# Modelling Forest Ecosysterms and Carbon Dynamics:

## *TRIPLEX Model Development and Application*

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# Topics Outline

## I. Model Overview

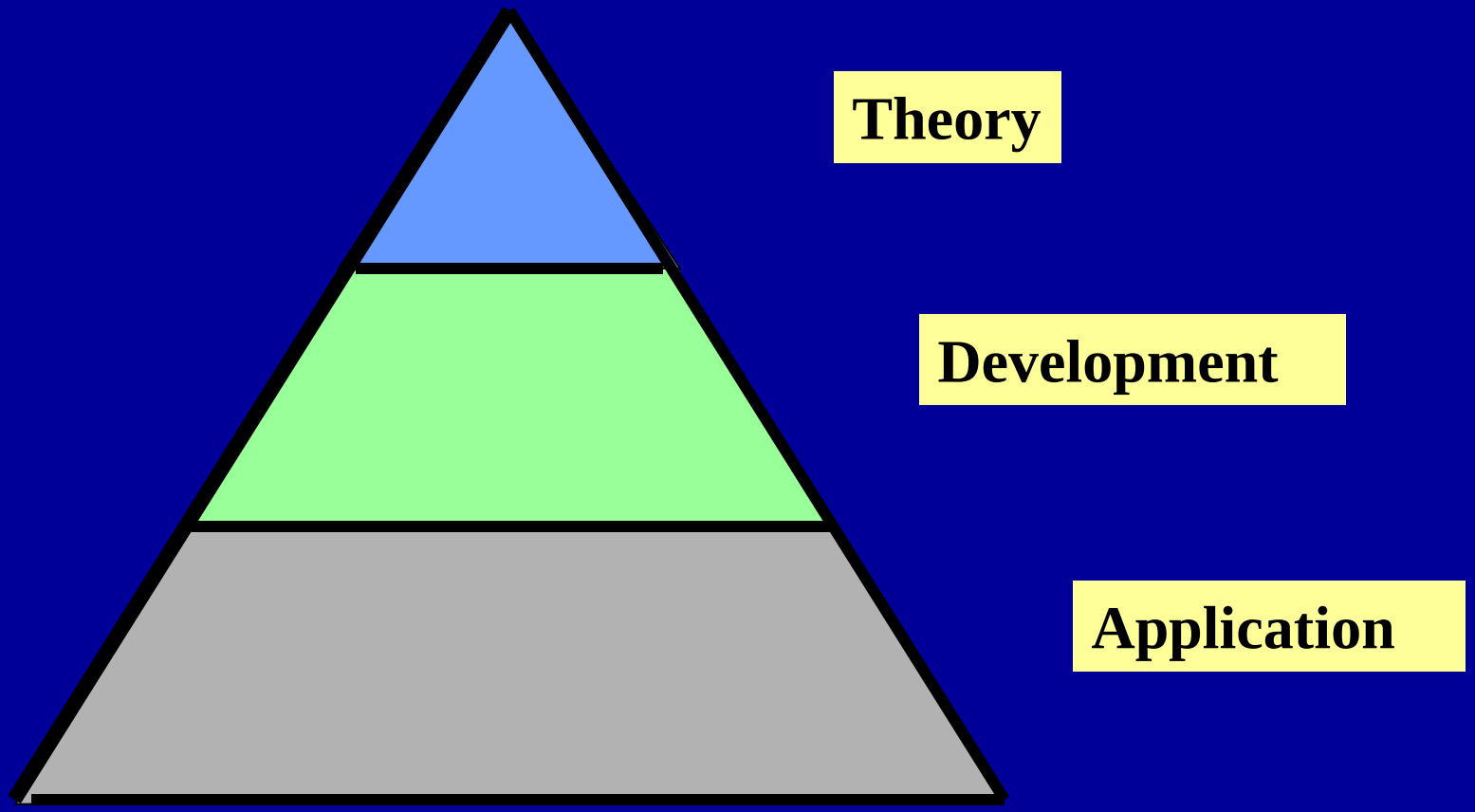
- What is a model?
- The roles of models

## II. TRIPLEX development and testing

- Canada
- China

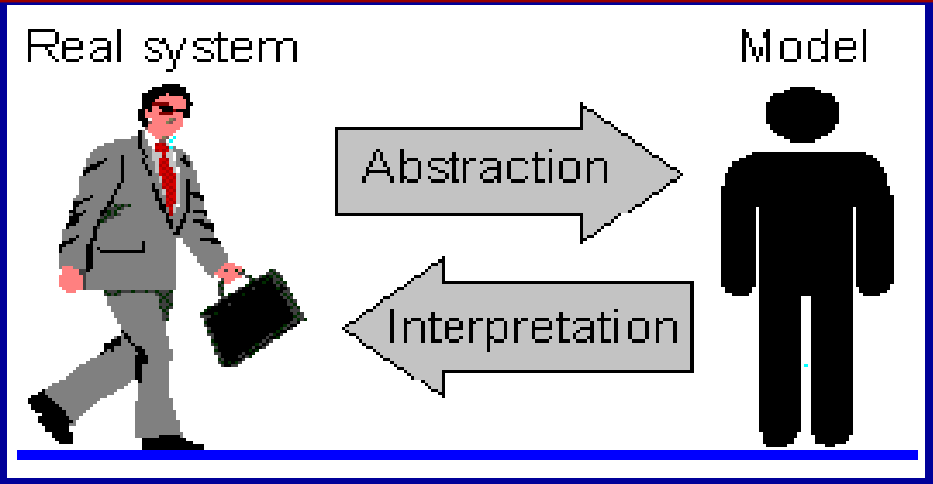
## III. Challenges Ahead for TRIPLEX model family development

# Ecological Modeling



# What is a Model ?

**Real system**



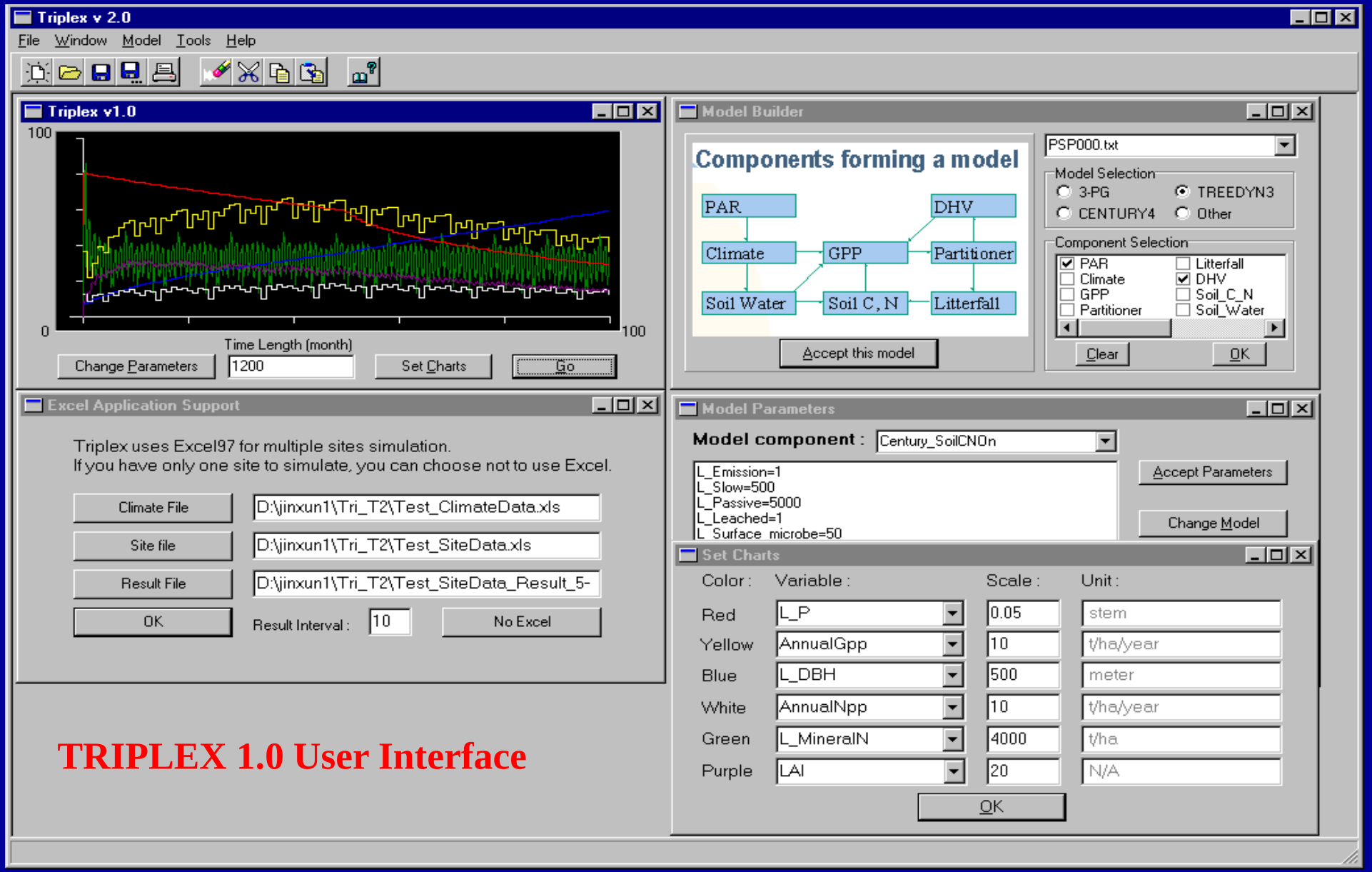

Model

- A model is an abstraction of a real system
- We use models in two ways:
  - conceptual model
  - formal model

# Real Biological System: Jack Pine Stands (Ontario, Canada)

# TRIPLEX: Computer Simulation Model

## (Peng et al. 2002)




**TRIPLEX 1.0 User Interface**

# The Roles of Simulation Models

- Models as *research tools*
  to increase our knowledge

- Models as *management tool*
  to help to make decisions

- Models as *education tools*
  to help to understand environmental change

# Development of Forest Simulation Models

## Forest modeling has a long history in Forestry:

- Development of a yield table by mensurationists in Germany in the early 1850s *(Vuokila, Y, 1965)*

- Model of tree growth using differential equations were first developed in the nineteenth century *(Greenhill, 1881).*

## Development of process models:

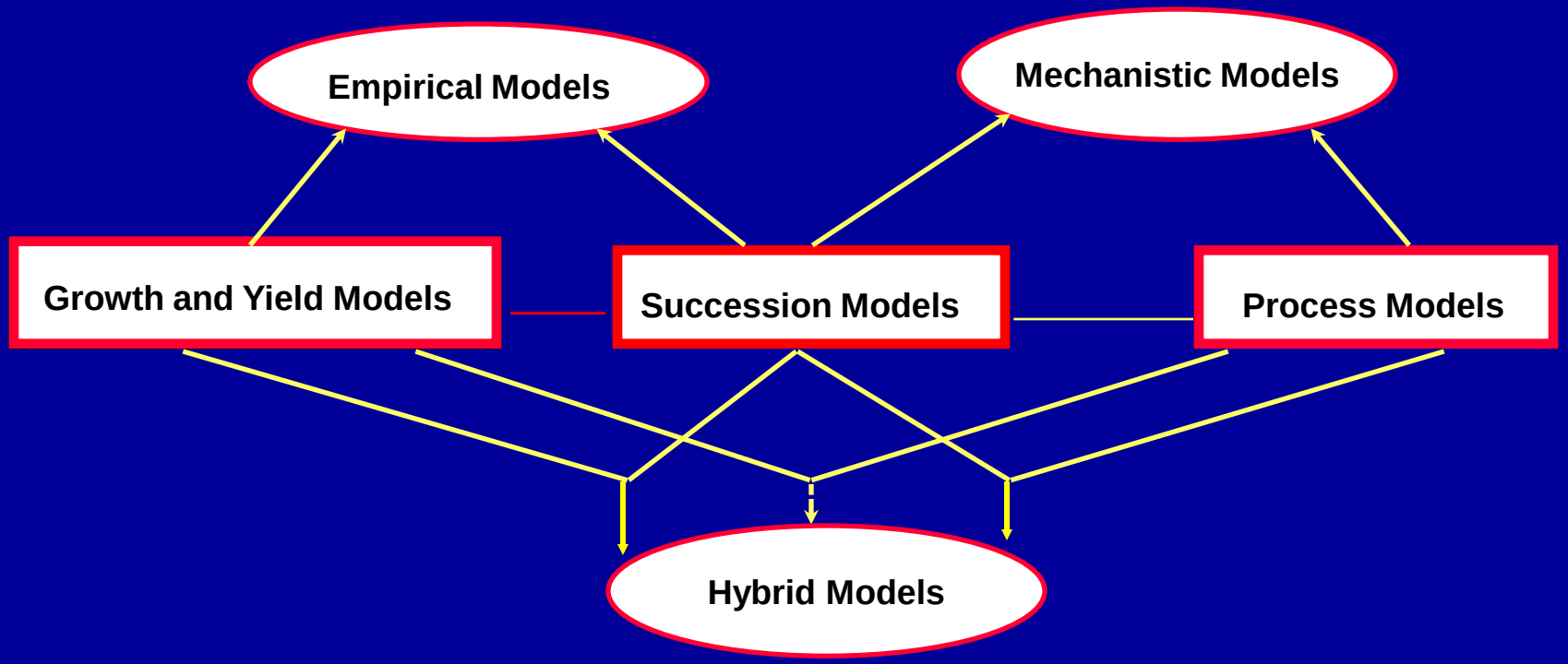
- IBP: The International Biological Program: Late 1960s and early 1970s

(*Reichle, 1981. In: Dynamics Properties of Forest Ecosystem, IBP 23, Cambridge University Press, p.683)*

- IGBP (International Geosphere Biosphere Program): Late 1980s – studying global change

- Sustainable Forest Management (SFM): early 1990s

# Forest Simulation Models




Increasing ability to predict growth under changed future conditions

Increasing model simulation options and flexibilities

Description moving towards Explanation

(Peng, 2000)

# Current Process-Based Models

## Spatial Scales

**A. Organ (Leaf or Canopy) models**

e.g. FOEST-BGC (Running and Coughlan, 1988); MAESTRO (Wang and Jarvis, 1990 ); BIOMASS (McMurtrie et al. 1990);

**B. Individual tree ecophysiological models**

e.g. ECOPHYS (Rauscher et al. 1990); TREGRO (Winstein and Yanai, 1994); TREE-BGC (Korol et al., 1994)

**C. Community models (gap or succession models)**

e.g. JABOWA (Botkin et al. 1972); FORET (Shugart and West, 1977); ZELIG (Smith and Urban, 1988); LINKAGE (Pastor and Post, 1985)

**D. Stand or Ecosystem models**

e.g. PnET (Aber and Federer, 1992); CENTURY (Parton et al. (1987), FORECAST (Kimmins , 1986)

**E. Landscape models**

e.g. FIRE-BGC (Keane et al., 1996 ); LANDIS (He et al. 1996)

**F. Global models**

e.g. BIOME3 (Haxeltine and Prentice, 1996); MAPSS (Neilson, 1993); IBIS (Foley et al., 1996), LPJ etc…

# Major Challenges for Sustainable Forest Management

- Sustaining forest ecosystem productivity
- Mitigating and/or adapting to the effects of global change
- Improving carbon sequestration potential of forests

# TRIPLEX Model Development History ( 8 years)

- **2000- 2002: TRIPLEX 1.0 ( OFRI, Sault Ste Marie, ON)**

- **2003-2005: TRIPLEX 1.0 Testing and application at stand and landscape Levels (SD, USA; UQAM, Montreal)**

**2004-2007: Application of TRIPLEX1.0 in China (Beijing U & Zhejiang U)**

- **2006-2007: TRIPLEX-Flux, TRIPLEX-Fire, TRIPLEX-DOC (UQAM)**

- **2008-present: TRIPLEX-Management, TRIPLEX-Aquatic (UQAM)**

# TRIPLEX Model Publications ( 2002-2009)

- **TRIPLEX1.0 Model**

**- Peng et al, (2002), Ecol. Model ; Liu et al. (2002), CEA**

- **TRIPLEX Application in Canada:**

**- Zhou et al (2004), EM&S; Zhou et al (2005), CJFR; Zhou et al. (2006), MASGC**

**TRIPLEX Application in China**

**- Zhang et al. (2008), EM; Peng et al. (2008), GPC**

- **New TRIPLEX-Flux, TRIPLEX-Fire, TRIPLEX-DOC**

**- Zhou et al (2008), EM; Sun et al. (2008), EM; Two MS (in preparation)**

- **TRIPLEX-Management, TRIPLEX-Aquatic**

**-Wang et al (2010), Wu et al (2009)**

- **TRIPLEX-Globe**

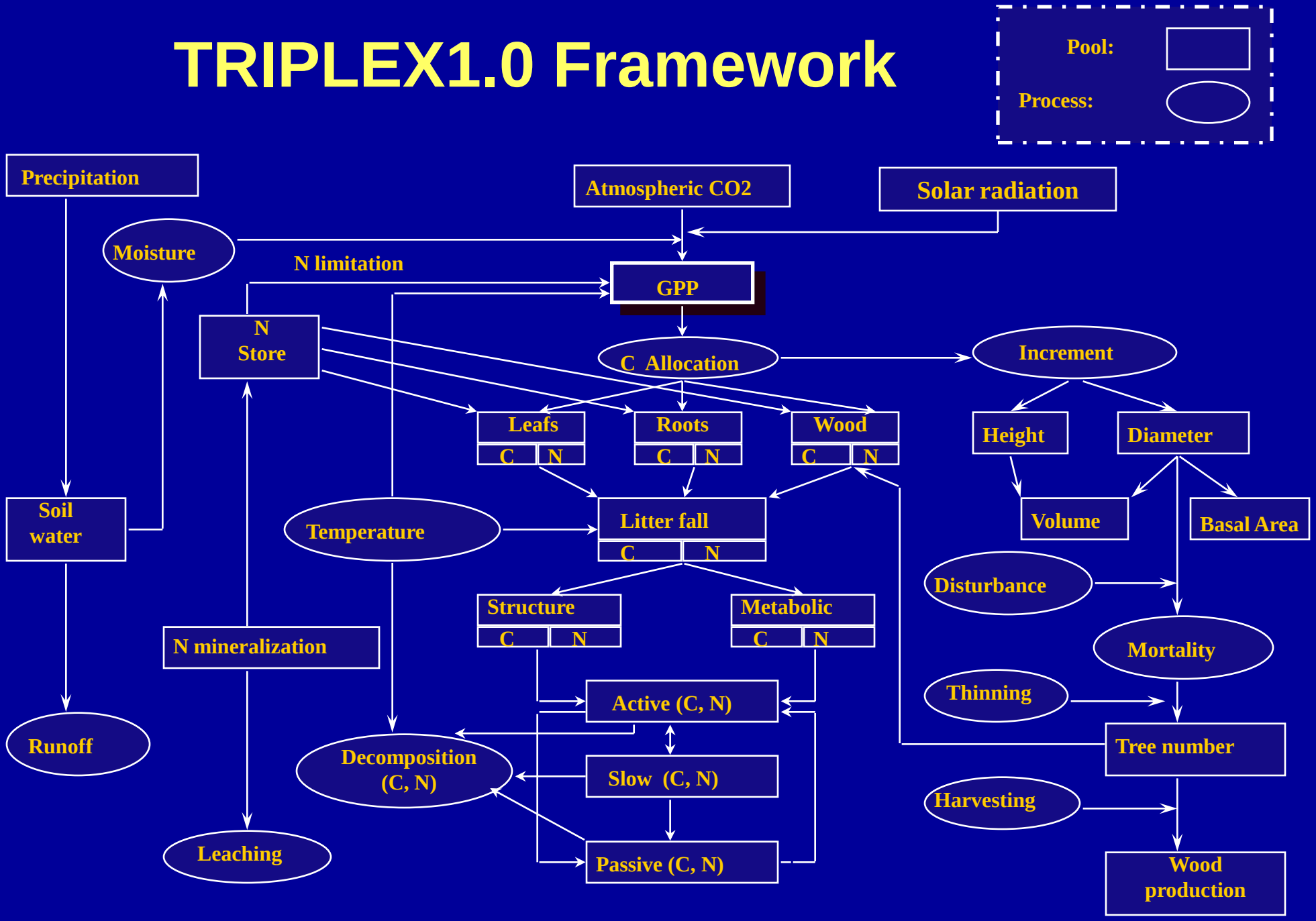
**-- Just started this year**

# TRIPLEX: A generic hybrid model for predicting forest growth and carbon and nitrogen dynamics

*(Peng et al. 2002, Ecol. Model)*

- **Developed based on well-established models:**
  - **3-PG (Landsberg and Waring, 1997)**
  - **TREEDYN3.0 (Bossel, 1996)**
  - **CENTURY4.0 (Parton et al., 1987, 1993)**
- **Bridges the gap between forest growth and yield and process-based C balance models**
- **Can be used for:**
  1) **Making forest management decisions (e.g., G&Y prediction)**
  2) **Quantifying forest carbon budgets**
  3) **Assessing the effects of climate change on forest ecosystems**

# TRIPLEX1.0 Framework



# Key Features of TRIPLEX1.0:

- **Driving variables (main inputs):**

  **Monthly climate data; tree & stand variables, LAI, soil texture, geo-location**

- **Mass balances:**

  **C, N, and water pools and fluxes fully balanced**

- **Time step:**

  **Monthly C flux and allocation calculation; annual tree growth, C , N, and water budget**

- **Outputs:**

  **H, DBH, BA, volume, NPP, biomass, soil C, N, and water dynamics**

- **Modelling strategy:**

  **OOP (objective-oriented programming - C++) and model reuse approaches**

# TRIPLEX Model Version 1.5

Can be downloaded from Dr. Peng's old Homepage at

http://flash.lakeheadu.ca/~chpeng/

Demonstration……..

# Challenge: Validation

**Calibration** is the estimation and adjustment of model parameters and constants to improve the agreement between model output and a data set.

**Validation** is testing a model to see how well it predicts. (How well does the model capture the structure, controls, and dynamics of a real forest ecosystem).

- **First questions is: what variable do we want to validate (test)?**
- **The second question is finding adequate data.**

# Variables for Validating Process Model

**Waring and Running (1998) recommend a group of variables that can be accurately measured in the field and reflect a range of forest interaction linked carbon, nitrogen and water cycles.**

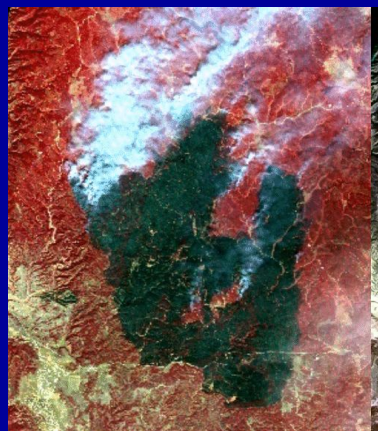
**These include:**

- **Leaf area index (LAI)**
- **Net primary productivity (NPP)**
- **Stem biomass**
- **Leaf litterfall**
- **Leaf nitrogen content**

- **Total Height**
- **Diameter at breast height (DBH)**
- **Basal Area (BA)**
- **Total Volume**

# Data for Validating Process Model

- Greenhouse or experimental data
- *Tree growth plots (PSP, TSP)*
- Forest inventory (NPP, Biomass)
- Flux tower ($CO_2$, NPP, NEP etc..)
- Remote Sensing (LAI, NDVI-NPP)
- Paleoecological data (tree-ring, pollen)

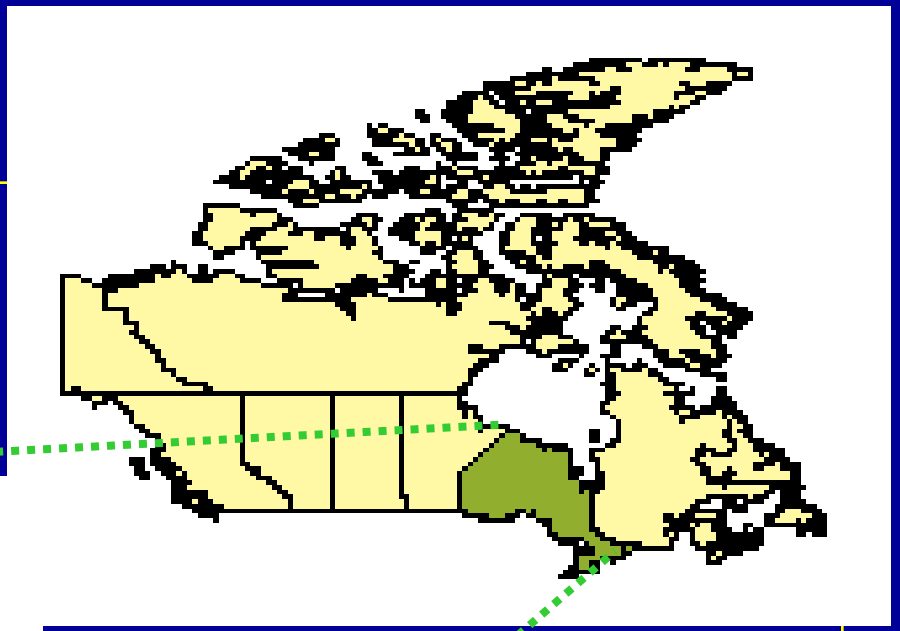


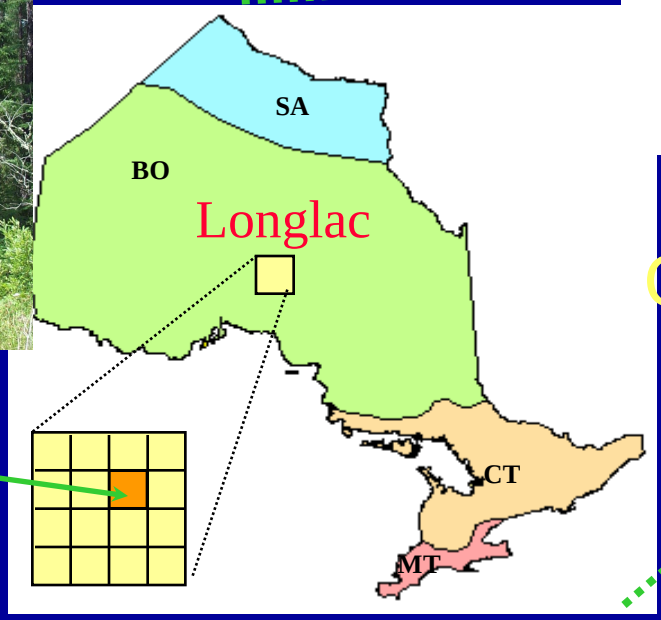

Click here to learn about tree rings & to try crossdating for yourself.

# One Case Study

**Location:** Longlac (Kimberly Clark Ltd.)

**Forest type:** Jack pine ( *Pinus banksiana* Lamb.)






Ontario

**12 PSP (0.08ha each)**

**BO: Boreal; CT: Cool Temperate; MT: Moderate Temperate; SA: Subartic**

# Calibration and Validation for TRIPLEX Model

We have 6 consecutive measurements (every 5 yr) for DBH, H, tree density (1952-1982)

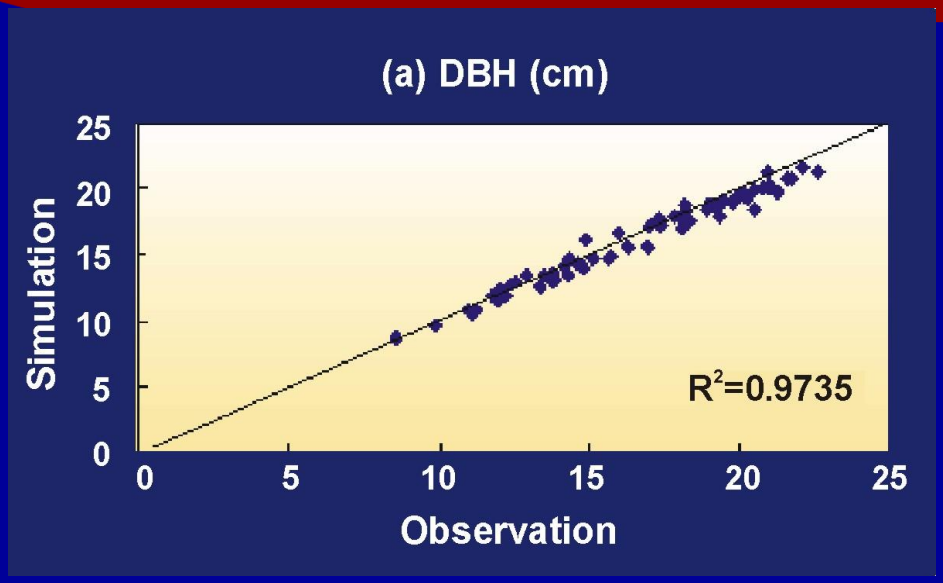
- Use first measurements (1952) to calibrate the TRIPLEX model

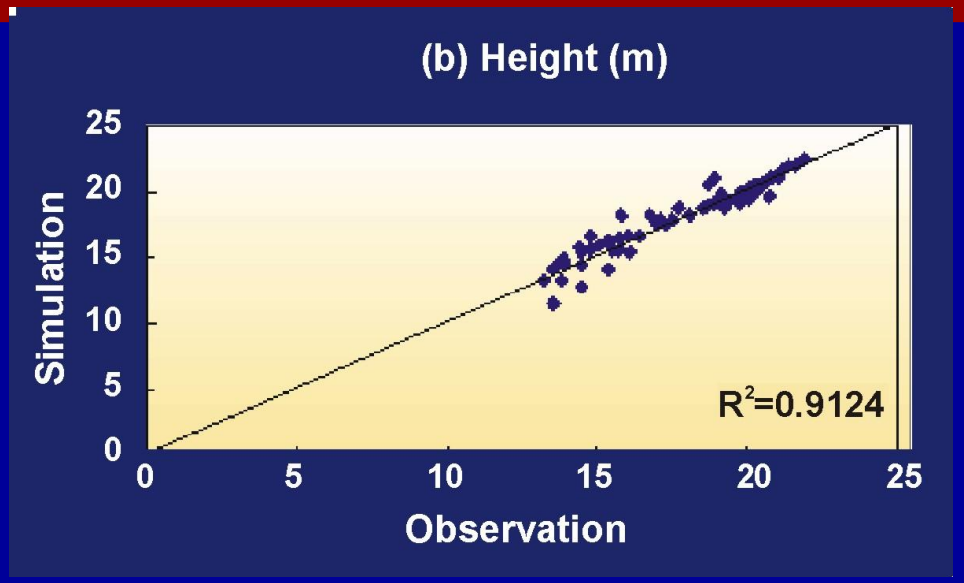
- Use the other 5 measurements to validate (1957 - 1982)

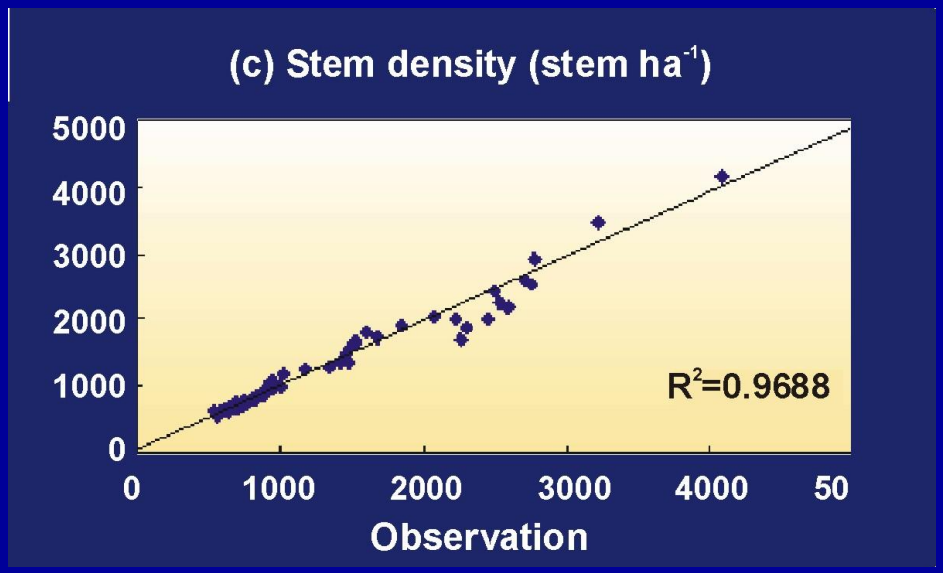
**(Peng et al., 2002, Ecol. Model; Liu et al (2002)**

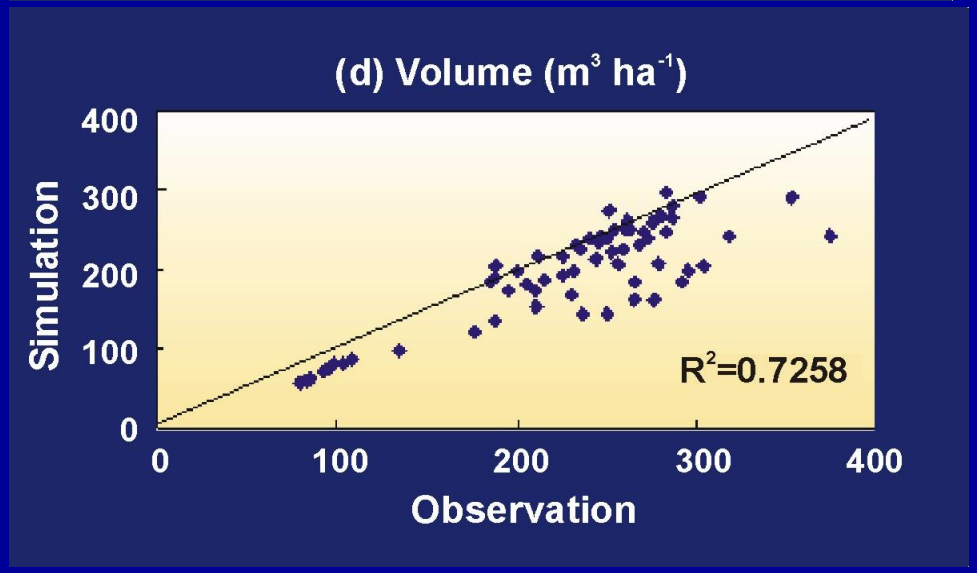
# Comparison of Simulations and Observations

*(solid diagonal is the 1:1 line; N=60)*



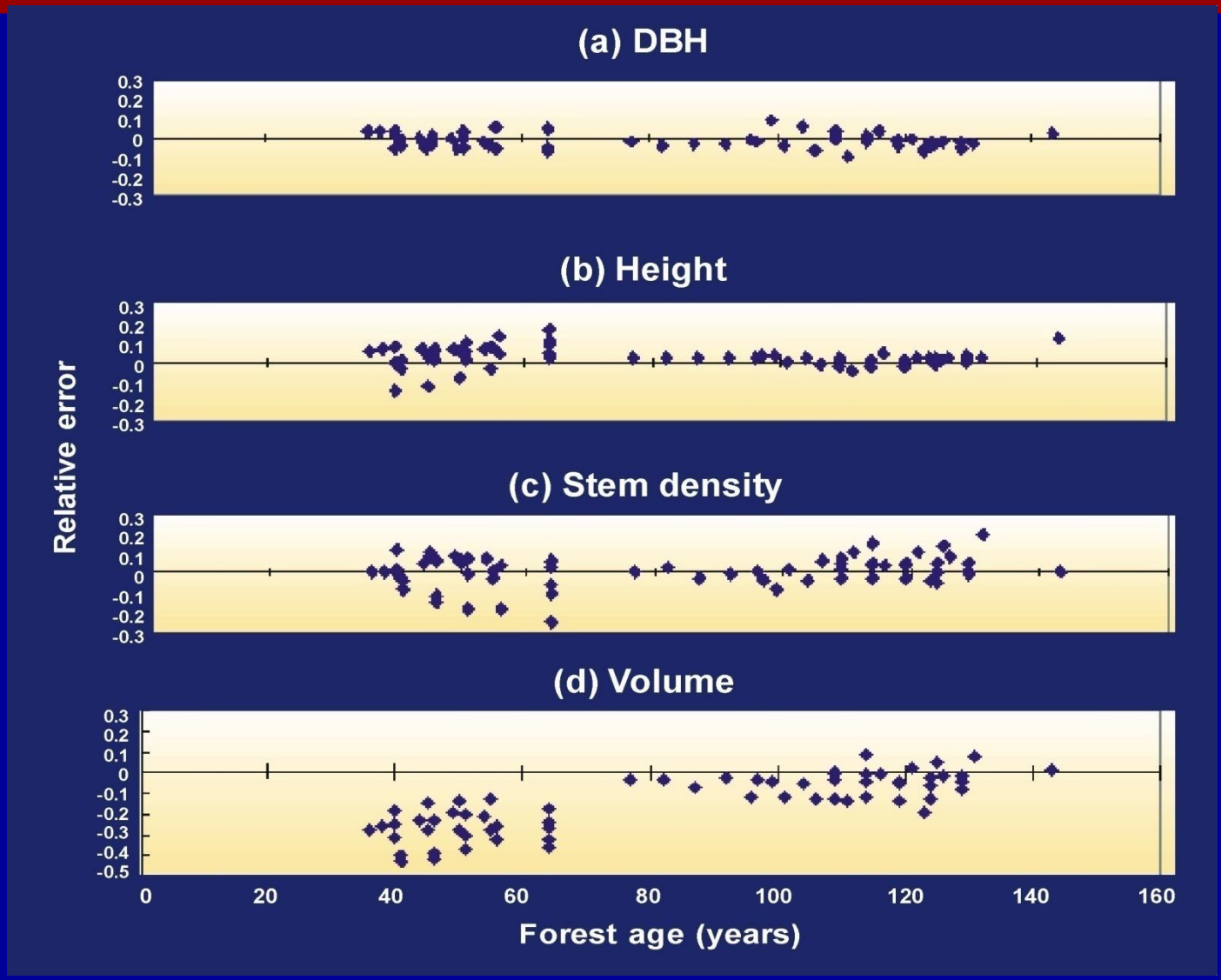



# Simulated Relative Errors for Stand Age

(=[simulation - observation]/observation)



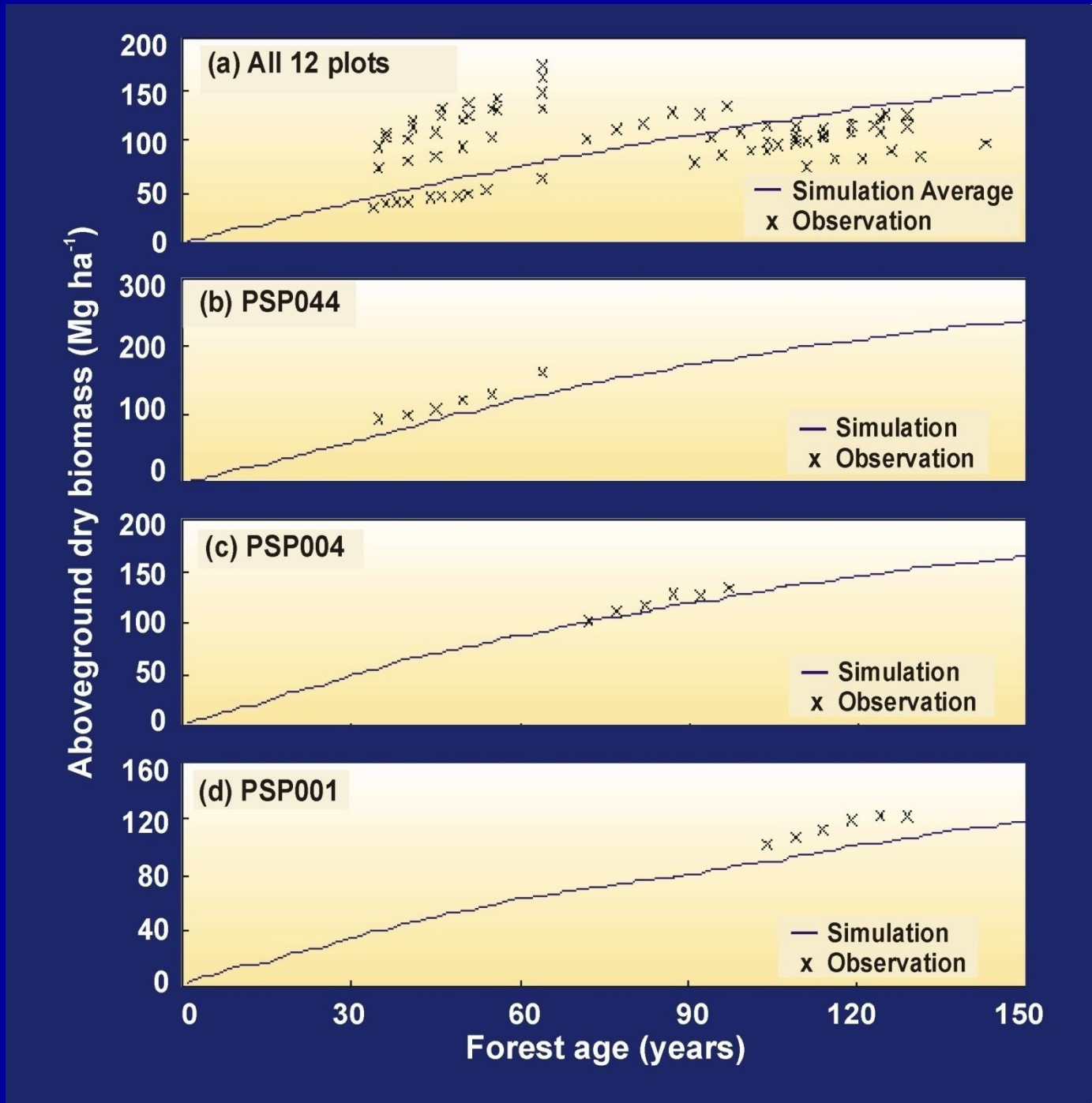

±10%

±15%

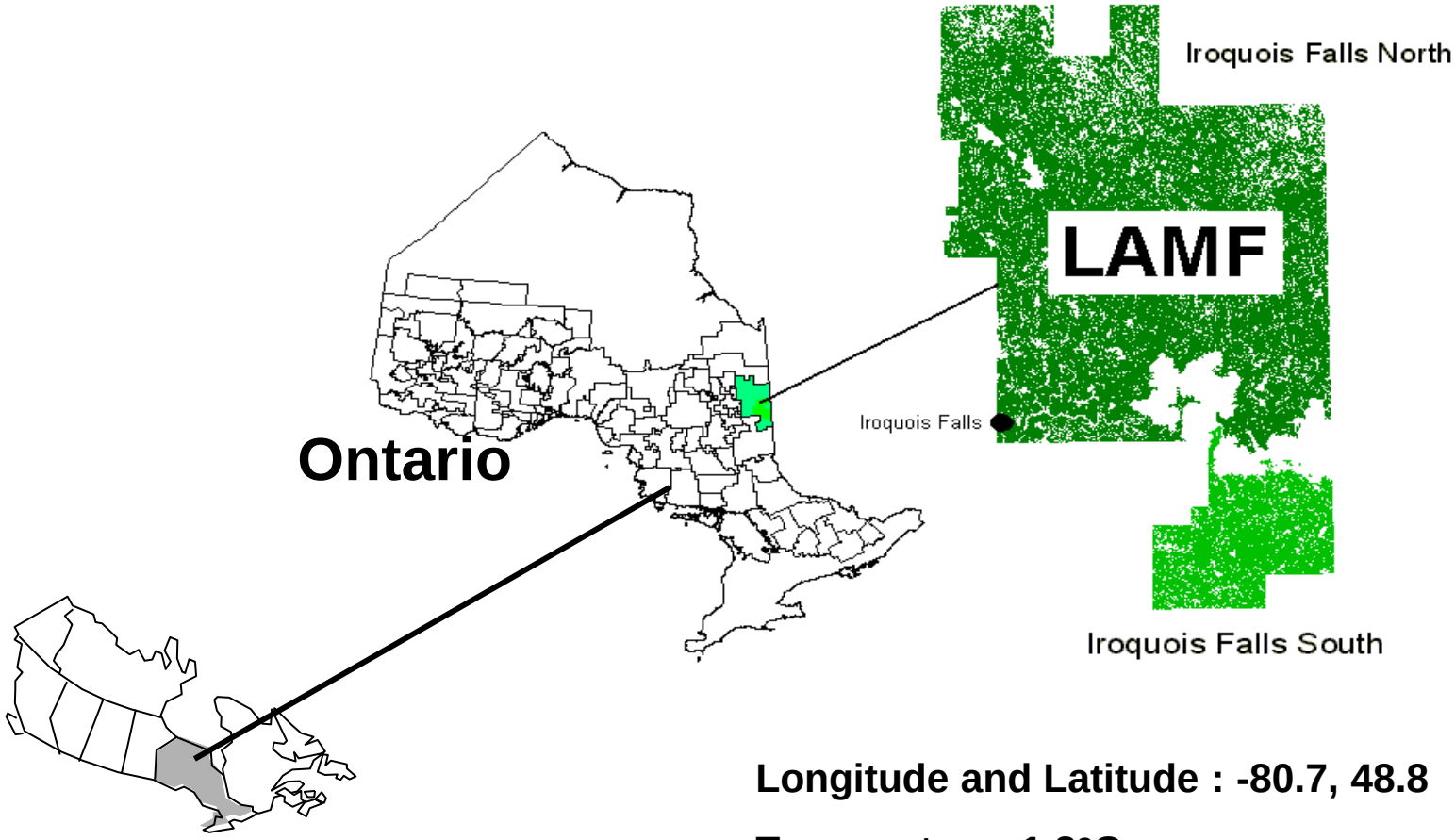
±20%

±25%

# Comparison of Averaged Simulations and Observations - *Aboveground Biomass (Hegyi, 1972)*



# Study area: Lake Abitibi Model Forest




**Longitude and Latitude : -80.7, 48.8**

**Temperature: 1.2°C**

**Precipitation: 814.8 mm**

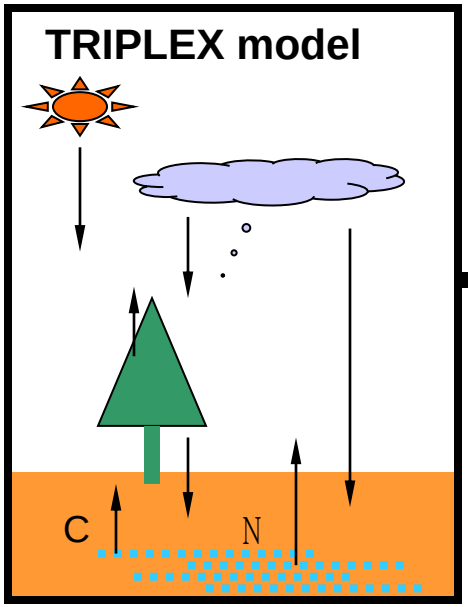
# Modeling Forest Growth and Carbon Dynamics at Landscape level in Lake Abitibi Model Forest

(May 12, 2002)

# Method

## Simulation Model

## Outputs




**Dynamics**

Biomass

NPP

Soil C & N

DBH

Height

Volume

……

**Spatial Distribution**

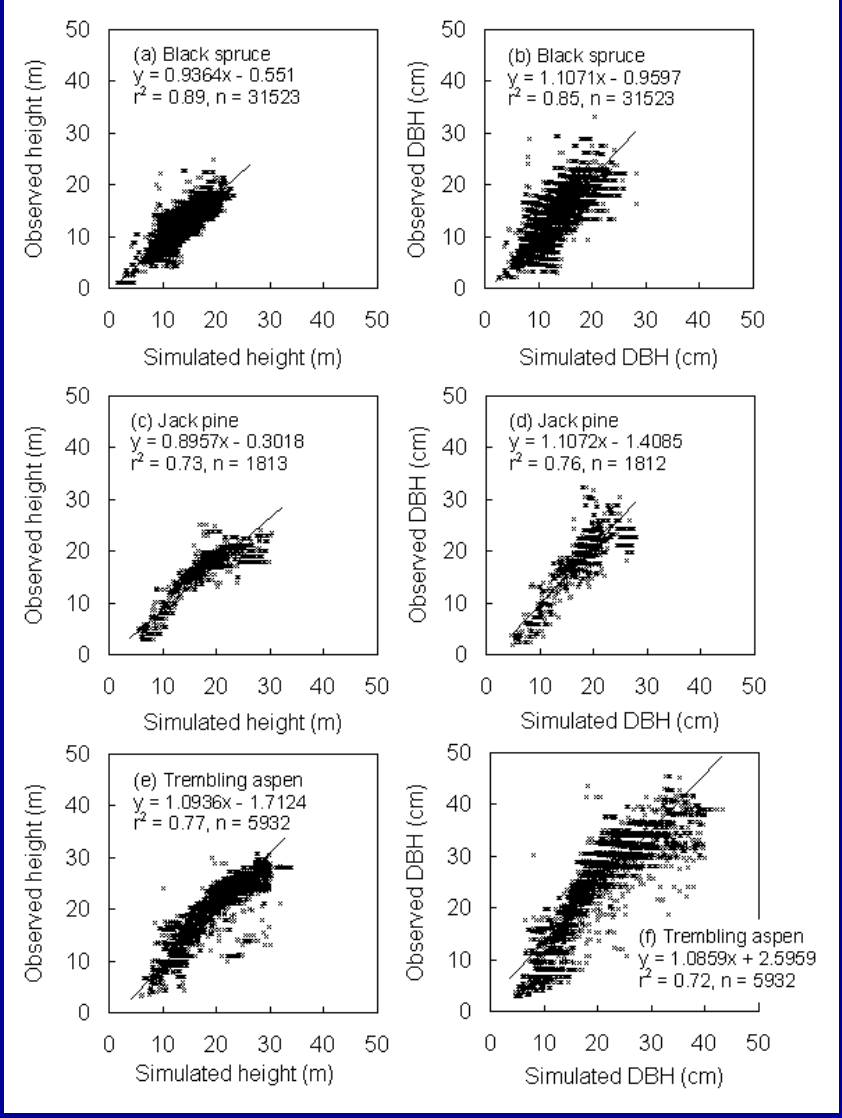
**GIS**

**ArcView**

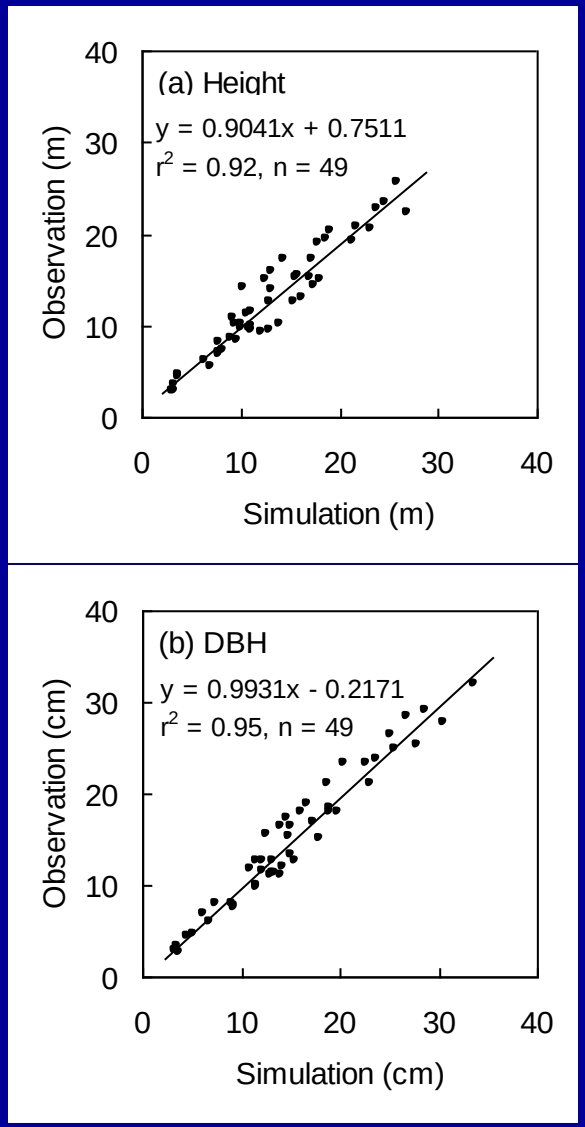
# Model inputs

| | |
|---|---|
| **Forest** | ● LAMF Local data (stands and spatial data) |
| **Soil** | ● Ontario Land Inventory Prime land Information System (OLIPIS)<br>● A soil profile and organic carbon data base for Canadian forest |
| **Climate** | ● Database from Environment Canada<br>● Canadian Centre for Climate Modeling (CCCMa database) |

# Model validation




**TRIPLEX vs. Forest Inventory**

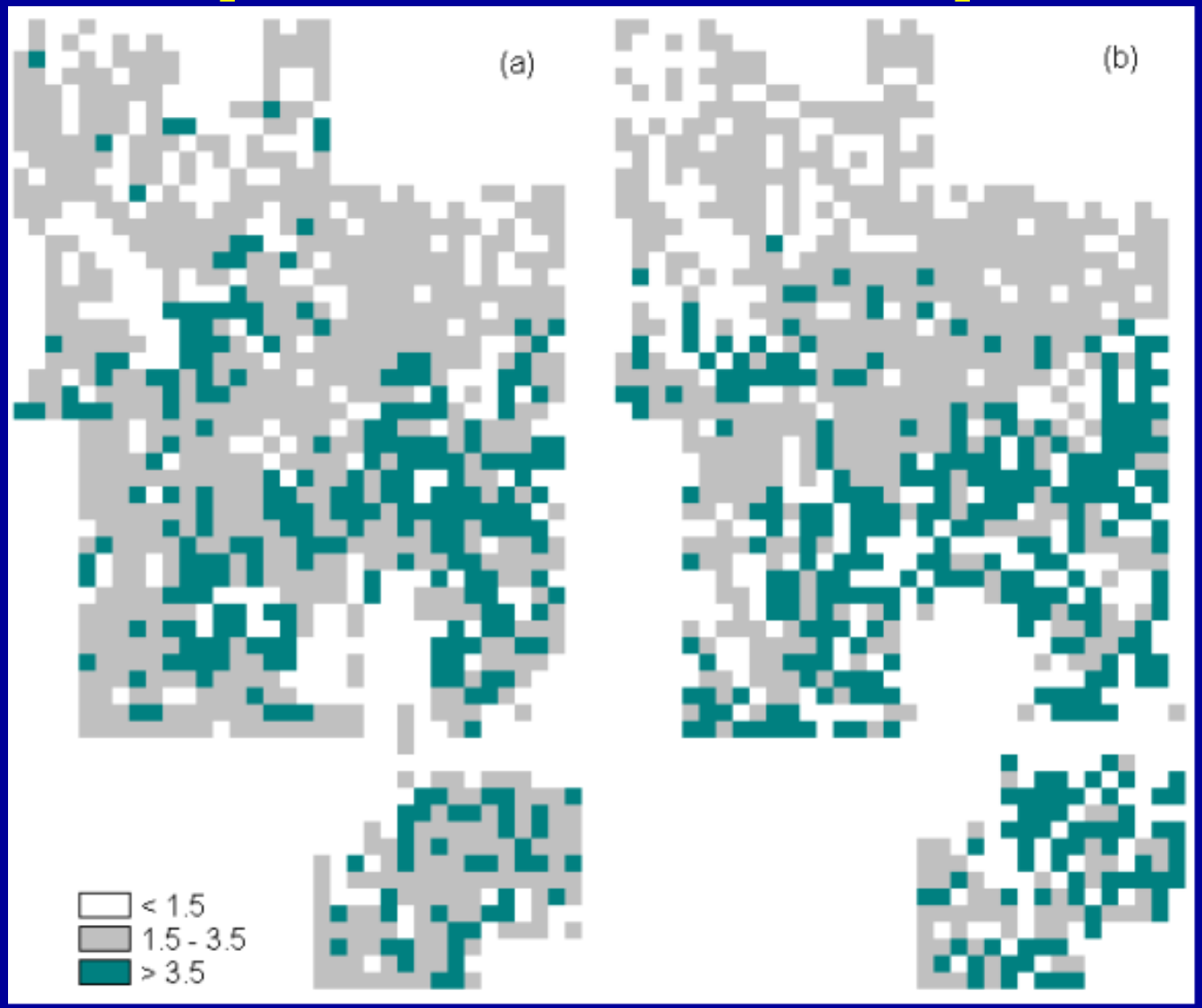



**TRIPLEX vs. PSP**

32 black spruce,
9 jack pine,
8 trembling aspen
plots
(measured in 1995)

(Zhou et al., 2005)

# NPP Spatial Distribution at Landscape Level



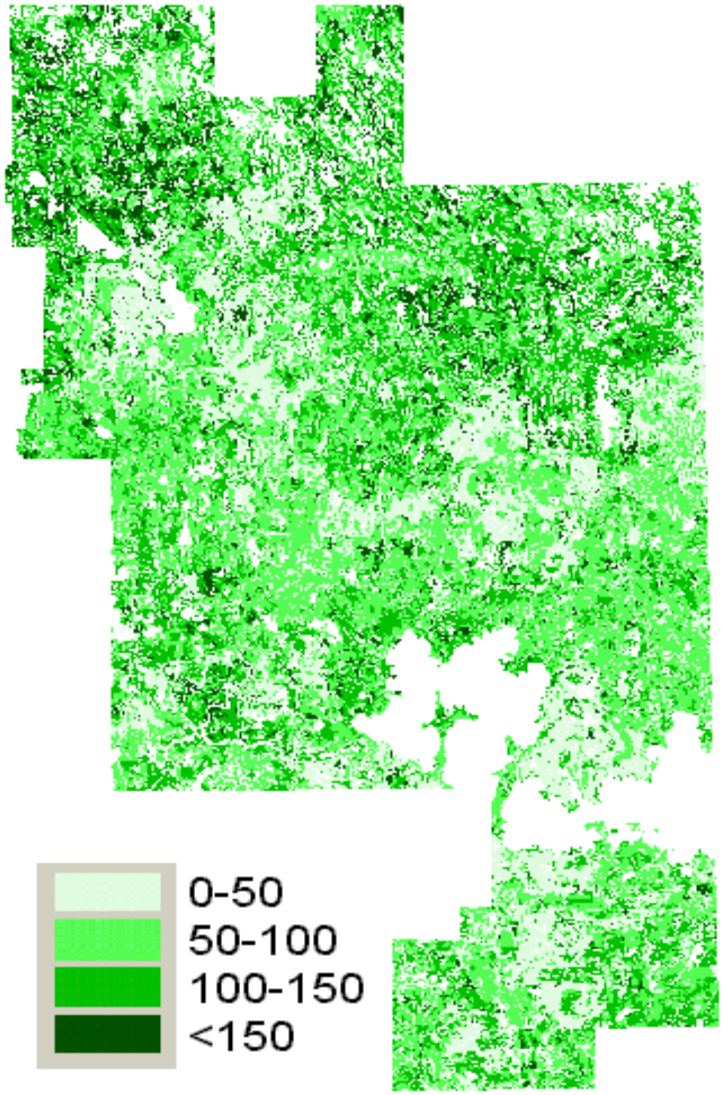

(a) TRIPLEX
(Zhou et al, 2005)

(b) Remote Sensing
(Liu et al, 2002)

*Fig. 4 The comparison between NPP (t C ha-1 yr-1) simulations at landscape (a) and remote sensing (b) levels for the LAMF in 1995. (a) was based on the TRIPLEX model simulation for 1995 (averaged 3.28 tC ha-1 yr-1, SD=0.79), and (b) was converted using spatial data from Liu et al. (2002) for 1994 (averaged 3.08 tC ha-1 yr-1, SD=1.15). The grid size is 3x3 km.*

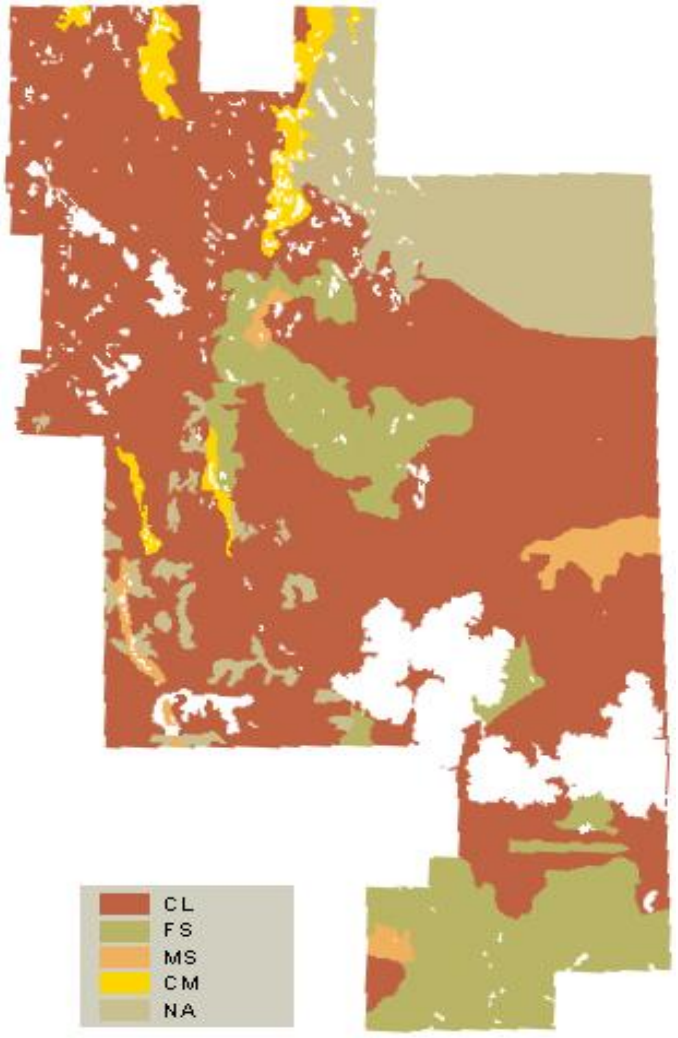
**Kappa Statistic (k) = 0.55**

**Good agreement if 0.55<K<0.7**



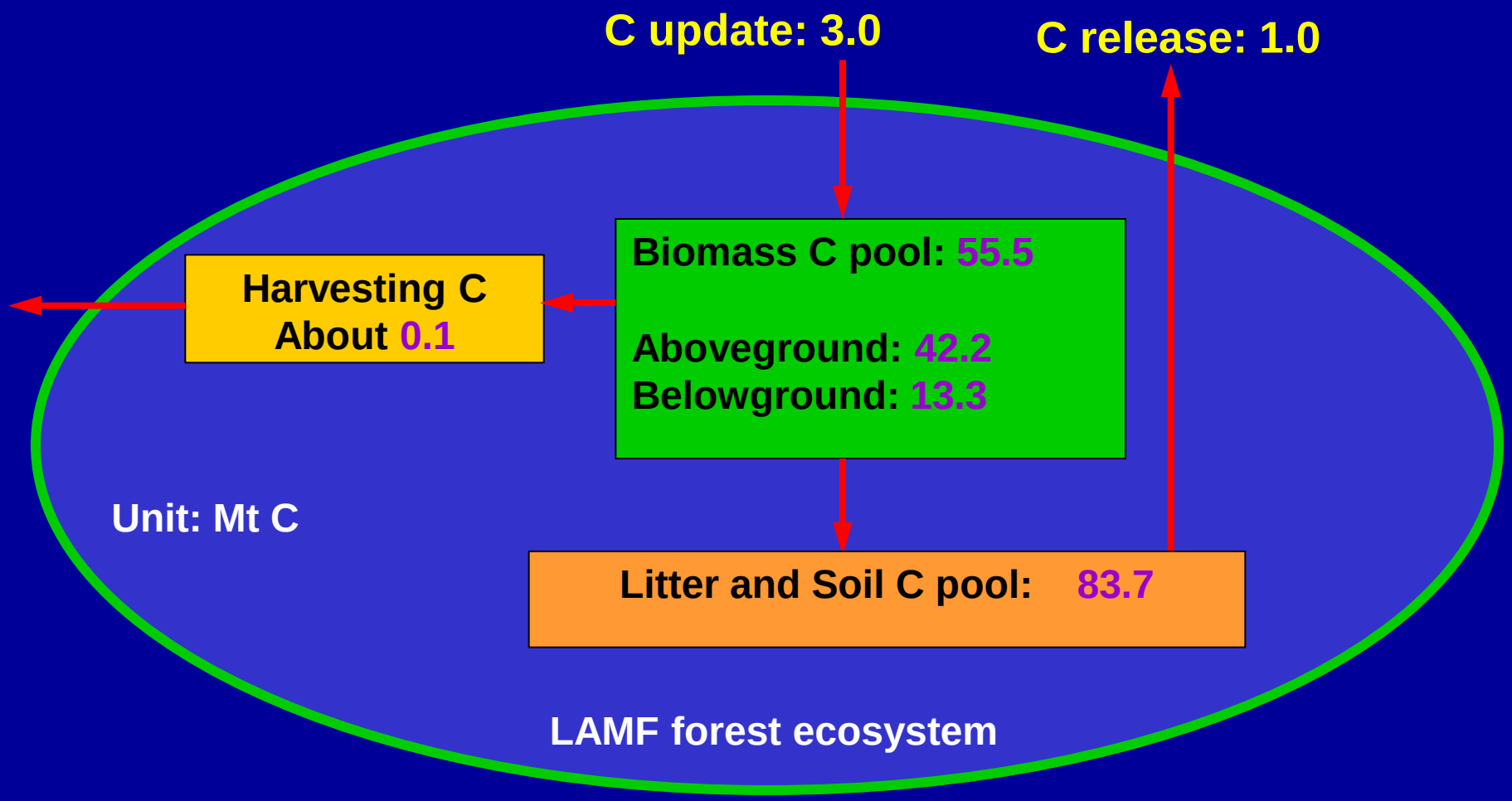

Simulated Biomass (t $ha^{-1}$) in 2000


Simulated NPP (tC $ha^{-1}yr^{-1}$) in 2000


**Simulated Soil carbon (tC ha$^{-1}$) in 2000**

**Soil texture**

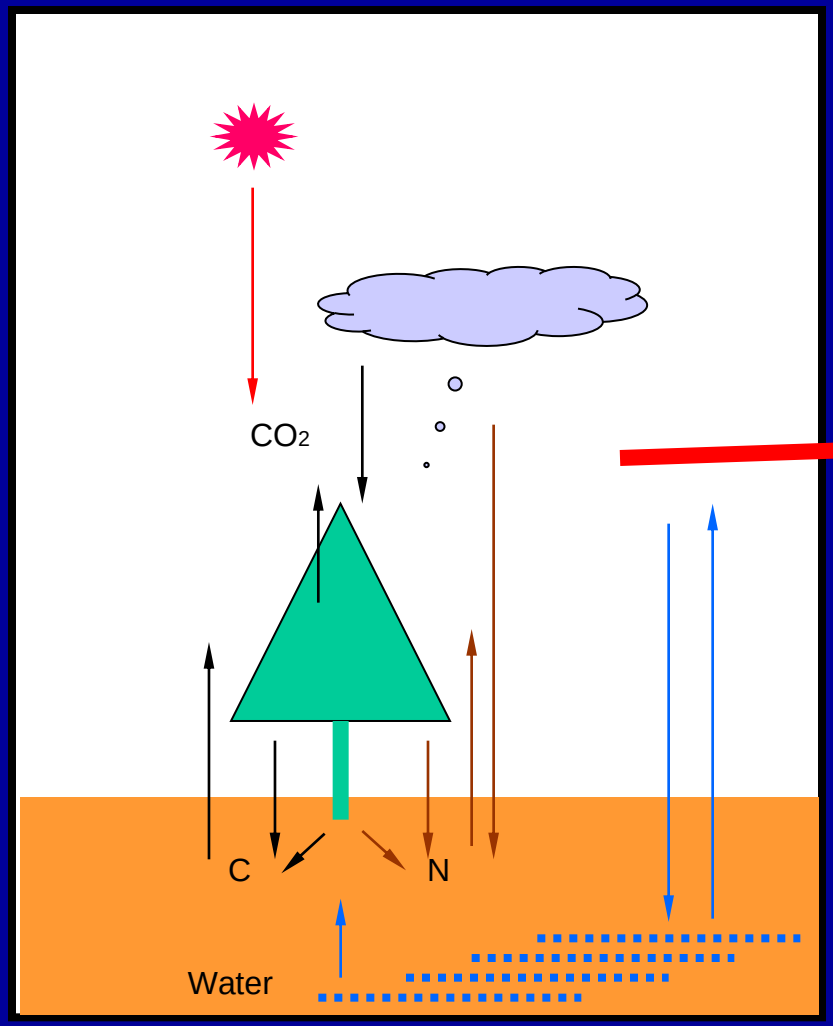



## C budget of LAMF forest ecosystem in 2000:

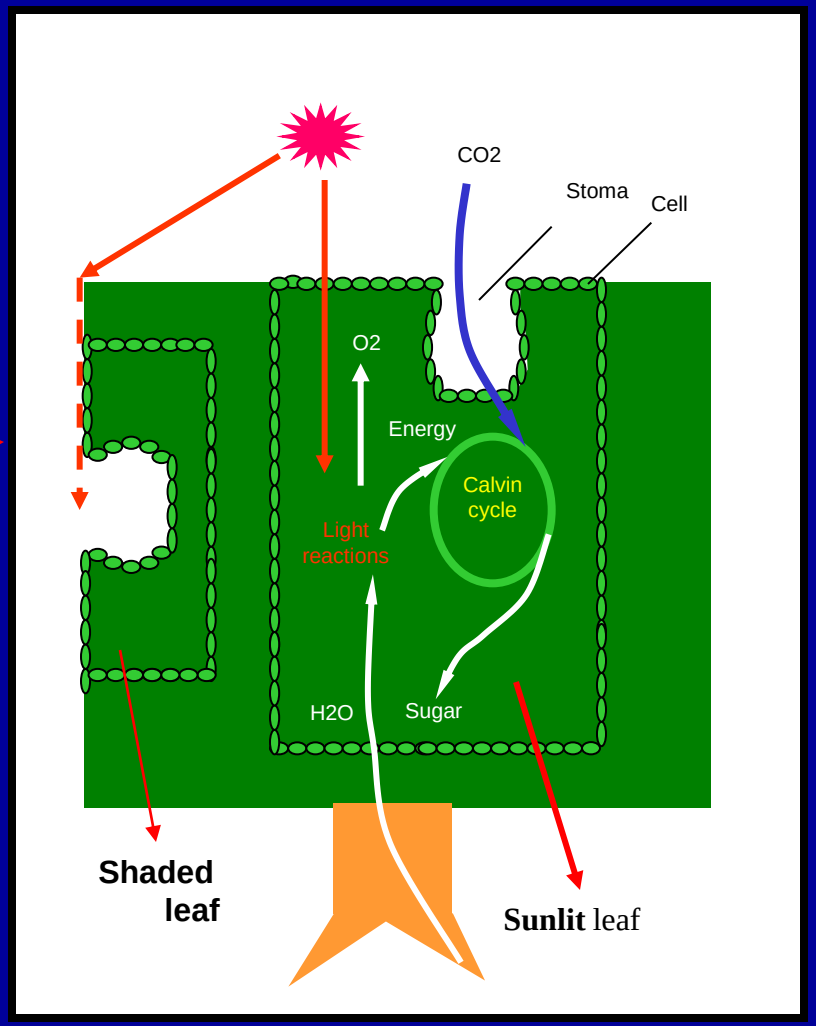
Net carbon balance (NCB) = 2.0 Mt C

# New TRIPLEX-Flux Model Development

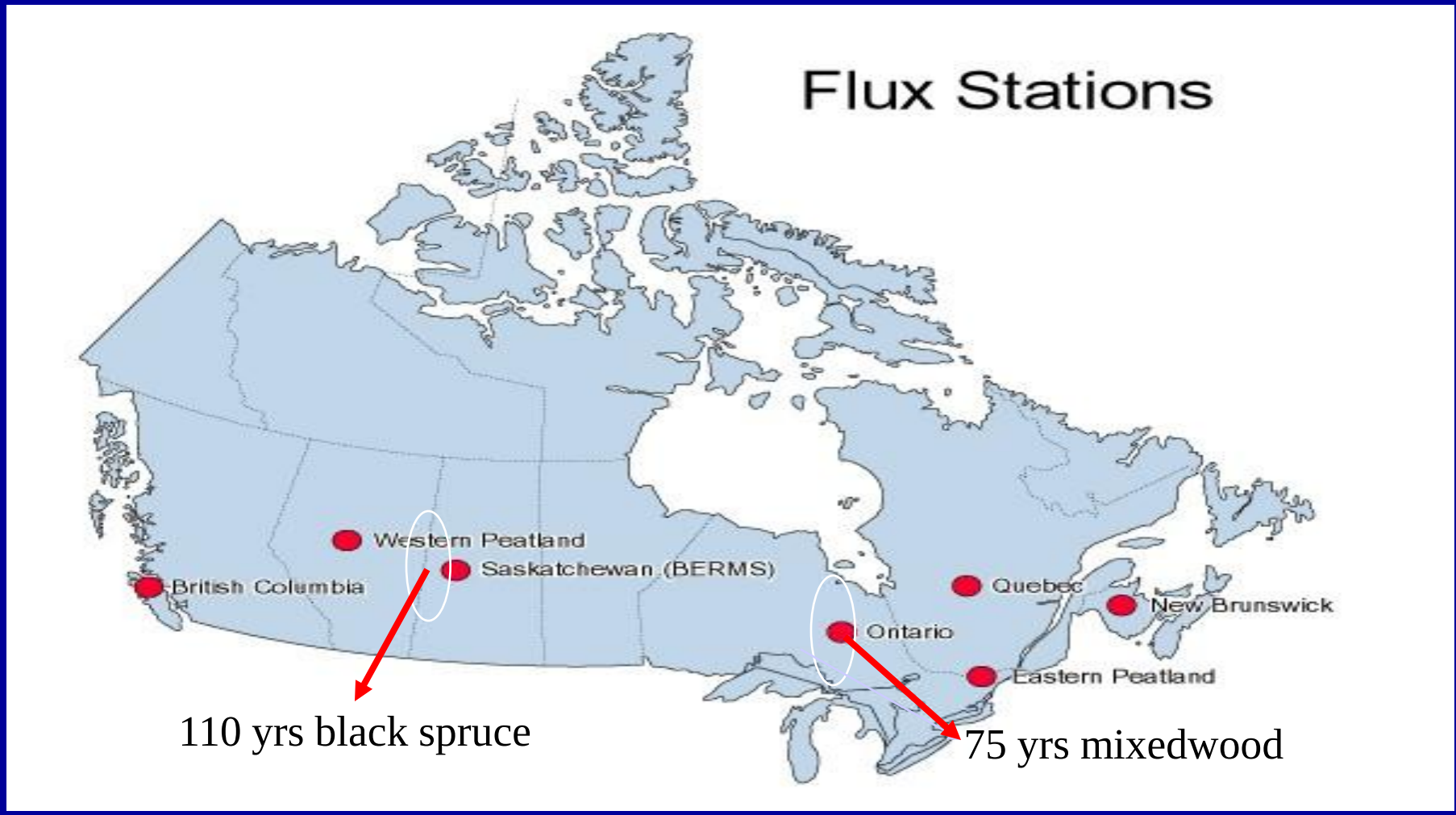
## TRIPLEX1.0 (big leaf, monthly)




## TRIPLEX-Flux (two leaves, daily)

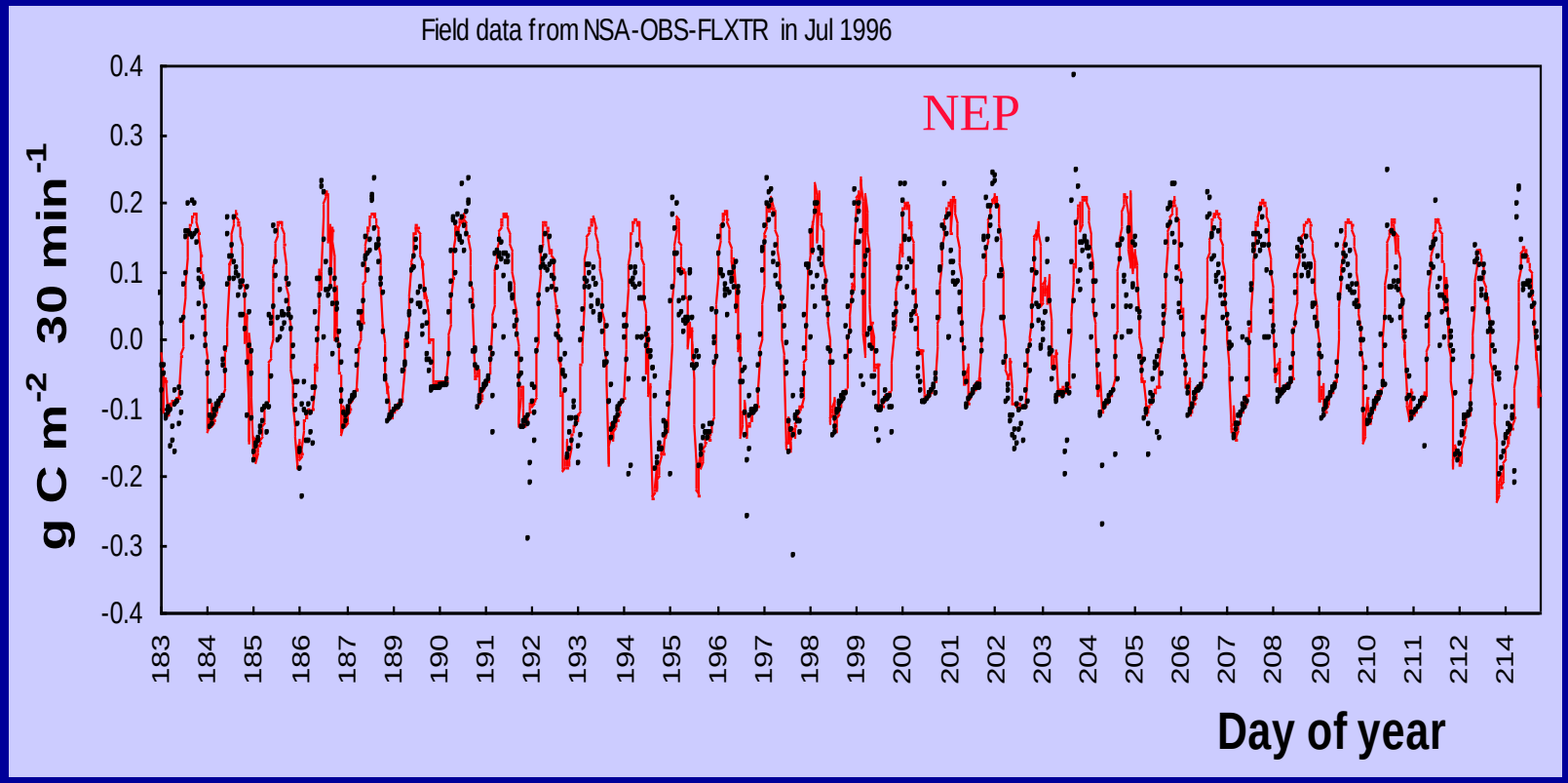


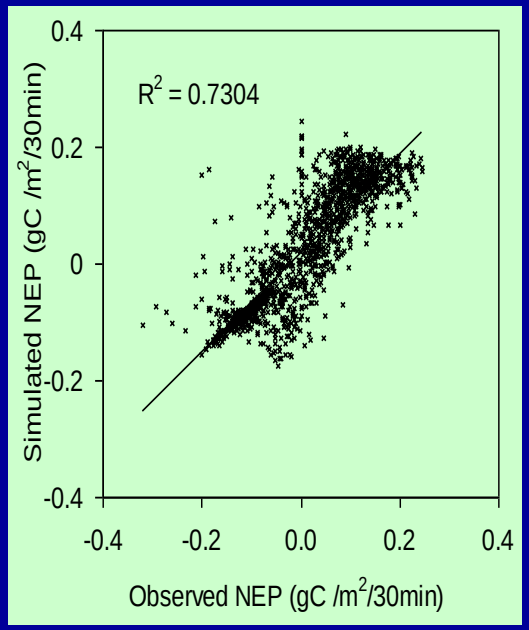
# Model Testing for 2 Flux tower sites




(Fluxnet-Canada)

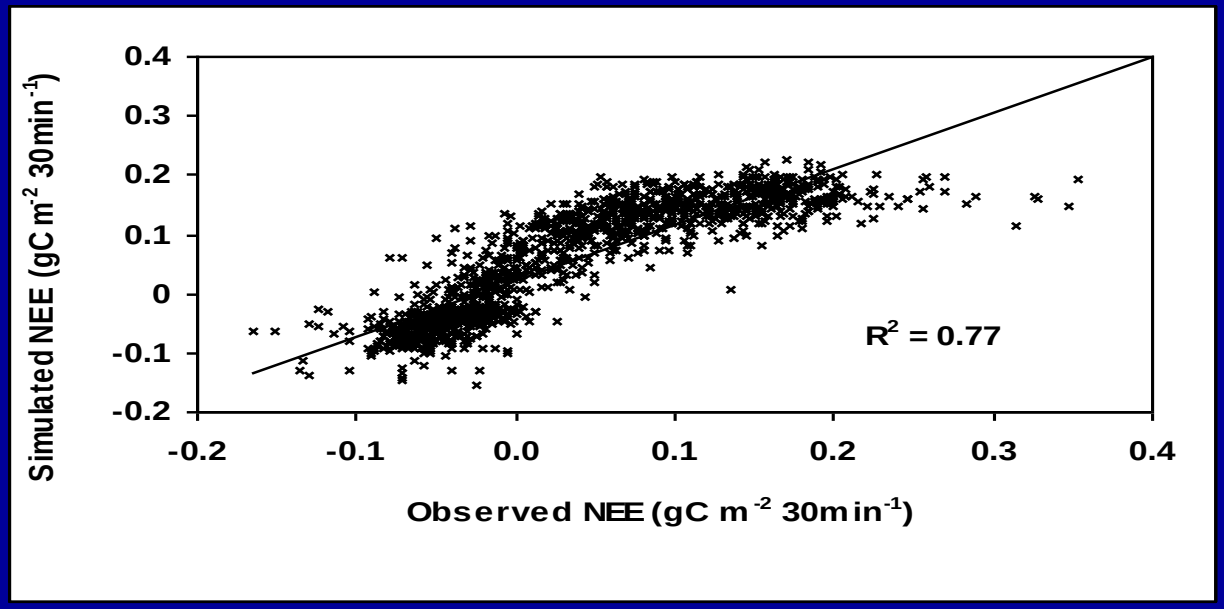
# Model Validation – OBS Flux Tower



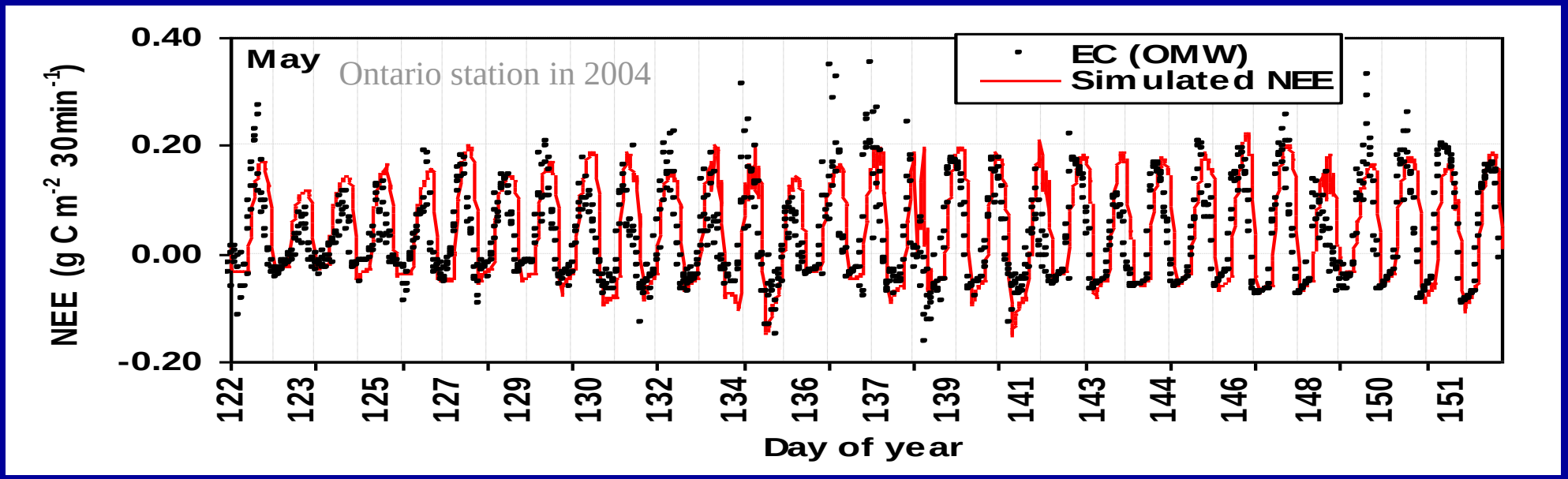




**Daily Simulation using TRIPLEX-flux** (Zhou et al, 2008)

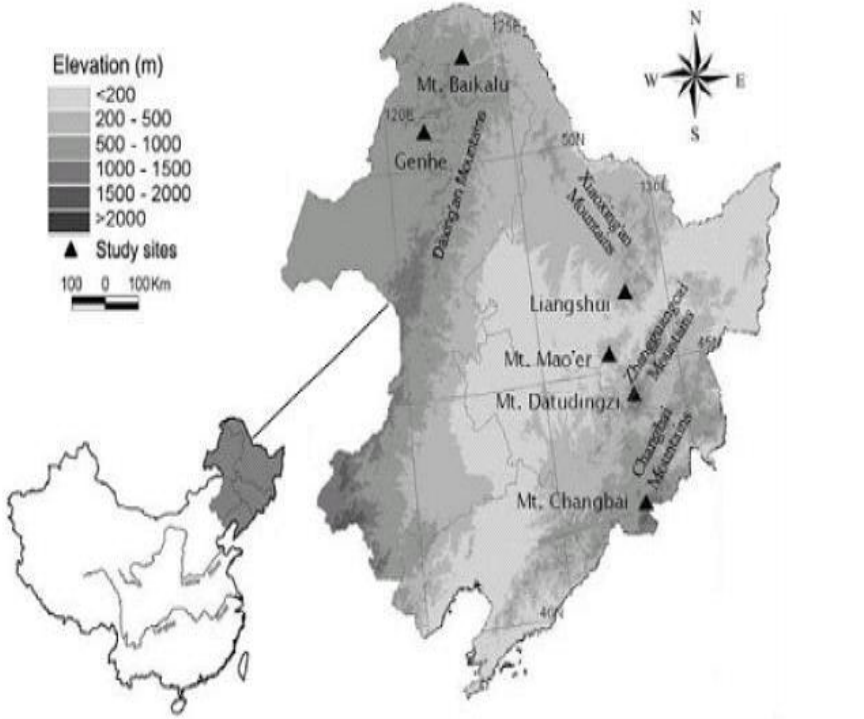
# Boreal Mixedwood Site (Ontario)



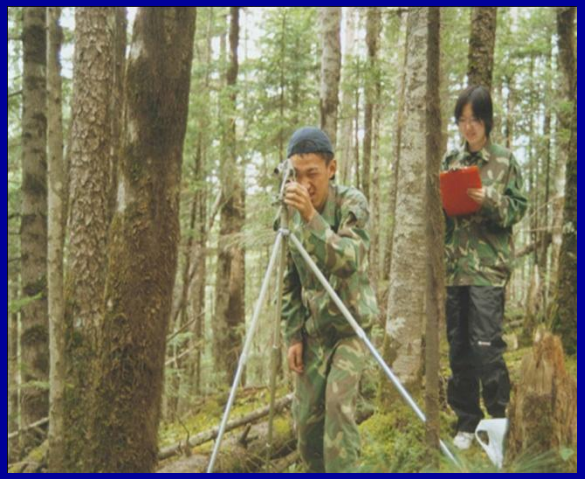

(Sun et al., 2008)



# Quantifying the response of forest carbon balance to future climate change in Northeastern China: Model validation and prediction









**(Peng et al., 2009, G.P.C)**

# Objectives

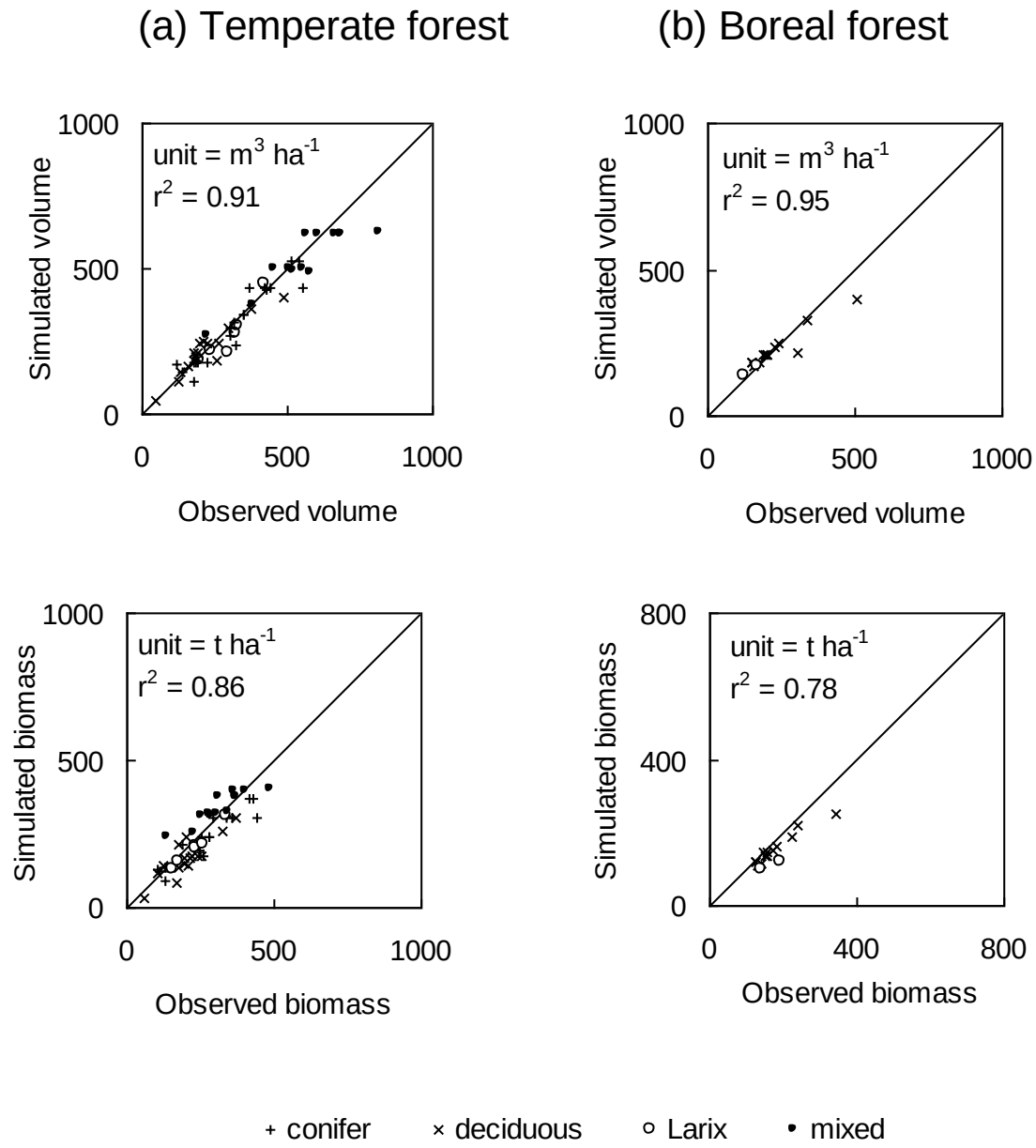
(1) Validate the TRIPLEX1.0 model using a comprehensive ground observations and measurements;

(2) Simulate the temporal and spatial response of NPP and carbon balance under projected future climate change and increasing $CO_2$ scenarios

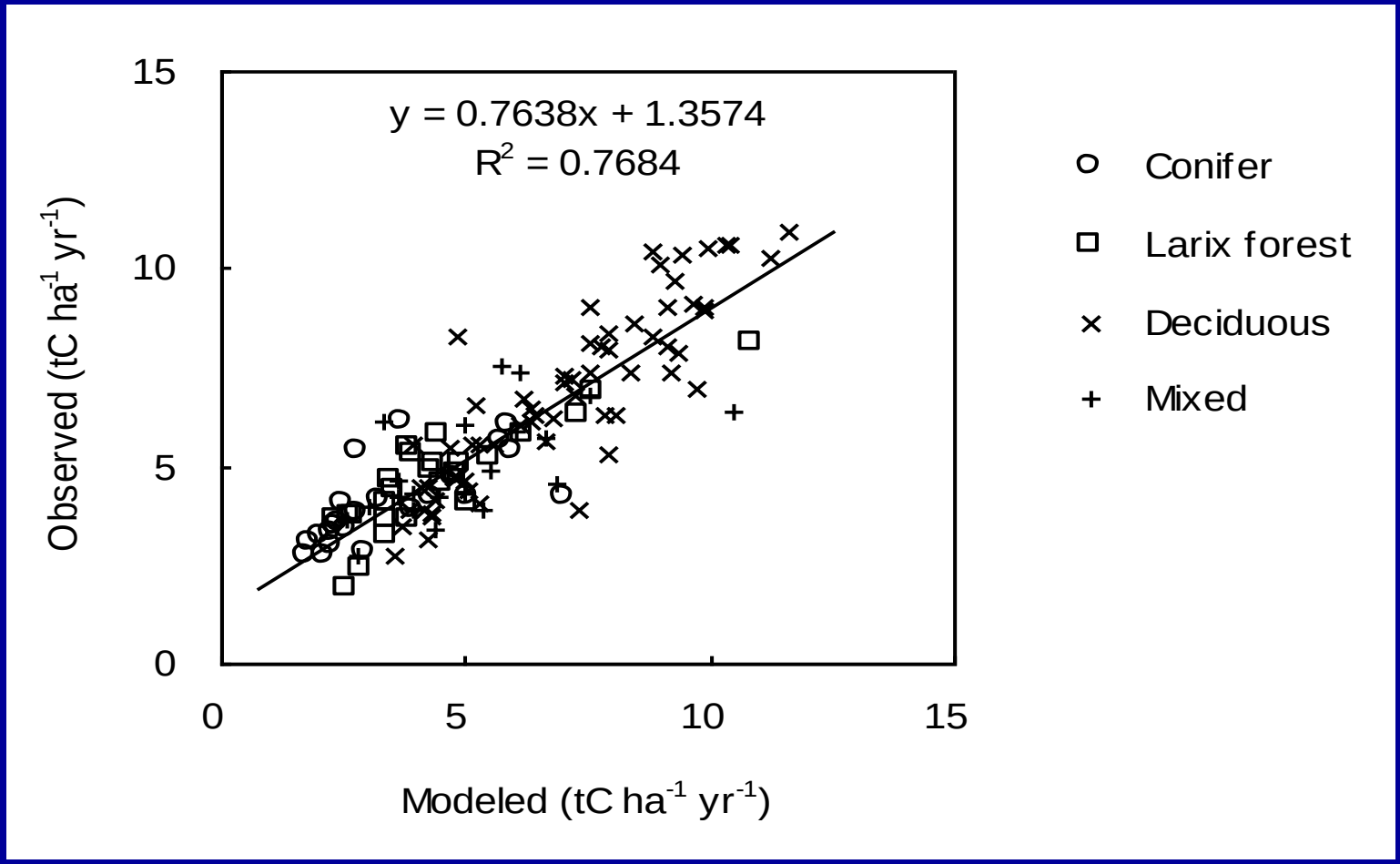
# Model Validation

**Comparisons of tree volume and aboveground biomass between model simulations and observed data that were measured from 70 forest plots across 6 sites in northeast of China during 2000-2004.**

(Peng et al, GPC, 2009)



# NPP (Net Primary Productivity)



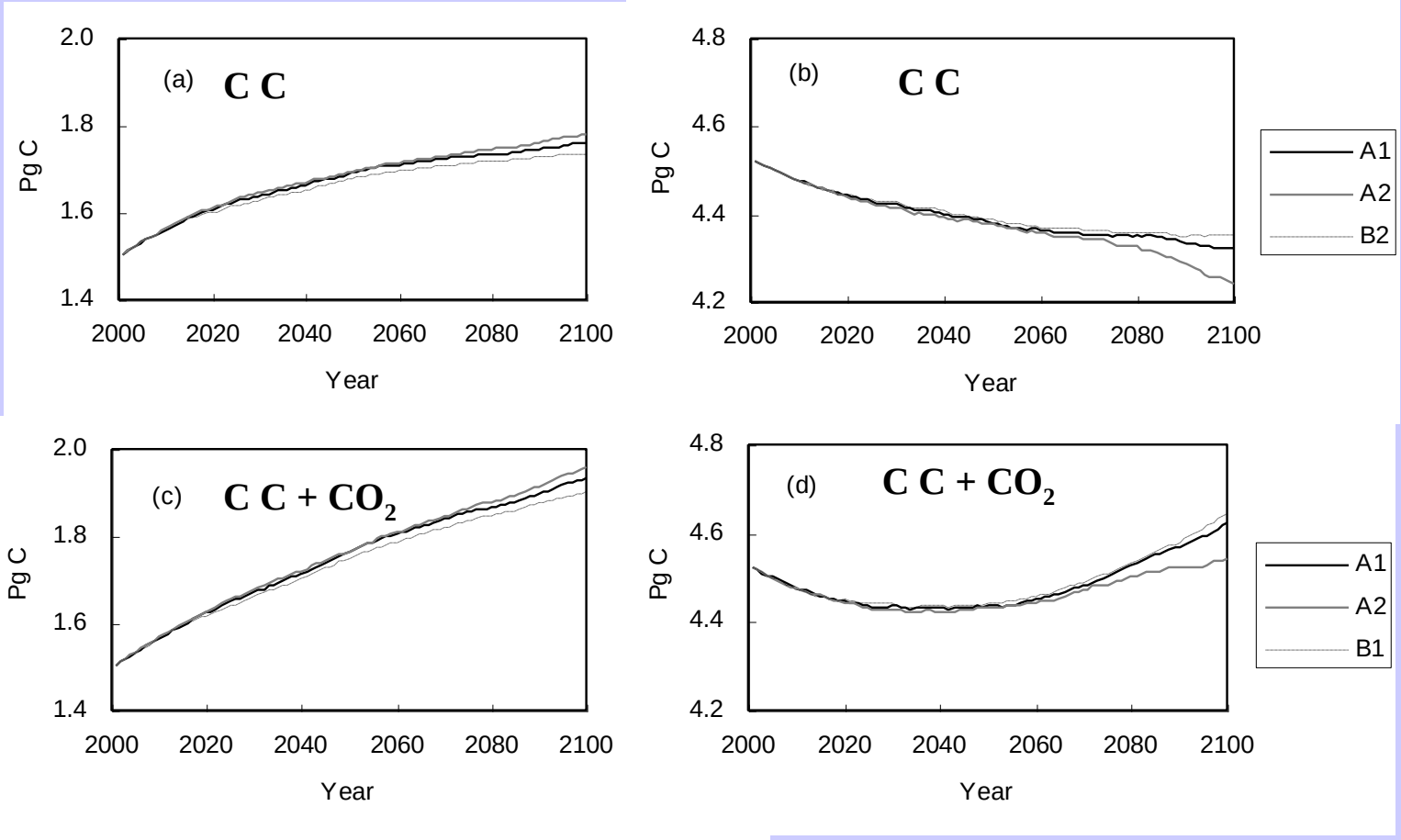

Comparison of simulated forest NPP against 133 observed forest NPP in northeastern China. The observed forest NPP data sets are obtained from the most comprehensive database complied by the PhD dissertation of Luo (1999) and Ni et al. (2001).

**CGCM3.1 (IPCC, 2005)**

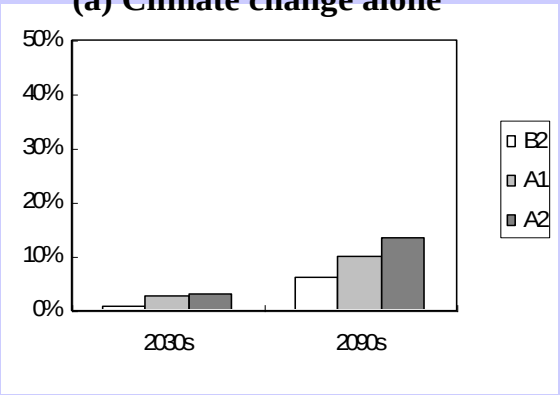
## Total Biomass

## Soil Carbon

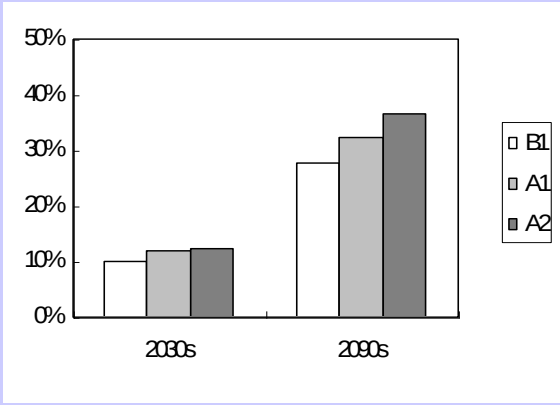
## (T: + 4, 3, 2 ºC )




**(a) Climate change alone**



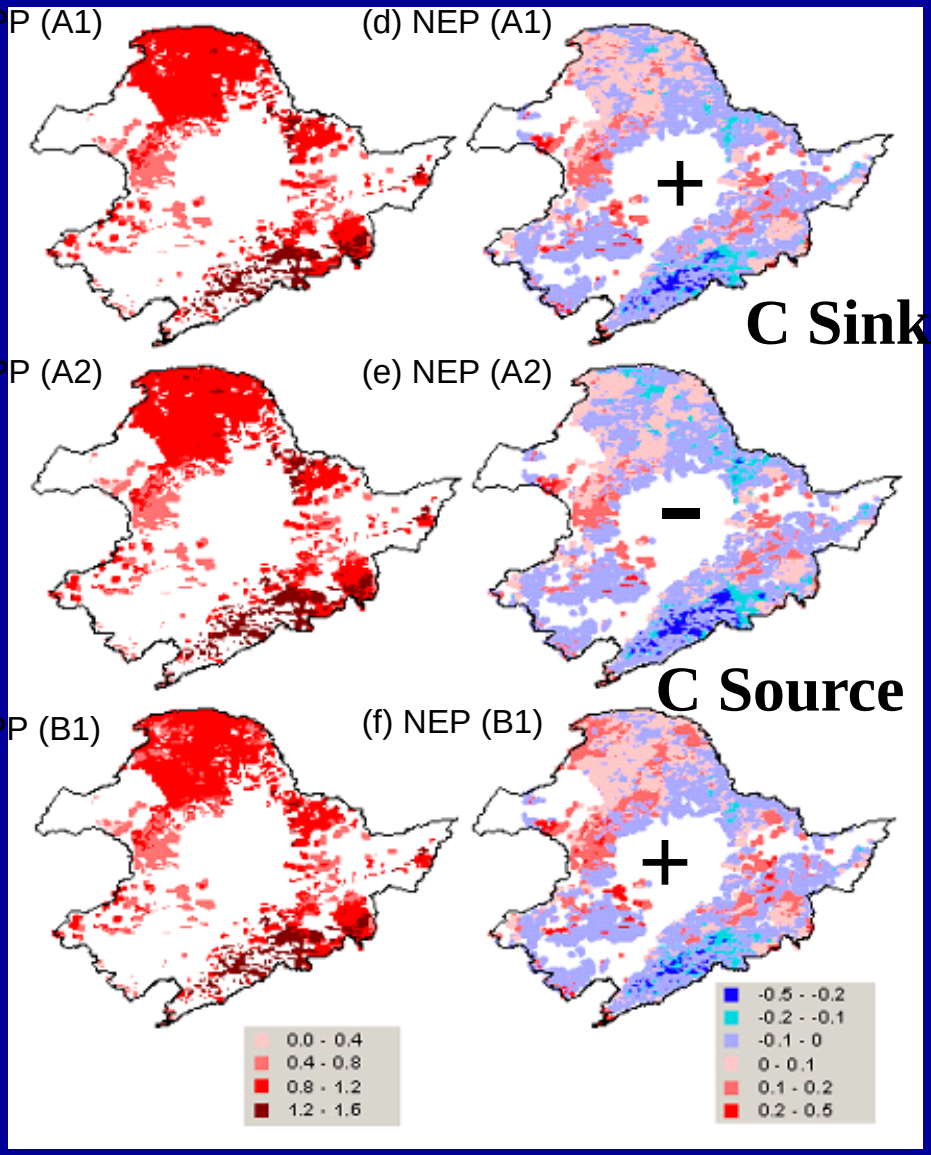

**(b) Climate change and increasing $CO_2$**

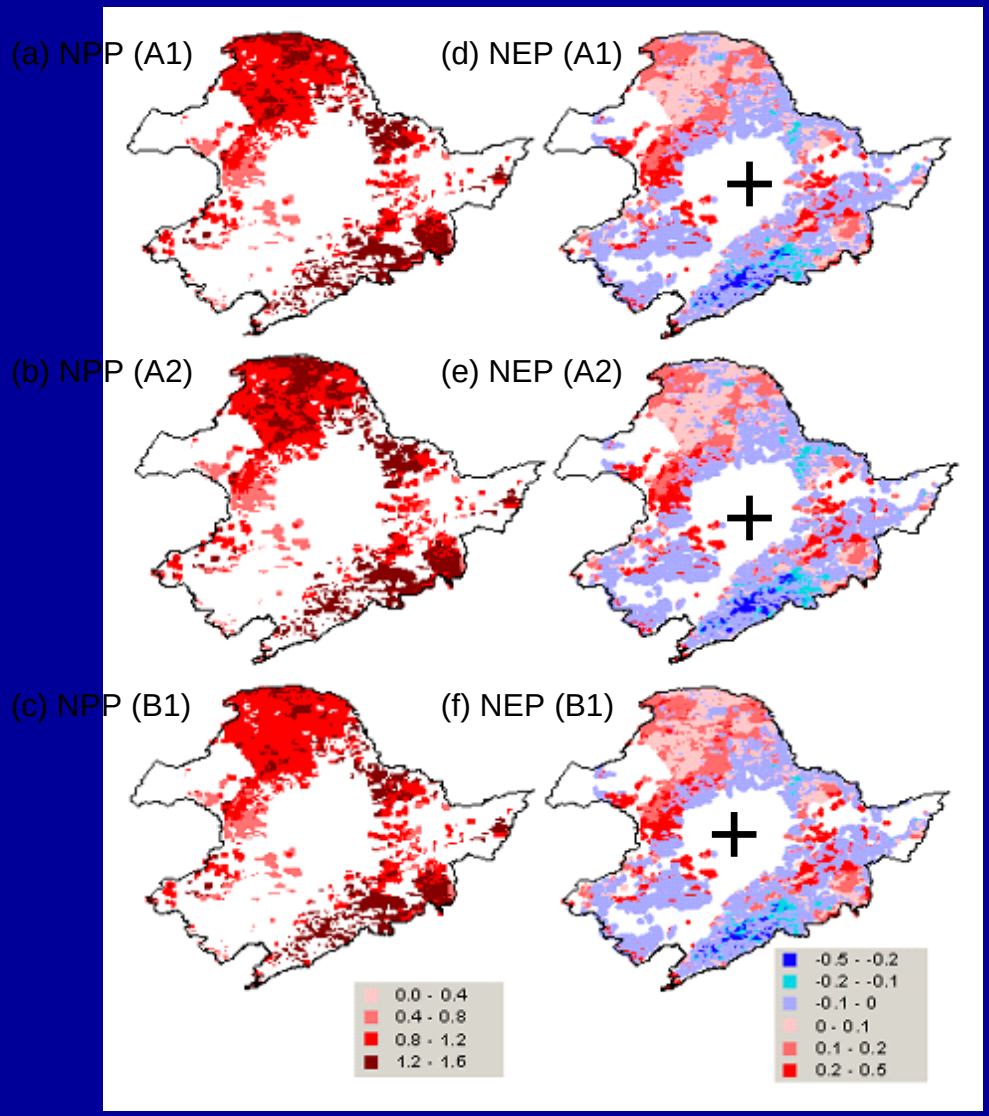



(CO2: +850, 700, 550ppm)

## (a) Climate change along (CC)

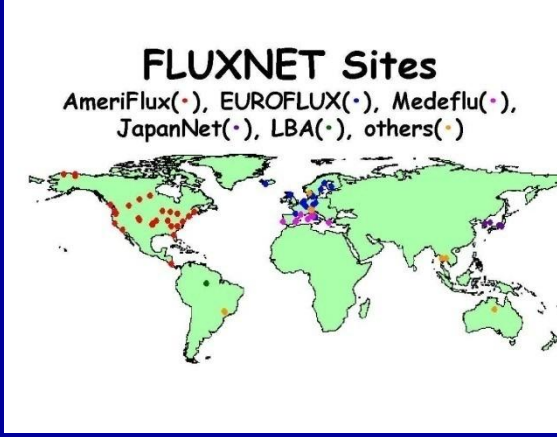
## (b) CC + CO2 fertilization effect



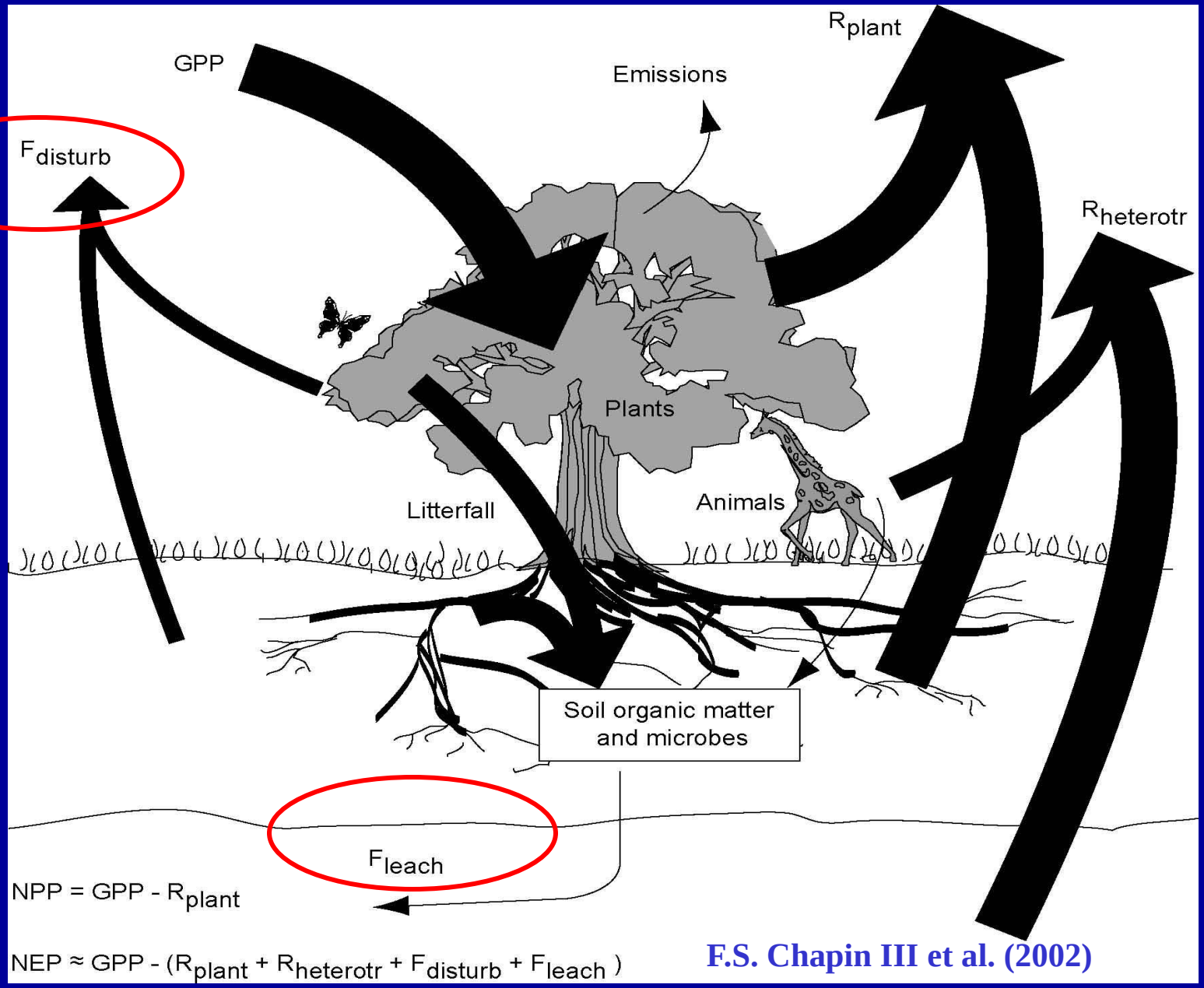
# Challenges for Science

- **Weaknesses in Scientific Understanding:**
  - *Allocation of C in plant tissues*
  - *Nutrient feedback*
  - *$CO_2$ fertilization at ecosystem scale* - is it real? important?
  - Projecting *changes in disturbance regimes (fire, insect, harvesting, ice damage…)*
  - *Wetlands, Peatland carbon dynamics*
  - *etc….*




Proposed Sites, Fluxnet-Canada

# Uncertainty in Ecosystem Carbon Budget



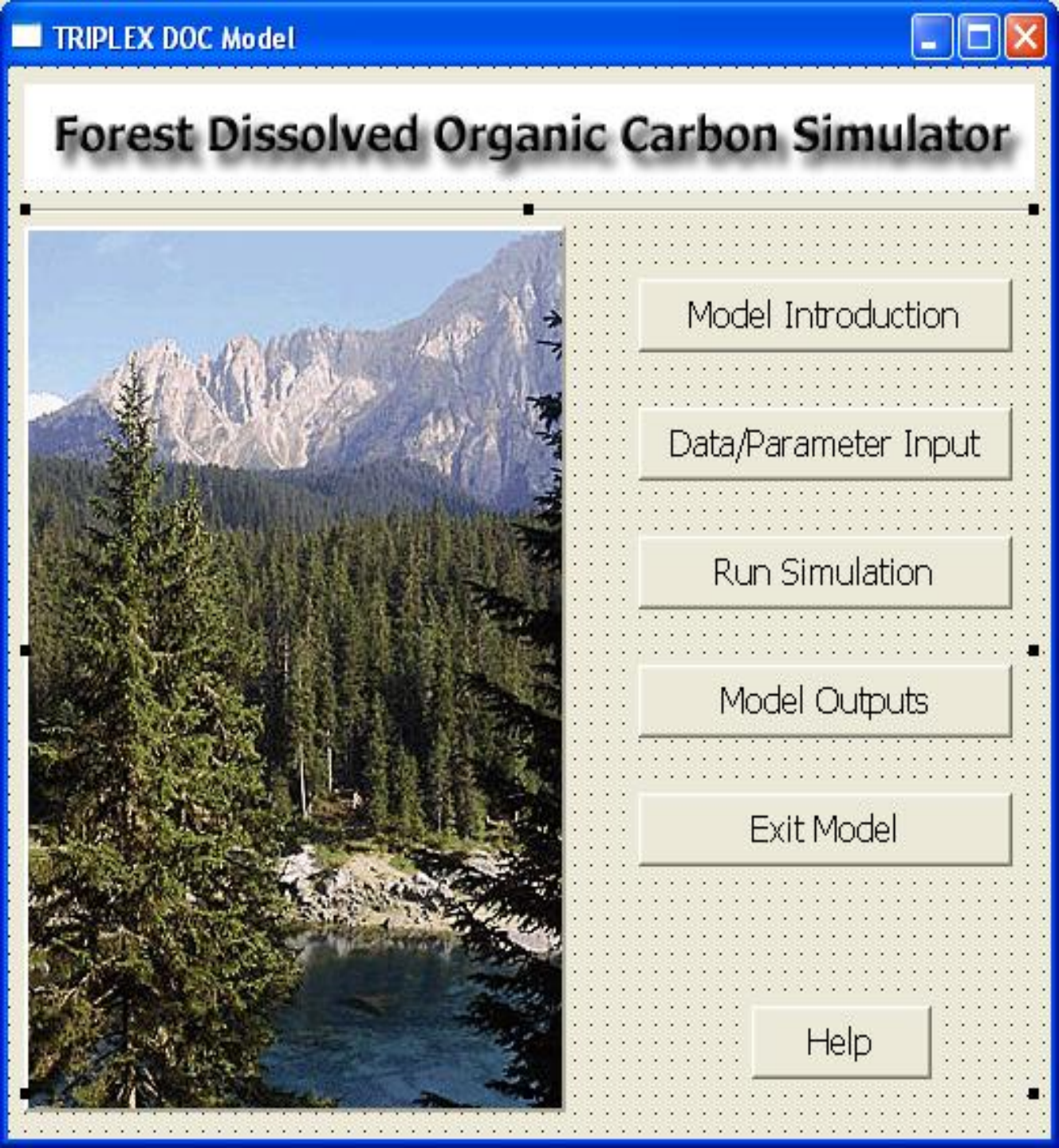

F.S. Chapin III et al. (2002)

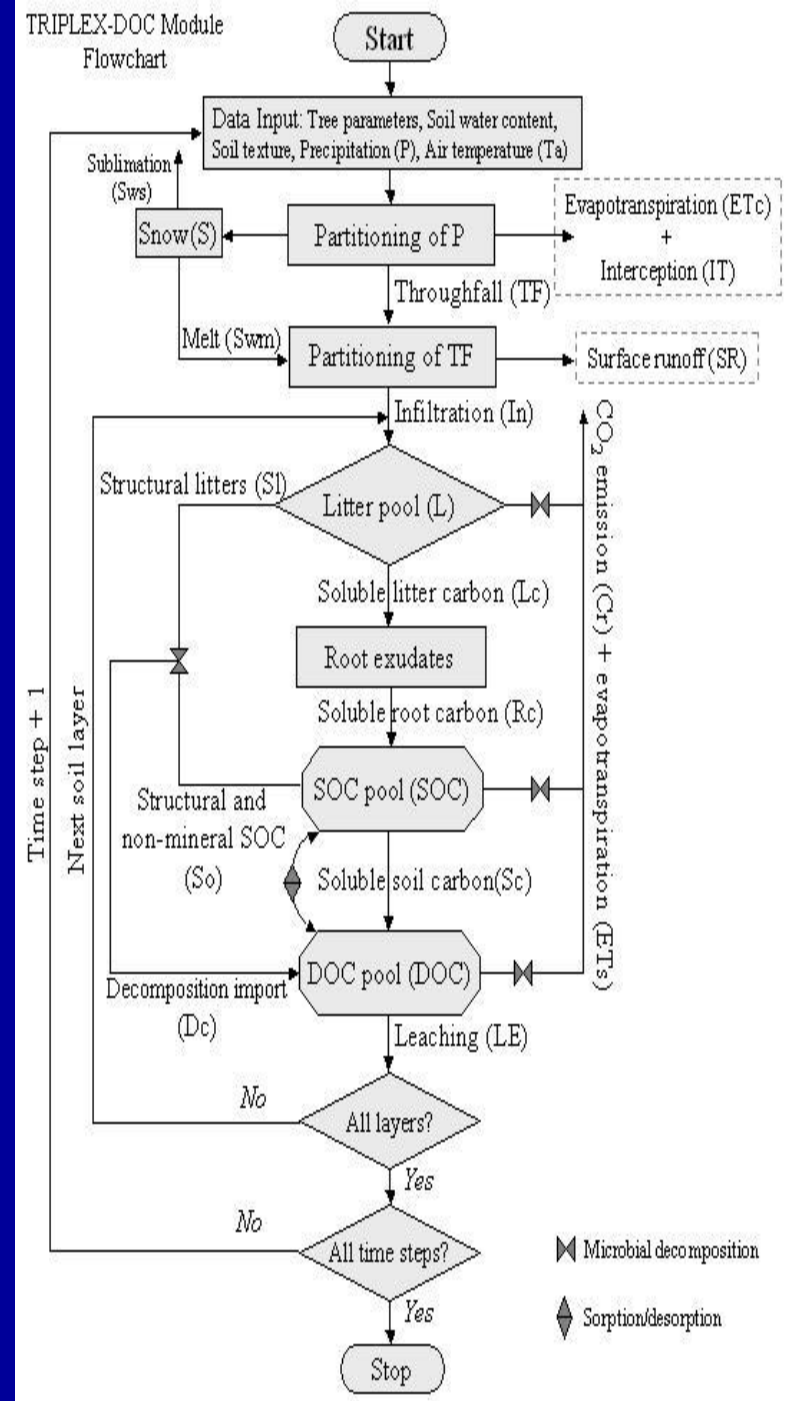
# Challenges for TRIPLEX Development

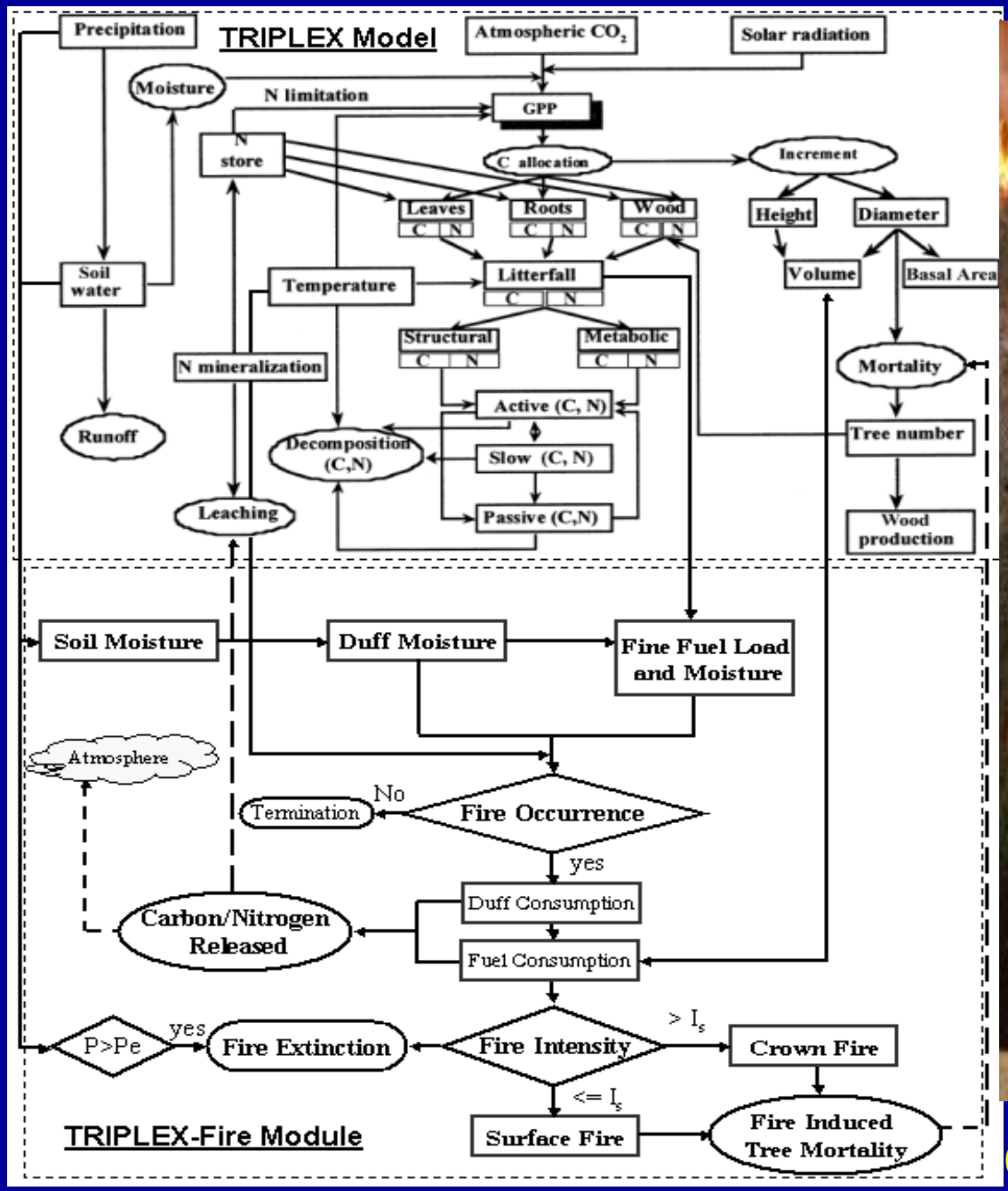
- **Continued testing of the model's ability to belowground biomass, soil C, N and water (BOREAS sites as well as Canada-Fluxnet)**

- **Developing submodels (TRIPLEX-Fire, TRIPLEX-DOC, TRIPLEX-management, TRIPLEX-Aquatic) to include the effects of $CO_2$ fertilization, ecosystem disturbances (fire, harvesting, insects, disease), land use, and forest management planning**

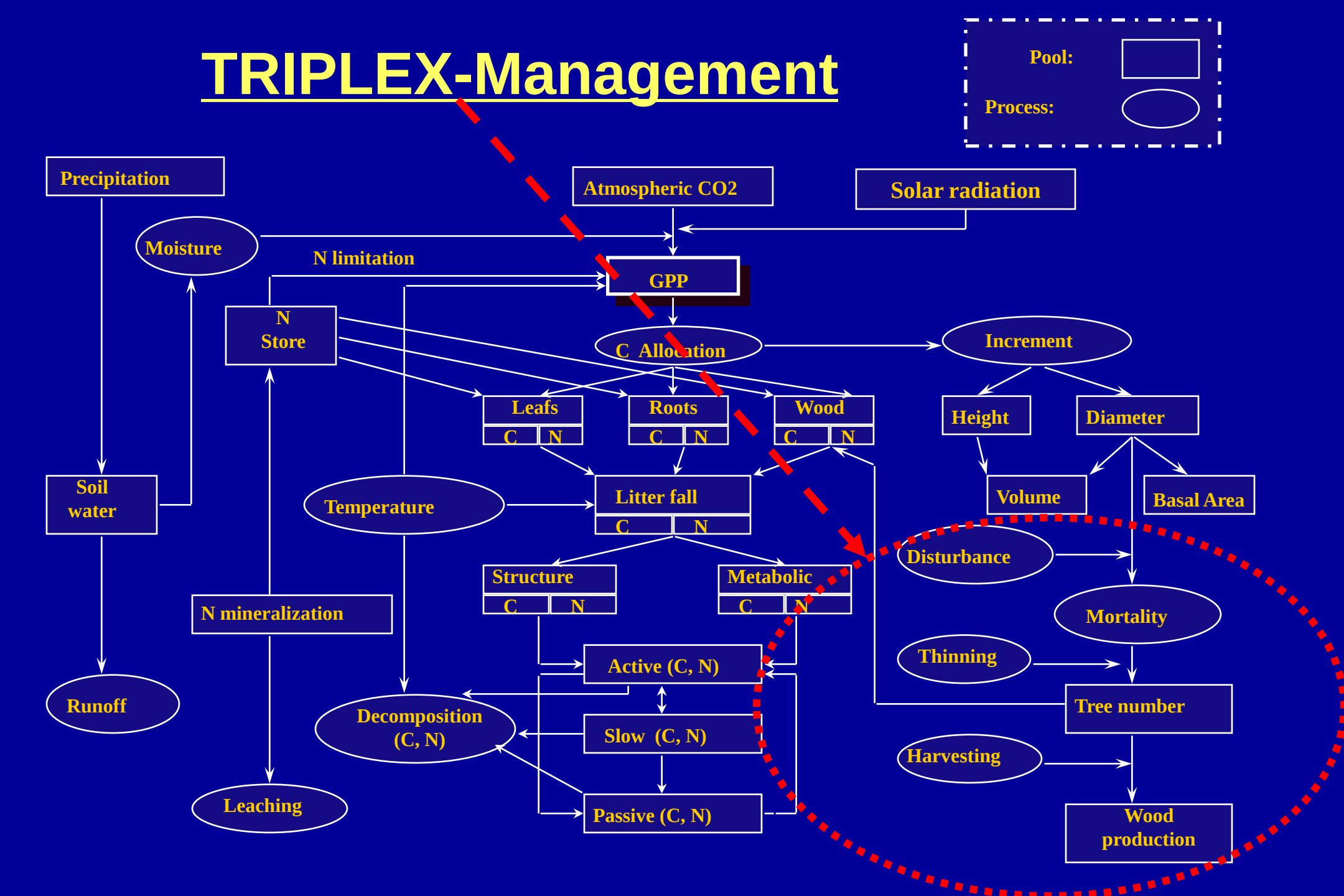
- **Scaling up — linking TRIPLEX with remote sensing and GIS**
  (estimated PAR, LAI through NDVI, etc…)


TRIPLEX DOC Model
Forest Dissolved Organic Carbon Simulator
Model Introduction
Data/Parameter Input
Run Simulation
Model Outputs
Exit Model
Help


TRIPLEX-DOC Module Flowchart
Start
Data Input: Tree parameters, Soil water content, Soil texture, Precipitation (P), Air temperature (Ta)
Sublimation (Sws)
Snow (S)
Partitioning of P
Evapotranspiration (ETc) + Interception (IT)
Throughfall (TF)
Melt (Swm)
Partitioning of TF
Surface runoff (SR)
Infiltration (In)
Structural litters (Sl)
Litter pool (L)
Soluble litter carbon (Lc)
Root exudates
Soluble root carbon (Rc)
SOC pool (SOC)
Structural and non-mineral SOC (So)
Soluble soil carbon (Sc)
DOC pool (DOC)
Decomposition import (Dc)
Leaching (LE)
No
All layers?
Yes
No
All time steps?
Yes
Stop
Time step + 1
Next soil layer
CO2 emission (Cr) + evapotranspiration (ETs)
Microbial decomposition
Sorption/desorption




**Ongoing: TRIPLEX-Fire Model**


TRIPLEX-Management
Pool:
Process:
Precipitation
Atmospheric CO2
Solar radiation
Moisture
N limitation
GPP
N
Store
C Allocation
Increment
Leafs
C
N
Roots
C
N
Wood
C
N
Height
Diameter
Soil
water
Temperature
Litter fall
C
N
Volume
Basal Area
Disturbance
Structure
C
N
Metabolic
C
N
N mineralization
Mortality
Thinning
Active (C, N)
Runoff
Decomposition
(C, N)
Slow (C, N)
Tree number
Harvesting
Leaching
Passive (C, N)
Wood
production

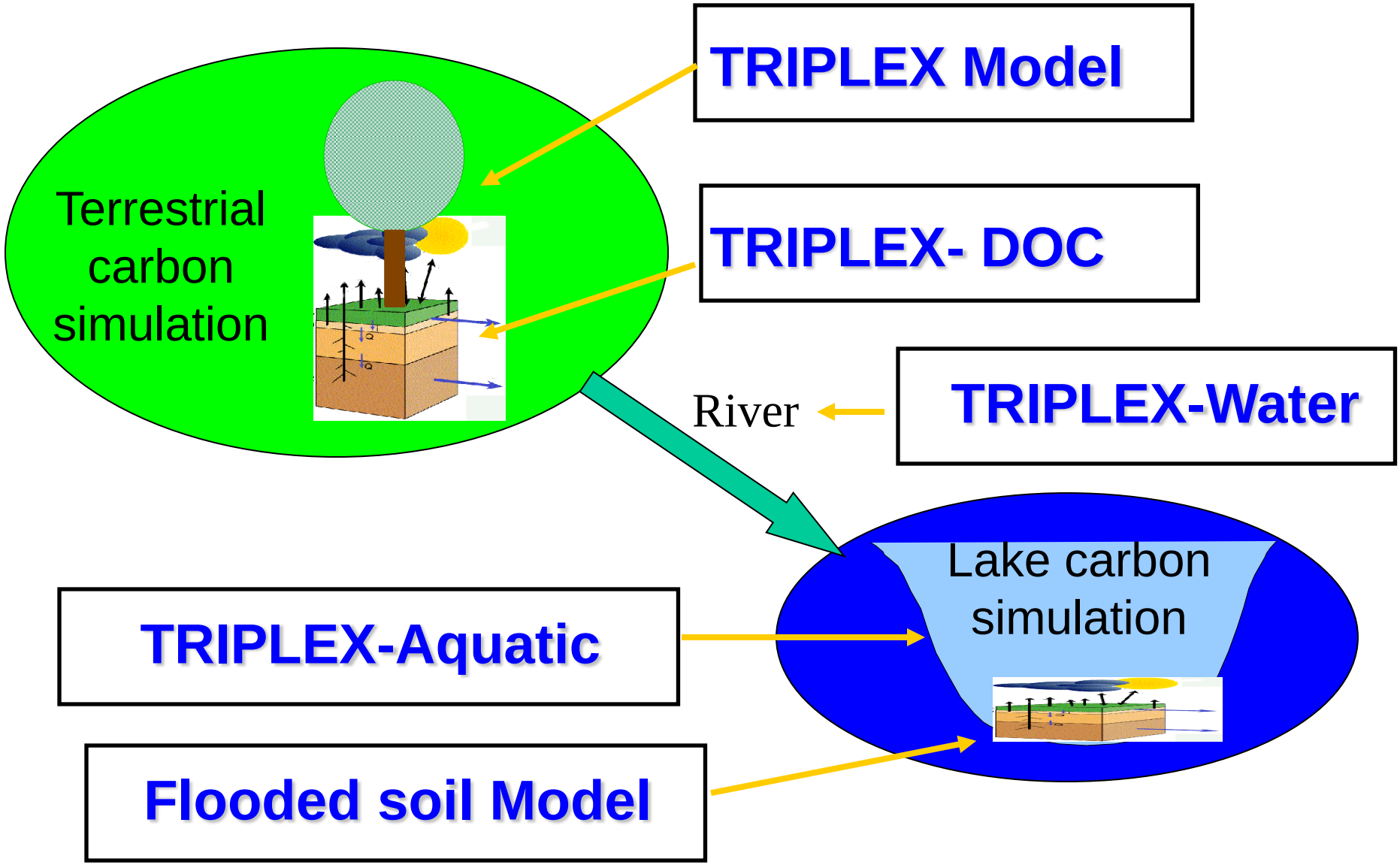
# Modeling and Coupling Terrestrial and Aquatic Ecosystems: Issues, recent development and future challenges

# TRIPLEX Family Framework

Empirical model + Process-based model

⇩

Coupled model



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***Mrs. Susan Parton,*** *Lake Abitibi Model Forest*

**Open for**
**Questions &**
**Collaborations !**

**Merci Beaucoup!**