Ecohydrologic controls on net ecosystem exchange of carbon in a wetland-rich forested landscape

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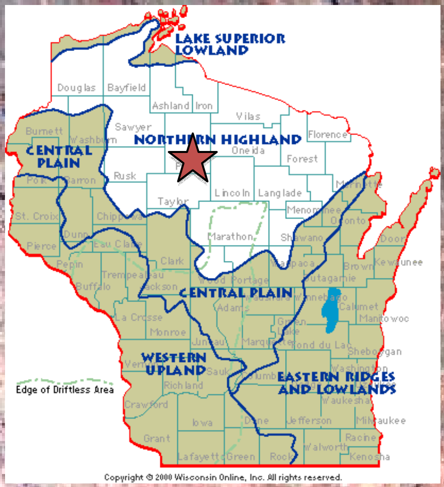
Introduction

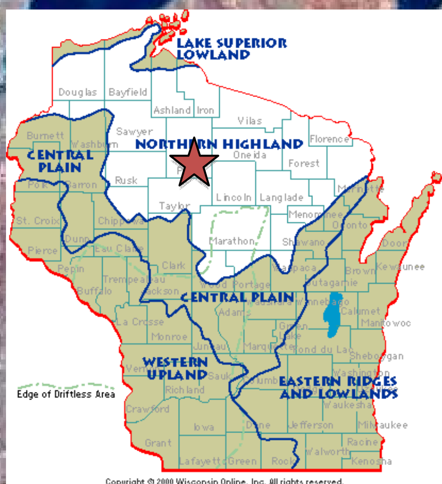
Wetlands represent up to a third of the global soil carbon

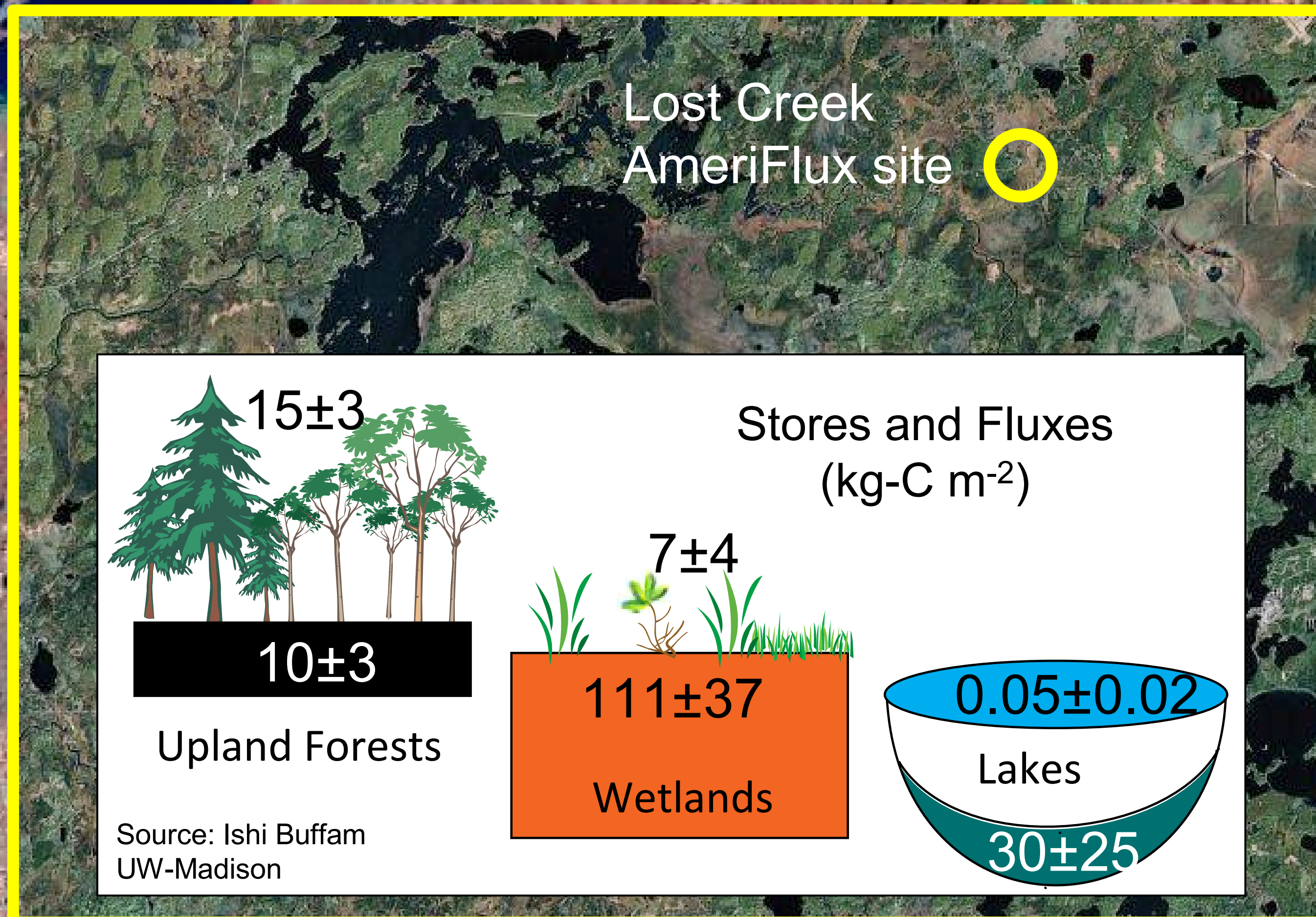
In the Northern Highlands region of Wisconsin wetlands store over half the carbon pool

Chequamegon National Forest and surrounding State forest



Introduction





Problem

Projected climate change effects include:

- Higher temperatures and increased precipitation
- Net drying due to increased evapotranspiration

Lowering water table increased CO_2 emission or changed wetlands from carbon sinks to sources

(*e.g.*, Silvola et al. 1996, Alm et al. 1999, Bubier at al. 2003)

No correlation between water table and long-term CO_2 emission

(*e.g.*, Updegraff et al. 2001, Lafleur et al. 2005, Sulman et al. 2009)

Questions

How do changes in water table height affect long- and short-term wetland evapotranspiration (E_T) and net ecosystem exchange of carbon (N_{EE}) at Lost Creek?

Is lateral subsurface flow here an important process for modeling wetland E_T and N_{EE}?

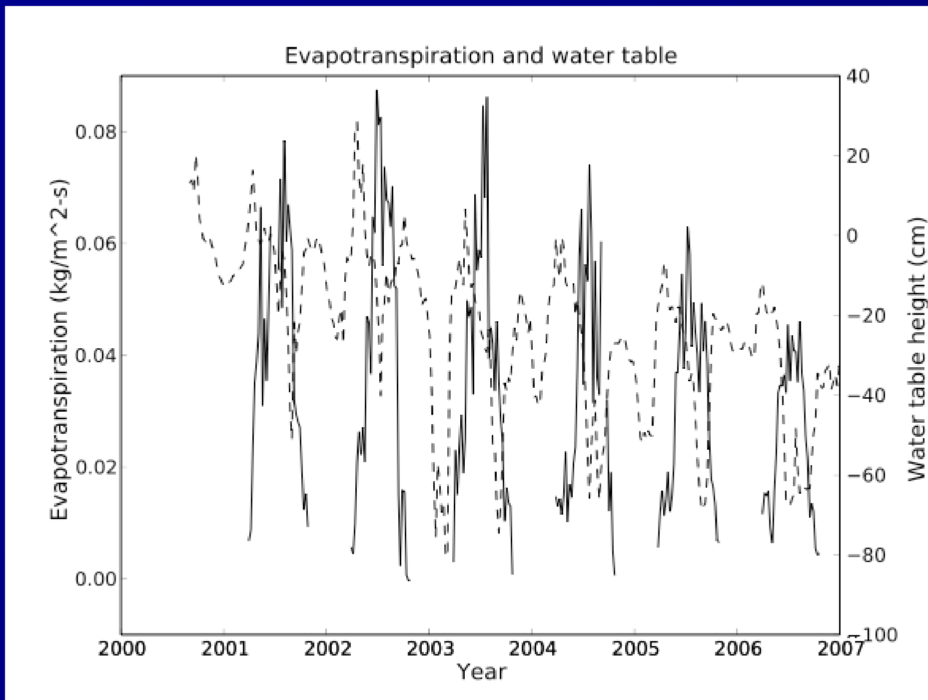
Lost Creek

Alder-willow fen

Poorly-drained sapric muck on glacial outwash sand

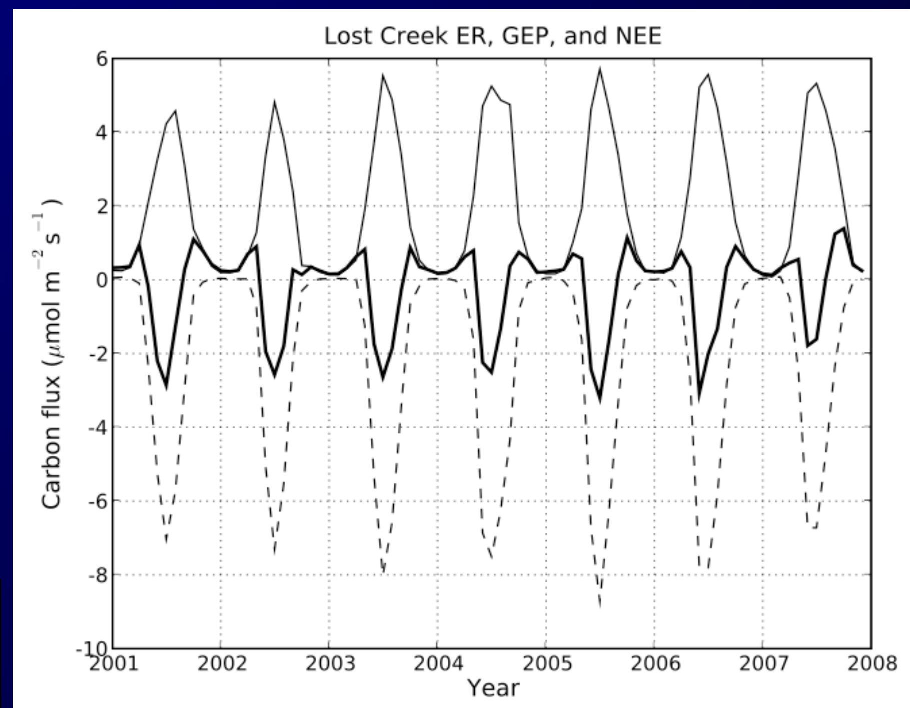
Wisconsin Online
http://www.wisconline.com/wisconsin/geoprovinces/northernhighland.html

Water table and flux responses



E$_T$ declined along with water table

- - - Water table
—— ET



Gross ecosystem production and ecosystem respiration increased as water table declined

—— ER
- - - GEP
—— NEE

Sulman et al., *Biogeosciences*, 2009
Mackay et al., WRR, 2007

Biogeochemical responses to changing water levels

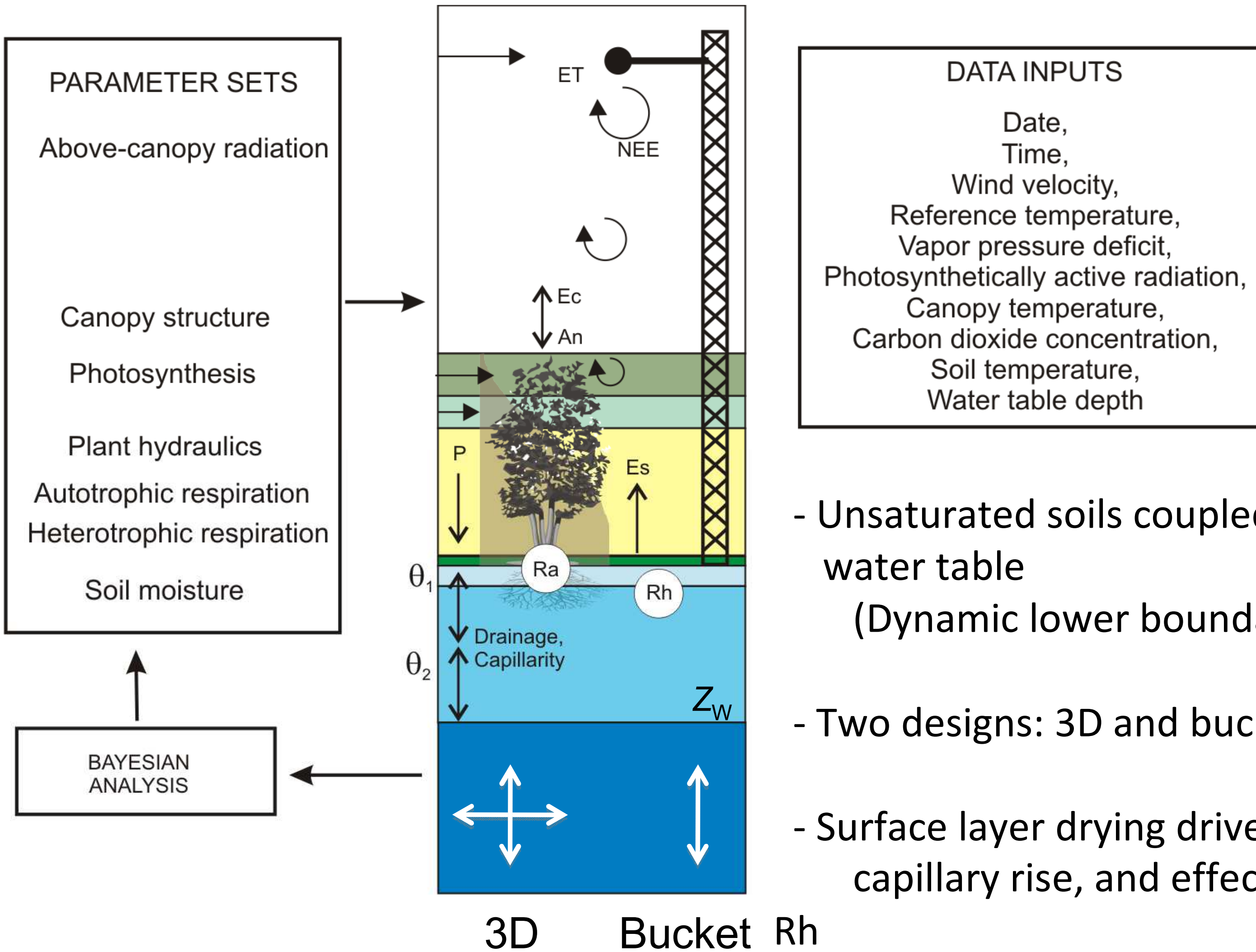
At high soil moisture levels

- Partial stomatal closure
- Reduced leaf nitrogen
- Reduced heterotrophic respiration

At low soil moisture levels

- Stomatal closure
- Reduced root carbon transport
- Reduced heterotrophic respiration

Simulation model: Design



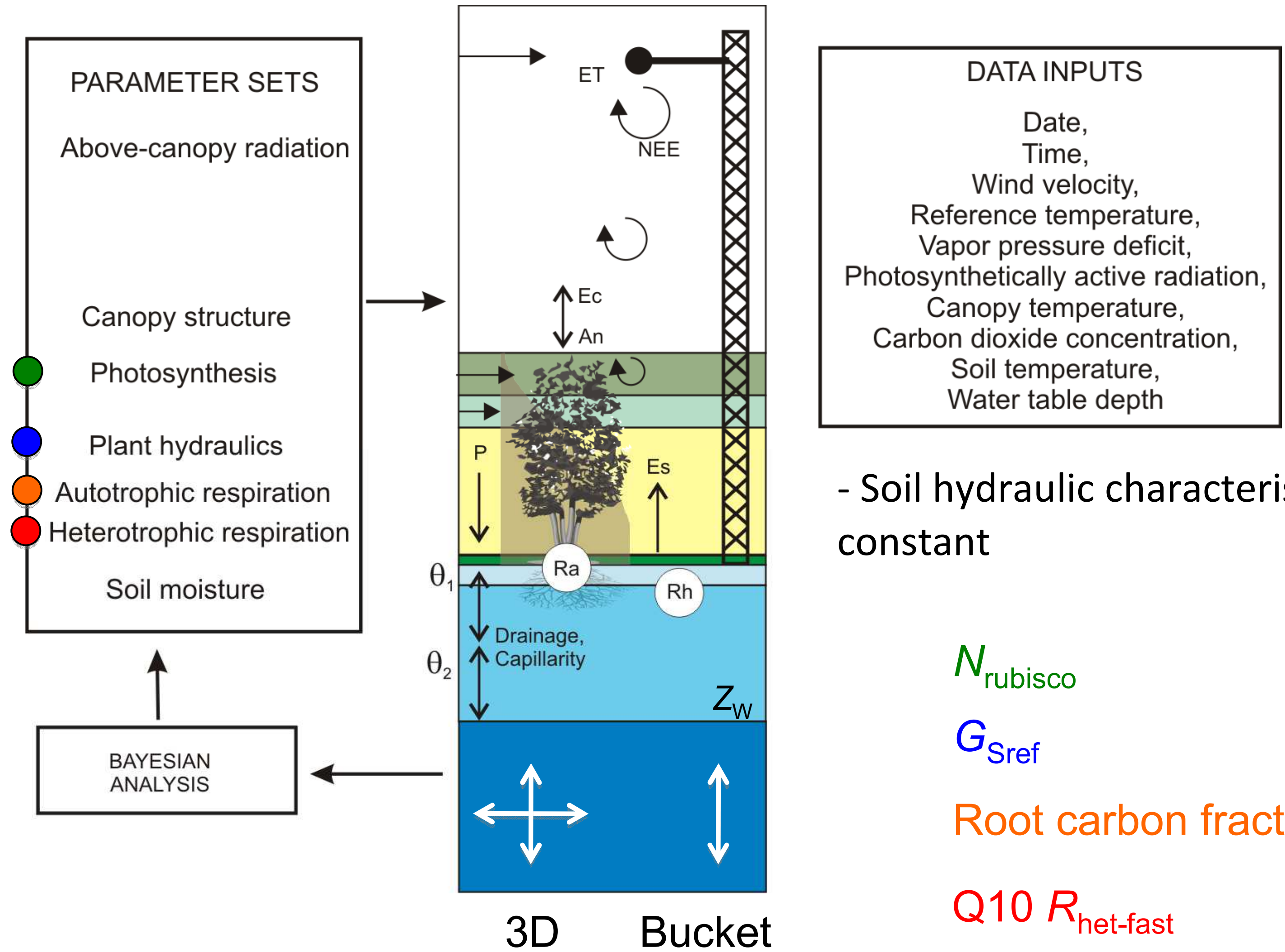
- Unsaturated soils coupled to water table (Dynamic lower boundary)

- Two designs: 3D and bucket

- Surface layer drying drives capillary rise, and effects Es & Rh

TREES (Terrestrial Regional Ecosystem Exchange Simulator)
(Mackay et al. 2003; Samanta et al., 2007, 2008;
Ewers et al. 2008; Loranty et al. 2008)

Simulation model: Parameterization



- Soil hydraulic characteristics held constant

$N_{rubisco}$

G_{Sref}

Root carbon fraction

Q10 $R_{het\text{-}fast}$

Bayesian analysis:
Combined carbon-water error model

$$p\left(\beta,\sigma_C^2 \middle| C\right) \propto \sigma_C^{-(n+2)} \prod_{i=1}^{n} \exp\left\{-\frac{1}{2\sigma_C^2}\left[C_i - C_{NEE}\left(x_i,\beta\right)\right]^2\right\}$$

X

$$p\left(\beta,\sigma_E^2 \middle| E\right) \propto \sigma_E^{-(n+2)} \prod_{i=1}^{n} \exp\left\{-\frac{1}{2\sigma_E^2}\left[E_i - E_T\left(x_i,\beta\right)\right]^2\right\}$$

N_{EE} terms scaled to E_T terms

Sampling done using Metropolis-Hastings (Metropolis, 1953; Hastings, 1970)

Bayesian analysis:
Measure of model relative acceptability

$$p_D = \overline{D(\theta)} - D(\bar{\theta})$$

Effective number of parameters

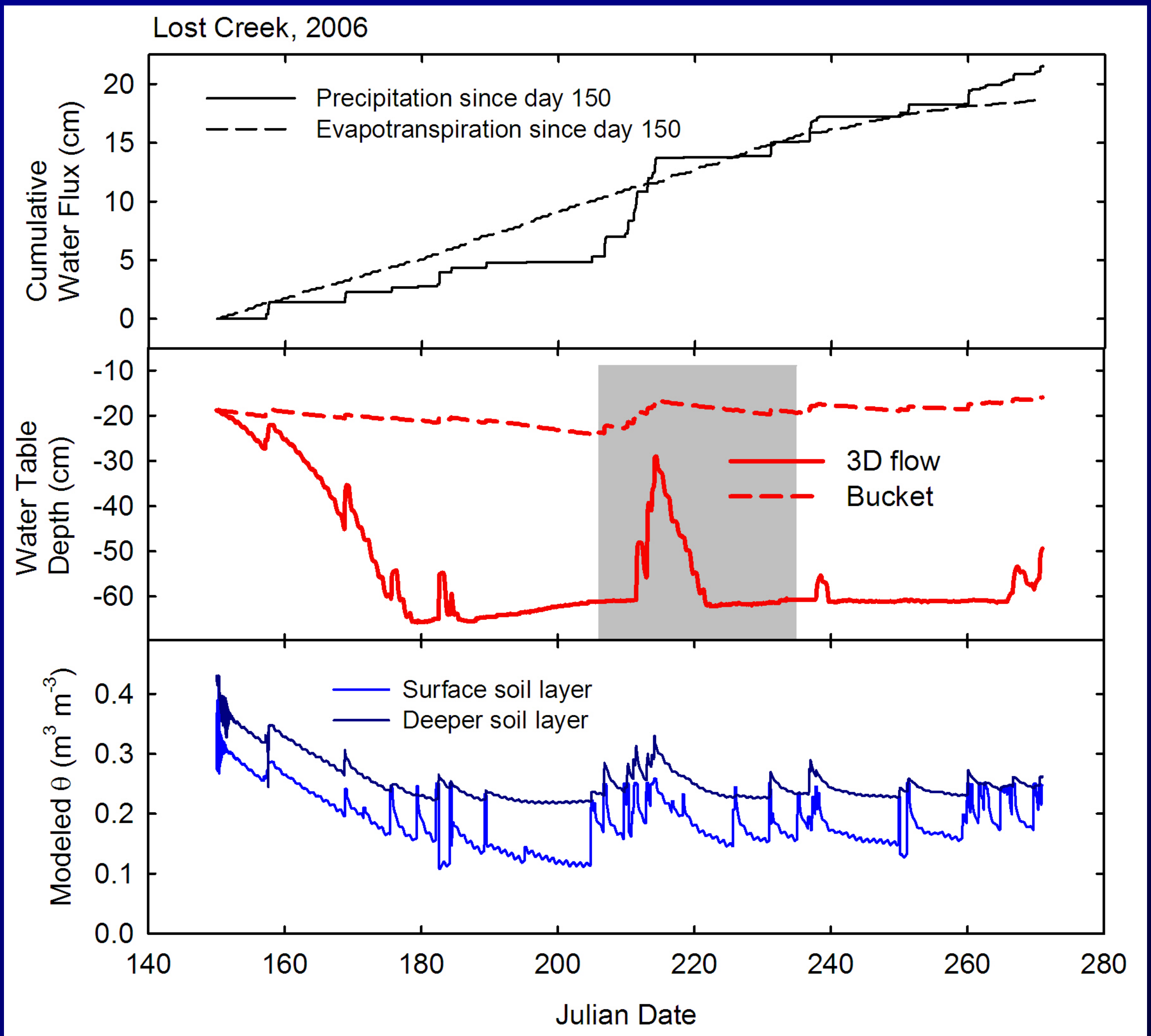
$$DIC = \overline{D(\theta)} + p_D$$

Deviance information criterion
(relative measure of model acceptability)

$$D(\theta) = -2\log\left[p(Y|\theta)\right] + 2\log\left[f(Y)\right] = -2\log\left[p(Y|\theta)\right]$$

Spiegelhalter et al. (2002), Samanta et al. (2008)

Groundwater- surface water coupling



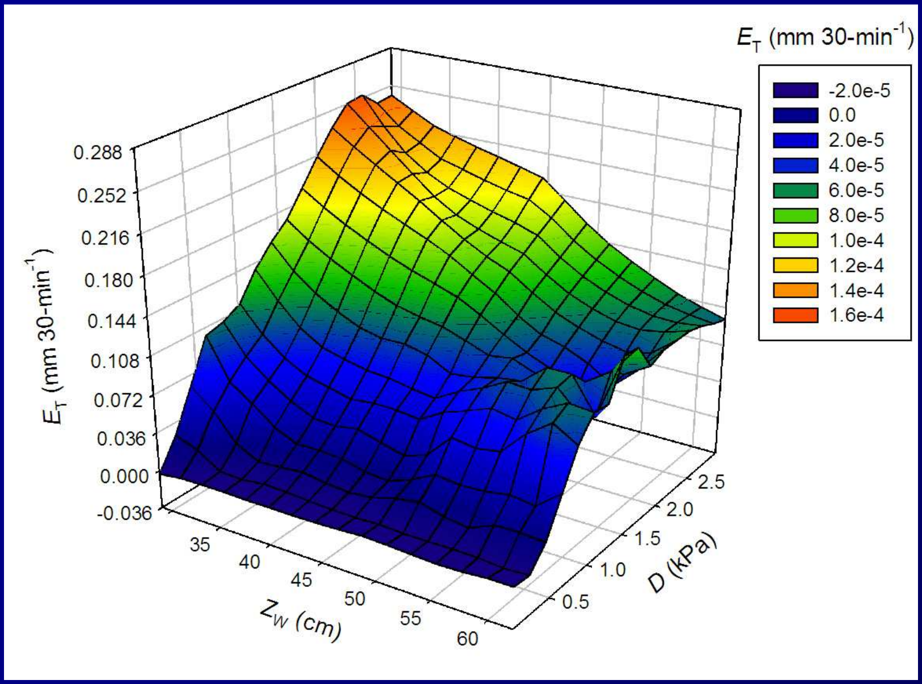
June-September precipitation and evapotranspiration

1D budget →
- timing YES
- amplitude NO

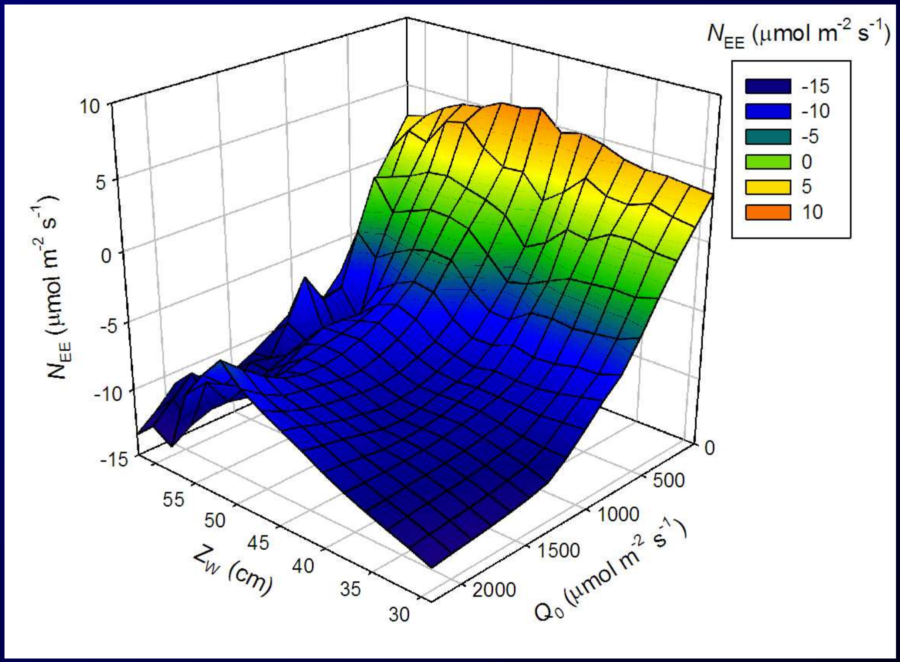
July 14 to August 13, 2006

Short-term flux responses to drivers

July 14 to August 13, 2006

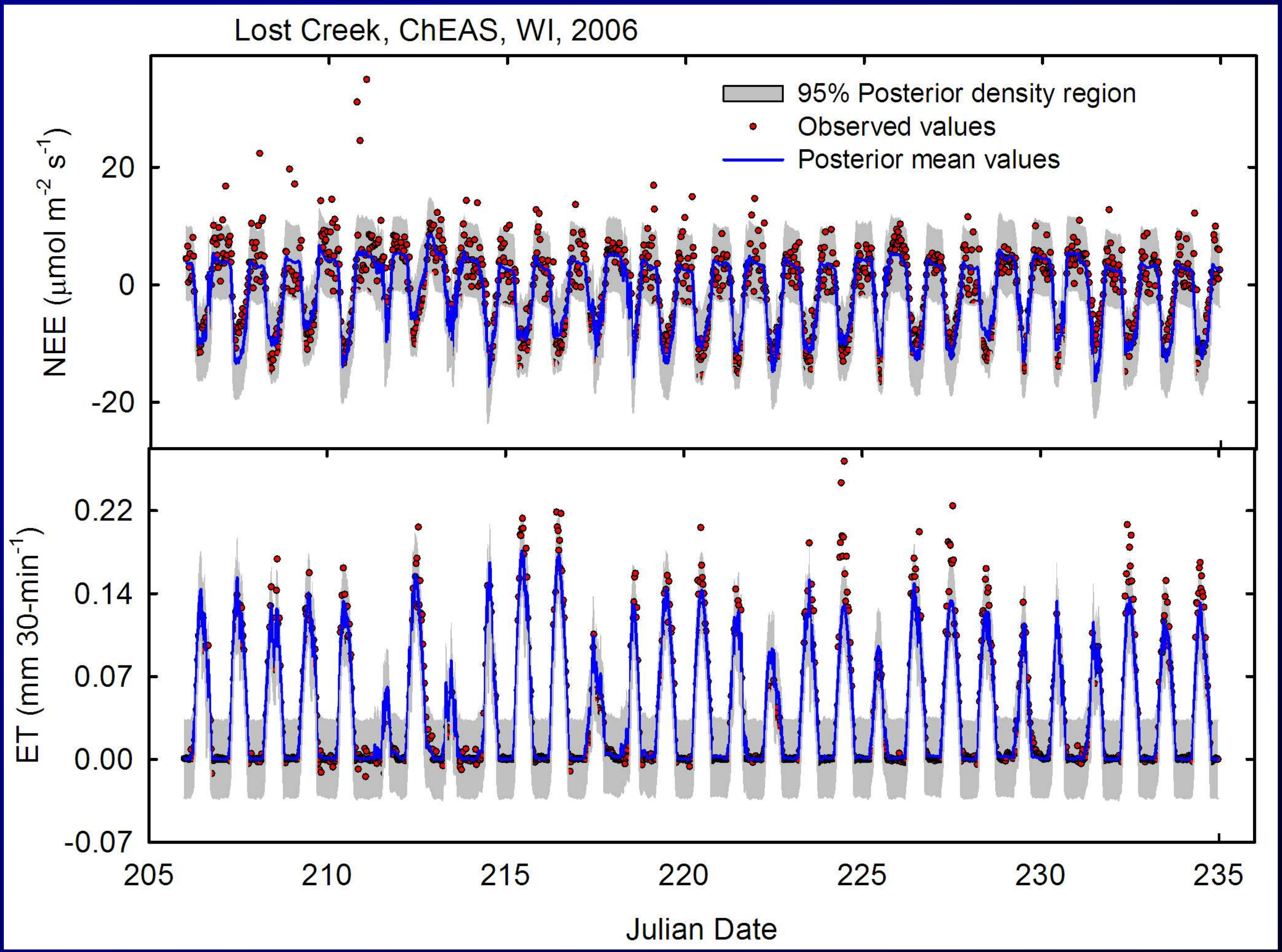


E_T is sensitive to water table height

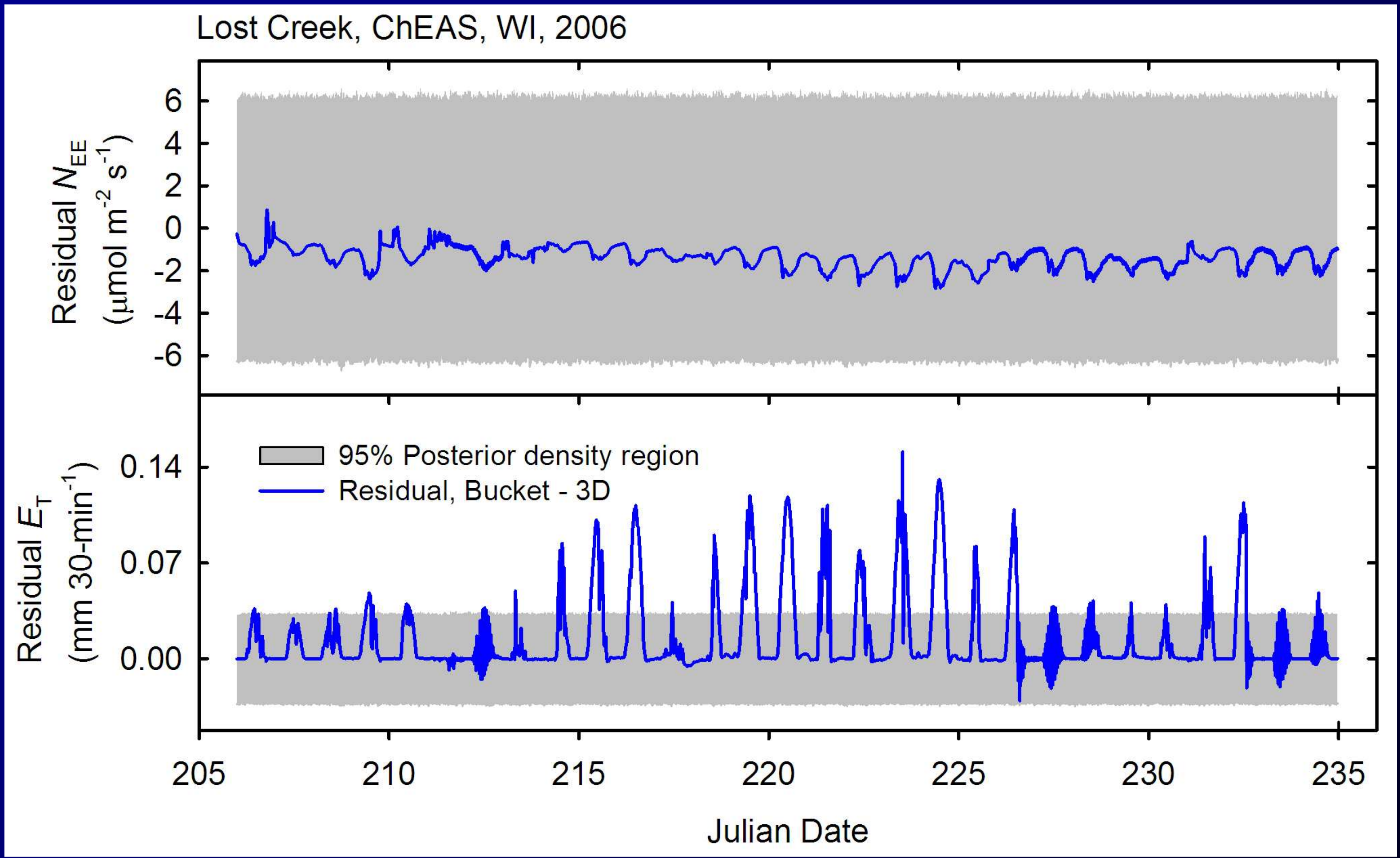


N_{EE} shows a weaker C “sink” as water table drops

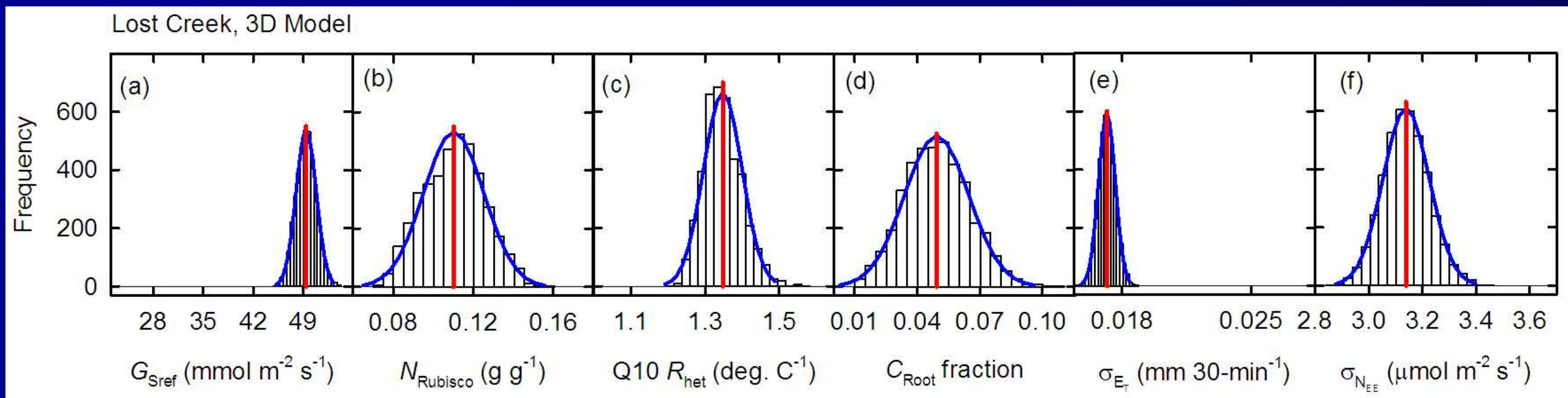
Simulation over the posterior parameter distributions



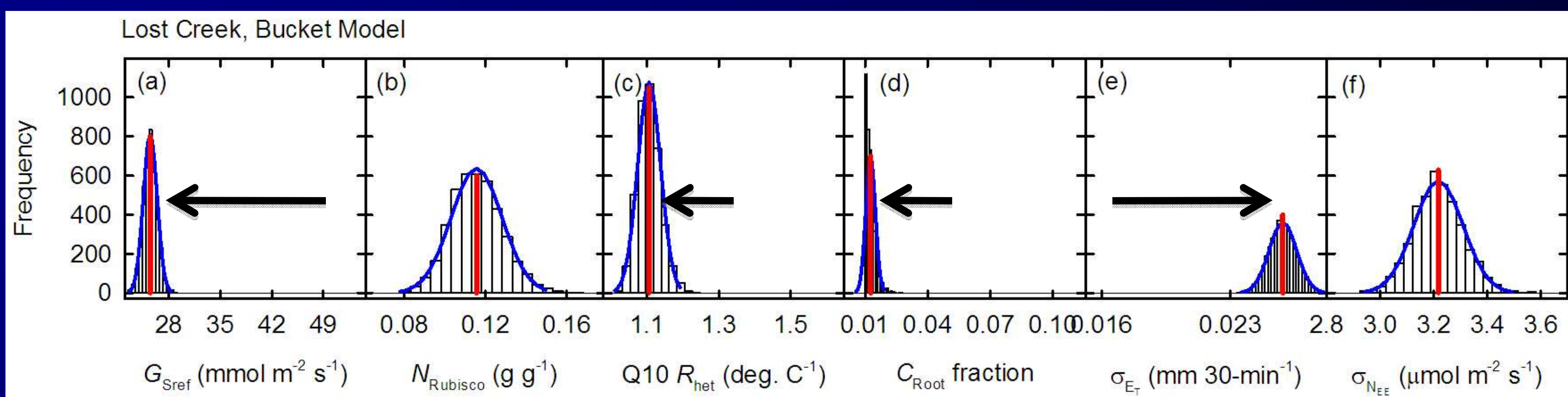
Neglecting lateral flow changes N_{EE} and E_T



Model structure diagnosis: Posterior parameter distributions

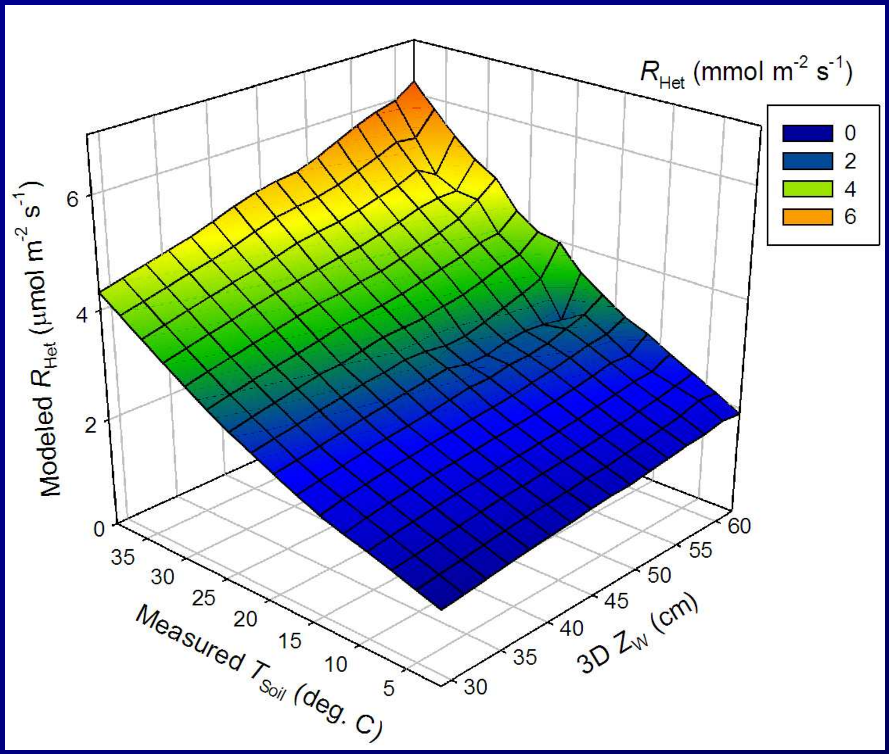


p_D = 5.7   DIC = -28208.7

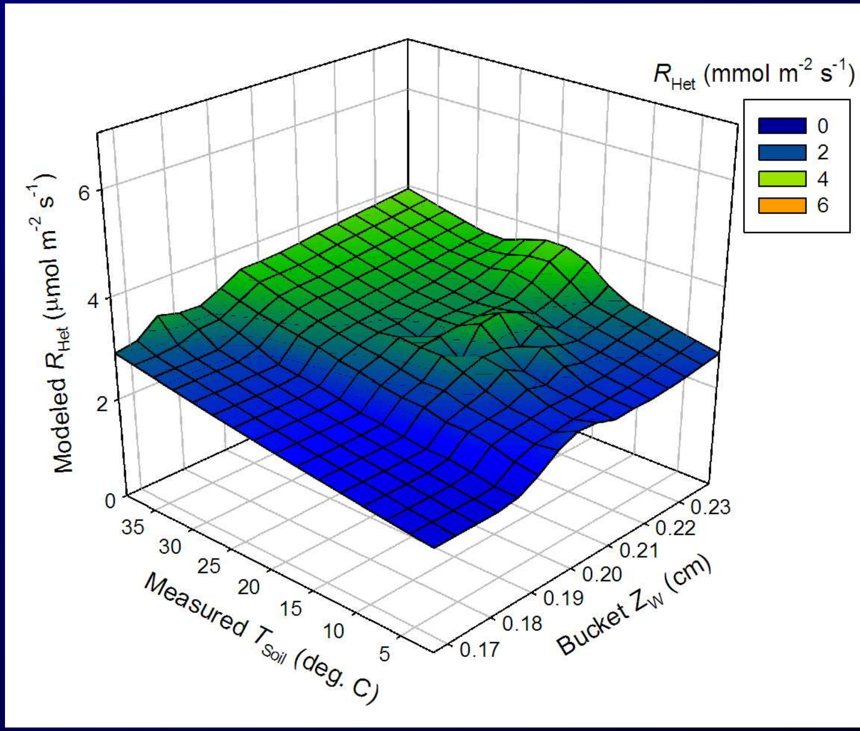


p_D = 5.1   DIC = -27599.0

Model structure diagnosis: Effects on heterotrophic respiration

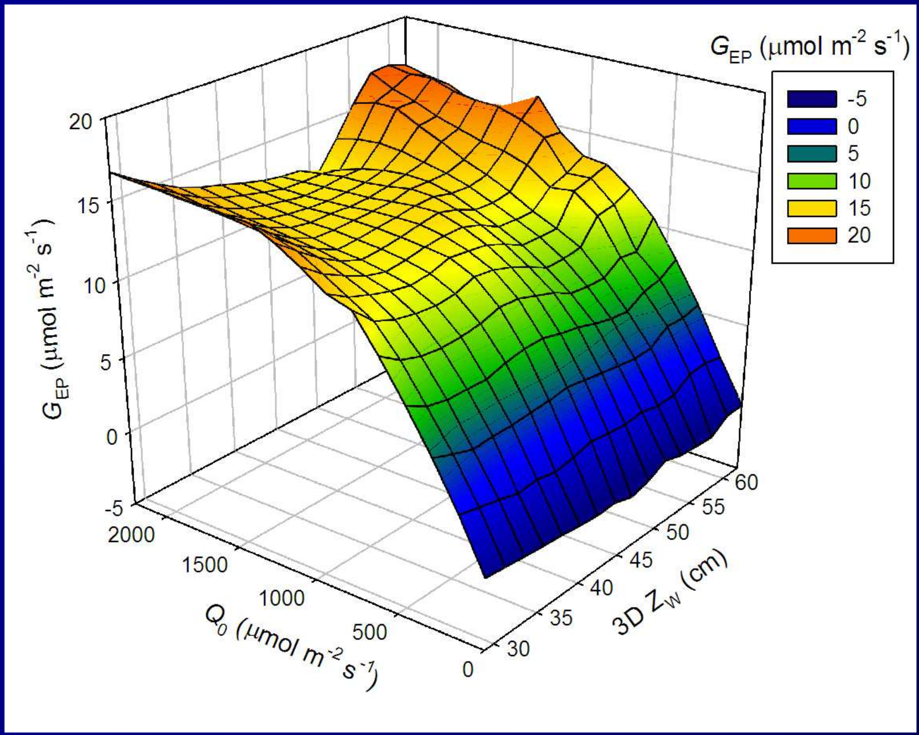


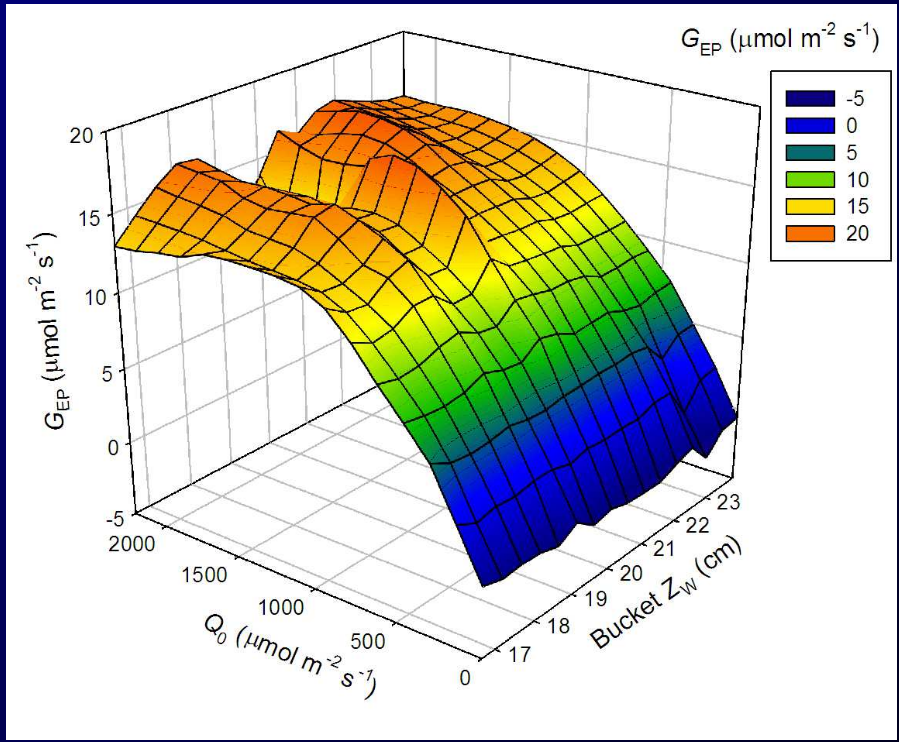
3D: R_{het} is sensitive to temperature at all water table depths 35 cm or greater



Bucket: R_{het} is insensitive to temperature at water table depths less than 23 cm

Model structure diagnosis:
Effects on gross ecosystem production





G_{EP} shows little to no change in sensitivity to light as water table changes

Conclusions

Changes in water table produced:

- statistically significant responses by E_T
- statistically insignificant (but relatively large) short-term responses by N_{EE}

Lateral subsurface flow is critical to predicting wetland E_T at all timescales, N_{EE} at short timescales

Key for climate or land use changes:

- rapid response of R_{het} (microbes)
- slow response of G_{EP} (plants)

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