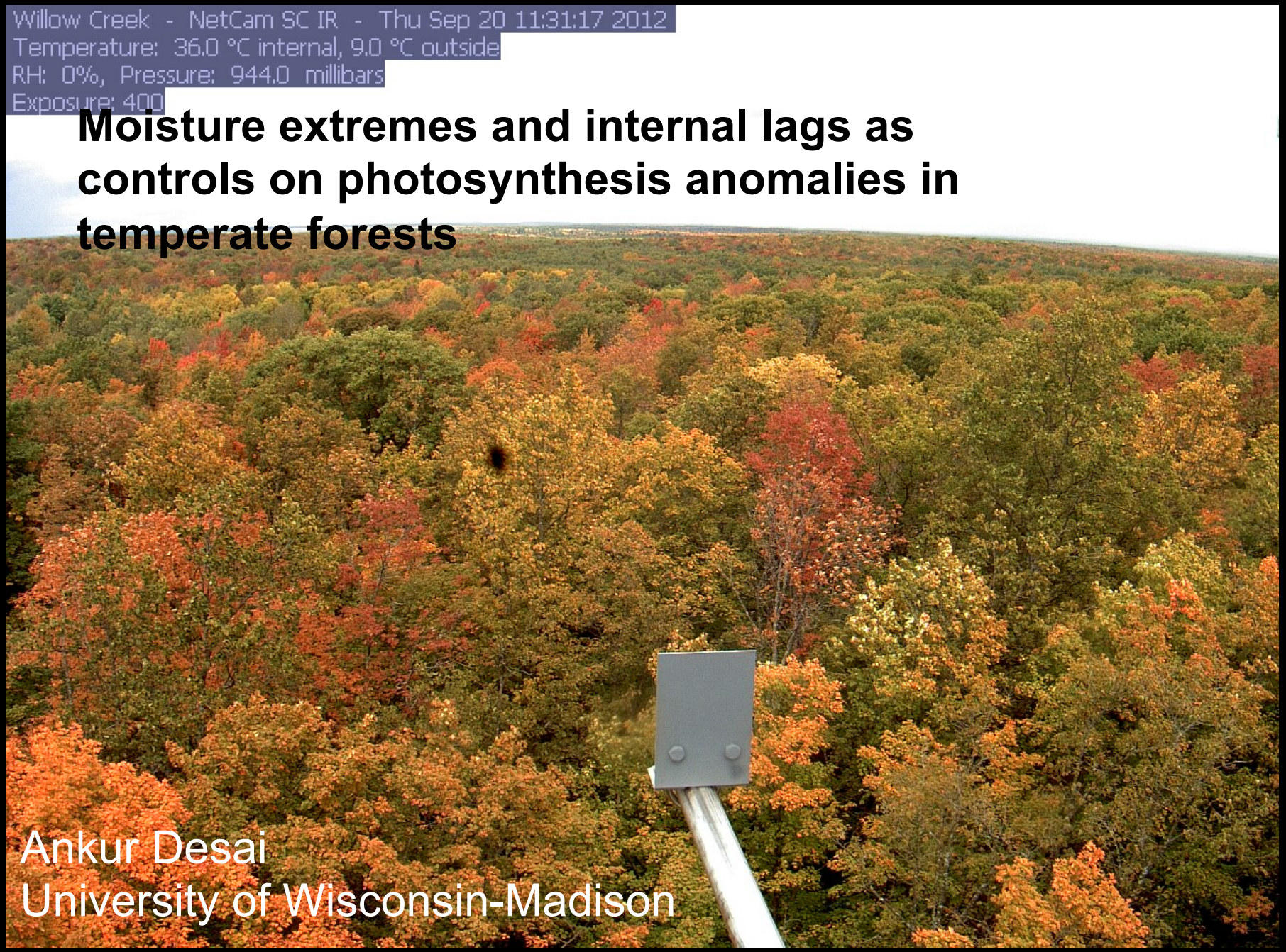

Moisture extremes and internal lags as controls on photosynthesis anomalies in temperate forests

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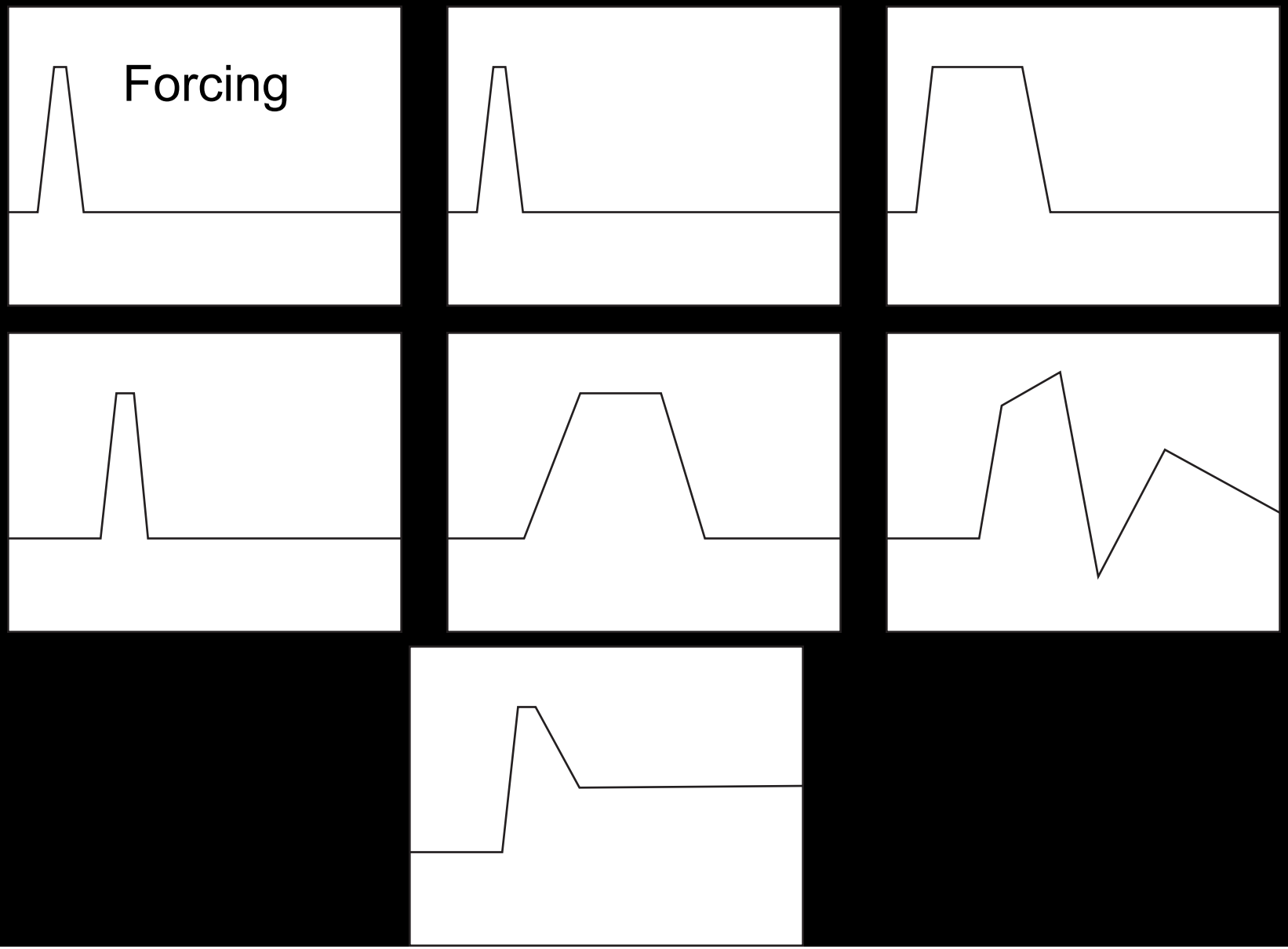
What is a climate extreme?

- A spike or pulse?
- A standardized anomaly?
- Variability around a steady forcing change?
- A forcing that develops an unusual response in a particular system?

What is the biogeochemical reponse?



What drives this response?

- Terrestrial ecosystems carbon assimilation and decomposition respond to:
  - Temperature
  - Light quantity and quality
  - Moisture availability
  - Nutrients (Nitrogen, CO_2, Phosphorous)
  - Disturbance (Fire, insects, hurricanes, …)
  - Land use (Logging, draining wetlands, …)
  - Competition, adaptation, evolution

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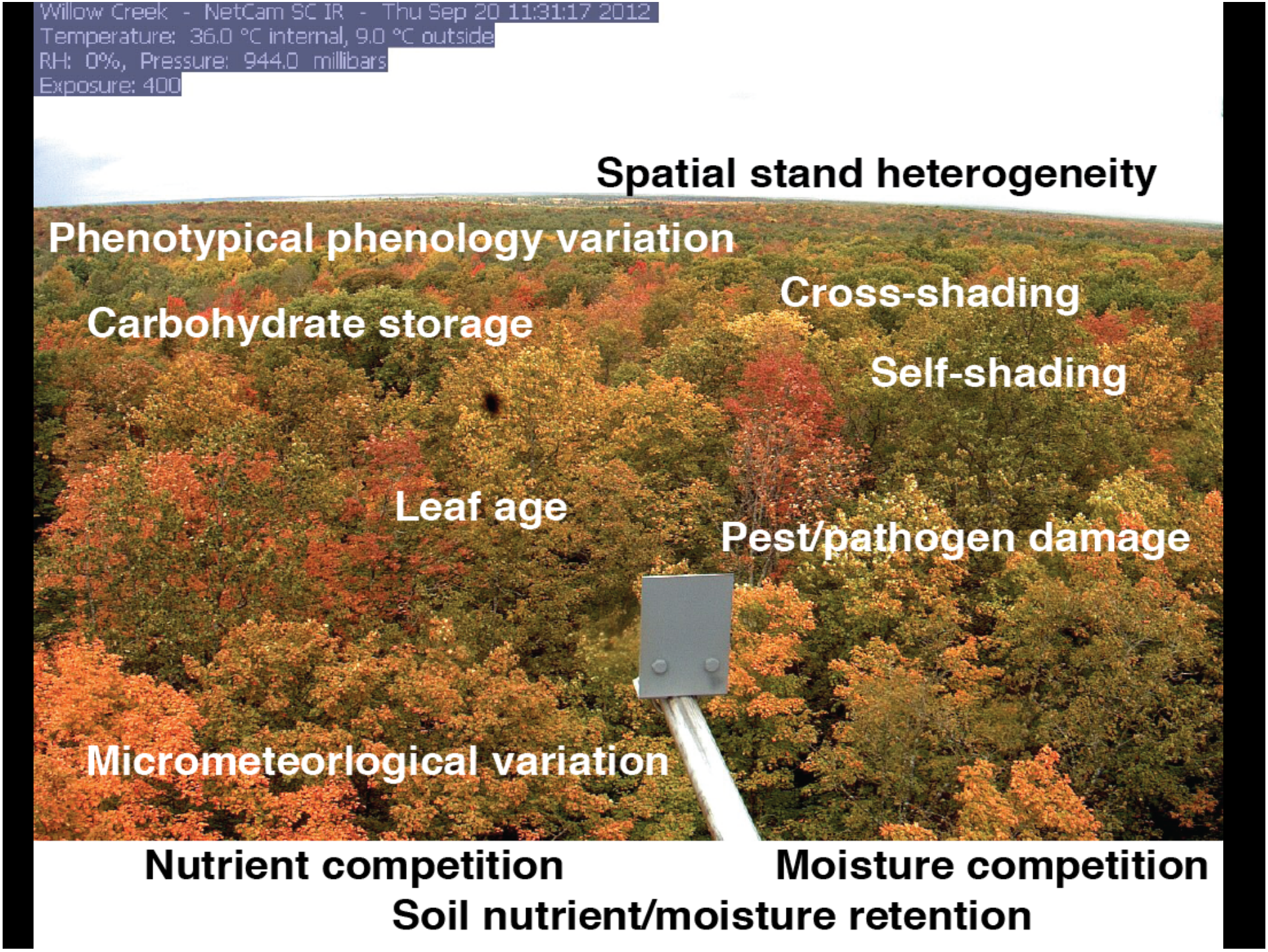
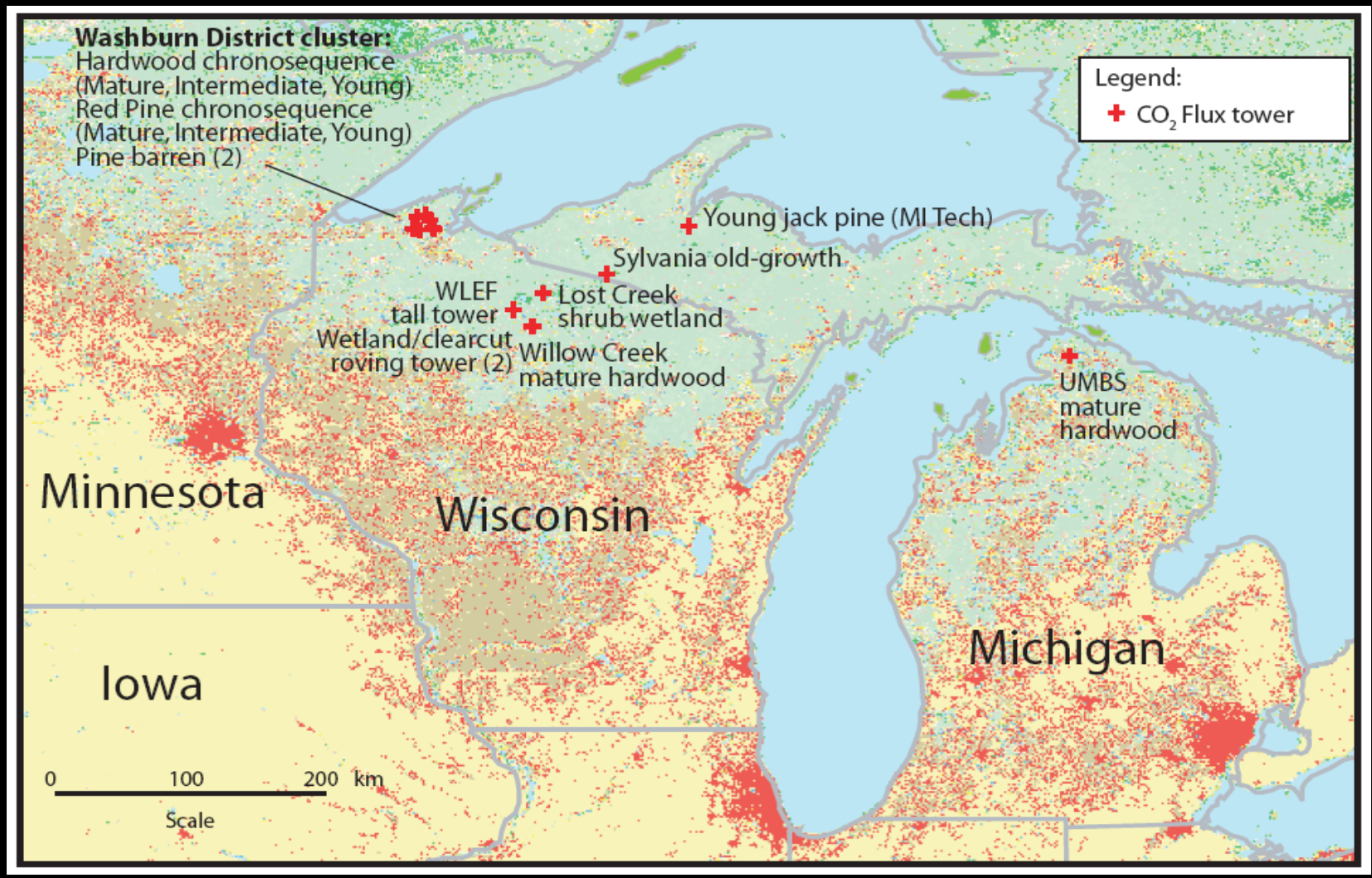
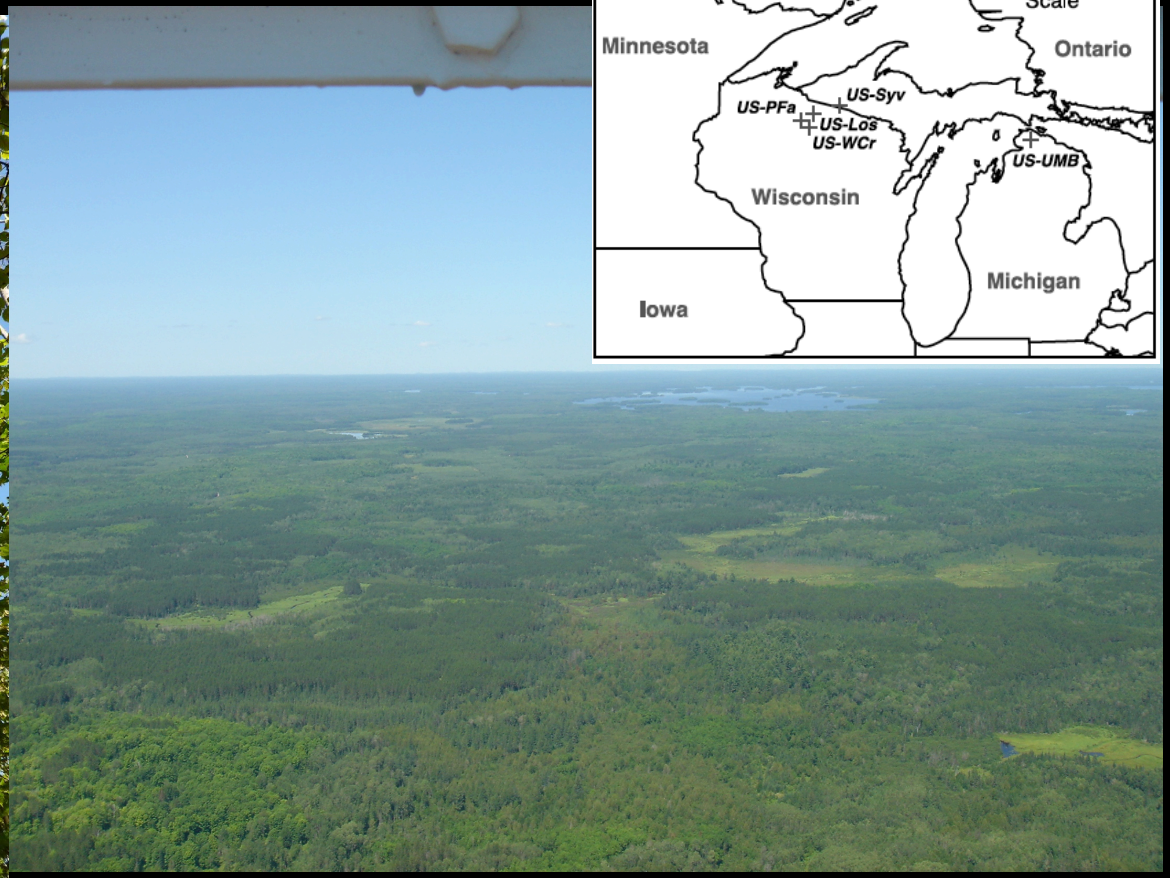
Coated With Algae

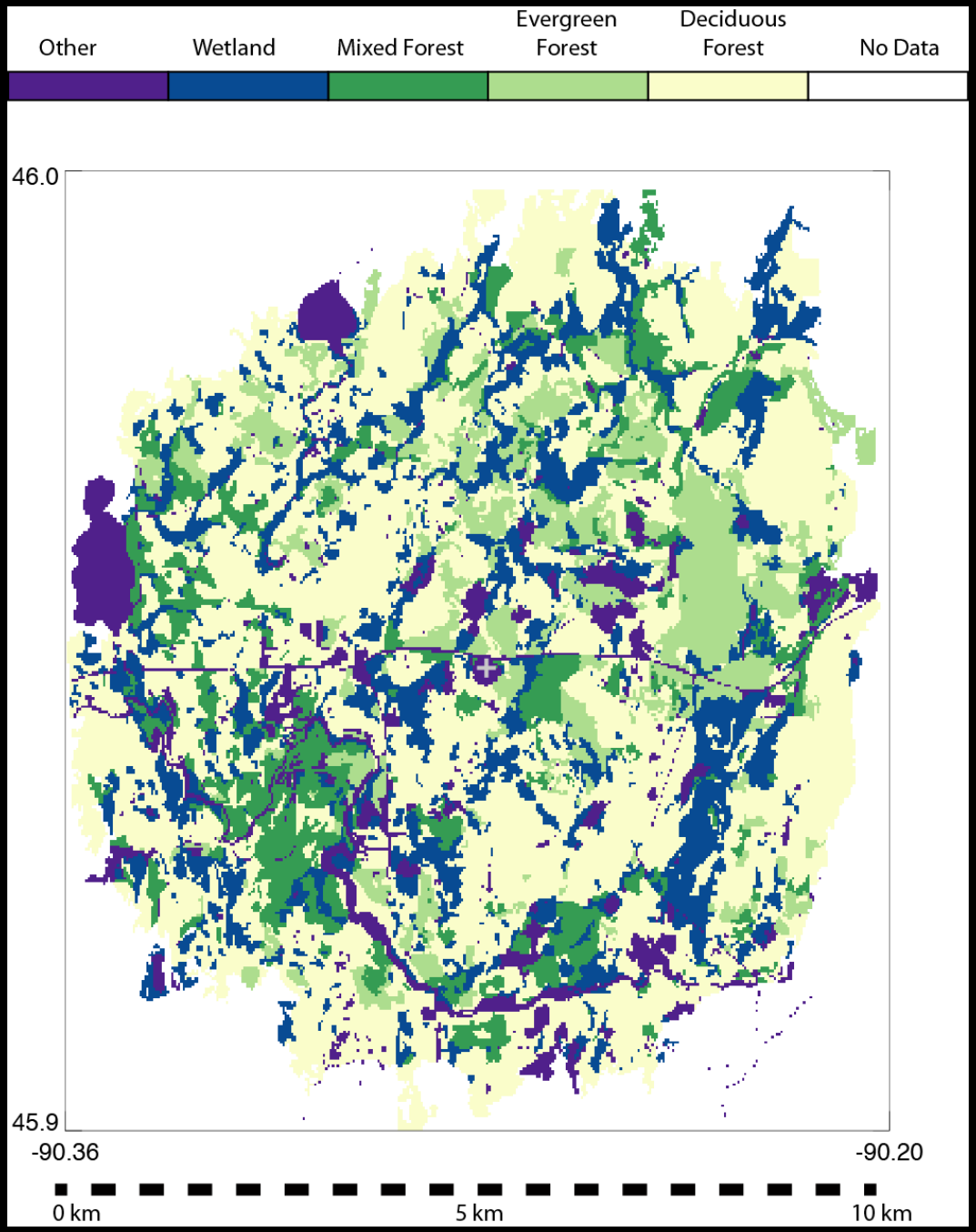
The satellite images show Lake Erie at two different times in 2011, when the lake suffered the worst algae bloom in decades. The first image shows the lake before the bloom started; the second shows the bloom at its greatest extent, covering much of the lake's western basin. Related Article »

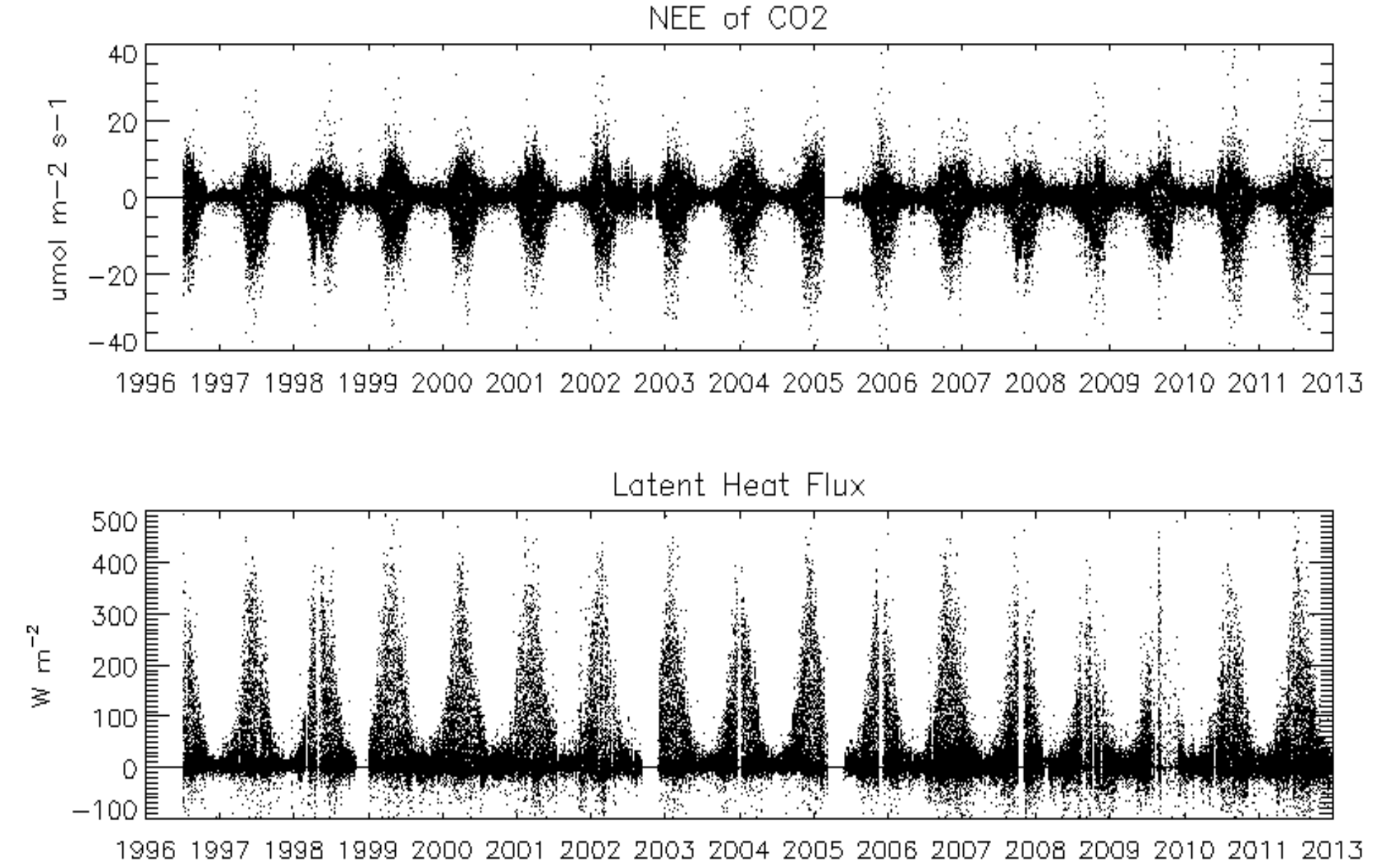

Willow Creek - NetCam SC IR - Thu Sep 20 11:31:17 2012
Temperature: 36.0 °C internal, 9.0 °C outside
RH: 0%, Pressure: 944.0 millibars
Exposure: 400
Spatial stand heterogeneity
Phenotypical phenology variation
Cross-shading
Carbohydrate storage
Self-shading
Leaf age
Pest/pathogen damage
Micrometeorlogical variation
Nutrient competition
Moisture competition
Soil nutrient/moisture retention

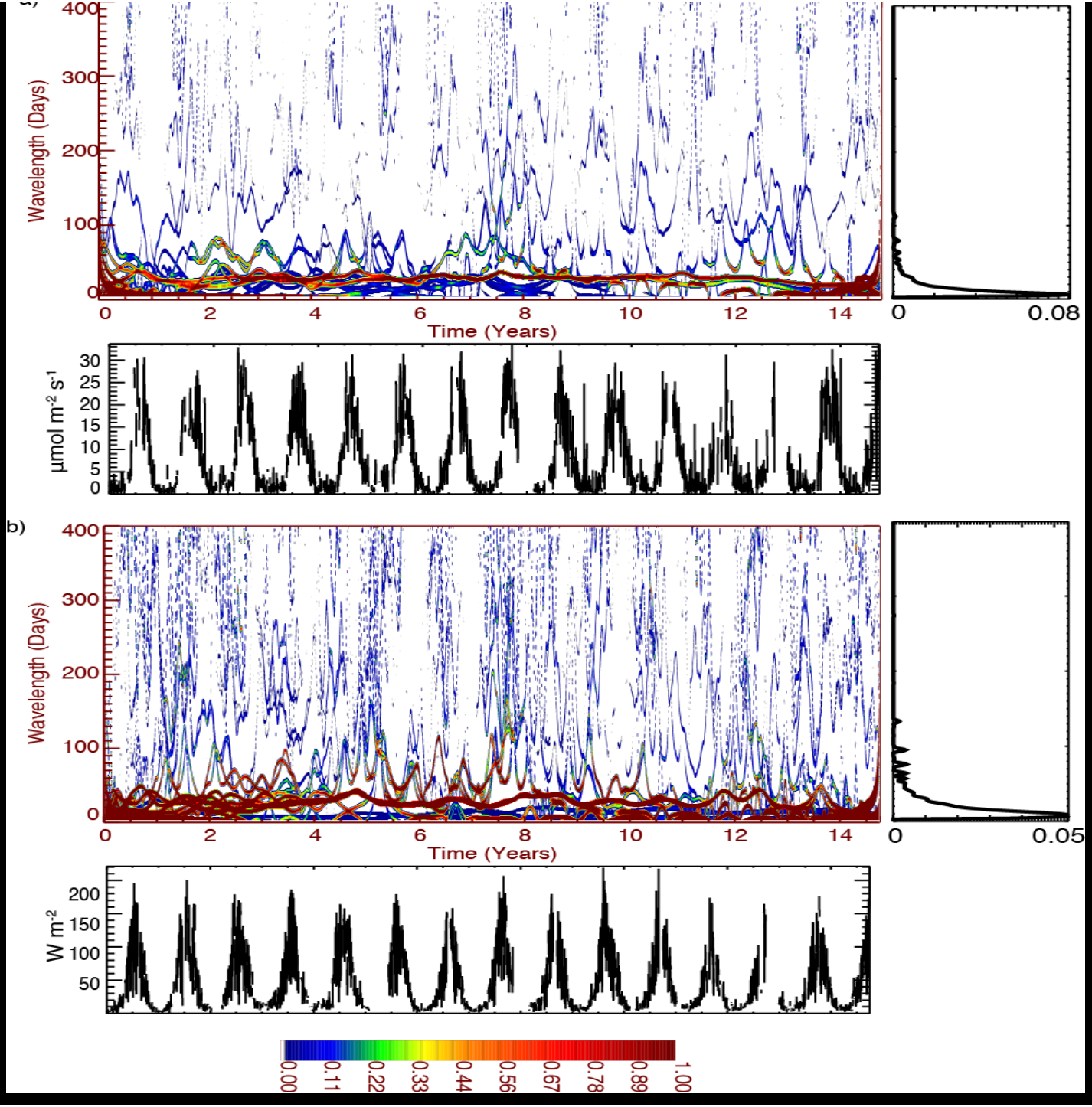

Washburn District cluster:
Hardwood chronosequence
(Mature, Intermediate, Young)
Red Pine chronosequence
(Mature, Intermediate, Young)
Pine barren (2)
Legend:
CO2 Flux tower
Young jack pine (MI Tech)
Sylvania old-growth
WLEF
tall tower
Lost Creek
shrub wetland
Wetland/clearcut
roving tower (2)
Willow Creek
mature hardwood
UMBS
mature
hardwood
Minnesota
Wisconsin
Michigan
Iowa
0
100
200 km
Scale

A very tall tower!



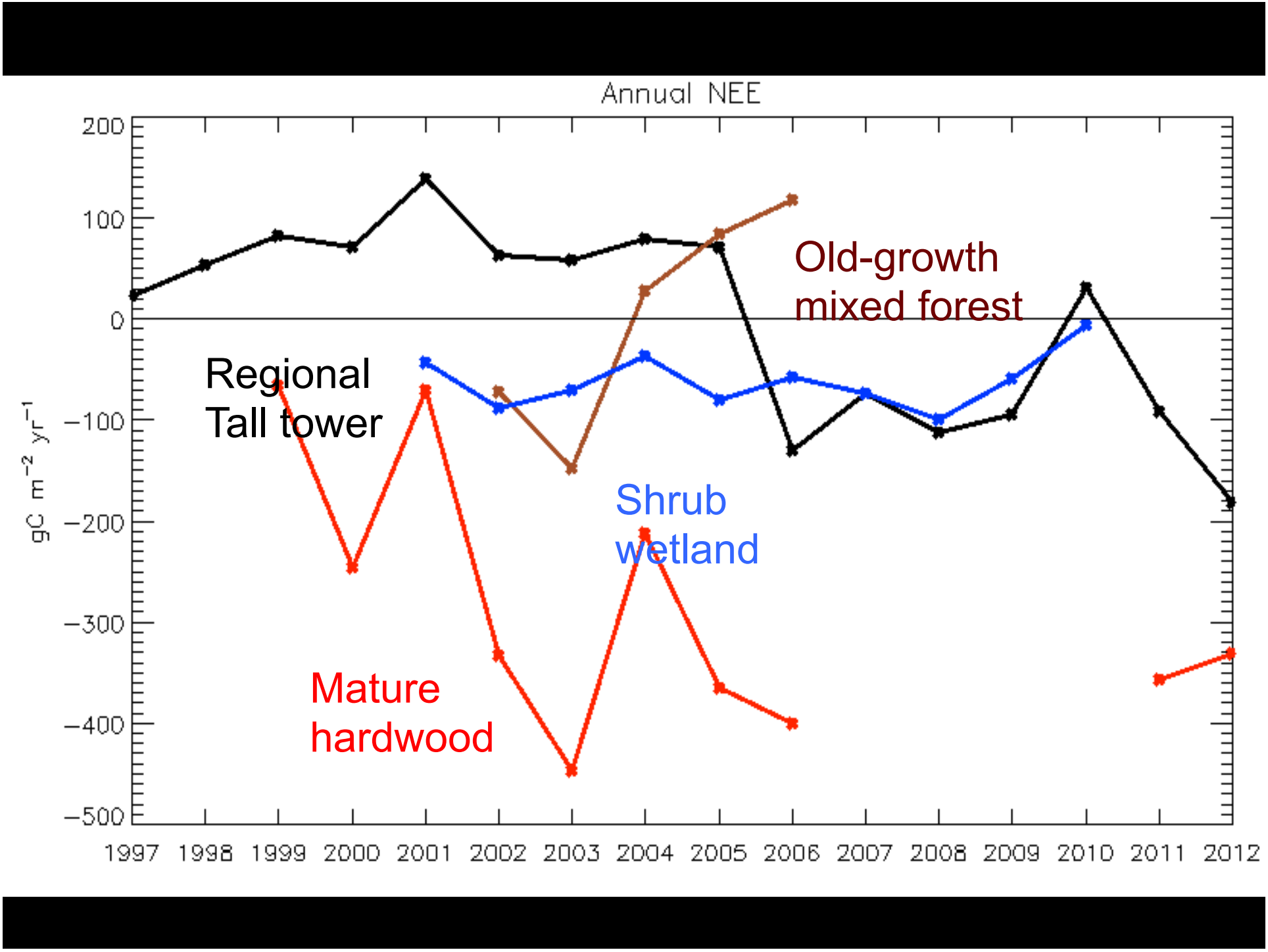

Other
Wetland
Mixed Forest
Evergreen Forest
Deciduous Forest
No Data
46.0
45.9
-90.36
-90.20
0 km
5 km
10 km


NEE of CO2
umol m−2 s−1
40
20
0
−20
−40
1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2013
Latent Heat Flux
W m−2
500
400
300
200
100
0
−100
1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2013


Wavelength (Days)
Time (Years)
µmol m-2 s-1
W m-2
b)
0.00
0.11
0.22
0.33
0.44
0.56
0.67
0.78
0.89
1.00

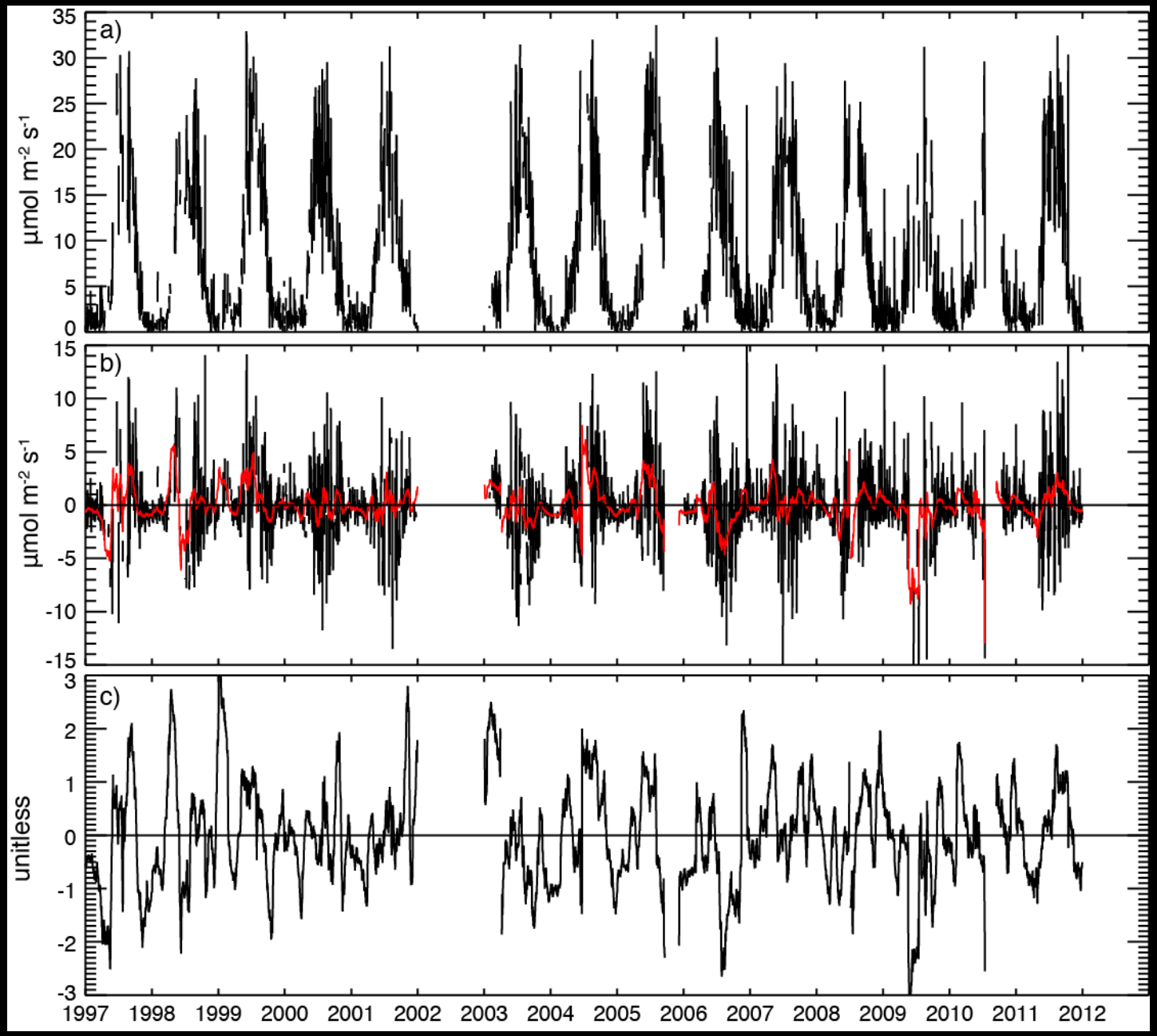
Problem 1

- The same climate forcing does not produce the same response across ecosystems – even when they're right next to each other!


Annual NEE
gC m^{-2} yr^{-1}
200
100
0
−100
−200
−300
−400
−500
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Old-growth
mixed forest
Regional
Tall tower
Shrub
wetland
Mature
hardwood

Problem 2

- NEE is a combination of ecosystem carbon cycle processes
- Partitioning into GPP and Reco relies on environmental drivers – making causal analysis circular!
- Use simple data-based metric to assess net “drawdown” from night to day
- Average across time and standarize the anomalies

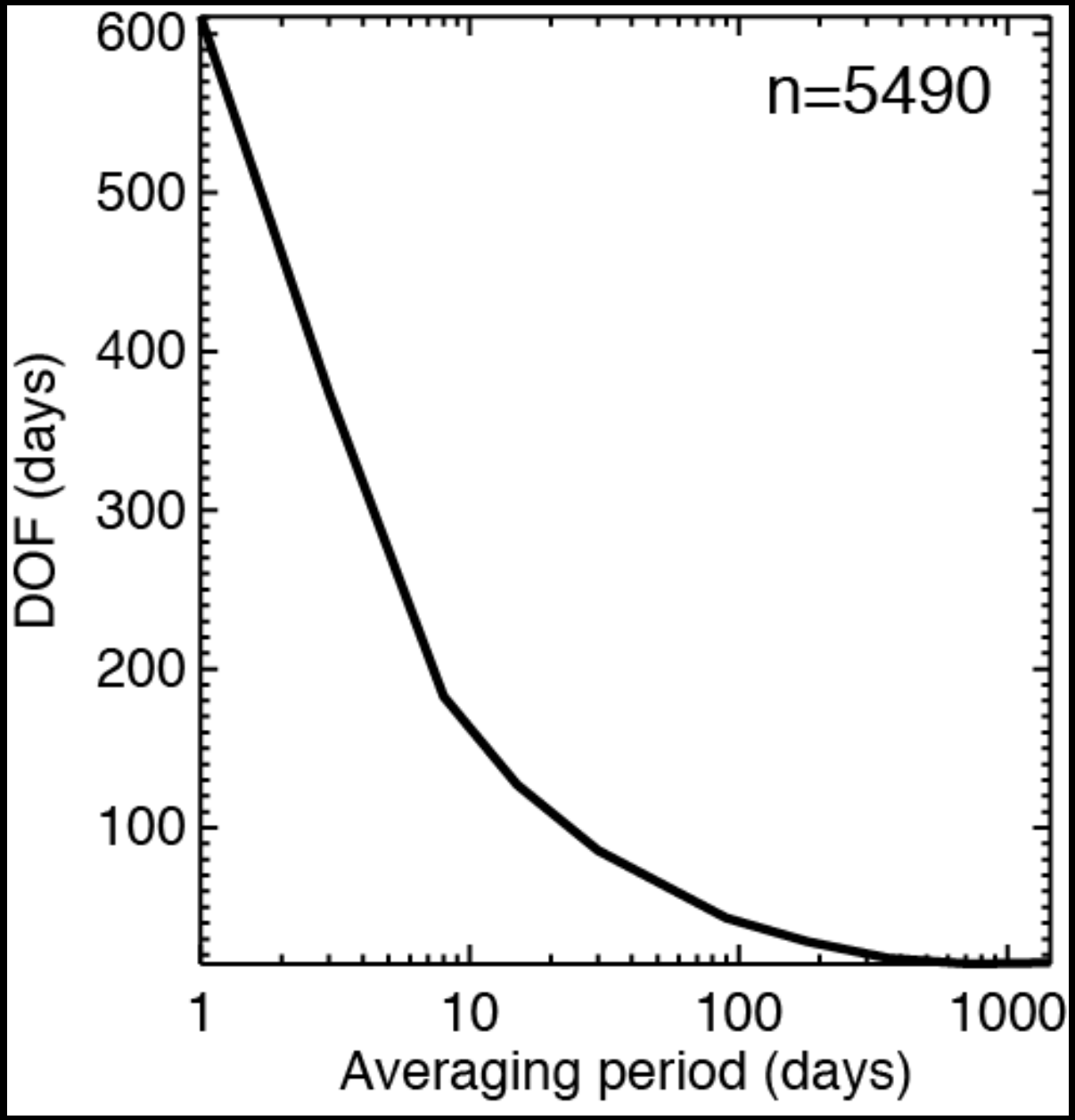

a)
b)
c)
µmol m-2 s-1
µmol m-2 s-1
unitless
35
30
25
20
15
10
5
0
15
10
5
0
-5
-10
-15
3
2
1
0
-1
-2
-3
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012

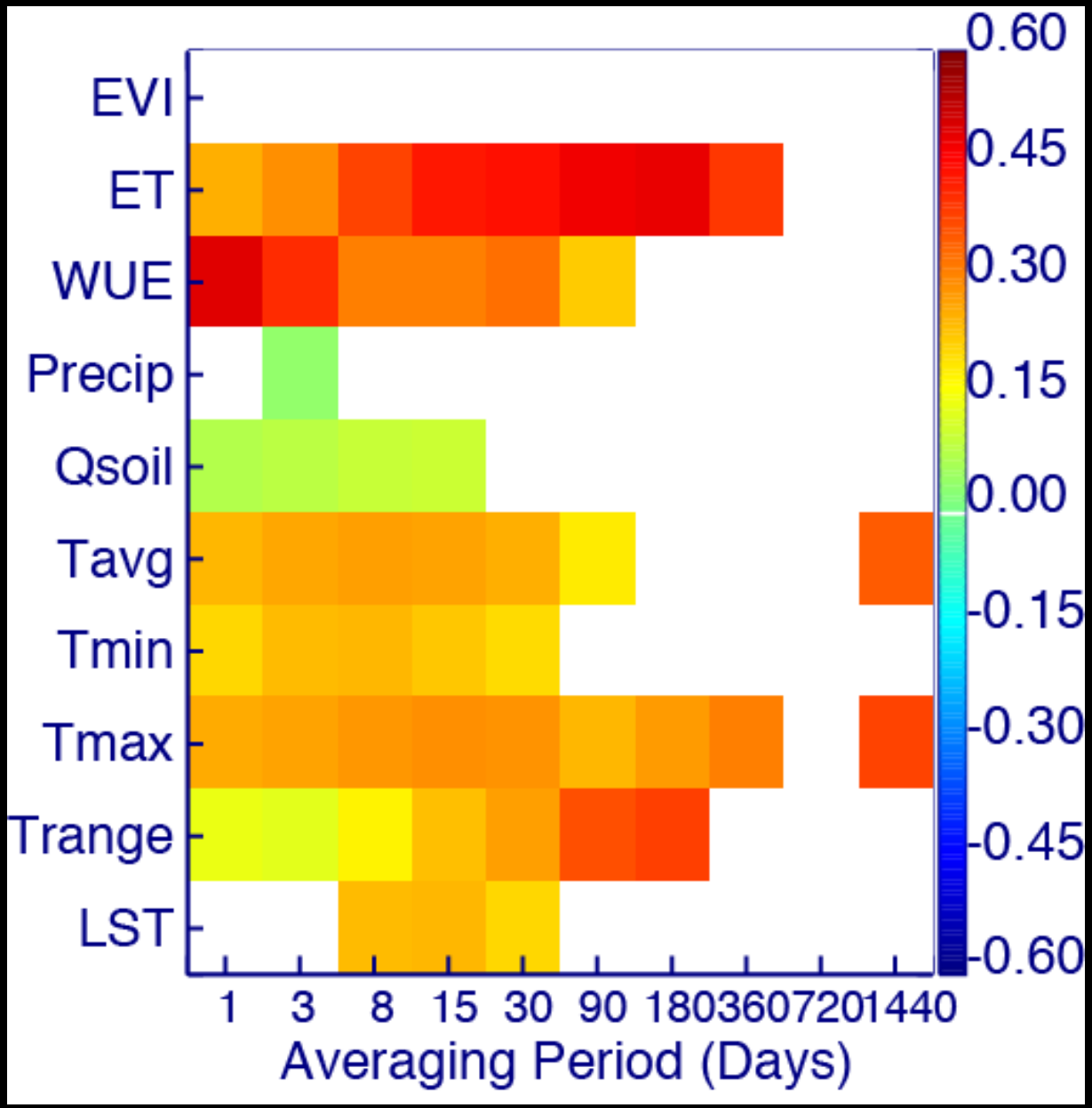
Problem 3

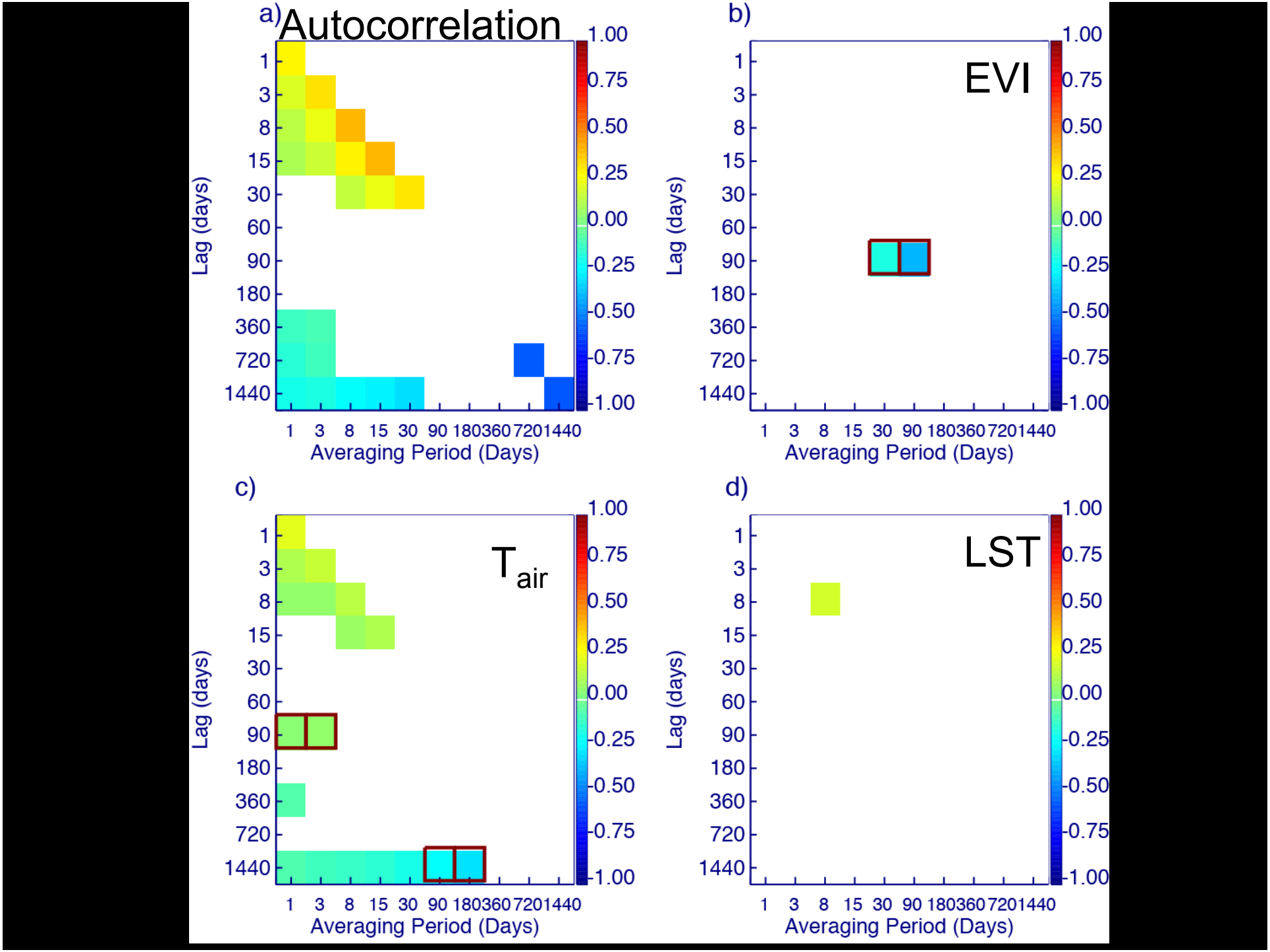
- Every flux tower based correlation is significant when you have thousands to tens of thousands of datapoints
  - Effect sizes may be small, though
- Account for autocorrelation using "reduced degrees of freedom" metric!

$$N_* = \frac{N}{\sum_{t=N/2}^{N}\left[\left(1-\frac{t}{N}\right)\rho_t^X \rho_t^Y\right]}$$

Bretherton et al., 1999, J Clim

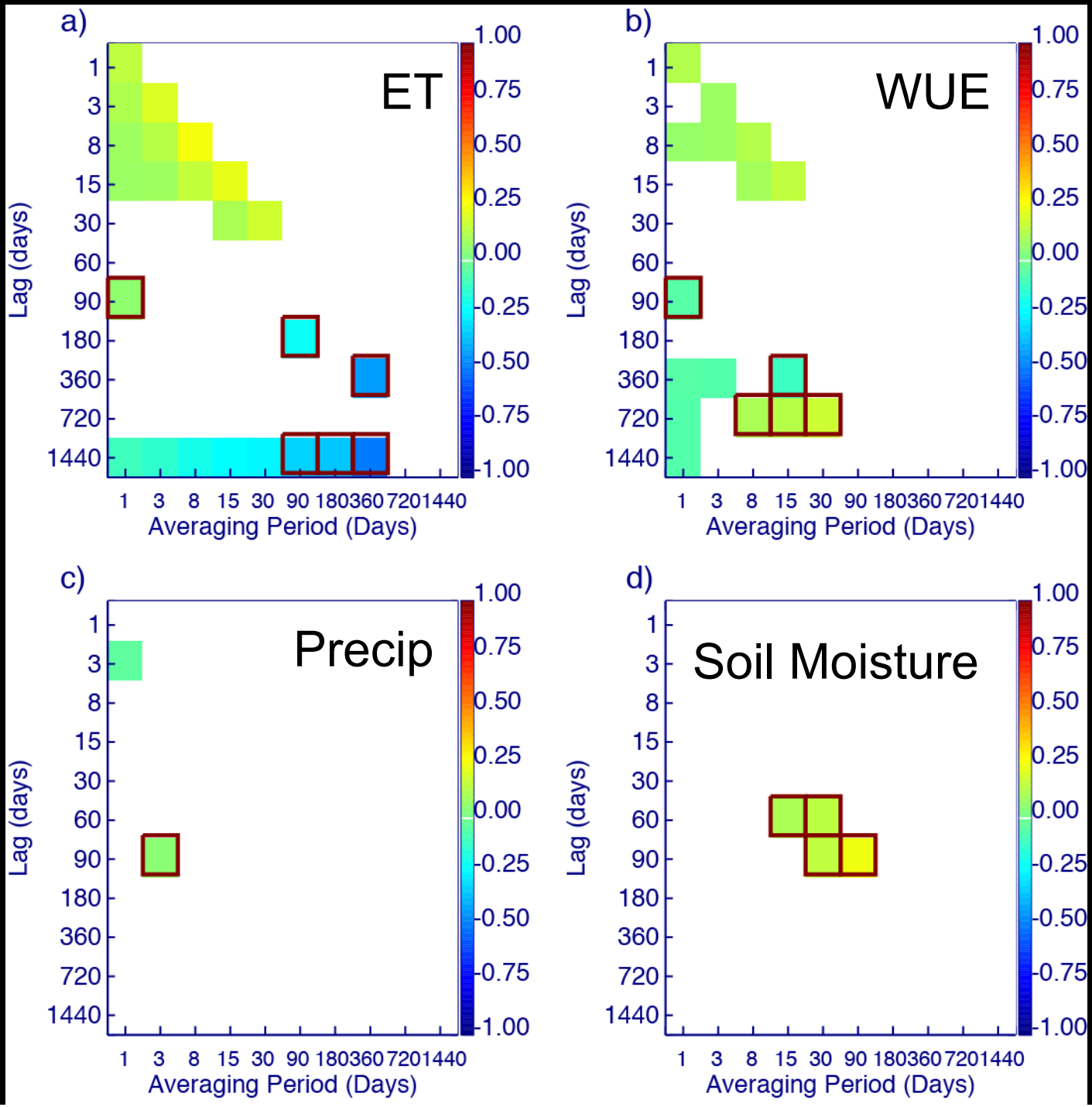

n=5490
600
500
400
300
200
100
DOF (days)
1
10
100
1000
Averaging period (days)


EVI
ET
WUE
Precip
Qsoil
Tavg
Tmin
Tmax
Trange
LST
0.60
0.45
0.30
0.15
0.00
-0.15
-0.30
-0.45
-0.60
1
3
8
15
30
90
180
360
720
1440
Averaging Period (Days)


a) Autocorrelation
b)
EVI
c)
T_{air}
d)
LST
Lag (days)
1
3
8
15
30
60
90
180
360
720
1440
Averaging Period (Days)
1 3 8 15 30 90 180 360 720 1440
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
-1.00

Important points 1

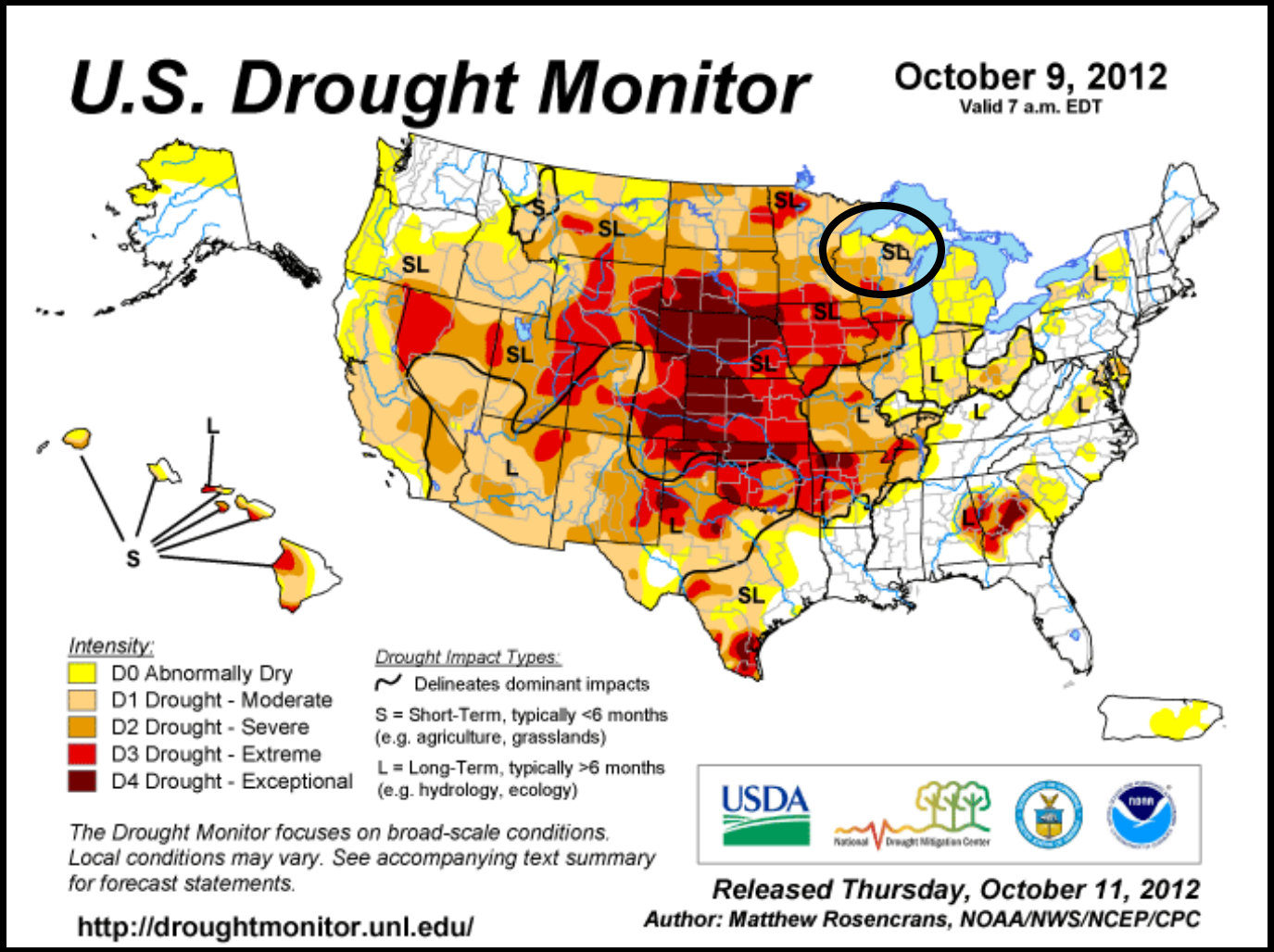
- Highly significant autocorrelations at daily to seasonal scales up to one month lag imply a strong biological feedback that can damp response to extremes
- Weak negative autocorrelations at multi-year scales also highlight slow press processes and oscillations
- Remotely sensed anomalies have little correlation to carbon flux even though mean seasonal variation correlates highly

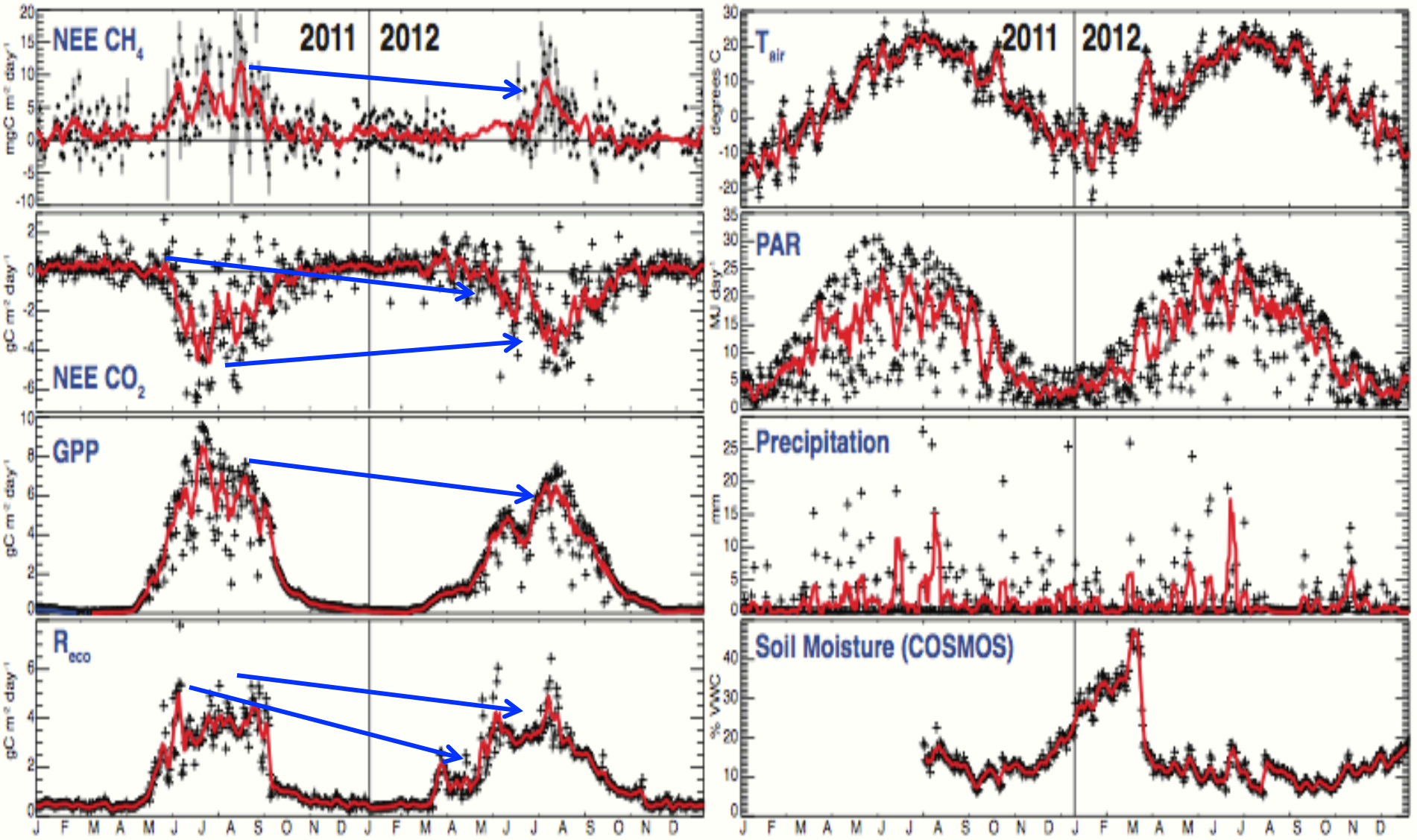

a)
ET
b)
WUE
c)
Precip
d)
Soil Moisture
Lag (days)
1
3
8
15
30
60
90
180
360
720
1440
1 3 8 15 30 90 180 360 720 1440
Averaging Period (Days)
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
-1.00

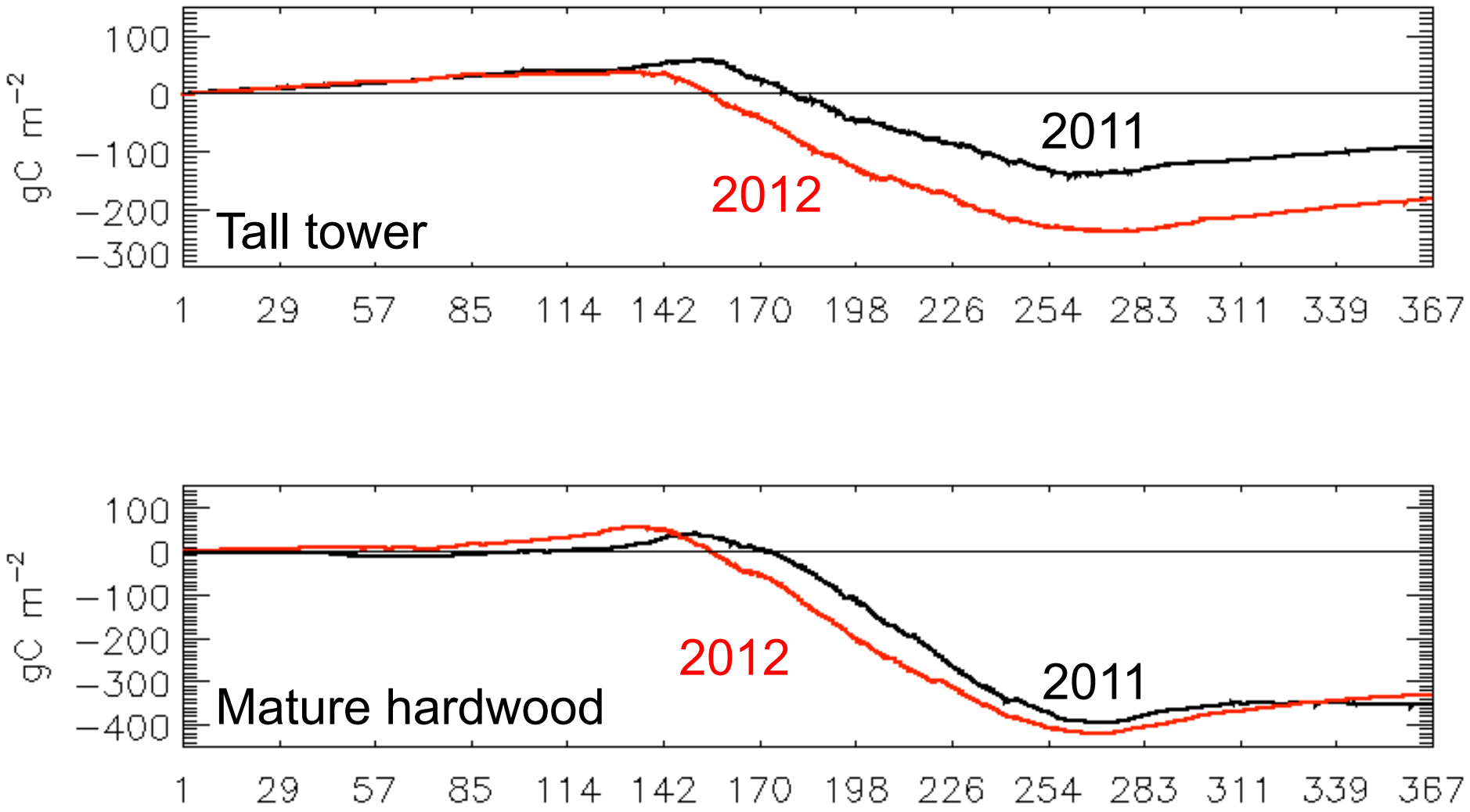
Important points 2

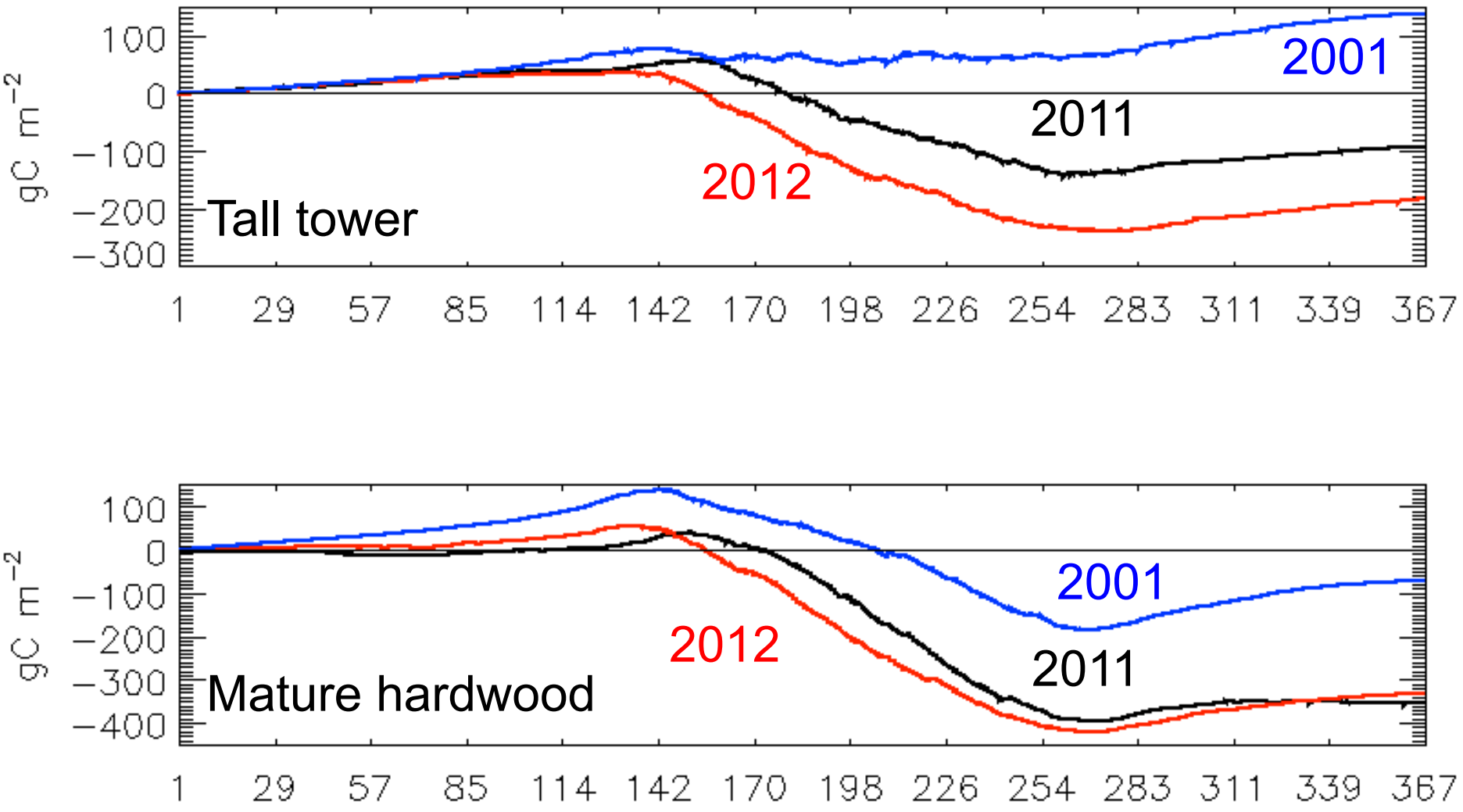
- Moisture extremes impact to regional carbon sequestration display significant seasonal lags and primarily influence monthly to seasonal uptake
- Positive correlations imply mesic forest is in-fact moisture limited, but not in the usual sense

What about 2012?




NEE CH4
2011
2012
mgC m-2 day-1
NEE CO2
gC m-2 day-1
GPP
gC m-2 day-1
Reco
gC m-2 day-1
J F M A M J J A S O N D J F M A M J J A S O N D
Tair
degrees C
PAR
MJ day-1
Precipitation
mm
Soil Moisture (COSMOS)
% VWC


100
0
−100
−200
−300
gC m−2
Tall tower
2011
2012
1
29
57
85
114
142
170
198
226
254
283
311
339
367
100
0
−100
−200
−300
−400
gC m−2
Mature hardwood
2012
2011
1
29
57
85
114
142
170
198
226
254
283
311
339
367


gC m^{-2}
100
0
−100
−200
−300
2001
2011
2012
Tall tower
1
29
57
85
114
142
170
198
226
254
283
311
339
367
gC m^{-2}
100
0
−100
−200
−300
−400
2001
2012
2011
Mature hardwood
1
29
57
85
114
142
170
198
226
254
283
311
339
367

Important points 3

- Warm, dry conditions more likely promoted a longer growing season through phenology than reduced uptake by stomatal closure
- Biotic disturbances and their frequency/ extremes may be more important than climate extremes in many places

Thanks!

- Contributors:
  - Jonathan Thom, Ke Xu, Arlyn Andrews, Dan Baumann, Bruce Cook, many others…
- Funding:
  - NSF, WI Focus on Energy, DOE
- Publications:
  - Desai, A.R., 2013. Influence and predictive capacity of climate anomalies on daily to decadal extremes in canopy photosynthesis. Photosynthesis Research, #PRES-S-12-00139, submitted.
  - Cook, B.D., Bolstad, P.V., Martin, J.G., Heinsch, F.A., Davis, K.J., Wang, W., Desai, A.R., and Teclaw, R.M., 2008. Using light-use and production efficiency models to predict forest production and carbon exchange during canopy disturbance events, Ecosystems, 11: 26-44, doi:10.1007/s10021-007-9105-0