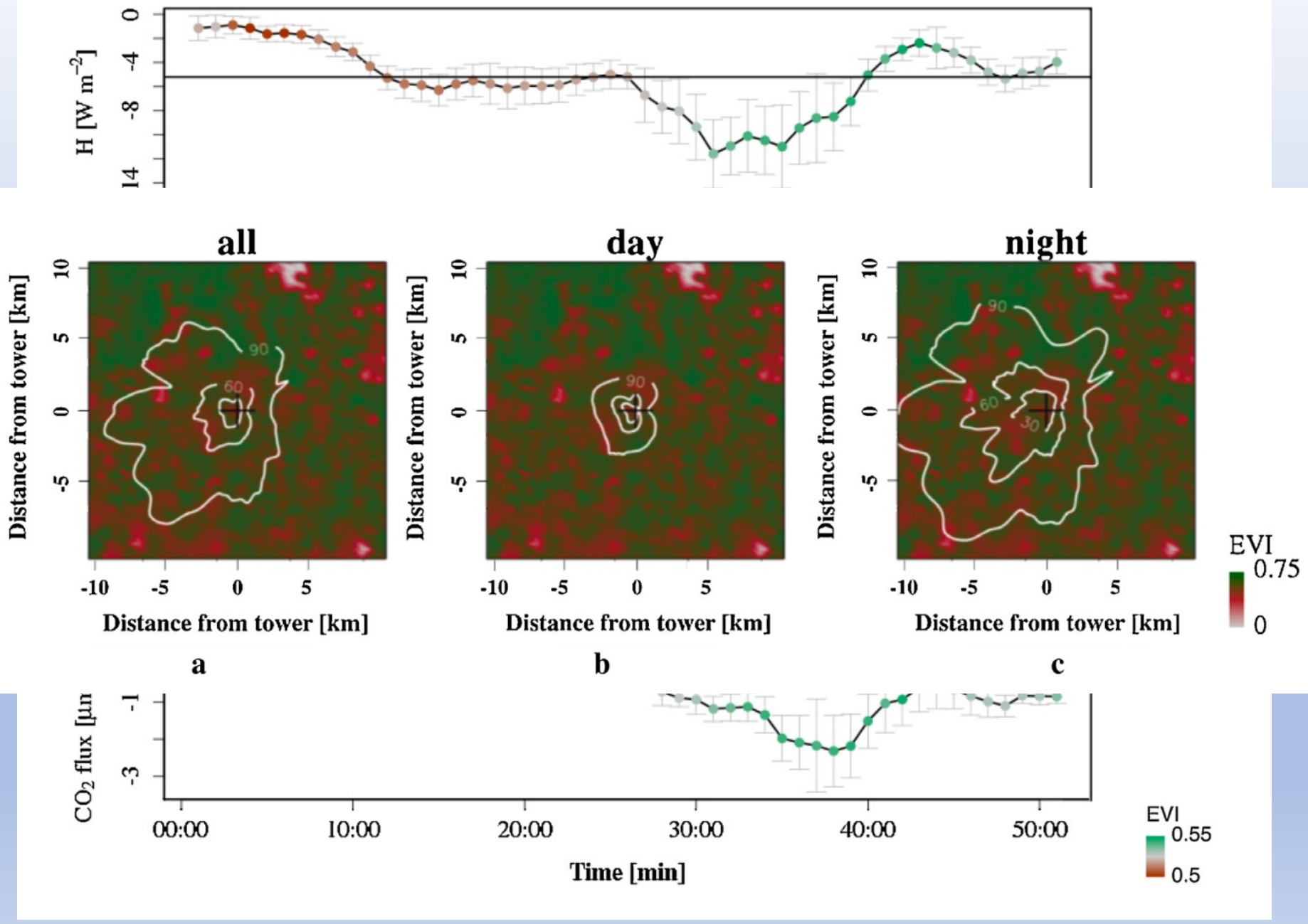


Adopted from a version by HaPE Schmid (KIT)

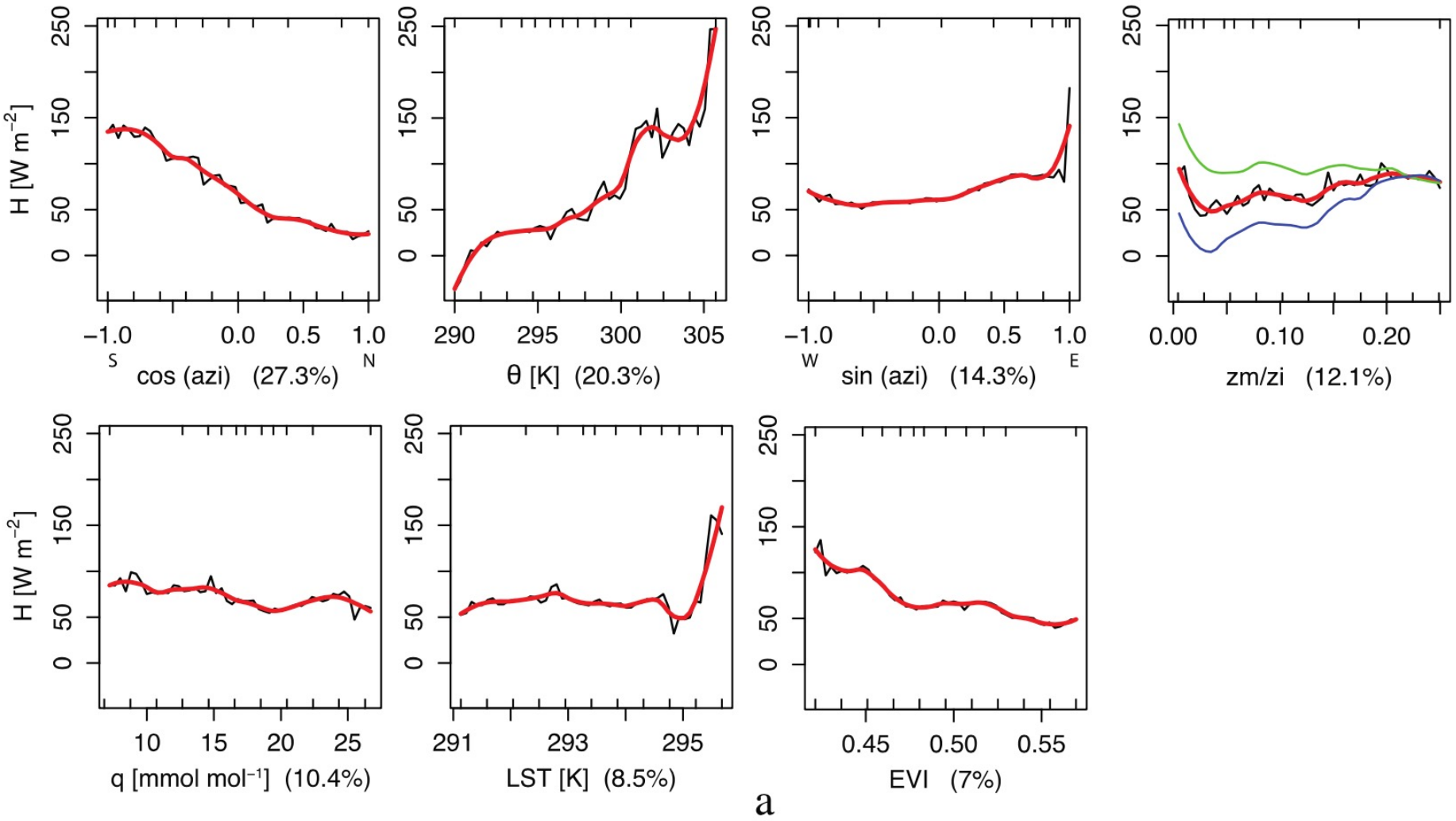
Take advantage of variation to map fluxes across space

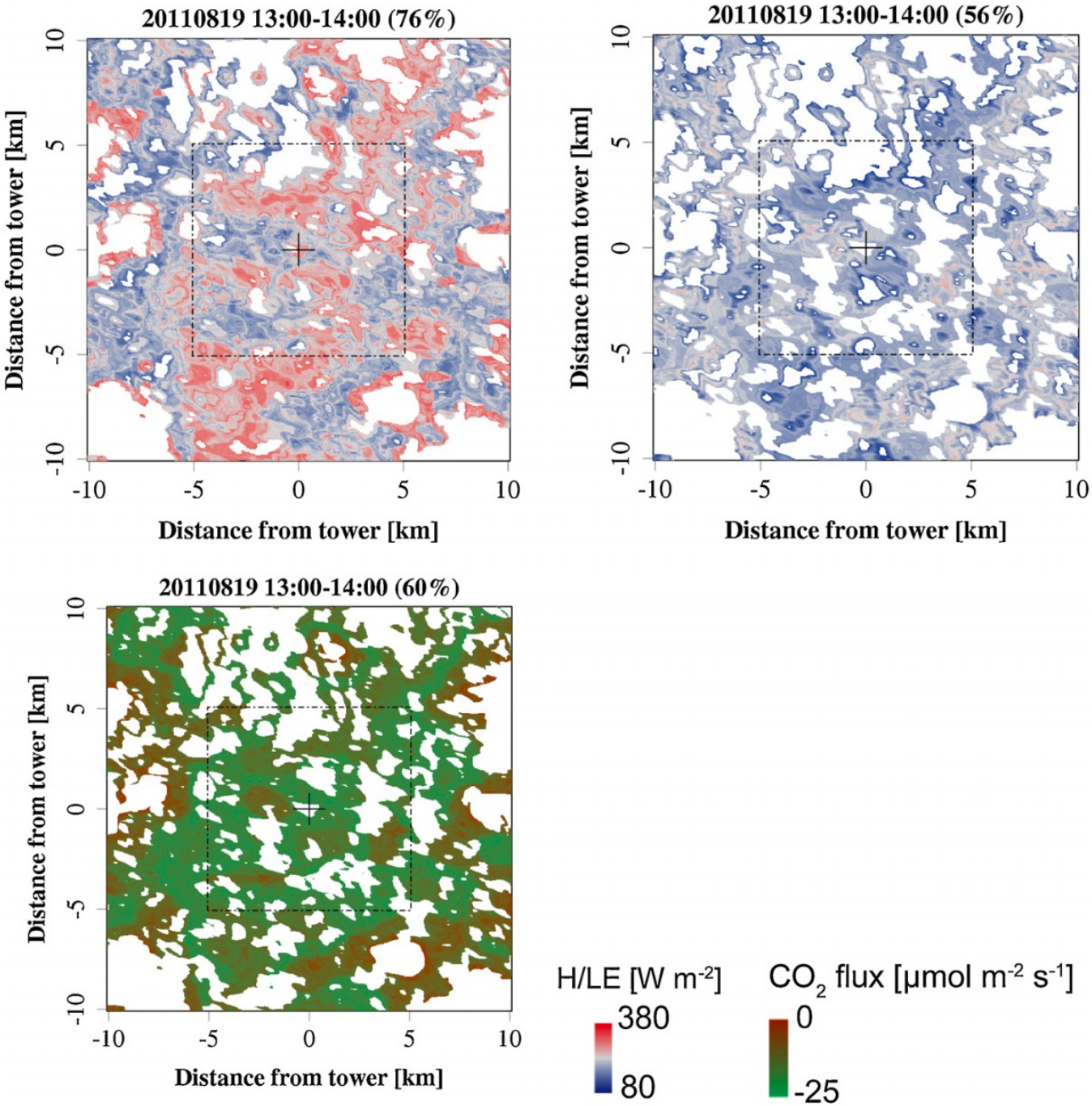


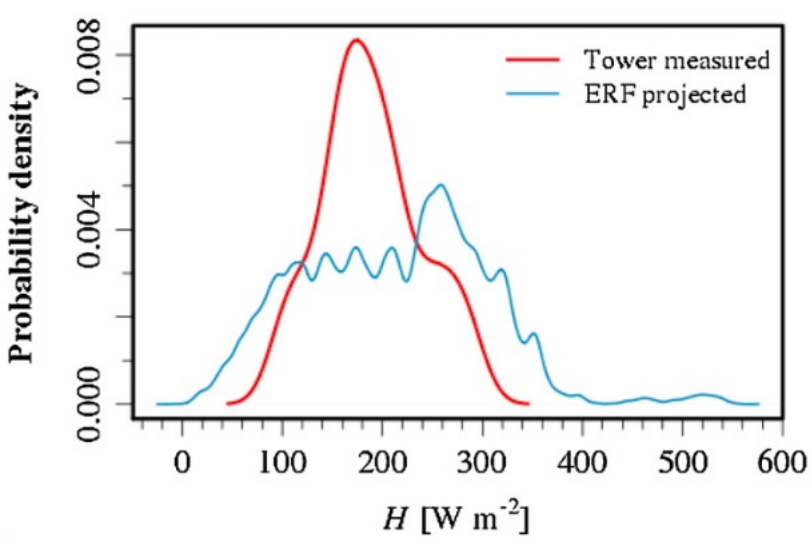
Metzger et al., Biogeosci 2013; Xu et al., AgForMet, 2017; Metzger et al., AMT, 2021


H [W m^{-2}]
0
-4
-8
14
all
day
night
Distance from tower [km]
10
5
0
-5
90
60
30
-10
-5
0
5
Distance from tower [km]
EVI
0.75
0
a
b
c
CO$_2$ flux [µm
-1
-3
00:00
10:00
20:00
30:00
40:00
50:00
Time [min]
EVI
0.55
0.5

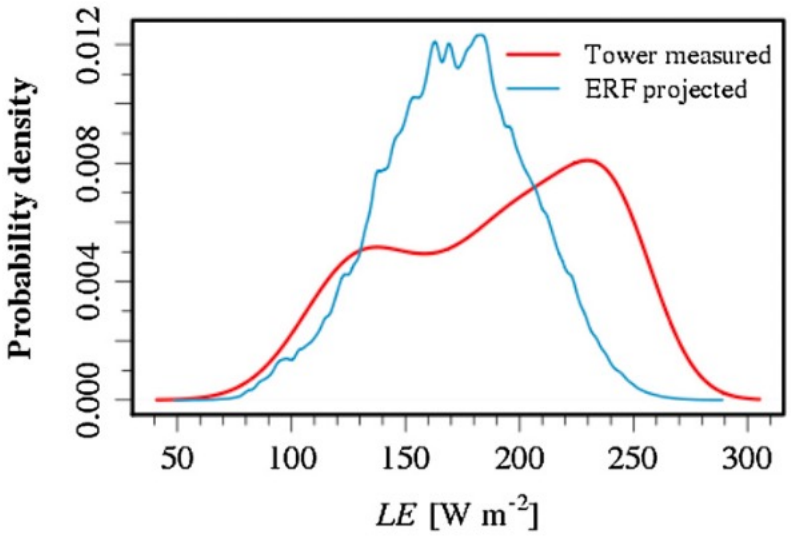
The Environmental Response Function method (Metzger et al 2013, Xu et al., 2017)



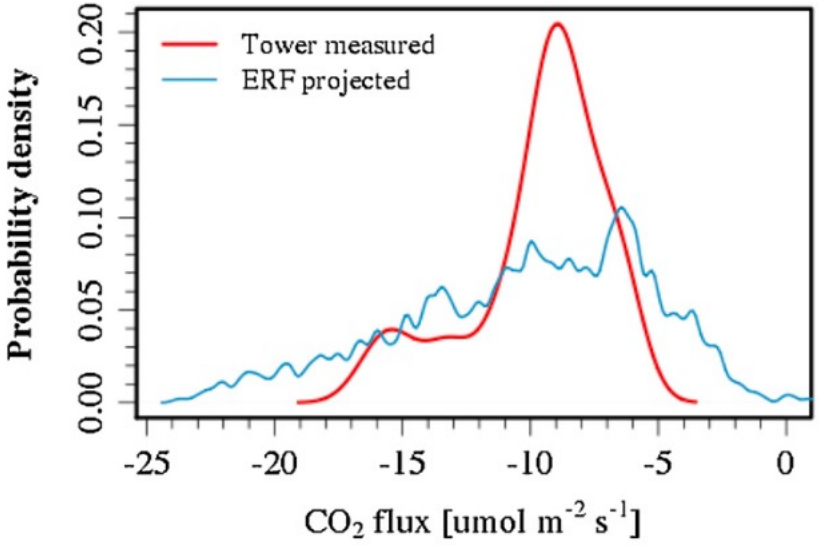

20110819 13:00-14:00 (76%)
20110819 13:00-14:00 (56%)
20110819 13:00-14:00 (60%)
Distance from tower [km]
Distance from tower [km]
-10
-5
0
5
10
H/LE [W m-2]
380
80
CO2 flux [µmol m-2 s-1]
0
-25


Probability density
0.000
0.004
0.008
Tower measured
ERF projected
0
100
200
300
400
500
600
H [W m-2]

(a)

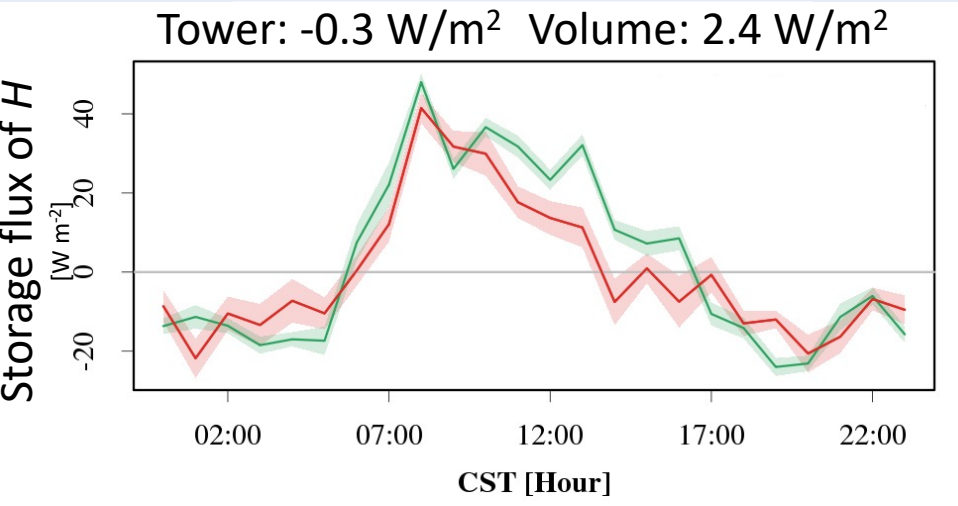

Probability density
0.000
0.004
0.008
0.012
Tower measured
ERF projected
50
100
150
200
250
300
LE [W m-2]

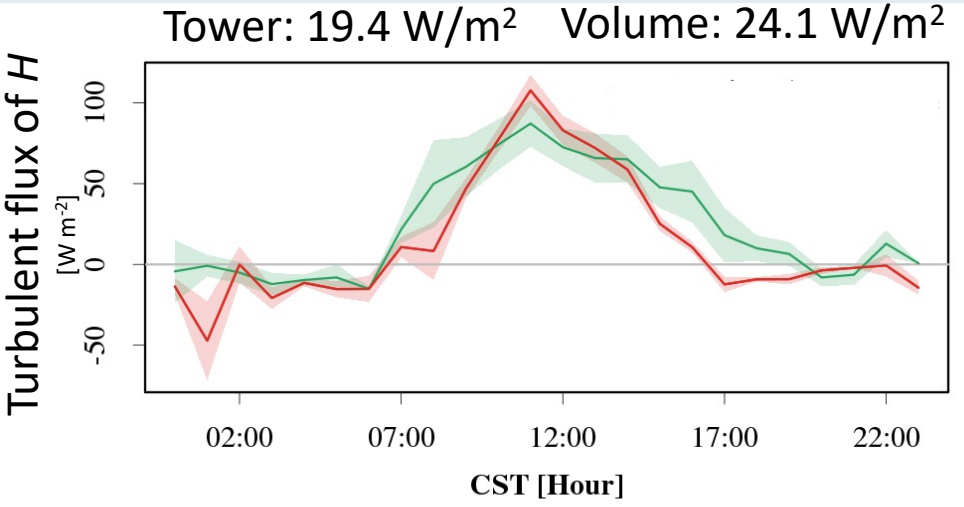
(b)

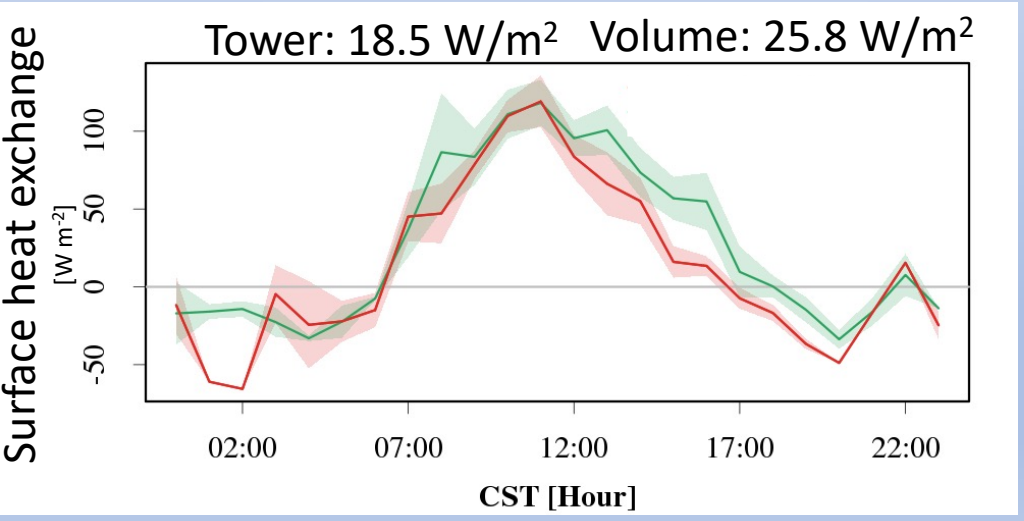

Probability density
0.00
0.05
0.10
0.15
0.20
Tower measured
ERF projected
-25
-20
-15
-10
-5
0
CO2 flux [umol m-2 s-1]

(c)

Energy balance as a QA/QC step



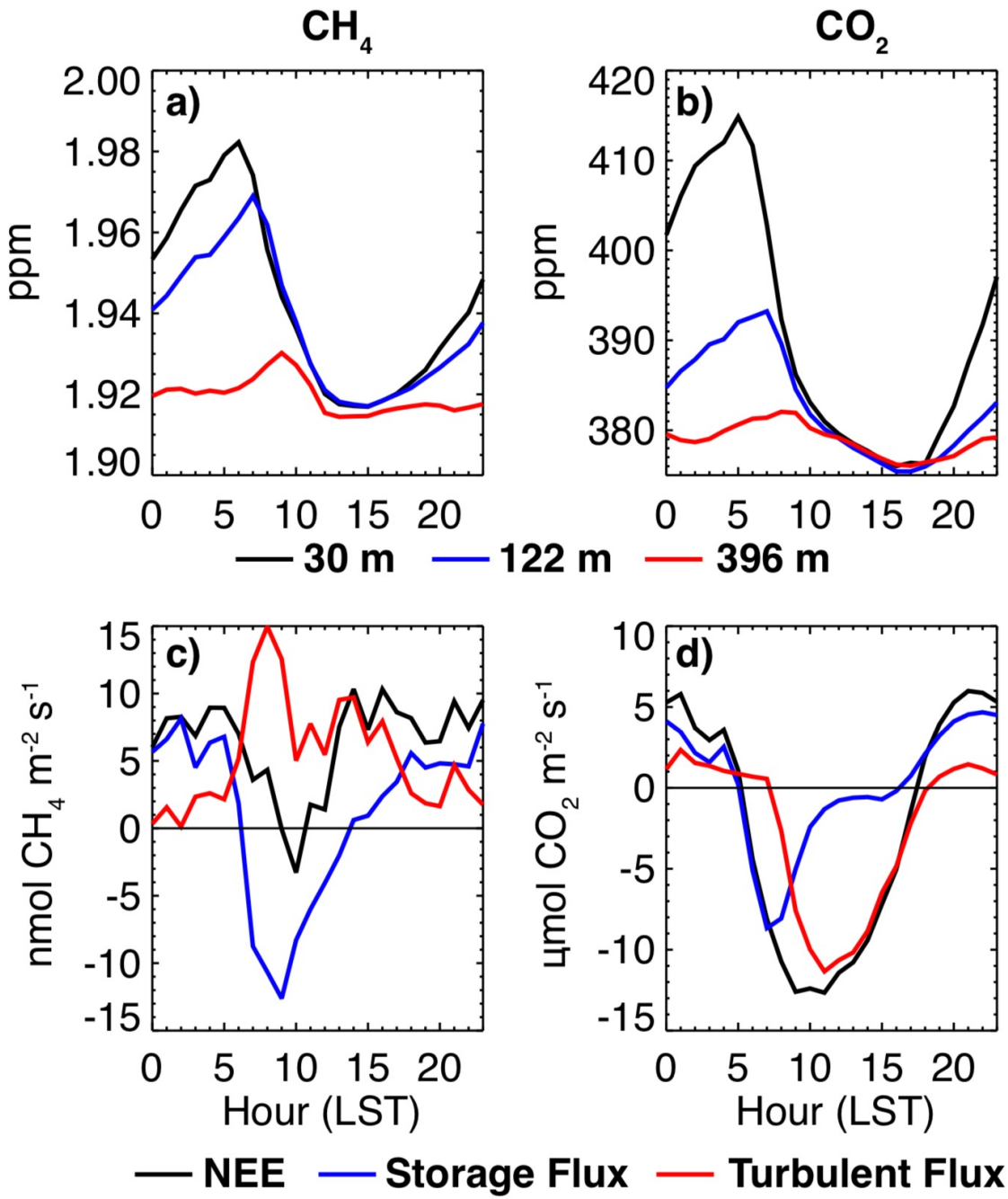




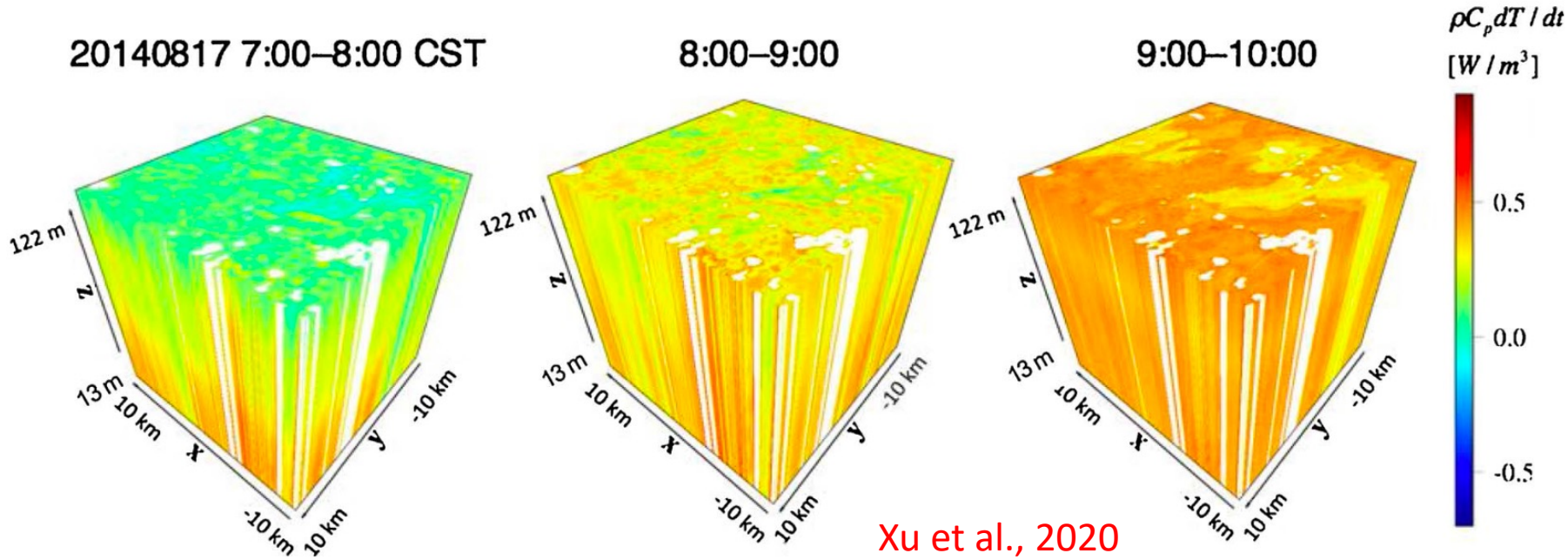
tower-observed

volume-rectified

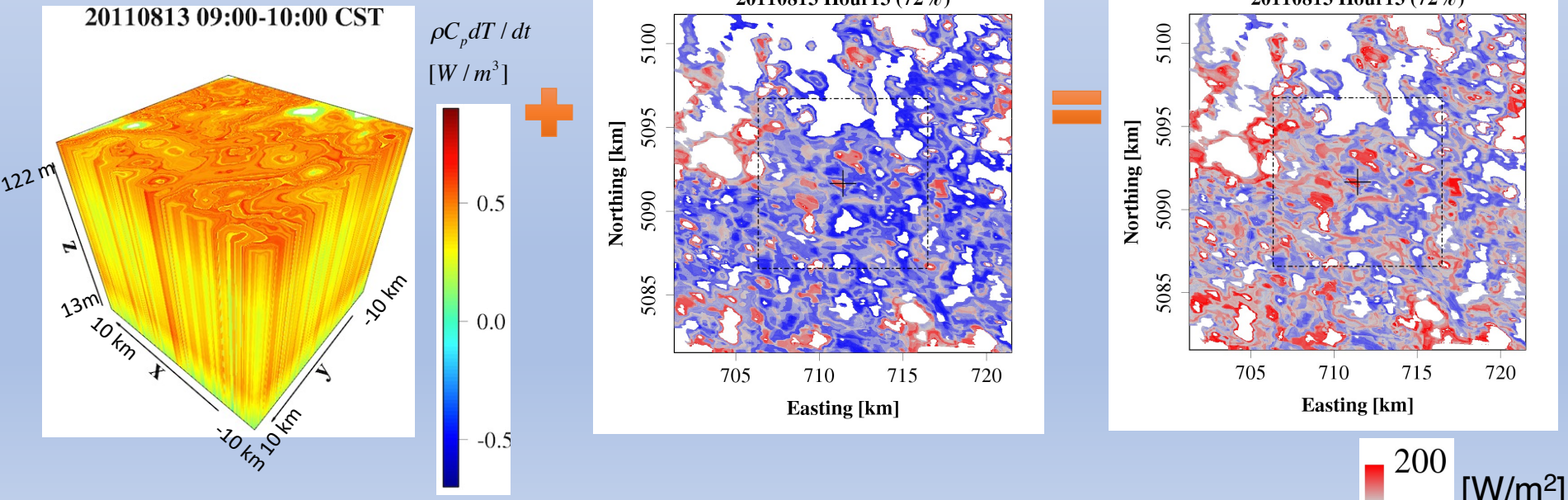
Tall towers need care and feeding

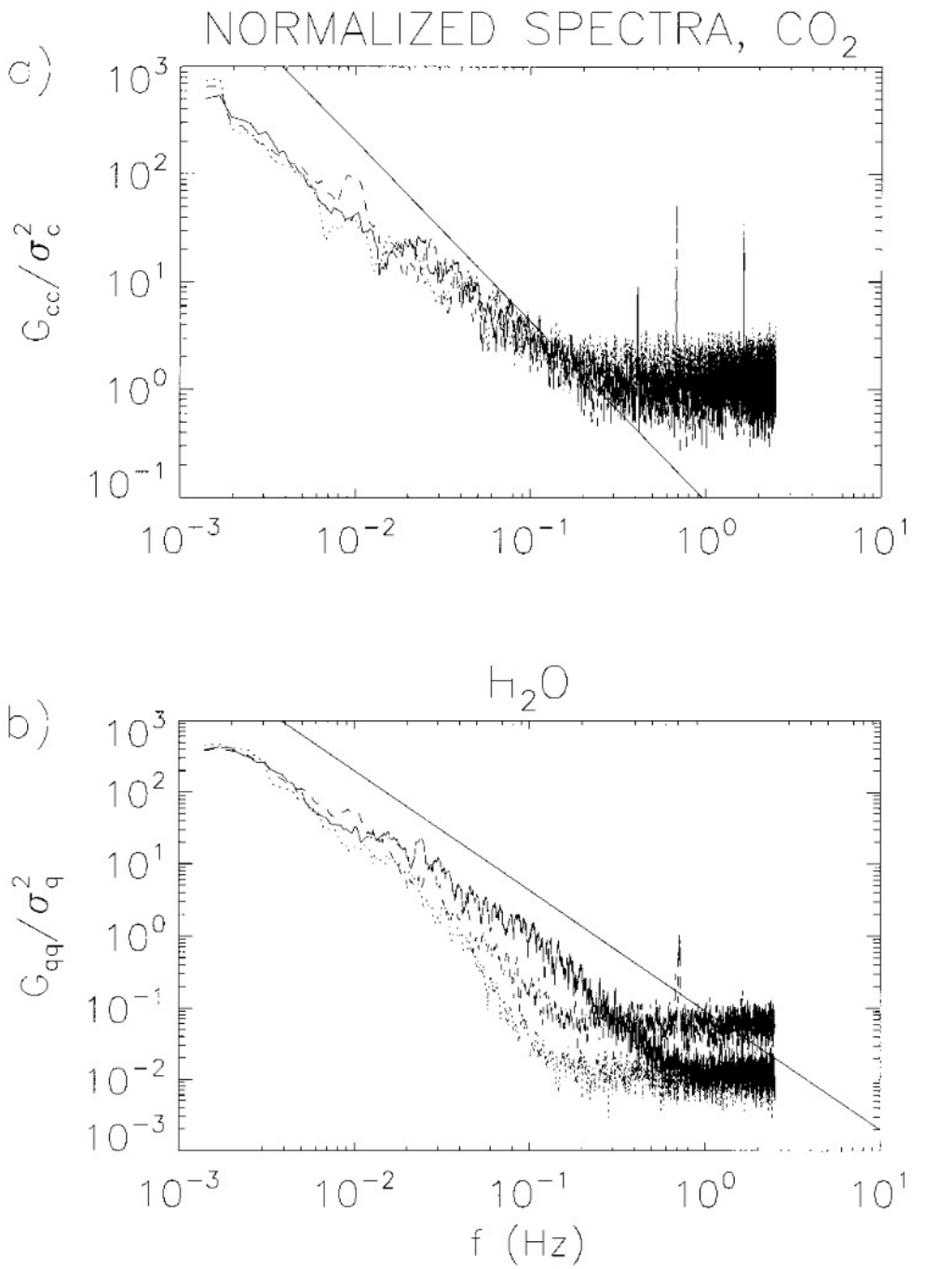


Desai et al., 2015


20140817 7:00–8:00 CST
8:00–9:00
9:00–10:00
$\rho C_p dT / dt$
$[W / m^3]$
122 m
z
13 m
10 km
x
-10 km
y
-10 km
10 km
0.5
0.0
-0.5

Xu et al., 2020


20110813 09:00-10:00 CST
$\rho C_p dT / dt$
$[W / m^3]$
122 m
z
13m
10 km
x
-10 km
y
-10 km
10 km
0.5
0.0
-0.5
20110813 Hour13 (72%)
Northing [km]
5085
5090
5095
5100
705
710
715
720
Easting [km]
20110813 Hour13 (72%)
Northing [km]
5085
5090
5095
5100
705
710
715
720
Easting [km]
200
-30
[W/m²]



Berger et al., 2001

AGU cross-journal special collection https://bit.ly/2TIYtEh

Deadline Extended to May 2022

Advances in Scaling and Modeling of Land–Atmosphere Interactions

Papers are invited for a new cross-journal special collection on insights in scaling land-atmosphere interactions from field experiments, data analyses, and modeling.

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