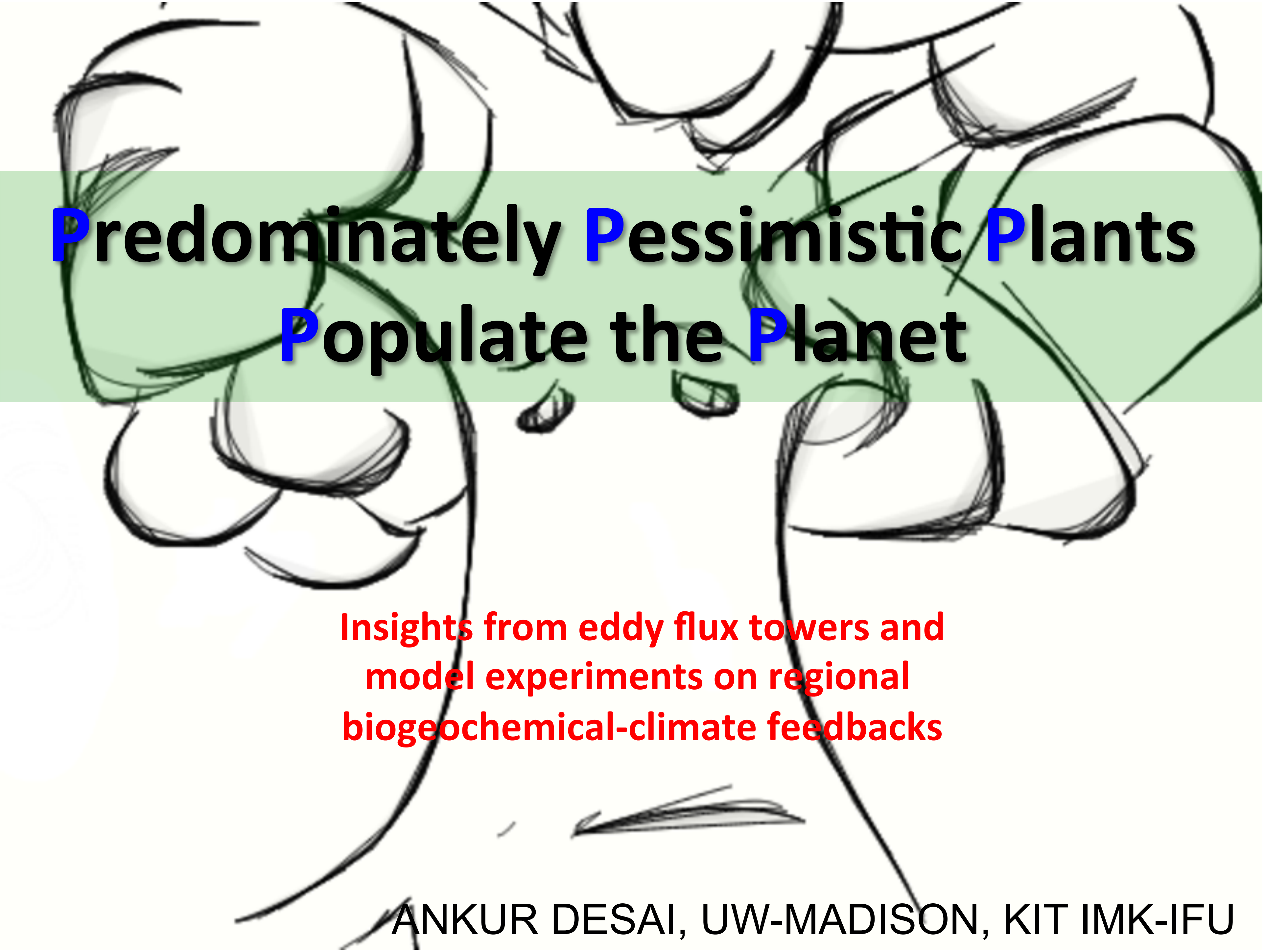


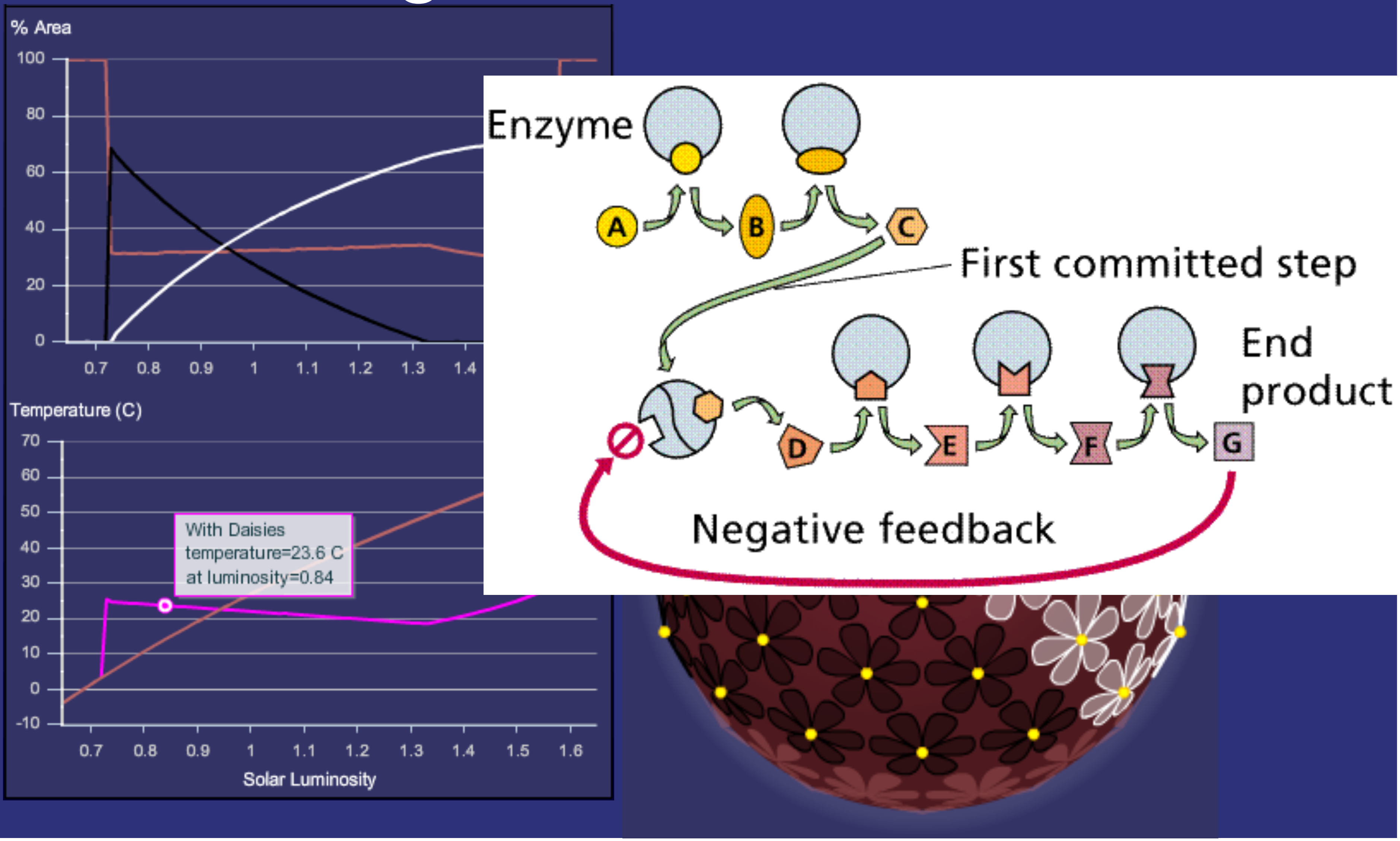
Predominately Pessimistic Plants Populate the Planet

Insights from eddy flux towers and model experiments on regional biogeochemical-climate feedbacks

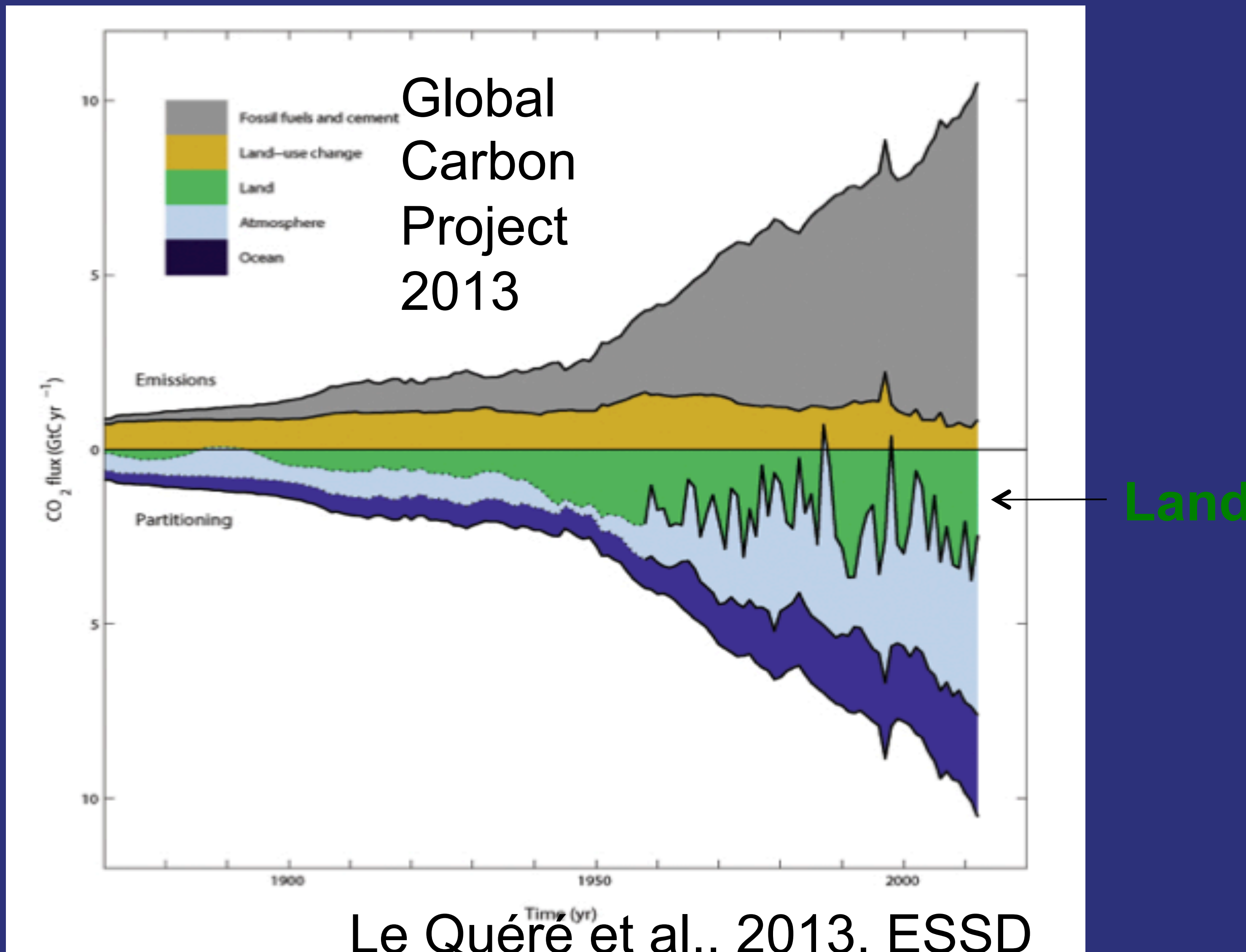
ANKUR DESAI, UW-MADISON, KIT IMK-IFU

PROVACATIVE?

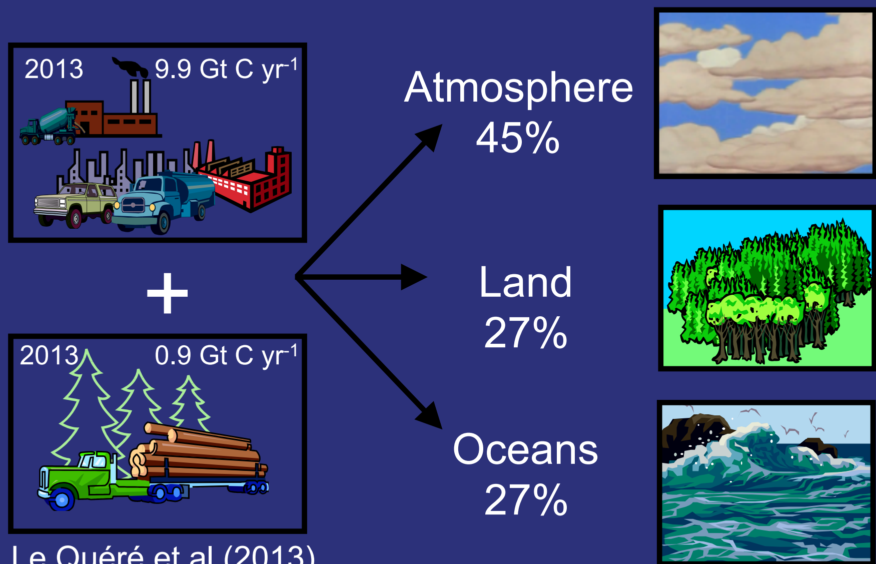
Negative Feedbacks



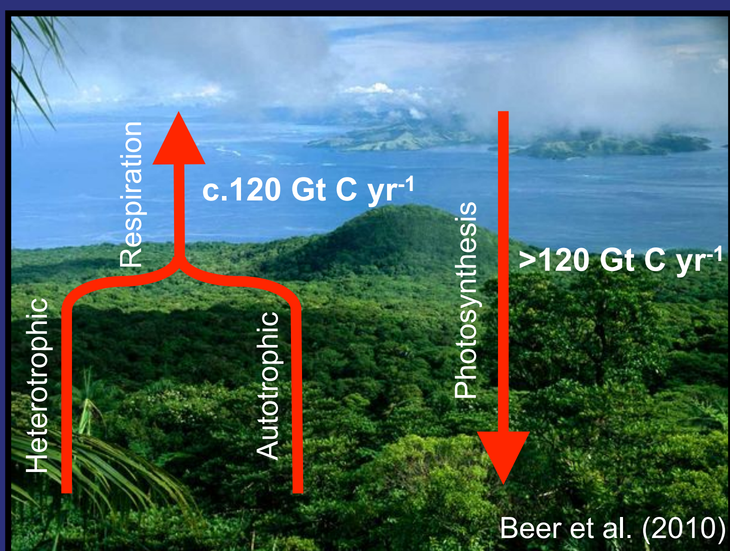
Terrestrial land sink is the largest source of variability in the atmospheric CO_2 growth rate

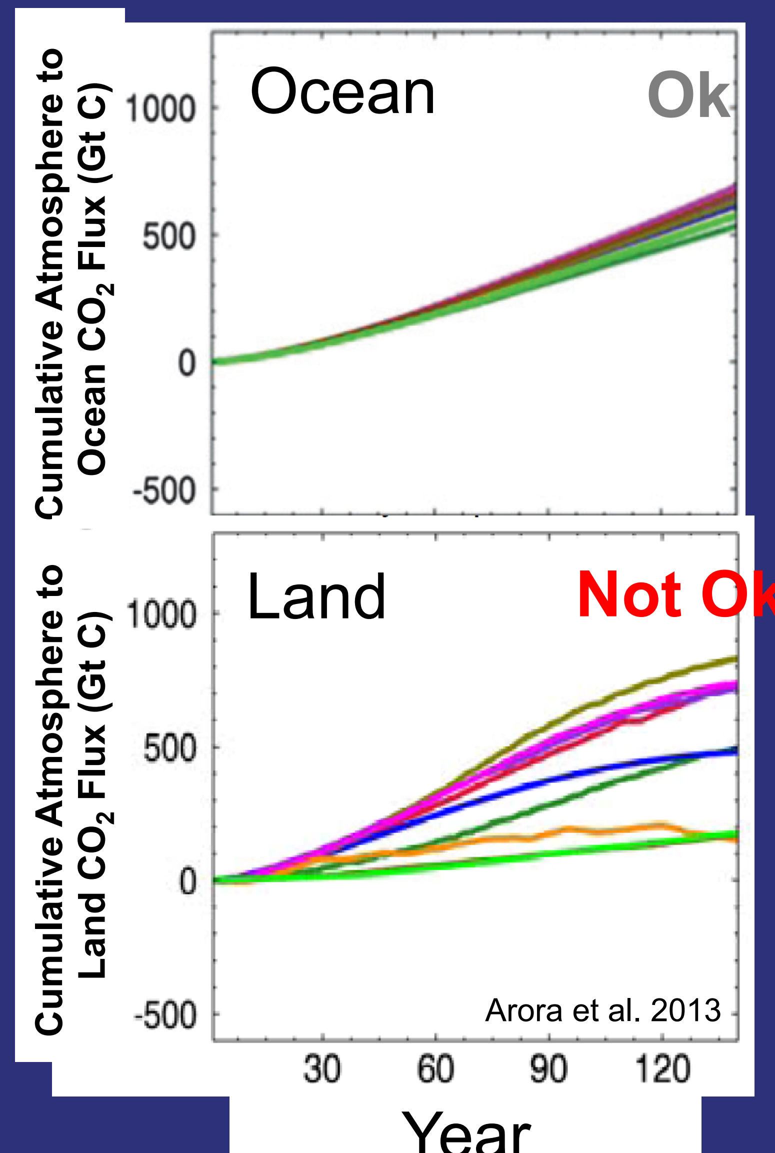


Terrestrial Biosphere CO_2 Flux Dominates Carbon Cycle Prediction Uncertainty

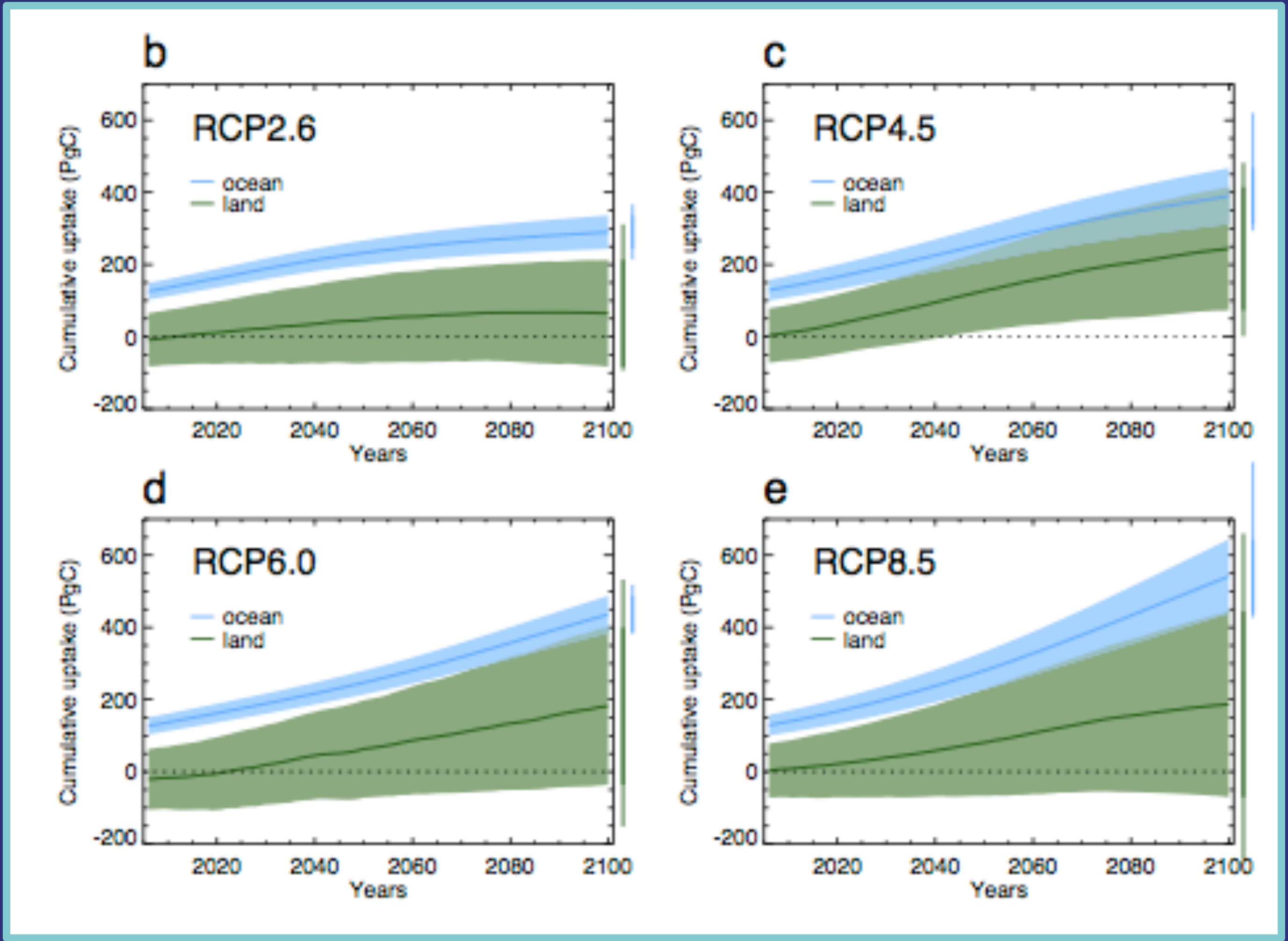


Le Quéré et al (2013)





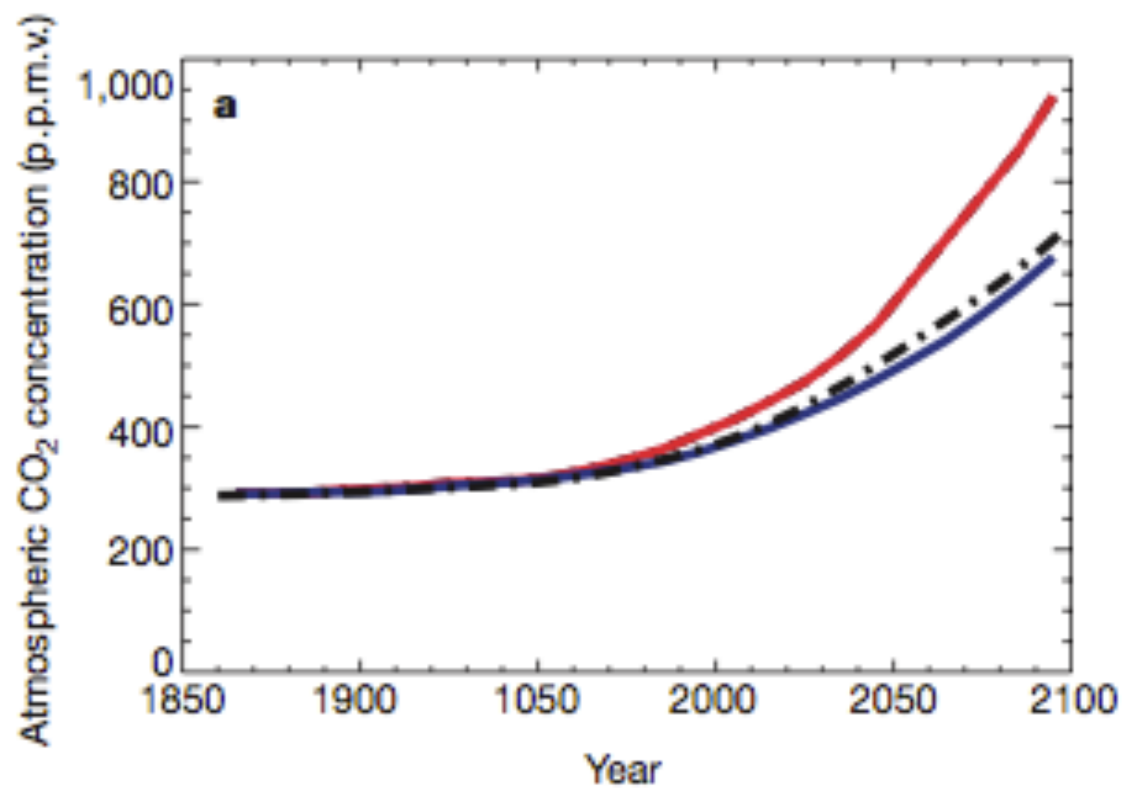
Terrestrial carbon cycle feedback is a leading order uncertainty for climate simulation



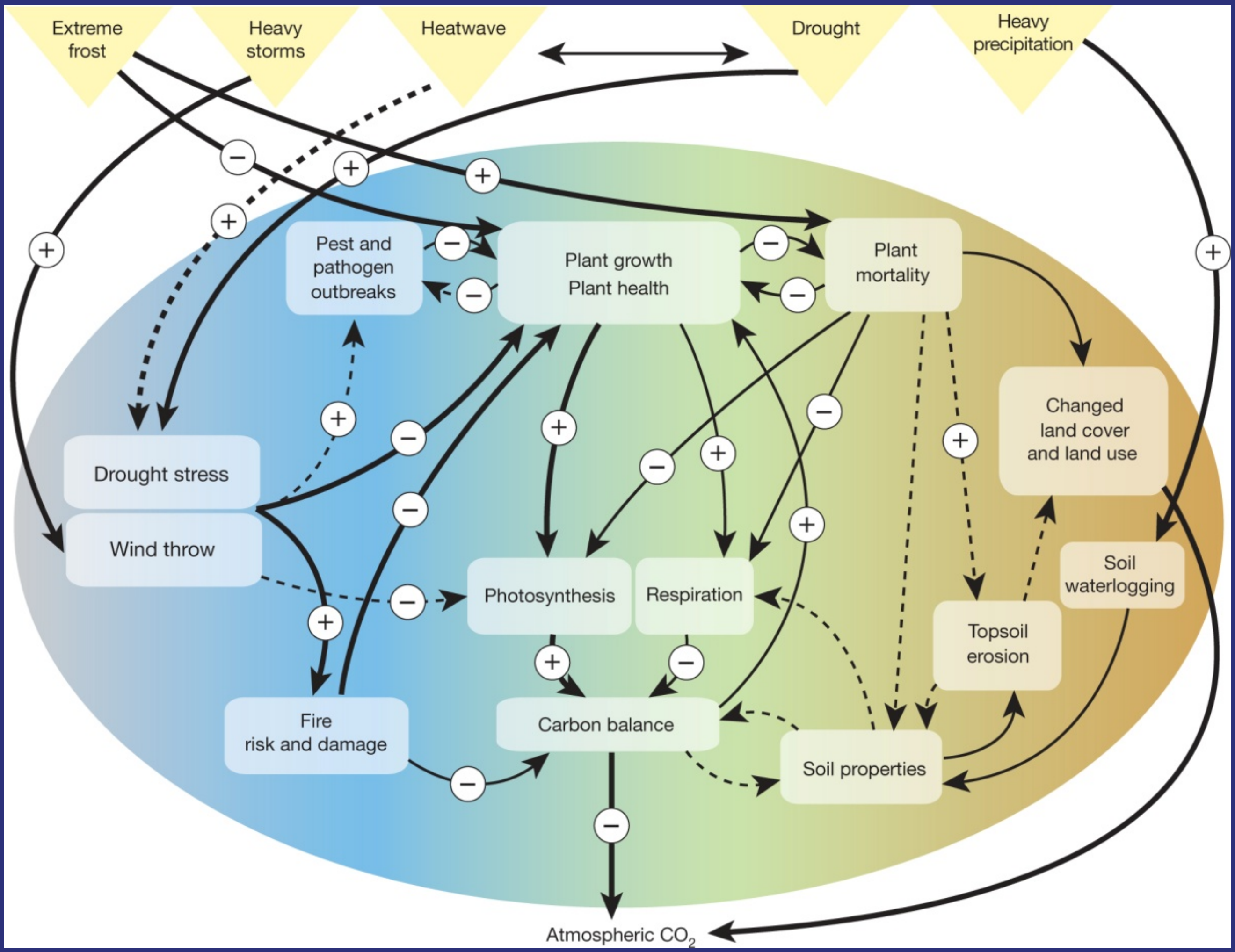
IPCC AR5 WG1 CH6 (draft)

Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model

Peter M. Cox*, Richard A. Betts*, Chris D. Jones*, Steven A. Spall* & Ian J. Totterdell†



Processes and feedbacks triggered by extreme climate events?



M Reichstein *et al. Nature* **500**, 287-295 (2013) doi:10.1038/nature12350

No one trusts a model except the one who wrote it; everyone trusts an observation except the one who made it – Harlow Shapley (by way of Matt Disney)

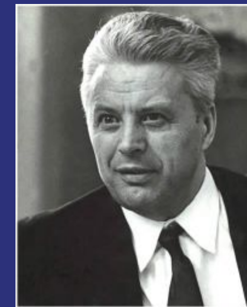
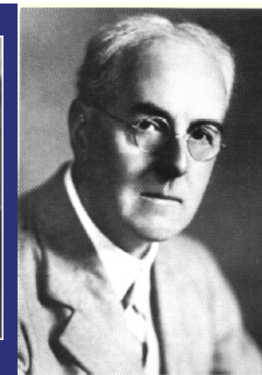
PROLOGUE


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

Eddy covariance is mature technology



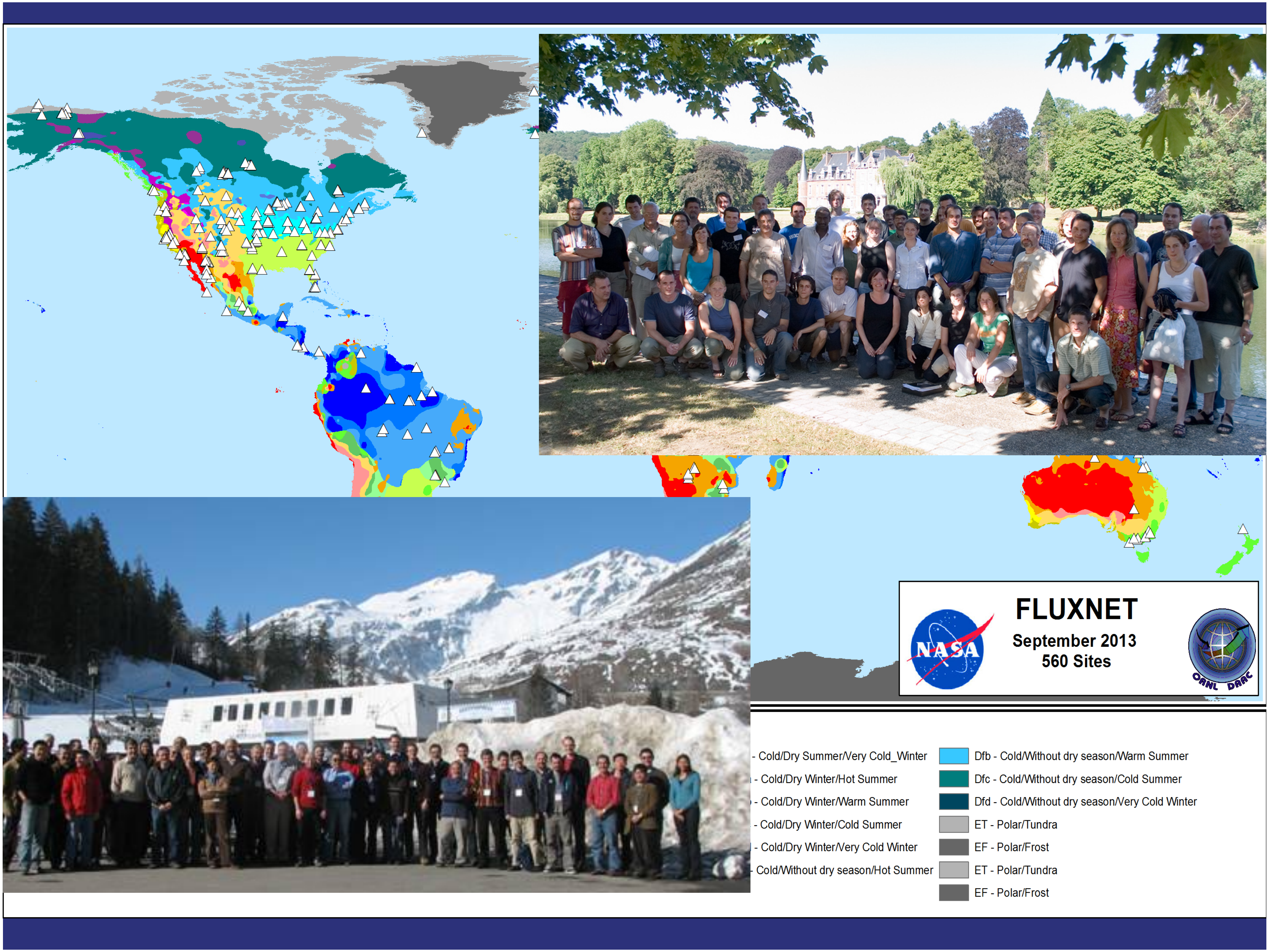
History

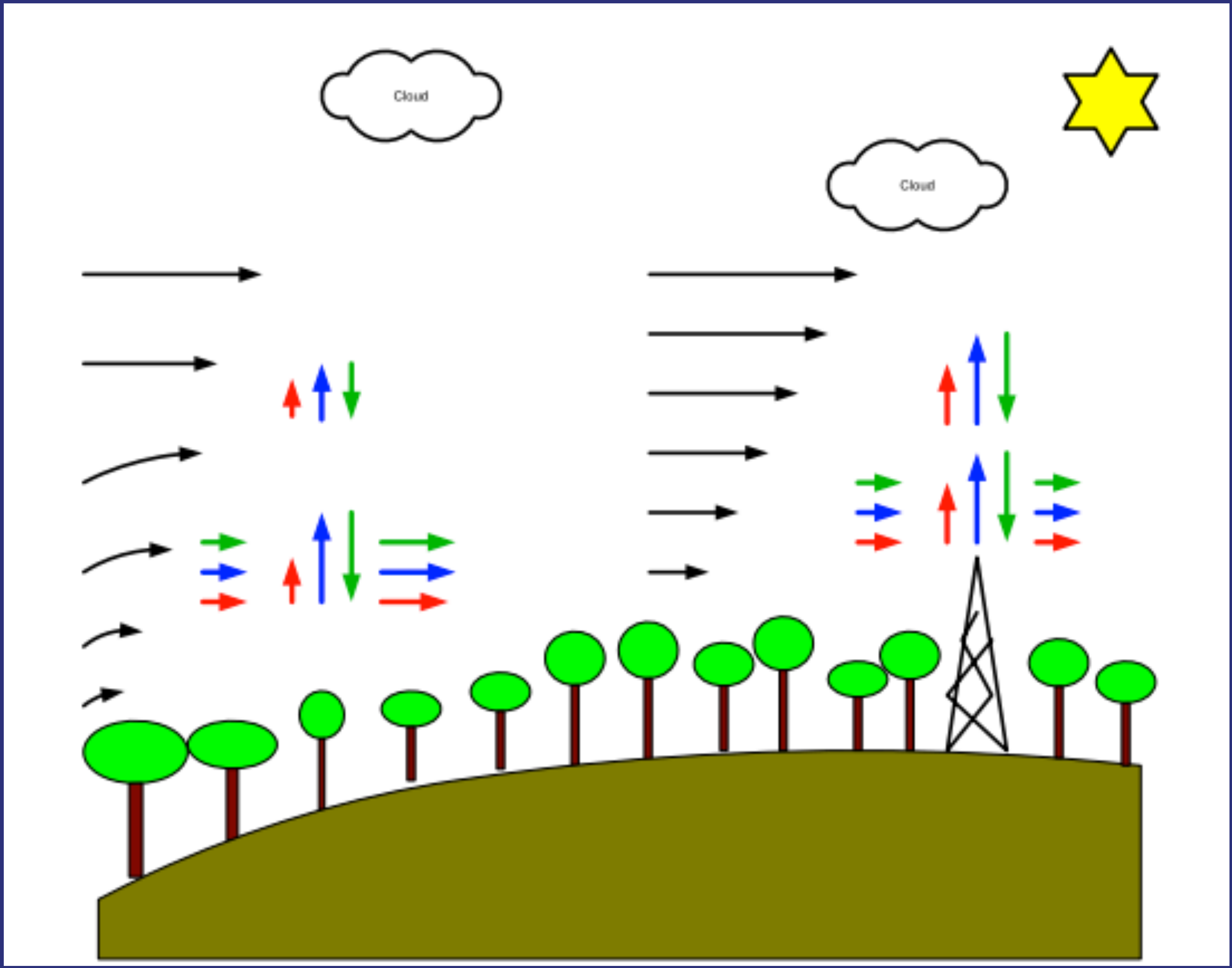




- 1880-1920s Turublence theory (Reynolds, Prandtl, Richardson, Taylor)
- 1940s-1950s Surface-layer theory (Monin-Obhukov, Kolmogorov), development of fast sensors for anemometry
- 1960s early measurements (Inoue, Wyngaard, Kaimal)
- 1970s forest fluxes (Raupach, Lenschow, Denmead)
- 1970s CO_2 fluxes (Desjardins, Leuning)
- 1980s Infrared gas analyzers (Verma, Anderson, Valentini)
- 1990s First long-term regional CO_2 flux networks (Wofsy, Baldocchi, Goulden, Law, Aubinet)
- 2000s Global syntheses (FLUXNET, Falge, Papale, Reichstein)
- 2010s Model-data integration, development of operational measurements (NEON, ICOS, you?)



FLUXNET
September 2013
560 Sites
NASA
ORNL DAAC
- Cold/Dry Summer/Very Cold_Winter
- Cold/Dry Winter/Hot Summer
- Cold/Dry Winter/Warm Summer
- Cold/Dry Winter/Cold Summer
- Cold/Dry Winter/Very Cold Winter
Cold/Without dry season/Hot Summer
Dfb - Cold/Without dry season/Warm Summer
Dfc - Cold/Without dry season/Cold Summer
Dfd - Cold/Without dry season/Very Cold Winter
ET - Polar/Tundra
EF - Polar/Frost
ET - Polar/Tundra
EF - Polar/Frost



D. Baldocchi

$$\overline{\frac{D\tilde{C}}{Dt}} = 0 \longrightarrow \overline{\frac{\partial \tilde{C}}{\partial t} + \widetilde{U}_j \frac{\partial \tilde{C}}{\partial x_j}} = 0$$

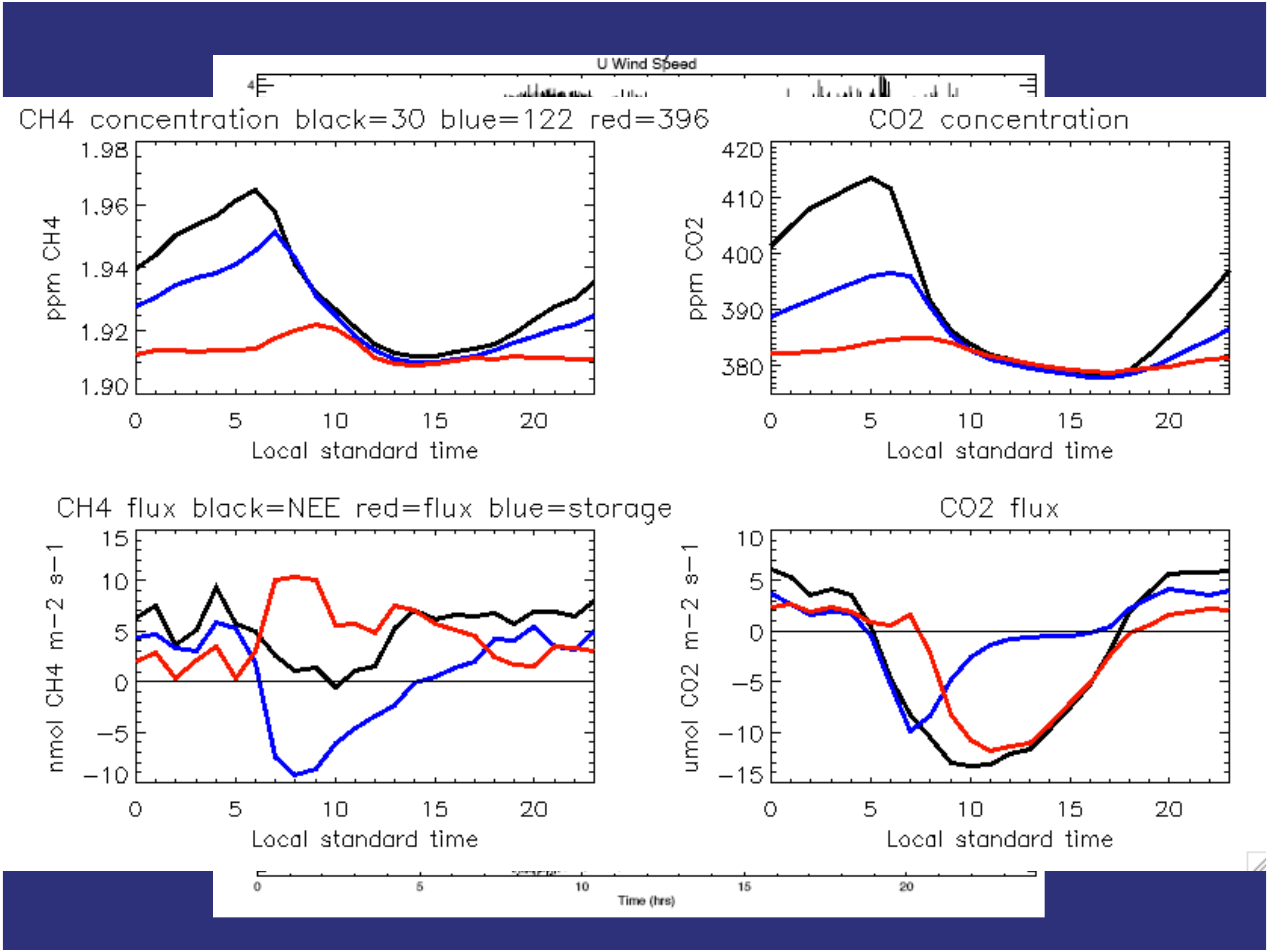
STORAGE TURBULENT-FLUX

$$\text{NEE} \equiv \int_0^{z_r} s\,dz + (\overline{w'c'})|_{z=0}$$

$$= \int_0^{z_r} \frac{\partial \bar{c}}{\partial t} dz + (\overline{w'c'})_r + \bar{w}_r(\bar{c}_r - \langle \bar{c} \rangle) \quad (4)$$

$$\frac{\partial \bar{C}}{\partial t} + \frac{\partial \bar{c}'}{\partial t} + \overline{\bar{U}_j \frac{\partial \bar{C}}{\partial x_j}} + \overline{u_j' \frac{\partial \bar{C}}{\partial x_j}} + \overline{\bar{U}_j \frac{\partial c'}{\partial x_j}} + \overline{u_j' \frac{\partial c'}{\partial x_j}} = 0$$

$$\frac{\partial \bar{C}}{\partial t} + \bar{U}_j \frac{\partial \bar{C}}{\partial x_j} + \overline{u_j' \frac{\partial c'}{\partial x_j}} = \frac{\partial \bar{C}}{\partial t} + \frac{\partial \overline{U_j C}}{\partial x_j} + \frac{\partial \overline{u_j' c'}}{\partial x_j} = 0$$

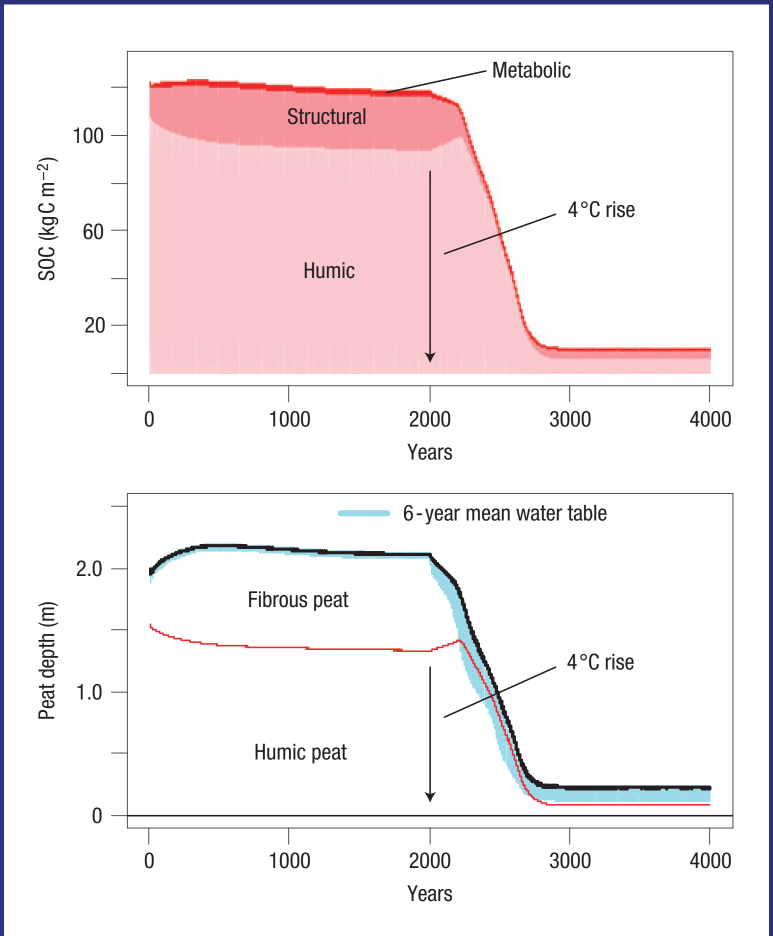

U Wind Speed
CH4 concentration black=30 blue=122 red=396
ppm CH4
Local standard time
CO2 concentration
ppm CO2
Local standard time
CH4 flux black=NEE red=flux blue=storage
nmol CH4 m−2 s−1
Local standard time
CO2 flux
umol CO2 m−2 s−1
Local standard time
Time (hrs)

Who we are


PROOF(?)

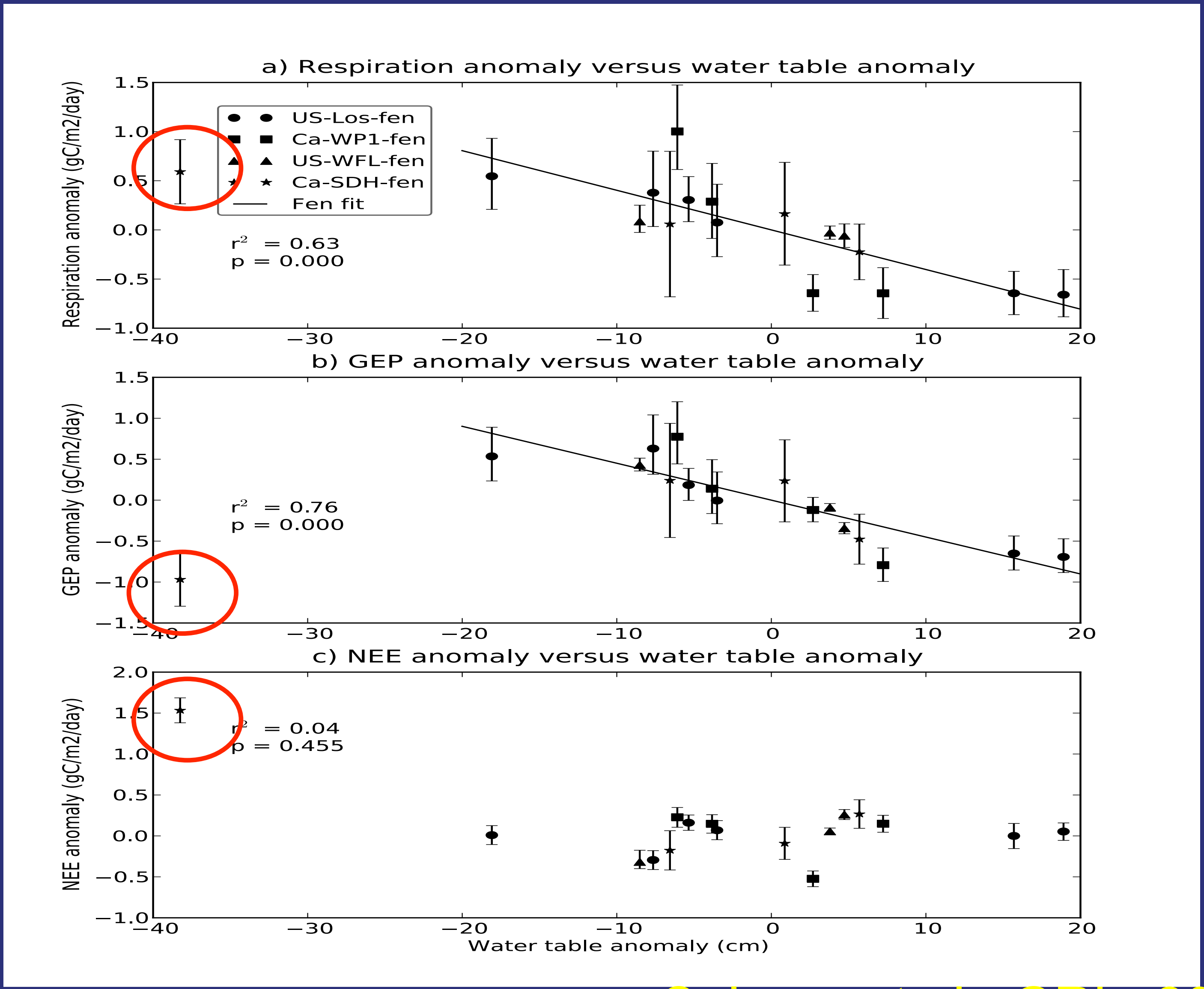
Peatland carbon is vulnerable to climate and hydrological change

- Peat carbon is preserved by cool temperatures and flooded conditions
- Warming and drying can disrupt the process and lead to carbon loss



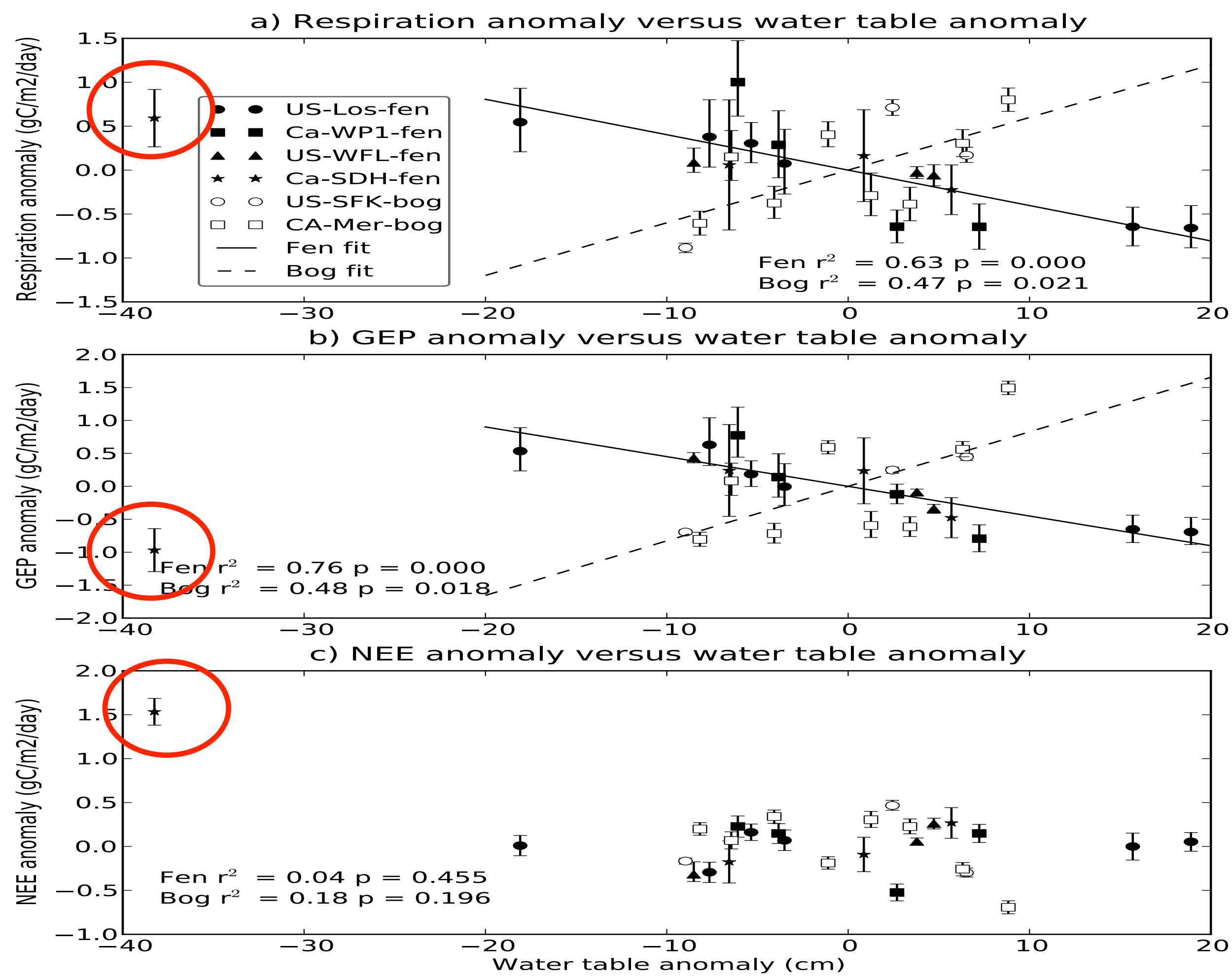
Ise et al 2008

Hydrology does not drive NEE in four fens



Sulman et al., GRL, 2010

Same for bogs, but in a different way



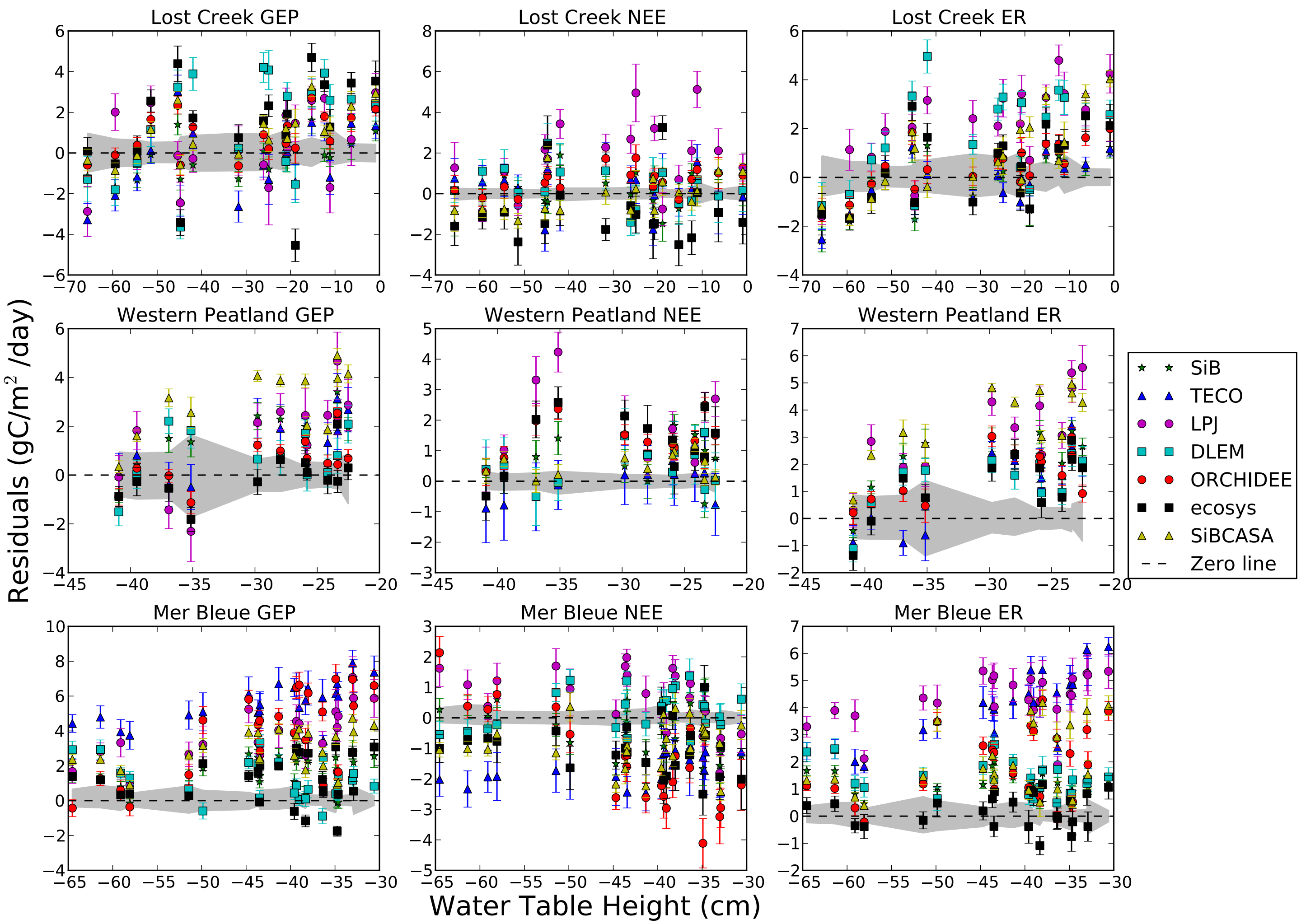
Sulman et al., GRL, 2010

How well did models simulate peatland processes?

Model name	Temporal resolution	Soil layers	Soil C pools	N cycle	Max soil moisture
DLEM	Daily	**2**	3	Yes	Saturation
Ecosys	Hourly	8	9	Yes	Saturation (with water table)
LPJ	Daily	**2**	2	No	**Field capacity**
ORCHIDEE	30-min	**2**	8	No	**Field capacity**
SiB	30-min	10	None	No	Saturation
SiBCASA	30-min	25	9	No	Saturation
TECO	30-min	10	5	No	Saturation

Sulman et al., JGR-G, 2011

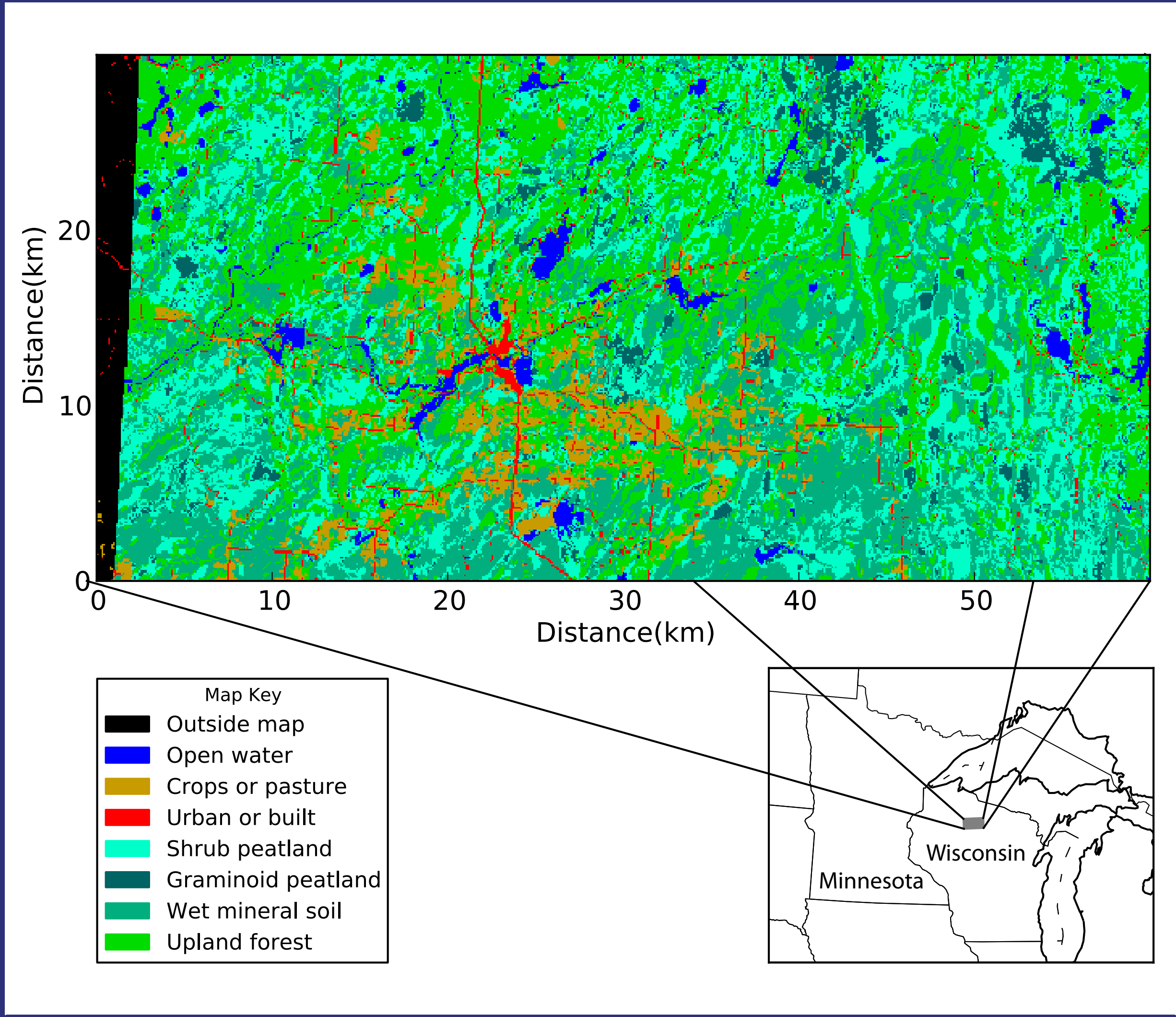
Monthly residuals were correlated with observed water table



Maybe longer term?

Ecoregion	Active area fraction
Upland	38%
Mineral wetland	27%
Shrub peat	29%
Graminoid peat	5%

LANDIS-II model



Sulman et al., Ecosystems, 2013

Water table effects on carbon balance

Peatlands:

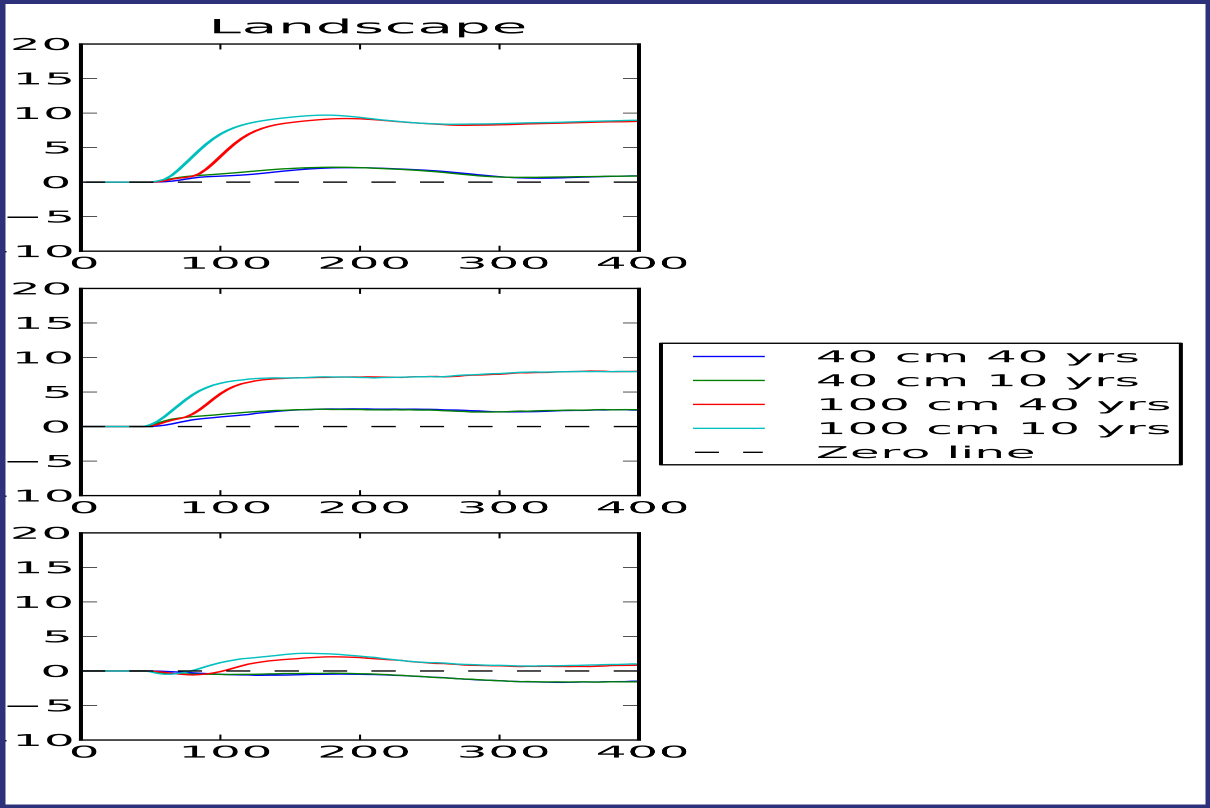
- 100 cm declines:
  - Short term: C gain
  - Long term: C loss
- 40 cm declines
  - Short term: C neutral
  - Long term: C loss

Mineral wetlands:

- C gain for both

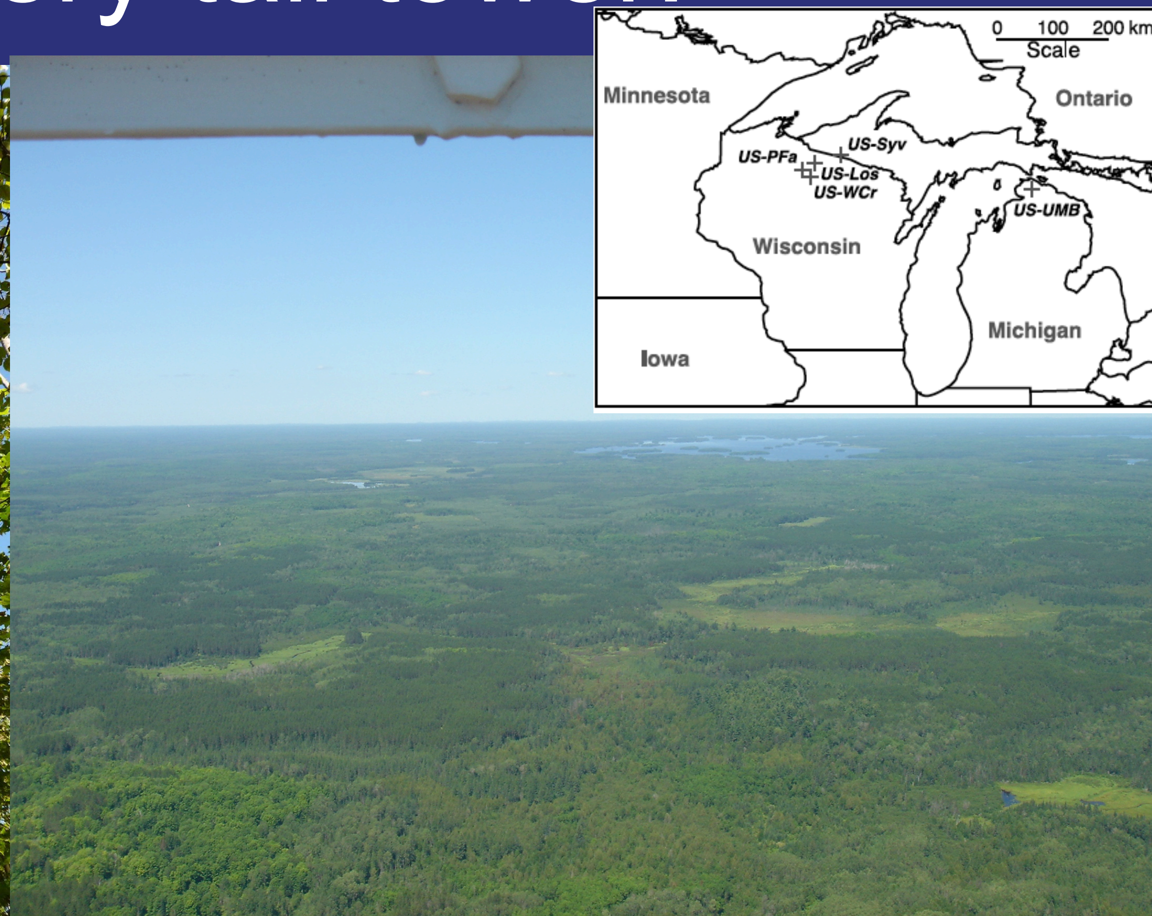
Whole landscape

- Short-term: C increase
- Long-term: C steady
- Time scale of decline made little difference

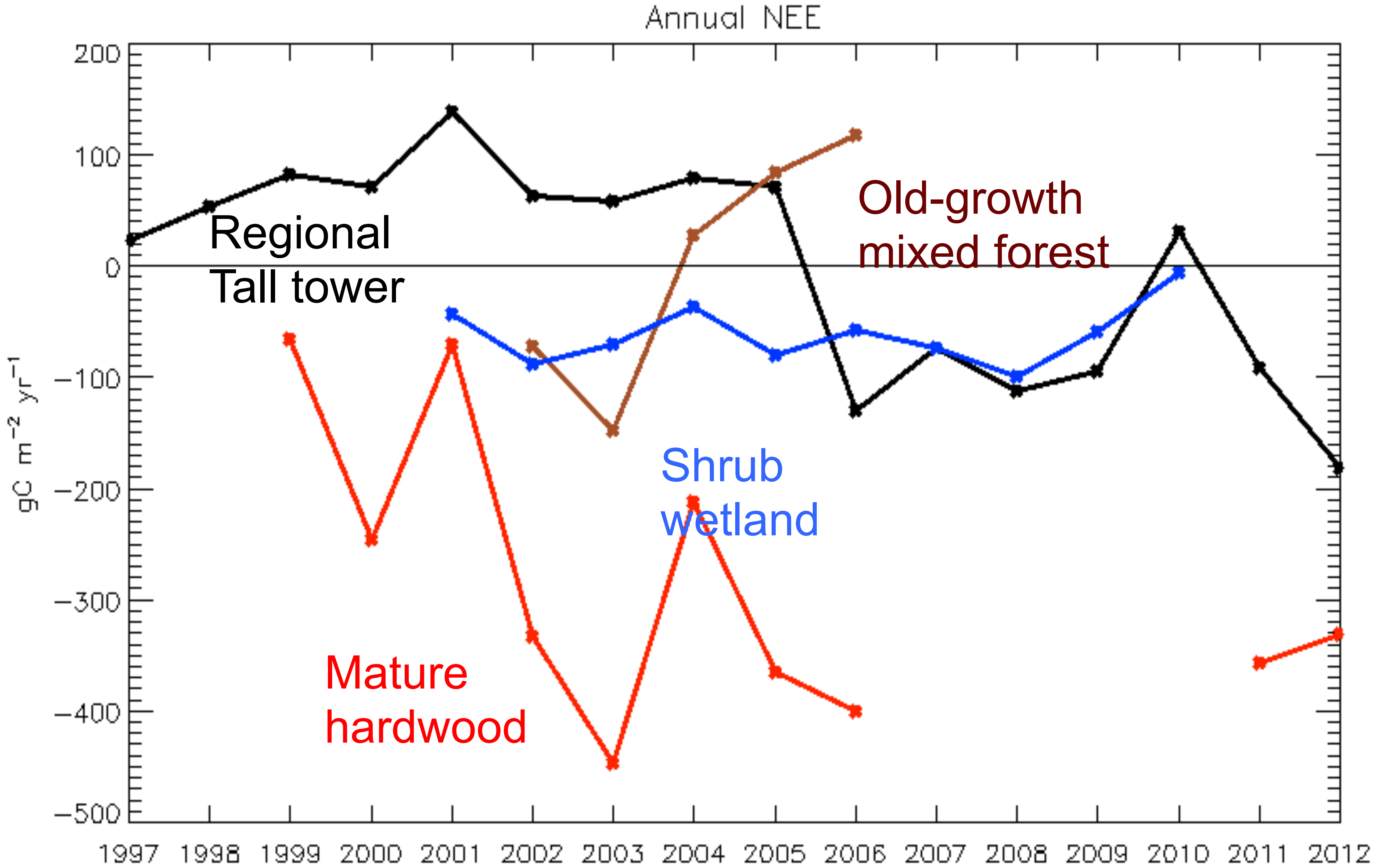


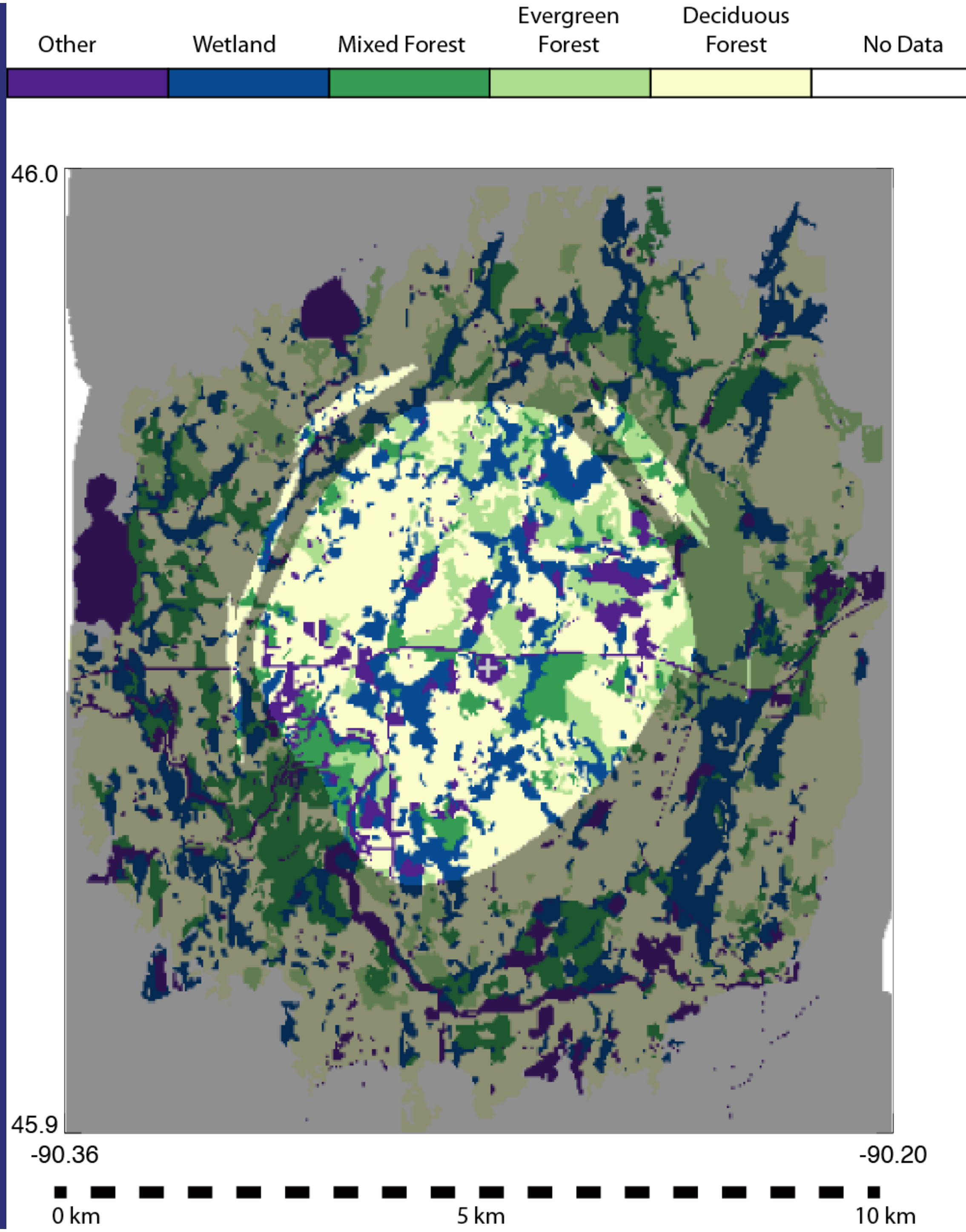
Net change from control run for shallow peat simulations: Different water table scenarios

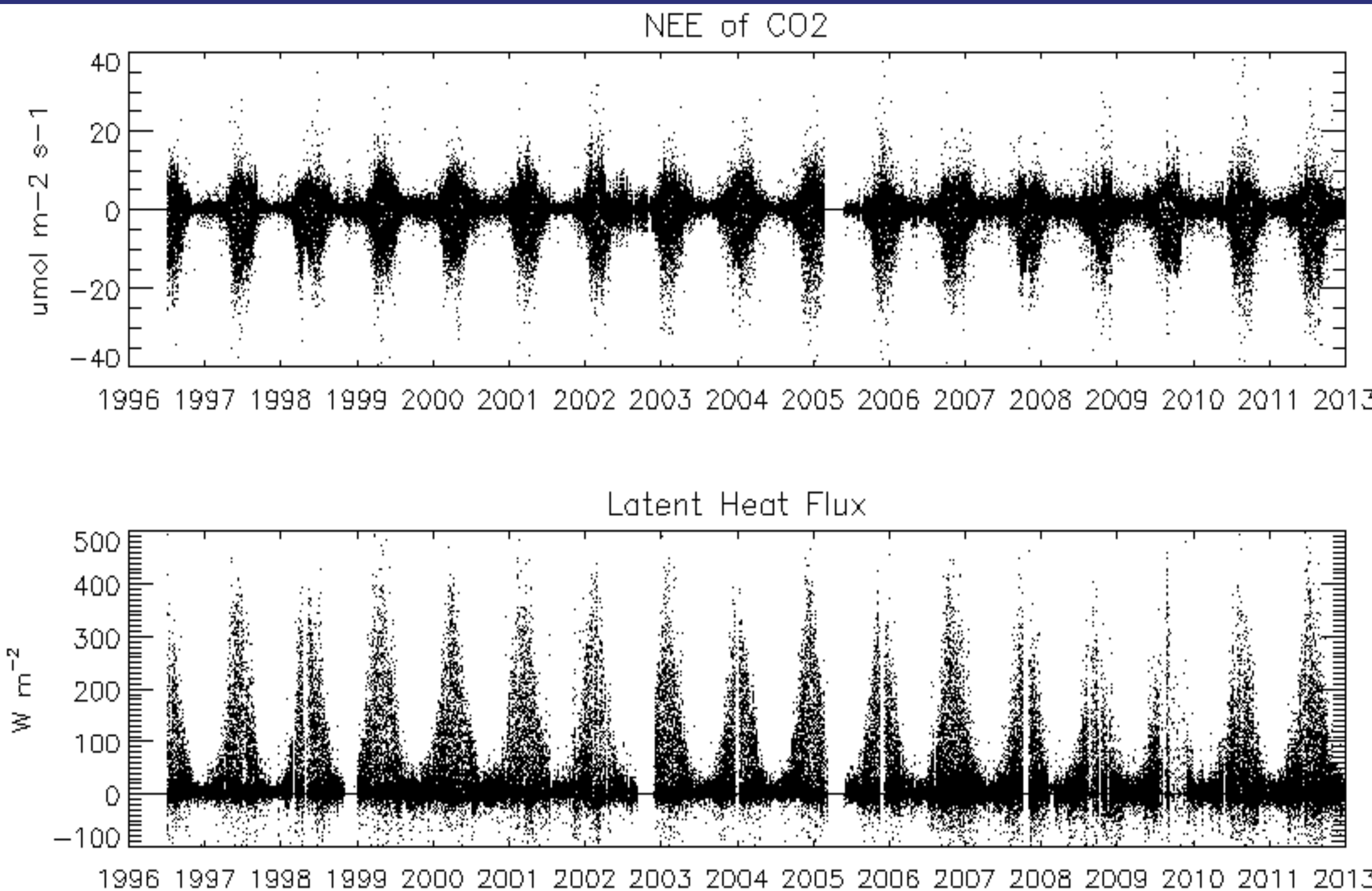
A very tall tower!



Desai, A.R., 2014. Influence and predictive capacity of climate anomalies on daily to decadal extremes in canopy photosynthesis. Photosynthesis Research, 119, 31-47, doi:10.1007/s11120-013-9925-z.

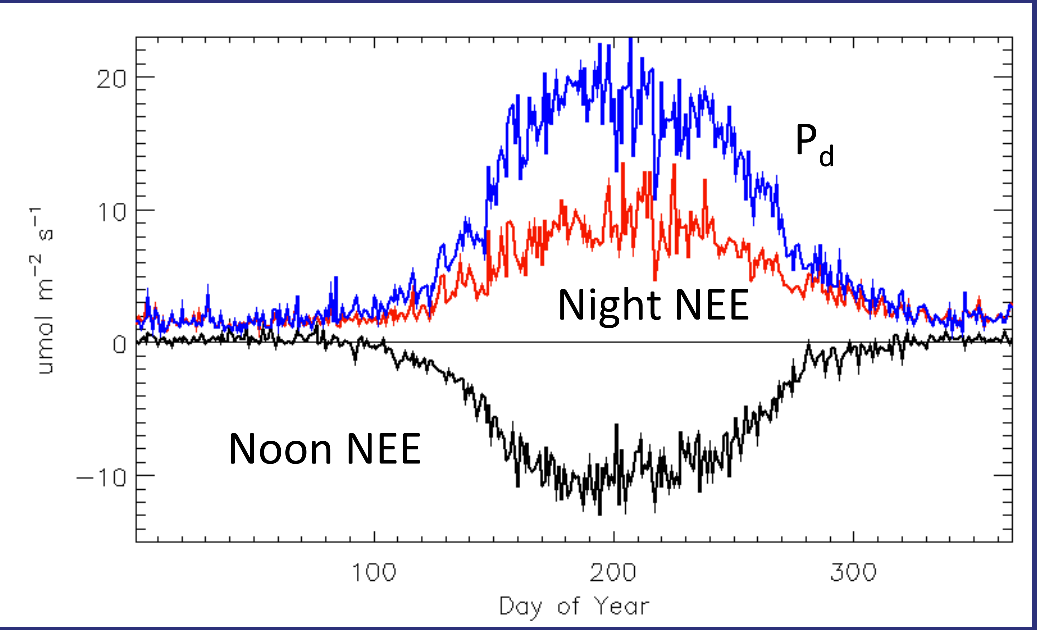

Annual NEE
gC m^{-2} yr^{-1}
200
100
0
−100
−200
−300
−400
−500
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Regional Tall tower
Old-growth mixed forest
Shrub wetland
Mature hardwood


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

From NEE to Productivity

- Flux tower derived "GPP" is sensitive to model selection and gaps (Desai *et al.*, 2008)
- INSTEAD: Use a data-based approach
  - P_d = Max nighttime observed NEE – Mean noon (10-14) NEE
    - Reject noon NEE is > 50% gap-filled

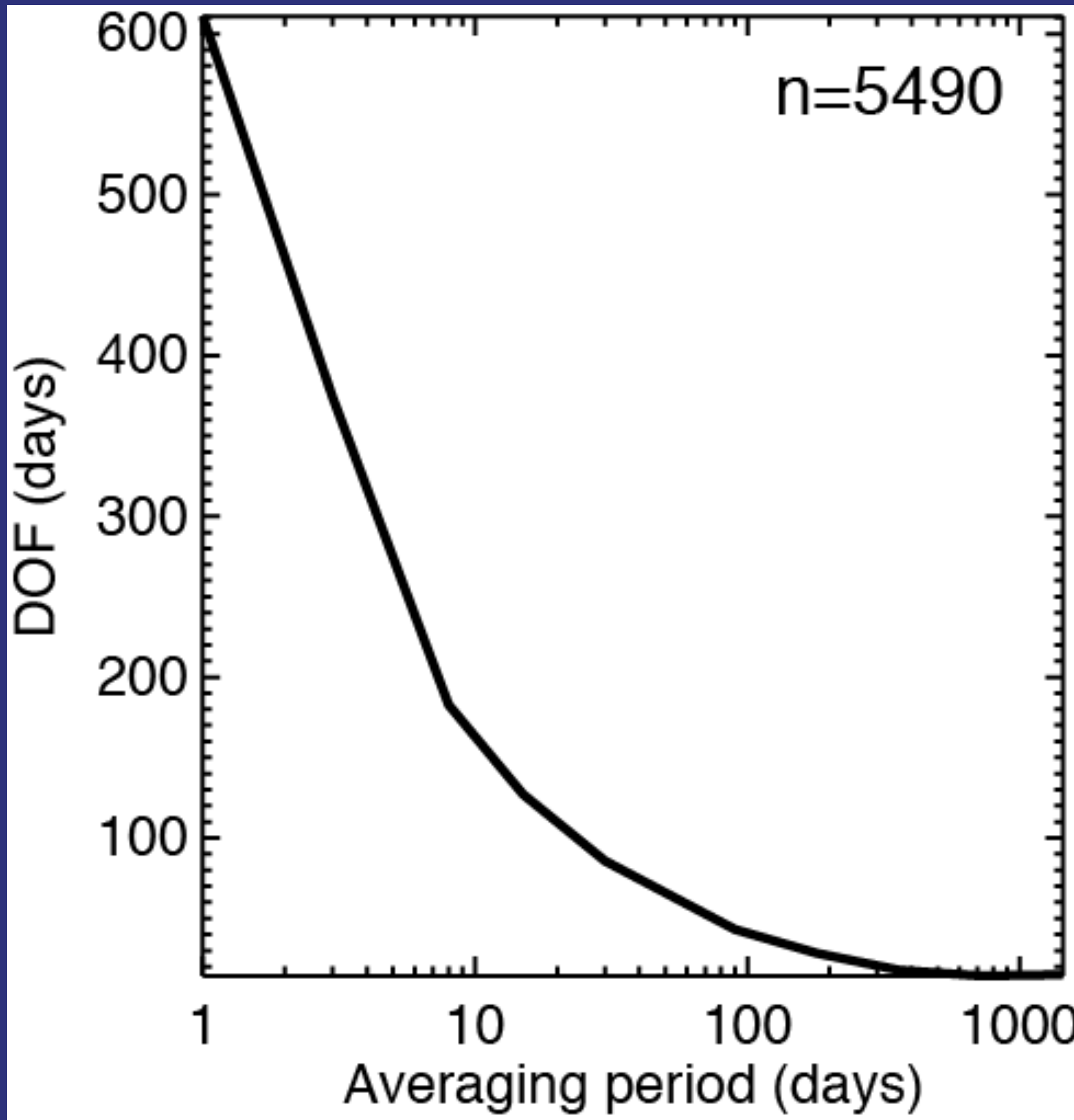


Problem

- 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



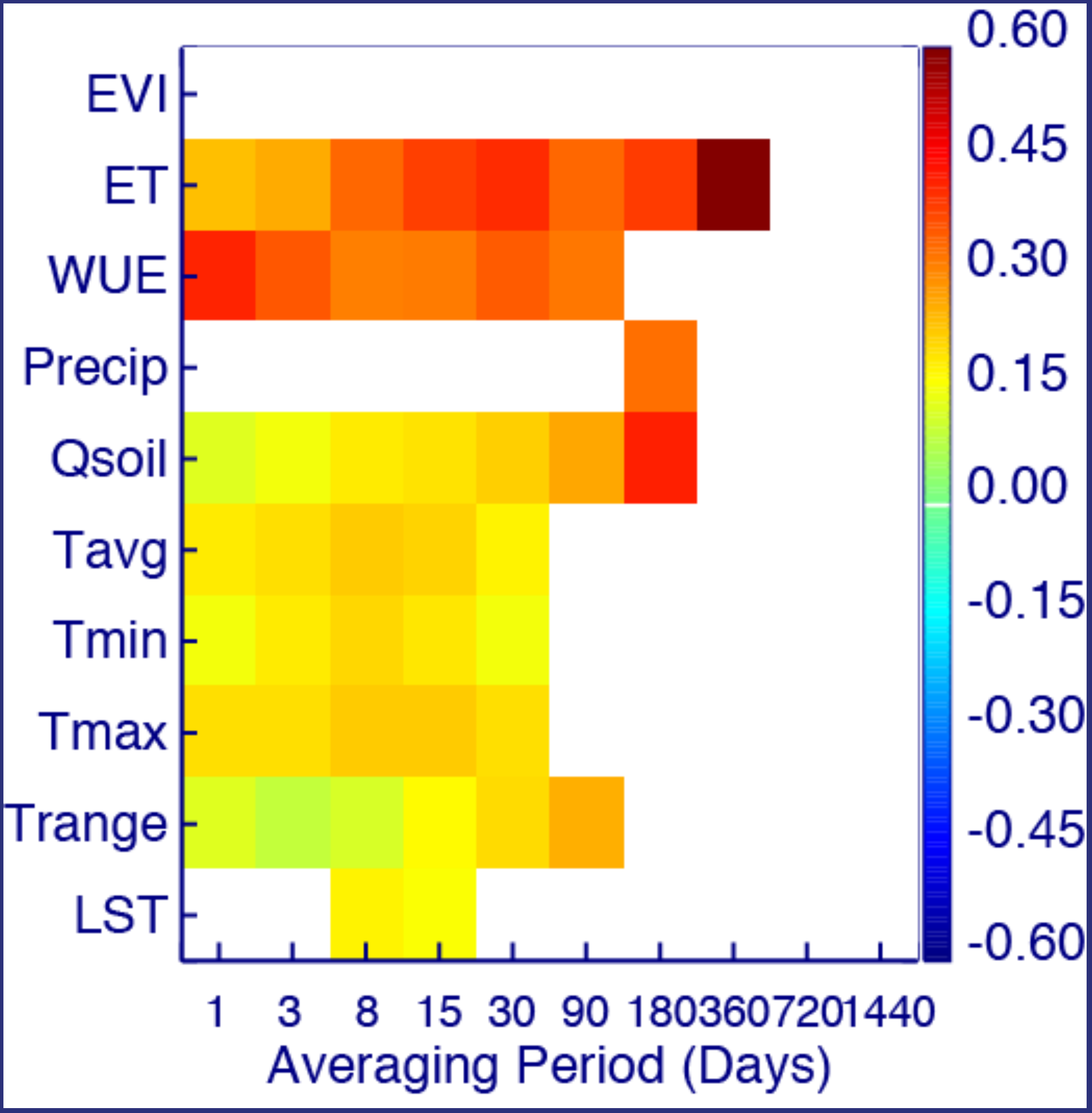
n=5490
DOF (days)
600
500
400
300
200
100
1
10
100
1000
Averaging period (days)

What to test?

Abbreviation	Description	Source
P_d	Photosynthetic drawdown	Flux tower
EVI	Enhanced Vegetation Index, 8-day average	MODIS TERRA/AQUA
ET	Evapotranspiration	Flux tower
WUE	Water Use Efficiency (P_d/ET)	Flux tower
P_{recip}	Daily precpitation	NCDC + NARR Reanalysis
Q_{soil}	10 cm soil moisture	NARR Reanalysis
T_{mean}	Daily temperature	Flux tower + NCDC
T_{min}	Minimum daily temperature	Flux tower + NCDC
T_{max}	Maximum daily temperature	Flux tower + NCDC
T_{range}	Daily temperature range (max - min)	Flux tower + NCDC
LST	Land Surface Temperature, 8-day day/night average	MODIS TERRA/AQUA

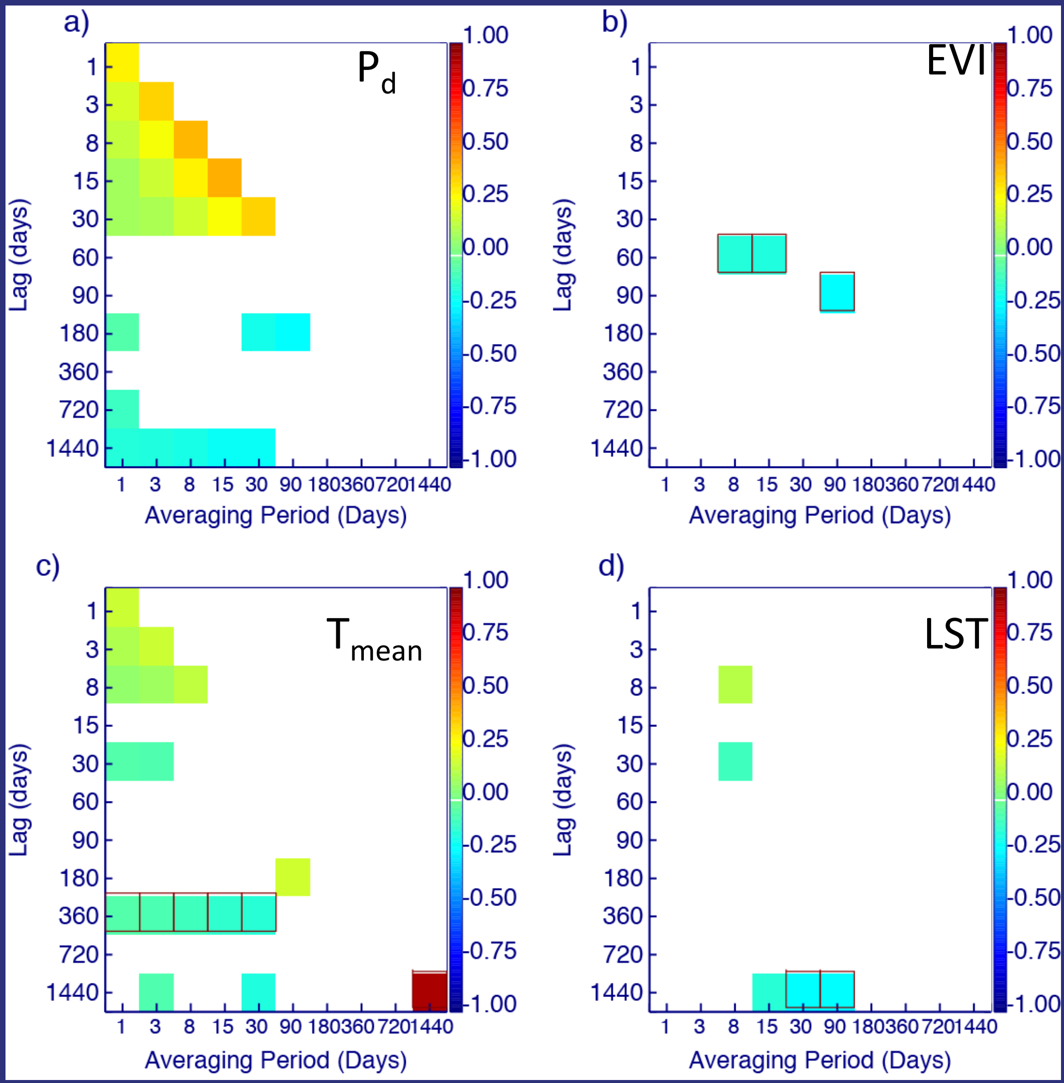
What do you get?

- Only significant correlations shown
- Moisture and temperature anomalies positively correlate with P_d at sub-annual scales



Lags are interesting

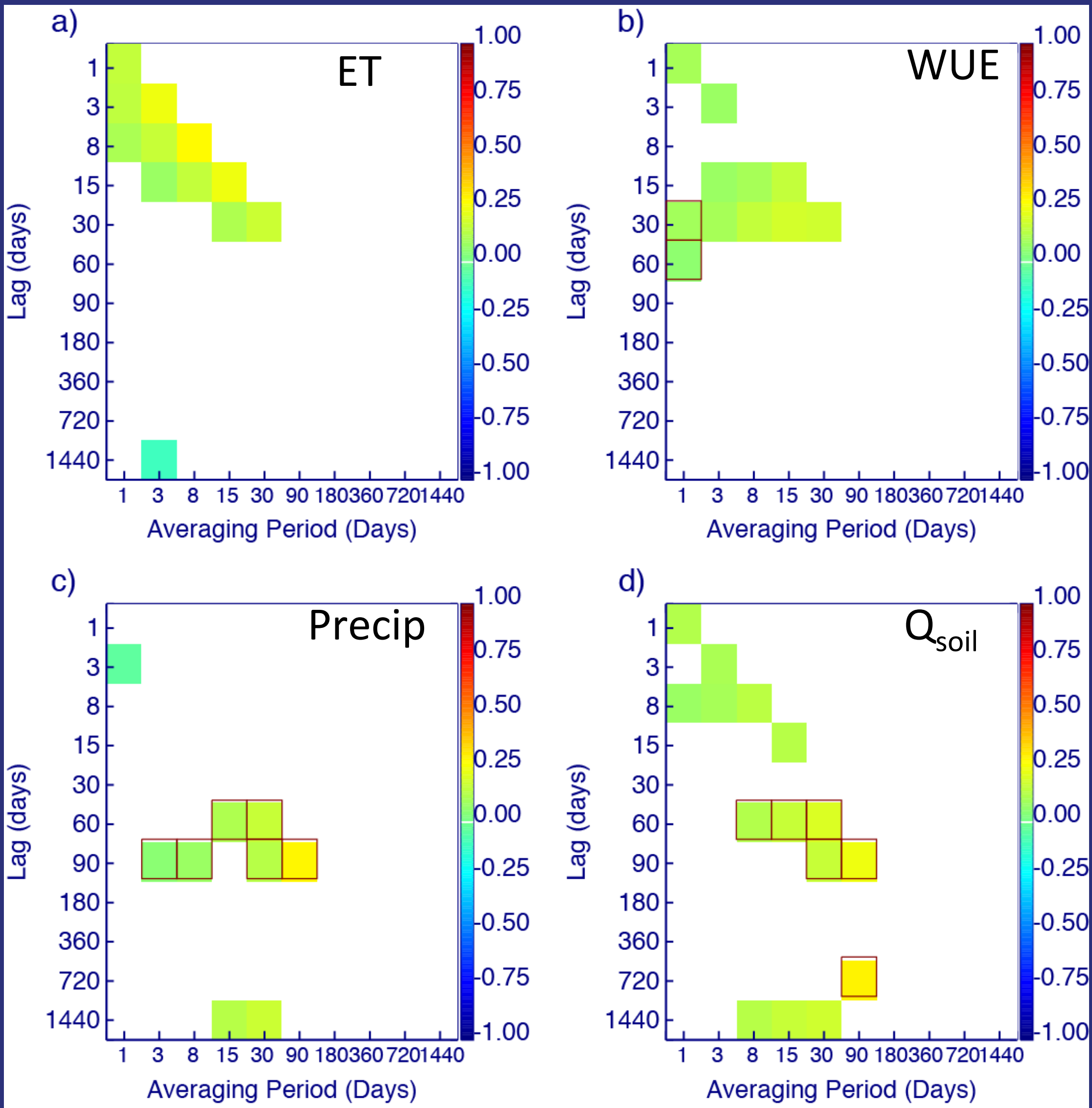
- Red squares = correlations > autocorrelation
- Remotely sensed variables (EVI,LST) have limited ability to predict P_d
- Previous year weekly-monthly temperature has a weak negative relationship to P_d



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

Moisture lags are even more interesting

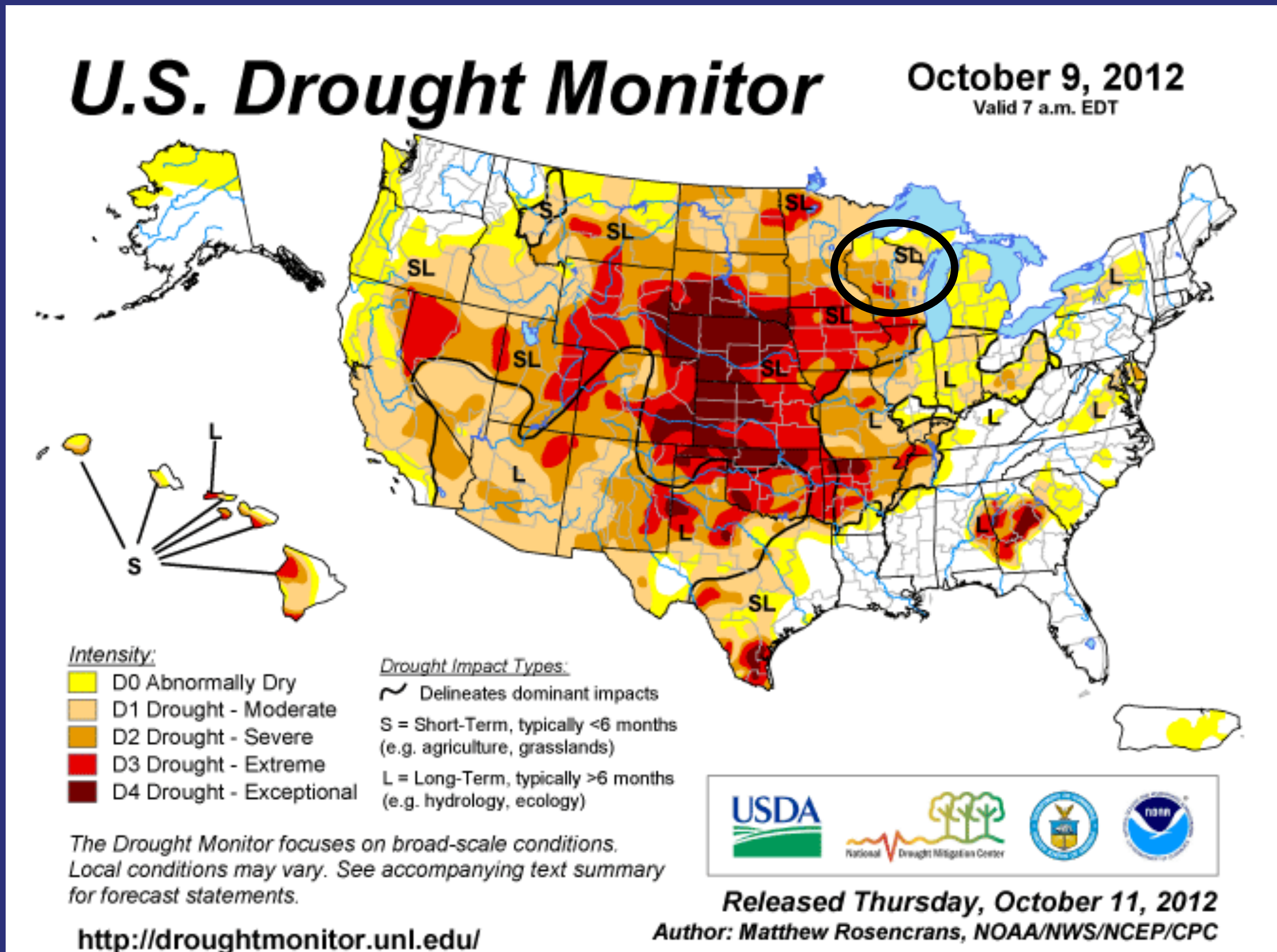


- Earlier season (2-3 month) weekly-seasonal precipitation/soil moisture has strongest predictive effect on P_d
- Beyond that, P_d autocorrelation dominates

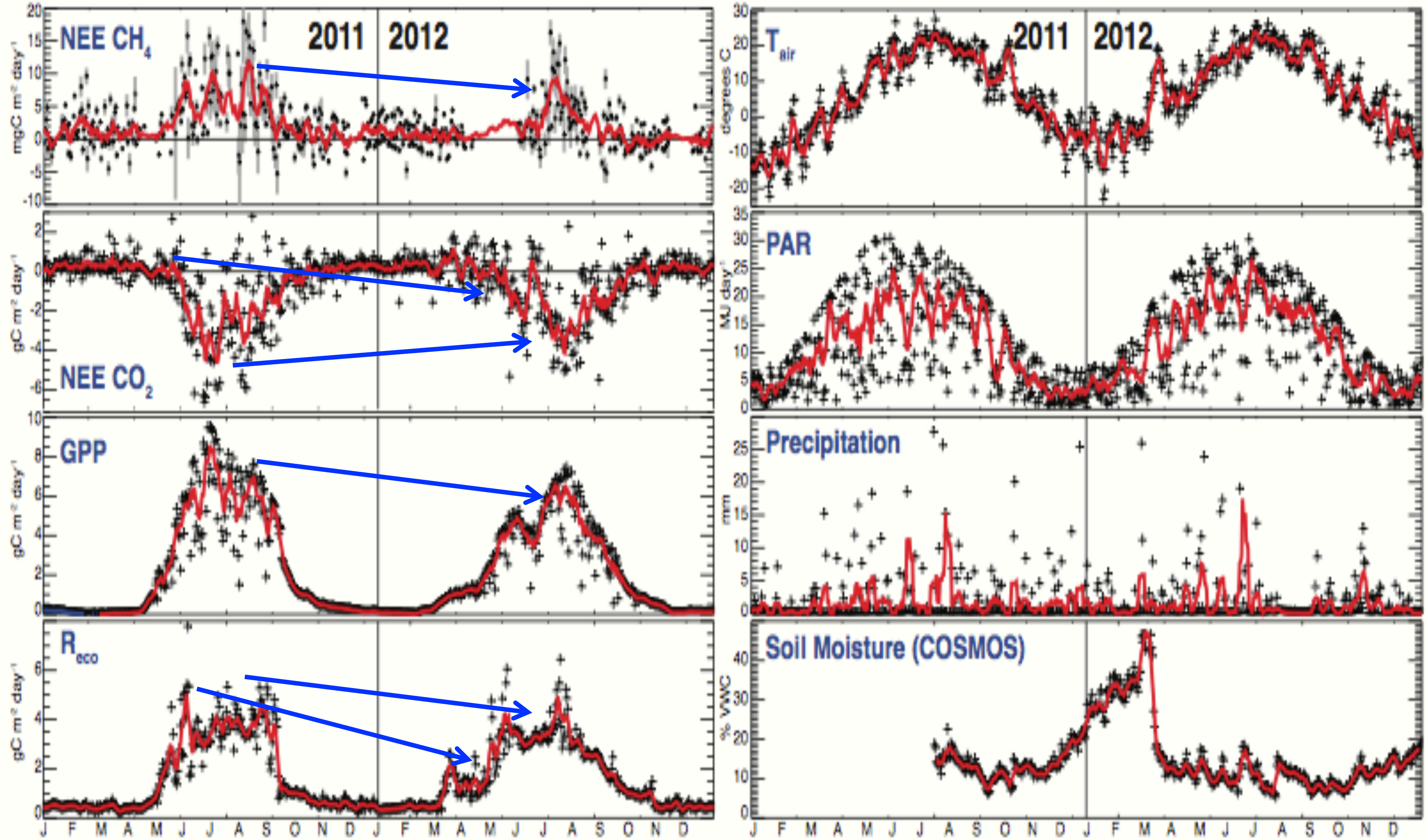
Important points 2

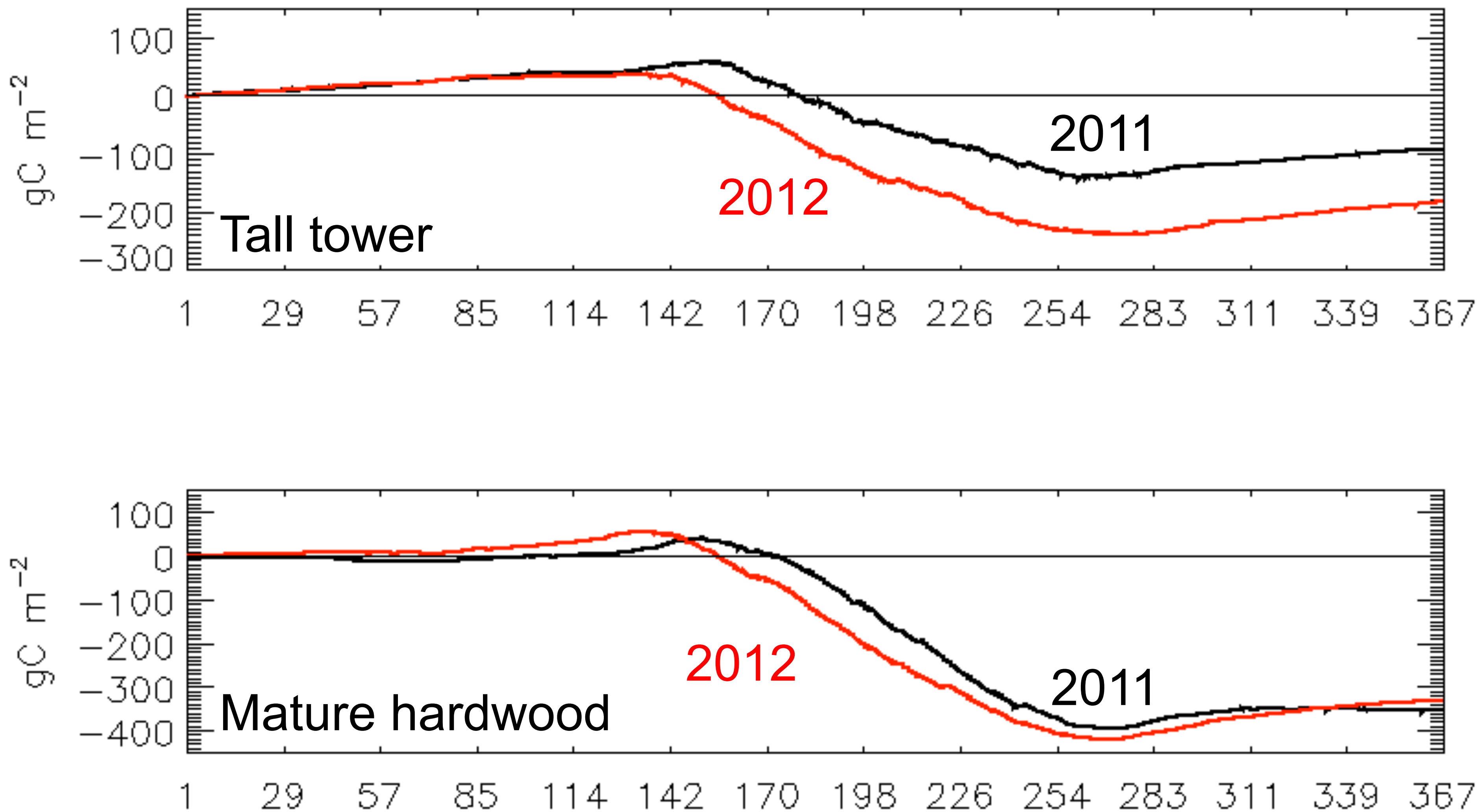
- Moisture extremes impact to regional carbon sequestration display significant seasonal lags and primarily influence monthly to seasonal uptake
- Positive correlations imply mesic forest is in-fact moisture limited, but not in the usual sense

What about 2012?

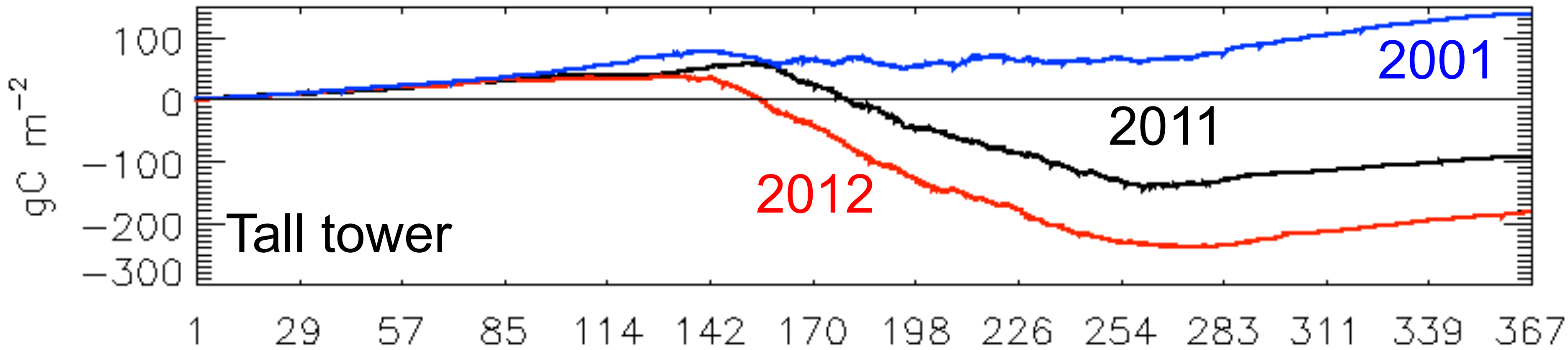


Wolf et al., in prep; Desai et al., in prep

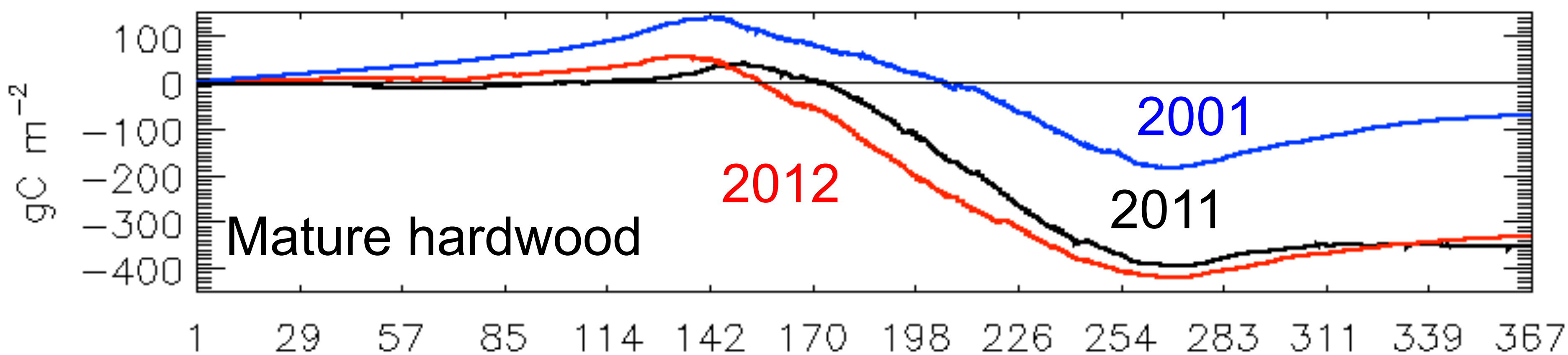

NEE CH4
2011
2012
mgC m-2 day-1
NEE CO2
gC m-2 day-1
GPP
gC m-2 day-1
Reco
gC m-2 day-1
J F M A M J J A S O N D J F M A M J J A S O N D
Tair
degrees C
PAR
MJ day-1
Precipitation
mm
Soil Moisture (COSMOS)
% VWC



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

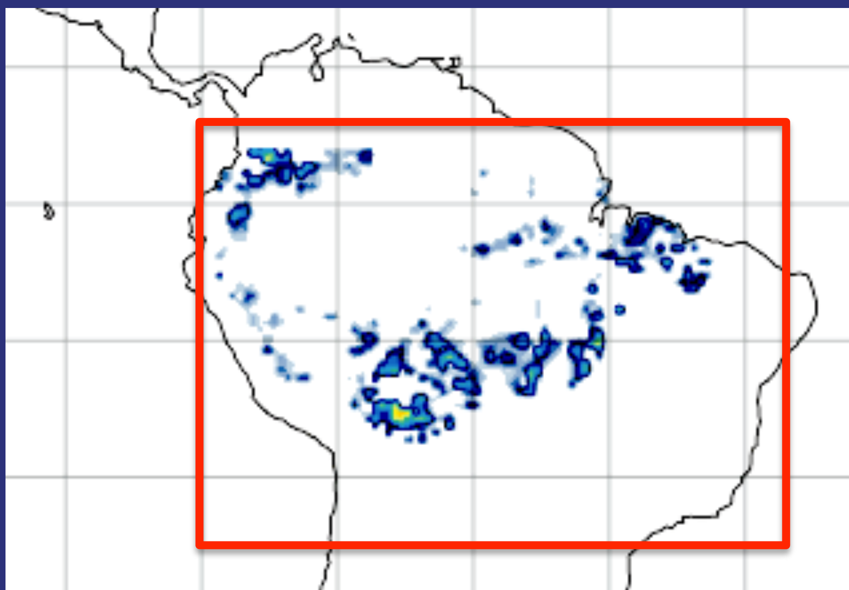

Important points 3

- 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

PROBLEMS


TROPICS ARE INTERESTING….

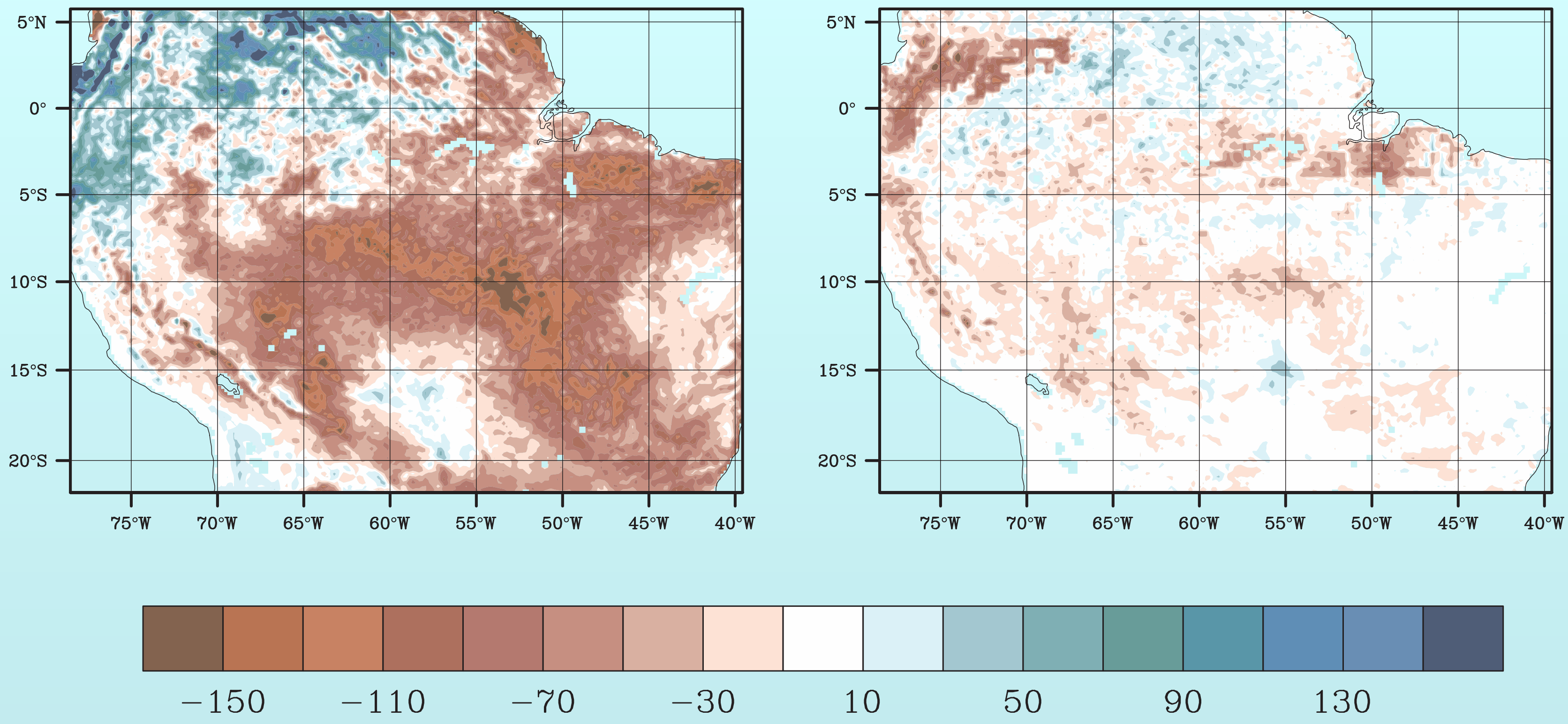
WRF-Noah Setup



Bagley, J.E., Desai, A.R., Harding, K.J., Snyder, P.K., and Foley, J.A., 2014. Drought and deforestation: Has land cover change influenced recent precipitation extremes in the Amazon? *J. Climate*, 27, 345-361, doi:10.1175/JCLI-D-12-00369.1.

- Spatial Resolution: 20km x 20km
- Timestep: 60 seconds
- For 2003, 2004, 2005, 2007, 2009, and 2010 the model was run from March 15 – October 15 with and without deforestation
- Total of 12 seven-month simulations completed with hourly output

Precipitation Rate (mm/month)



Dry Season Anomaly

Deforestation perturbation

Amazon Rainforest Percent Changes with Deforestation

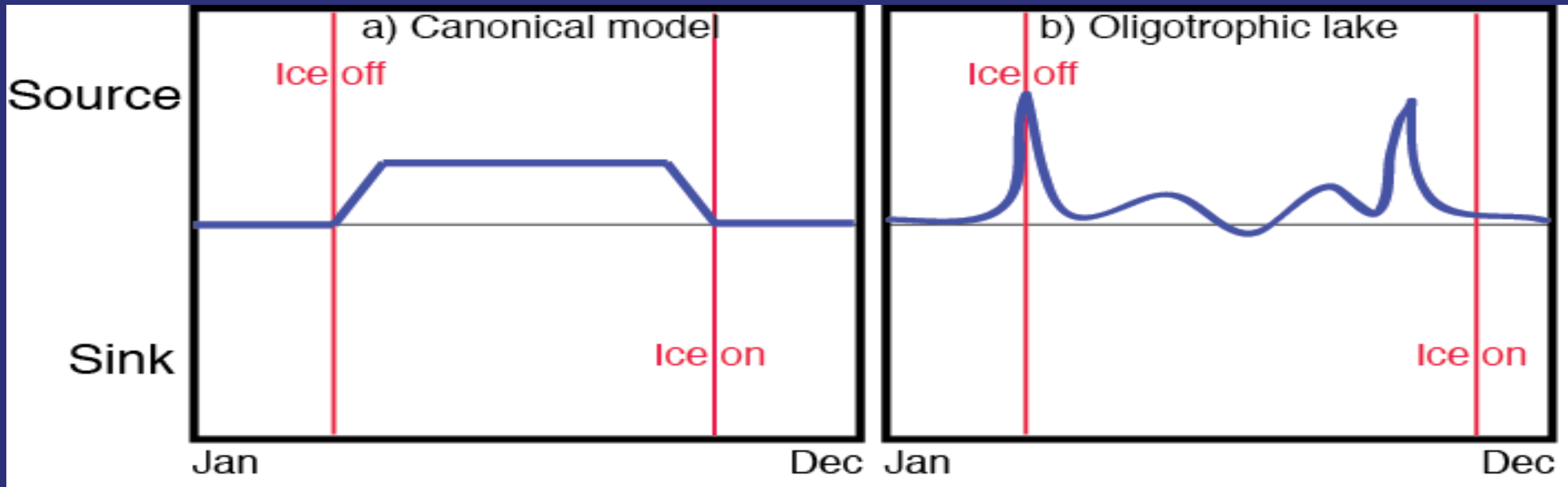
In nearly every measure the impact of deforestation is greater during drought years

	July - September	
	Pluvial Years	**Drought Years**
% Δ Precipitation Rate	-4.99%	-5.93%
% Δ Sensible Heat Flux	+.48%	+4.28%
% Δ Latent Heat Flux	-3.63%	-5.57%
% Δ Net Surface Radiation	-2.41%	-2.70%
% Δ Boundary Layer Height	-.11%	+1.36%
% Δ Rel. Soil Moisture Top Layer	-3.00%	-4.38%
% Δ Rel. Soil Moisture Bot. Layer	+3.50%	+5.09%
% Δ 2m Specific Humidity	-.77%	-1.31%
% Δ Level of free convection	+2.62%	+.52%
% Δ Lifting condensation level	+1.29%	+3.94%

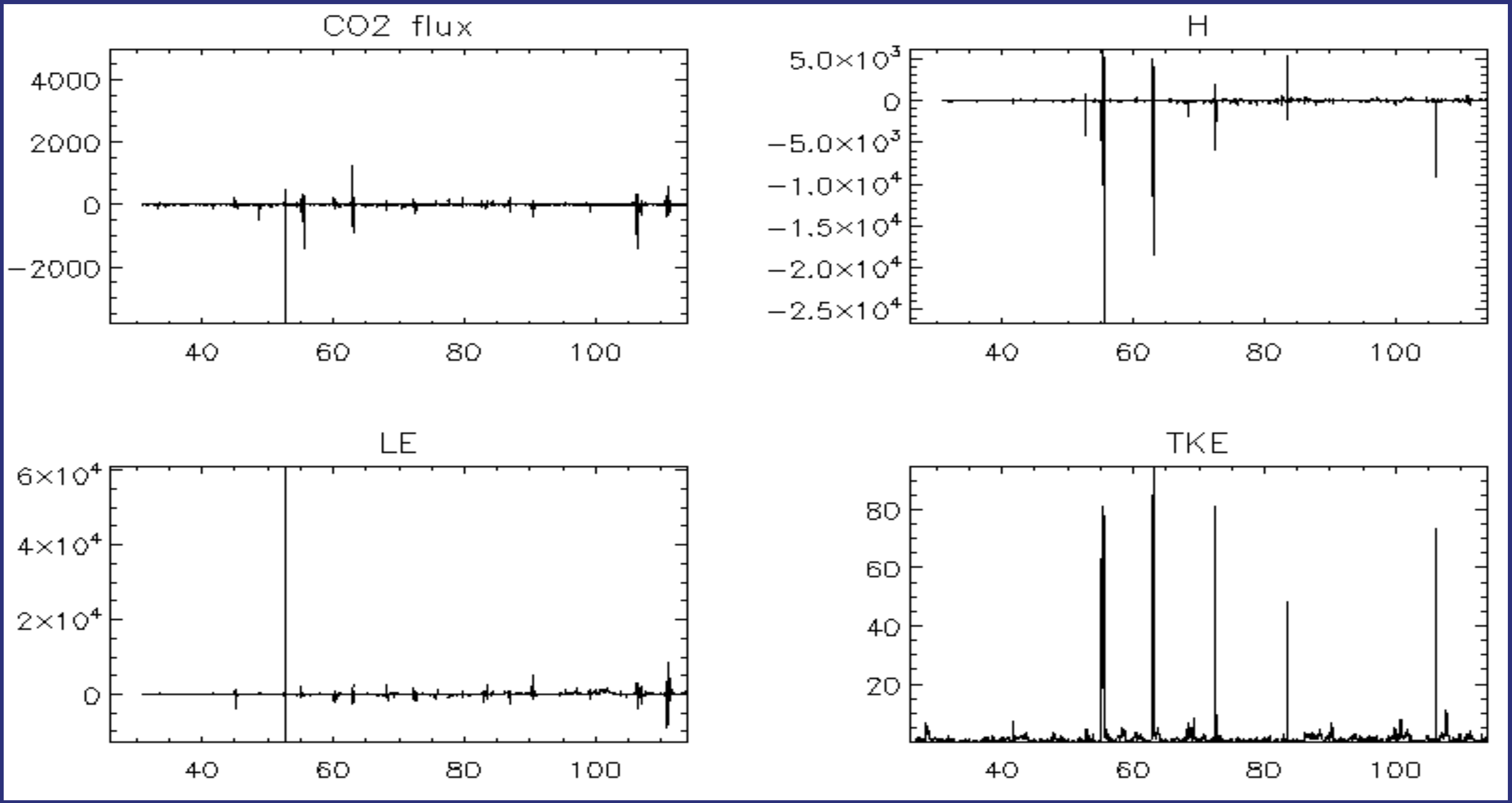
PREDICTIONS

In the future…

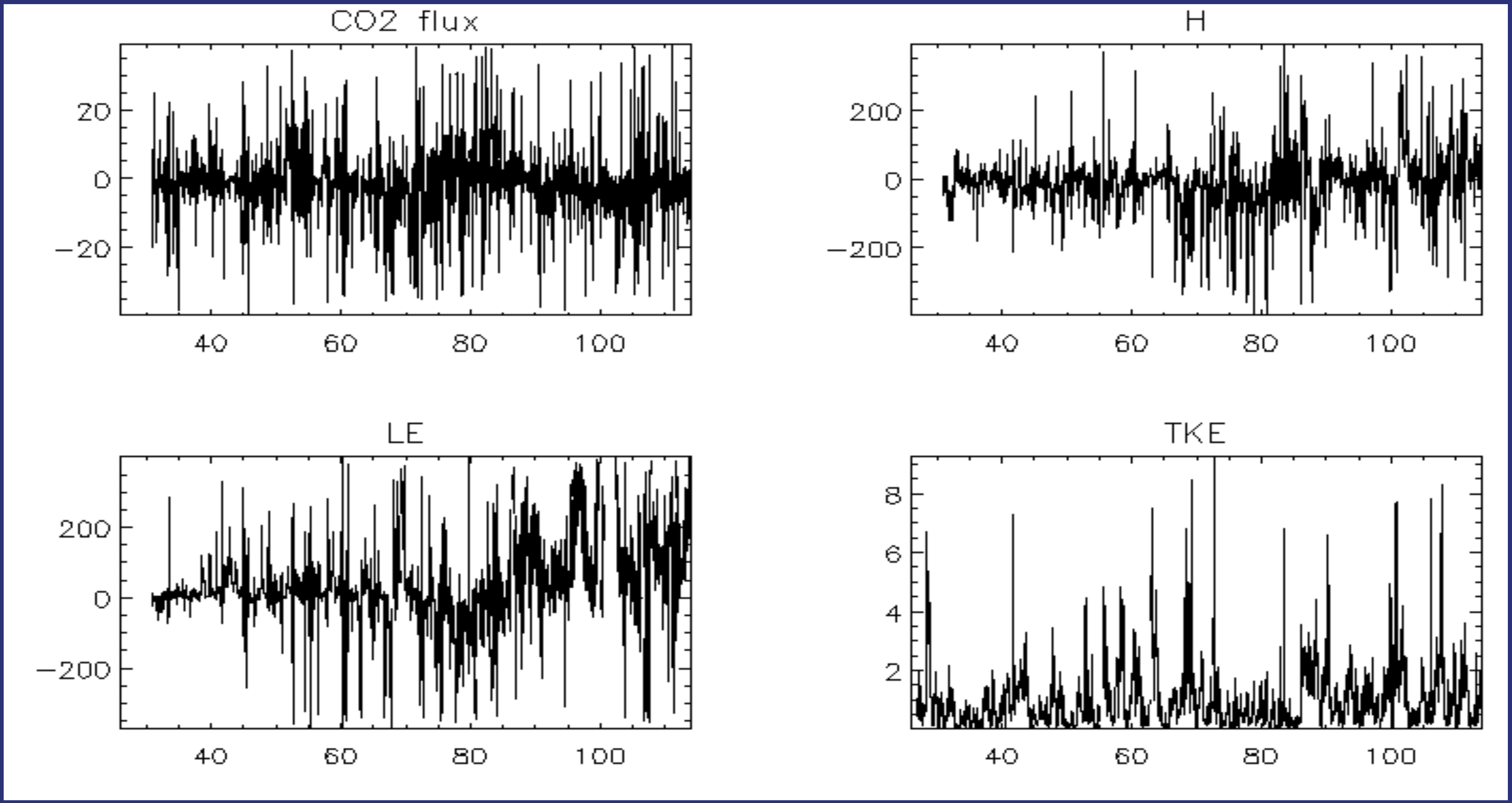
- As models get more sophisticated and realistic, a greater number of negative (restoring) feedbacks will be successfully resolved
- However, this does not negate the very real risk of climate change on thresholds, long-term shifts, and other ecosystem state changes *regardless* of the feedback direction
- Further, some systems may be more sensitive than others


Source
Sink
a) Canonical model
Ice off
Ice on
Jan
Dec
b) Oligotrophic lake
Ice off
Ice on
Jan
Dec

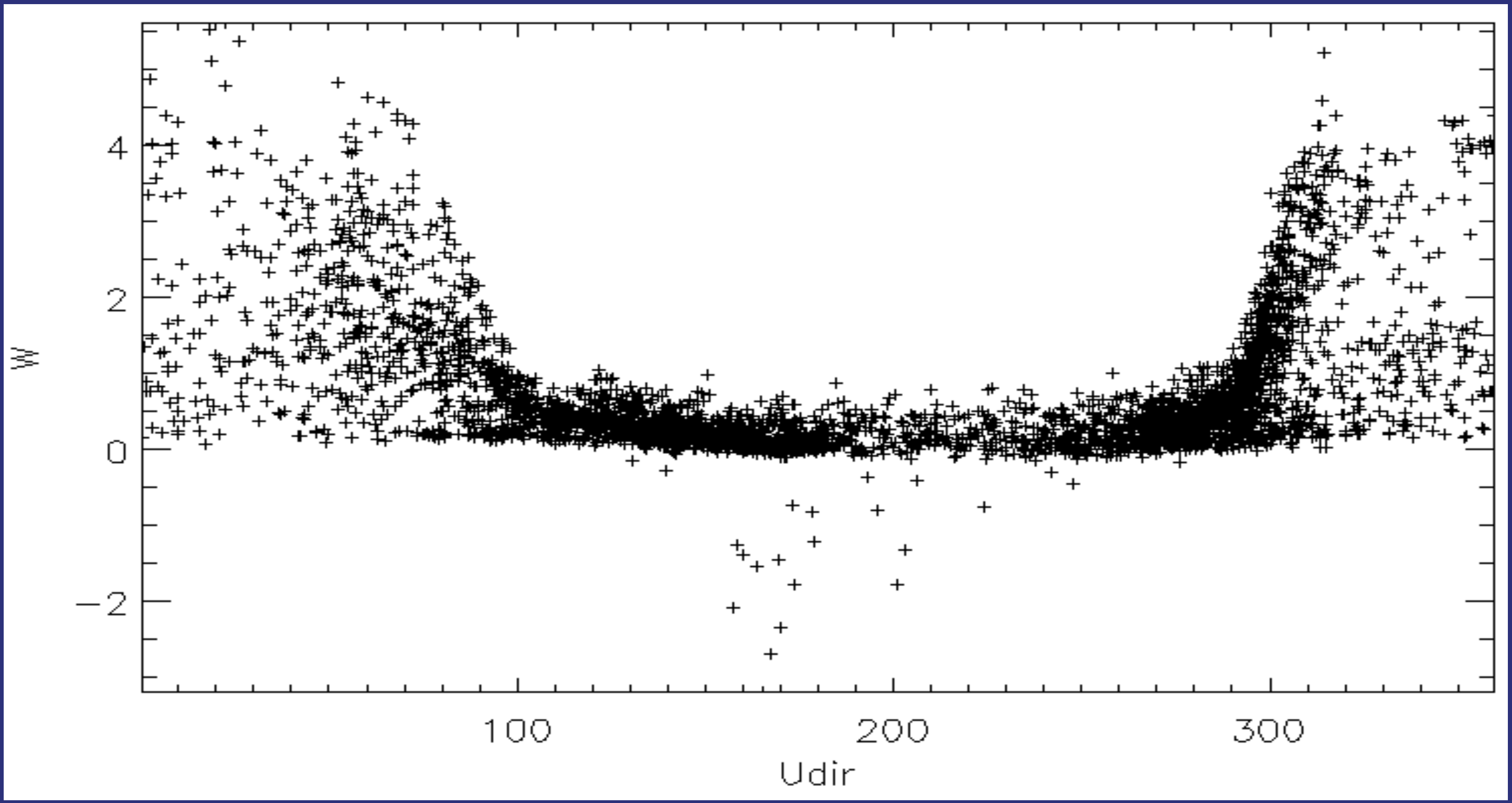
Great data?

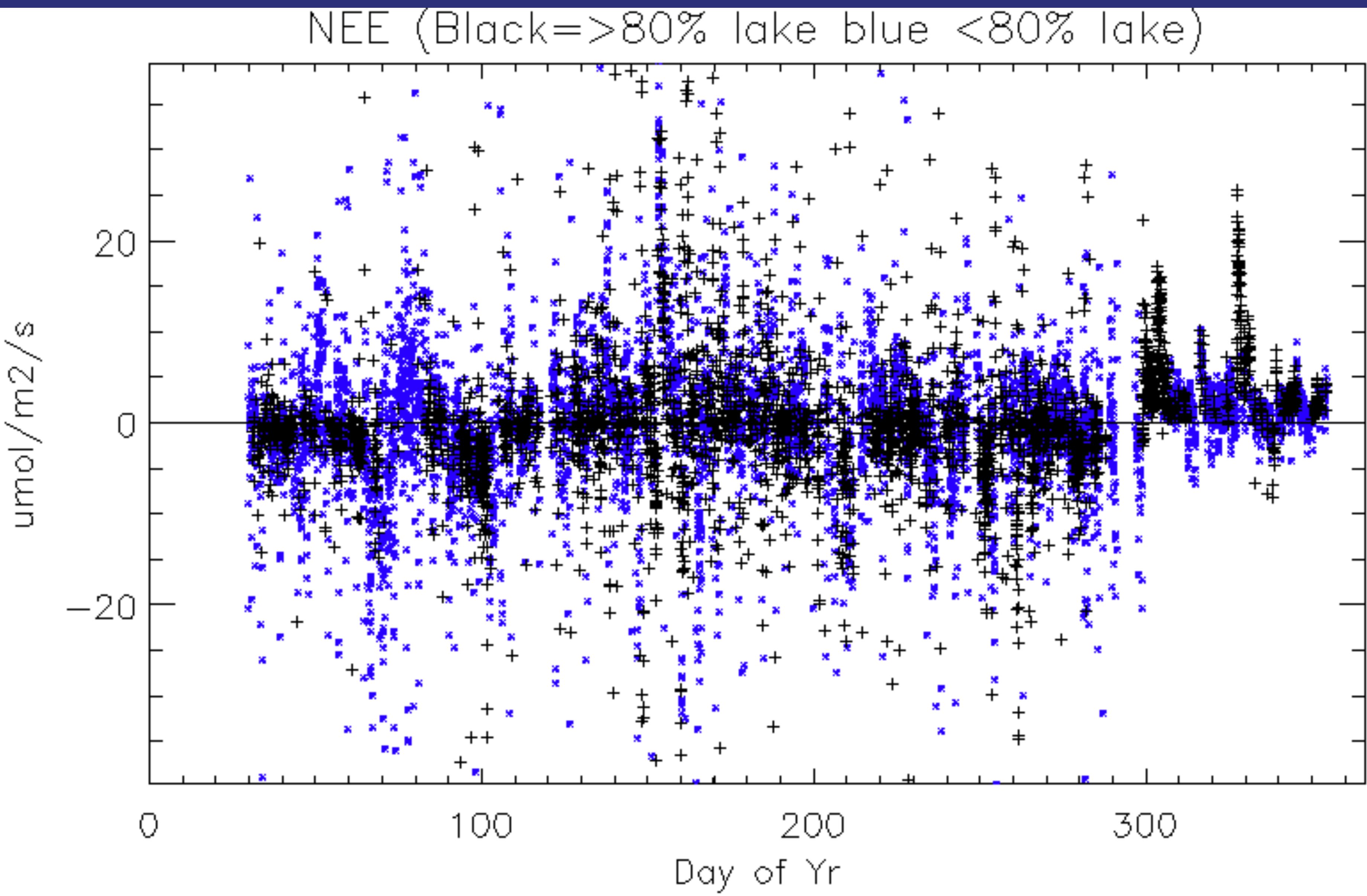

CO2 flux
4000
2000
0
−2000
40
60
80
100
H
5.0×10³
0
−5.0×10³
−1.0×10⁴
−1.5×10⁴
−2.0×10⁴
−2.5×10⁴
LE
6×10⁴
4×10⁴
2×10⁴
TKE
80
60
40
20

Oh – that's better

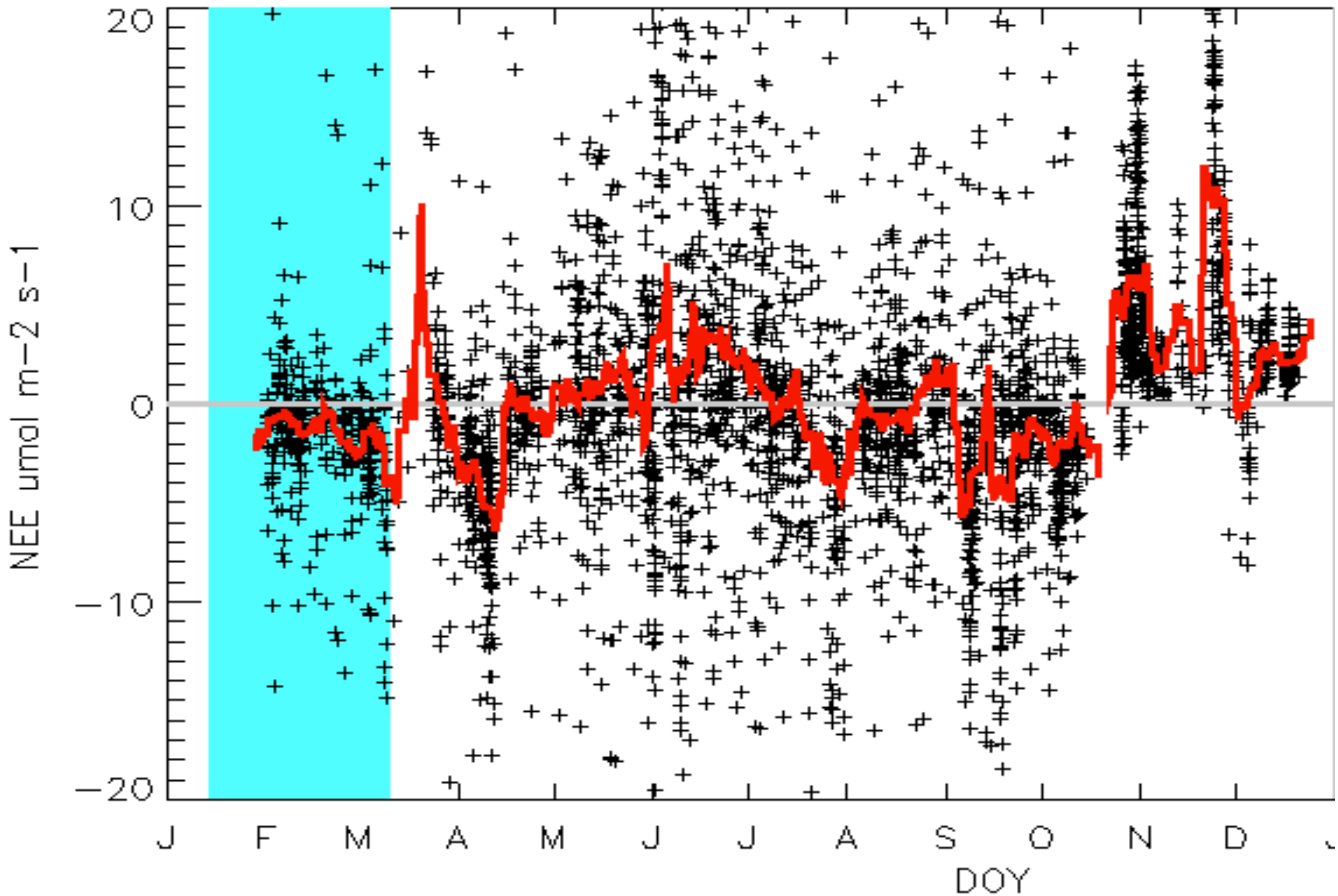


About that building flow





NEE (Black=>80% lake blue <80% lake)
umol/m2/s
20
0
−20
0
100
200
300
Day of Yr



20
10
0
−10
−20
NEE umol m−2 s−1
J
F
M
A
M
J
J
A
S
O
N
D
DOY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The Penultimate Slide

Thanks!

- Contributors:
  - Jonathan Thom, Ke Xu, Arlyn Andrews, Dan Baumann, Bruce Cook, Dave Moore, Britt Stephens, Justin Bagley, Ben Sulman, Malgorzata Golub, Mike Dietze, many others…
- Funding:
  - NSF, NOAA, DOE, USDA, WI Focus on Energy