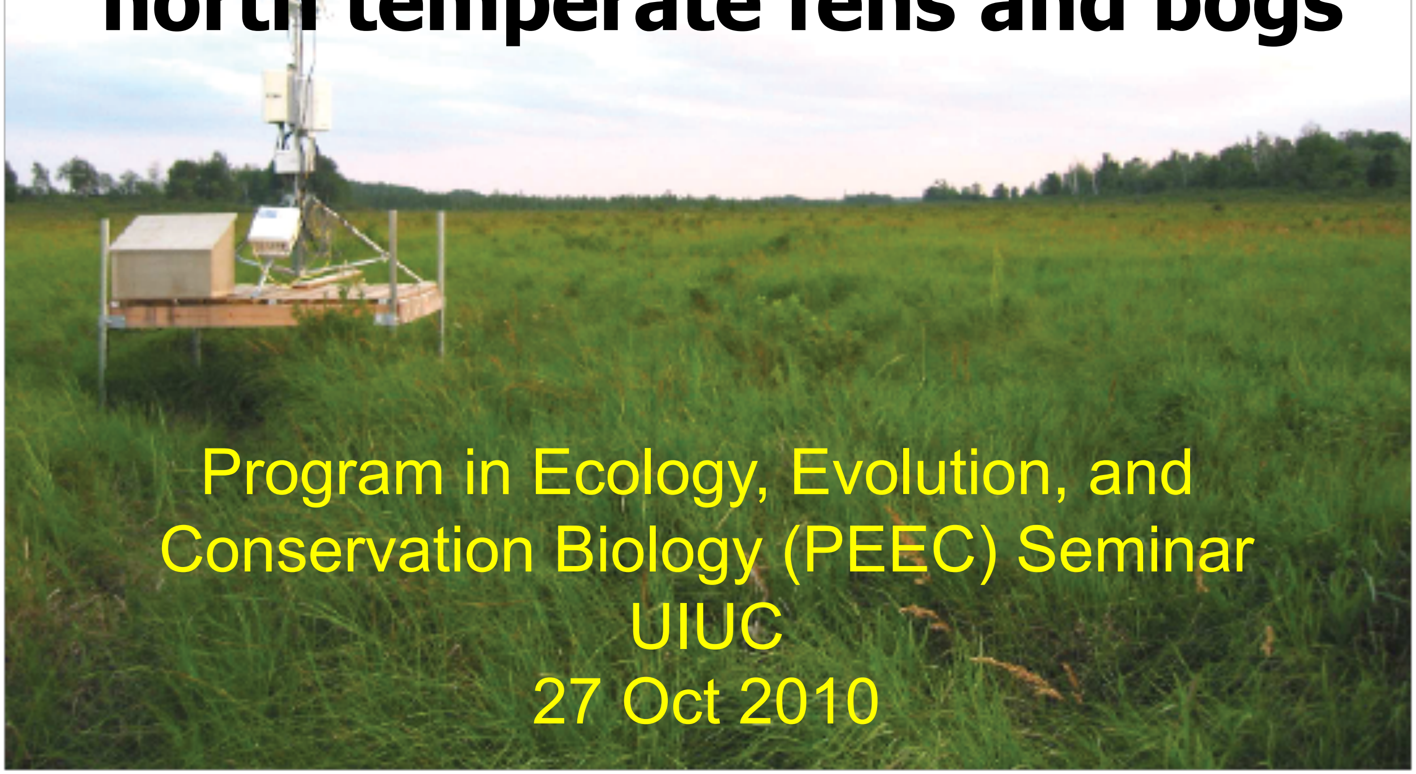
When is a wetland a wetland?

Carbon and water cycles in north temperate fens and bogs



Program in Ecology, Evolution, and Conservation Biology (PEEC) Seminar
UIUC
27 Oct 2010

Ankur R Desai, Asst. Professor
Dept. of Atmospheric & Oceanic Sciences
University of Wisconsin-Madison

Biogeo-what?

- **Land and ocean ecosystems** have biophysical and biogeochemical dependences on the atmosphere
  - **Biophysical** – Interactions of moisture, heat, solar radiation between ecosystems and atmosphere
  - **Biogeochemical** – Cycling of nutrients, especially carbon and nitrogen

- As the **atmosphere** changes, both of these are changing in ecosystems! Leading to:

SURPRISE!

SURPRISE!

- **Ecosystems** are generally evolutionarily adapted to regional climate and its short-term variability

- **Expectations** of how these ecosystems respond to climate variation form the basis of ecosystem ecology and biogeochemistry

- But: **Surprises** are likely given the complex interplay between ecosystems and climate

SURPRISE!

- Surprises are no fun for ecosystem **management**

- But: It's also how science **progresses**

- And: We are likely entering an era where surprises will be more **common**.

Why?

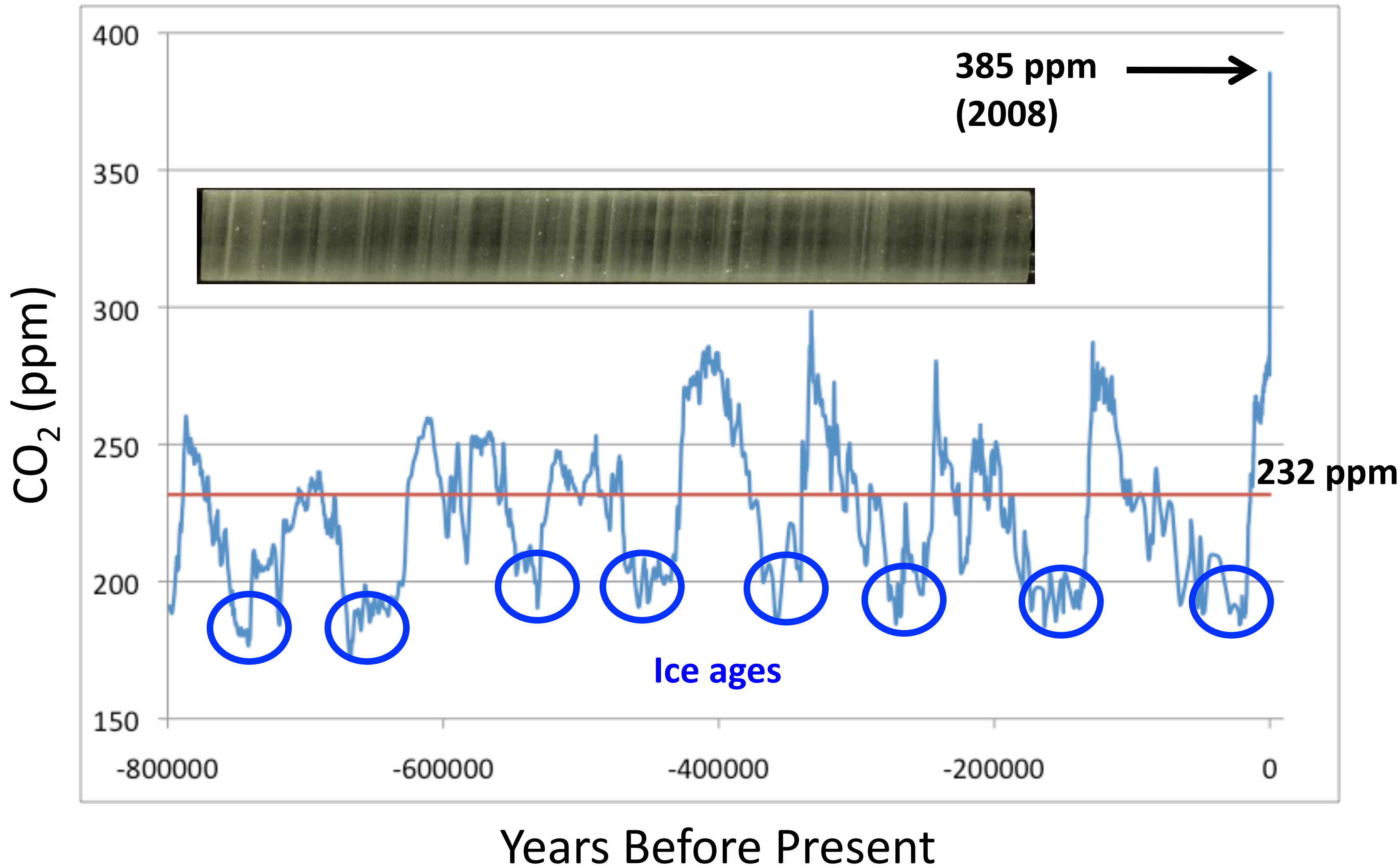
Our Era

- From 1990-2005:
  - World **Population** increased 22% to ~6,500,000,000 people
  - Global **oil consumption** grew 25% to 85,000,000 barrels per day
  - Gross World Product (**GWP**) grew 40% to $59,380,000,000,000 US dollars

- Population **doubling** times have increased
  - 1850-1930, 80 years, 1-2 billion
  - 1930-1975, 45 years, 2-4 billion
  - 1975-*2015*, 40 years, 4-8 billion

Source: UCAR

Why? CO_2!

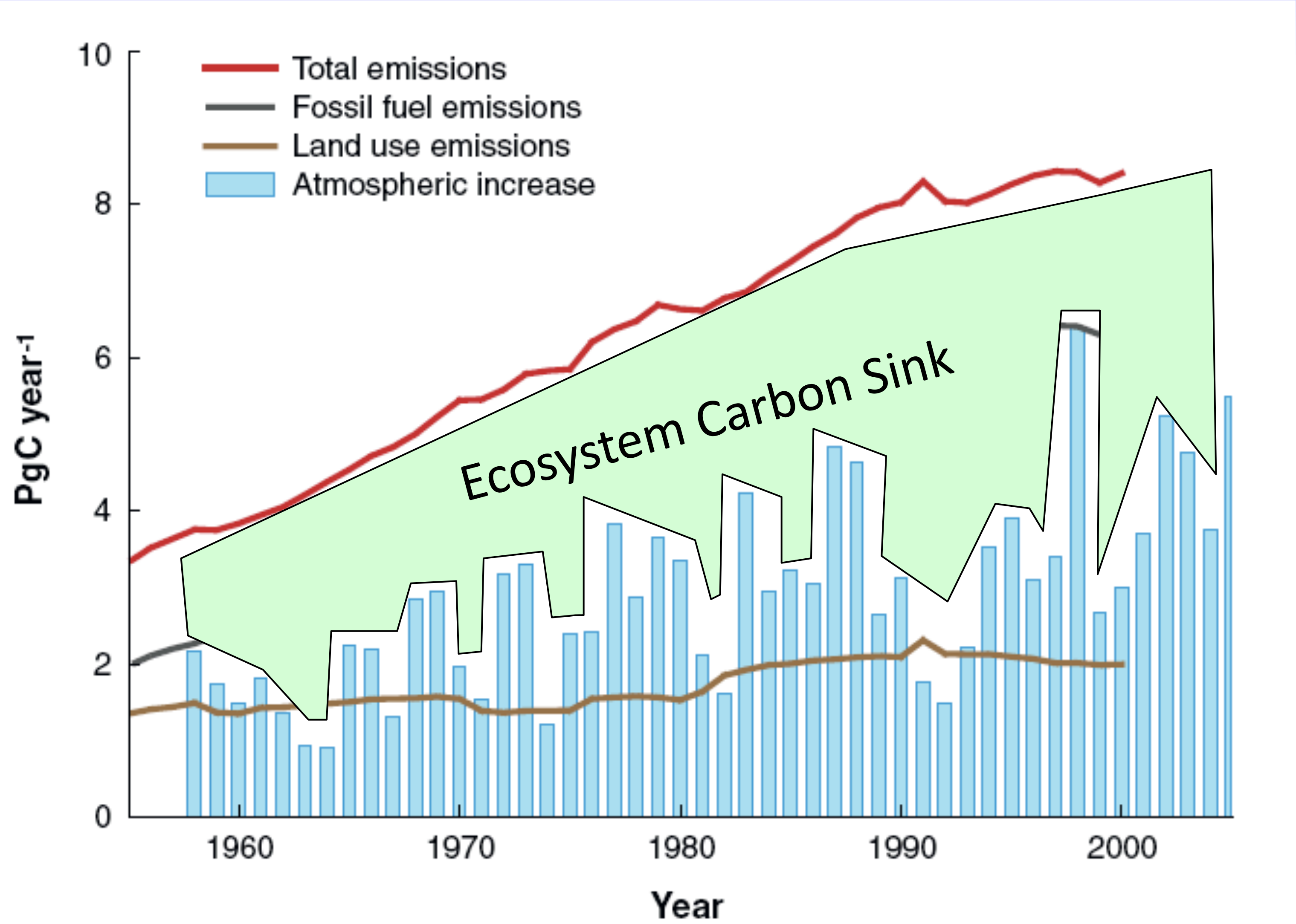


Source: Lüthi et al (2008), CDIAC, & Wikimedia Commons

Since 1990

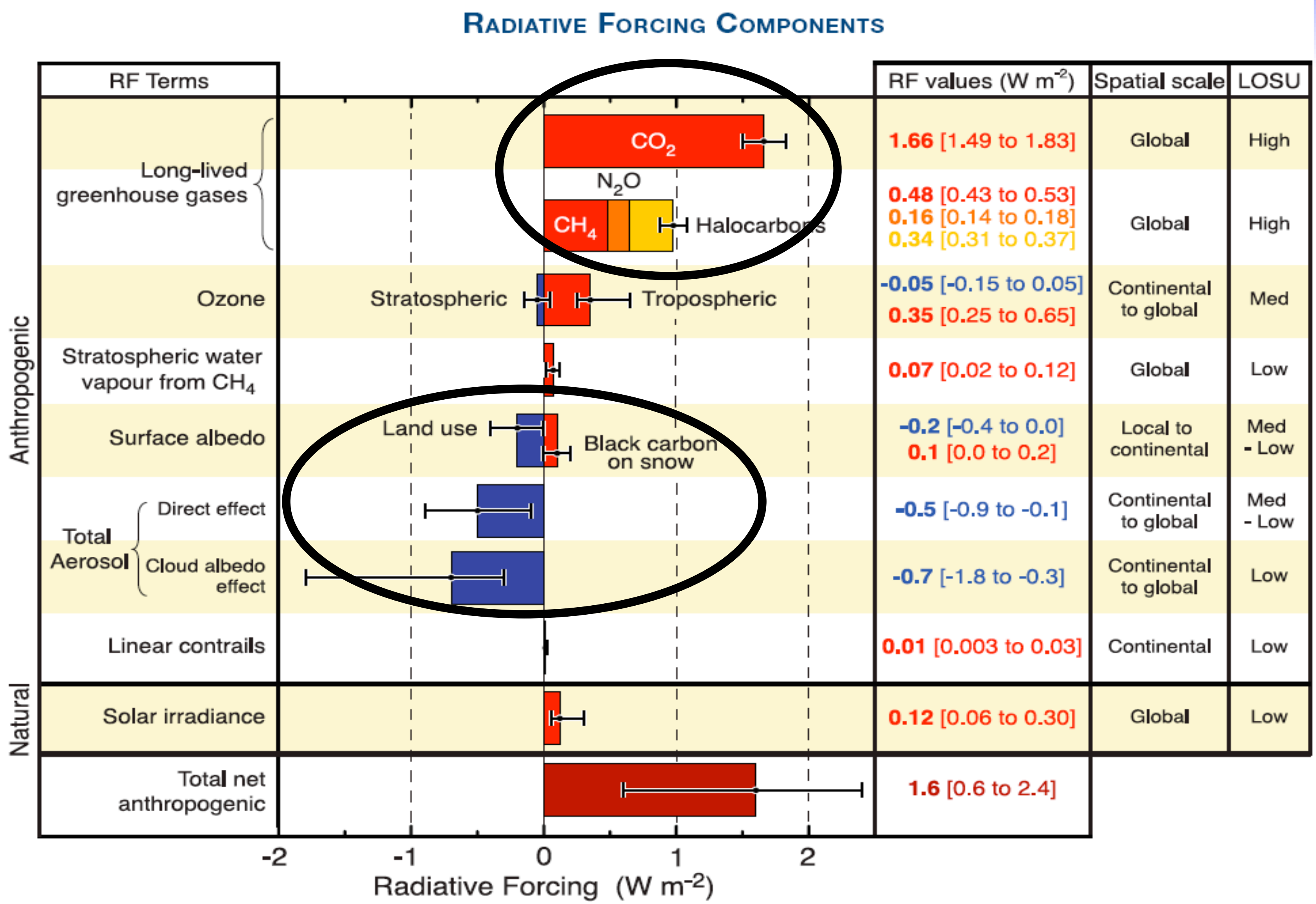
- Global annual CO_2 **emissions** grew 25% to 27,000,000,000 tons of CO_2
- CO_2 in the **atmosphere** grew 10% to 385 ppm
- At current rates, CO_2 is likely to **exceed** 500-950 ppm sometime this century
- But: Rate of atmospheric CO_2 increase is about half the rate of emissions increase. **Why?**

Where Is The Carbon Going?



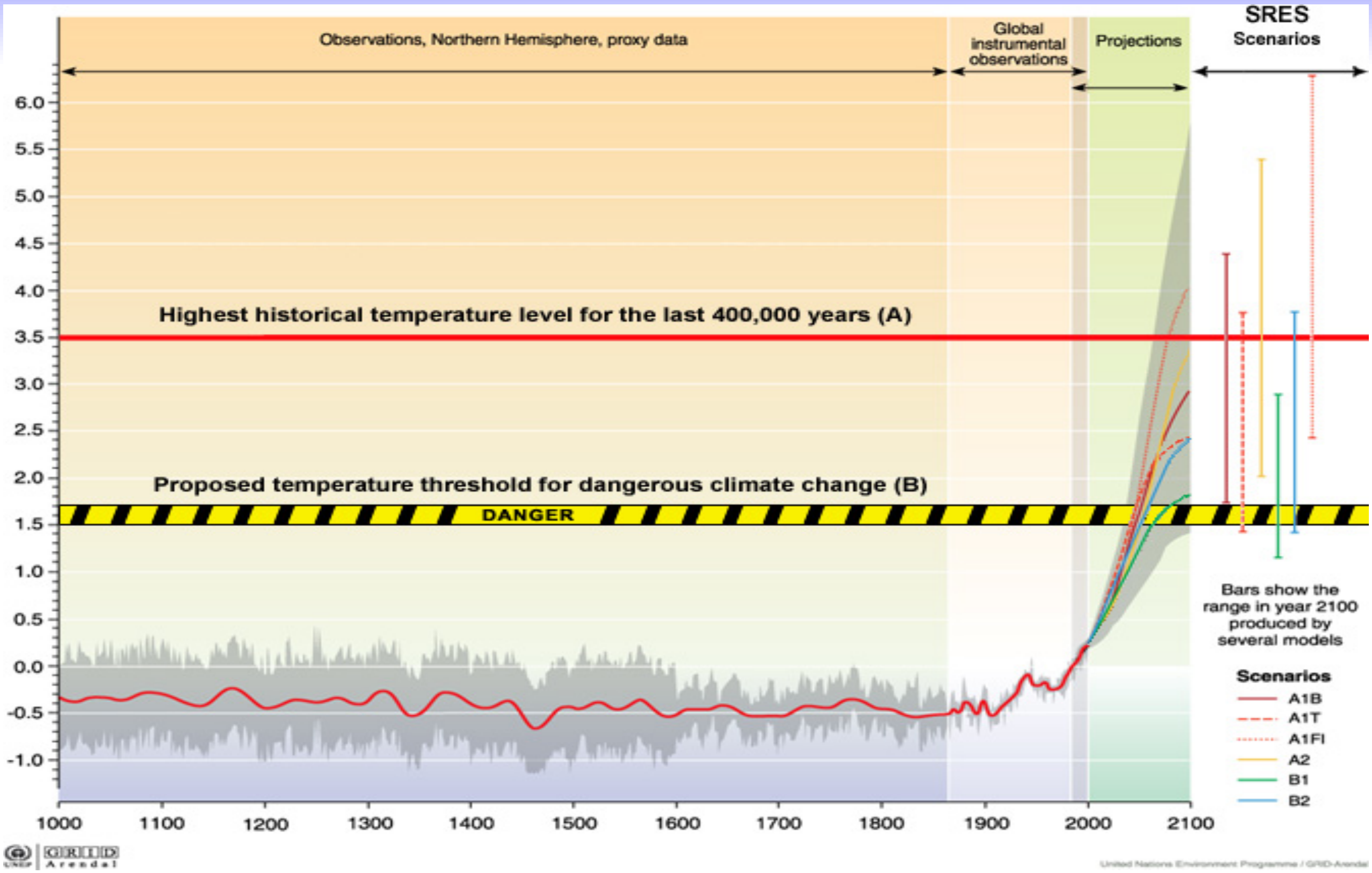
Houghton et al. (2007)

What's The Big Deal?



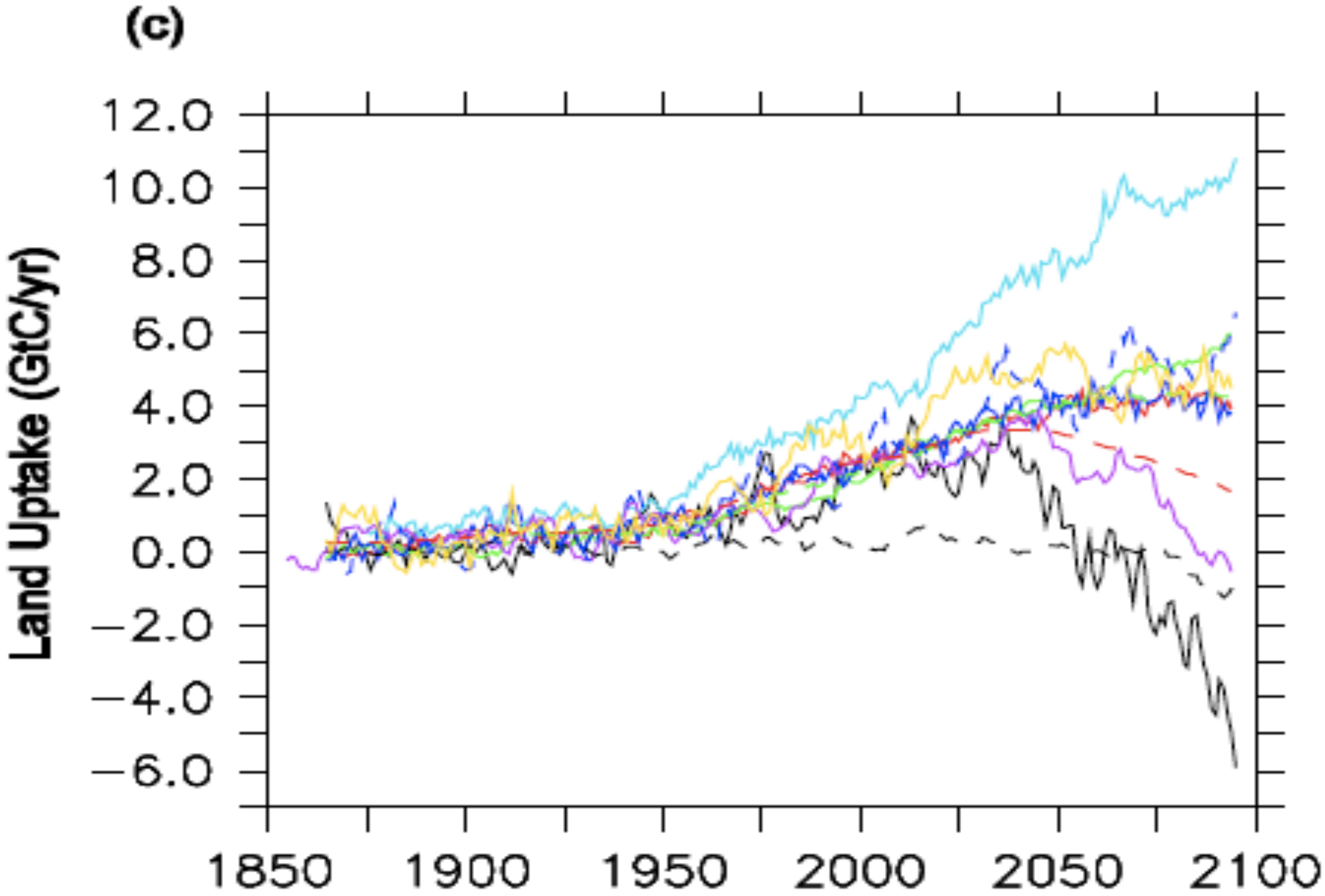
IPCC, 4th AR, (2007)

The Big Deal



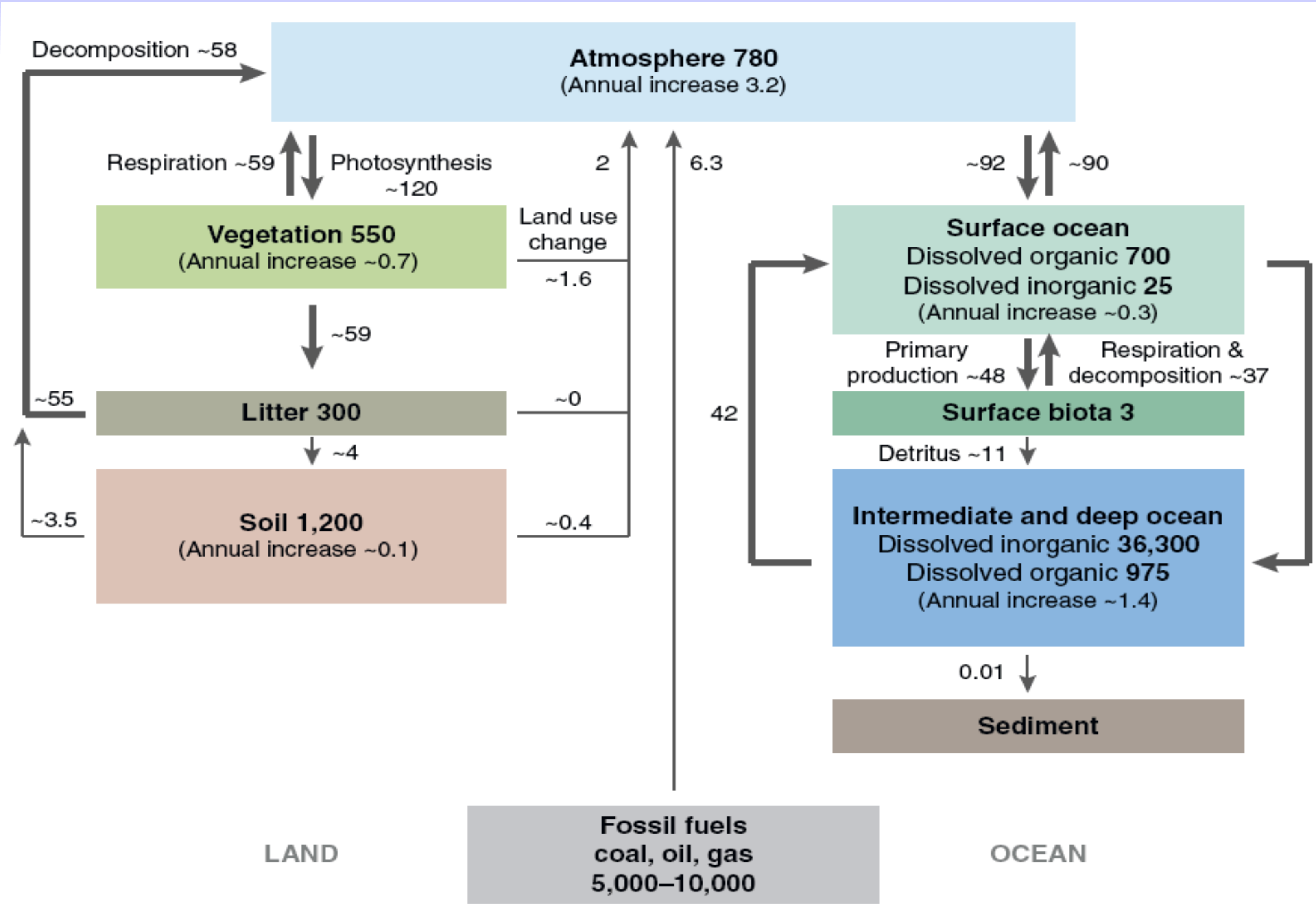
IPCC AR4 (2007)

A Small Problem



Friedlingstein et al. (2005)

Carbon Cycle



Houghton et al. (2007)

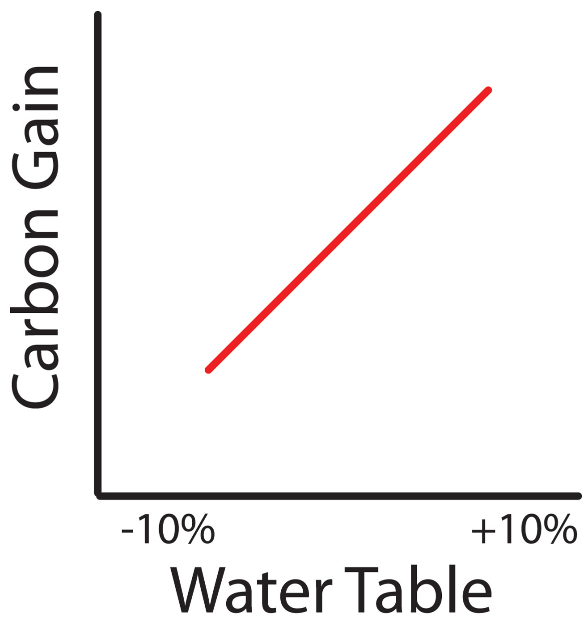
No Surprises Here

- The better we can reduce **uncertainty** of how ecosystem carbon/water/energy cycling responds to climate, the better we can model future climate change and impacts

- I will present **a story** to illustrate surprises of ecosystem responses to a changing climate based on research conducted by my lab and collaborators

A Wetland Story

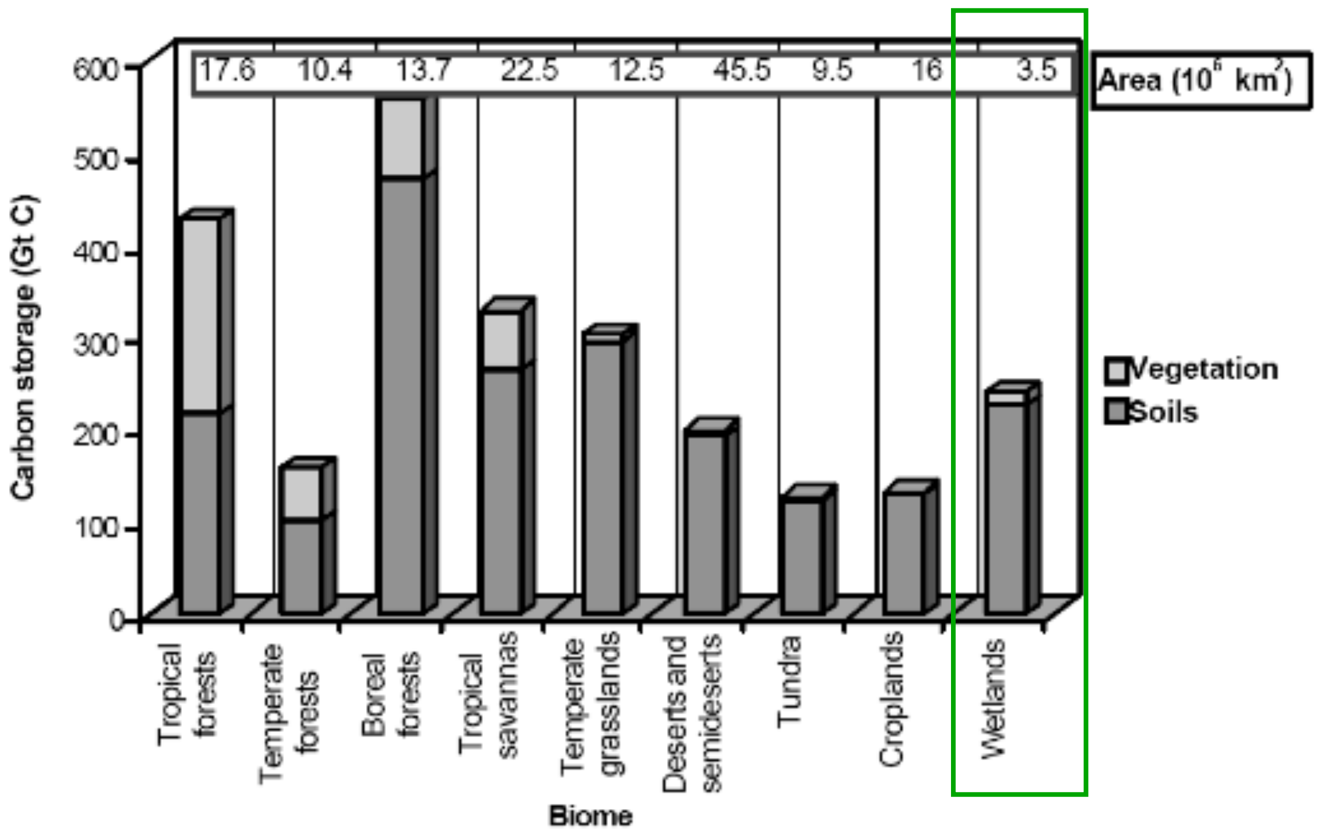
- Expectation:
  - Wetlands store carbon under wet conditions
- Therefore:
  - Restoration of north temperate wetlands should lead to increased carbon sequestration



Wetland Carbon

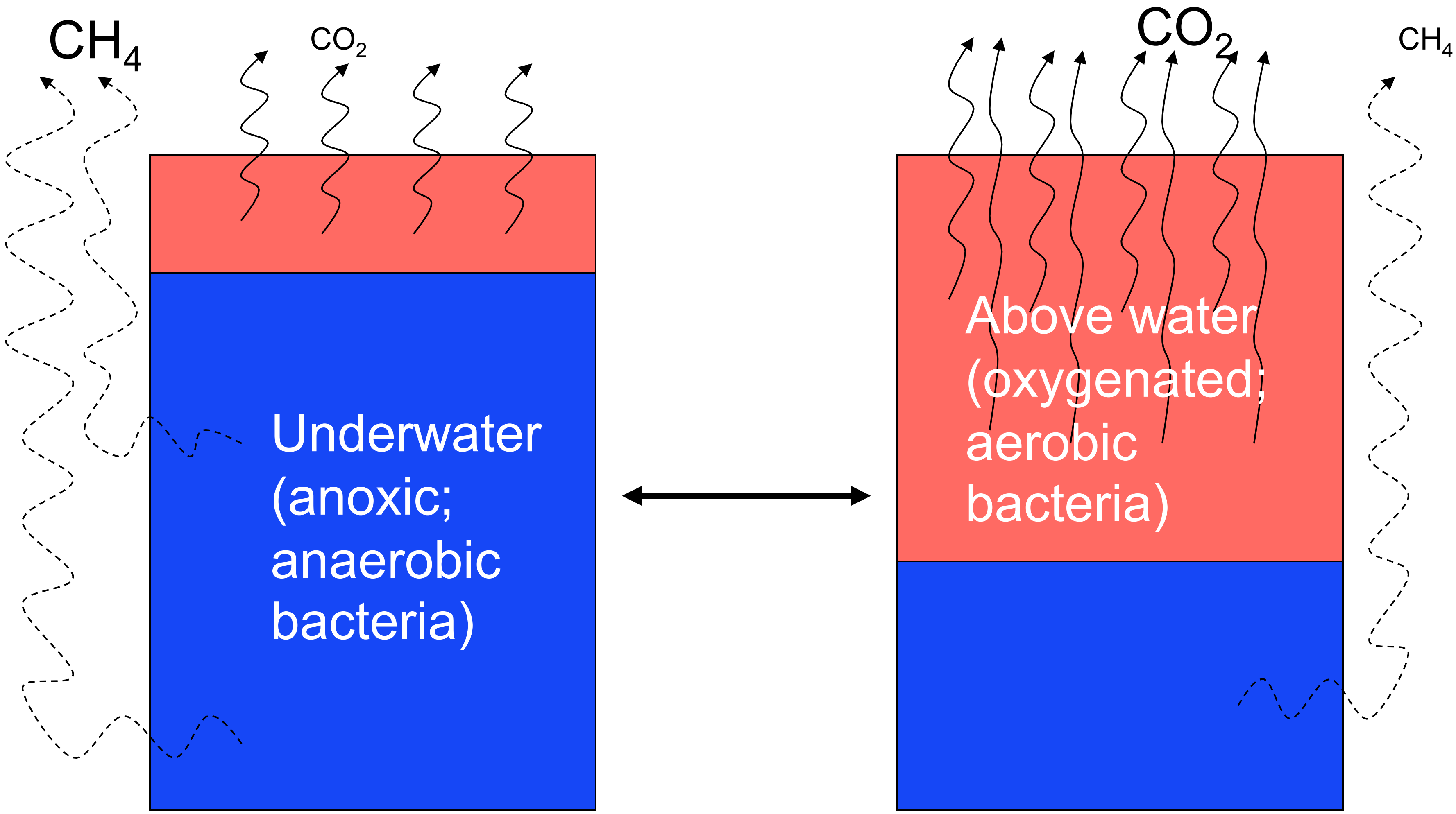
Boreal and subarctic wetlands contain an estimated 455 Pg soil carbon.

This is up to 1/3 of total global soil carbon pool (Gorham, 1991)

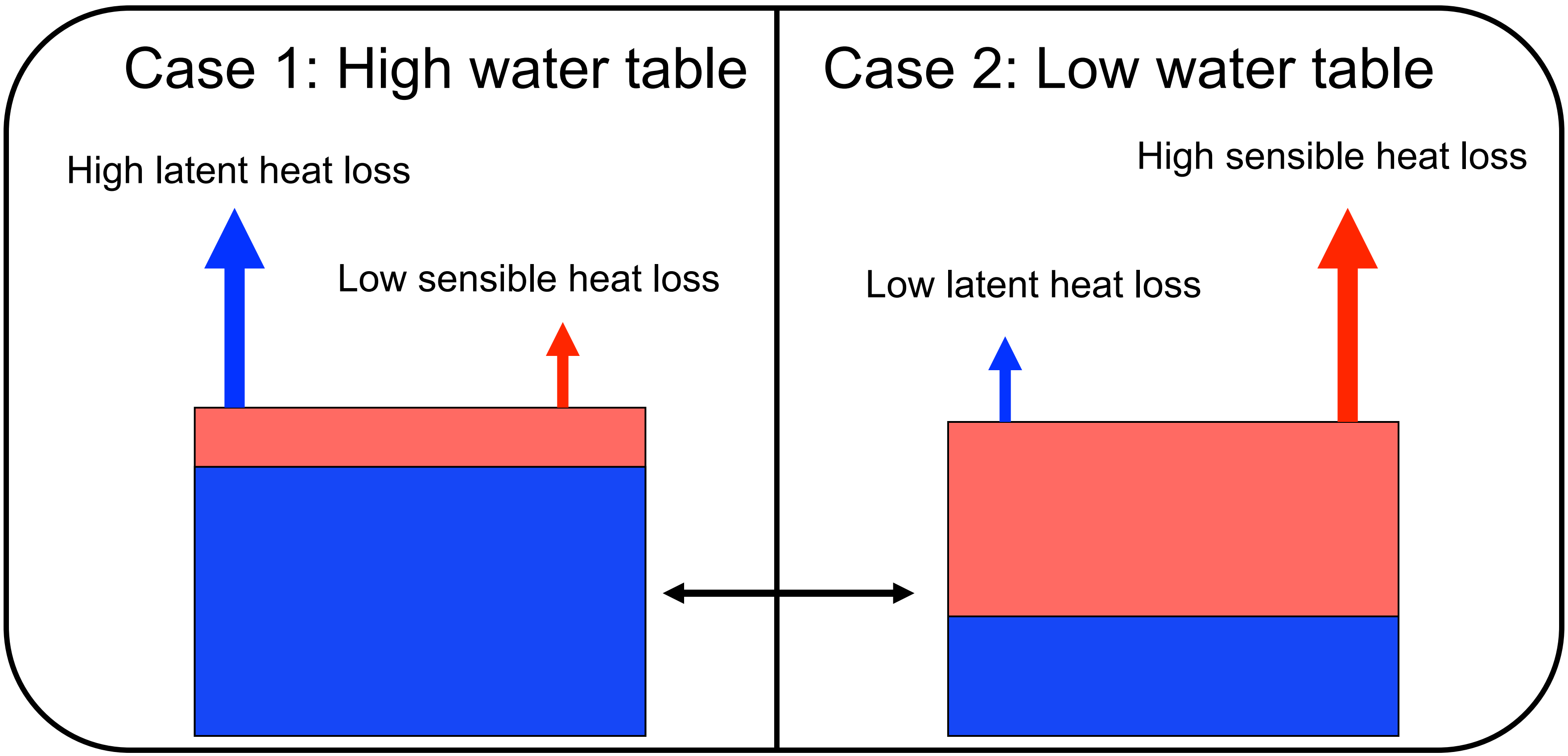


Mitra et al, 2005, Curr. Sci.

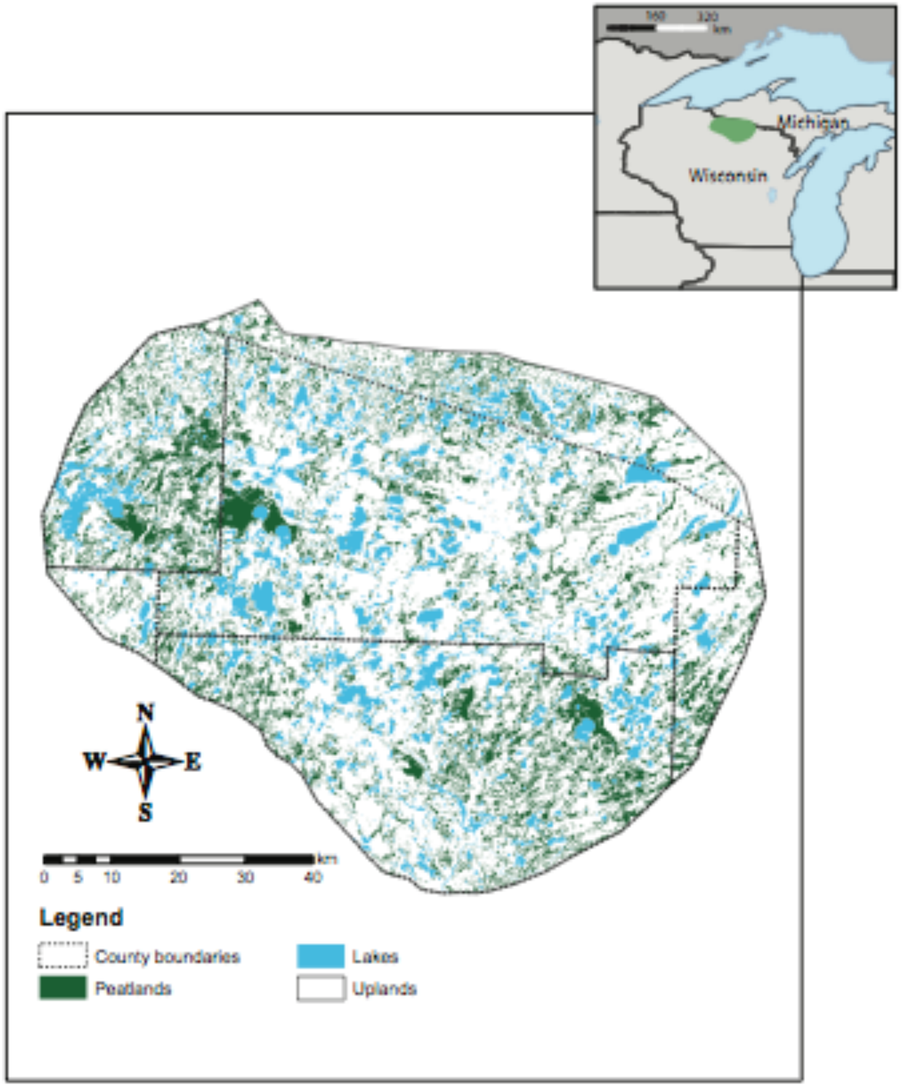
Biogeochemical Interactions



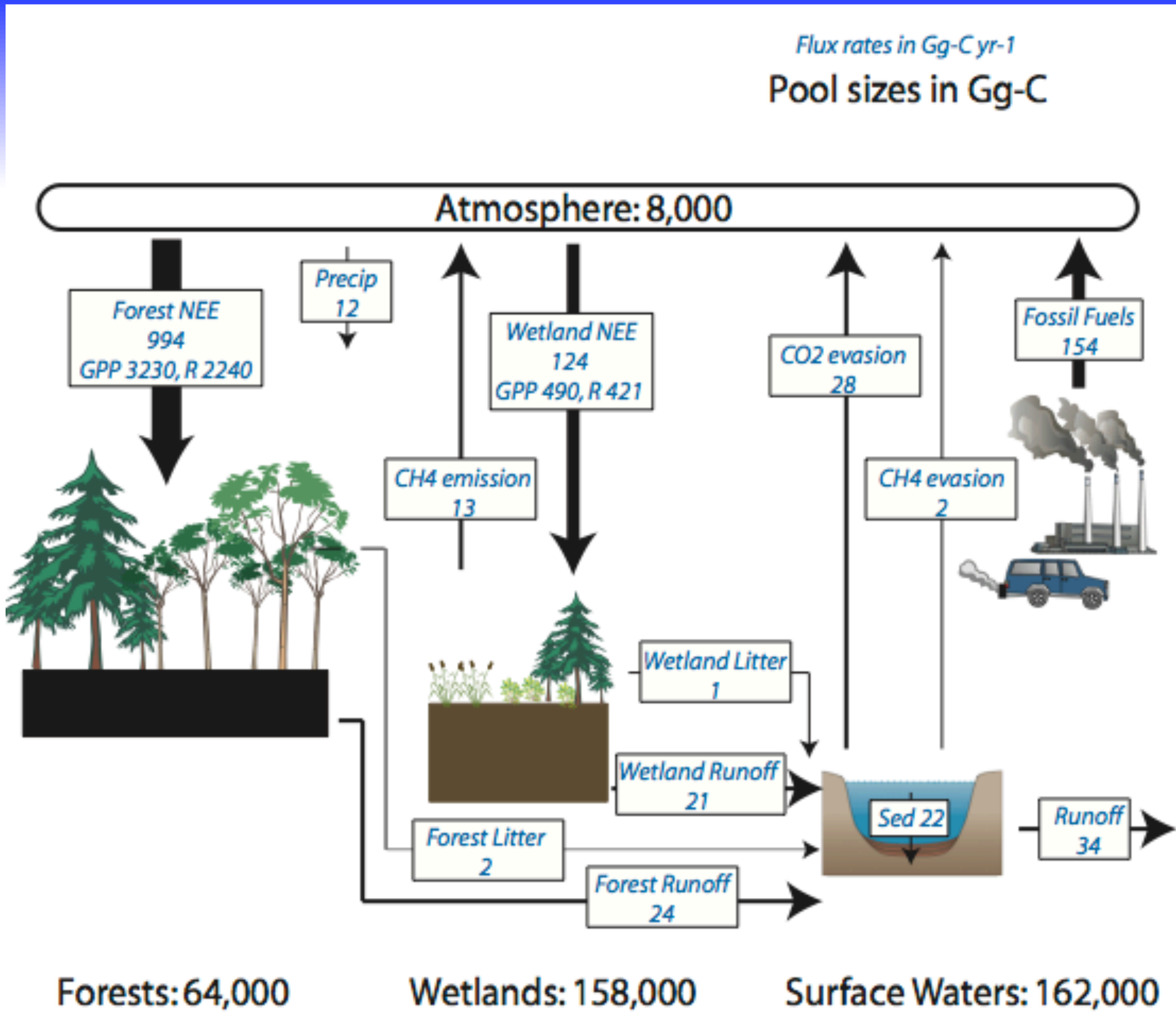
Biophysical Interactions



Northern Highlands



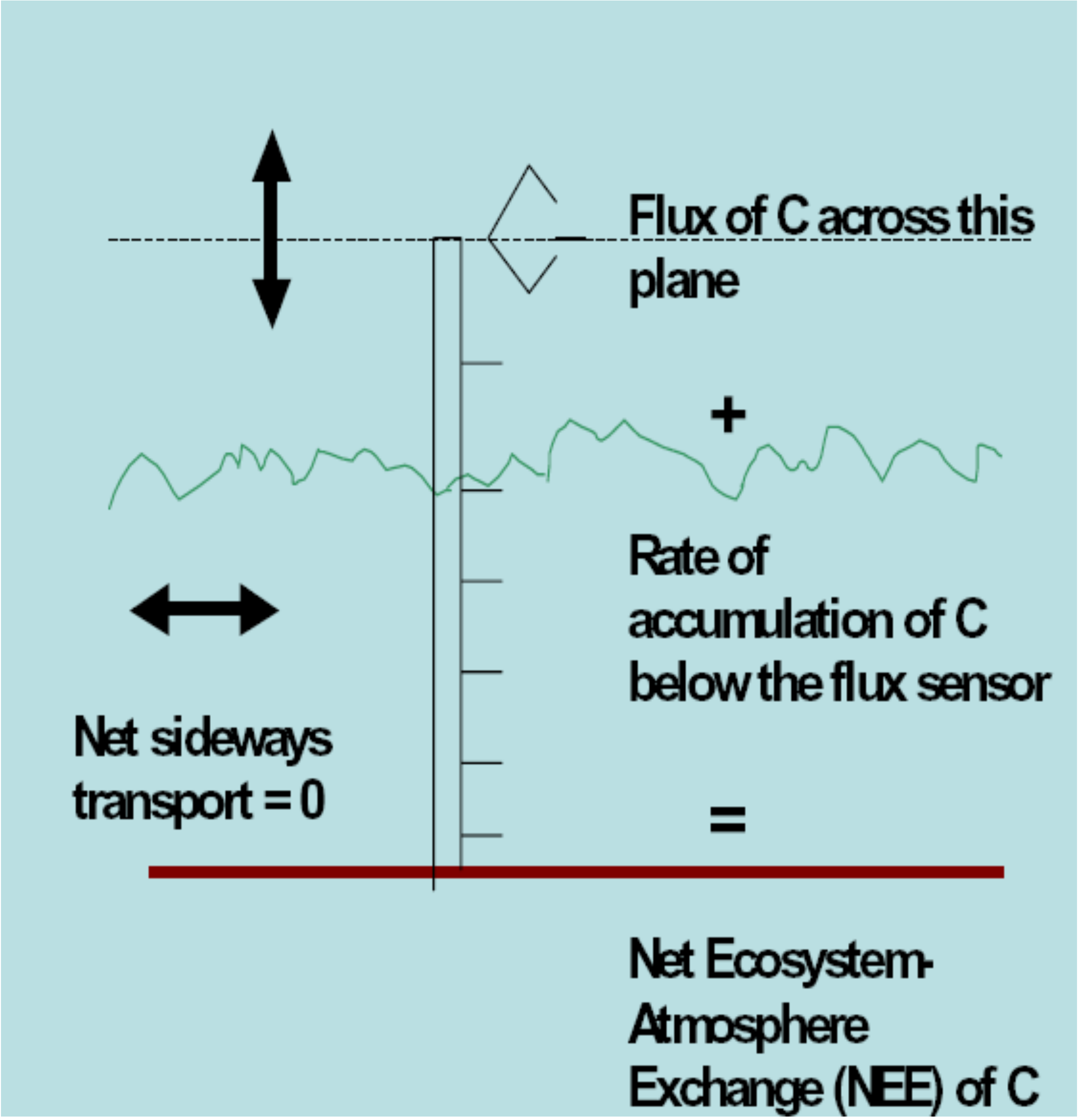
Buffam et al. (2010) GCB

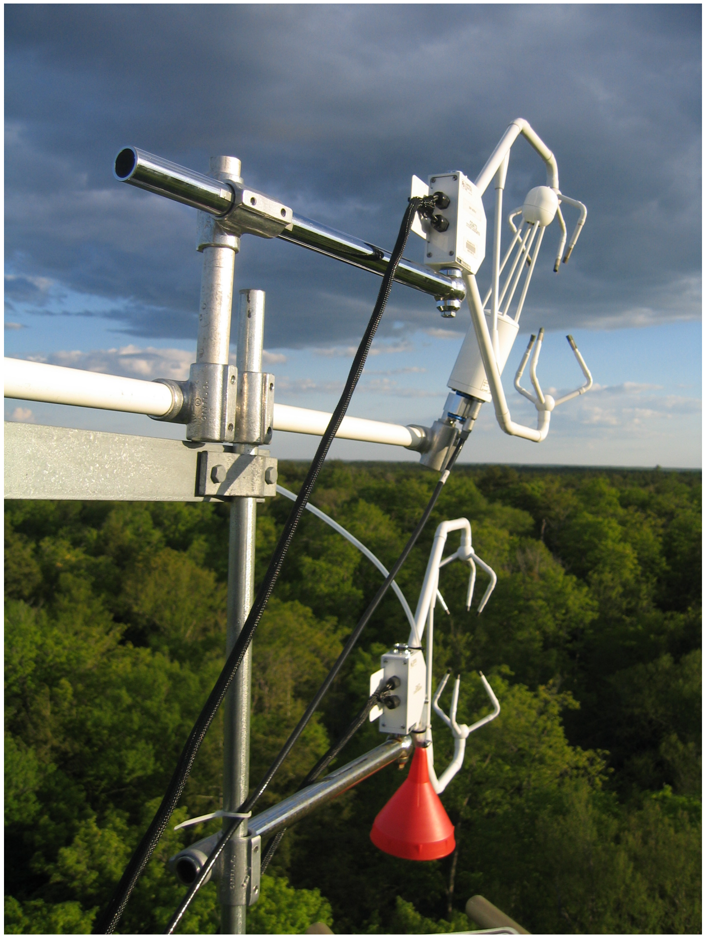


Buffam et al. (2010) GCB

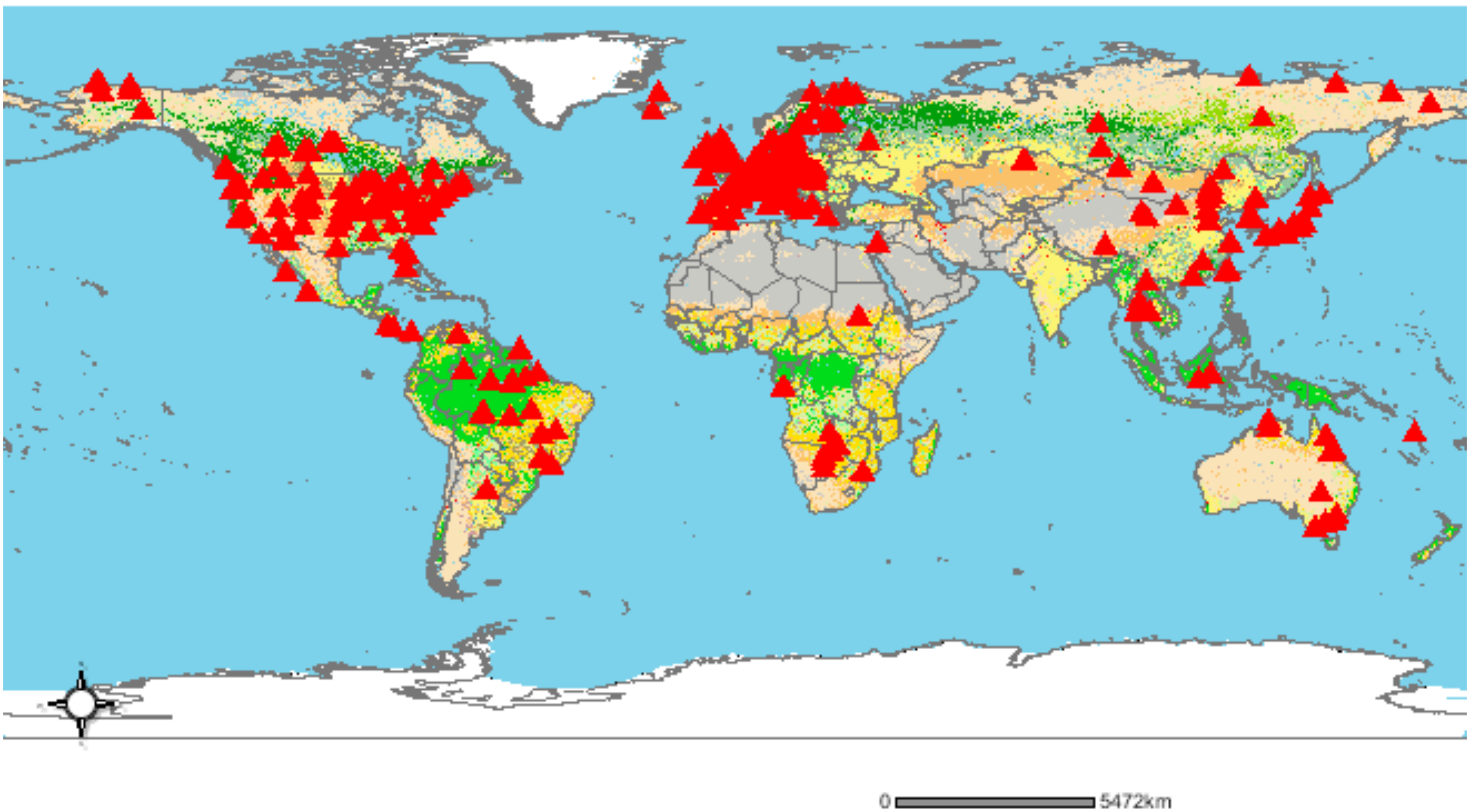
A Tower

A Useful Tower

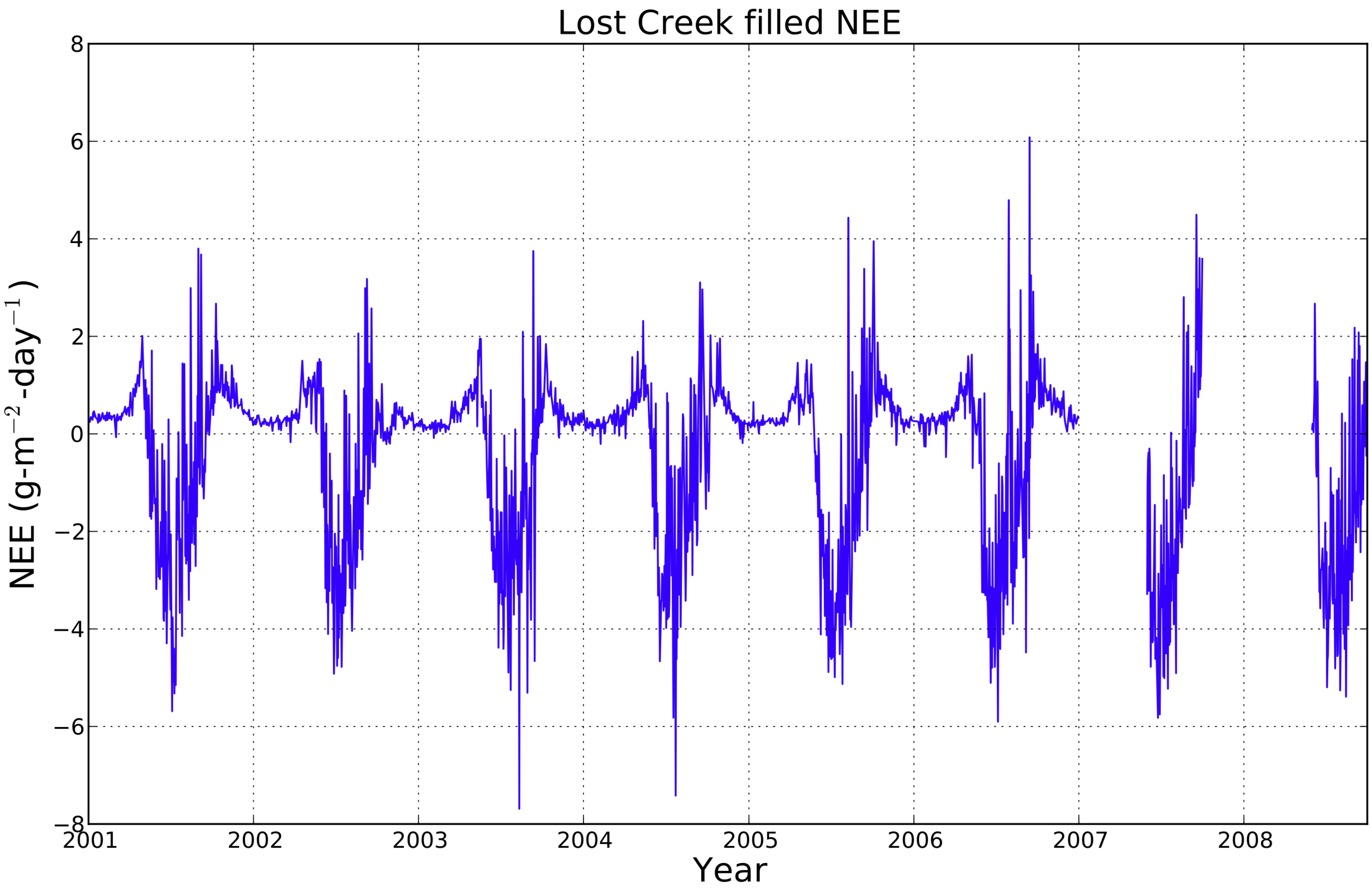




Many Useful Towers



A Useful Tower With Data



Methods

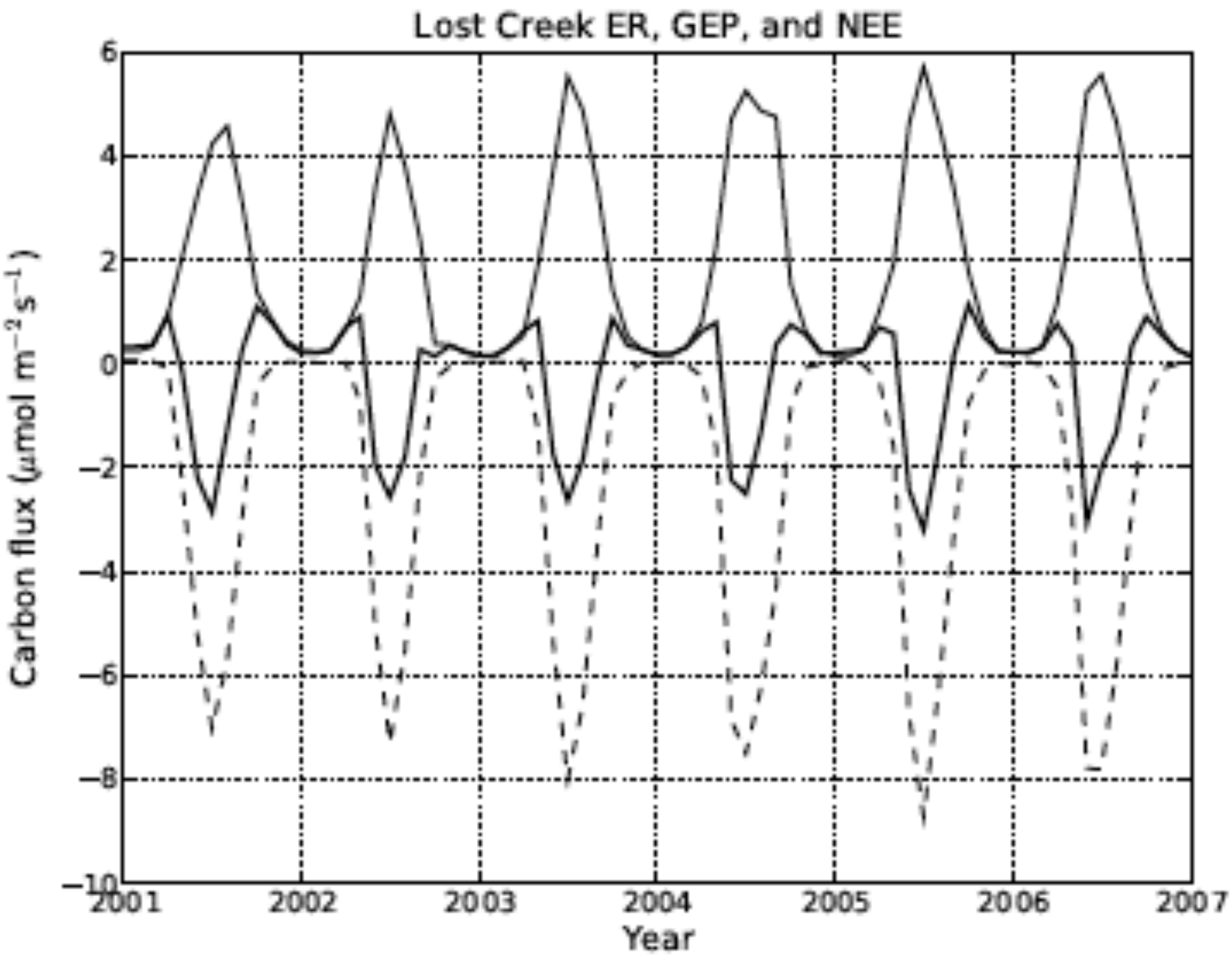
- Multi-year flux tower **Net Ecosystem Exchange (NEE)** observed, quality controlled, gap-filled (Desai et al., 2005)

- Rates of photosynthesis – **Gross Primary Production (GPP)** and **Ecosystem Respiration (ER)** derived from moving window regression of NEE to environmental variables; NEE = ER-GPP (Desai et al., 2008)

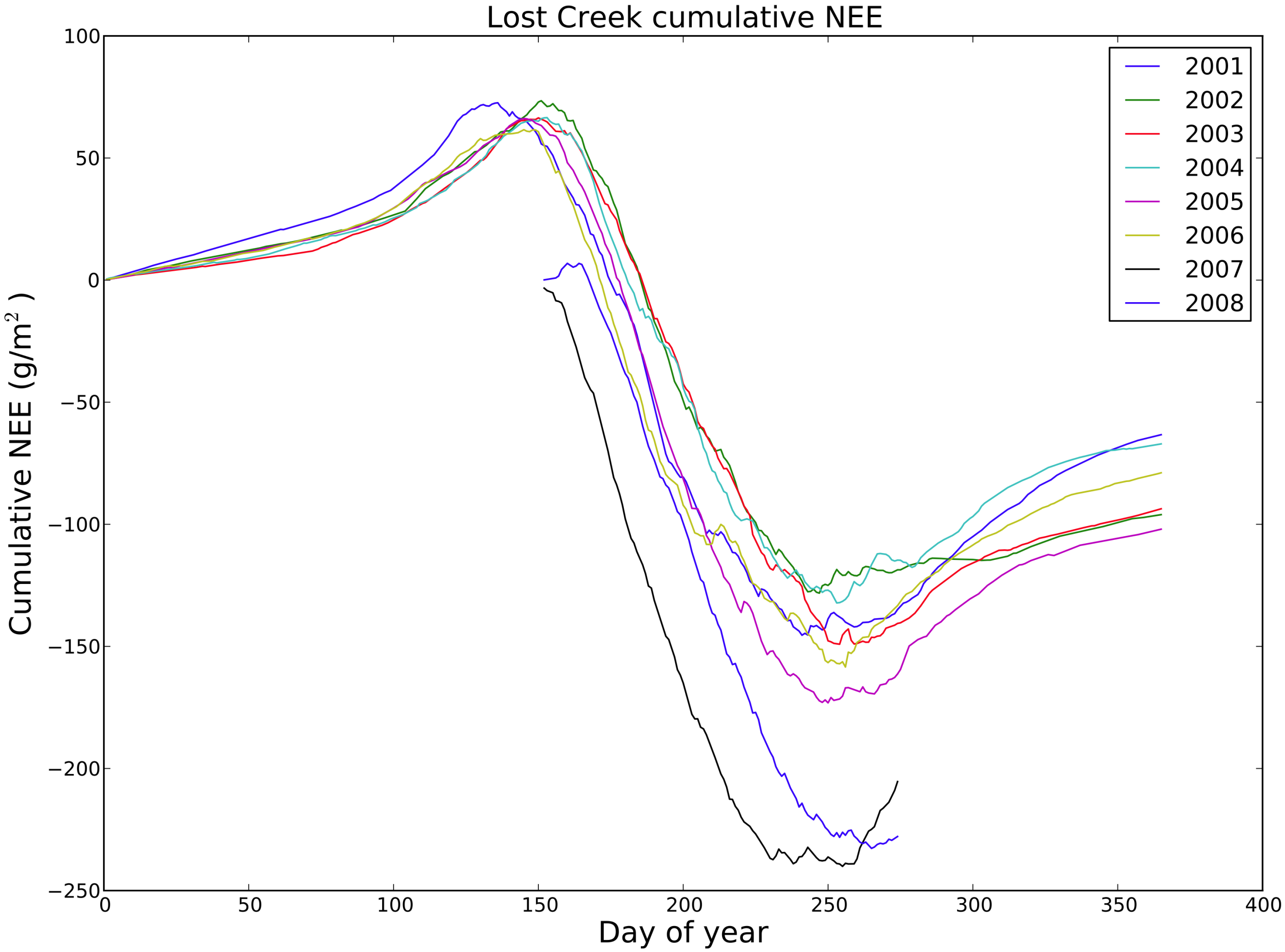
- Results compared to seasonal **water table depth** observations at each site (Sulman et al., submitted)

- Six state-of-the-art **ecosystem models** parameterized and run at three sites with same meteorological forcing and biometric info (Shroeder et al., in prep)

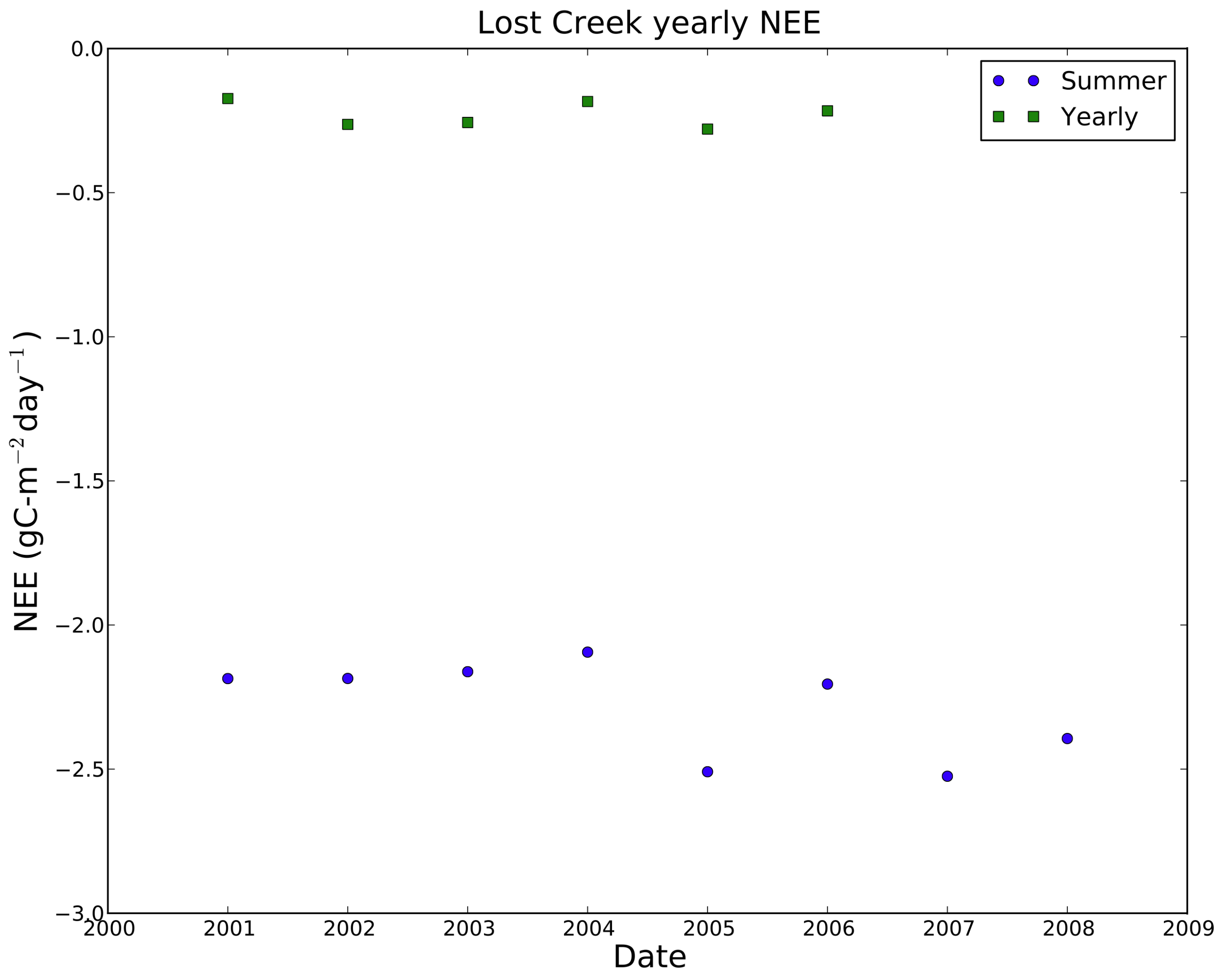
Wetland Carbon Fluxes



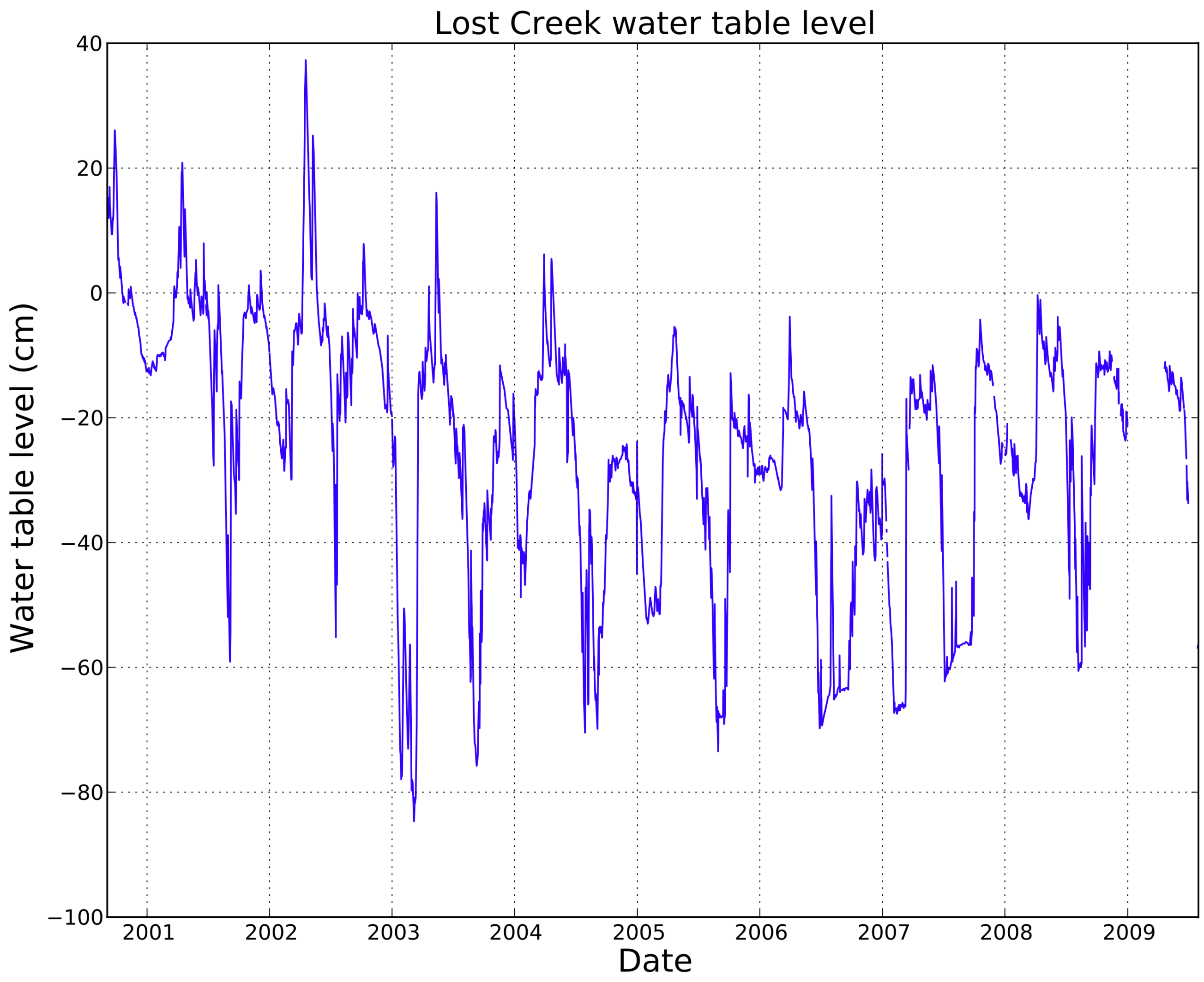
Seasonal Variability



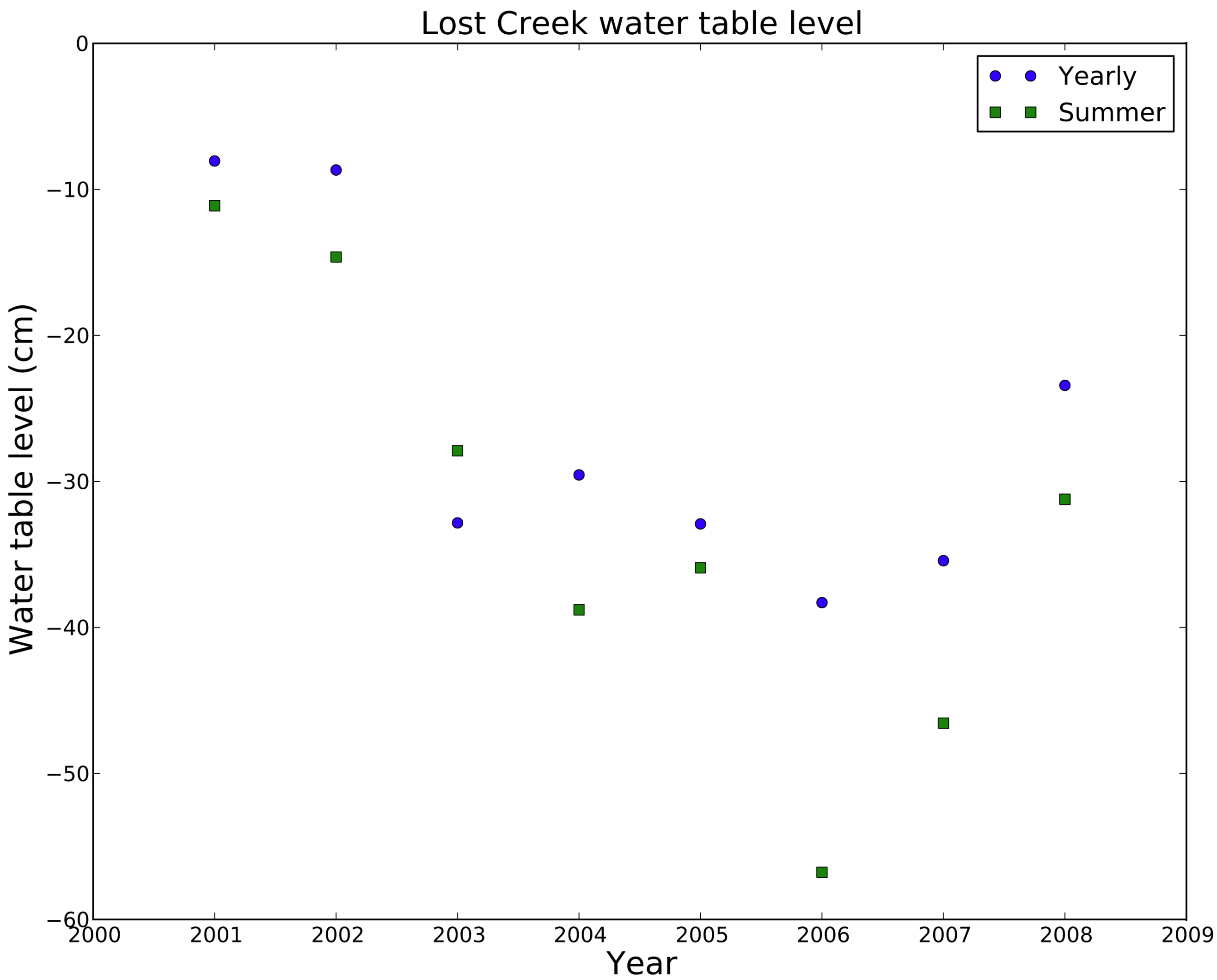
Interannual Variability



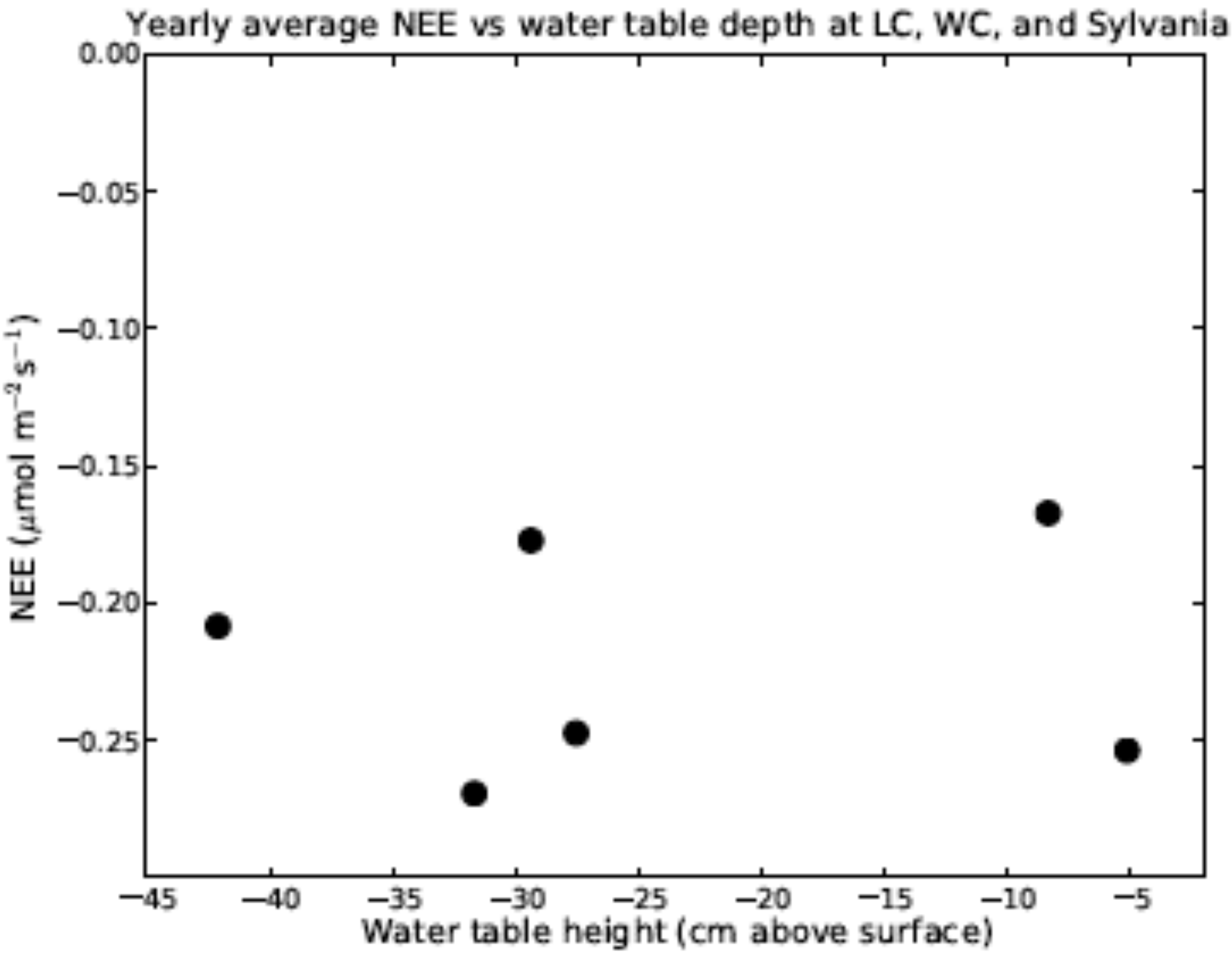
Natural Experiment



Declining Water Table



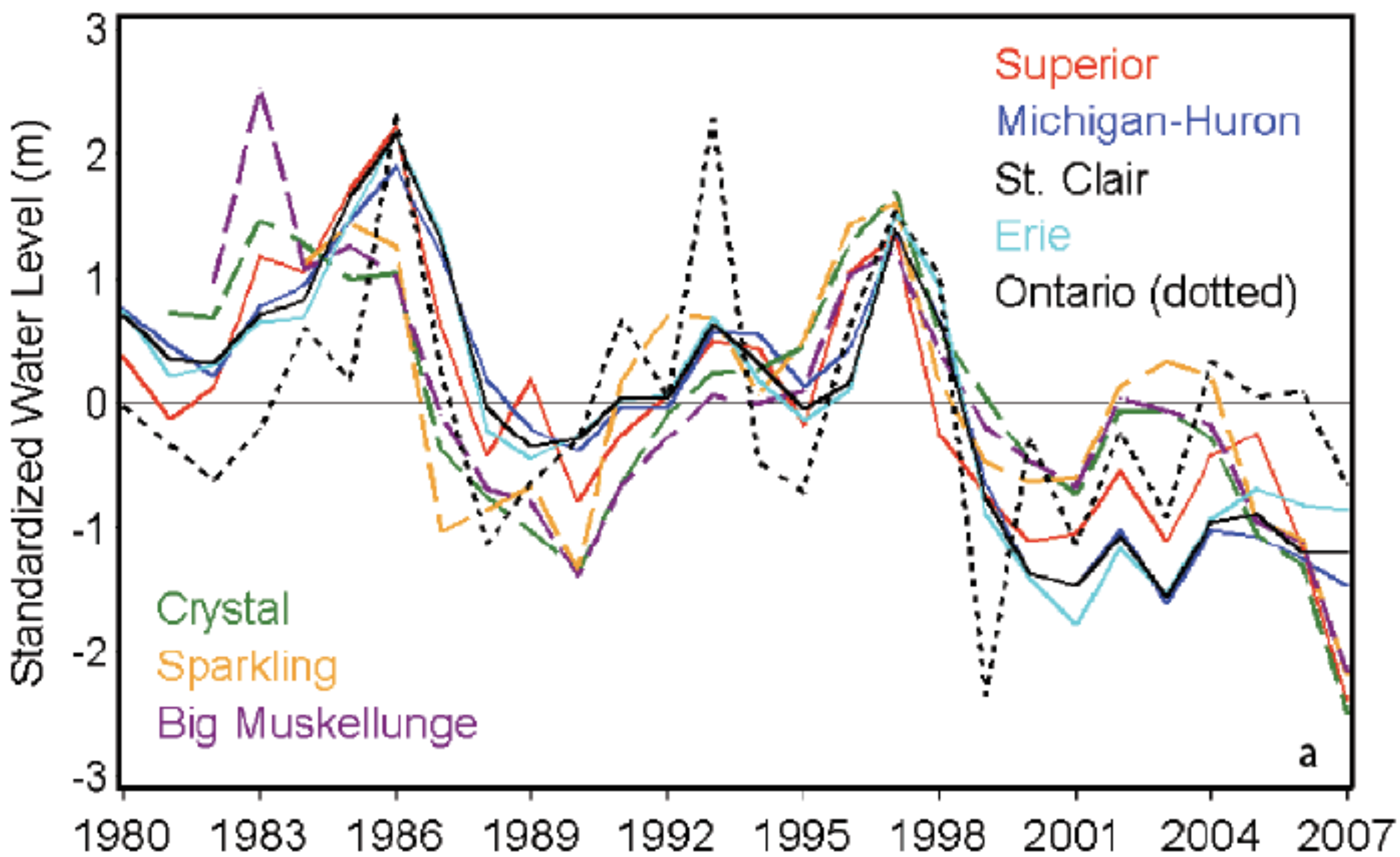
Trend?



Sulman et al. (2009) Biogeosci.

SURPRISE!

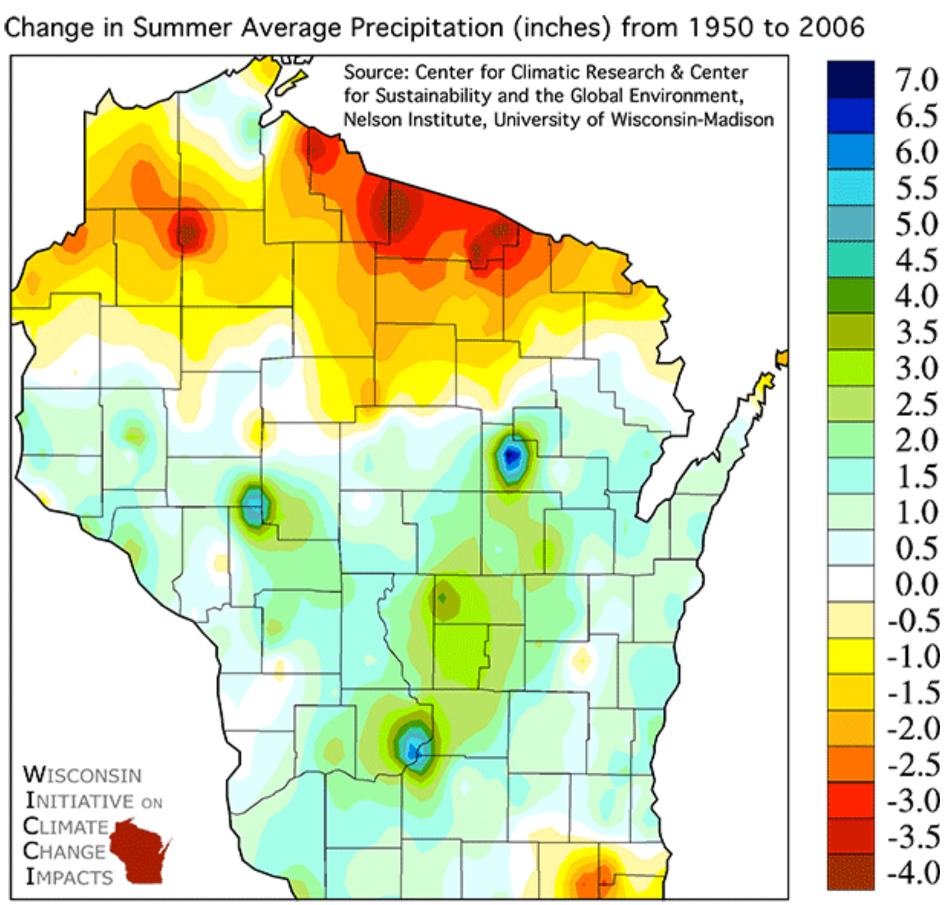
Lakes Levels Are Dropping

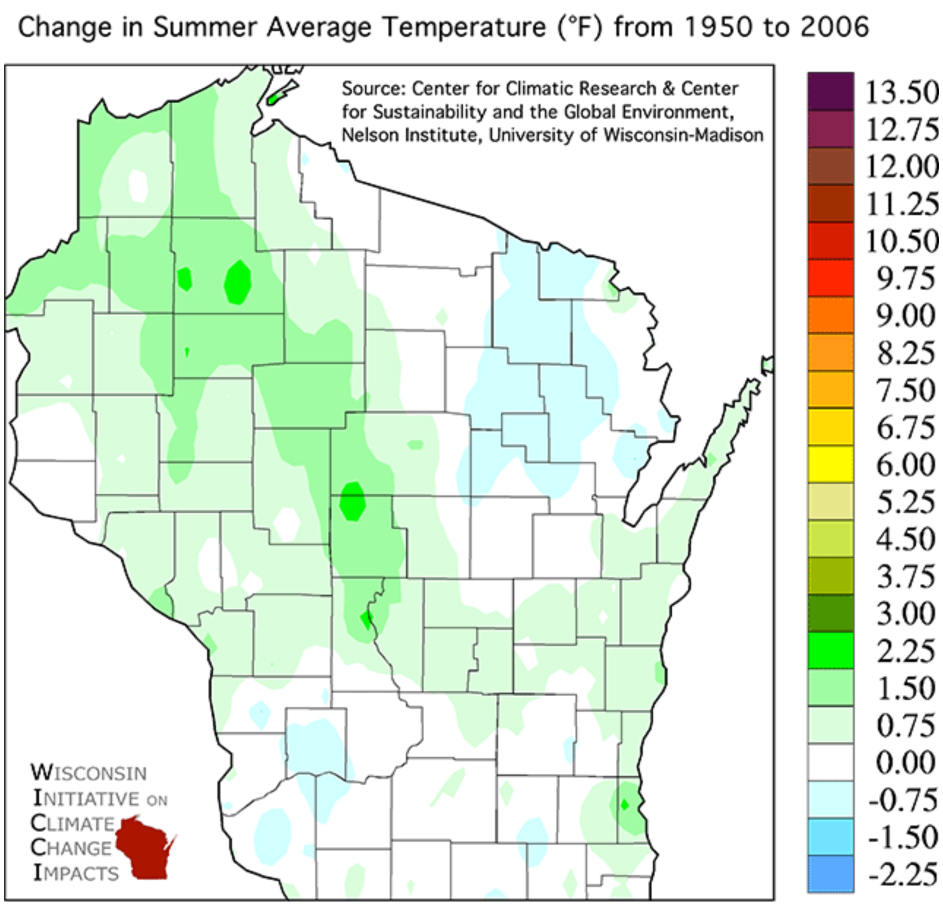


Stow et al. (2008)

Regional Climate Trends

- Statistically-interpolated station data 1950-2006

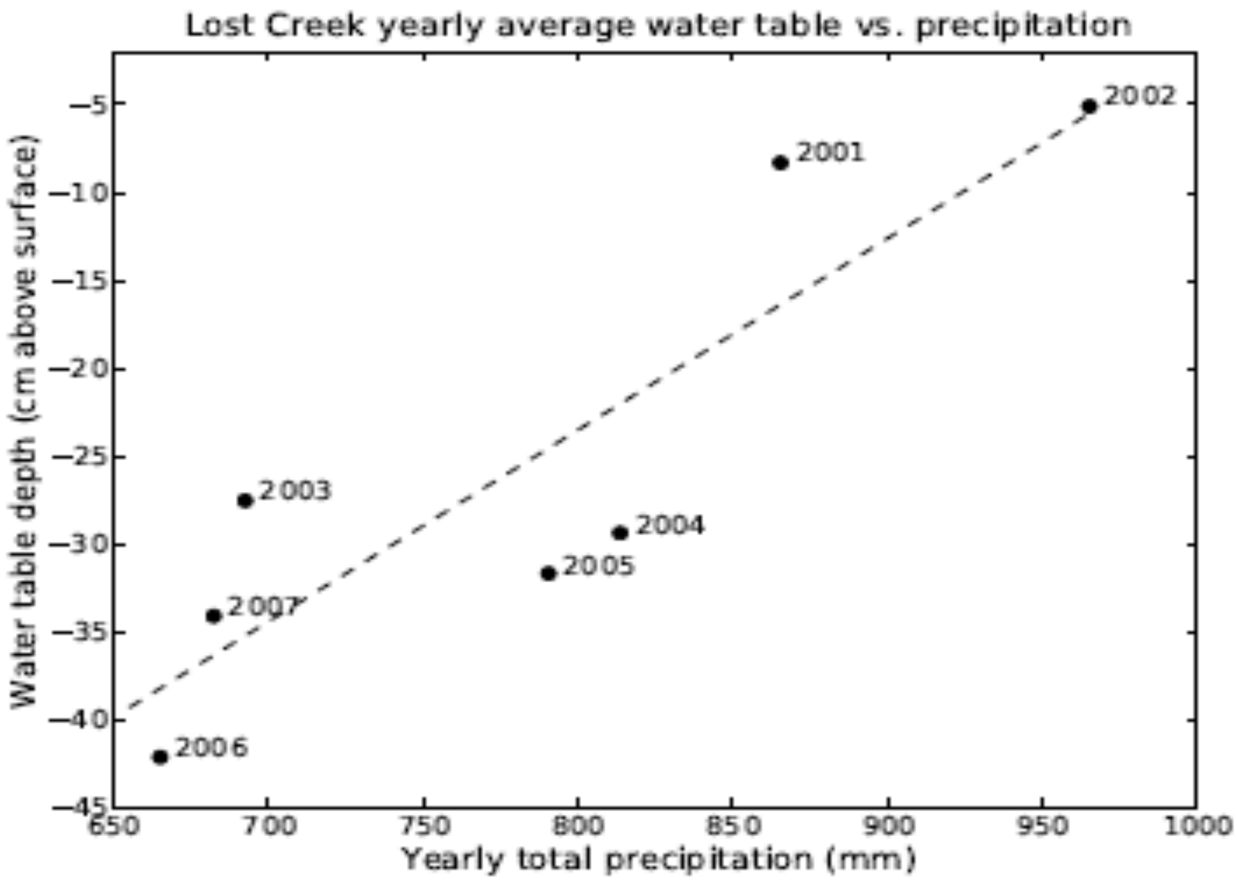




WICCI (2009)

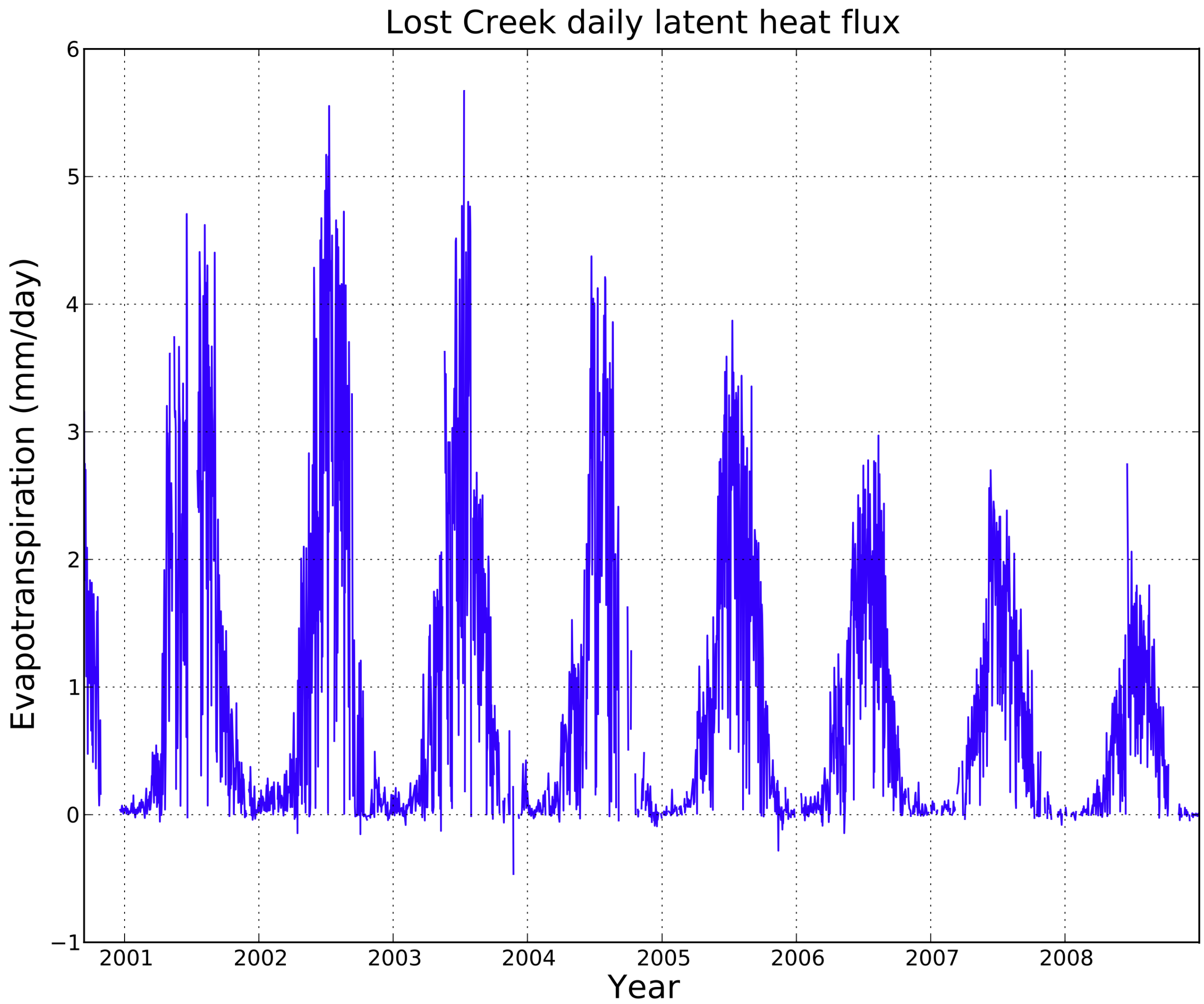
What Drives Water Table?

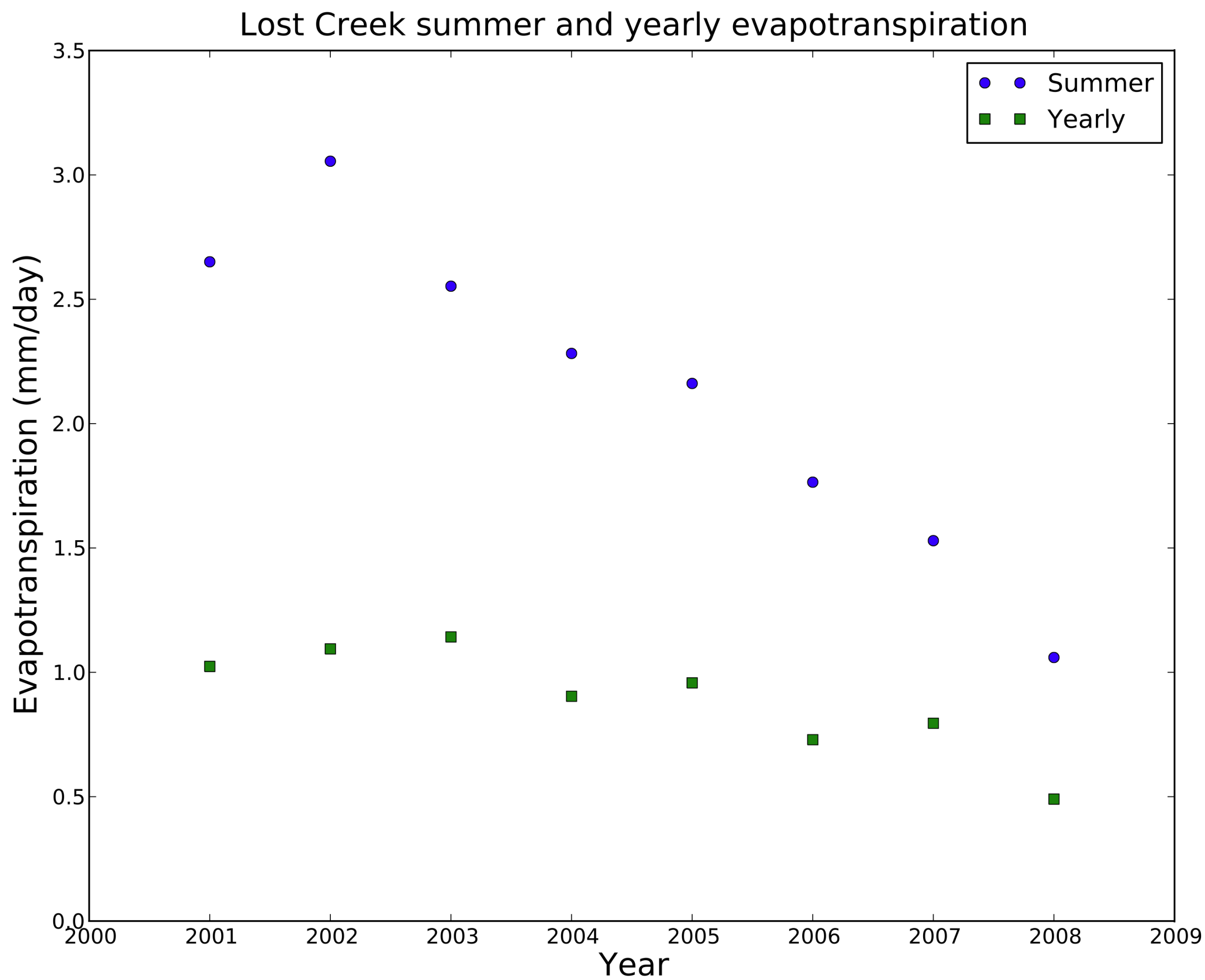
- Water table elevation is driven by precipitation and evaporation



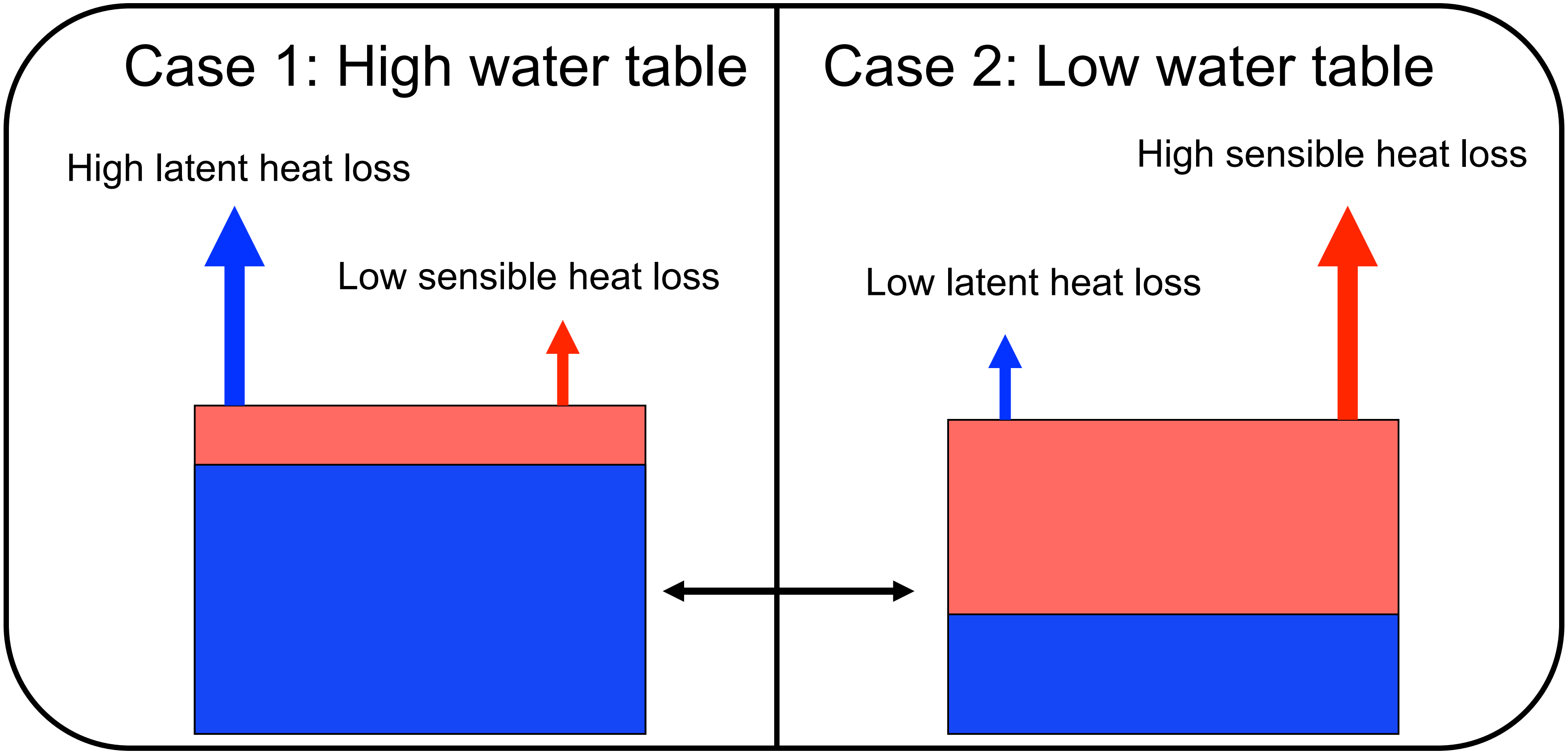
Sulman et al. (2009) Biogeosci.

Evapotranspiration



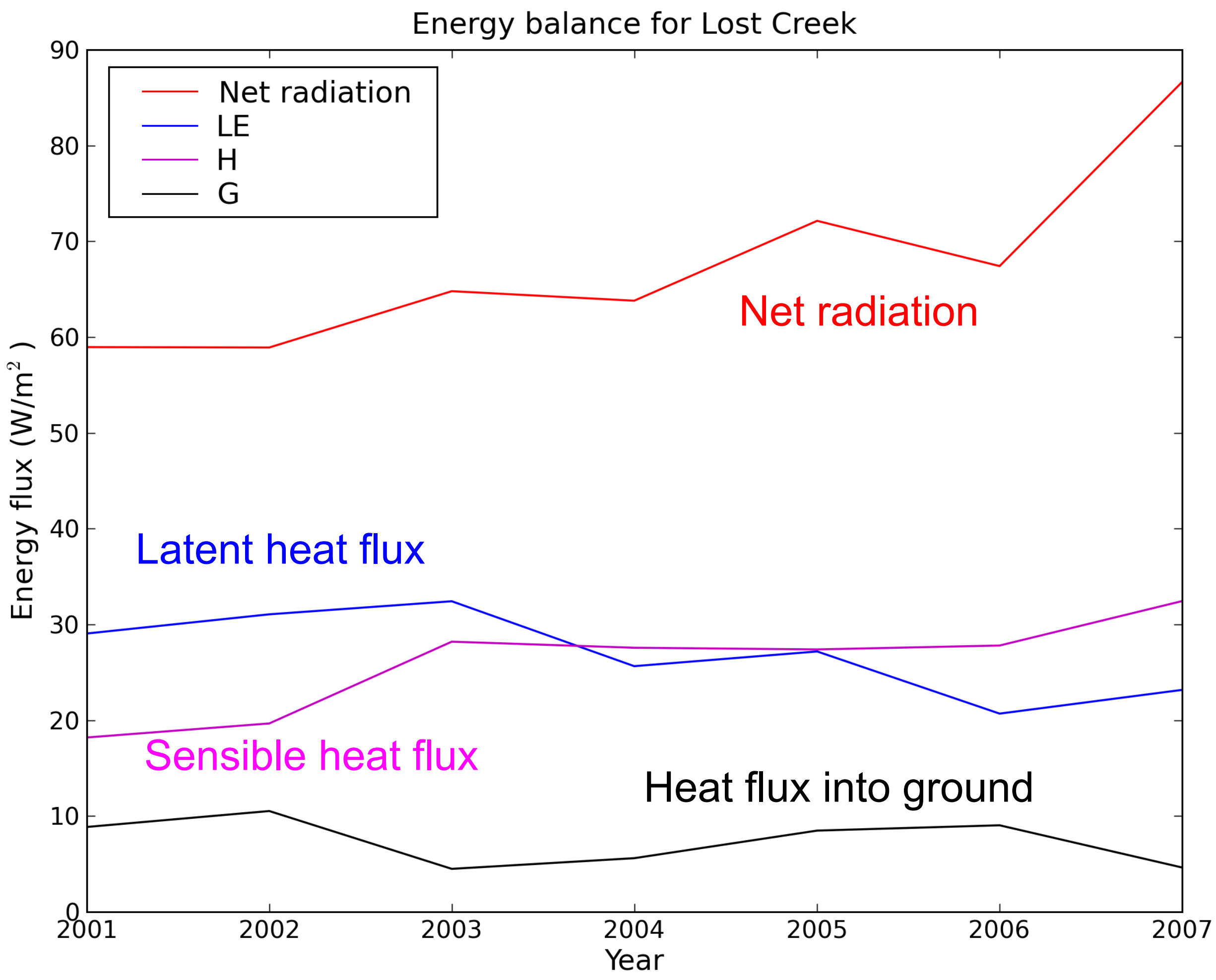

Lost Creek summer and yearly evapotranspiration
Summer
Yearly
Evapotranspiration (mm/day)
Year
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009

Biophysical Interactions



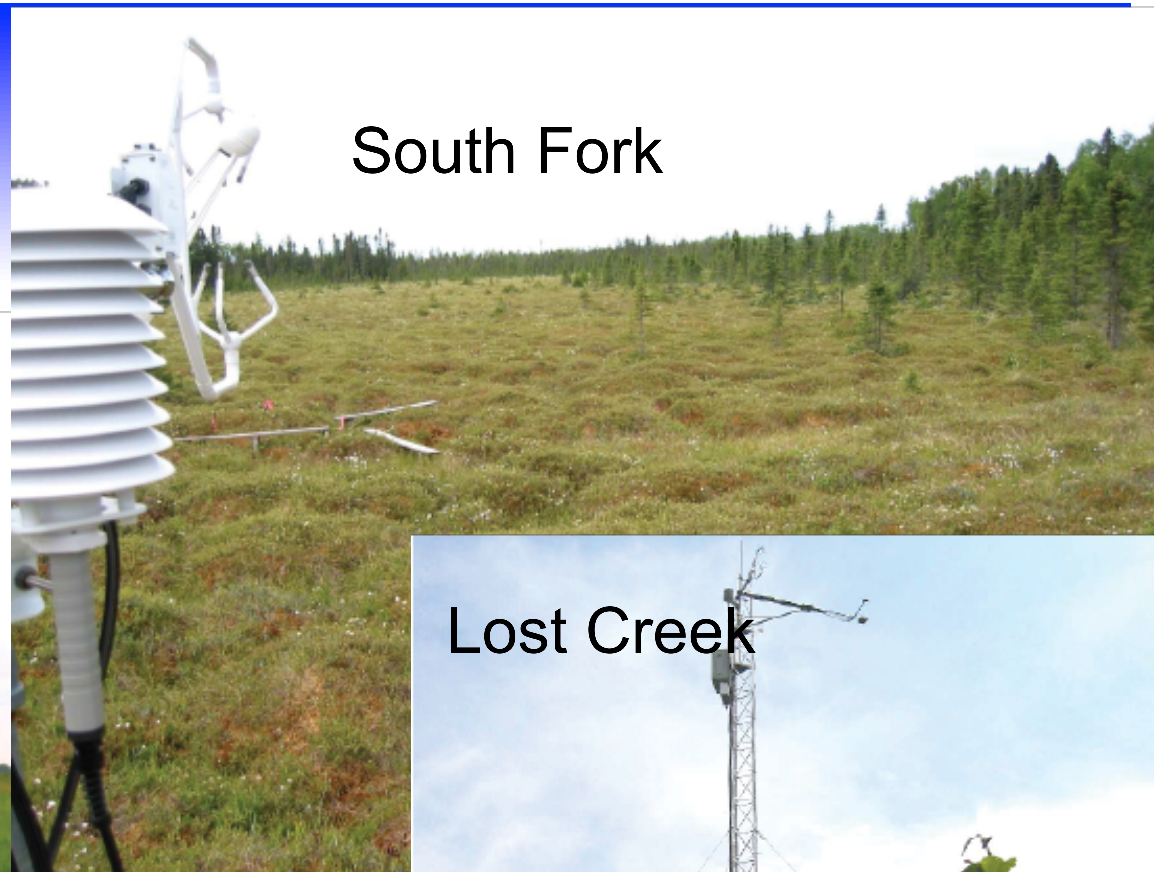
Energy Balance

- Net radiation increased due to increasing incoming radiation and decrease in albedo
- Sensible heat flux increased relative to latent heat flux
- If these changes occur on a large scale, they can have significant effects on regional climate (Sampaio et al. 2007, Foley et al. 2003)

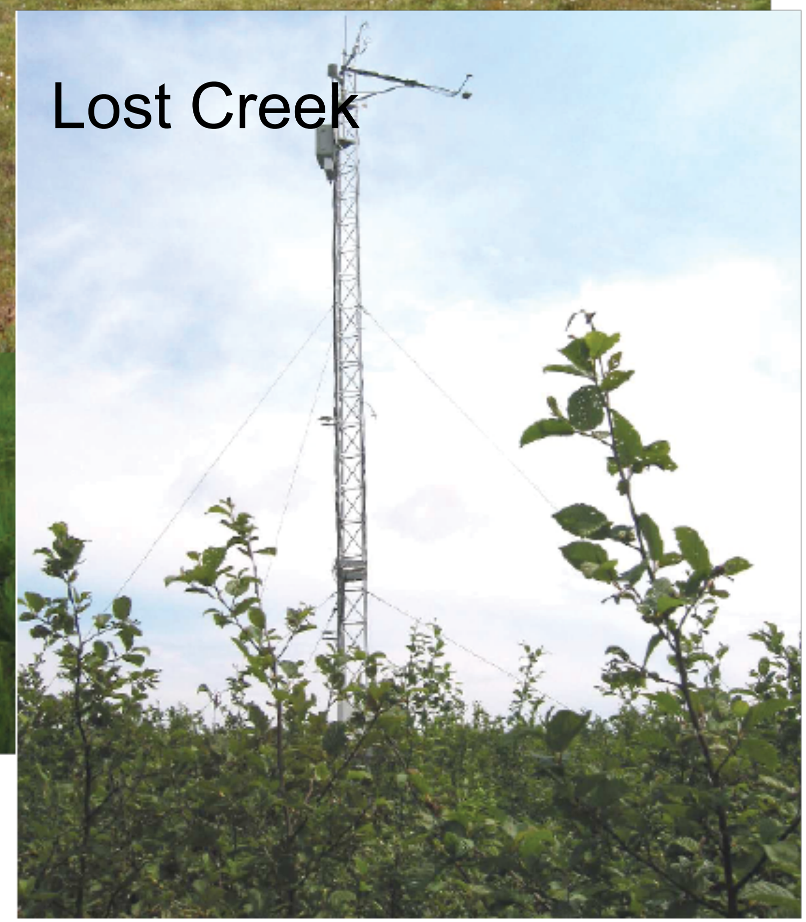


A Wet Place

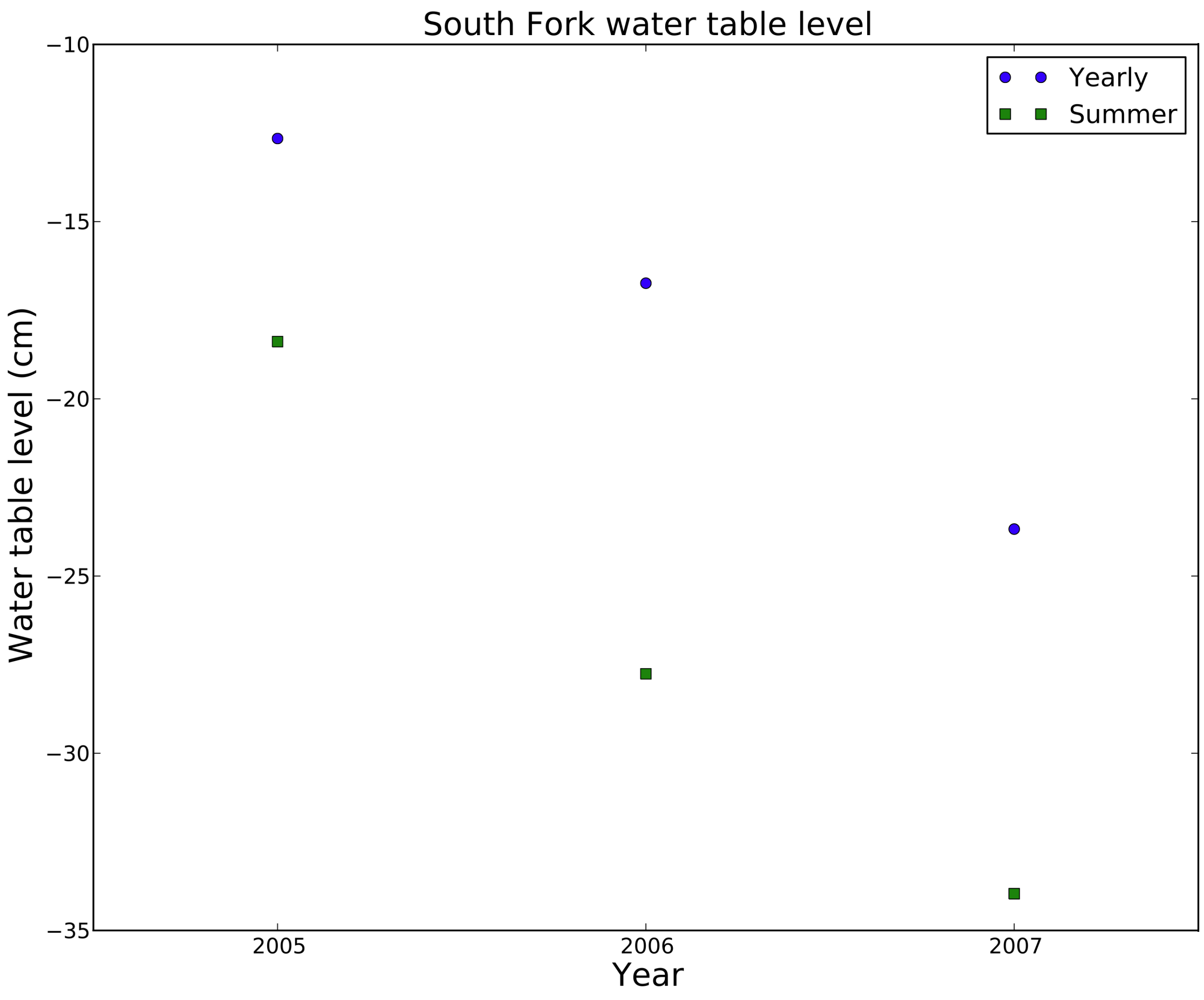
Hardwood chronosequence
(Intermediate, Young)
Young Jack Pine
Red Pine chronosequence
(Clearcut, Young, Mature)
South Fork
bog
Sylvania old-growth
Lost Creek
shrub fen
Wilson Flowage
meadow
Willow Creek
mature hardwood
UMBS
mature
hardwood
Minnesota
Wisconsin
Michigan
Iowa
0
100
200km
Scale

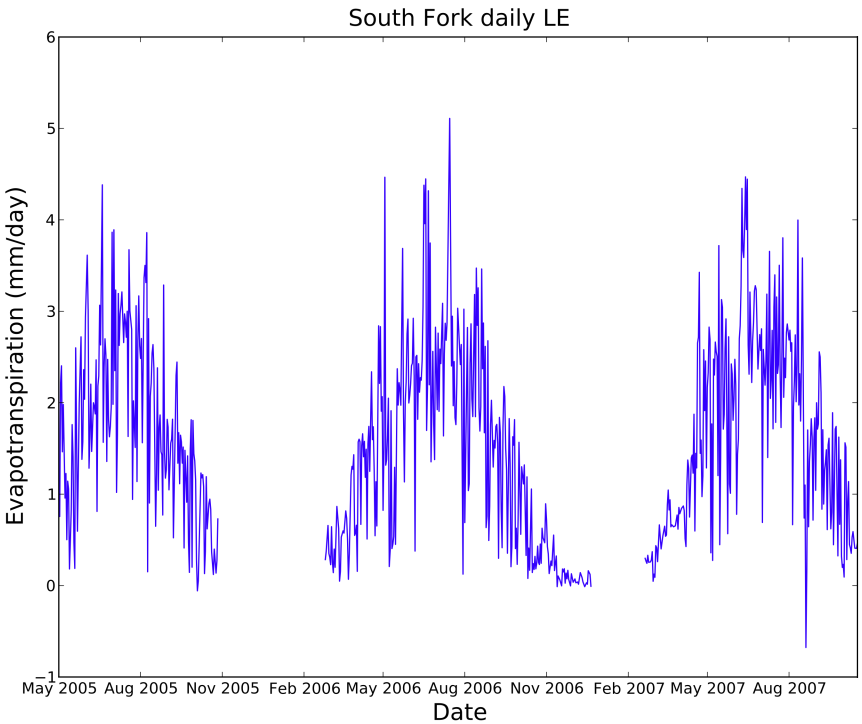

South Fork


Wilson Flowage


Lost Creek

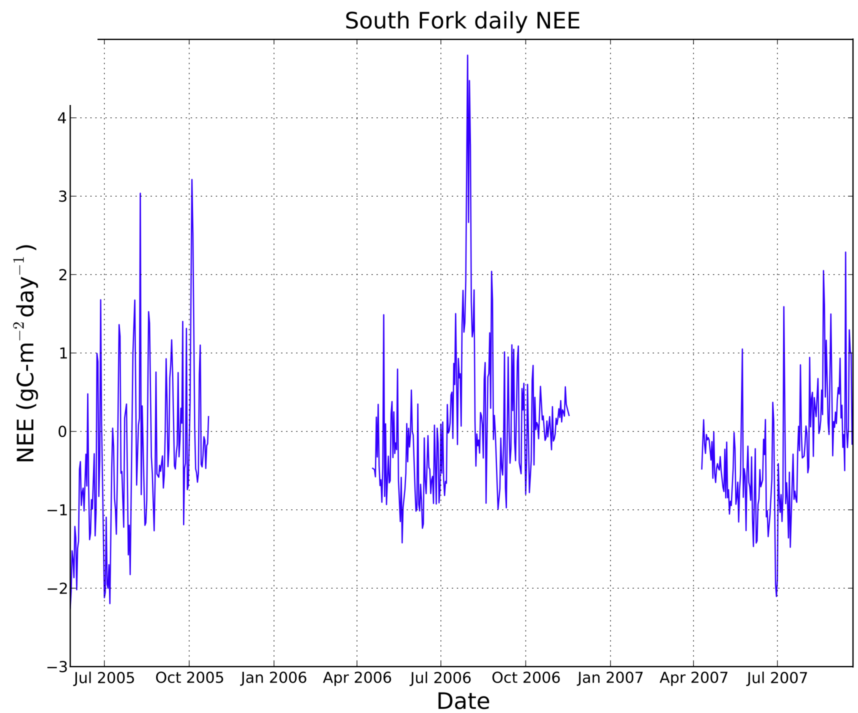
A Bog


South Fork water table level
Water table level (cm)
Year
Yearly
Summer
−10
−15
−20
−25
−30
−35
2005
2006
2007

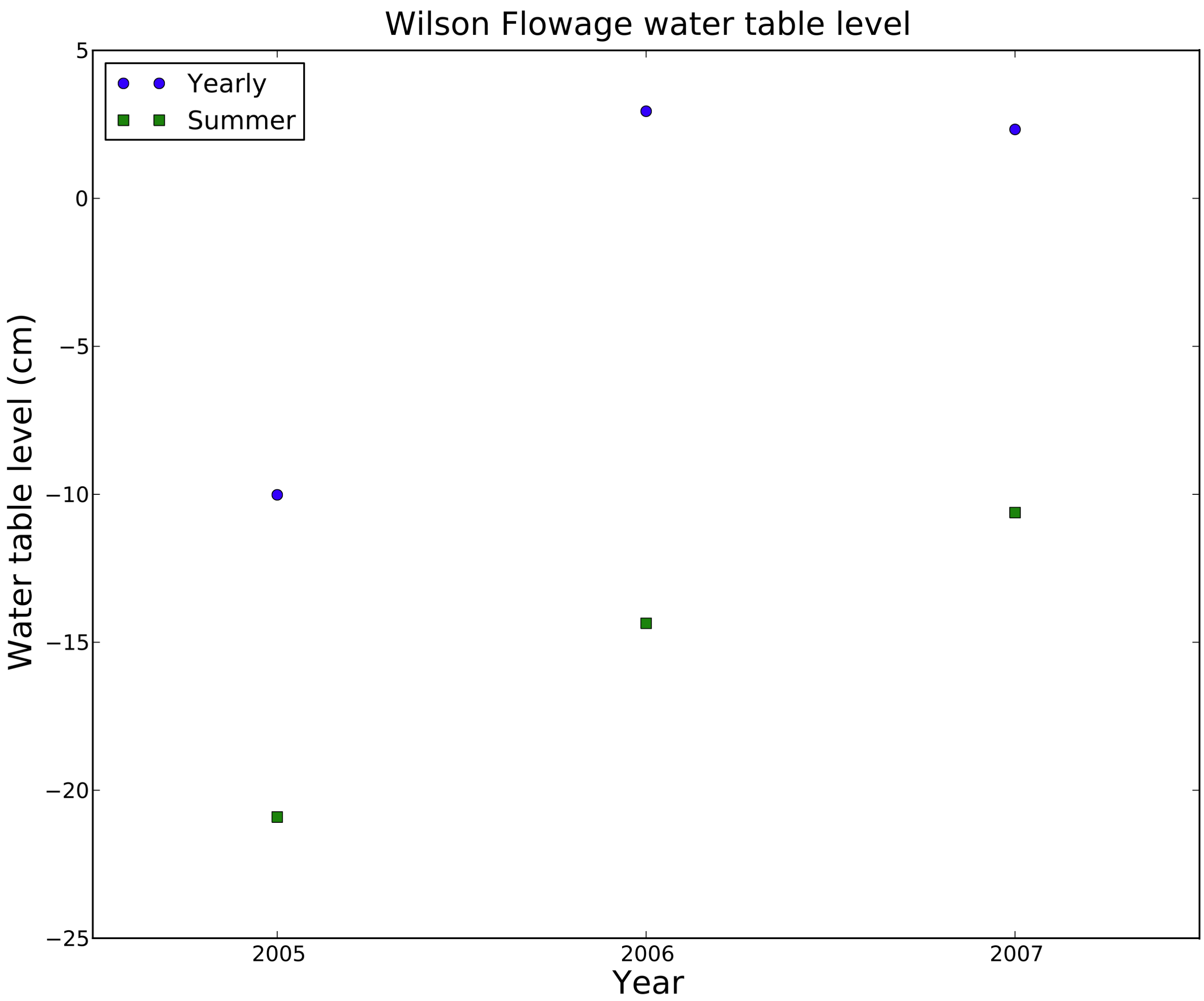

South Fork daily LE
Evapotranspiration (mm/day)
Date
May 2005
Aug 2005
Nov 2005
Feb 2006
May 2006
Aug 2006
Nov 2006
Feb 2007
May 2007
Aug 2007
−1
0
1
2
3
4
5
6

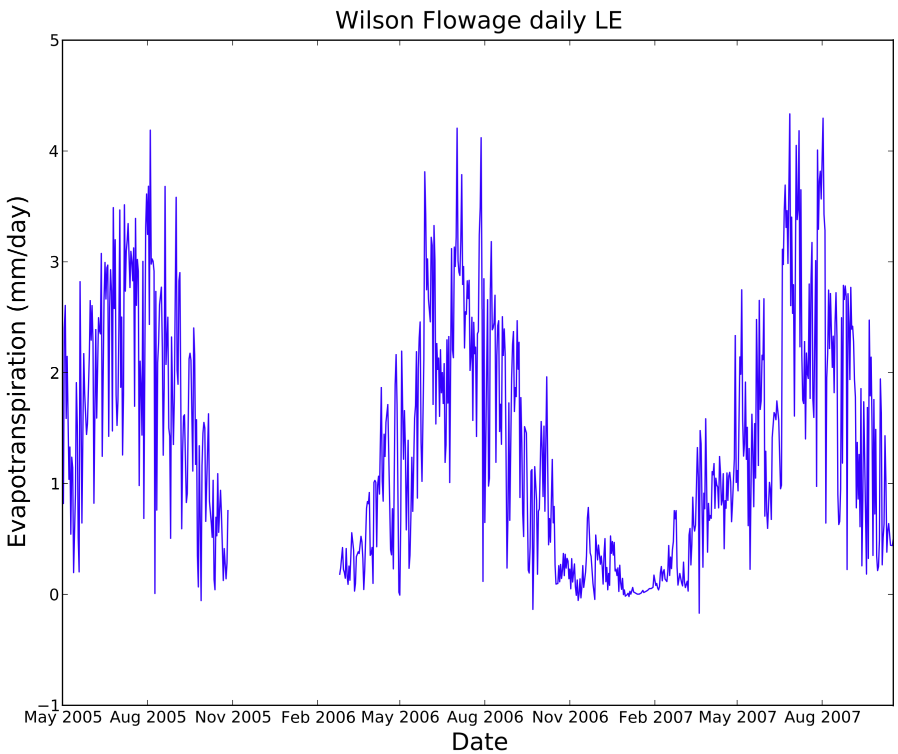
<-ET

NEE->


South Fork daily NEE
NEE (gC-m^{-2}day^{-1})
Date
Jul 2005
Oct 2005
Jan 2006
Apr 2006
Jul 2006
Oct 2006
Jan 2007
Apr 2007
Jul 2007
−3
−2
−1
0
1
2
3
4

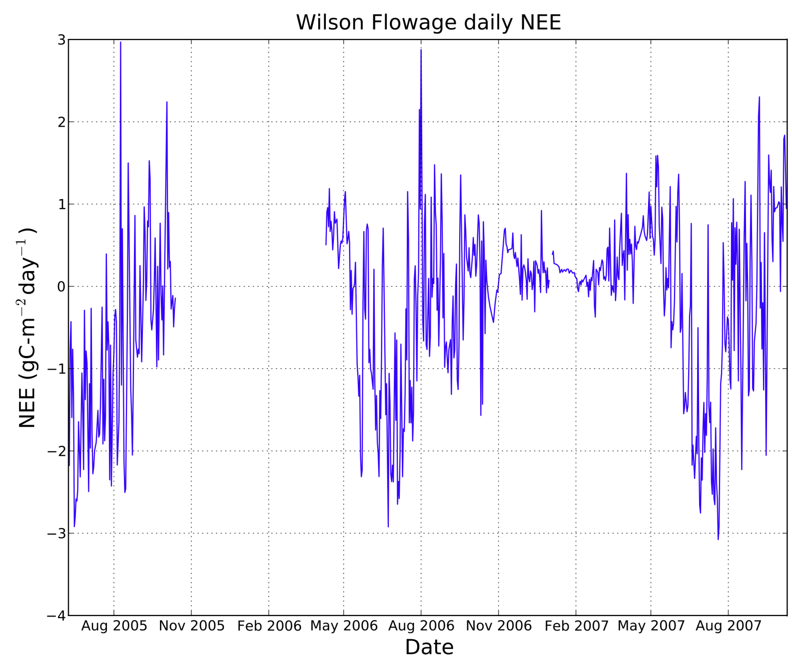
A Fen


Wilson Flowage water table level
Yearly
Summer
Water table level (cm)
Year
5
0
−5
−10
−15
−20
−25
2005
2006
2007


Wilson Flowage daily LE
Evapotranspiration (mm/day)
5
4
3
2
1
0
−1
May 2005 Aug 2005 Nov 2005 Feb 2006 May 2006 Aug 2006 Nov 2006 Feb 2007 May 2007 Aug 2007
Date

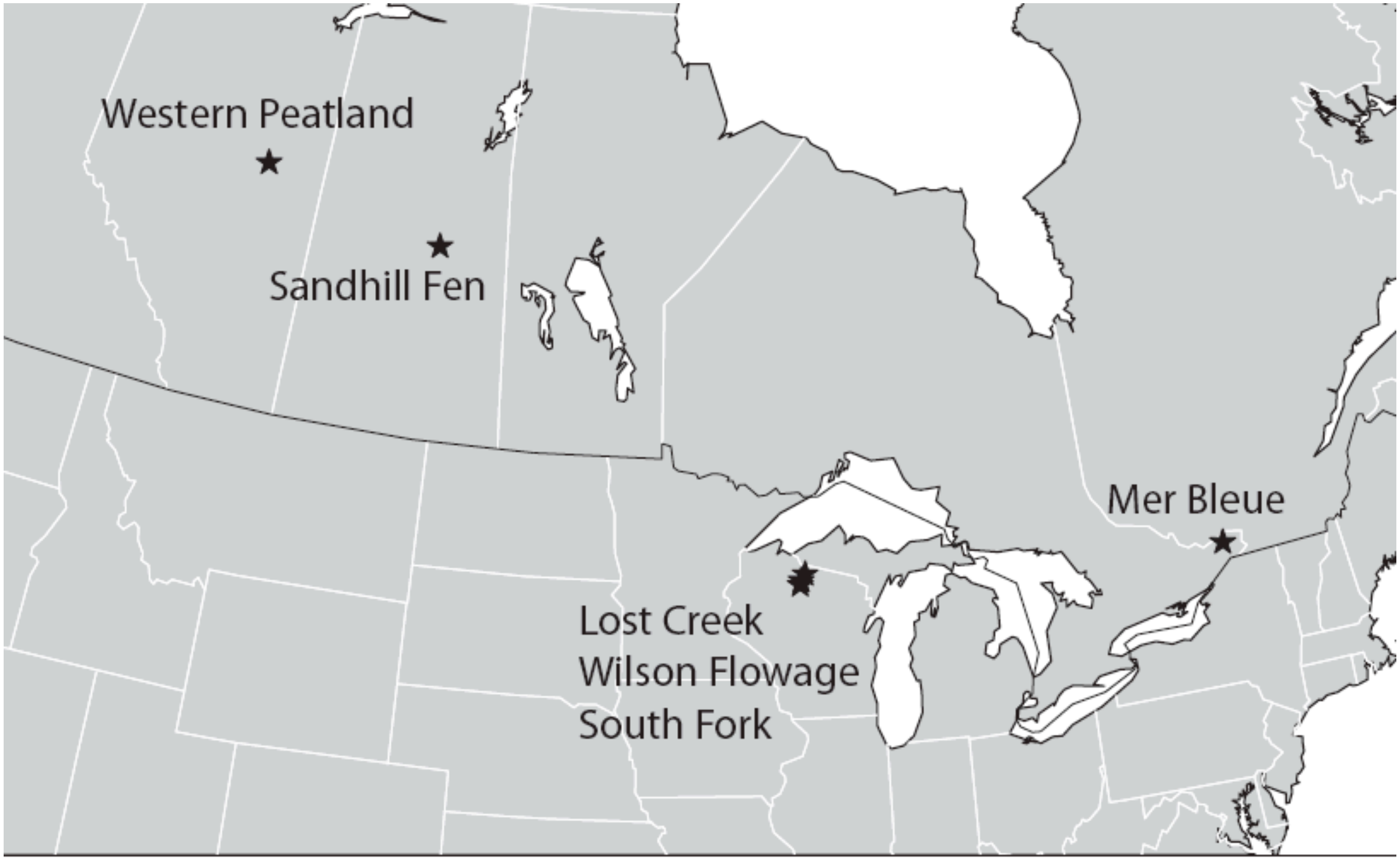
<-ET

NEE->

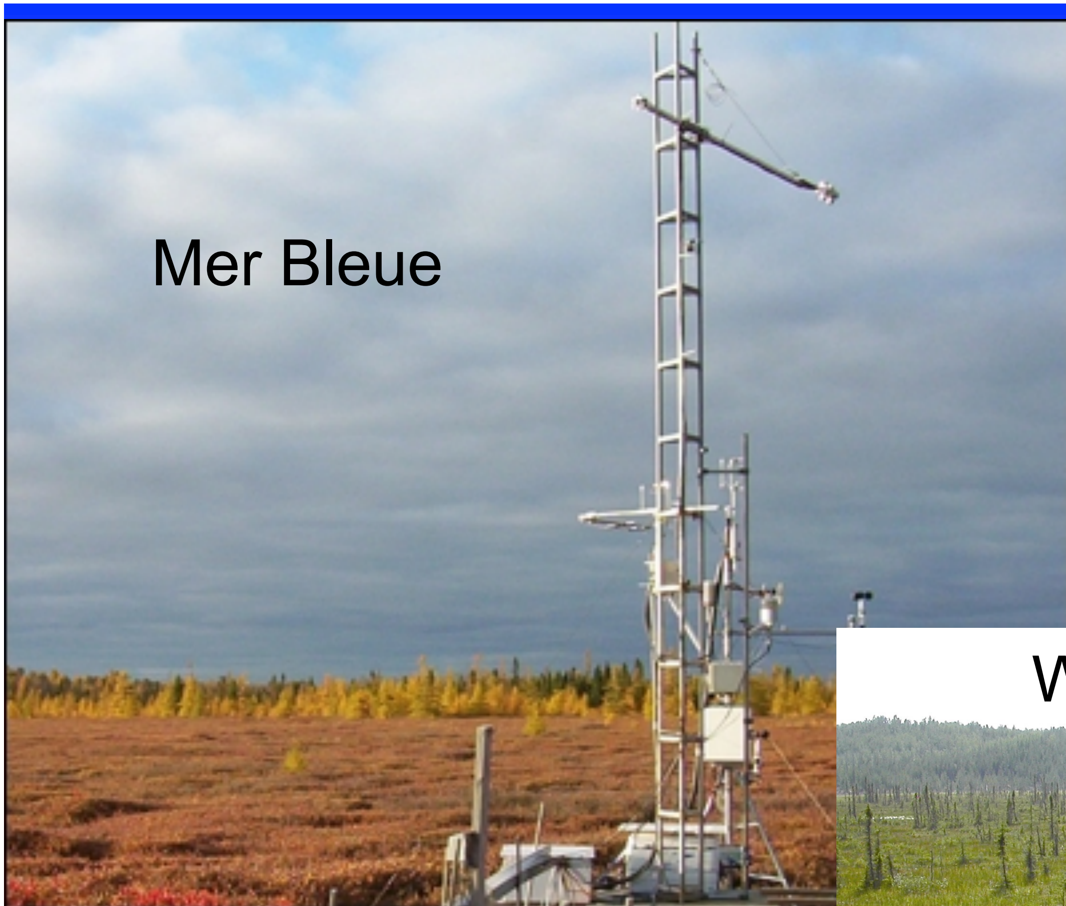

Wilson Flowage daily NEE
NEE (gC-m⁻² day⁻¹)
3
2
1
0
−1
−2
−3
−4
Aug 2005 Nov 2005 Feb 2006 May 2006 Aug 2006 Nov 2006 Feb 2007 May 2007 Aug 2007
Date

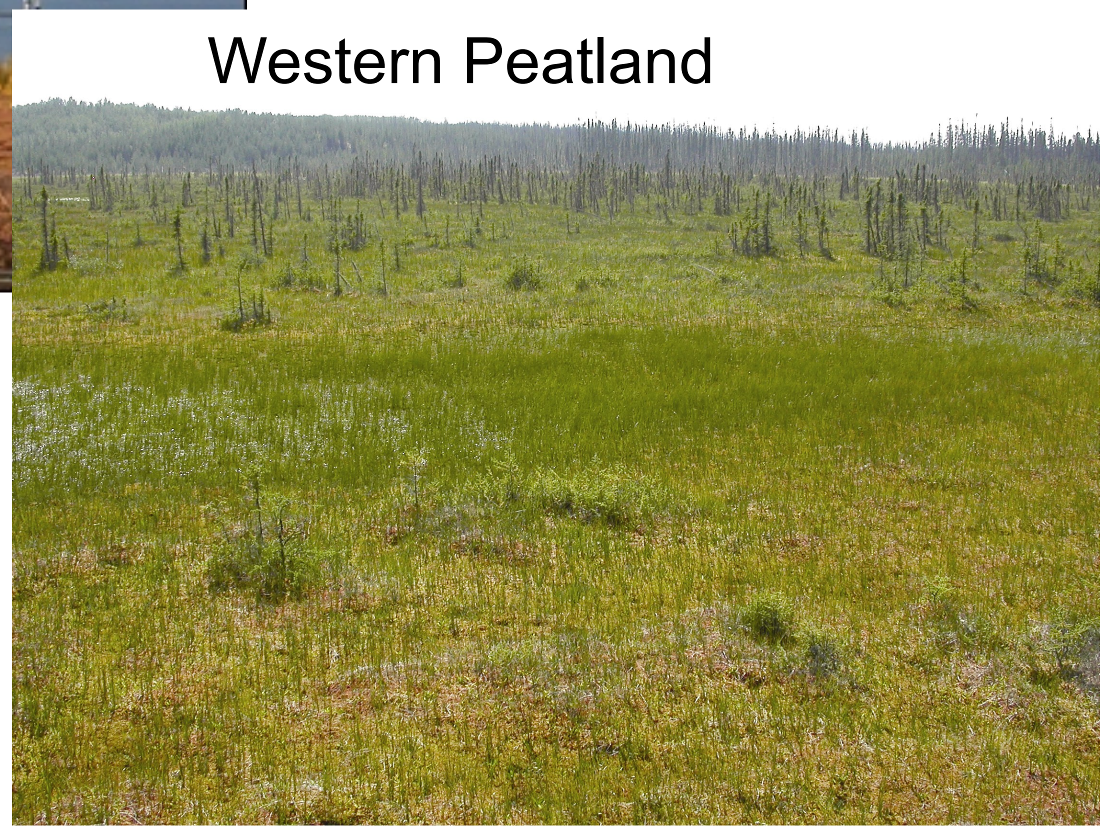
Some Wet Places

- 27 site-years of data

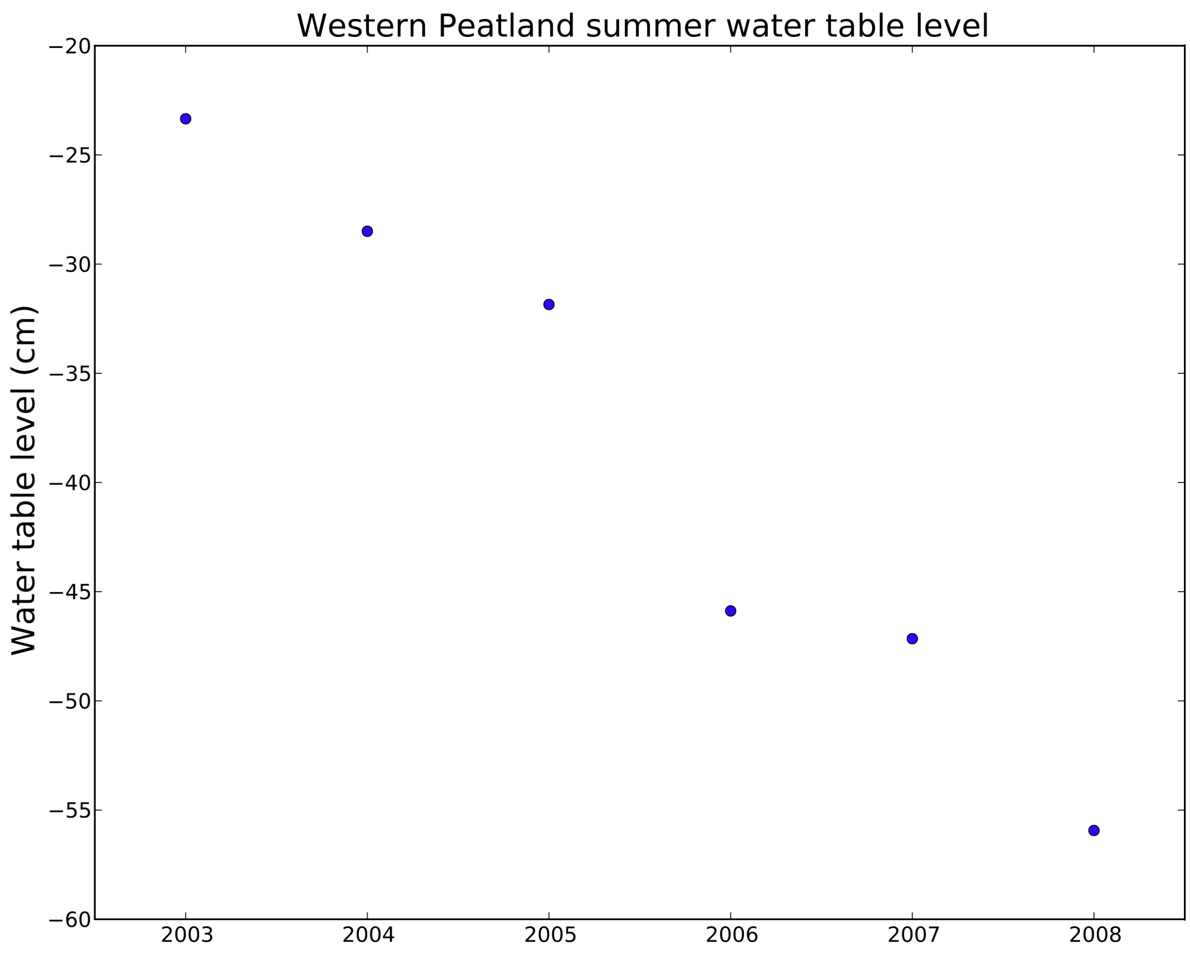


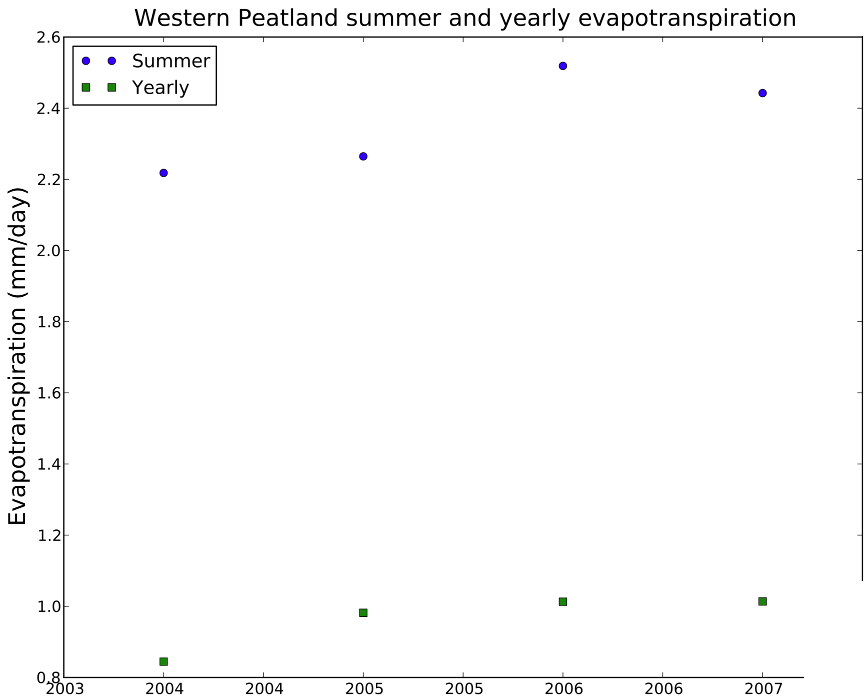
Sulman et al. (2010) GRL


Mer Bleue


Western Peatland

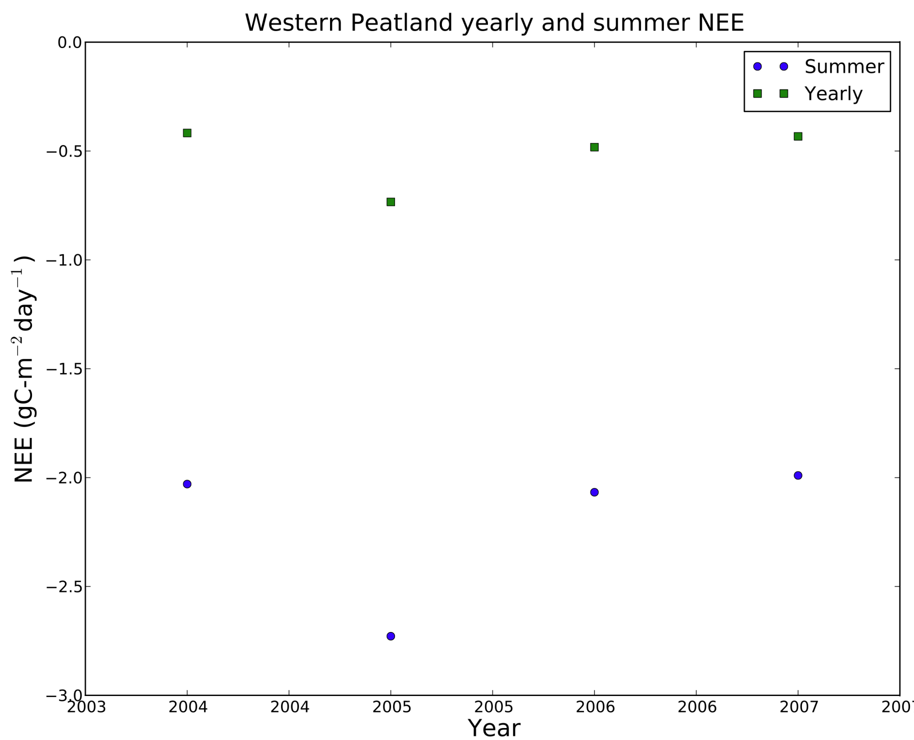
Western Peatland (Alberta)



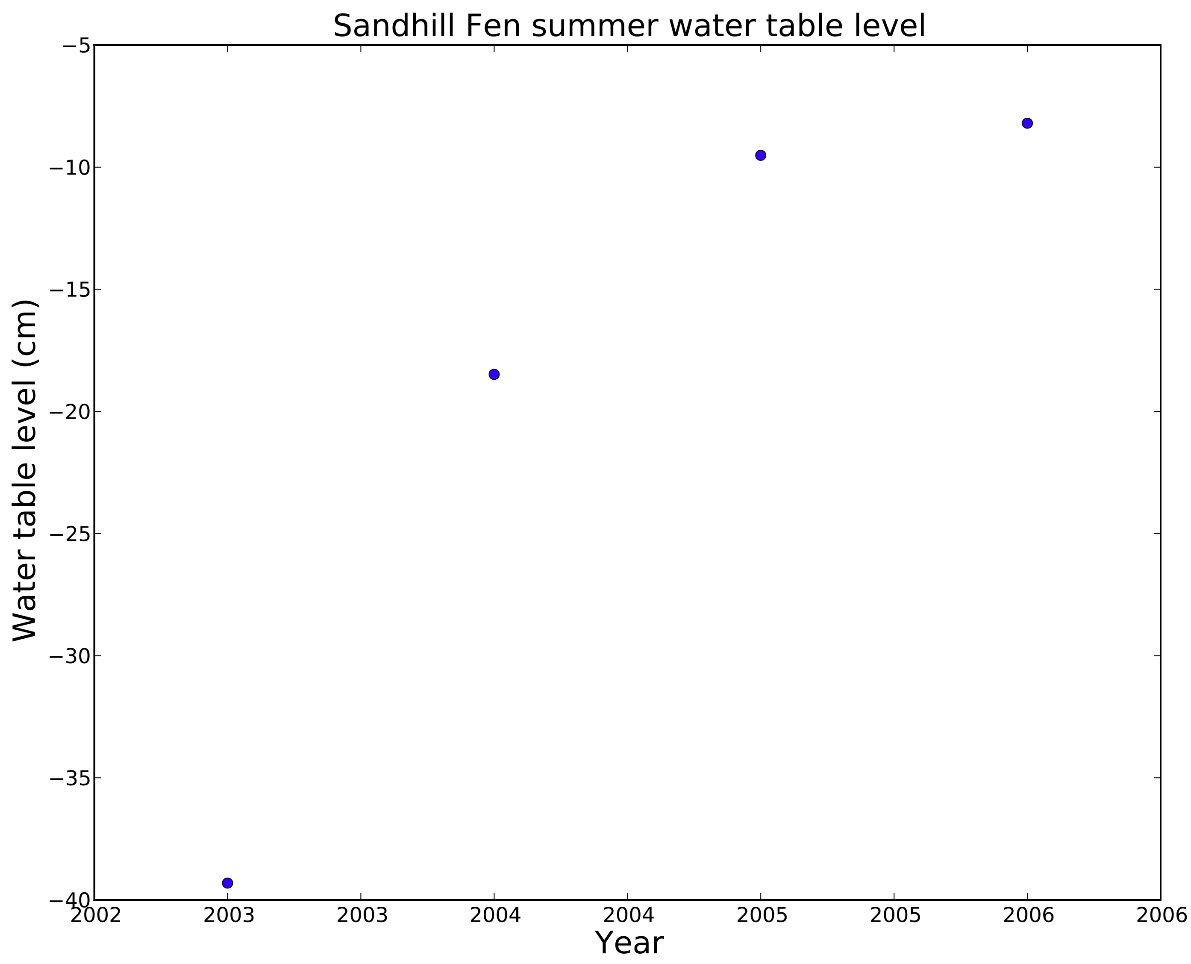

Western Peatland summer and yearly evapotranspiration
Evapotranspiration (mm/day)
Summer
Yearly
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
2003
2004
2004
2005
2005
2006
2006
2007

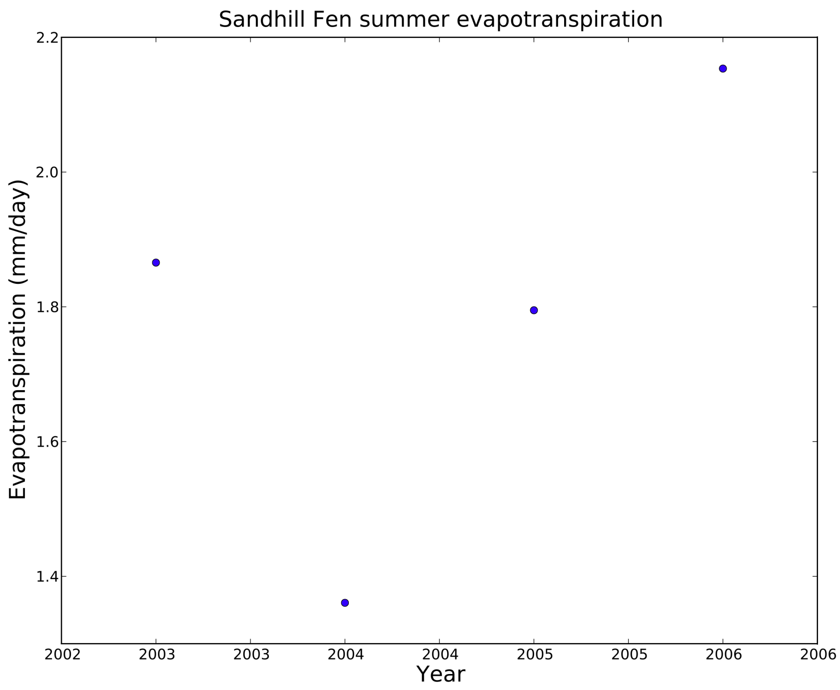
<-ET

NEE->


Western Peatland yearly and summer NEE
NEE (gC-m^{-2}day^{-1})
Summer
Yearly
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
−3.0
2003
2004
2004
2005
2005
2006
2006
2007
2007
Year

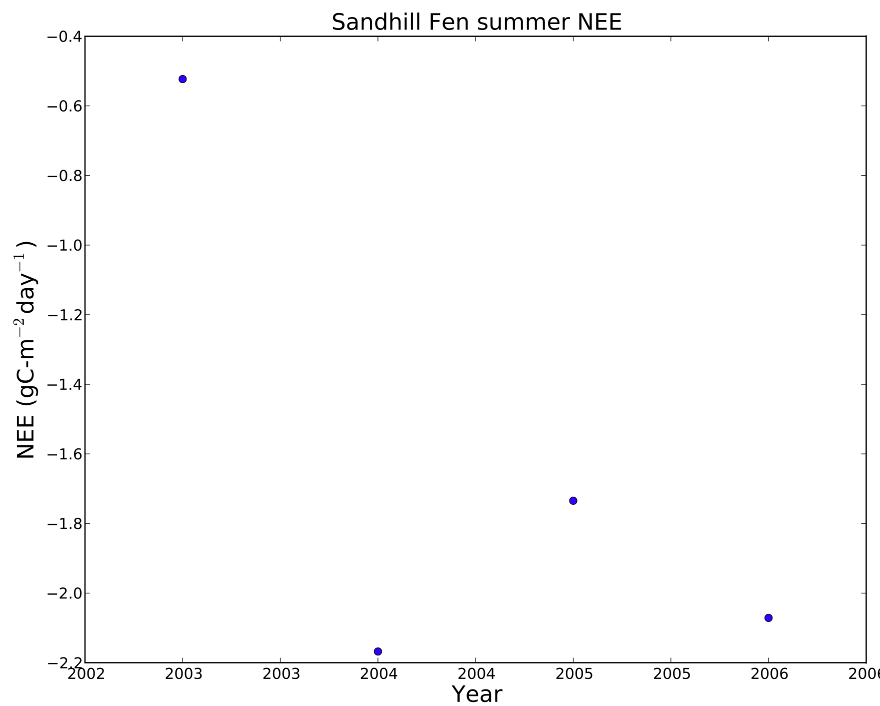
Sandhill Fen (Sask)



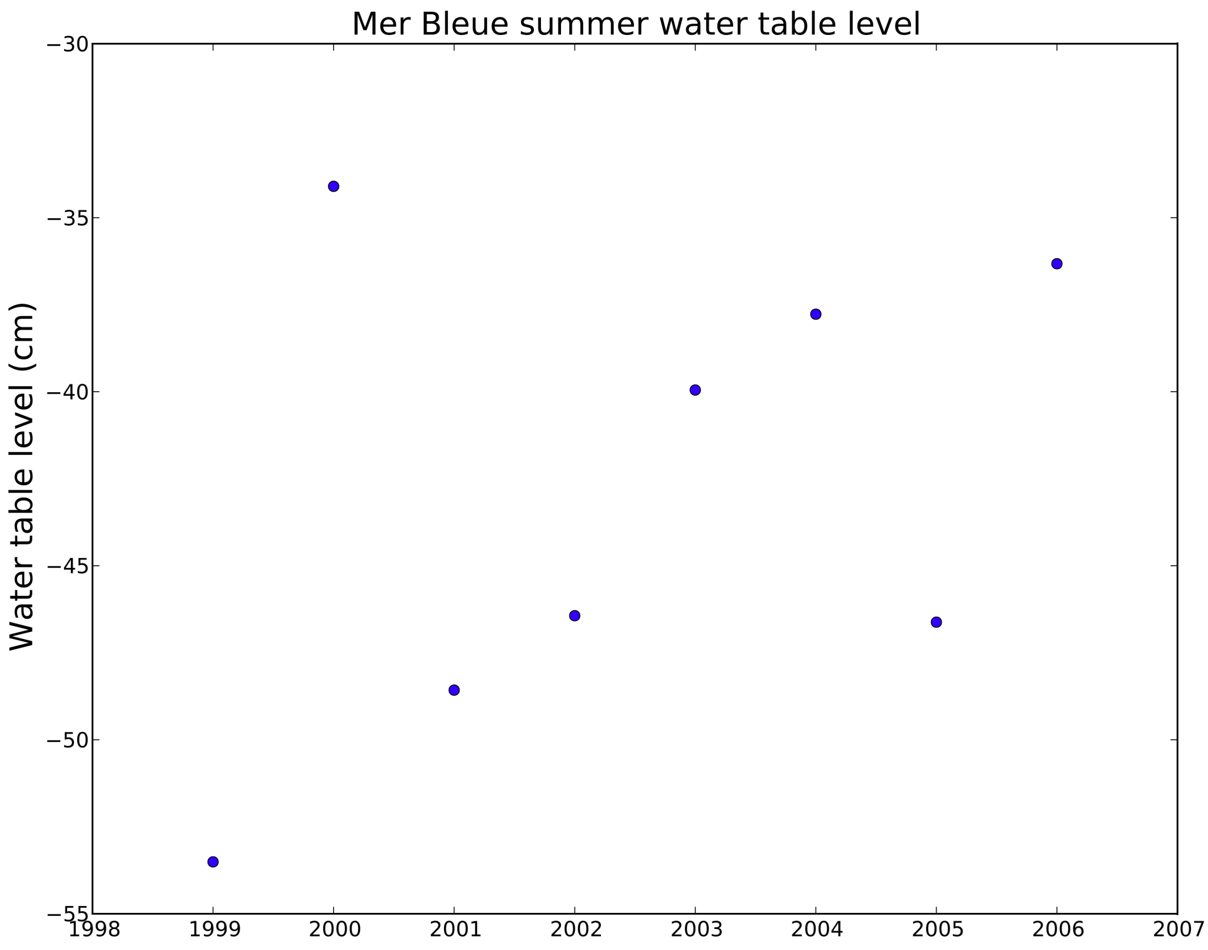

Sandhill Fen summer evapotranspiration
Evapotranspiration (mm/day)
Year
2.2
2.0
1.8
1.6
1.4
2002
2003
2003
2004
2004
2005
2005
2006
2006

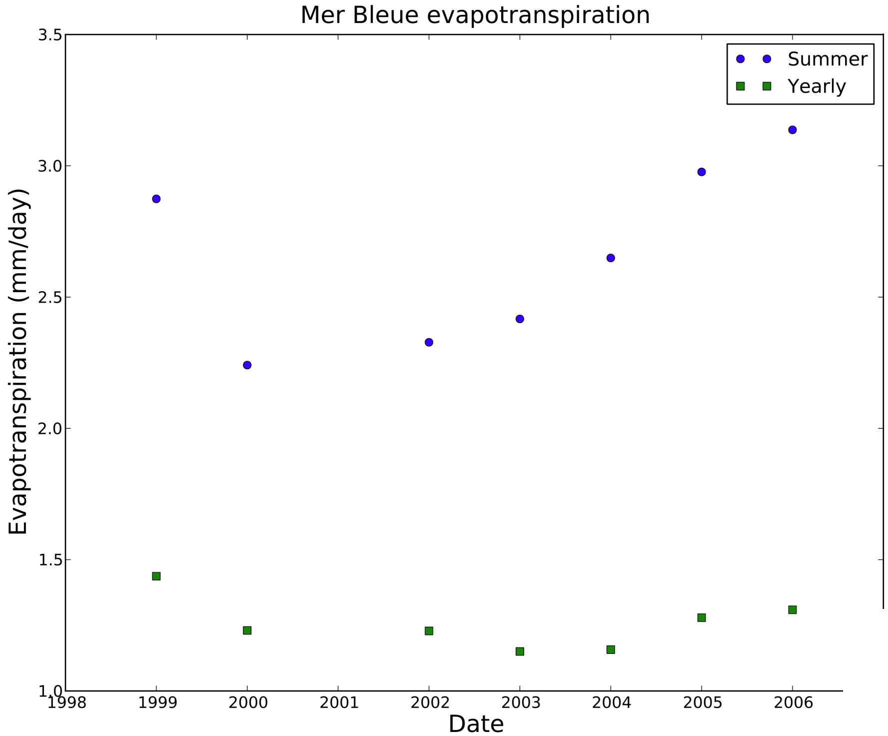
<-ET

NEE->


Sandhill Fen summer NEE
NEE (gC-m^{-2}day^{-1})
Year
−0.4
−0.6
−0.8
−1.0
−1.2
−1.4
−1.6
−1.8
−2.0
−2.2
2002
2003
2003
2004
2004
2005
2005
2006
2006

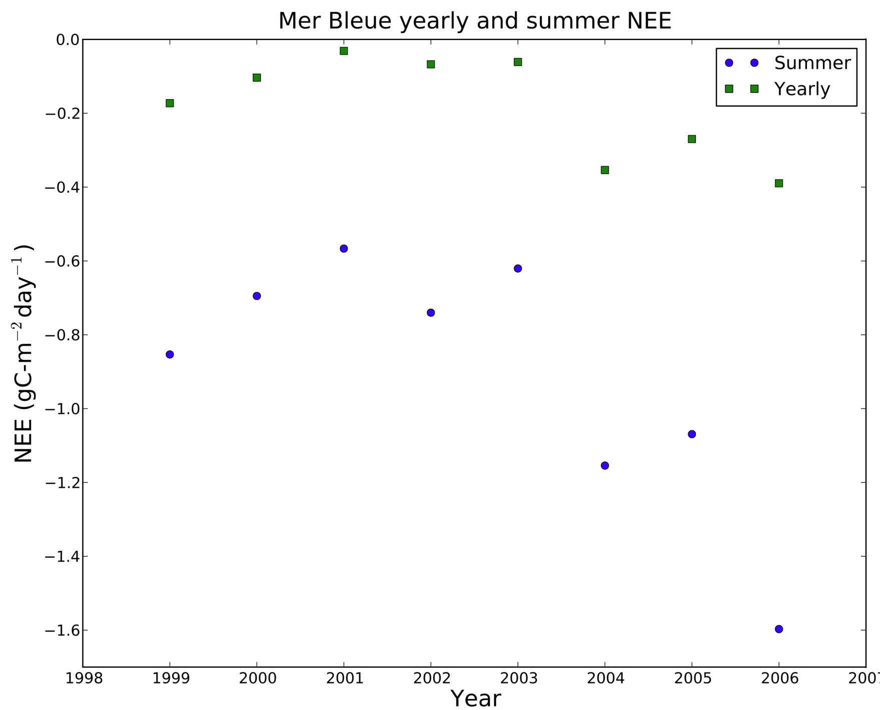
Mer Bleue (Ont)

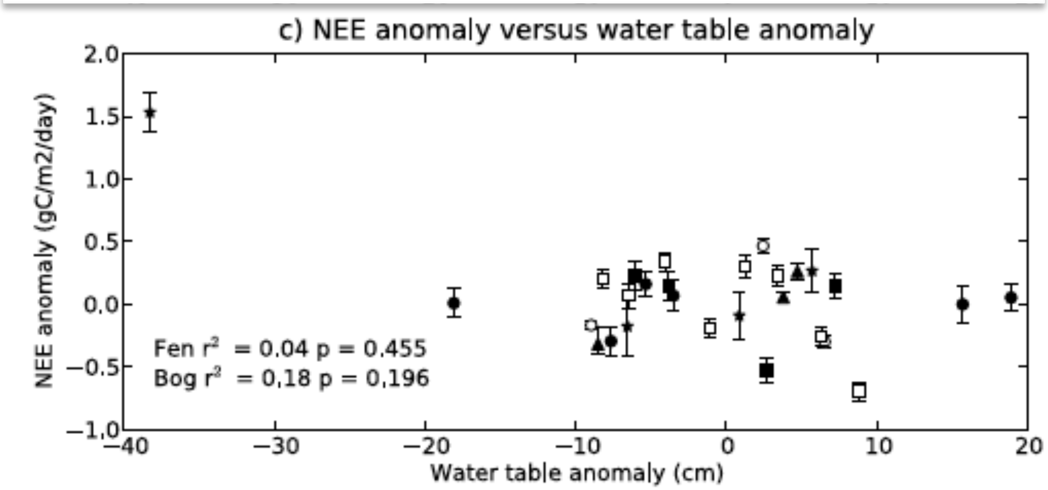



Mer Bleue evapotranspiration
Summer
Yearly
Evapotranspiration (mm/day)
Date
3.5
3.0
2.5
2.0
1.5
1.0
1998
1999
2000
2001
2002
2003
2004
2005
2006

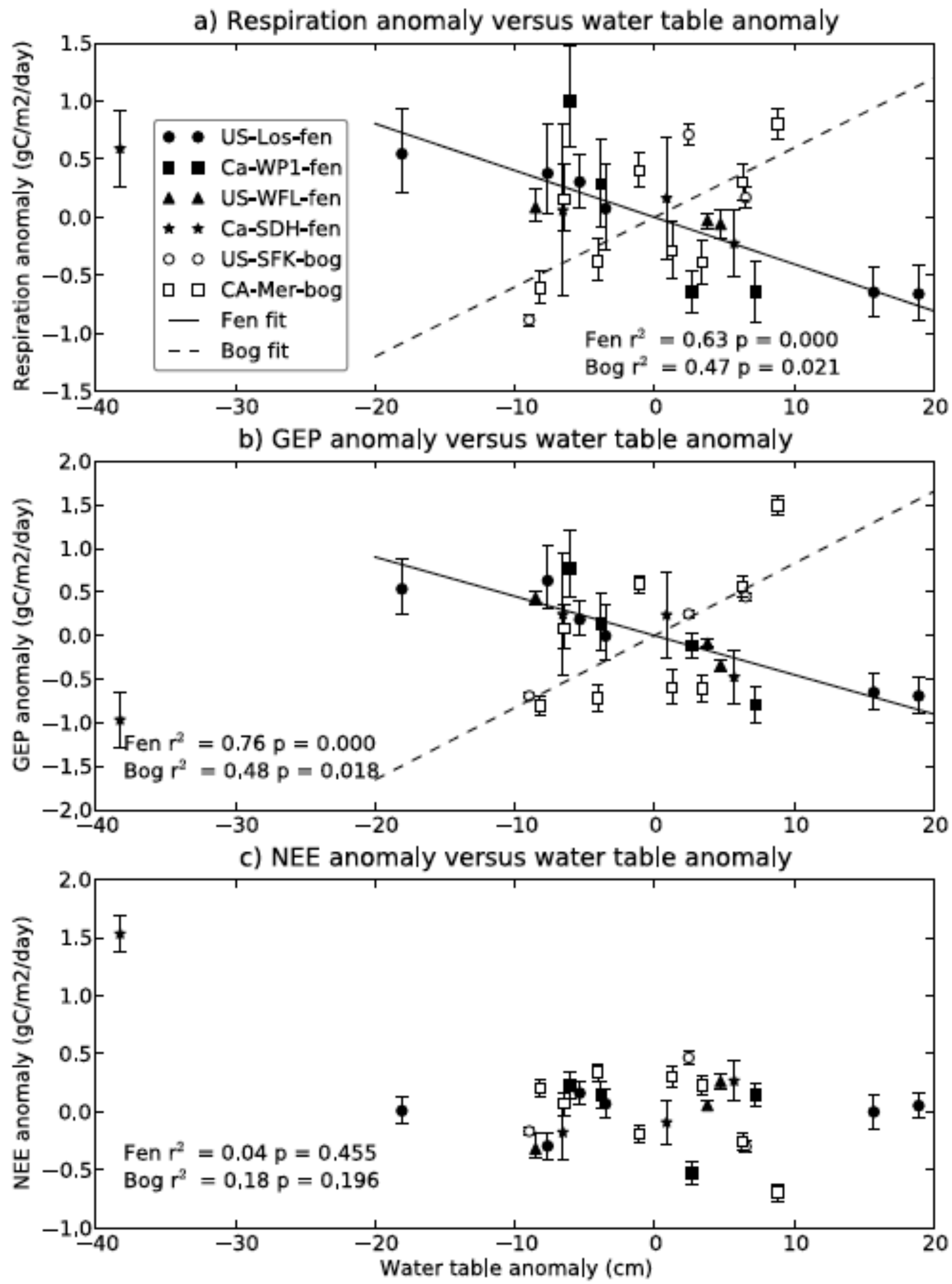
<-ET

NEE->


Mer Bleue yearly and summer NEE
Summer
Yearly
NEE (gC-m^{-2} day^{-1})
Year
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2
−1.4
−1.6
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007



Sulman et al. (2010) GRL



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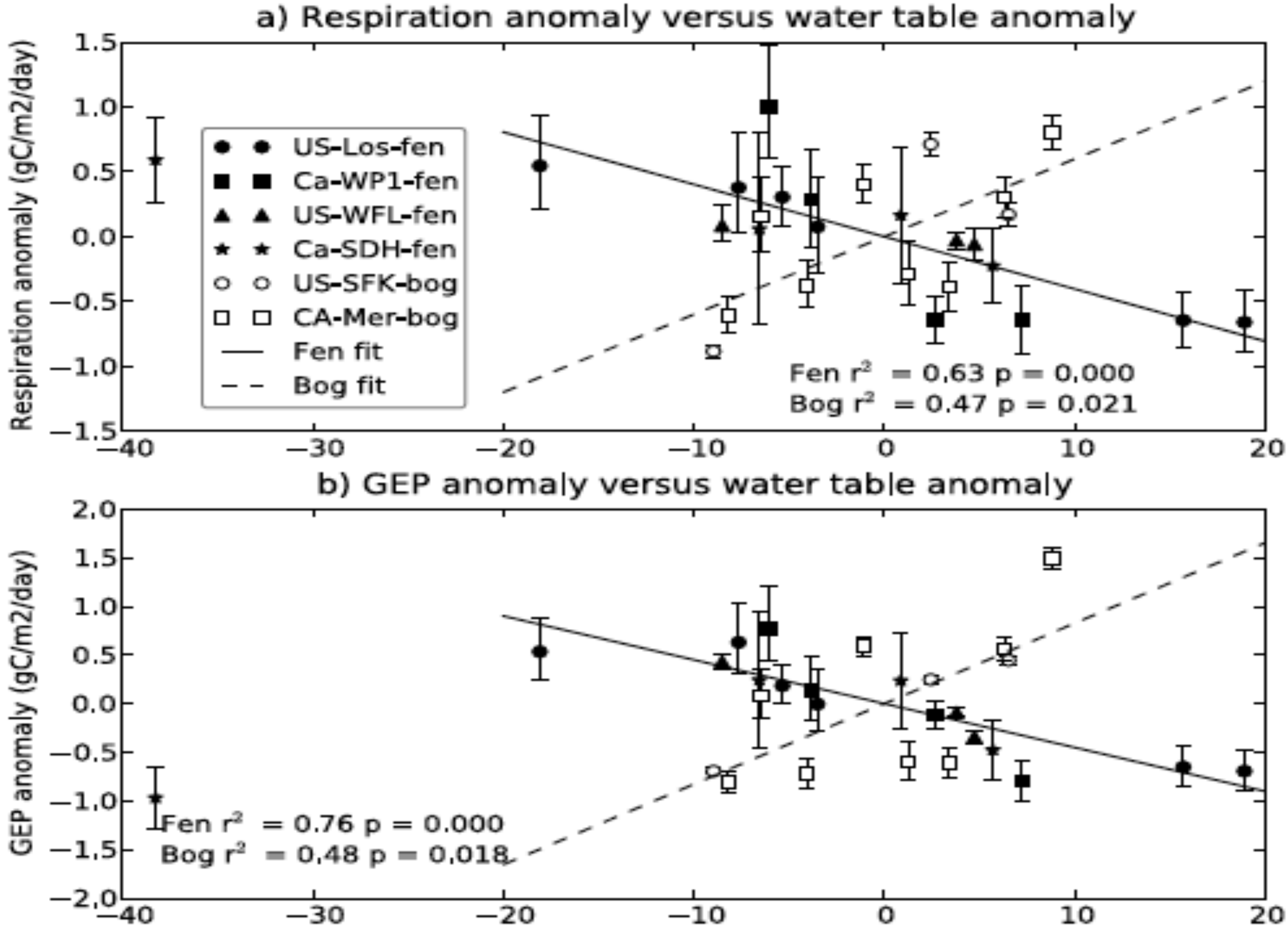


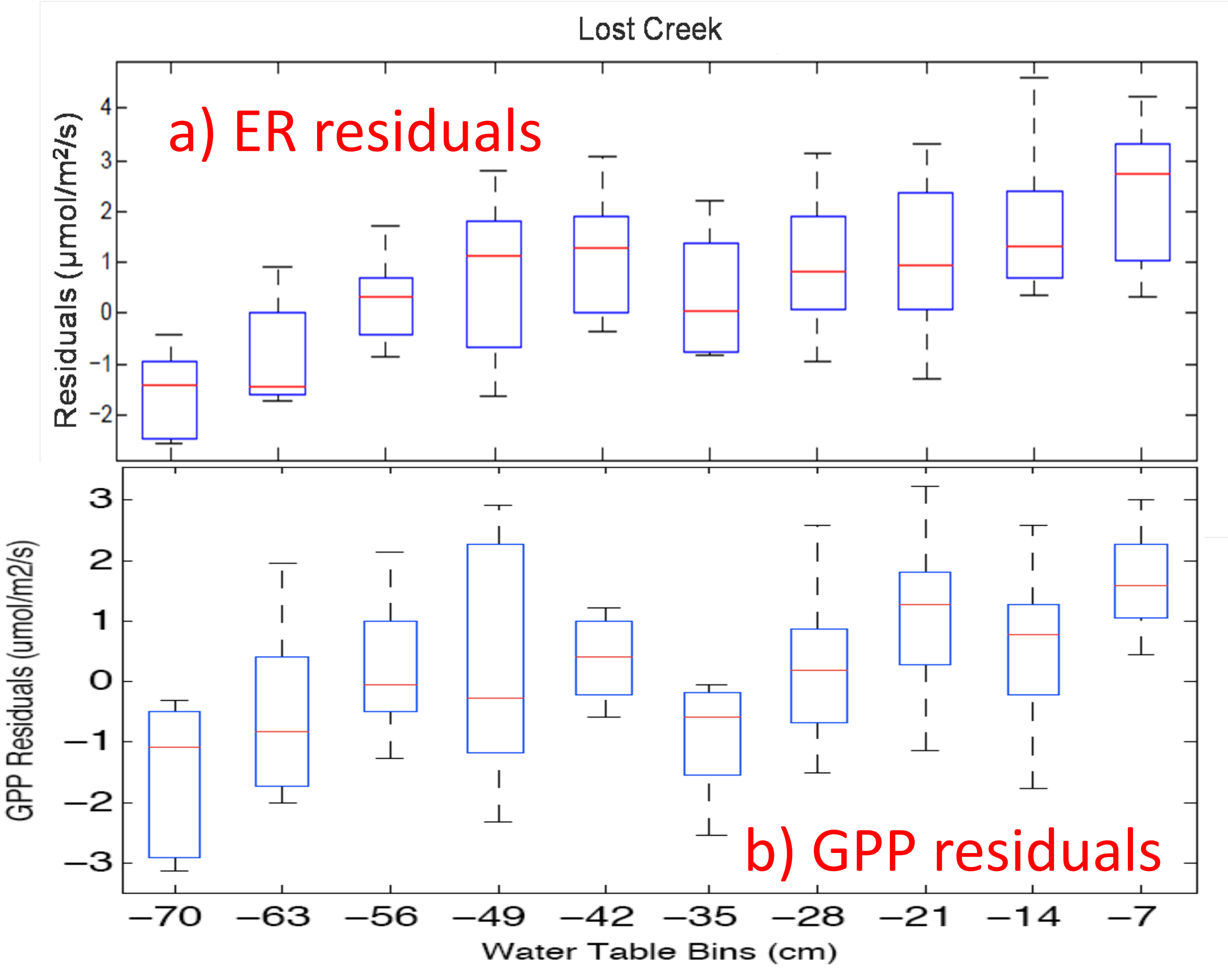
Sulman et al. (2010) GRL

A Ha!

- Productivity and decomposition have consistent, similar relationships to water table elevation in north temperate wetlands
- But: Fens and bogs respond in opposite fashion
  - relationship stronger in fens
- The net effect is limited response of NEE to water table in both fens and bogs
- Interannual and long-term may respond differently

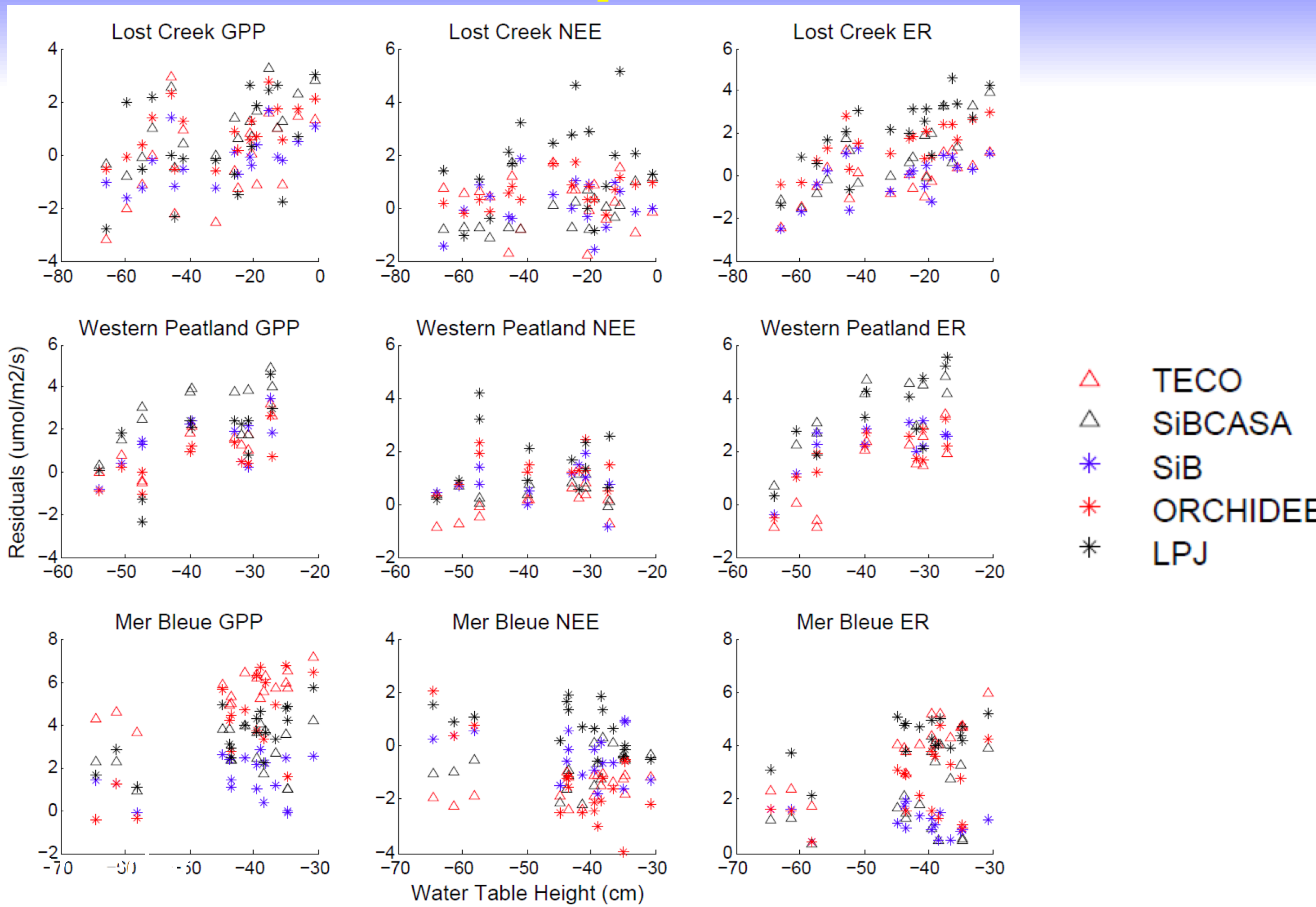
Do Models Get This?

- Six model, three site intercomparison
  - Residuals = Modeled flux – Observed flux



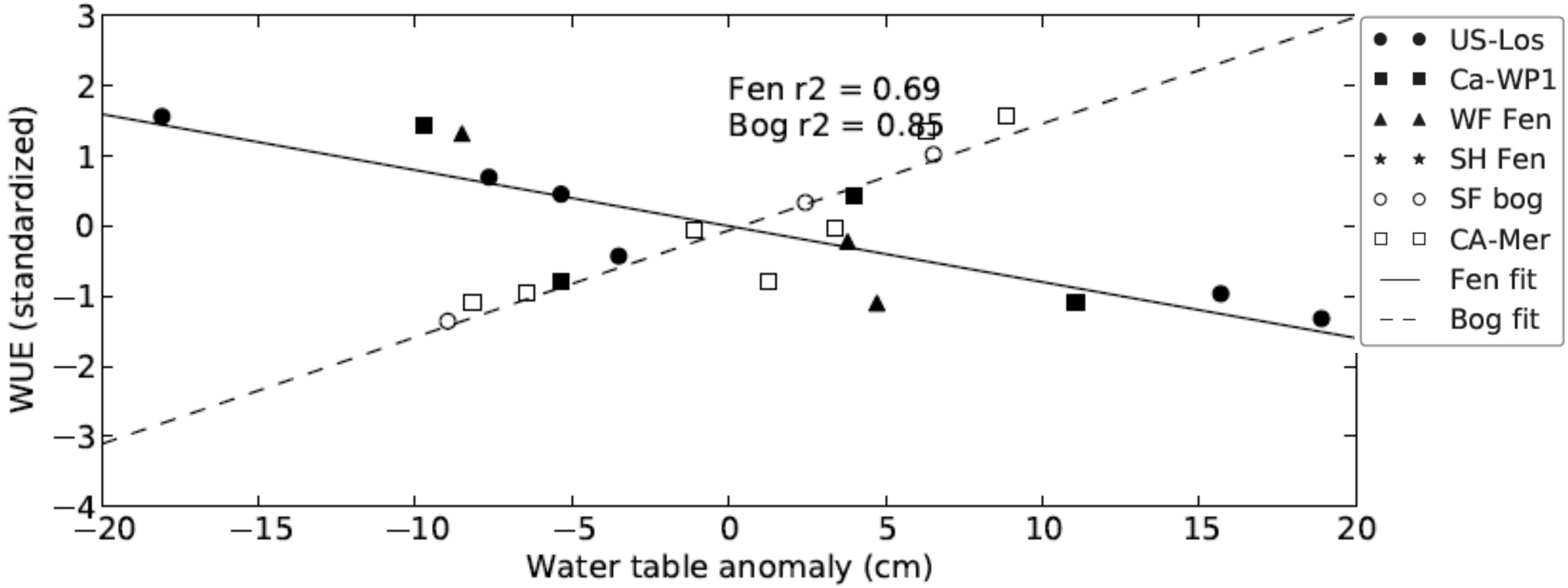
Courtesy of N. Shroeder, UW

Discrepancies



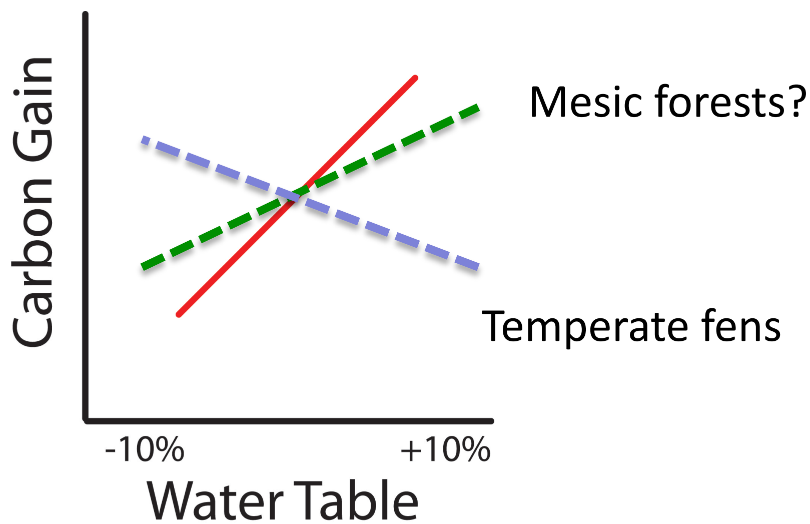
What's Driving This?

- Adaptation of plants to drying conditions leads to increases in water use efficiency, especially for fens, maybe?



Morals For Wetlands

- Wetland carbon cycling is not a monotonic function of water table
  - Fens may be more resilient to climate change than bogs
- Plants adapt to change, but the timescale depends on the kind of ecosystem



From Sites to Regions

- The fundamentals of ecology and micrometeorology have been mostly studied at the **plot** scale
- The fundamentals of surface-atmosphere interaction influence on the climate systems have been mostly studied **globally**
- **Regions** (landscapes, watersheds, continents) are where climate-ecosystem interactions are least understood and likely to hold the most surprises
  - It's also the relevant scale for ecosystem management

And Of The Region?

- Northern Wisconsin is a mix of upland forest (70%) and wetland (30%)
  - Should regional CO_2 fluxes respond to hydrologic setting?

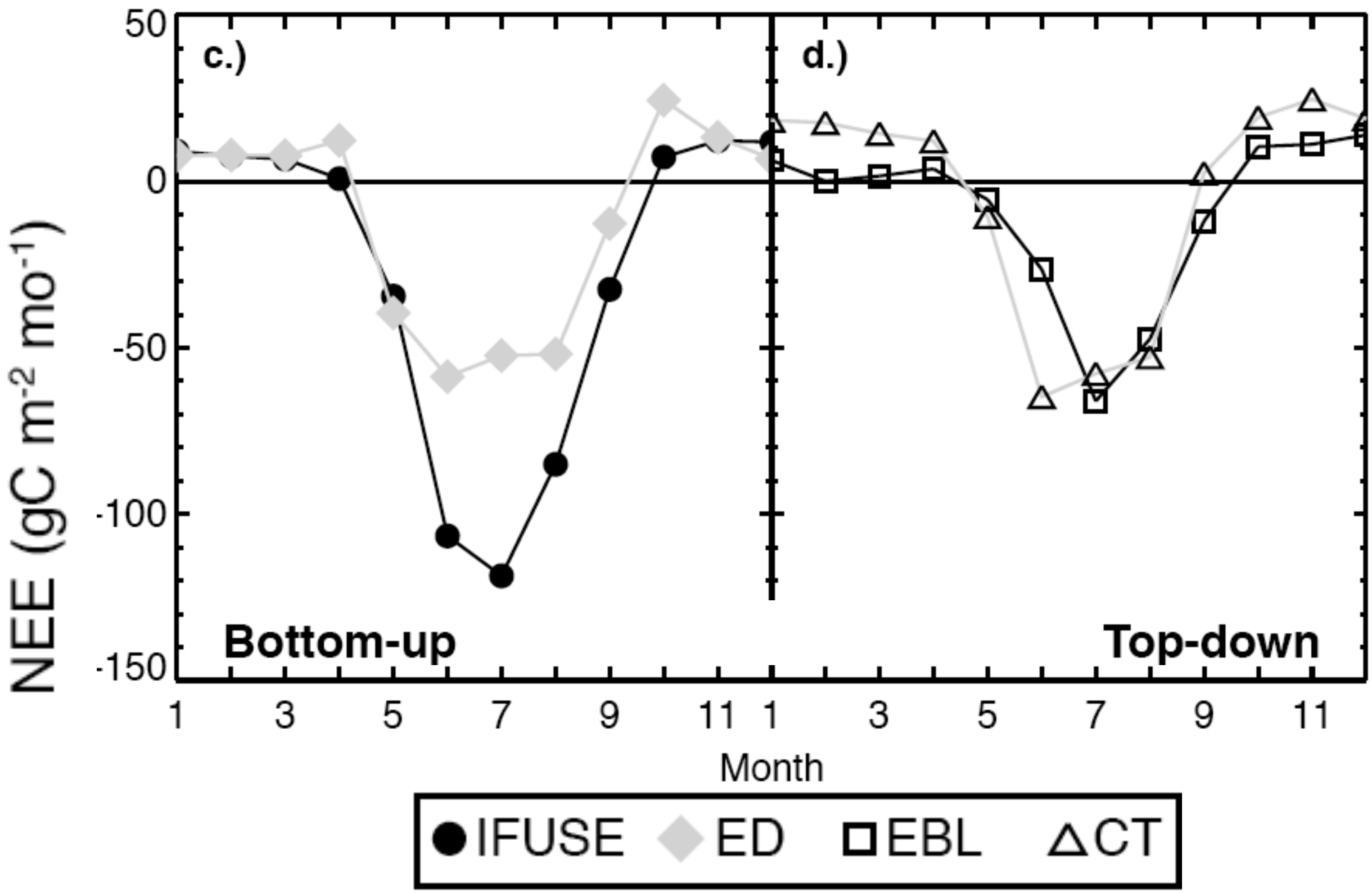
- We can estimate regional fluxes using
  - top-down by **inverse** or **boundary layer budget** approaches, or
  - bottom-up from **forest inventory** or **flux-tower** optimized ecosystem modeling.

Methods

- Bottom-up (scaling)
  - **IFUSE – Interannual Flux-Tower Upscaling Experiment**
    - 12 regional flux towers categorized by land cover and age are used to parameterize simple regional model using MCMC approach (Desai et al., 2008; in prep)
  - **ED – Ecosystem Demography Model v1.5**
    - Height-and-age cohort succession model tuned to Forest Inventory and Analysis (FIA) data (Desai et al., 2007)
- Top-down (atmospheric budgets)
  - **EBL – Equilibrium Boundary Layer**
    - 1-D boundary layer budget inferred from WLEF 447-m tall tower CO_2 profile, NOAA marine CO_2 flask network, and NARR reanalysis subsidence rates (Helliker et al, 2004)
  - **CT – CarbonTracker v2009**
    - Global, nested-grid inverse model based on CASA surface model, global surface continuous and flask CO_2 network, and Ensemble Kalman Filter tracer-transport assimilation with TM5 winds (Peters et al., 2007)

Regional Flux

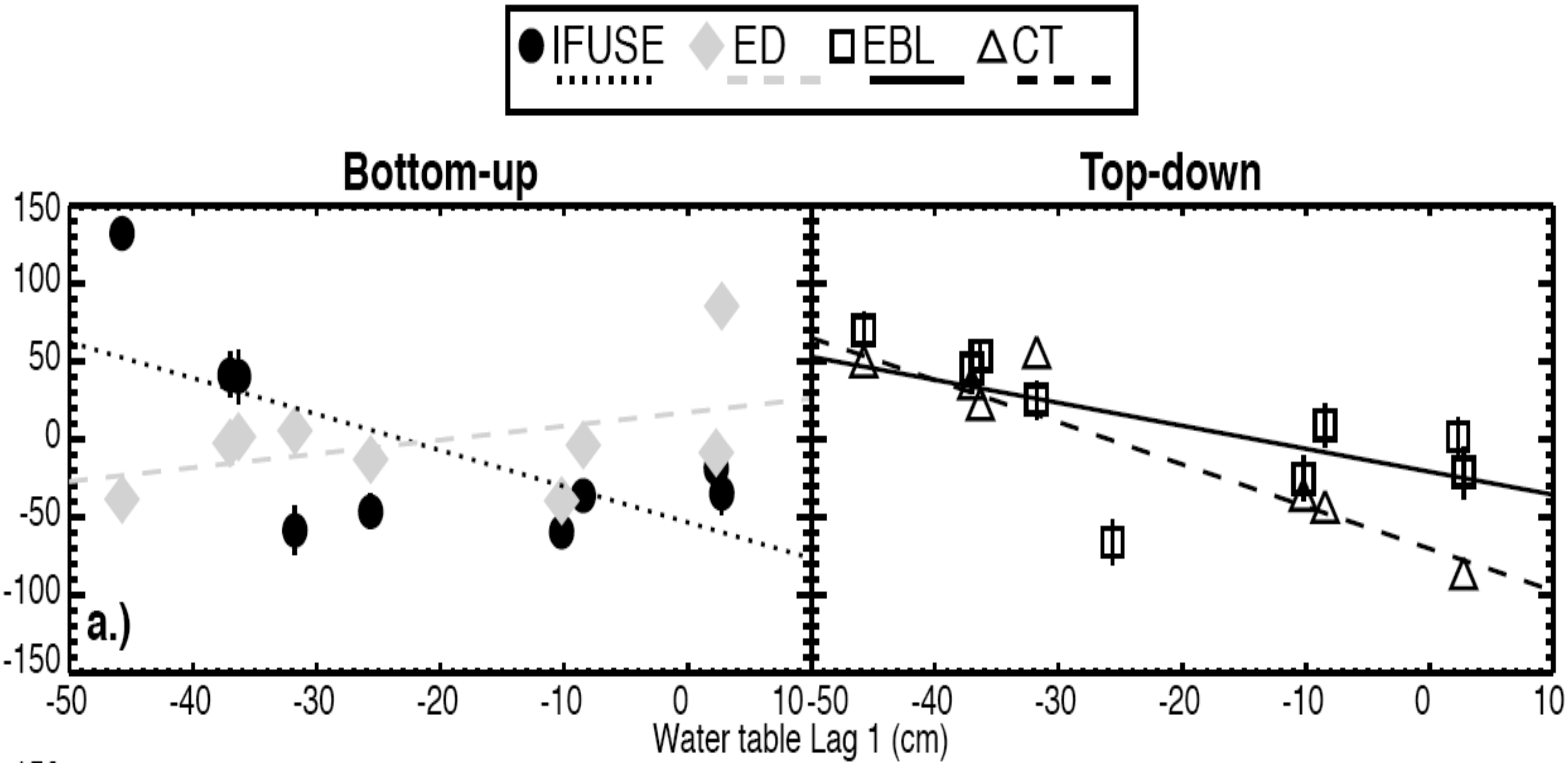
- Magnitudes vary, but variability is similar



Desai et al (2010) JGR-G

Regions and Water

- Prior year water table strong influences anomalies in regional NEE



Desai et al (2010) JGR-G

Morals: Nothing Is Simple

- Carbon and water cycling **linkages** require close examination in ecosystem models
  - Moisture stress covaries with temperature and precipitation

- Complex **interactions** between the physical environment and *all* biological systems (e.g., insects, microbes) should not be underestimated – it's where the surprises often hide
  - Lag effects, and positive/negative feedbacks can be complex
  - Models that incorporate, test, and verify these interactions can help us anticipate surprises

- Slow, steady rates of change allow us to anticipate and react to surprises; **rapid** climate surprises are likely to exacerbate ecosystem surprises
  - Policies that slow climate change or destabilization are wise with respect to minimizing ecosystem disruption

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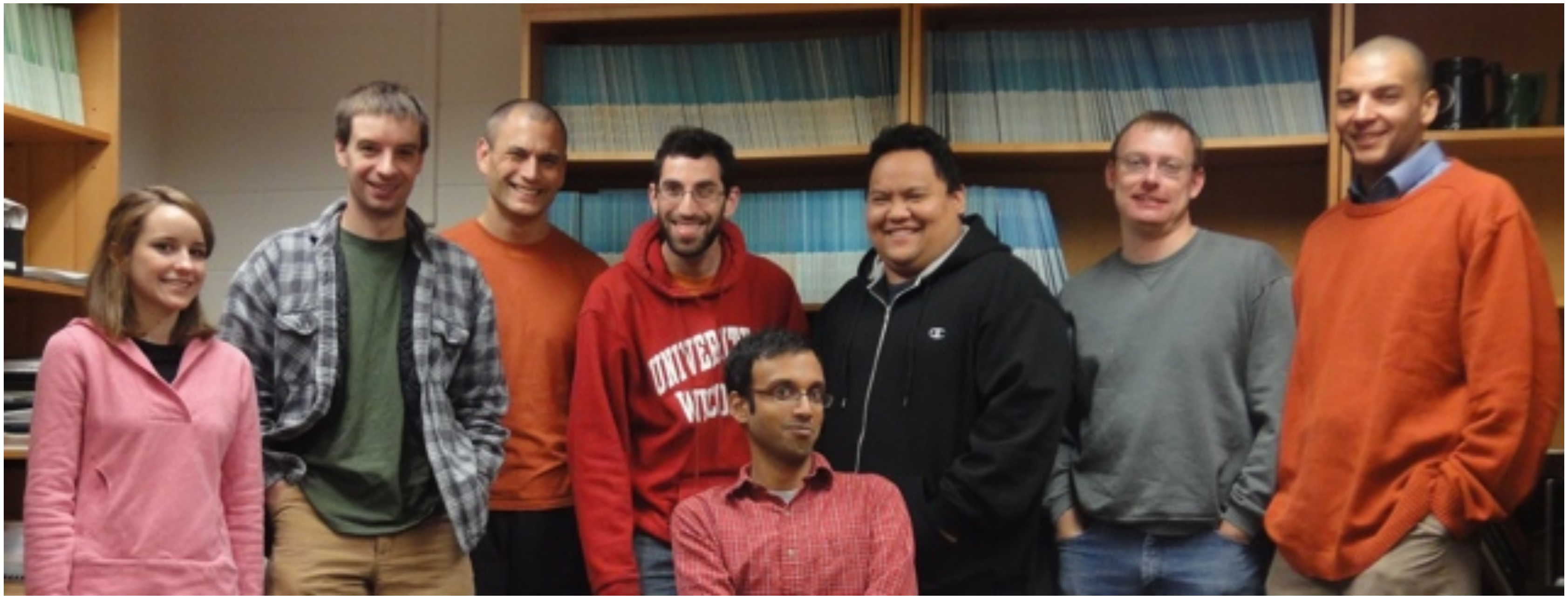
- Desai Ecometeorology Lab (flux.aos.wisc.edu):



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