Simulating terrestrial ecosystems: current progress and future perspectives

Takeshi Ise
Kyoto University

About myself

- Forest ecology
- Climate change
- Simulation modeling

- University of Wyoming

- University of Wyoming
  - Intensive field ecology
  - How can I use my knowledge to solve global environmental problems?

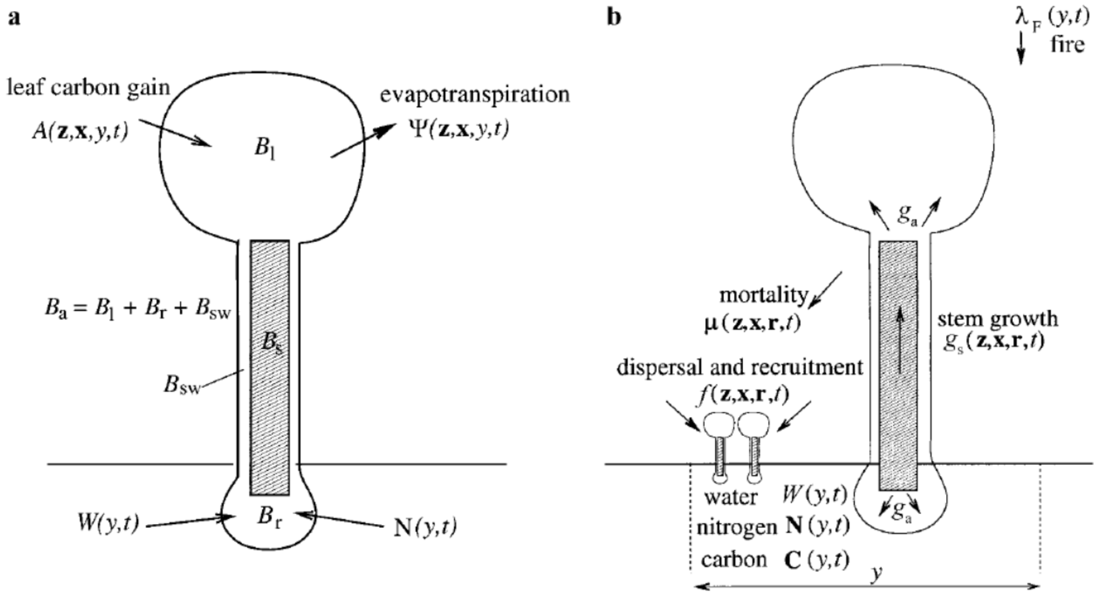
- Harvard University
  - Modeling forest dynamics
  - Prediction concerning environmental problems

$$\underbrace{\frac{\partial}{\partial t}n(\mathbf{z},\mathbf{x},a,t)}_{\text{change in plant density}} = \underbrace{-\frac{\partial}{\partial z_s}[g_s(\mathbf{z},\mathbf{x},\bar{\mathbf{r}},t)n(\mathbf{z},\mathbf{x},a,t)]}_{\text{growth in stem}}$$

$$\underbrace{-\frac{\partial}{\partial z_a}[g_a(\mathbf{z},\mathbf{x},\bar{\mathbf{r}},t)n(\mathbf{z},\mathbf{x},a,t)]}_{\text{growth in active tissue}}$$

$$\underbrace{-\frac{\partial}{\partial a}n(\mathbf{z},\mathbf{x},a,t)}_{\text{aging of plant community}}$$

$$\underbrace{-\mu(\mathbf{z},\mathbf{x},\bar{\mathbf{r}},t)n(\mathbf{z},\mathbf{x},a,t).}_{\text{mortality}}$$

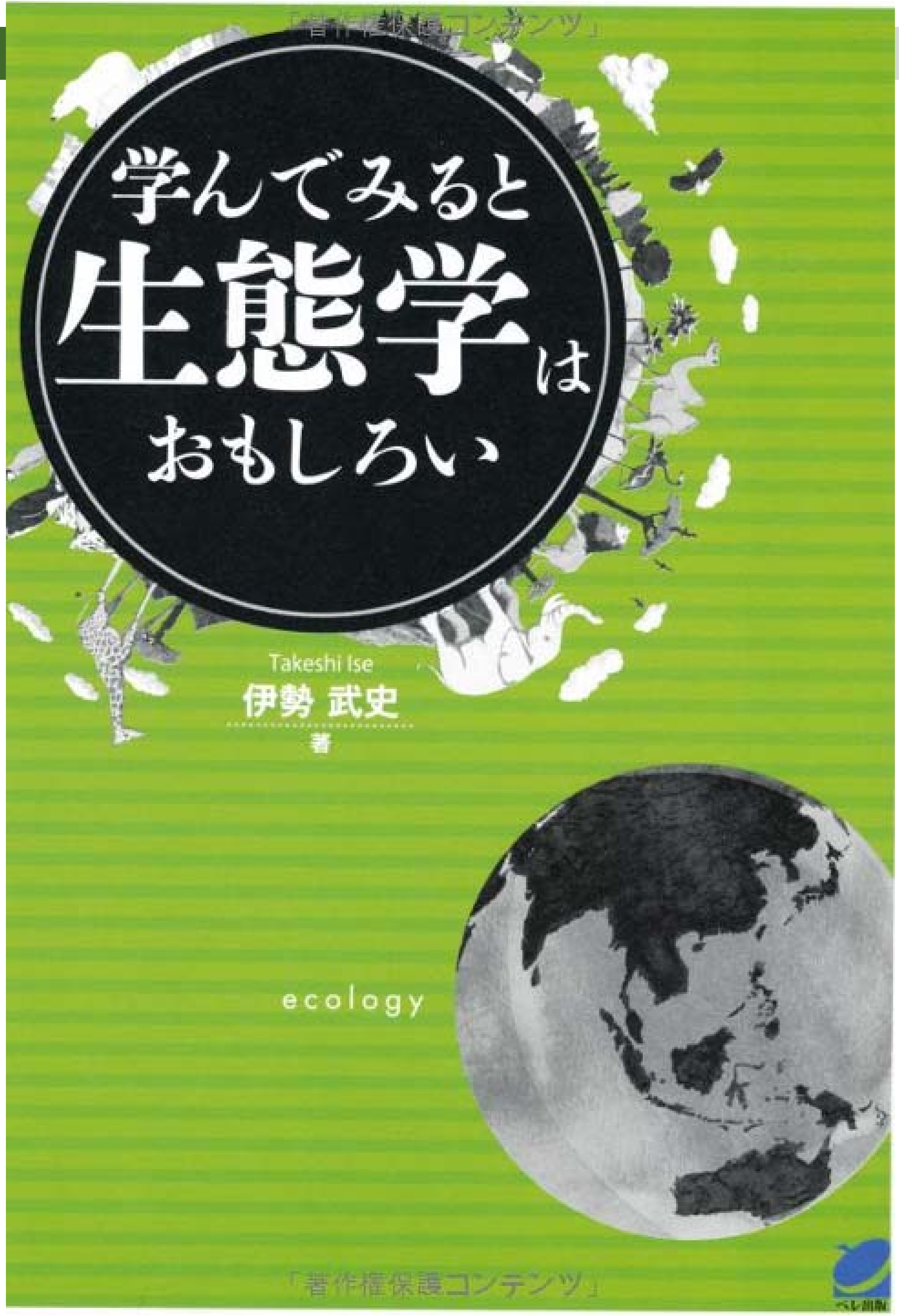


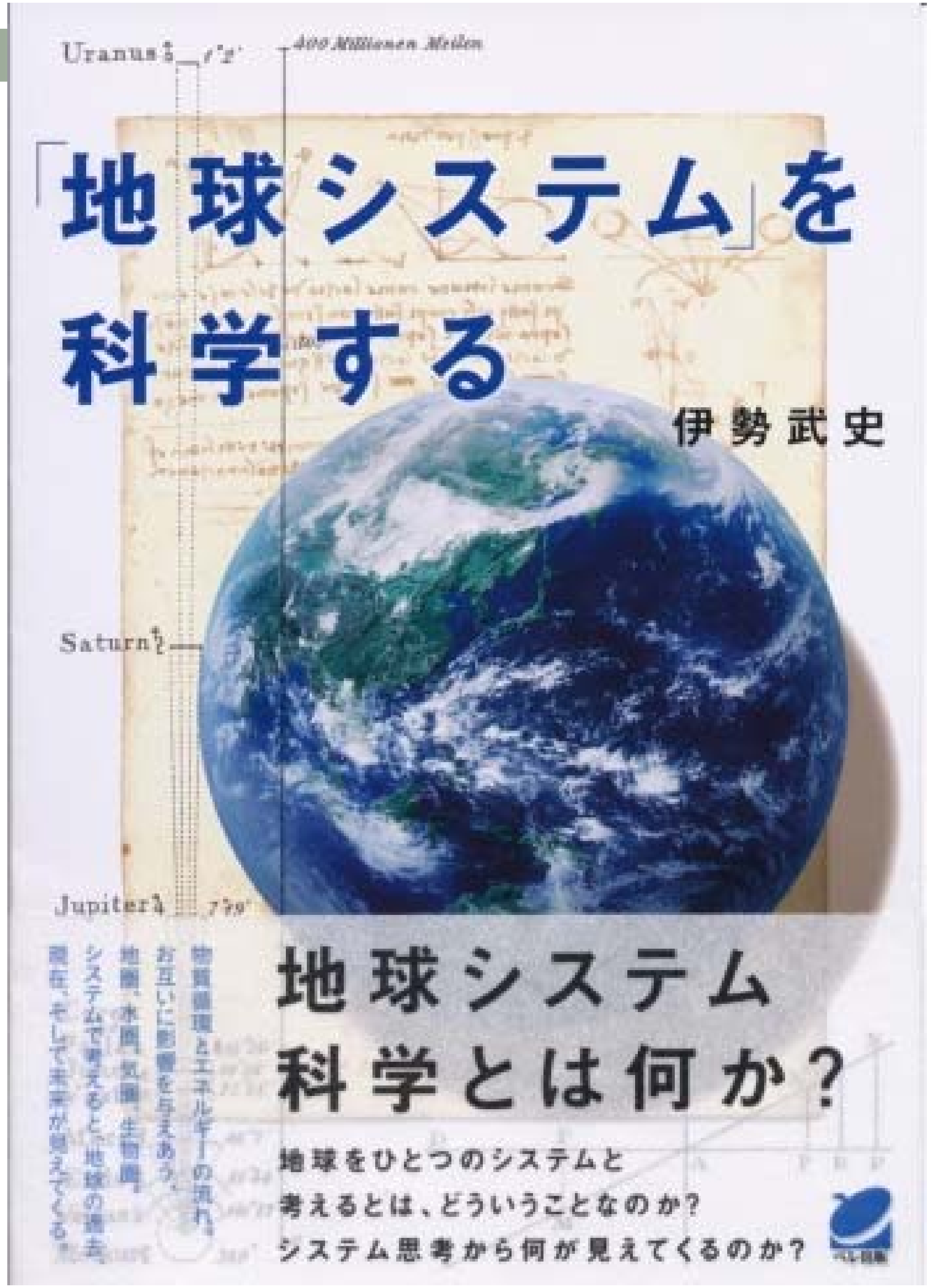
- JAMSTEC
  - The Earth Simulator
  - Building terrestrial ecosystem submodel as a component of the Earth System Model
  - “An ecologist among experts in physics”

- University of Hyogo (2011-2014)

Your next door!

- Kyoto University (2014-)

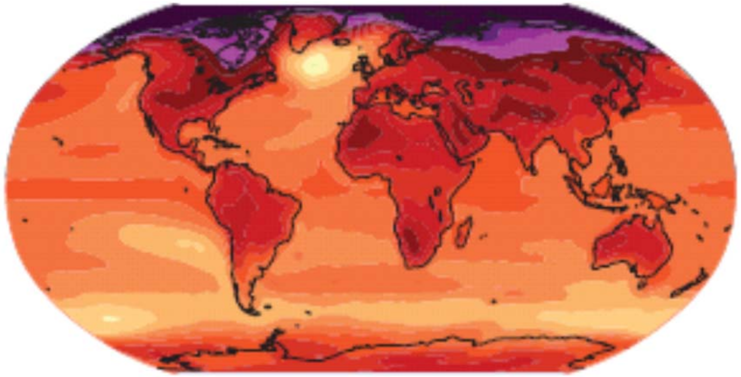

「著作権保護コンテンツ」
学んでみると
生態学は
おもしろい
Takeshi Ise
伊勢 武史
著
ecology
「著作権保護コンテンツ」



Uranus
400 Millionen Meilen
「地球システム」を
科学する
伊勢武史
Saturn
Jupiter
物質循環とエネルギーの流れ、
お互いに影響を与えあう、
地圏、水圏、気圏、生物圏。
システムで考えると、地球の過去、
現在、そして未来が見えてくる。
地球システム
科学とは何か?
地球をひとつのシステムと
考えるとは、どういうことなのか?
システム思考から何が見えてくるのか?

Climate change: importance of terrestrial ecosystems

changing climate



- Changes in
  - Temperature
  - Precipitation

Carbon cycle

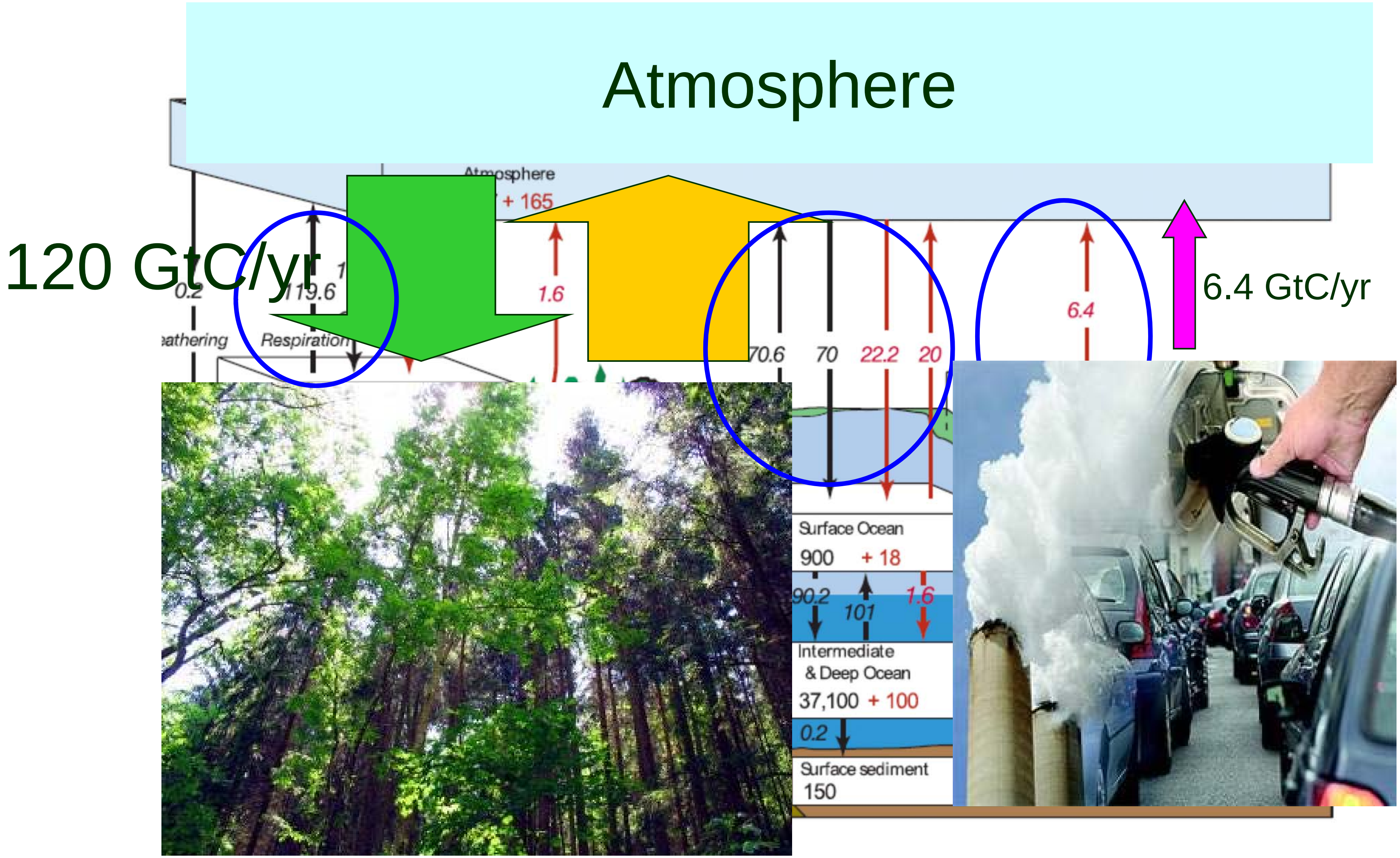
Positive feedback?

Negative feedback?

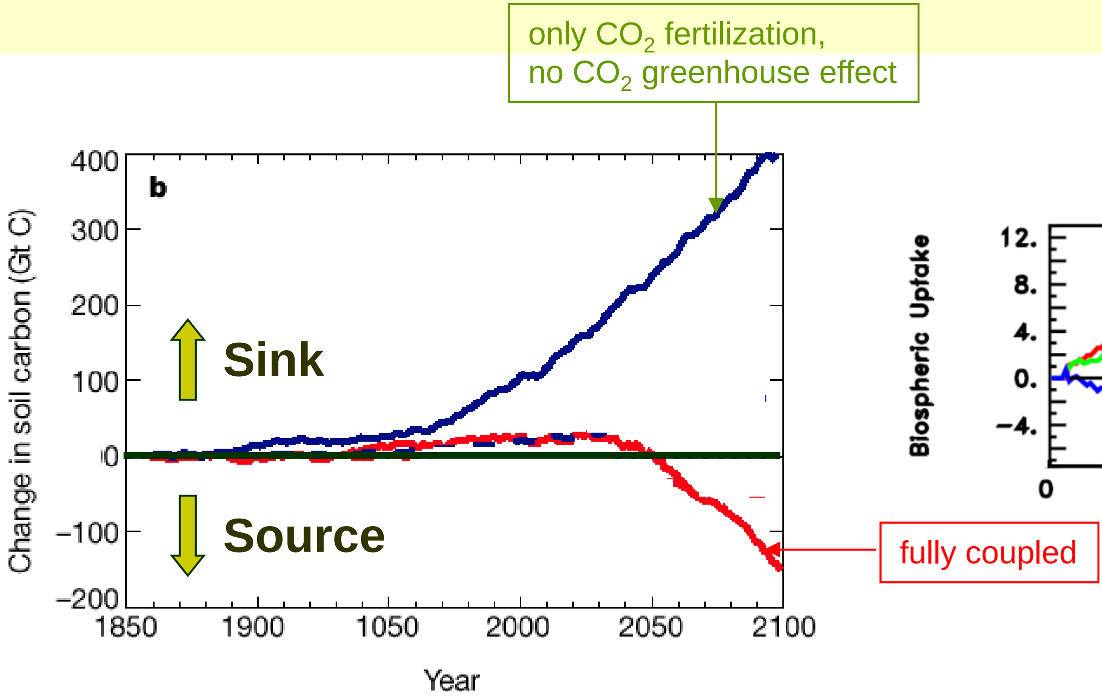
ecosystem

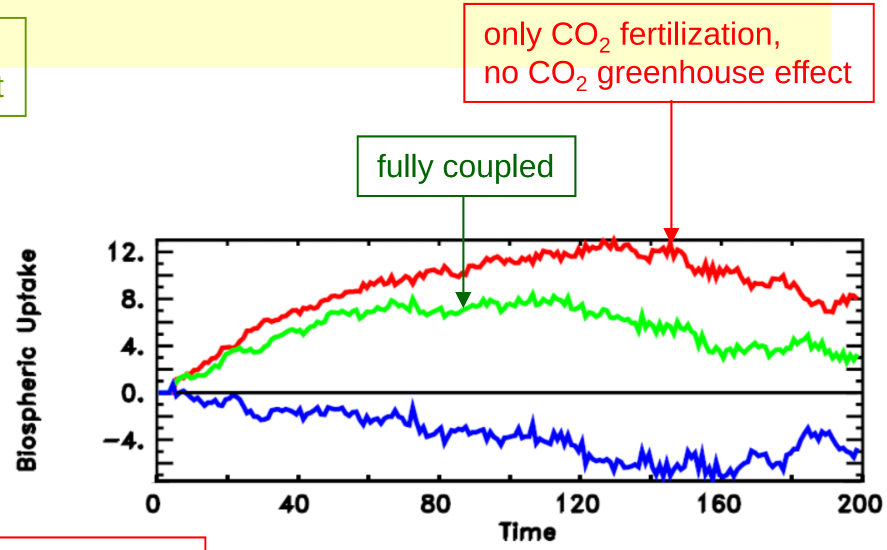
- Changes in
  - Biomass?
  - Fire?
  - Soil carbon?

Carbon cycle



Importance of ecosystem





Cox et al. (2000)

uncertainties

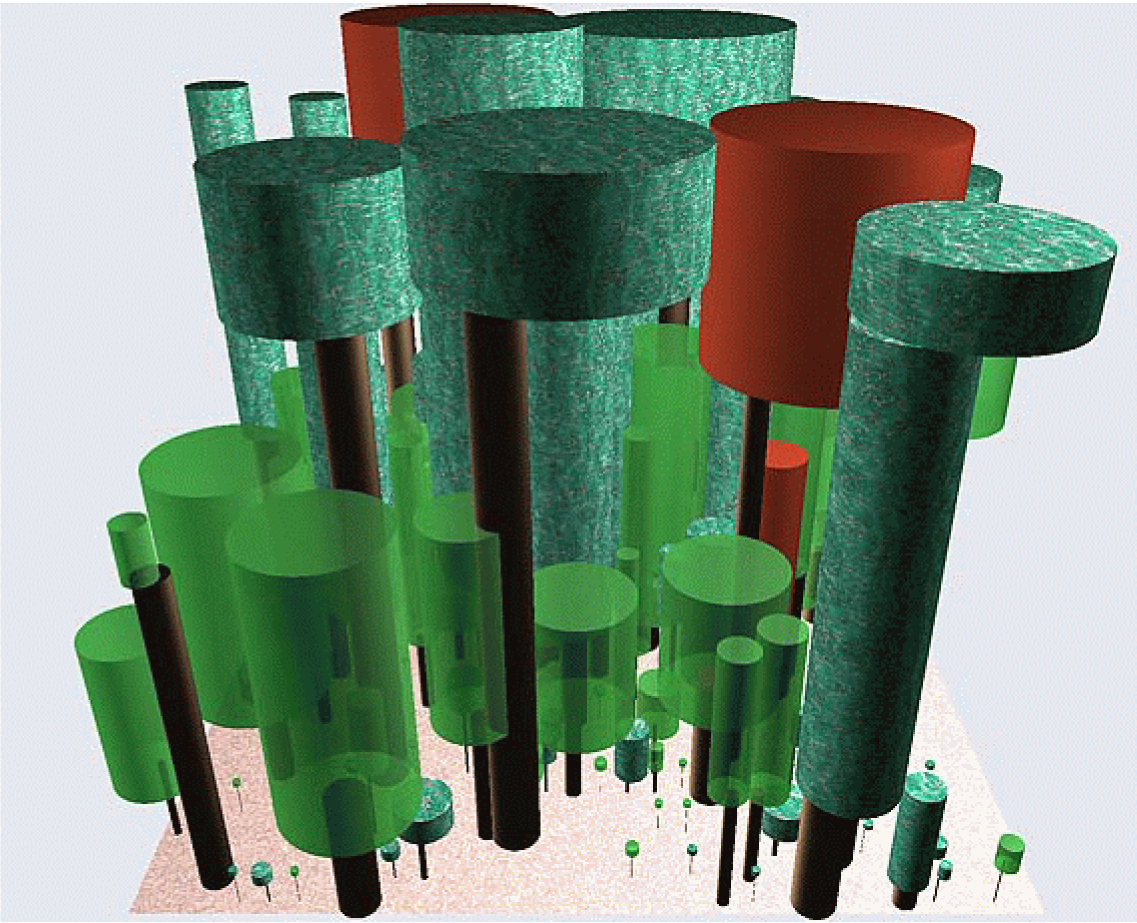
Friedlingstein et al. (2001)

Modeling terrestrial ecosystems

- Types of simulation models

Big-leaf models (bucket models)	**vs.**	Individual-based models
Phenomenon-based Models (“regression”)	**vs.**	Process-based models
Static models	**vs.**	Dynamic models

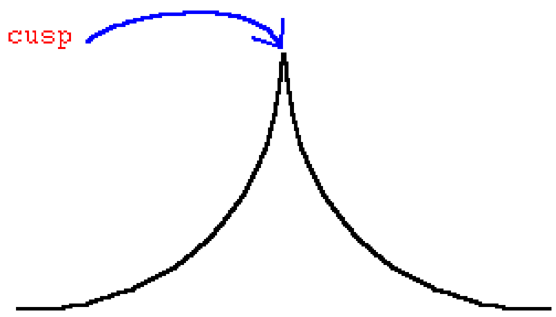
Modeling terrestrial ecosystems



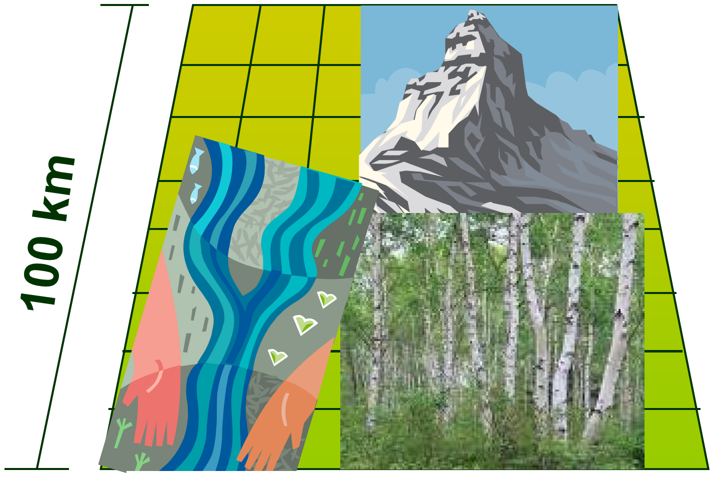
- Lots of variables and parameters
  - Temperature
  - Precipitation
  - Soil type
  - Time since disturbance
  - Species competition
  - Species characteristics
    - Suitable climate
    - Suitable soil
    - Suitable time after disturbance
  - Physiology
    - Photosynthetic rates
    - Wood density
    - Leaf thickness
    - deciduousness

Modeling terrestrial ecosystems

- Our challenges
  - Lots of parameters!
  - Heterogeneity!
  - Weak theories (comparing against physics)!
  - Abrupt changes (i.e., cusp)!



vs.



2 topics about soil organic carbon

- Physics-based simulation
- Parameter estimation using annealing and maximum likelihood

High temperature sensitivity of peat decomposition due to physical-biogeochemical feedback

Takeshi Ise
Kyoto University

- Ise, T., A.L. Dunn, S.W. Wofsy, and P.R. Moorcorft. 2008. High temperature sensitivity of peat decomposition due to physical-biogeochemical feedback

nature geoscience

The New York Times

OBSERVATORY

Rising Temperatures May Dry Up Peat Bogs, Causing Carbon Release

Ahmad Zamroni/AFP/Getty Images

Higher temperatures were found to cause water tables in bogs to drop and more peat to decompose.

By HENRY FOUNTAIN
Published: October 13, 2008

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It's increasingly clear that the effects of climate change will be felt — or are already being felt — in all corners of the globe, in all kinds of ecosystems.

Even, it appears, in peat bogs. A study in Nature Geoscience suggests that northern bogs may lose a significant portion of their peat as global temperatures rise. Organic matter in the peat will decompose, releasing carbon into the atmosphere.

Ordinarily peat bogs are a huge carbon sink. They consist of marsh grasses, trees and other organic matter that, because of the wet, oxygen-starved conditions, don't decay much. What's more, peat generally begets more peat: because it holds so much water and blocks drainage, as it

Related

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Observatory: The Thrill of the Hunt Is Not Lost on Bonobos (October 14, 2008)

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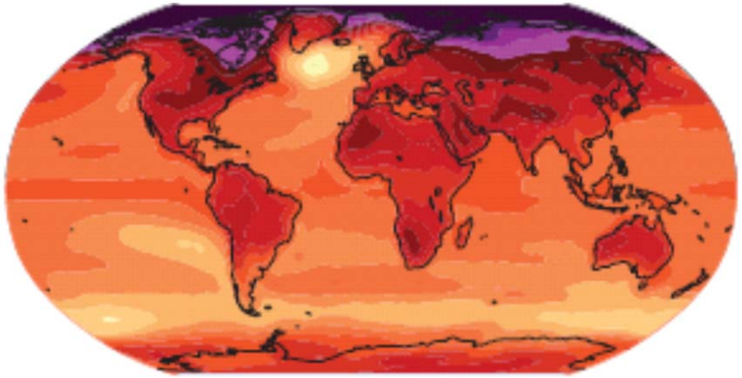
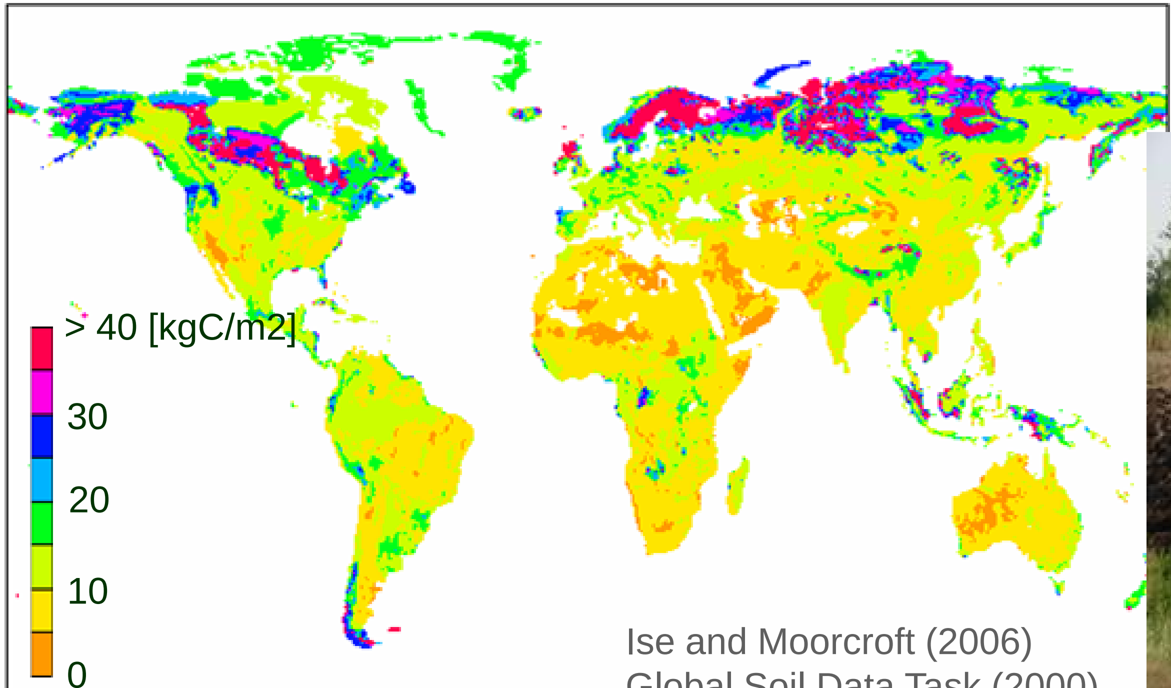
High Sensitivity of Peat Decomposition to Climate Change Through Water-table Feedback (Nature Geoscience)

Why peatland?



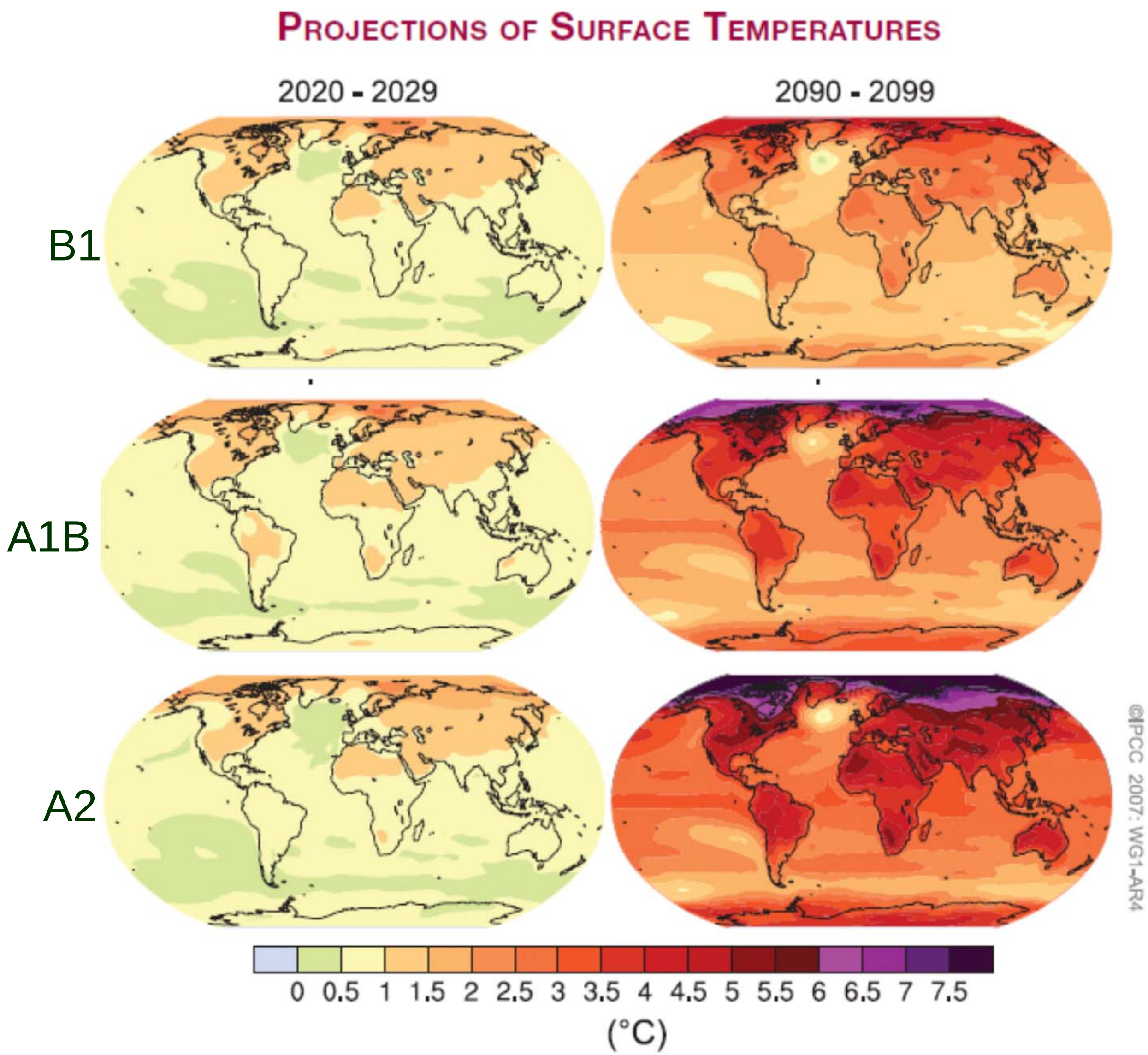
Soil carbon

•1500 GtC (2x in the atmosphere)
•up to 30% in northern peatlands



Ise and Moorcroft (2006)
Global Soil Data Task (2000)

Boreal region under climate change



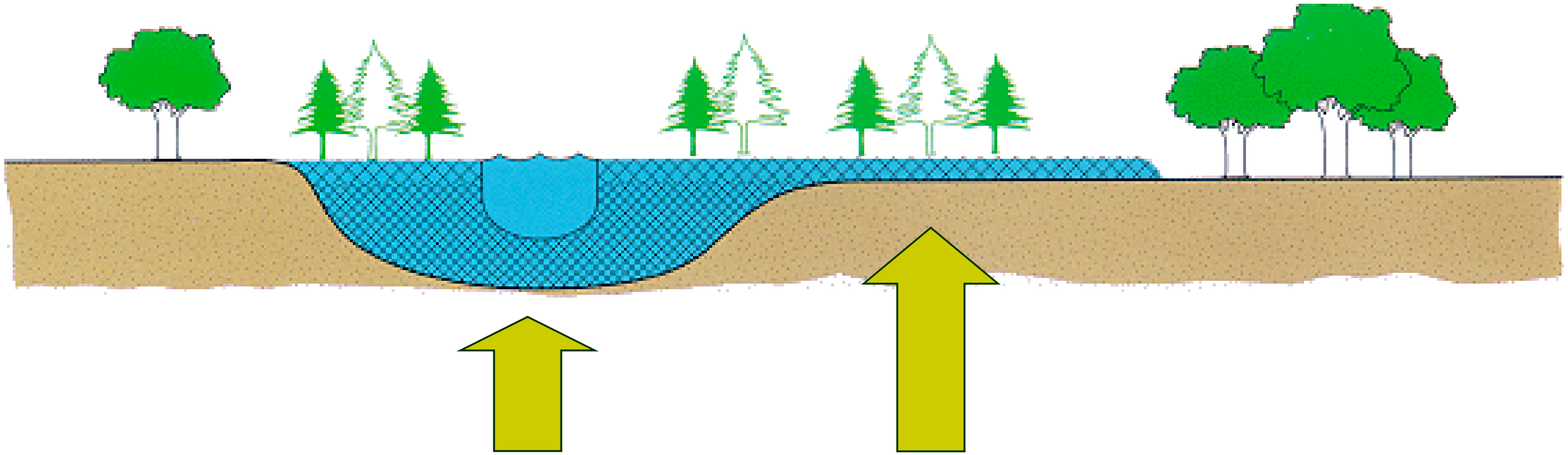
- **Peatland carbon cycle**
  - **Continental bog**
  - **Fen**

- Peatland biogeochemistry
  - **Continental bog**
  - Fen

- Bog
  - Disconnected from regional hydrology

http://gsc.nrcan.gc.ca/landscapes/

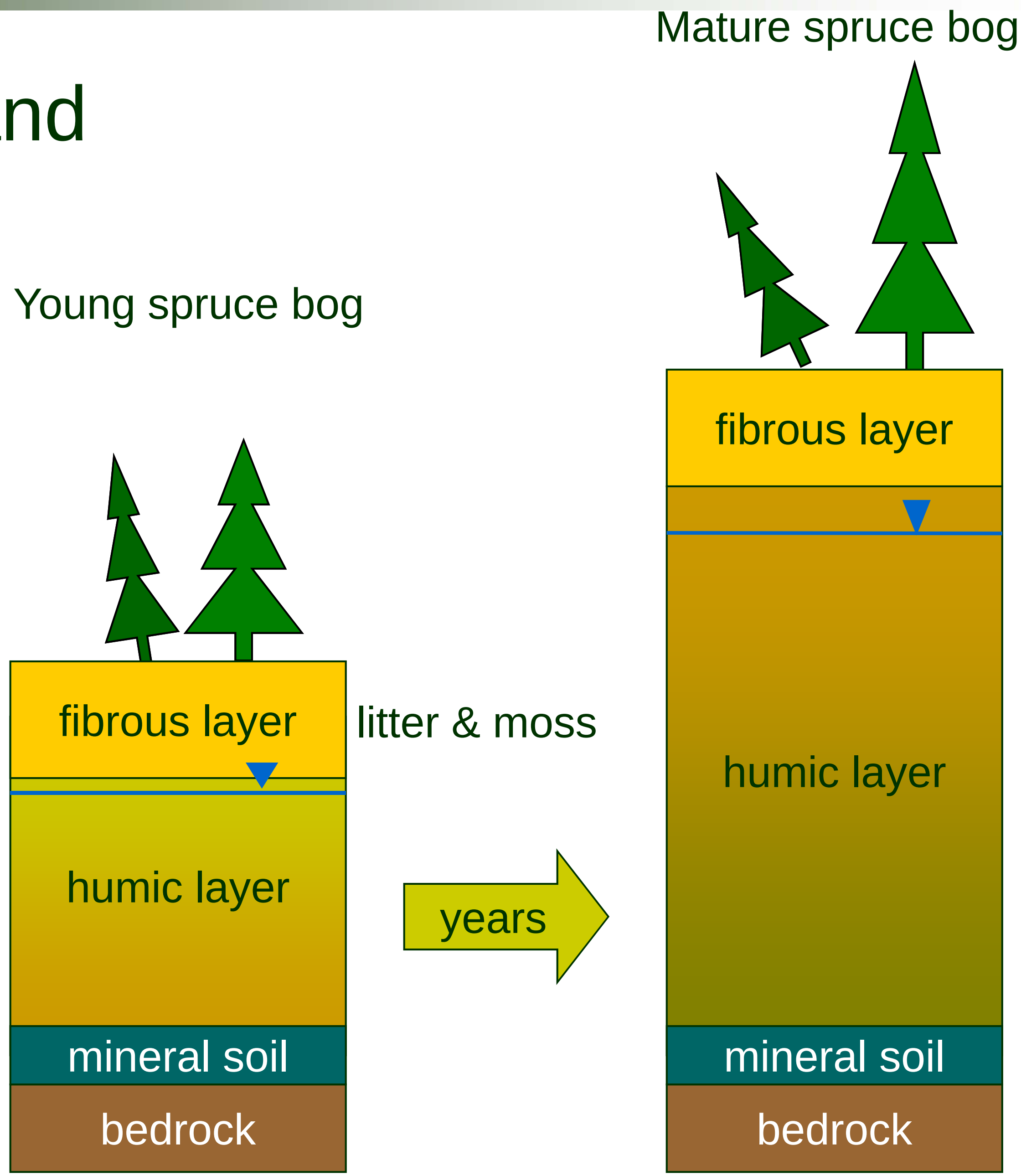
http://www.na.fs.fed.us/spfo/pubs/n_resource/wetlands/wetlands9_organic.htm



(Anderson, Foster, & Motzkin 2003)

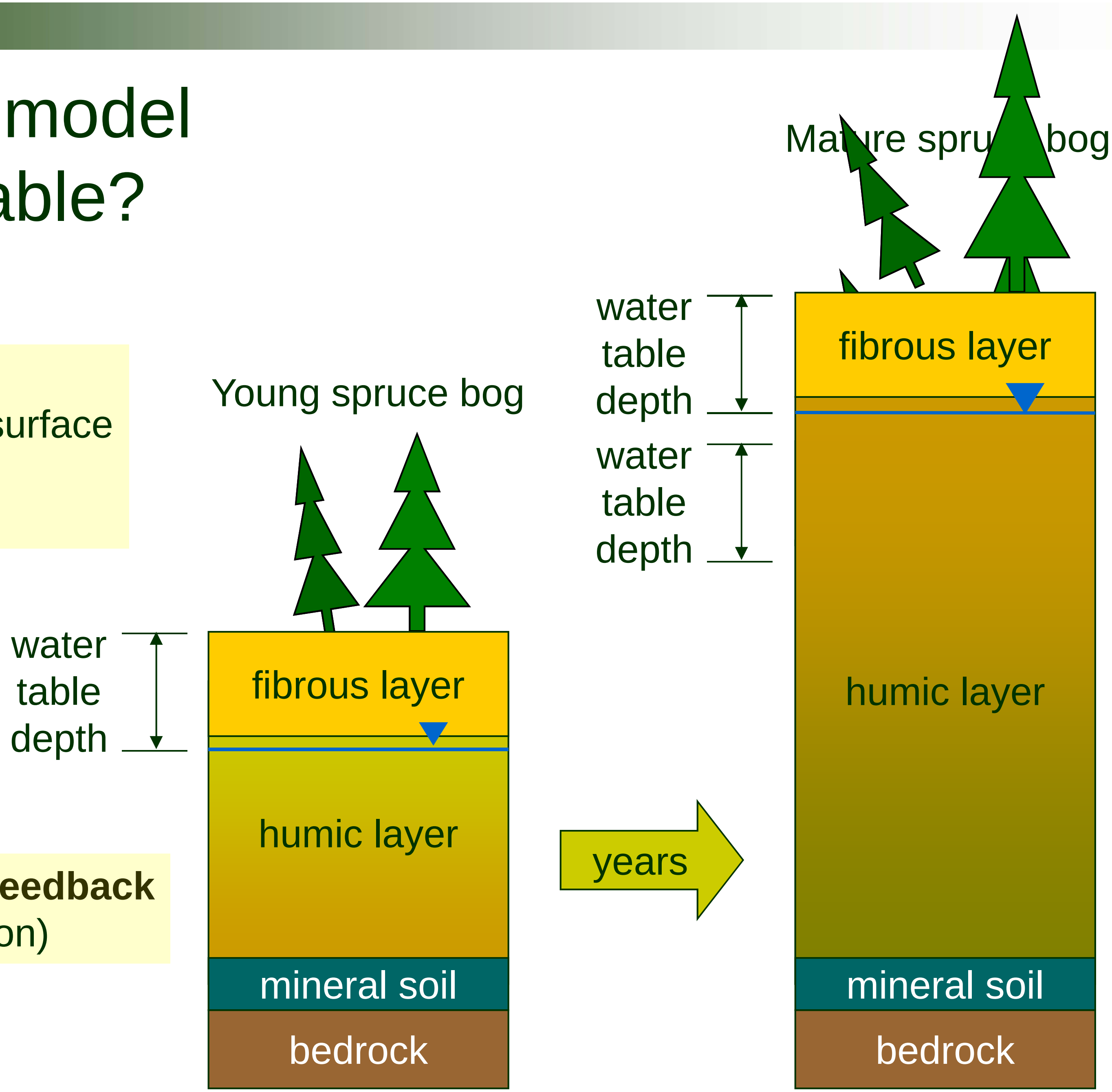
SOC in peatland

- Peat column gains height
- Rise in water table



How to model water table?

Hypothesis:
Constant from surface
(Clymo 1984)



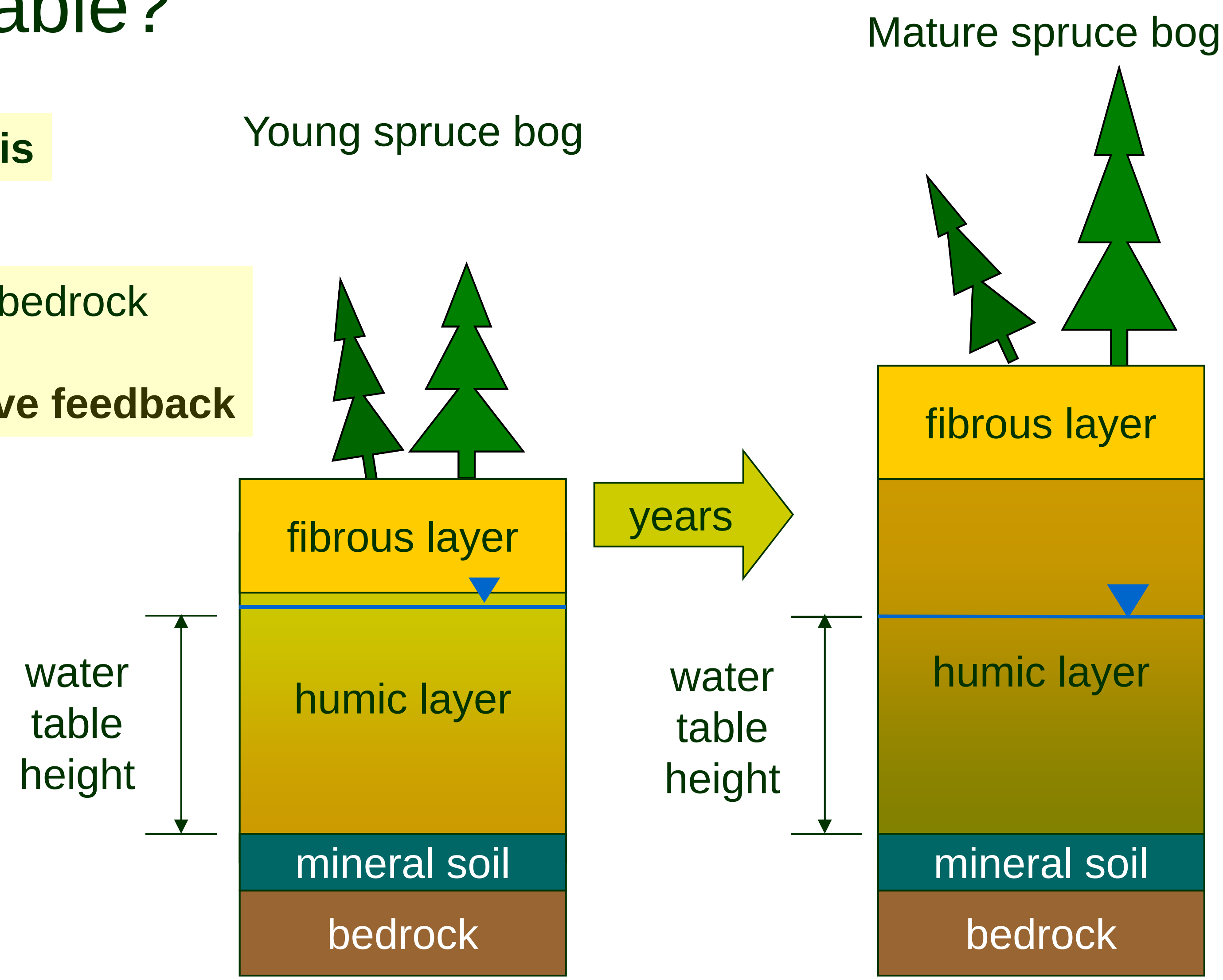
Strong positive feedback
(paludification)

How to model water table?

Null hypothesis

Constant from bedrock

Strong negative feedback

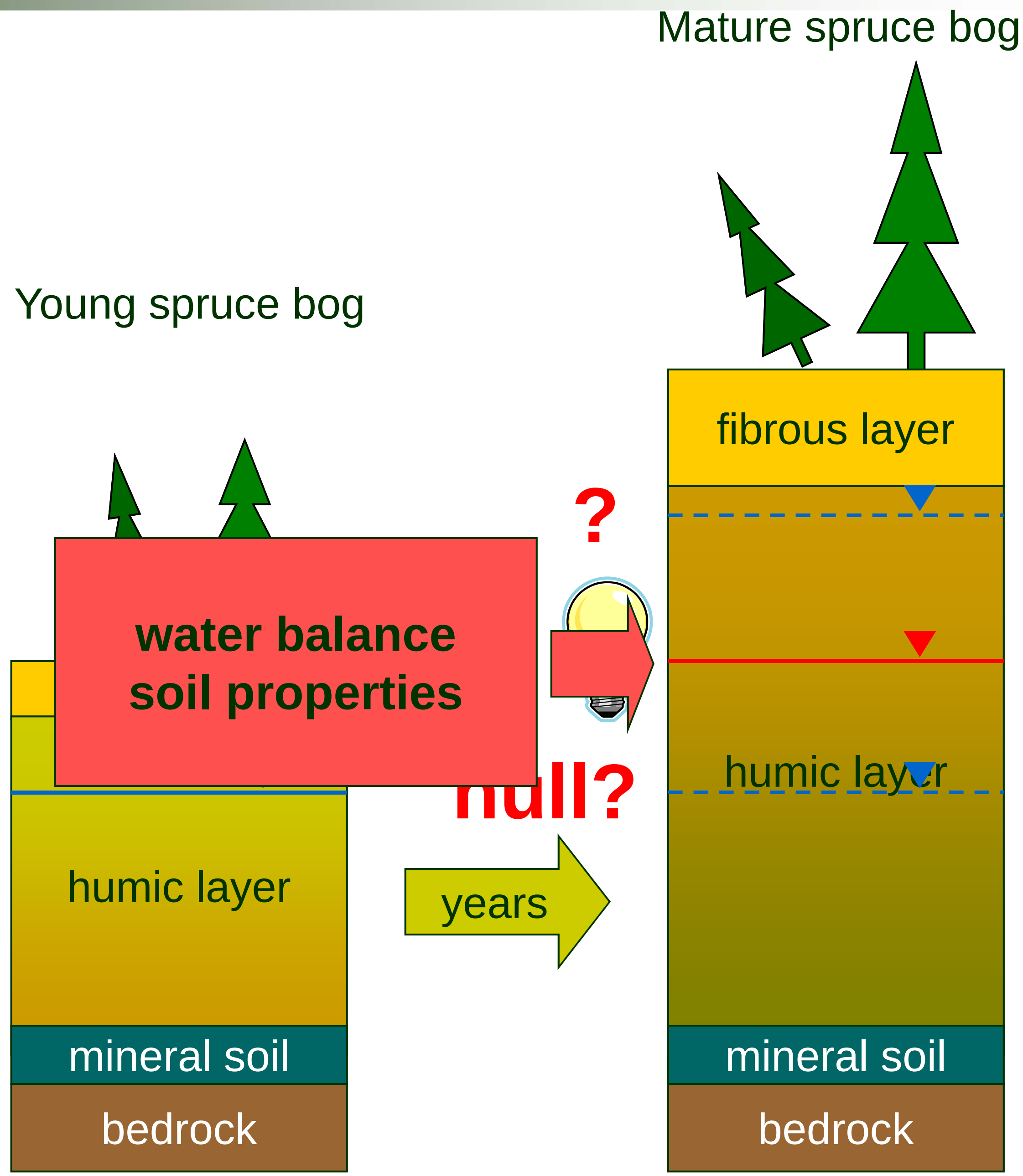


How to model water table?

Which hypothesis ?

Somewhere in between

Needs for mechanistic simulation!

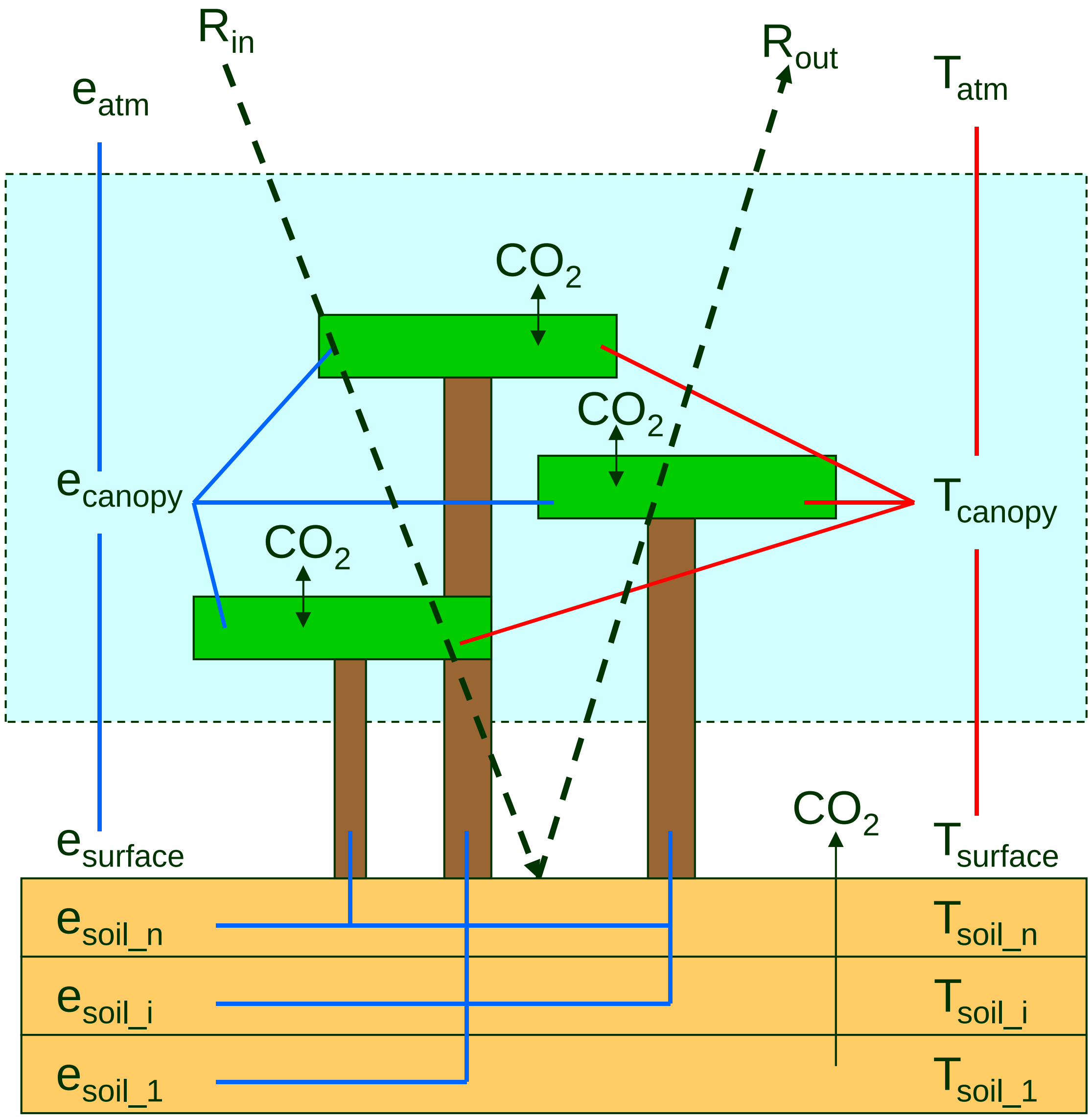


ED2

Process-based land-surface model

Fast timescale fluxes
- carbon
- water
- energy

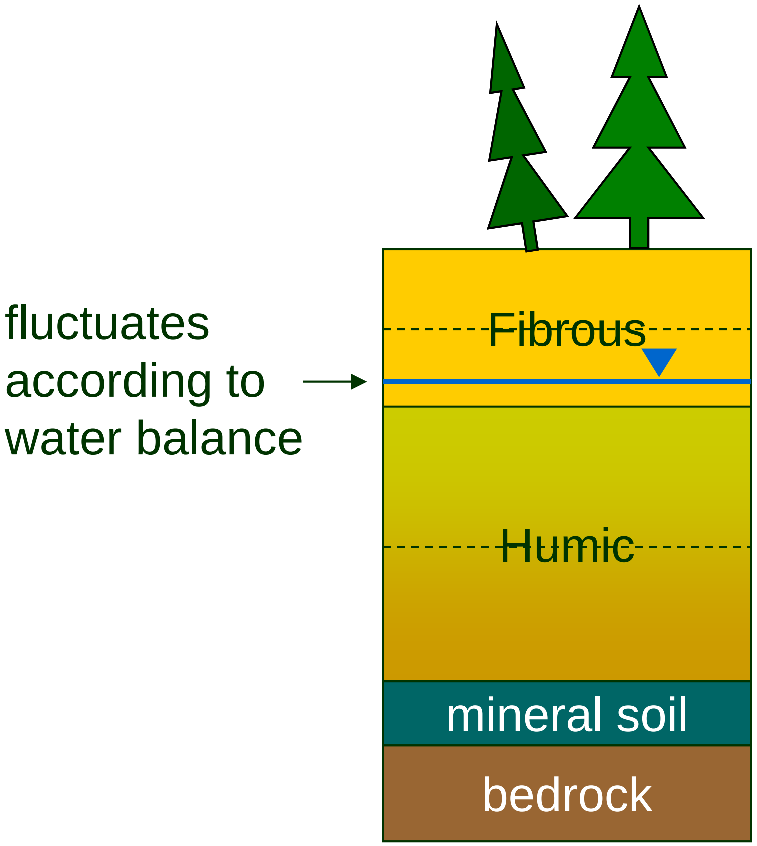
- Input data
  - update in 30 minutes
  - meteorological variables (SW, LW, air temperature, precipitation, humidity, wind speed/direction, and [CO_2])



ED1: Moorcroft et al. 2001. Ecological Monographs 71:557-585.
ED2: Medvigy et al. 2006. Ph.D Thesis. Harvard University.

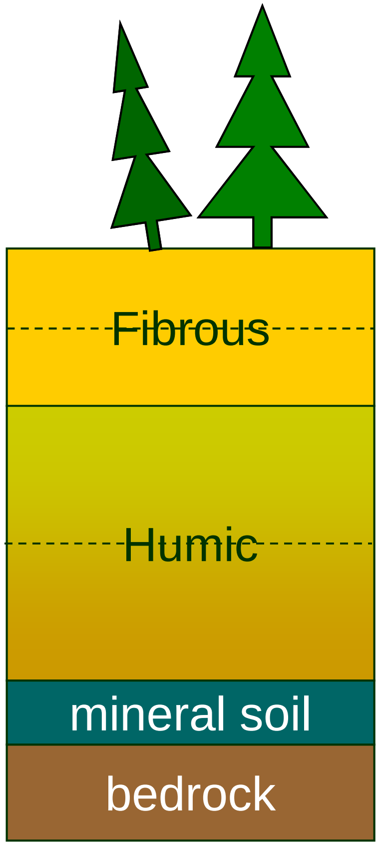
Biogeochemical model

- Two peat types
  - Fibrous
  - Humic
- Simulation of SOC
- **Real-time conversion to peat depth**
- Simple, but powerful
  - Reproduce feedbacks



Biogeochemical model

Decomposition

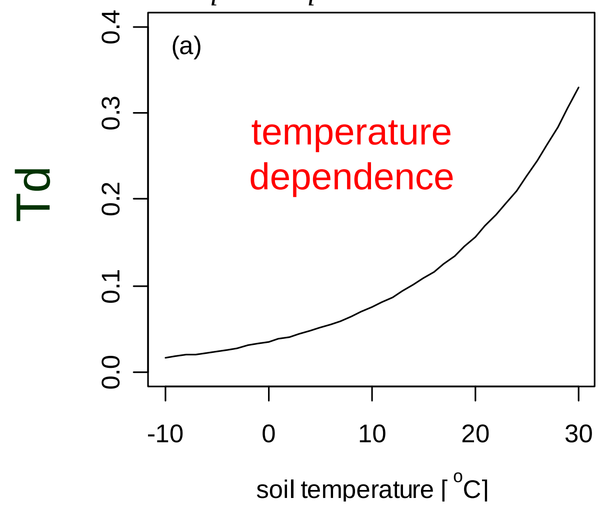


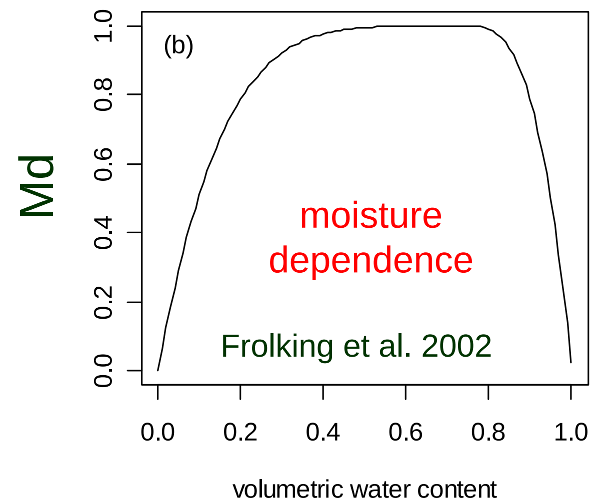
$$\frac{dC_{met}}{dt} = I_{met} - r_{met} C_{met}$$

$$\frac{dC_{str}}{dt} = I_{str} - r_{str} C_{str}$$

$$\frac{dC_{hum}}{dt} = h_m r_{str} C_{str} - r_{hum} C_{hum}$$

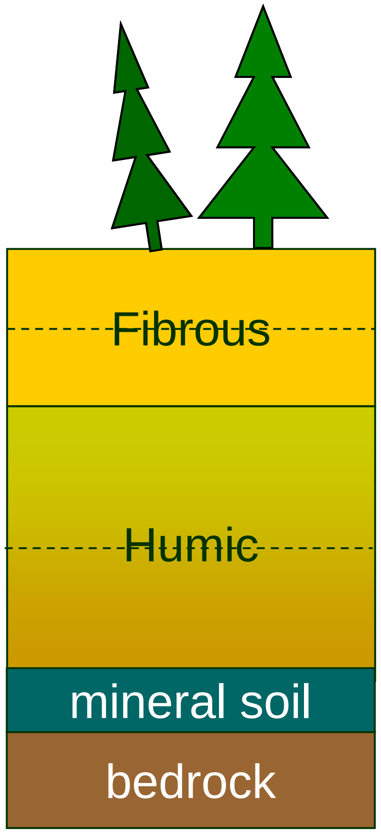
$$r_i = k_i \cdot Td \cdot Md$$





2 simulations

Dynamic peat depth model



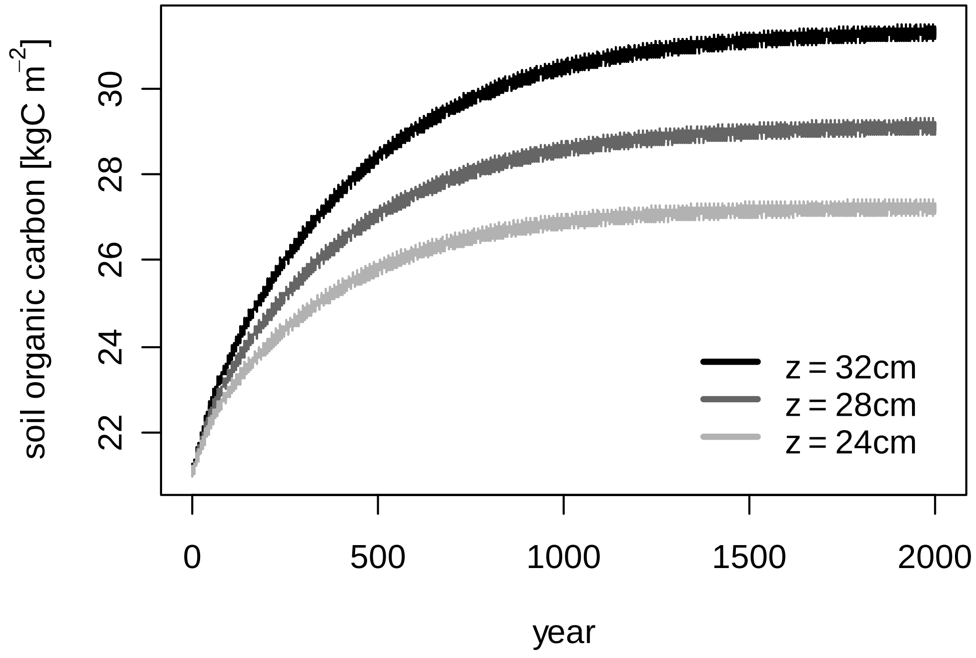
$$C_{fib} = C_{met} + C_{str}$$

$$Z_{fib} = \frac{C_{fib}}{F_{fib} D_{fib}}$$

$$Z_{hum} = \frac{C_{hum}}{F_{hum} D_{hum}}$$

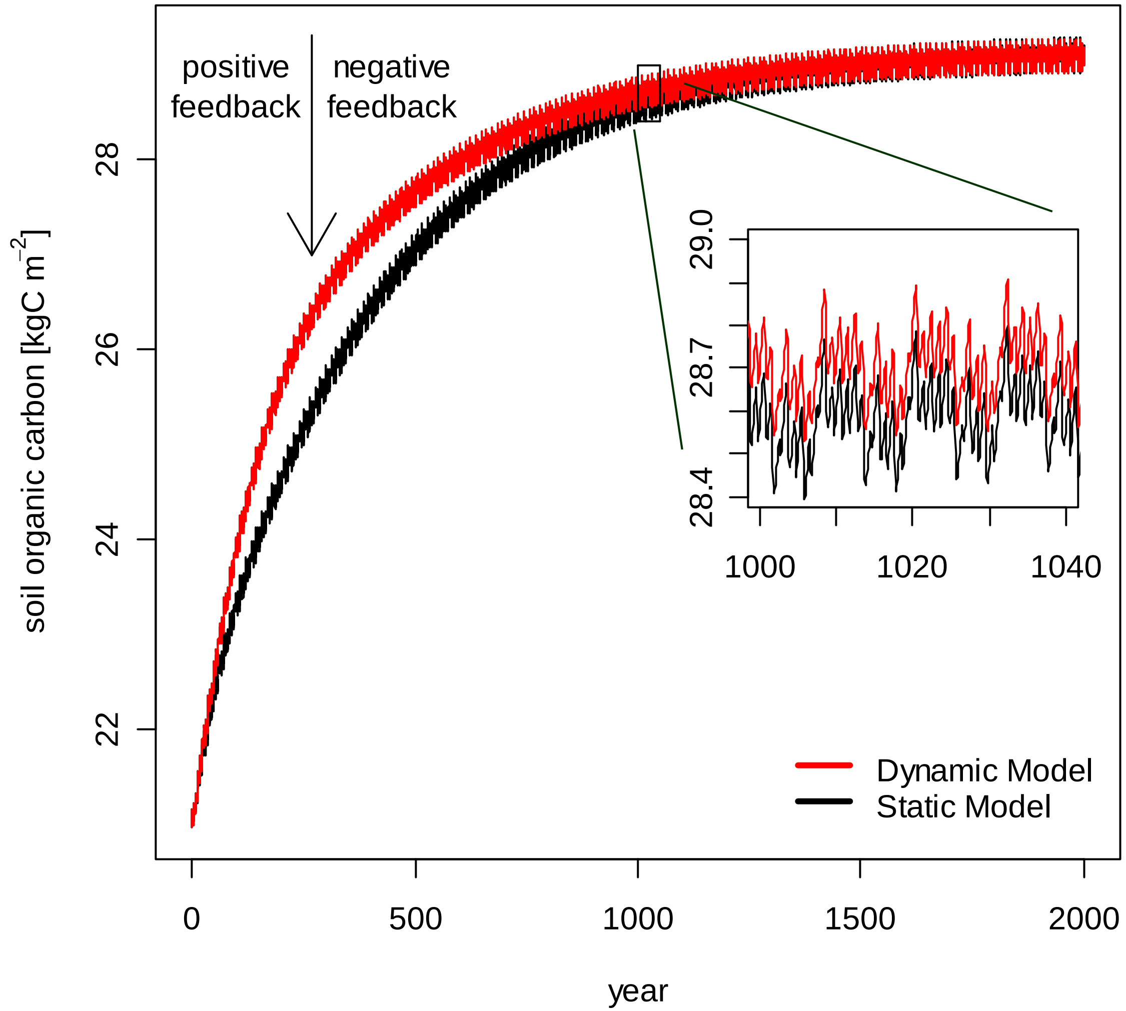
Equilibrium SOC: self-regulatory

Static model (mineral soil model)



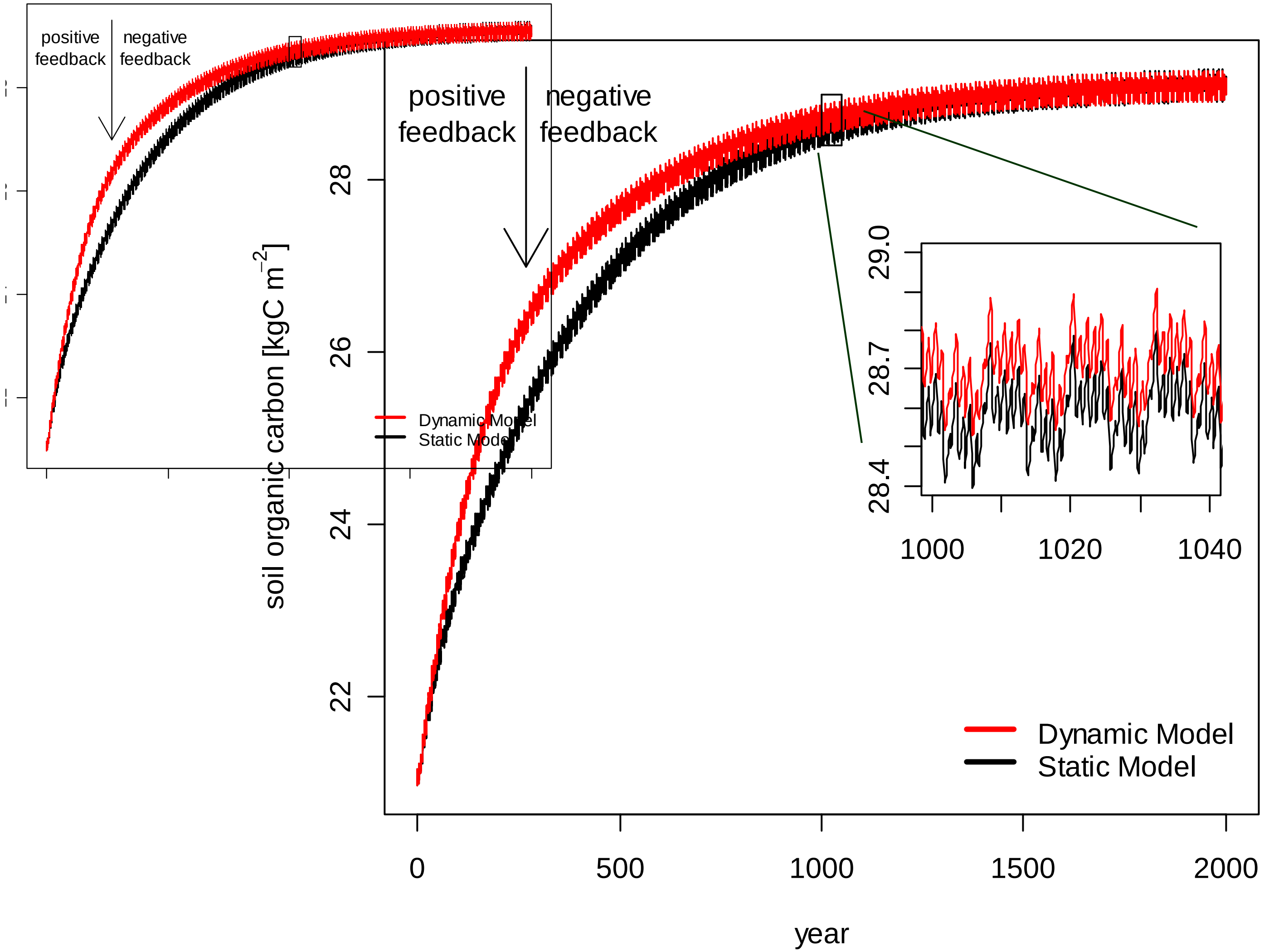
Equilibrium SOC: sensitive to initialization

Results

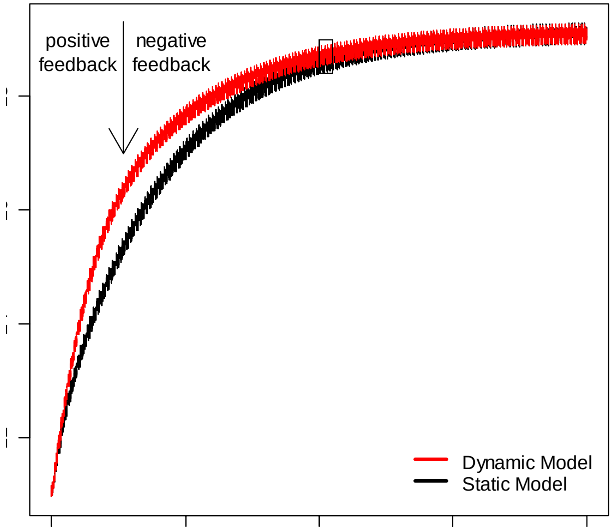


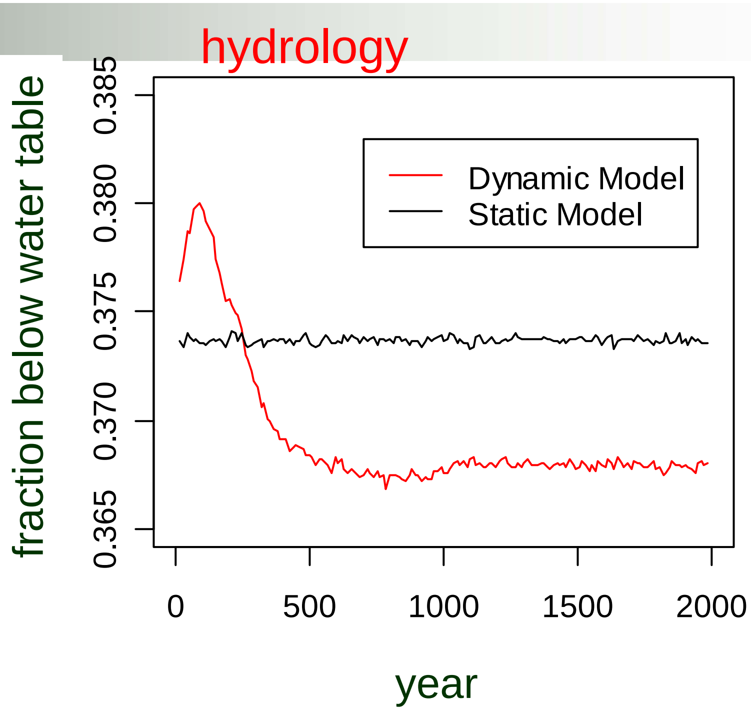
positive feedback
negative feedback
soil organic carbon [kgC m^{-2}]
22
24
26
28
29.0
28.7
28.4
1000
1020
1040
0
500
1000
1500
2000
year
Dynamic Model
Static Model

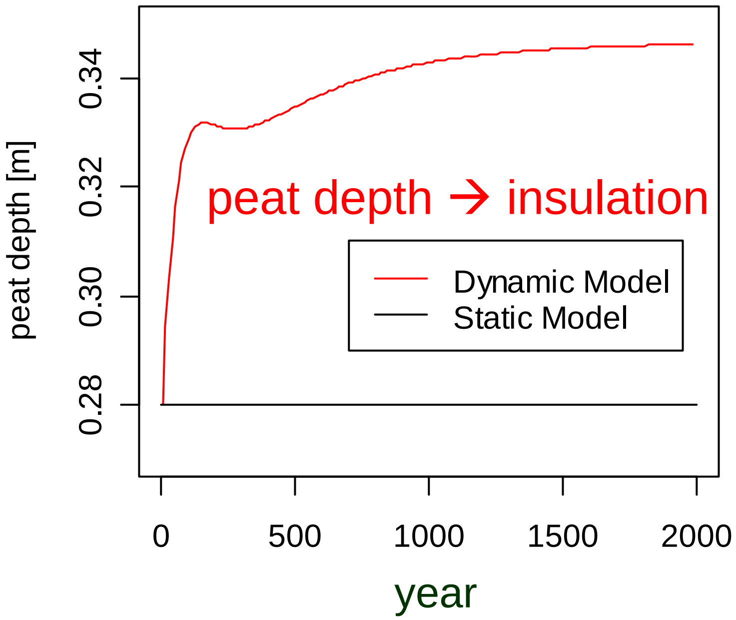
Results


positive feedback
negative feedback
Dynamic Model
Static Model
soil organic carbon [kgC m^{-2}]
22
24
26
28
0
500
1000
1500
2000
year
29.0
28.7
28.4
1000
1020
1040
Dynamic Model
Static Model

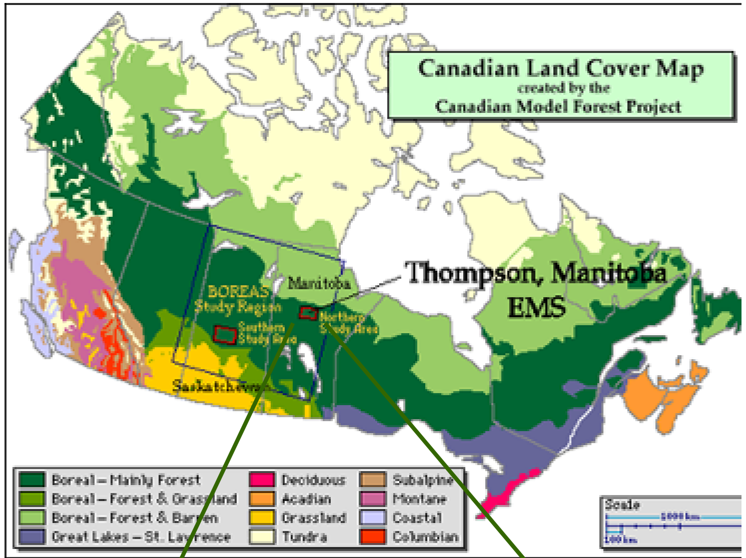
Results


positive feedback
negative feedback
Dynamic Model
Static Model

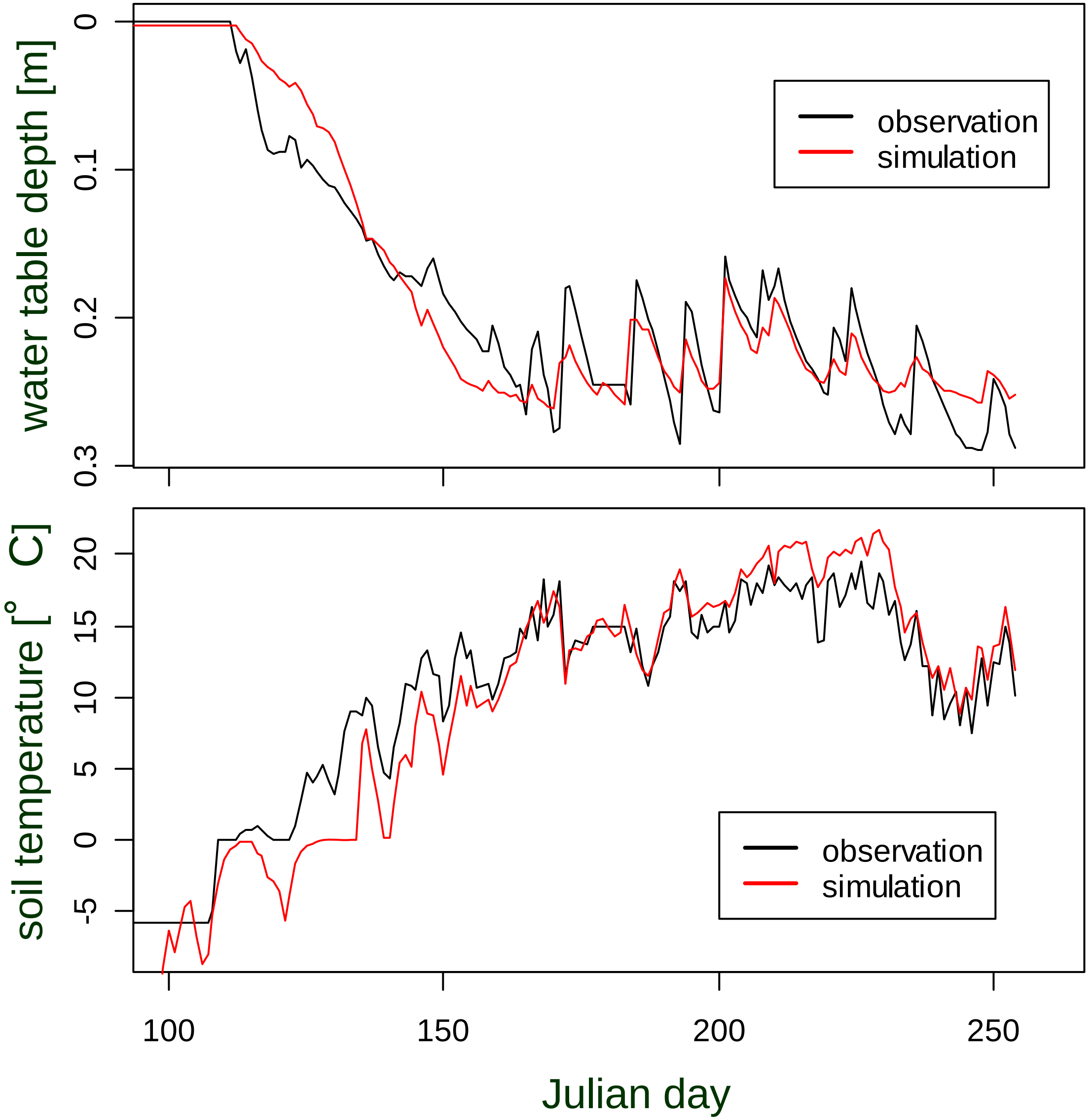

hydrology
fraction below water table
0.365
0.370
0.375
0.380
0.385
Dynamic Model
Static Model
0
500
1000
1500
2000
year


peat depth [m]
0.28
0.30
0.32
0.34
peat depth → insulation
Dynamic Model
Static Model
0
500
1000
1500
2000
year

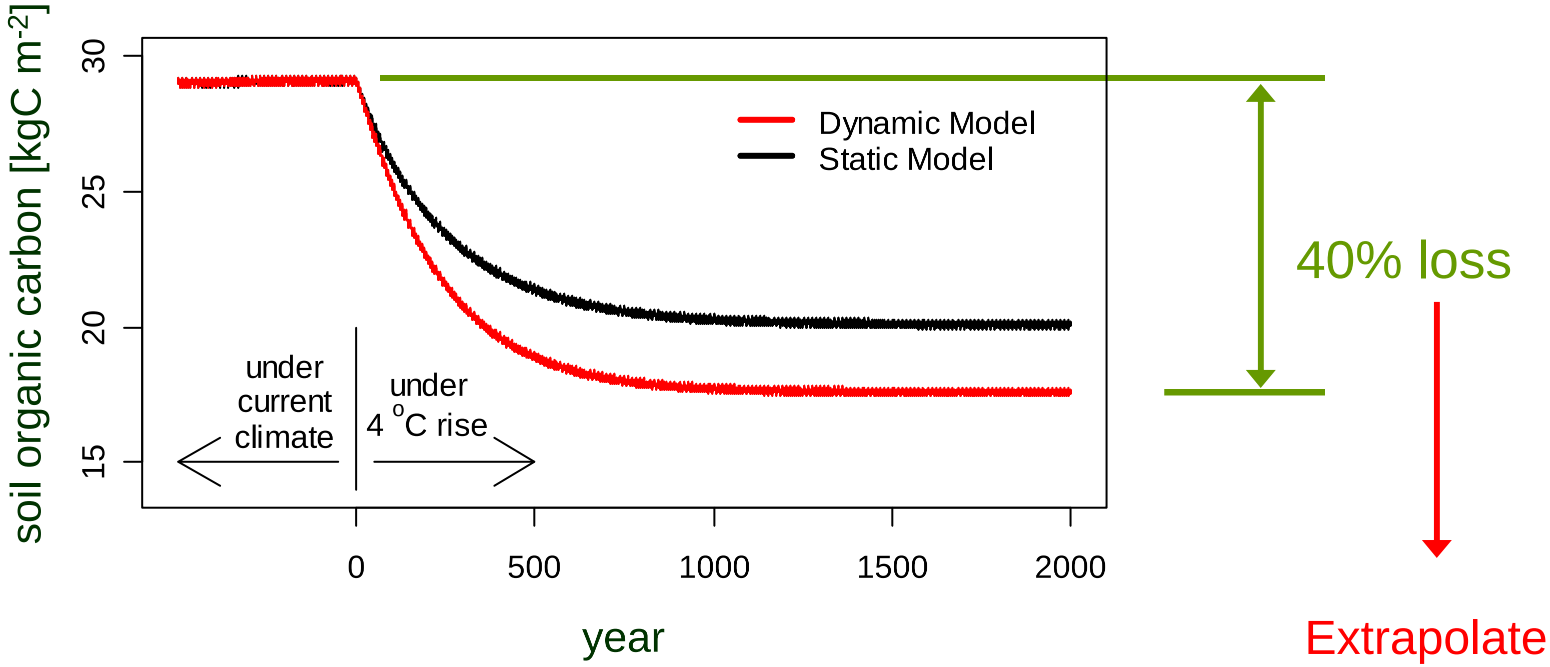
Results



Comparison: BOREAS NOBS, 2003
(Dunn, Barford, Wofsy, Goulden, & Daube 2007)



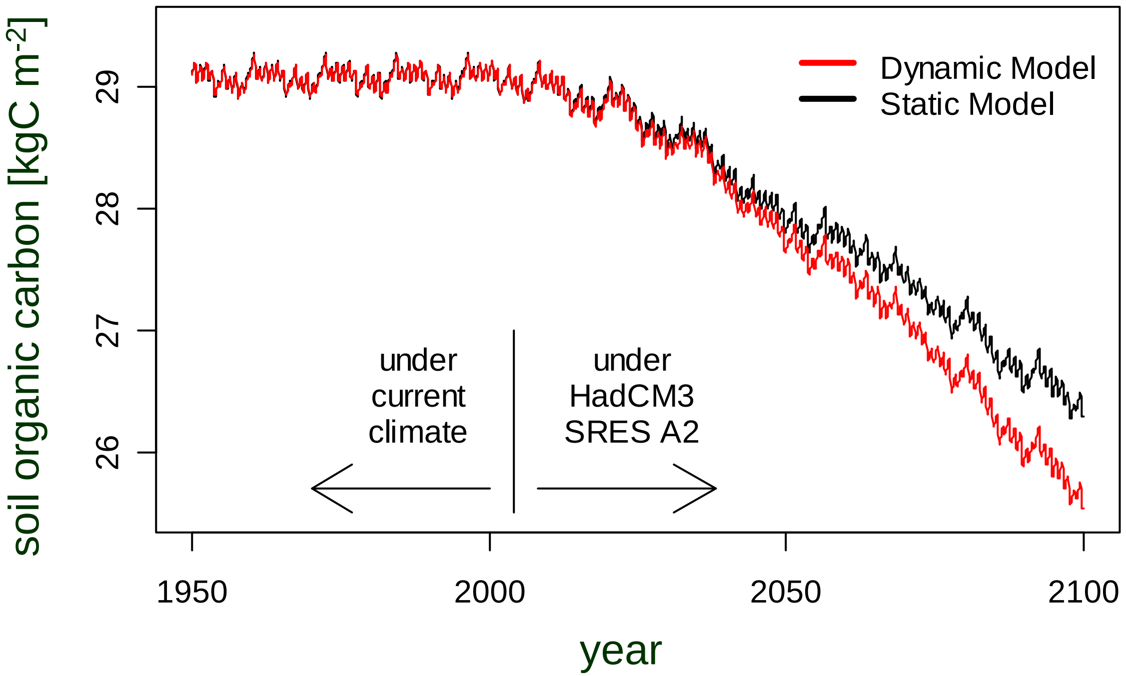
Climate change: equilibrium



Extrapolate over northern peatlands,

72-182 PgC
34-87 ppm

Climate change: transient



~10% loss

Extrapolate over northern peatlands,

18-46 PgC
9-22 ppm

HadCM3 SRES A2 at 2099
+ 4.3 ° C
+ 42.1 mm

Summary:
continental bog

- Both positive and negative feedback processes are important determinants of peatland dynamics

- Effects of climate change and on climate change will be more pronounced than previously thought

Acknowledgements

- Advisors
  - Paul R. Moorcroft
  - David R. Foster
  - James J. McCarthy
  - Steven C. Wofsy
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