Carbon Sinks in North America Forests

Jing M. Chen
University of Toronto

Main Contributors:
Min Zhang, Oliver Sonnentag, Ajit Govind, Feng Deng, Gang Mo, Liming He,
Peter Czurylowicz, Michael Sprintsin, Beiping Zhang, Ray Nassar***, University of Toronto***
Kaz Higuchi, Douglas Chan, Doug Worthy, & Lin Huang, ***Environment Canada***
Yude Pan, Rich Birdsey, Kevin McCullough, ***USDA Forest Service***
Werner Kurz, Graham Stinson, & David Price, ***Canadian Forest Service***
Andy Black, Brian Amiro, Alan Barr, Harry McCaughey, Hank Margolis,
Nigel Roulet, Carole Coursolle, Robert Grant, Altaf Arain, *etc.*, ***Canadian Carbon Program***
Wouter Peters, Pieter Tans, ***ESRL, NOAA***
Maartin Krol, ***Wageningen Research University***

University of Toronto

2nd Canadian SMAP Workshop
16-17 November, 2010, Montreal

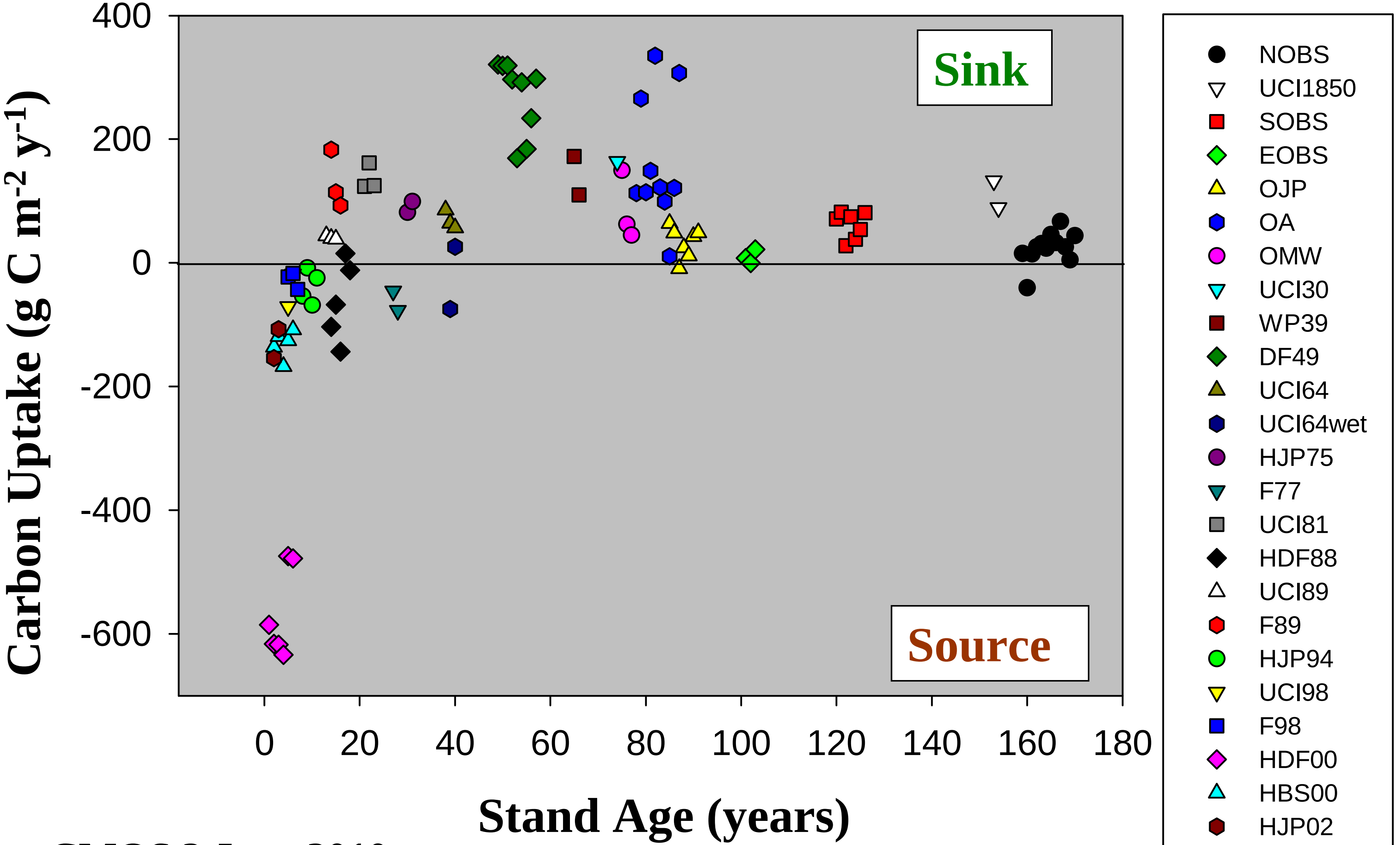
CANADIAN CARBON PROGRAM PROGRAMME CANADIEN DU CARBONE

Outline

- Introduction to recent estimates of carbon sinks in North America forests as part of CCP
- Coupling between water and carbon cycles

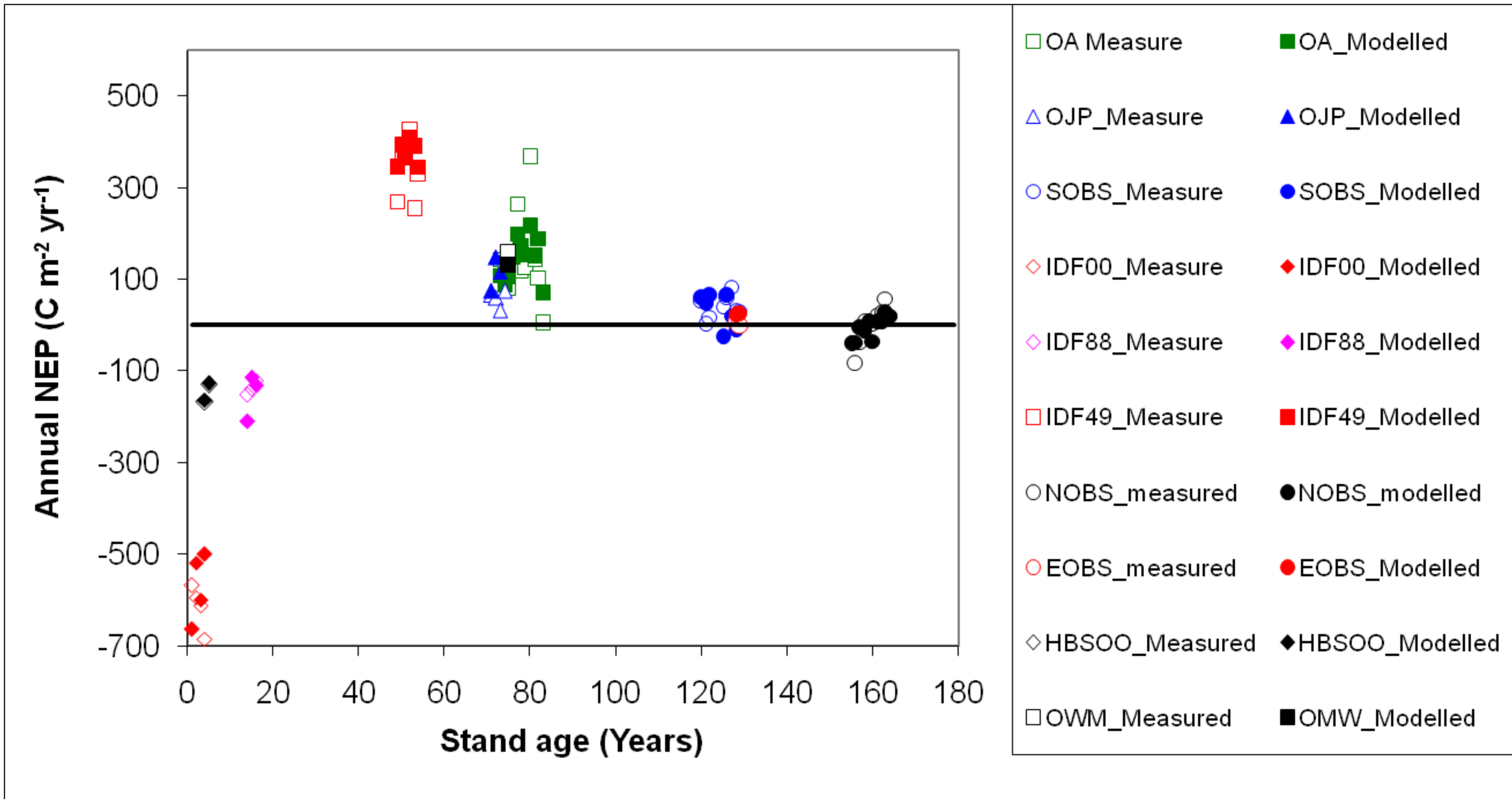
CCP Synthesis: Forest Age and Carbon Uptake

(courtesy: Carole Coursolle & Hank Margolis)



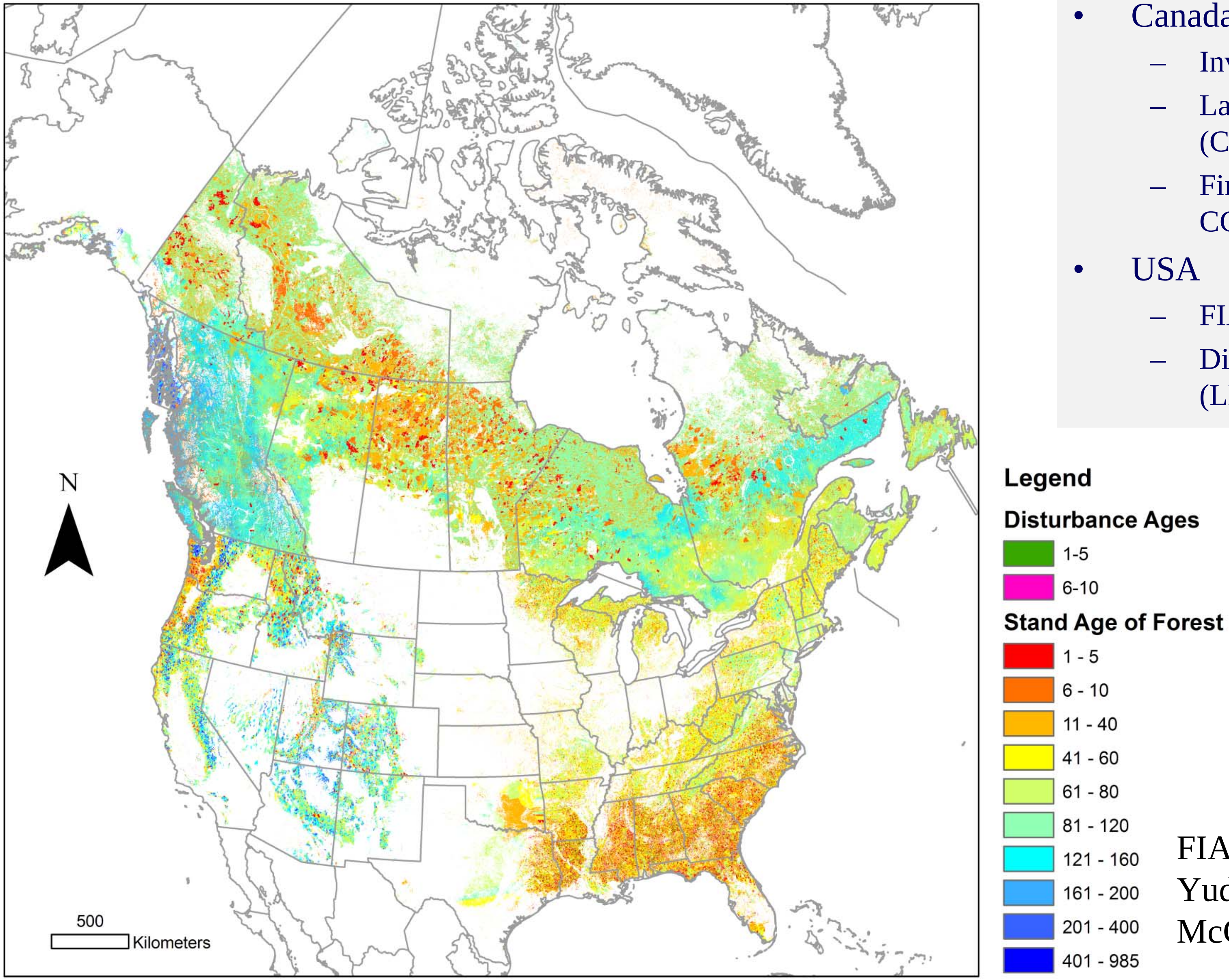
CMOS 2 June 2010

Measured and Modeled NEP at CCP Tower Sites Against Forest Stand Age



Data sources: Andy Black, Harry McCaughey, Paul Jarvis, Alan Barr, Brian Amiro, Hank Margolis
InTEC model: Chen et al. (2000, *GBC*); Chen et al. (2003, *Tellus*); Ju et al. (2006, *Tellus*)

North America Forest Stand Age Distribution in 2000
(Version 2)

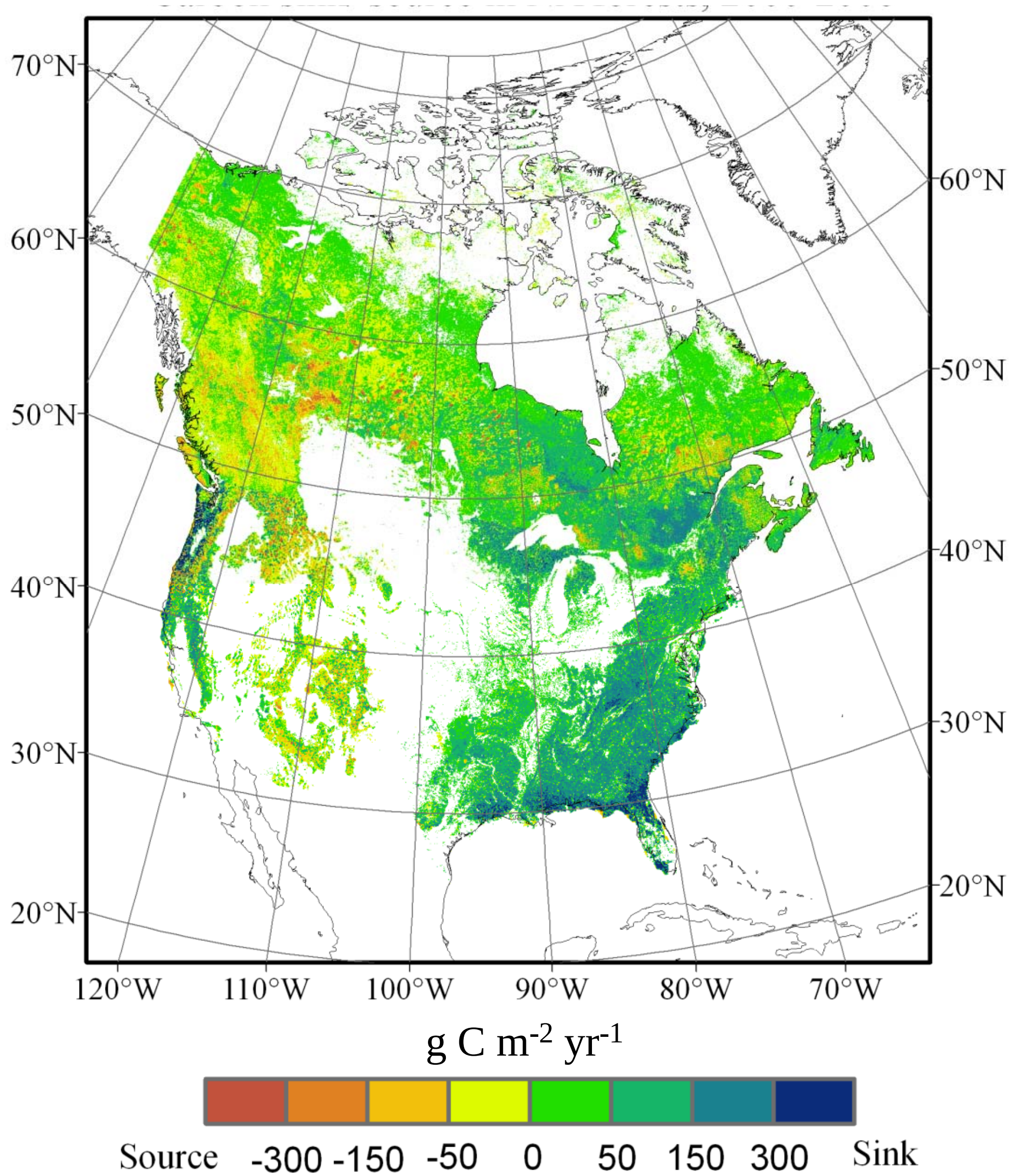


- Canada:
  - Inventory (CFS)
  - Large Fire Polygons (CFS)
  - Fire Scars (U of T, CCRS)
- USA
  - FIA (USDA)
  - Disturbance (LEDAPS, NASA)

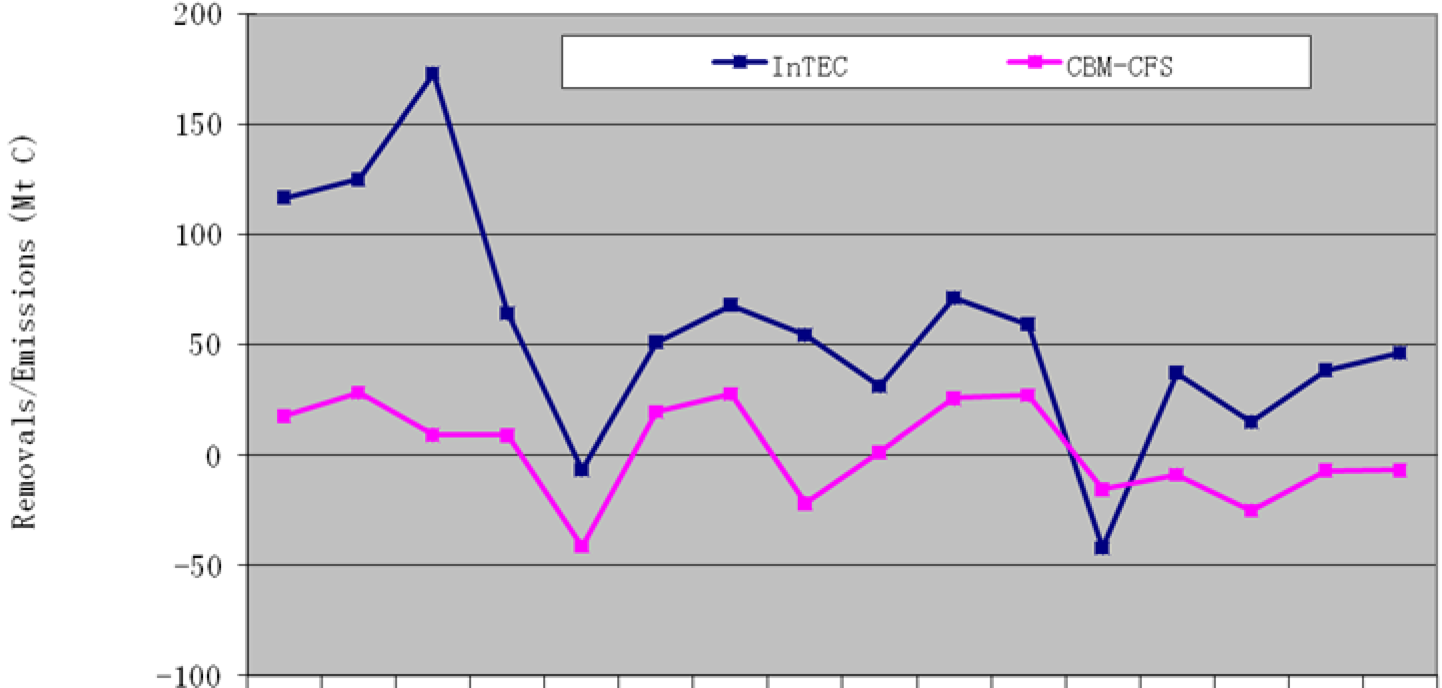
FIA data: Rich Birdsey, Yude Pan, Kevin McCullough

Carbon Sink and Source Distribution in North America Forests

Resolution: 1 km; Model: InTEC; 2000-2006

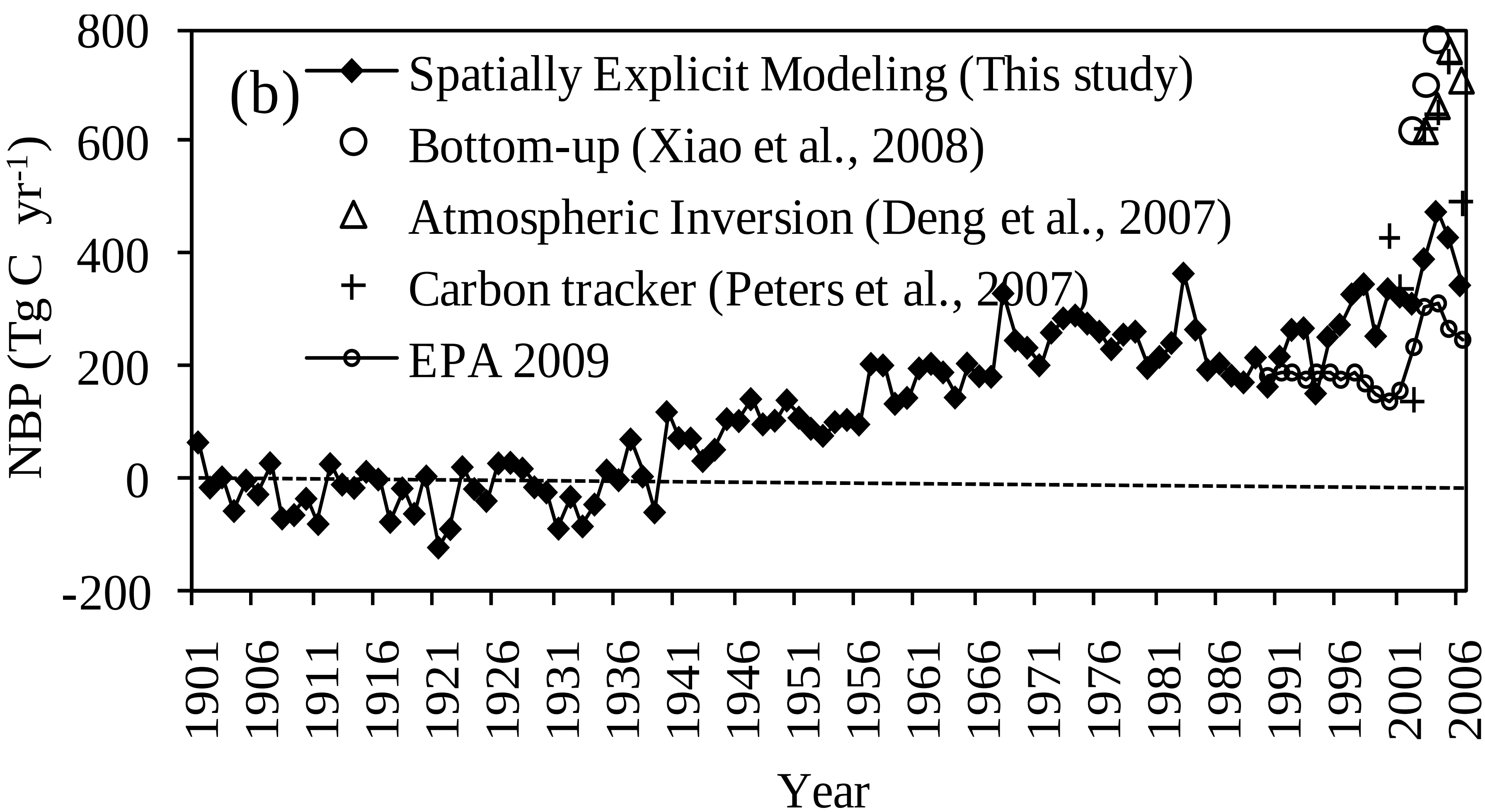


Comparison of Carbon Sinks/Sources in Canada's Managed Forest between InTEC and CBM-CFS3



	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
InTEC	116.9	125.1	173	64.4	-6.5	51.2	68.1	54.4	31.2	71.3	59.3	-42	37.3	14.9	38.4	46.4
CBM-CFS	17.6	28.2	9.3	8.9	-41.2	19.5	27.6	-21.8	1.4	25.7	27	-15.4	-8.7	-25	-6.8	-6.7

Comparison of InTEC Model Results with Existing Estimates of Carbon Sinks in Conterminous US Forests



Coupling of Water and Carbon Cycles at Landscape and Regional Levels

Jing M. Chen
Department of Geography
University of Toronto

Contributions from three Ph.D. theses by
Weimin Ju, Ajit Govind, Oliver Sonnentag

University of Toronto

CANADIAN CARBON PROGRAM PROGRAMME CANADIEN DU CARBONE

Coupling of Water and Carbon Cycles at Different Levels

- Leaf level

  Stomatal conductance to water is linearly related to the photosynthesis rate (Ball, 1988)

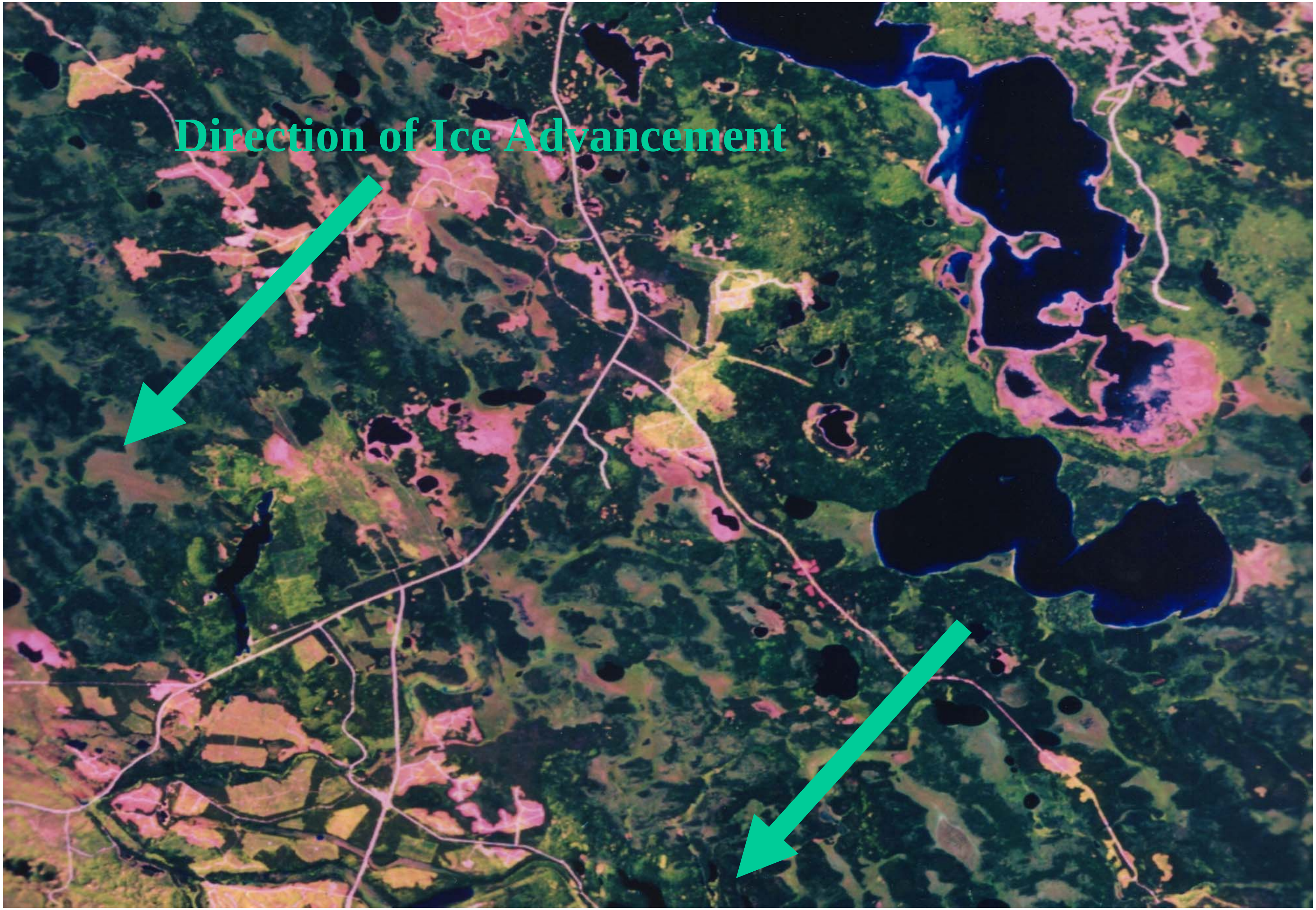
- Canopy level

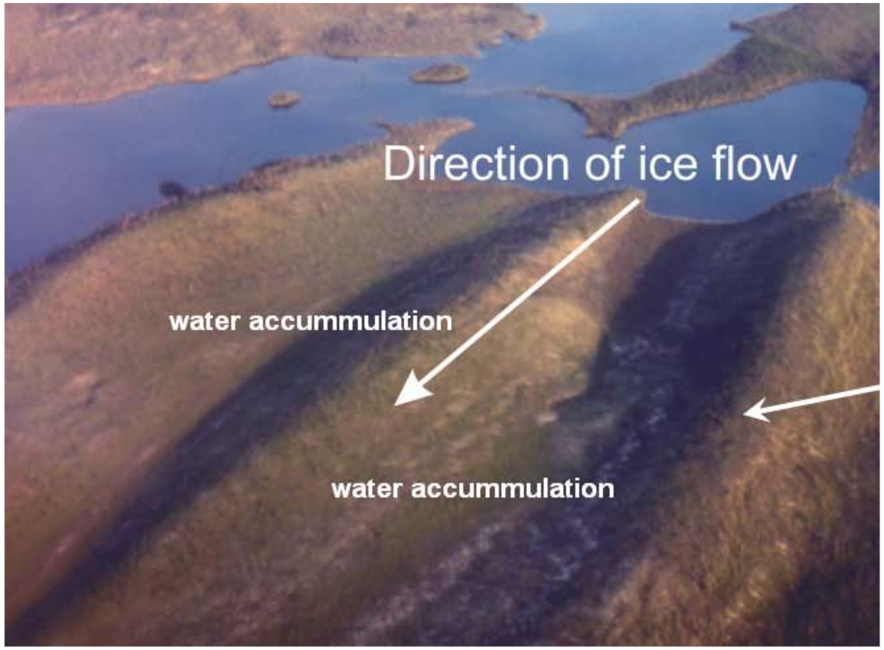
  Big-leaf models are being replaced by two-leaf or multi-layer models (Leuning et al., 1995; De Pury and Farqhuar 1997; Wang and Leuning, 1997; Chen et al., 1999); and two-leaf ET models have also been developed for tight coupling between water and carbon cycles (Liu et al., 2003; Ju et al., 2006; Govind et al., 2009; Chen, 2010)

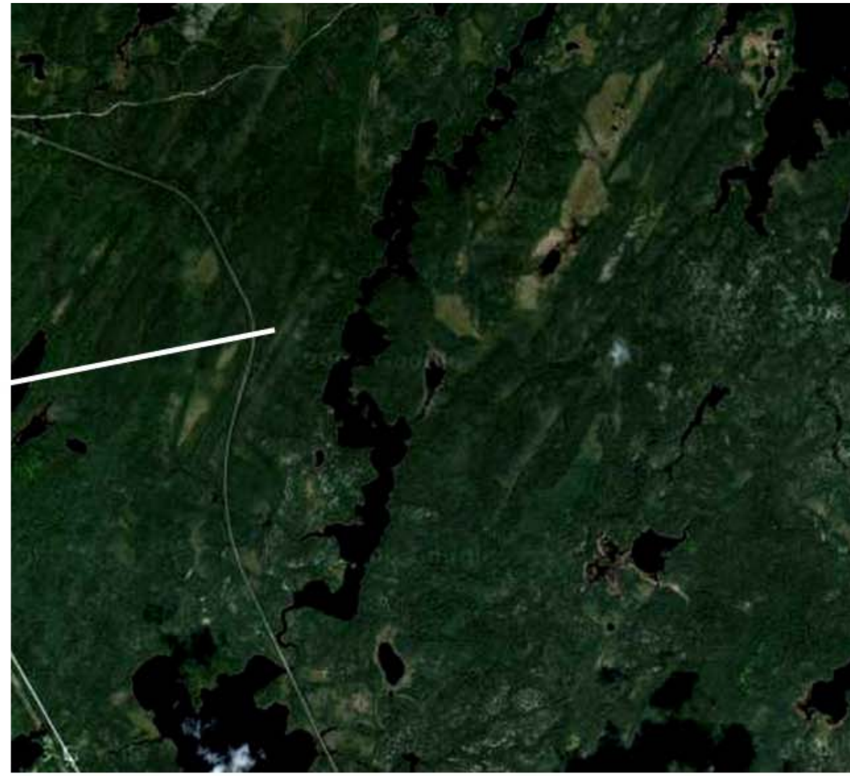
- **Landscape level**
- **Regional level**
- Global Level

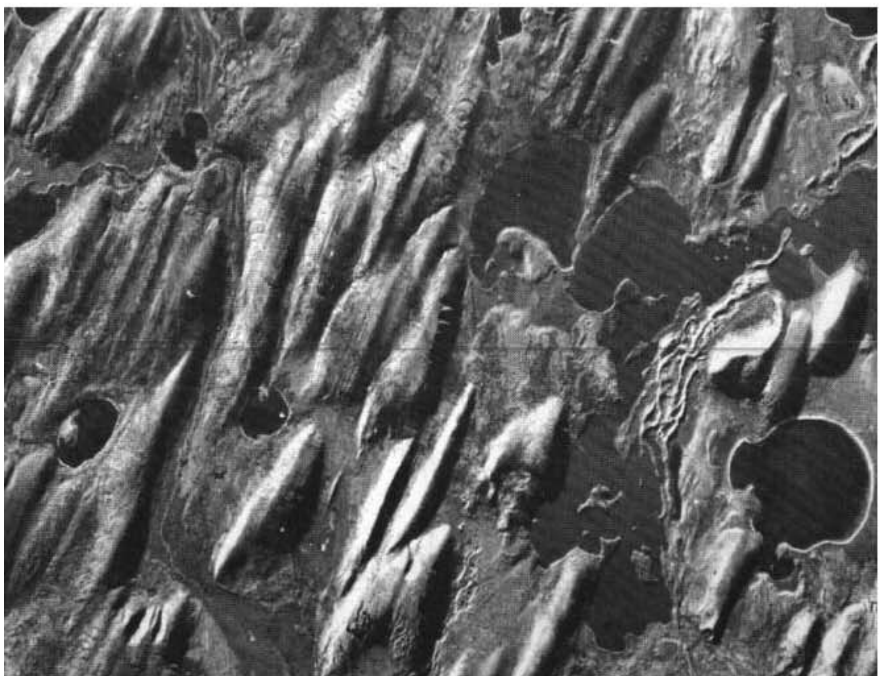
Typical Boreal Landscape

(Ground moraines, southern Saskatchewan)





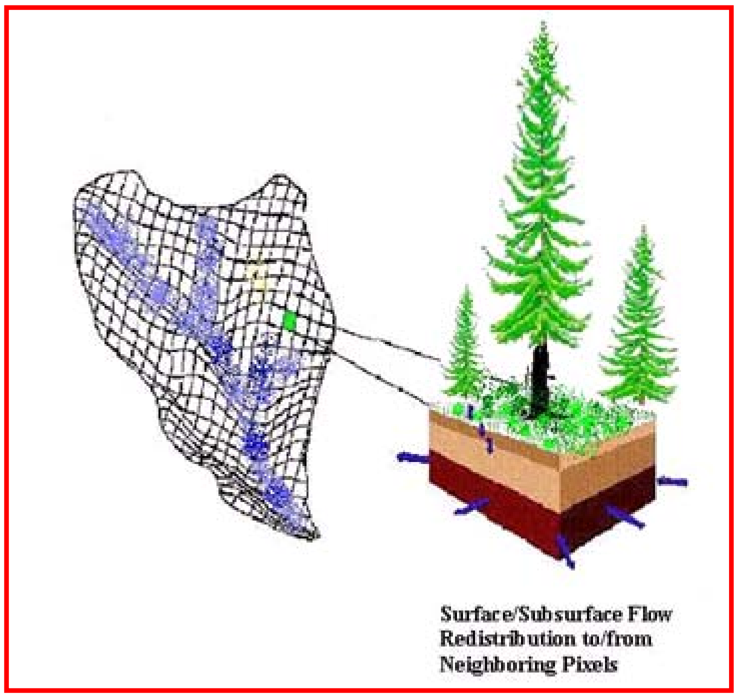




Typical Boreal Landscape

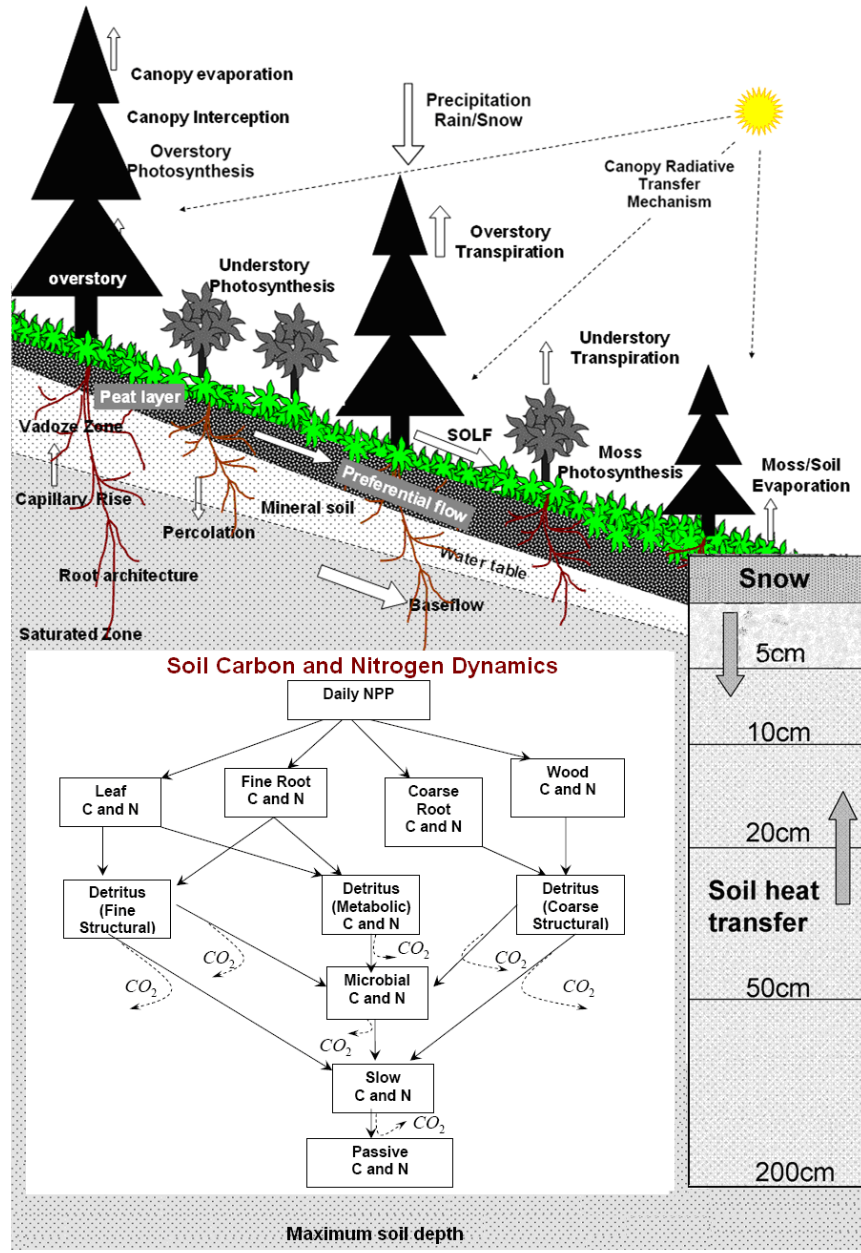
(Drumlins, Northern Quebec)

Hydro-ecological Model
(daily time steps)



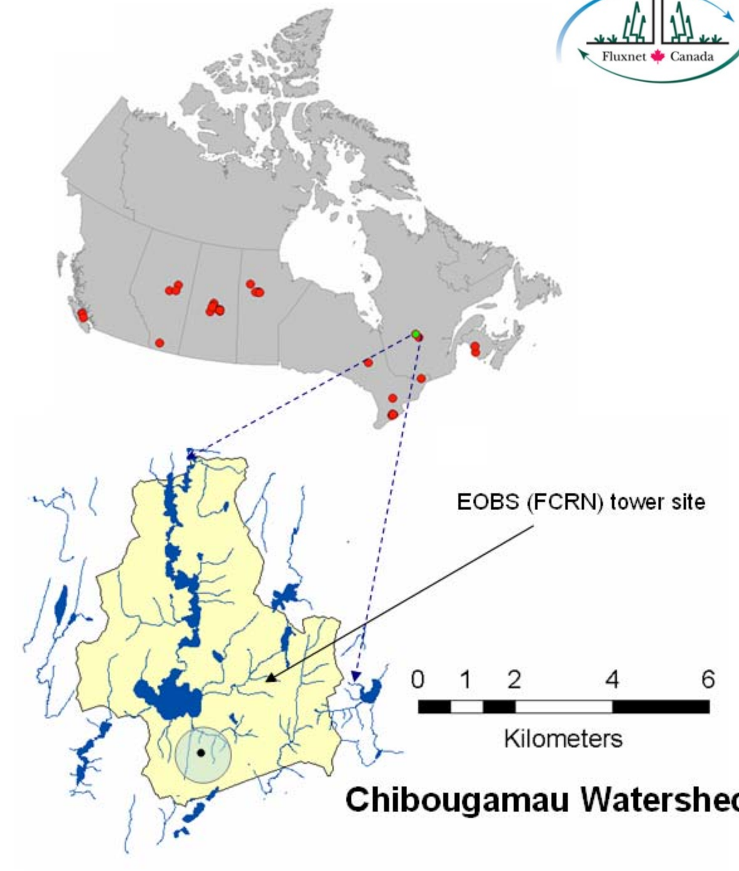
BEPS: Chen et al., (1999, *EM*)
TerrainLab: Chen et al., (2005, *JH*)
(Based on Wigmosta et al. (1994, *WRR*)

BEPS-TerrainLab V2.0



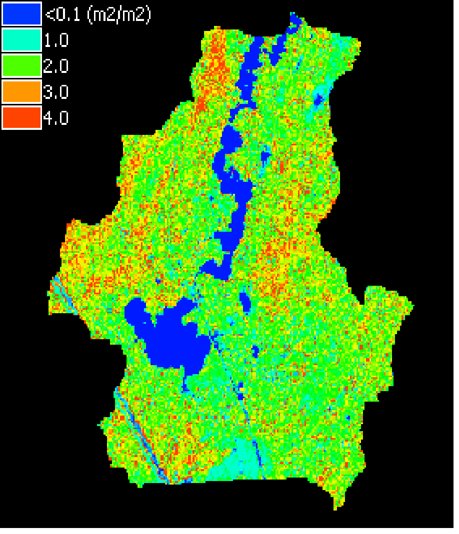
Forested Watershed

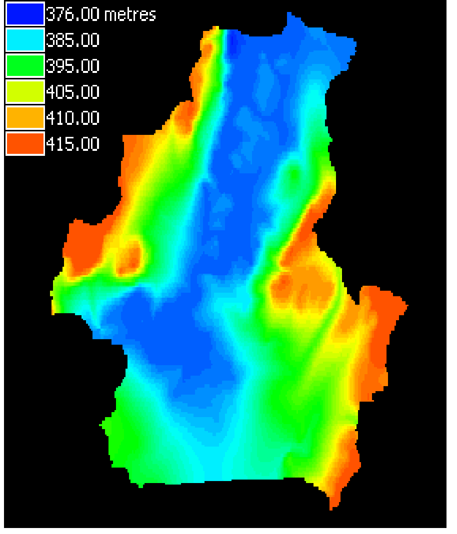
Fluxnet and the Canadian Carbon Program (*Fluxnet-Canada*)

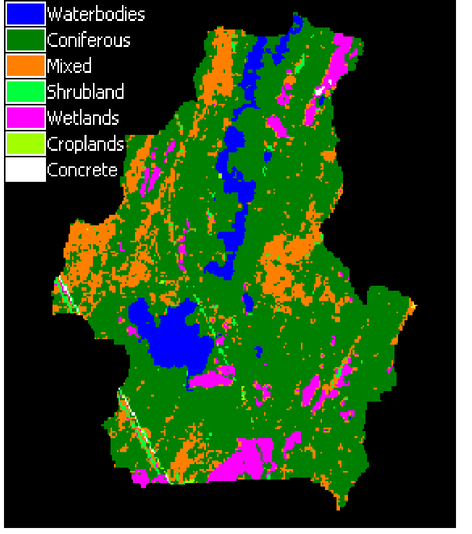


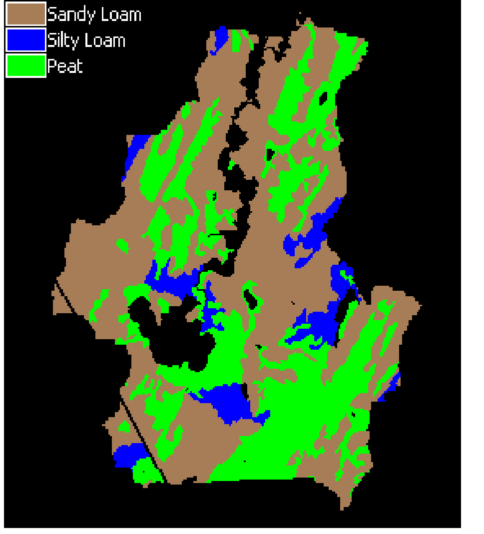
Study site:

Eastern Old Black Spruce Site (EOBS)
49.69247° N / 74.34204° W
Mean Annual Temp. 0°C.
Precip. 960 mm
(Site PI: Hank Margolis, U. Laval)





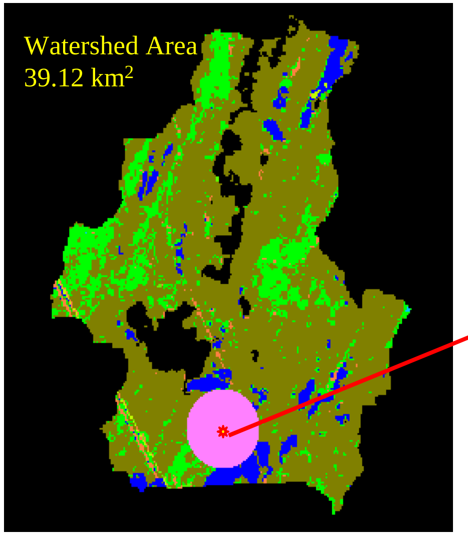




Leaf Area Index ***DEM*** ***Land cover*** ***Soil Texture***

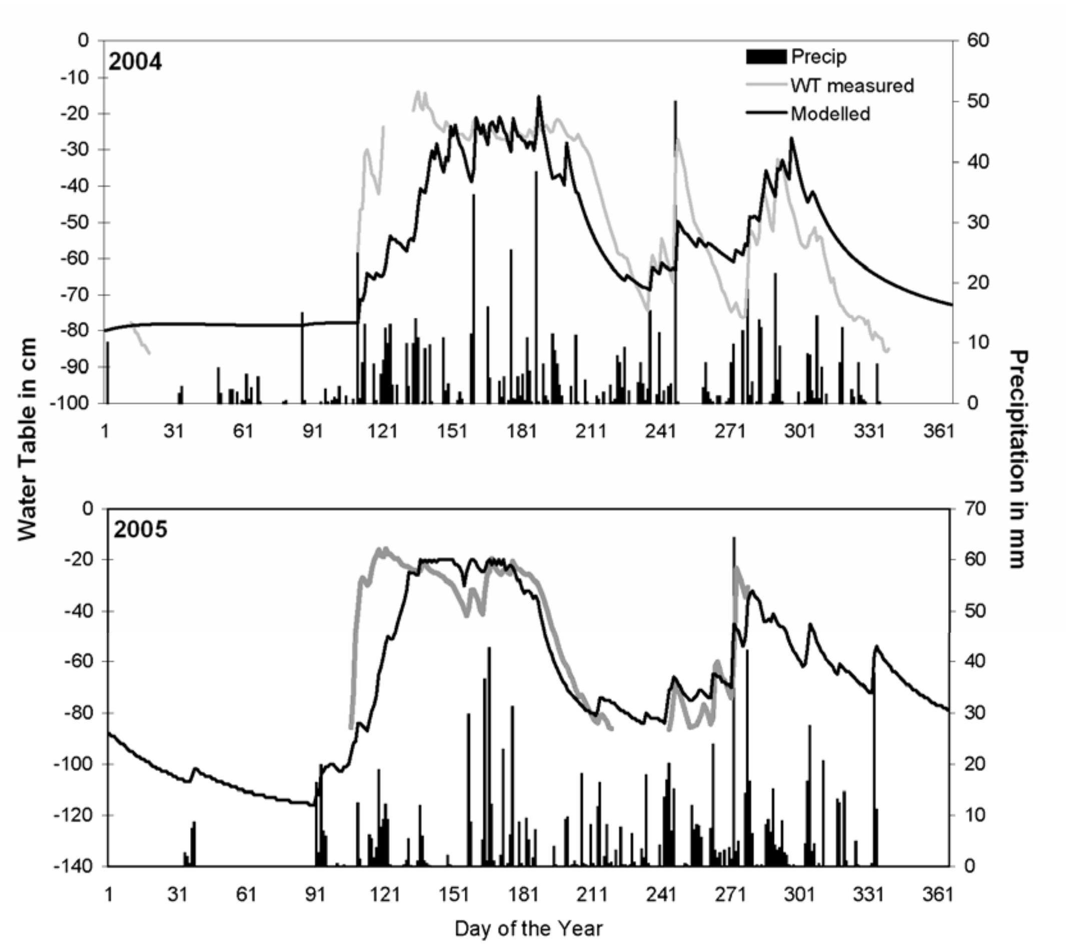
Input data for the *BEPS-TerrainLab V2.0* model (daily time step)

Tower Footprint

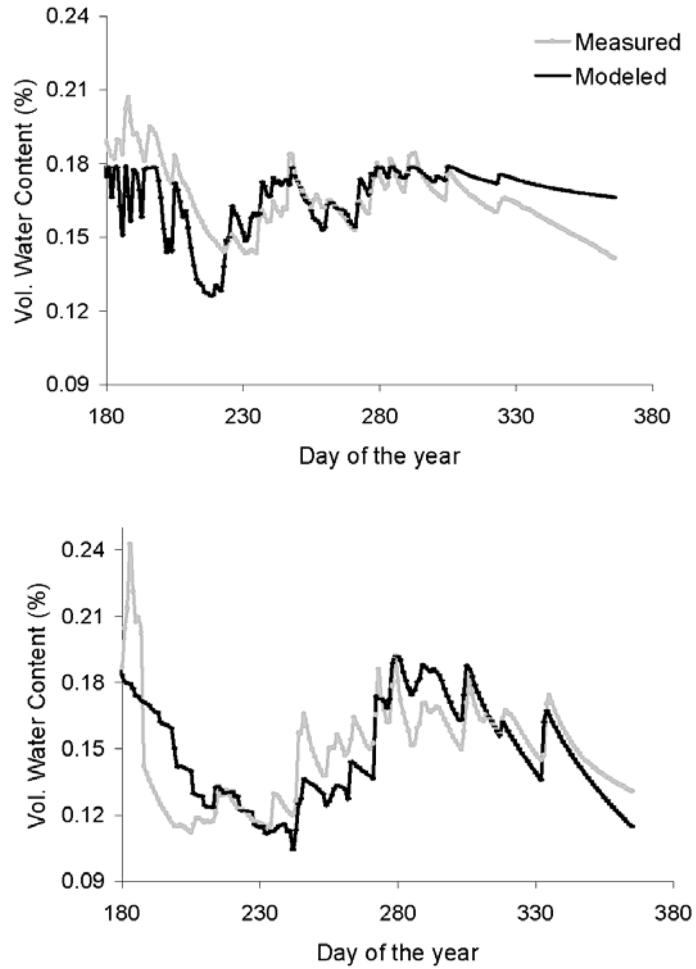


Validation of Simulated Hydrological Variables at the EOBS site

Water Table

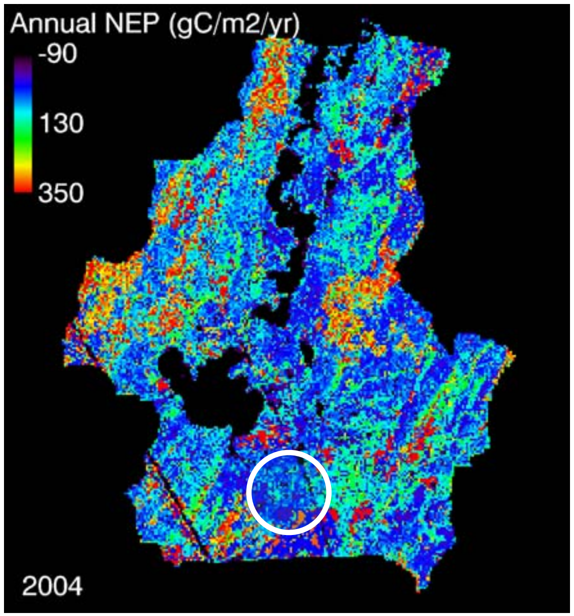


Volumetric Water Content



Govind *et al.*, (a, submitted to *JH*)

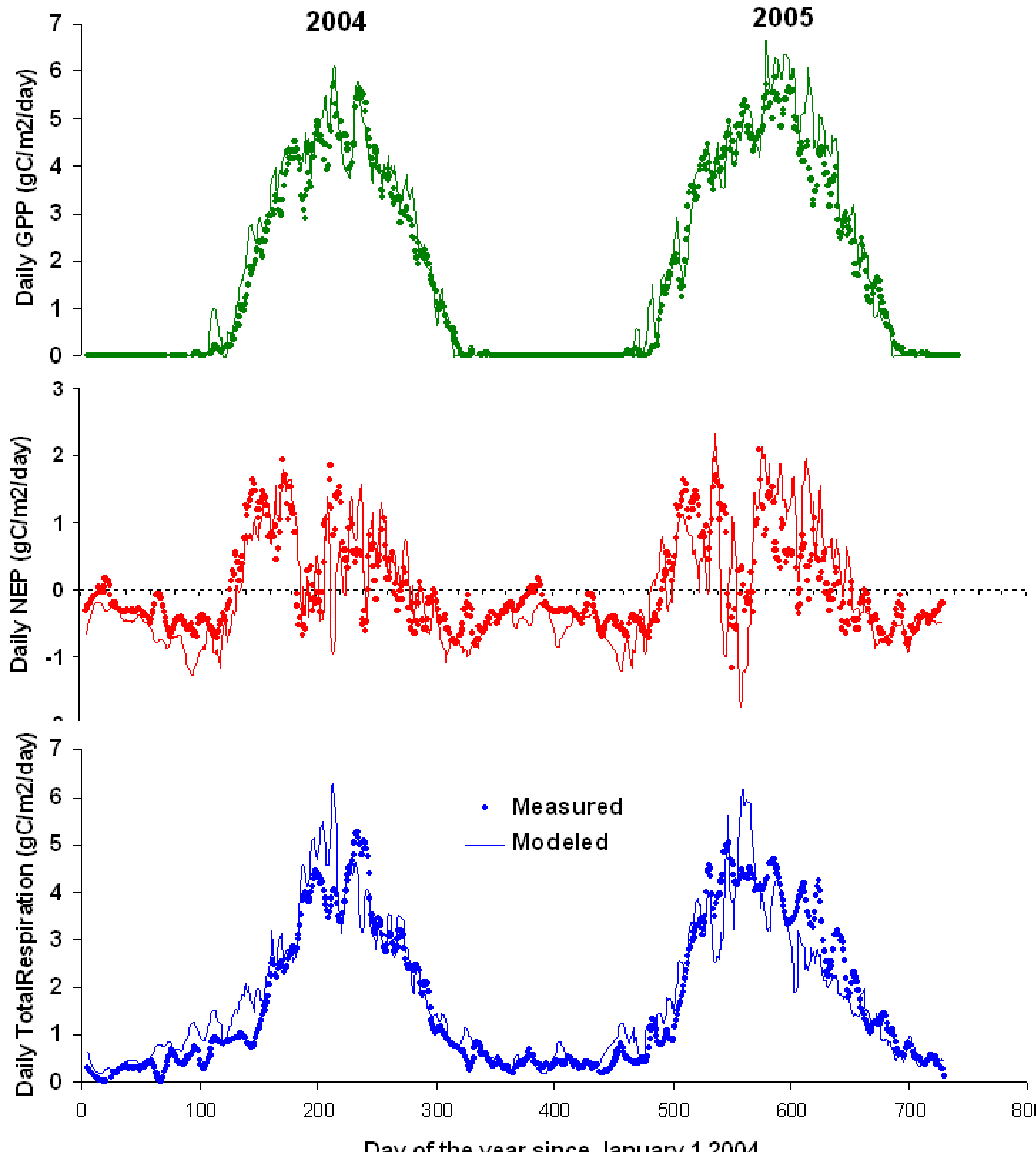
Carbon Cycle Components at the EOBS Tower Site



GPP

NEP

Ecosystem Respiration

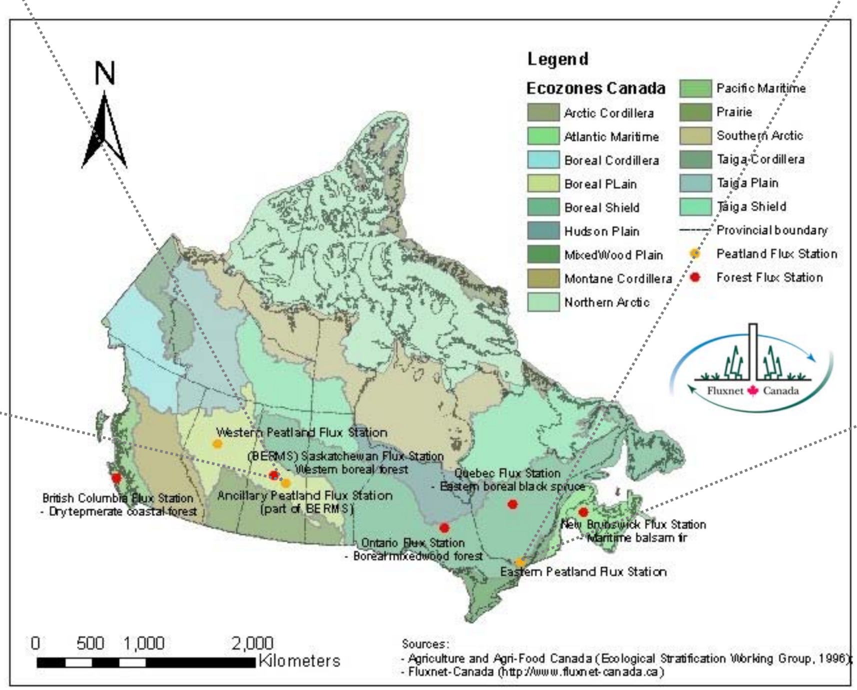


Peatlands

Two Extreme Northern Peatlands

Sandhill fen

Moderately nutrient-rich minerotrophic peatland within the Boreal Plain ecoregion

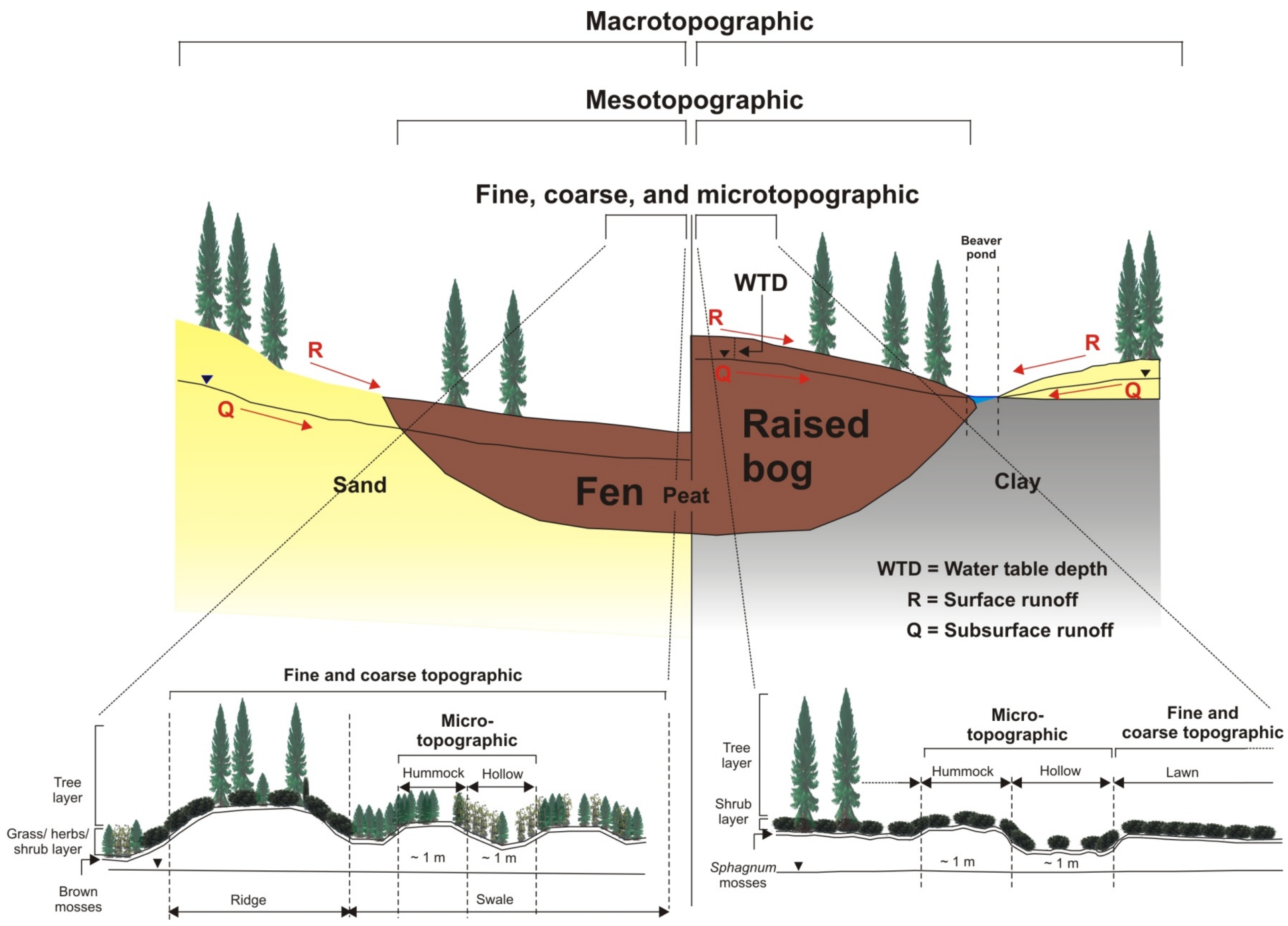


Mer Bleue bog

Raised ombrotrophic peatland located within the Mixed-wood Plain ecoregion

(http://www.fluxnet.ornl.gov/fluxnet/index.cfm)

Topographic Scales of Northern Peatlands

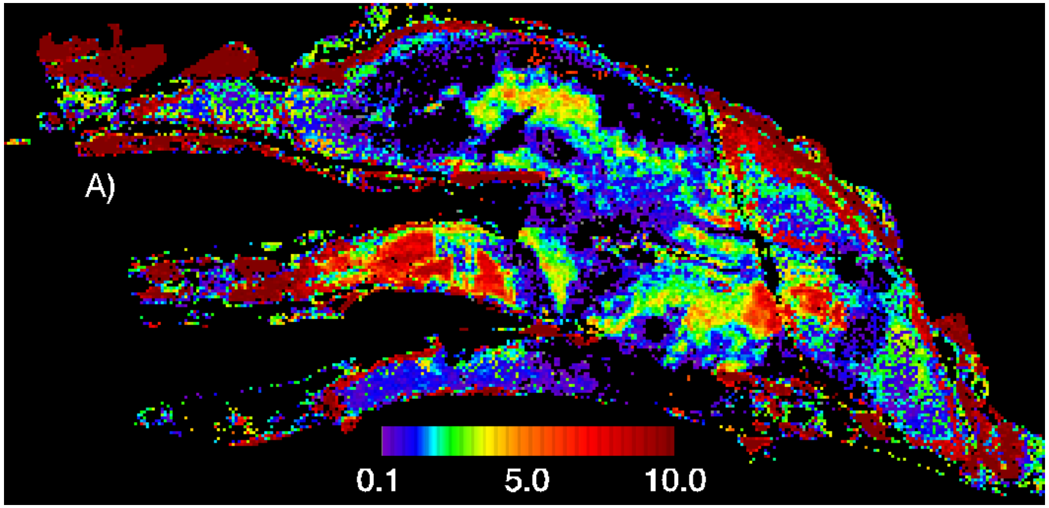


(not drawn to scale)

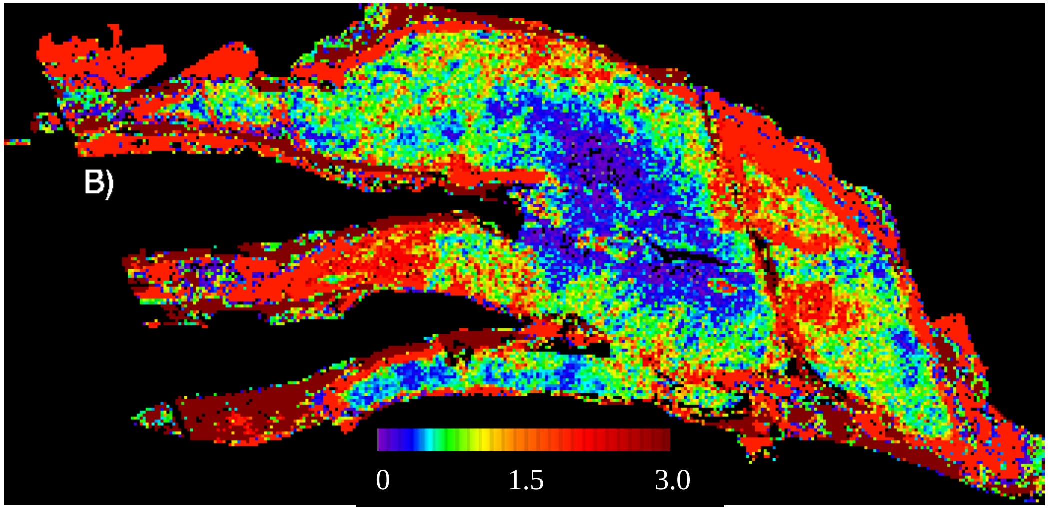
Mapping LAI Based on Remote Sensing of Canopy Shadow Fractions

(Mer Bleue bog [45.4N, 75.5W], 28 km^2, Ontario, 2004)

tree LAI



shrub LAI



Sonnentag, *et al.*, (2007, *AFM*) and (2007, *RSE*)

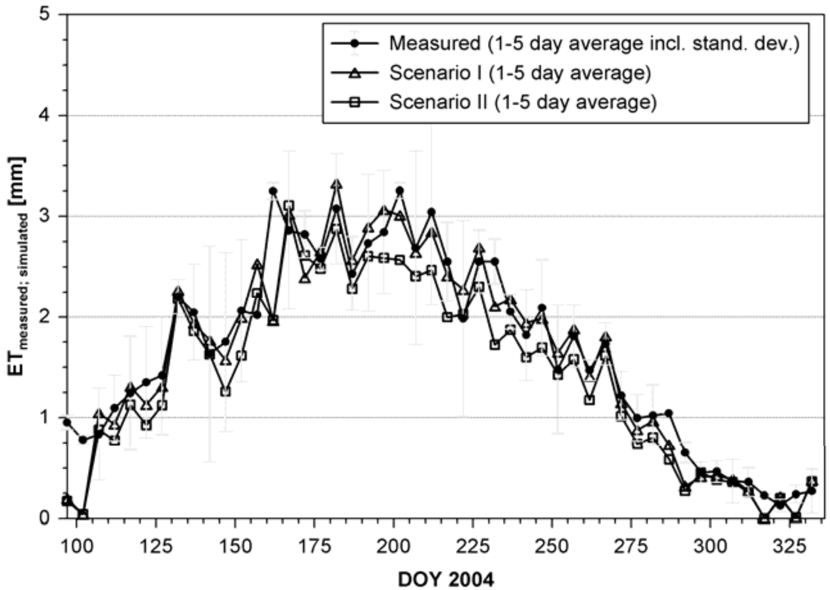
Scenarios

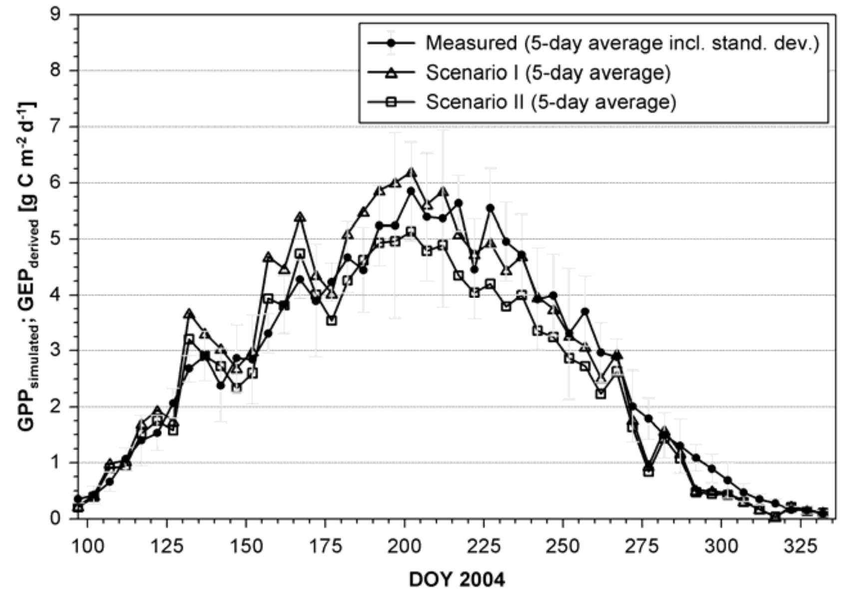
Scenario I: topographically-driven lateral subsurface flow

Scenario II: **no** topographically-driven lateral subsurface flow

Validation of ET and GPP Simulations with Tower Data

(Mer Bleue bog [45.4N, 75.5W], tower footprint, 2004)

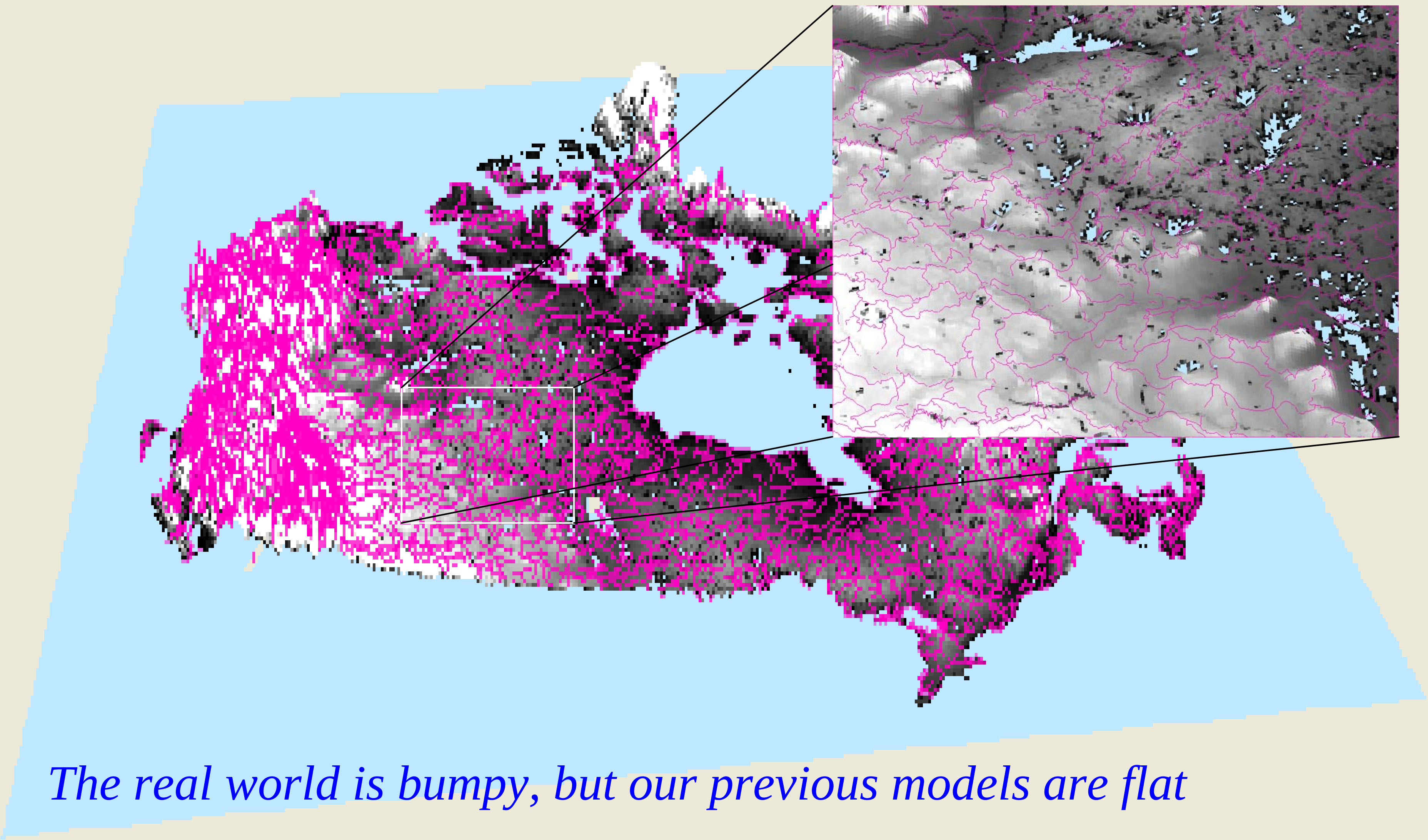




Canada-wide Coupled Water and Carbon Cycle Modeling

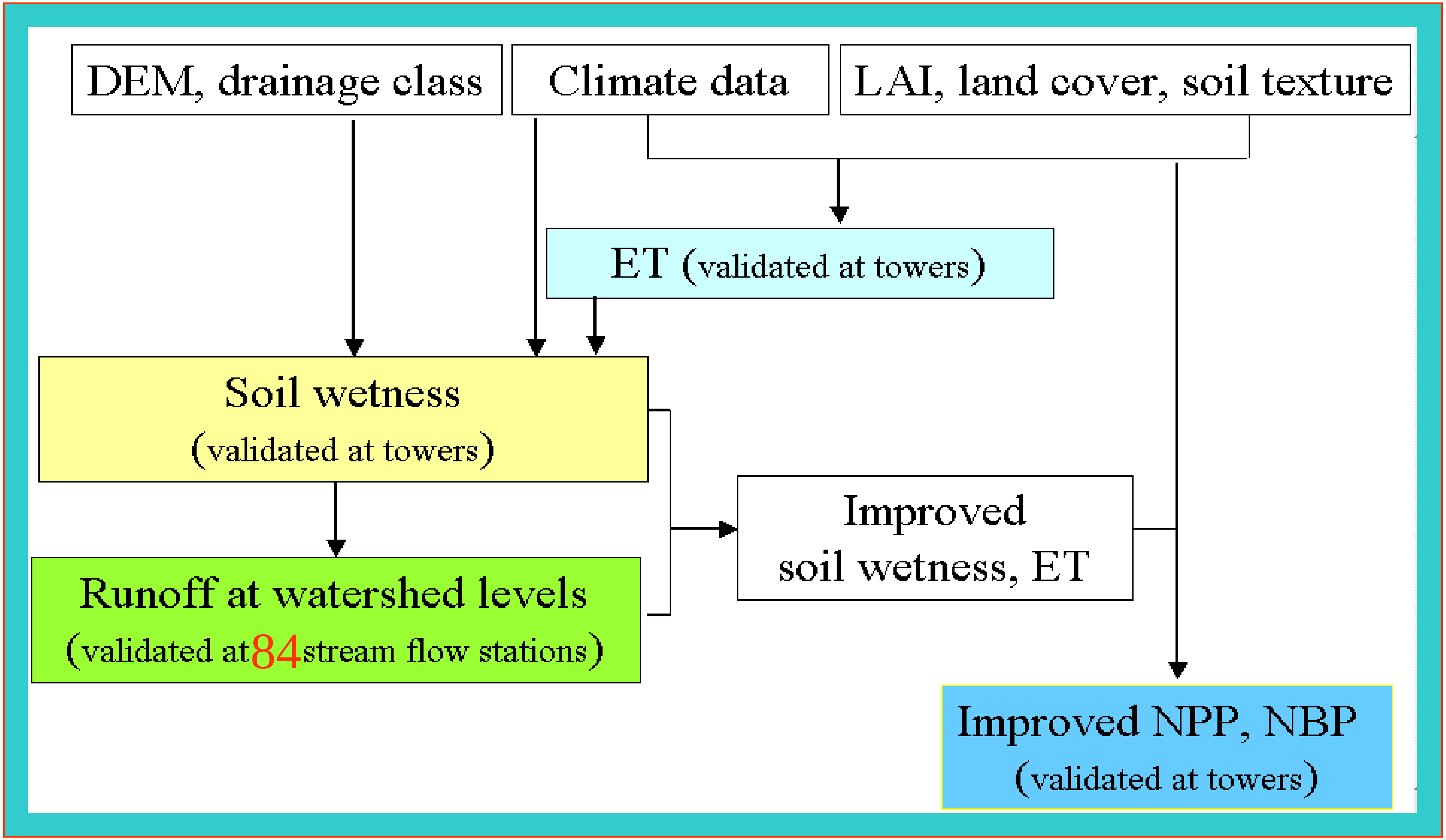
Topographical Landscape of Canada and Watershed Boundaries

(100 vertical height amplification, 2015 watersheds in total)

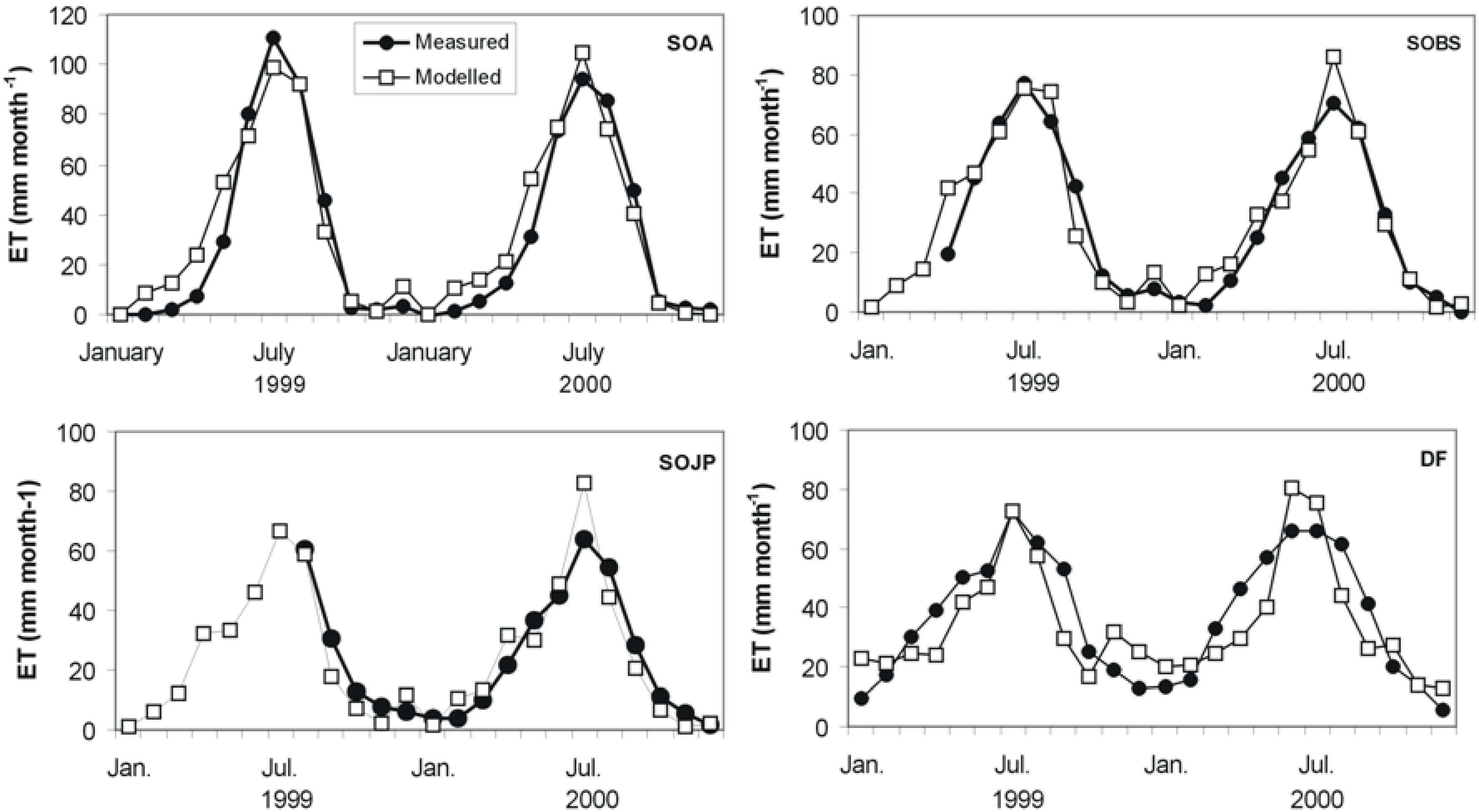


The real world is bumpy, but our previous models are flat

Scheme for Using Runoff Data for Improving Carbon Modeling

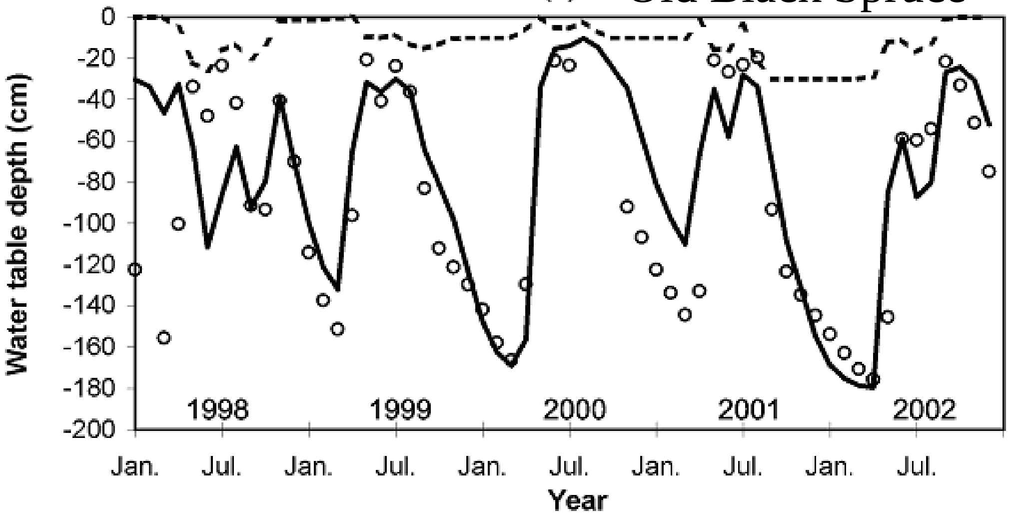


Validation of simulated monthly ET with eddy-covariance measurements

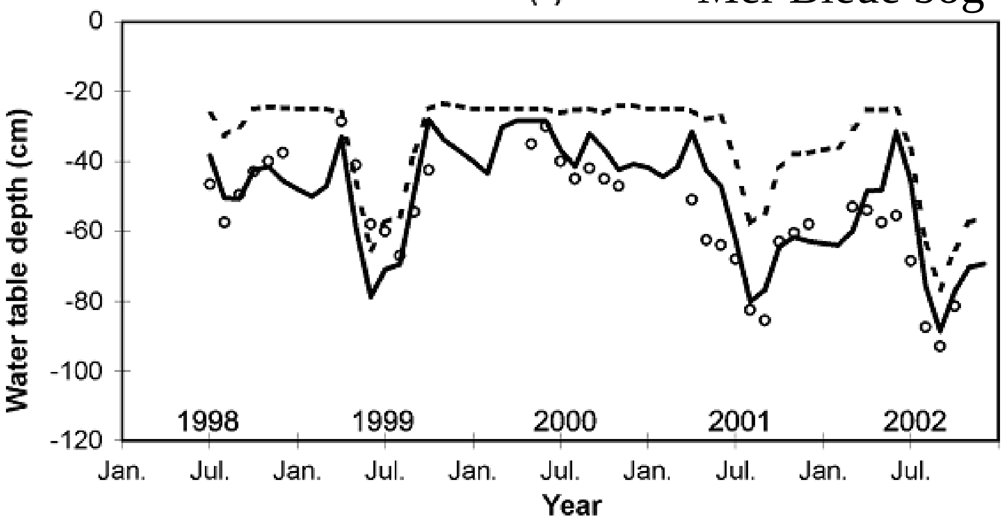


The effect of lateral base flow on water table simulation

(a) Old Black Spruce



(b) Mer Bleue bog



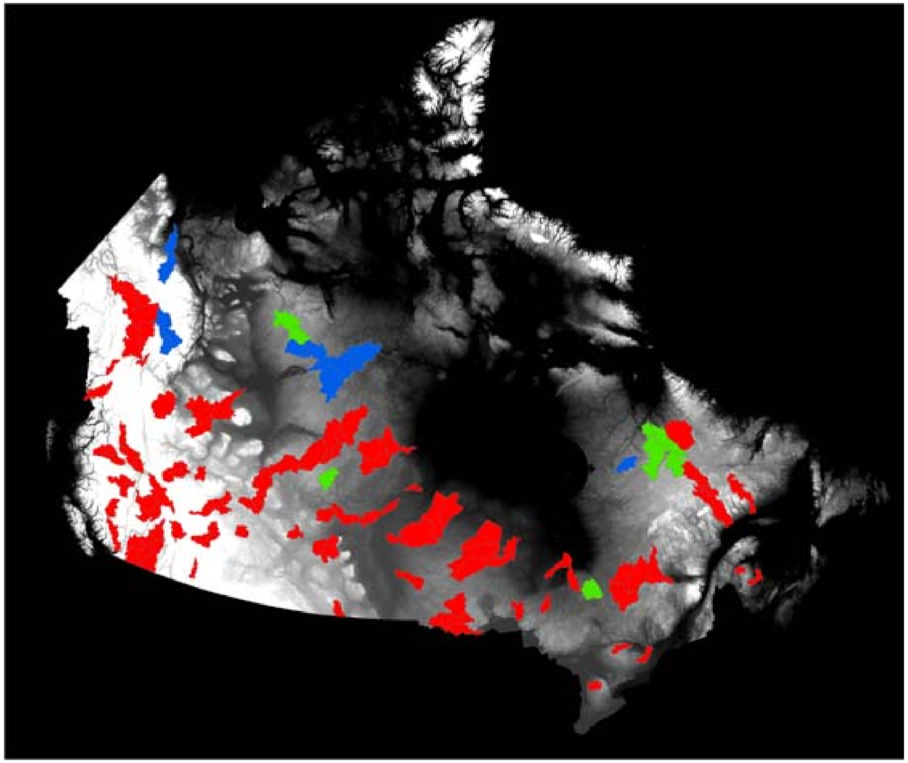
-- 1-d model

— Modeled with lateral base flow

o Measured

Data sources:
Andy Black and Nigel Roulet

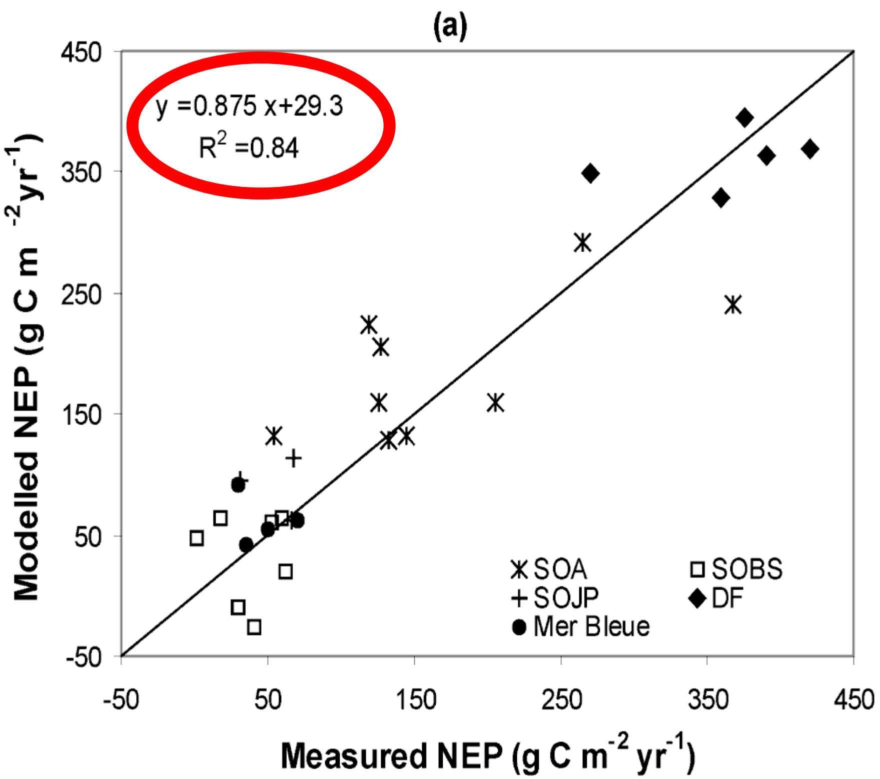
Water budget validation with streamflow data

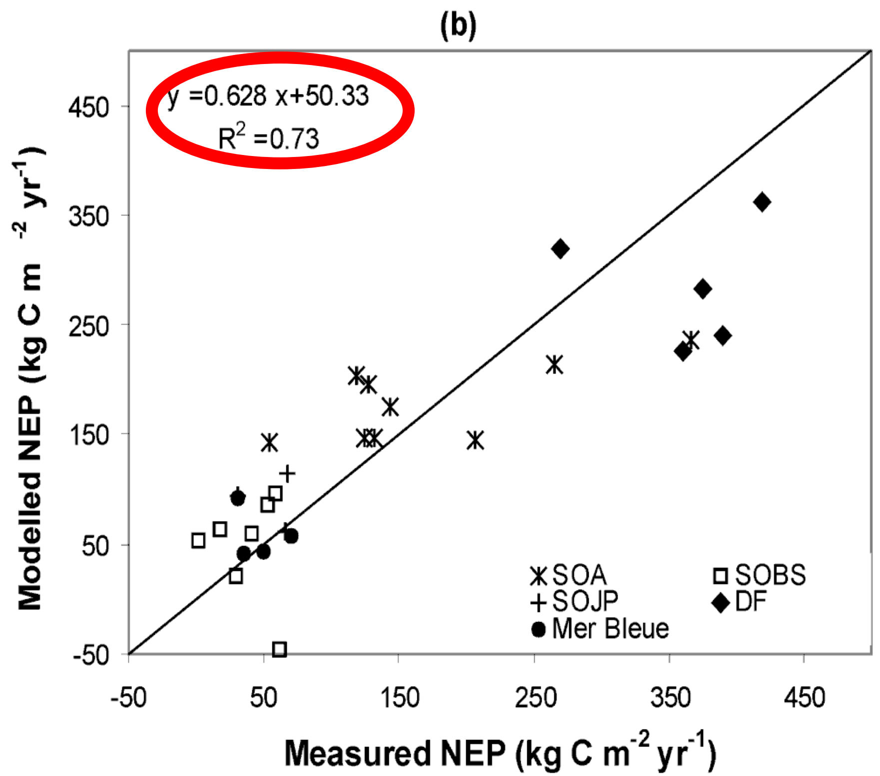


at 0.01 signifcance level
at 0.05 signifcance level
not significant

R^2	≥0.6	0.5~0.6	0.4~0.5	0.3~0.4	<0.3
Number of stream flow stations	13	22	17	18	14

Lateral subsurface flow and NEP simulations

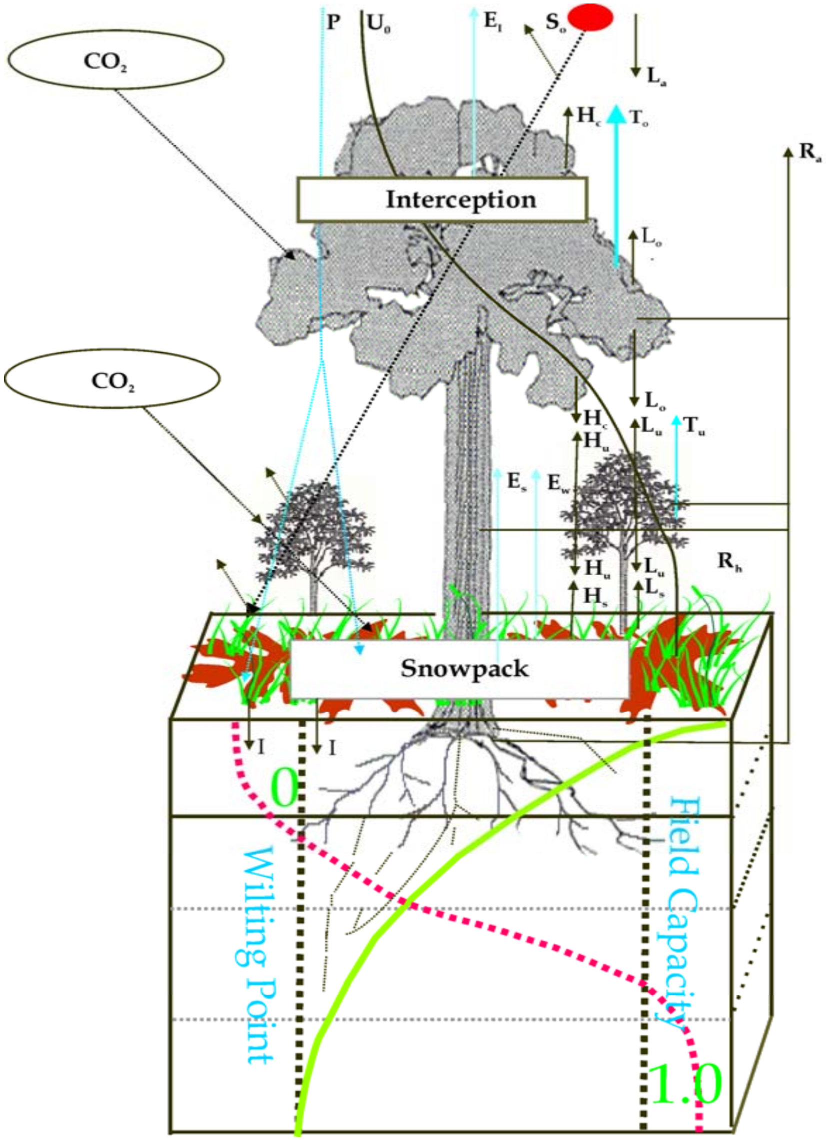




Lateral flow considered

No lateral flow

A new scheme calculating soil water scaling factor for stomatal conductance



Old Scheme (Simulation 1):

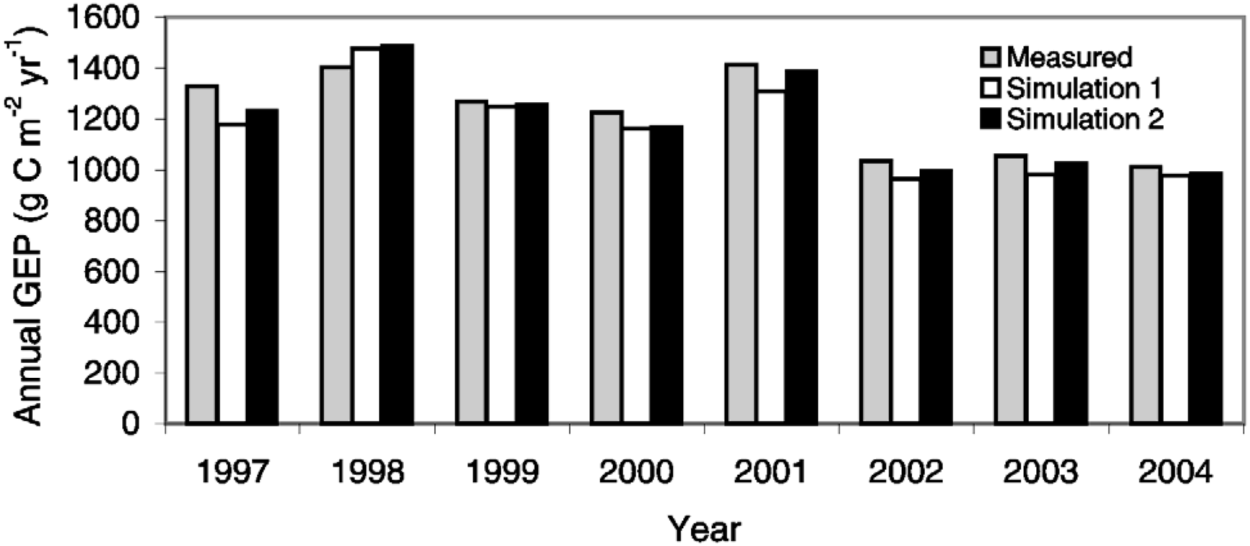
$$f(\psi) = \sum_{i=1}^{N} f(\psi_i) R_i$$

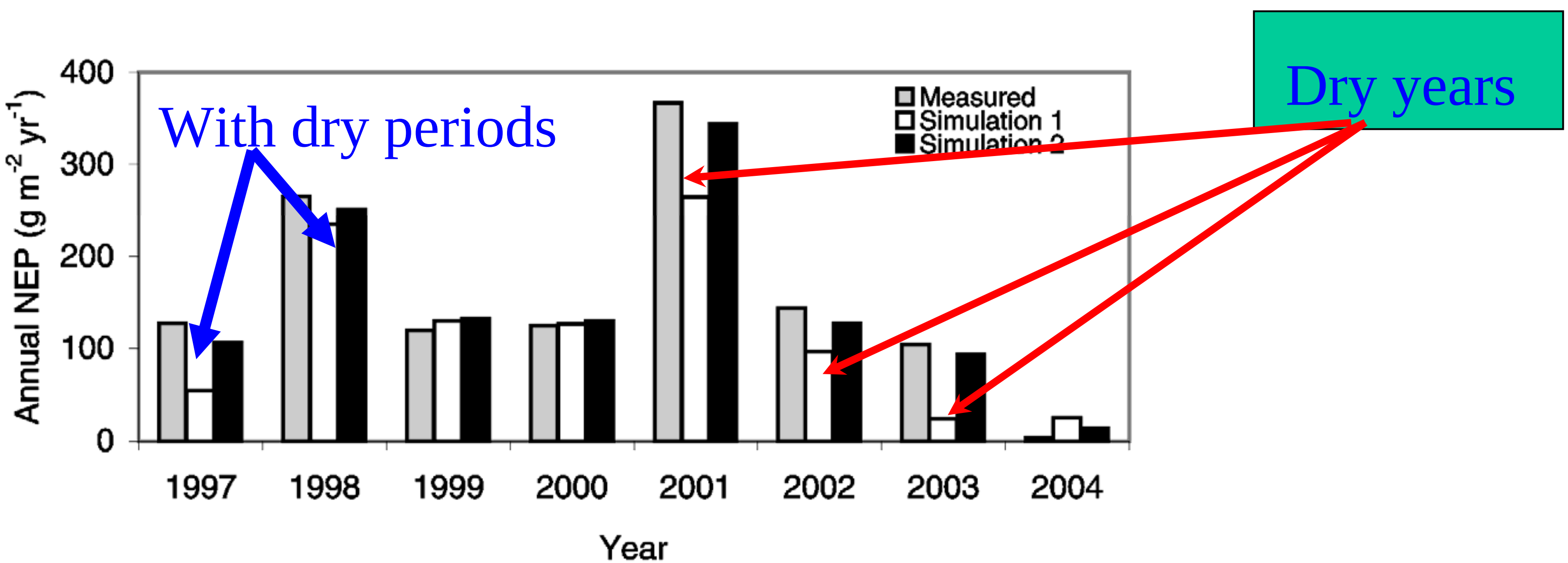
New Scheme (Simulation 2):

$$f(\psi) = \sum_{i=1}^{N} f(\psi_i) w_i$$

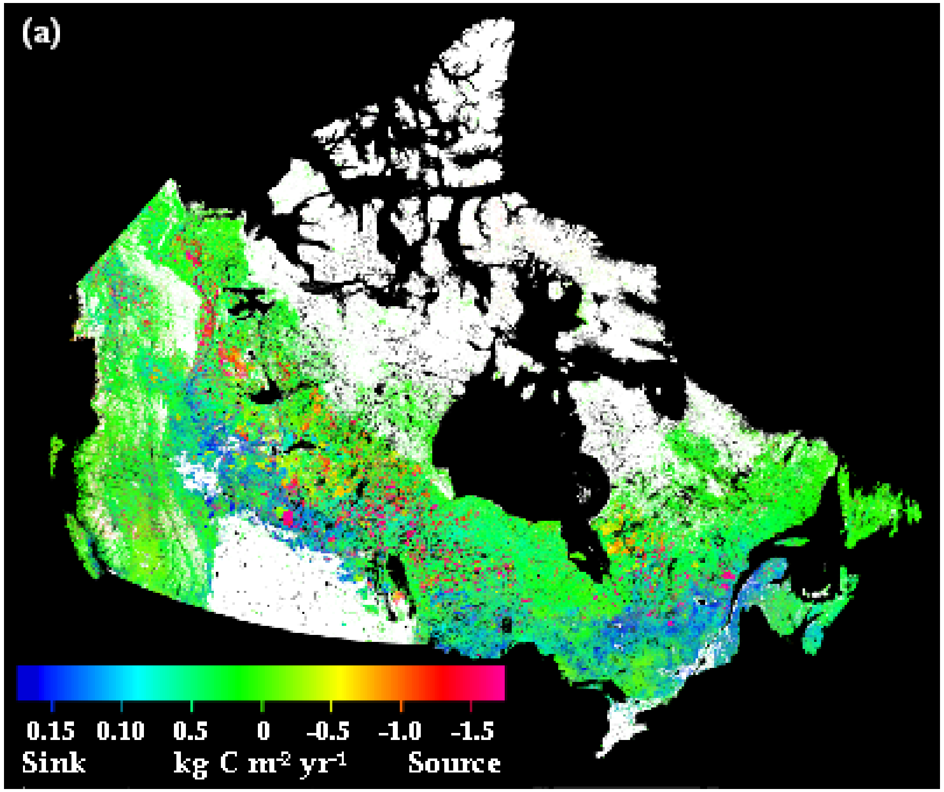
$$w_i = R_i f(\psi_i) / \sum_{i=1}^{N} R_i f(\psi_i)$$

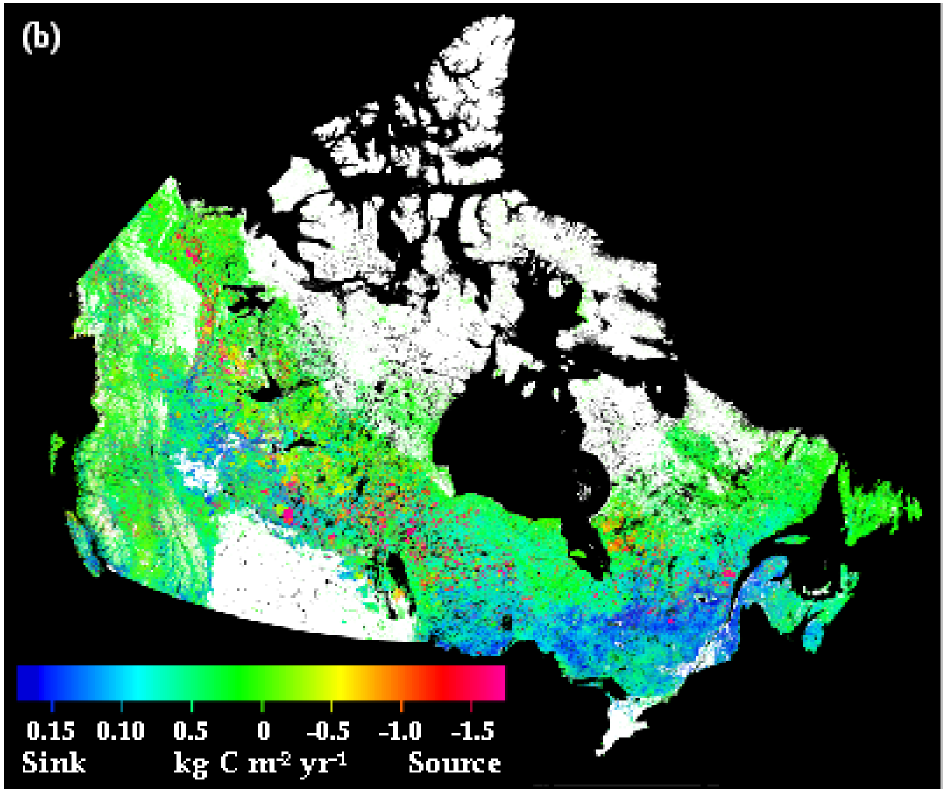
Sensitivity of simulated annual NEP to the parameterization of the effect of soil moisture content on stomatal conductance





Carbon Source and Sink Maps
produced with and without wetland processes

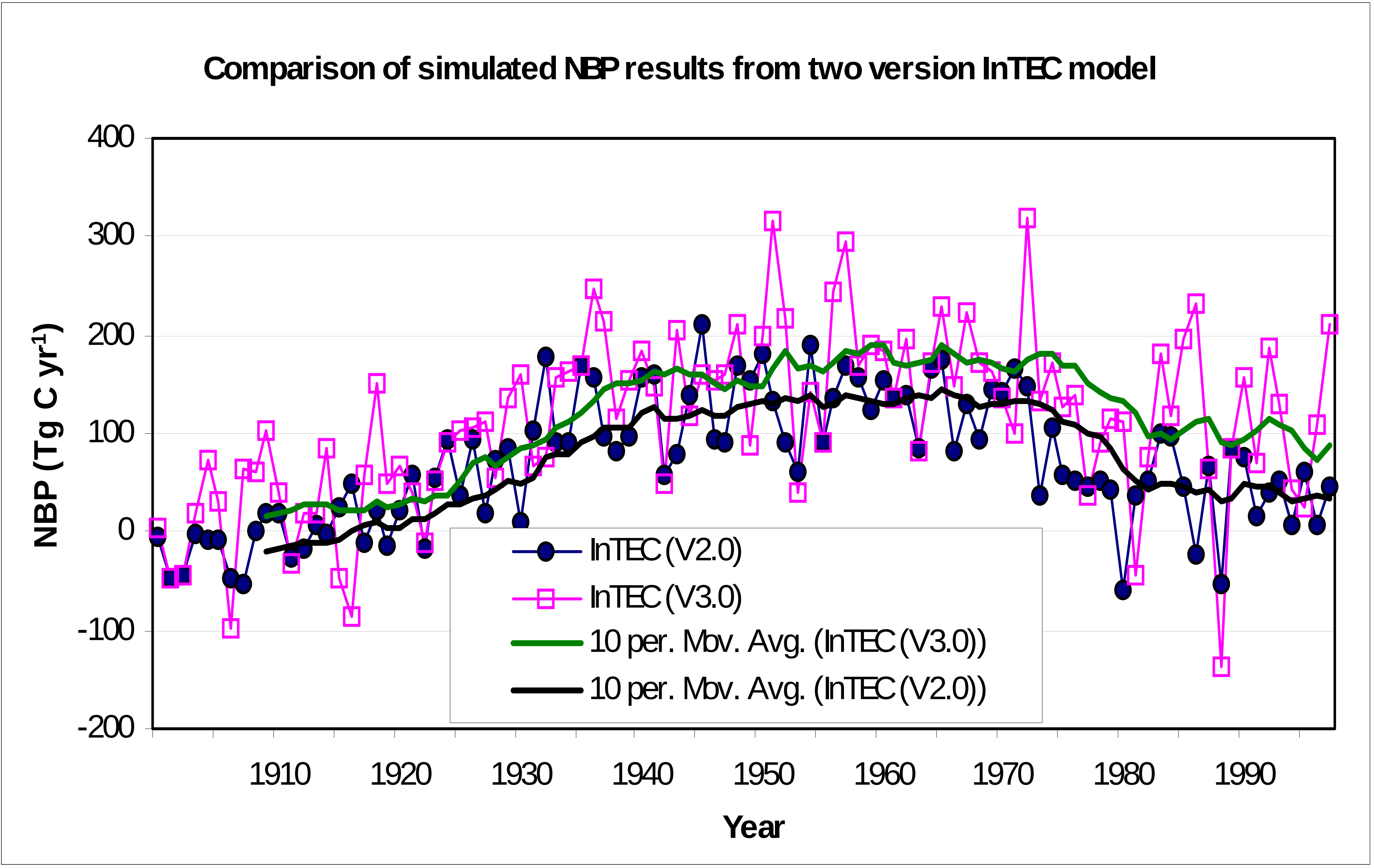




InTEC V2 without lateral hydrology and wetland processes

InTEC V3 with lateral hydrology and wetland processes

Ju *et al.*, (2005, *Tellus*)



Ju *et al.*, (2005, *Tellus*)

Summary

- Although boreal landscapes are relatively flat, the lateral subsurface water flow is often the dominant component of the water budget, and spatially explicit modeling of this component is important in quantifying the water and carbon exchanges with the atmosphere.

- In both wetland and forest watersheds with excessive precipitation, the vertical carbon flux is more affected by the lateral water redistribution than the vertical water flux.

- Accounting for the lateral water redistribution to wetlands at the national scale, the size of carbon sinks increased by about 60 MtC/y in recent decades.

Acknowledgement: This research is supported by the Canada Fluxnet and the Canadian Carbon Program funded by CFCAS, NSERC and BIOCAP. It is also supported by CFCAS individual grants.