Nested Inversion of the North America Carbon Flux with Forest Stand Age and ^{13}C Constraints

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Canadian Carbon Program

University of Toronto

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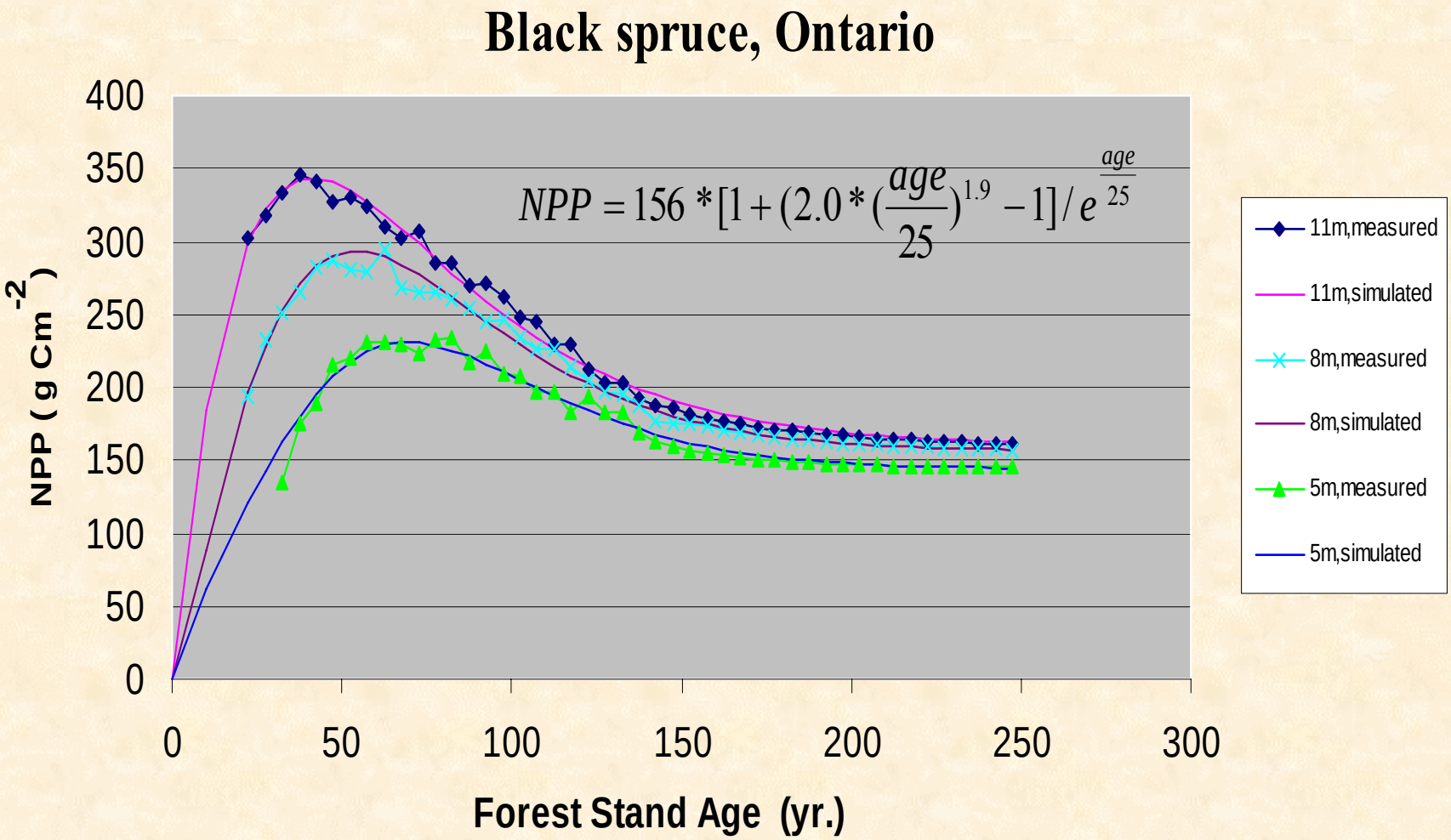
CANADIAN CARBON PROGRAM PROGRAMME CANADIEN DU CARBONE

Outline

- Bottom-up
  - Forest age and carbon cycle in Canada
  - Forest age and carbon cycle in USA
  - Continent-wide forest age map and age factor map
- Top-down
  - Comparison of inversion results with Carbon Tracker
  - Inversion with and without the age factor map
  - Comparison with bottom-up results in Canada
- Tightening the top constraint with ^{13}C
  - Data and model preparations

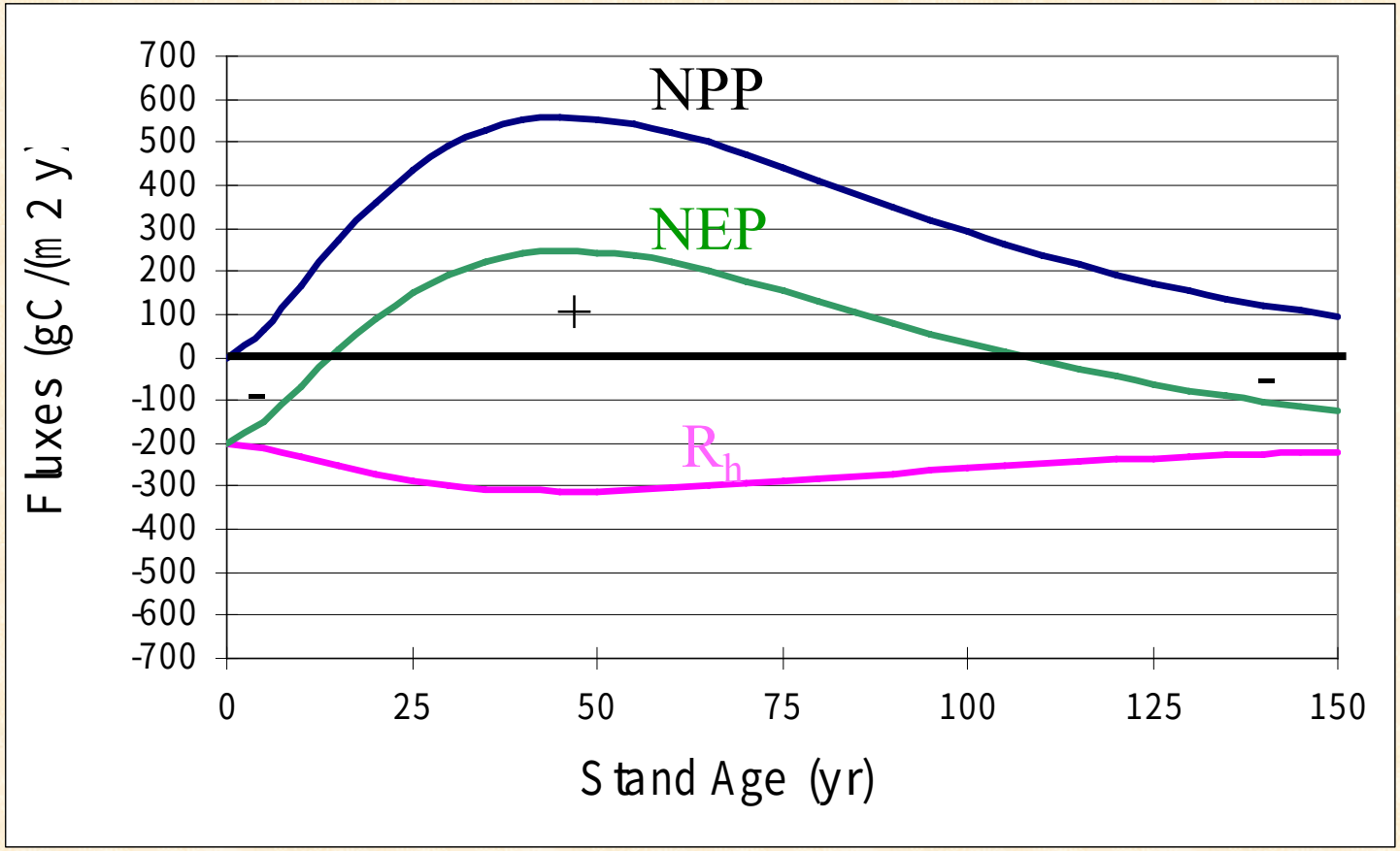
Bottom-up

Variation of NPP with Forest Stand Age

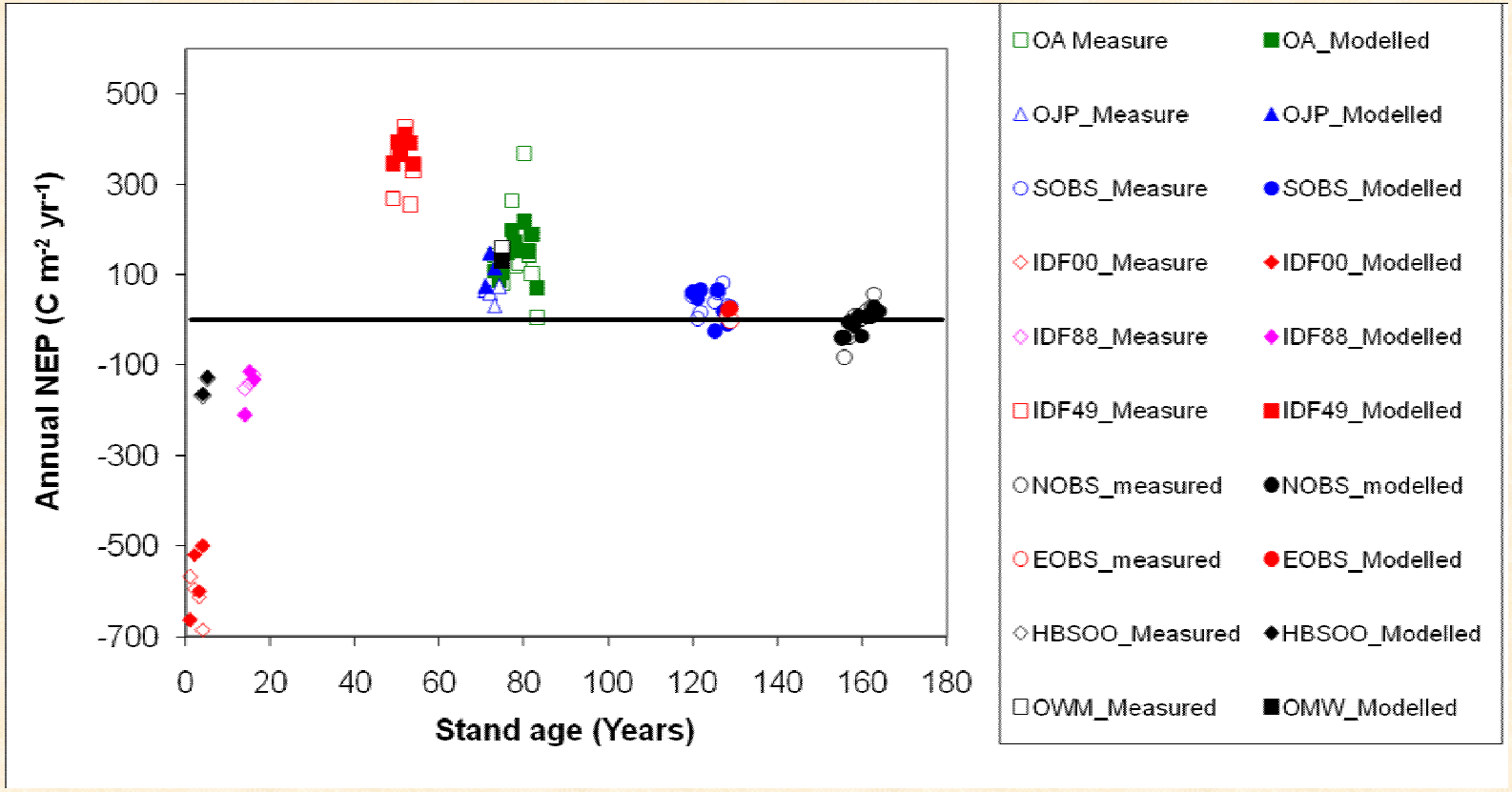


Ref.: Chen et al. (2002); Chen et al. (2003)

NPP varies much more than Rh, causing large NEP variations with age

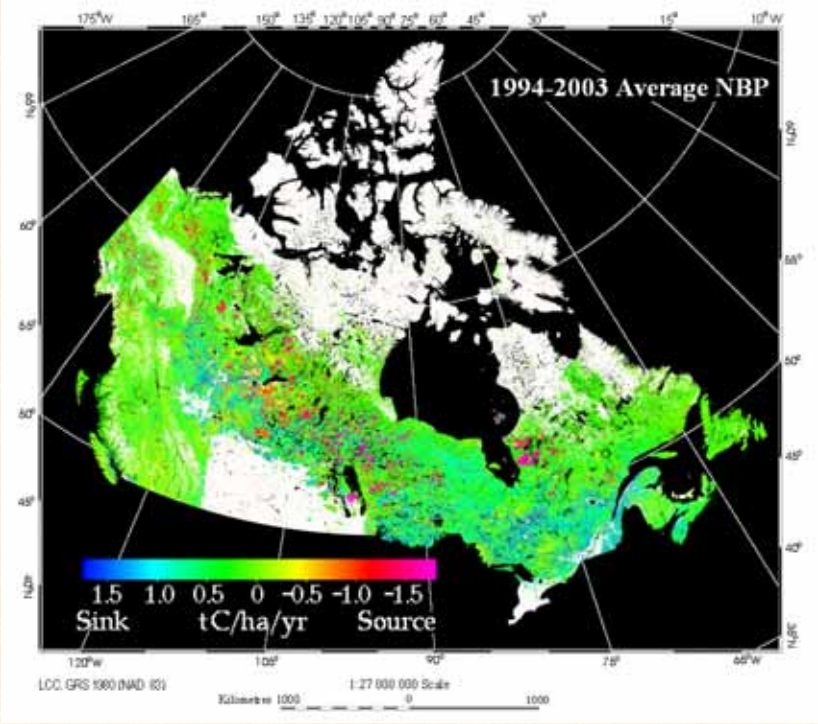


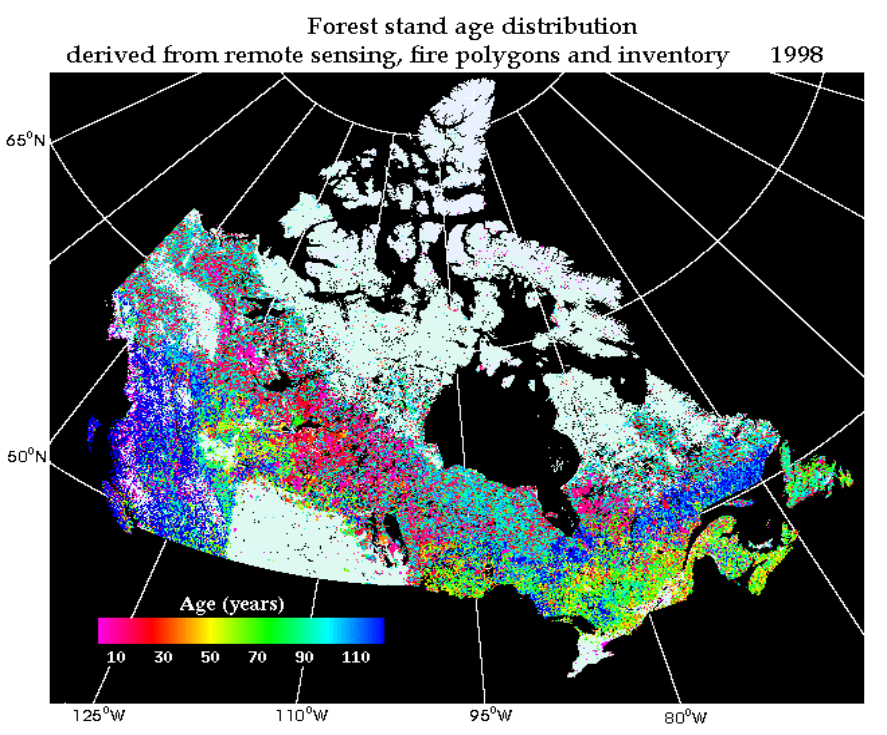
Measured and Modeled NEP at CCP Tower Sites Against Forest Stand Age



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*)

Spatial Distribution Patterns of Net Biome Productivity (NBP) and Forest Age

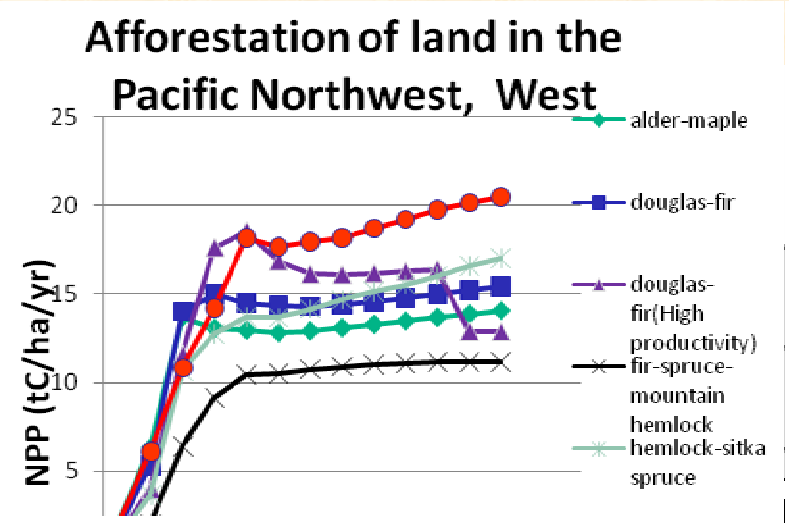


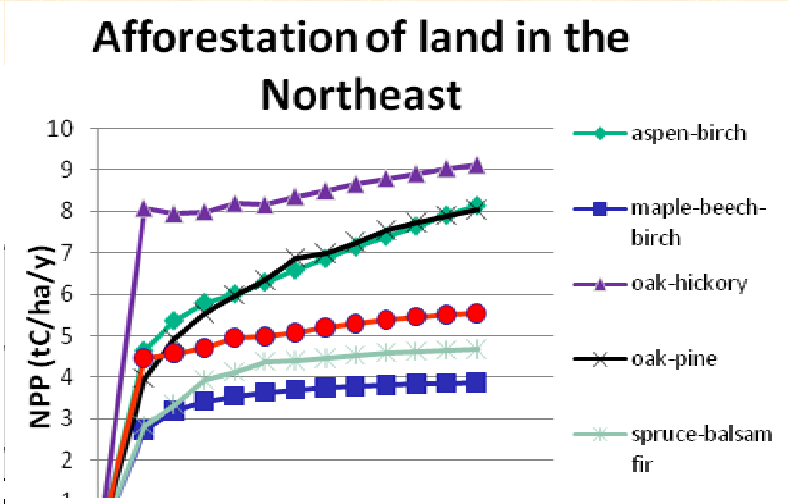


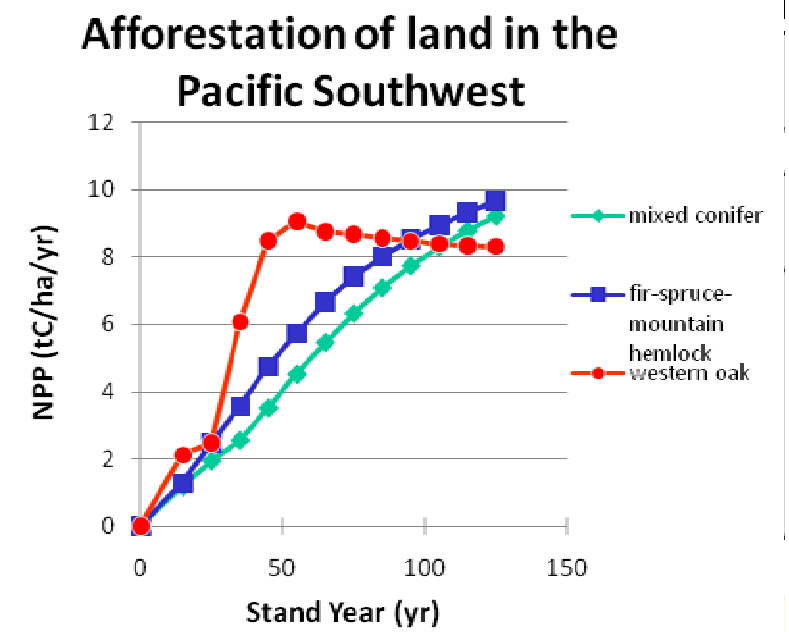
Simulation period 1901-2003
Including disturbance and non-disturbance factors

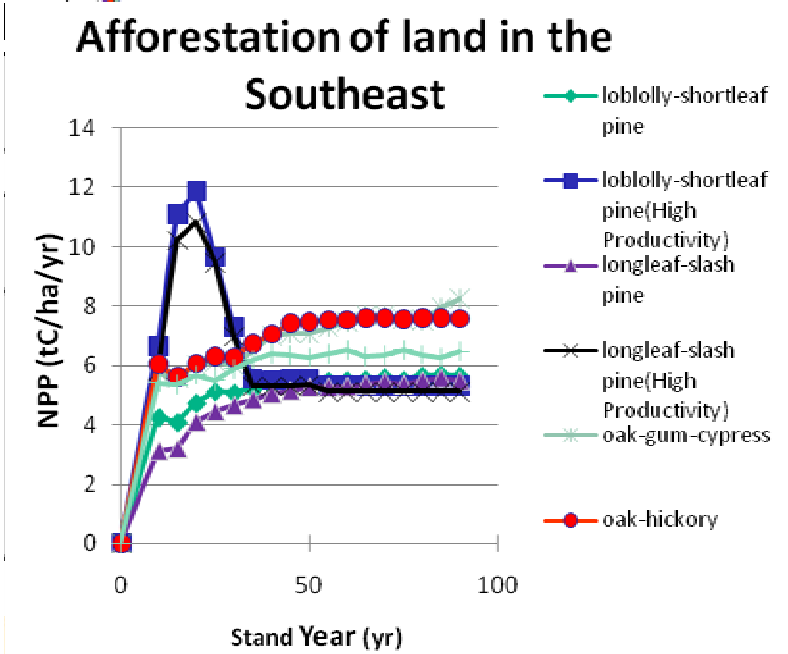
Chen et al. (2003, *Tellus*); Ju et al. (2006, *Tellus*)

NPP-Age Relationships Derived from FIA biomass and mortality data



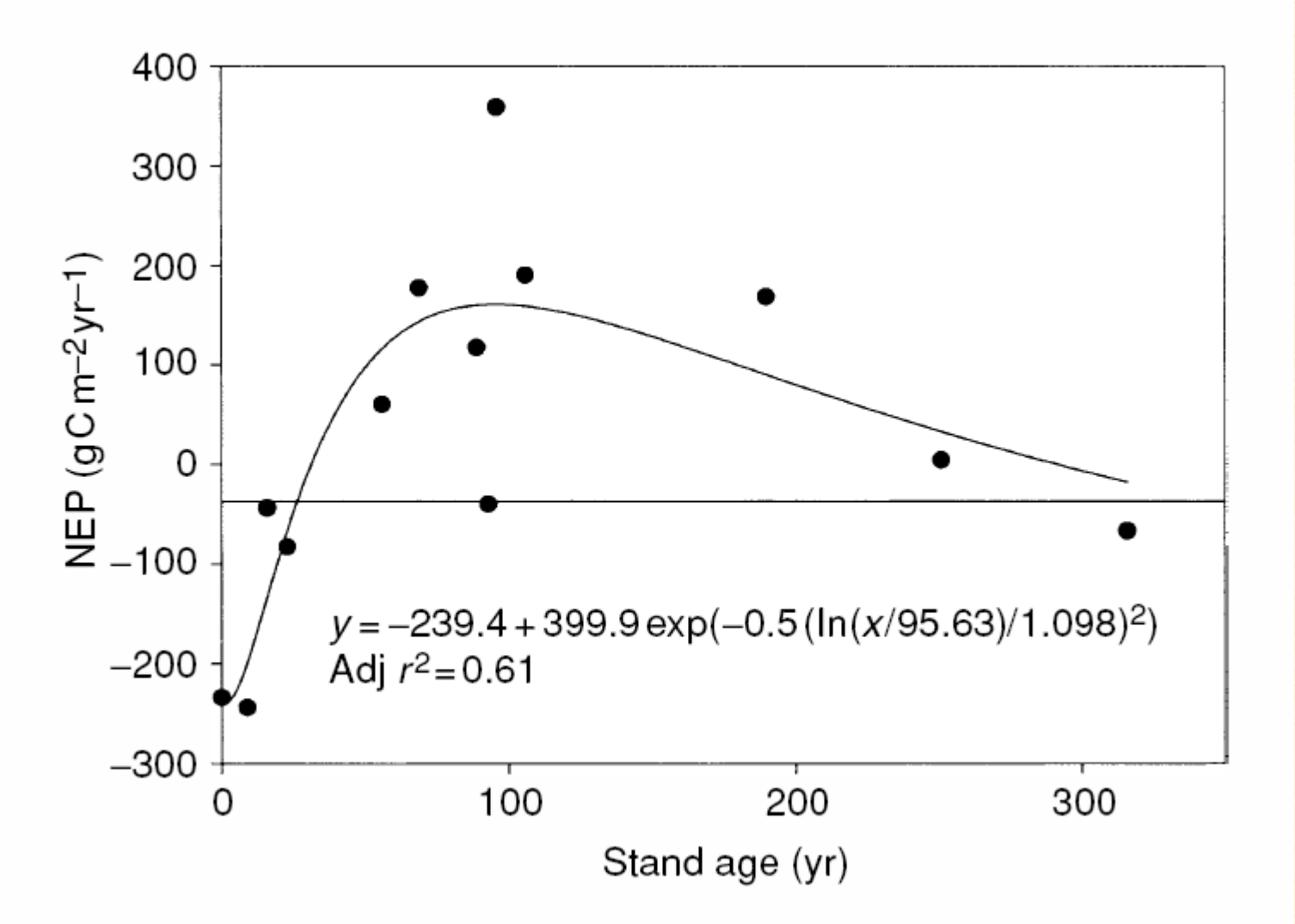






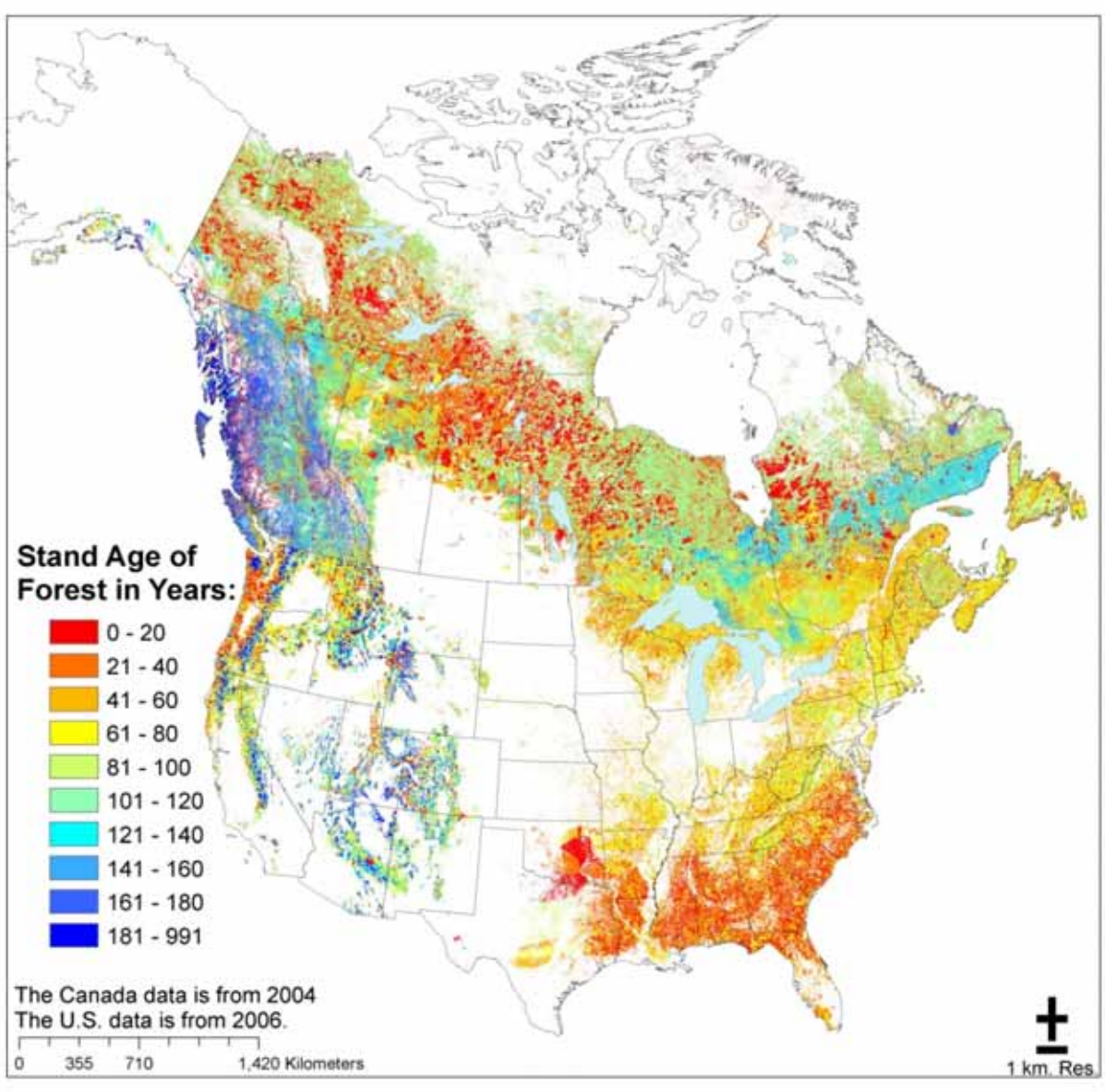
NEP vs. Forest Age in Oregon, USA

Law et al., (2003, *GCB*)



North America Forest Stand Age Distribution in 2000

(Version 1)

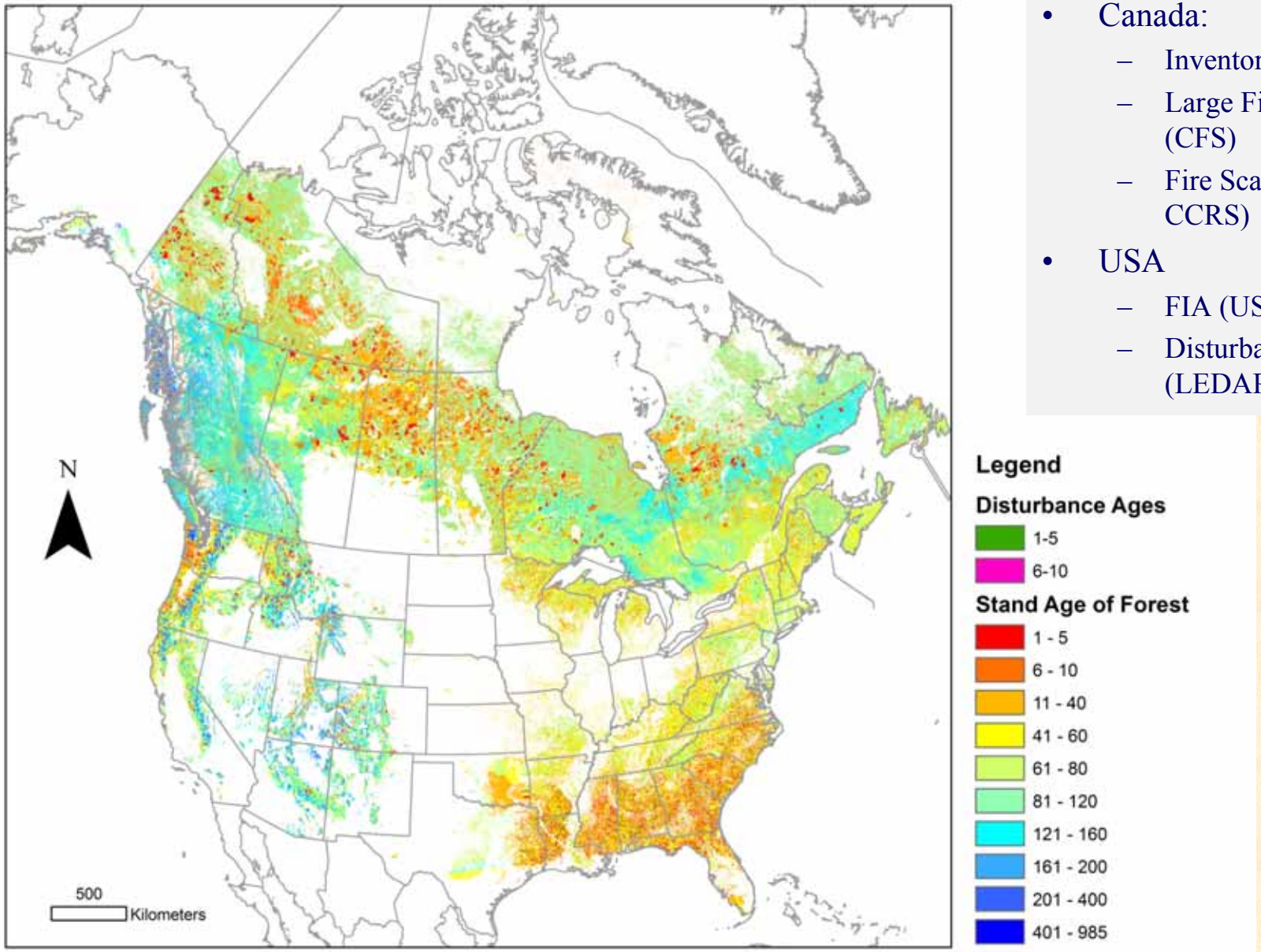


- Canada:
  - Inventory (CFS)
  - Large Fire Polygons (CFS)
  - Fire Scars (U of T, CCRS)
- USA
  - FIA (USDA)

FIA data: Rich Birdsey, Yude Pan, Kevin McCullough

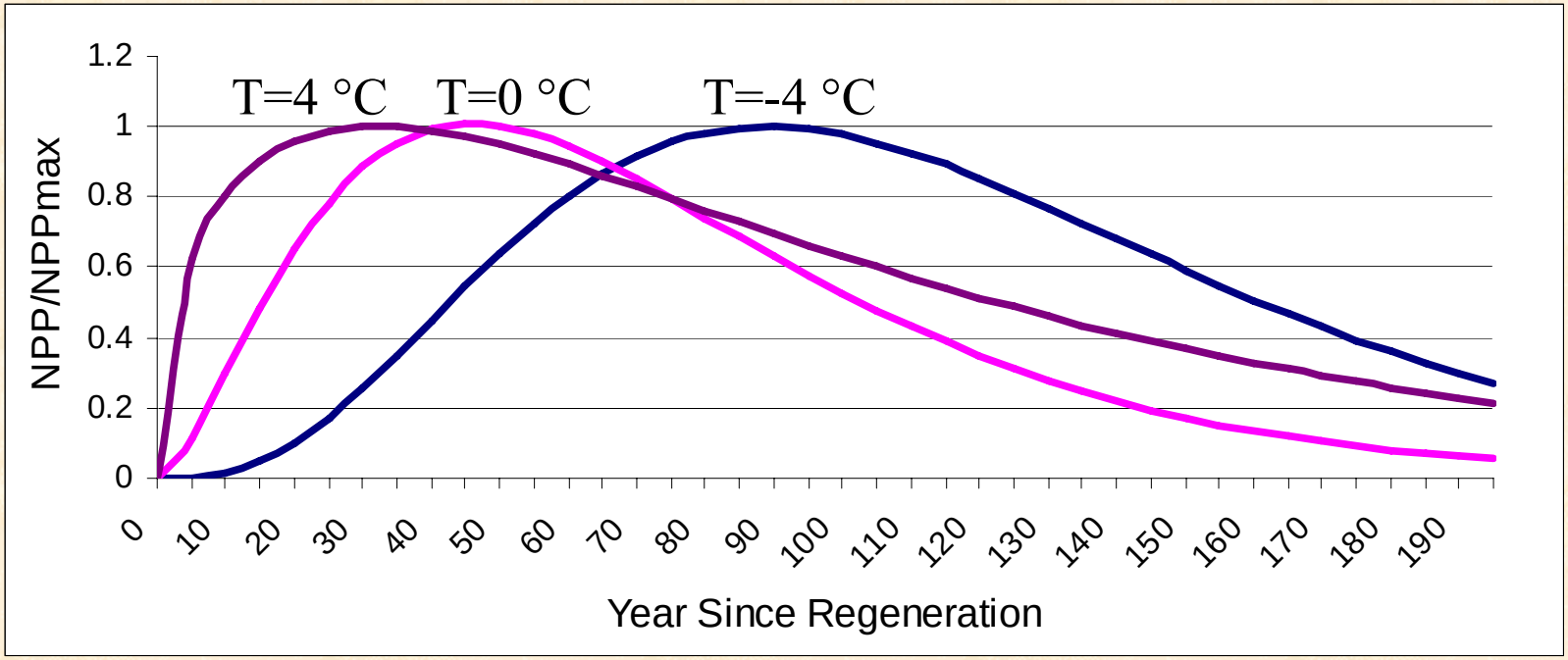
North America Forest Stand Age Distribution in 2000

(Version 2)



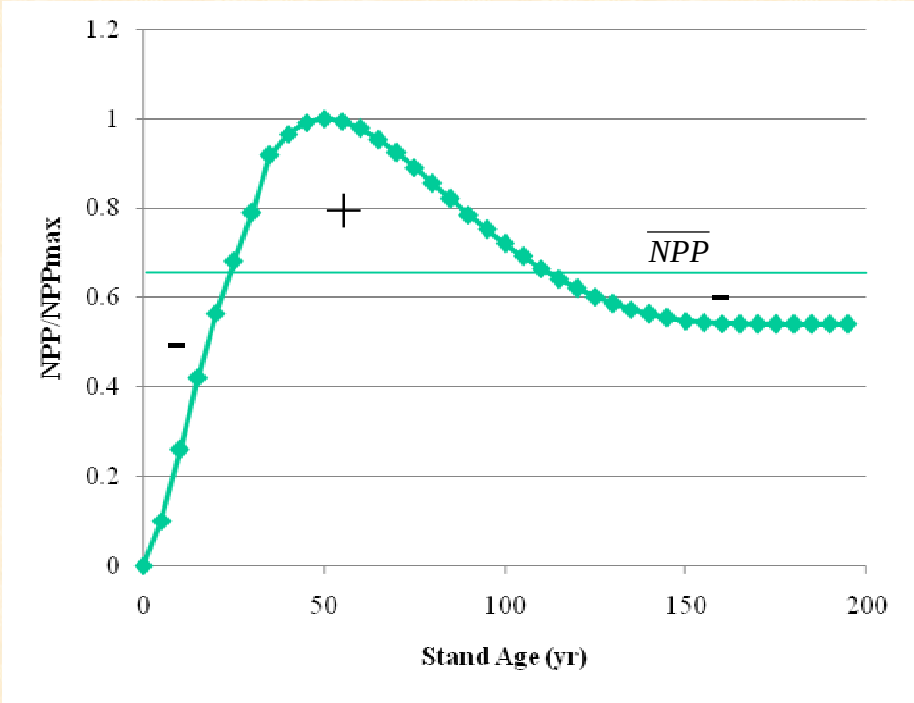
- Canada:
  - Inventory (CFS)
  - Large Fire Polygons (CFS)
  - Fire Scars (U of T, CCRS)
- USA
  - FIA (USDA)
  - Disturbance (LEDAPS, NASA)

Normalized Regrowth Curves As Determined by the Annual Mean Temperature



With the regrowth curve shape determined by temperature, we can estimate NPP at any year from a measured NPP at a given age

Age Factor for Inversion



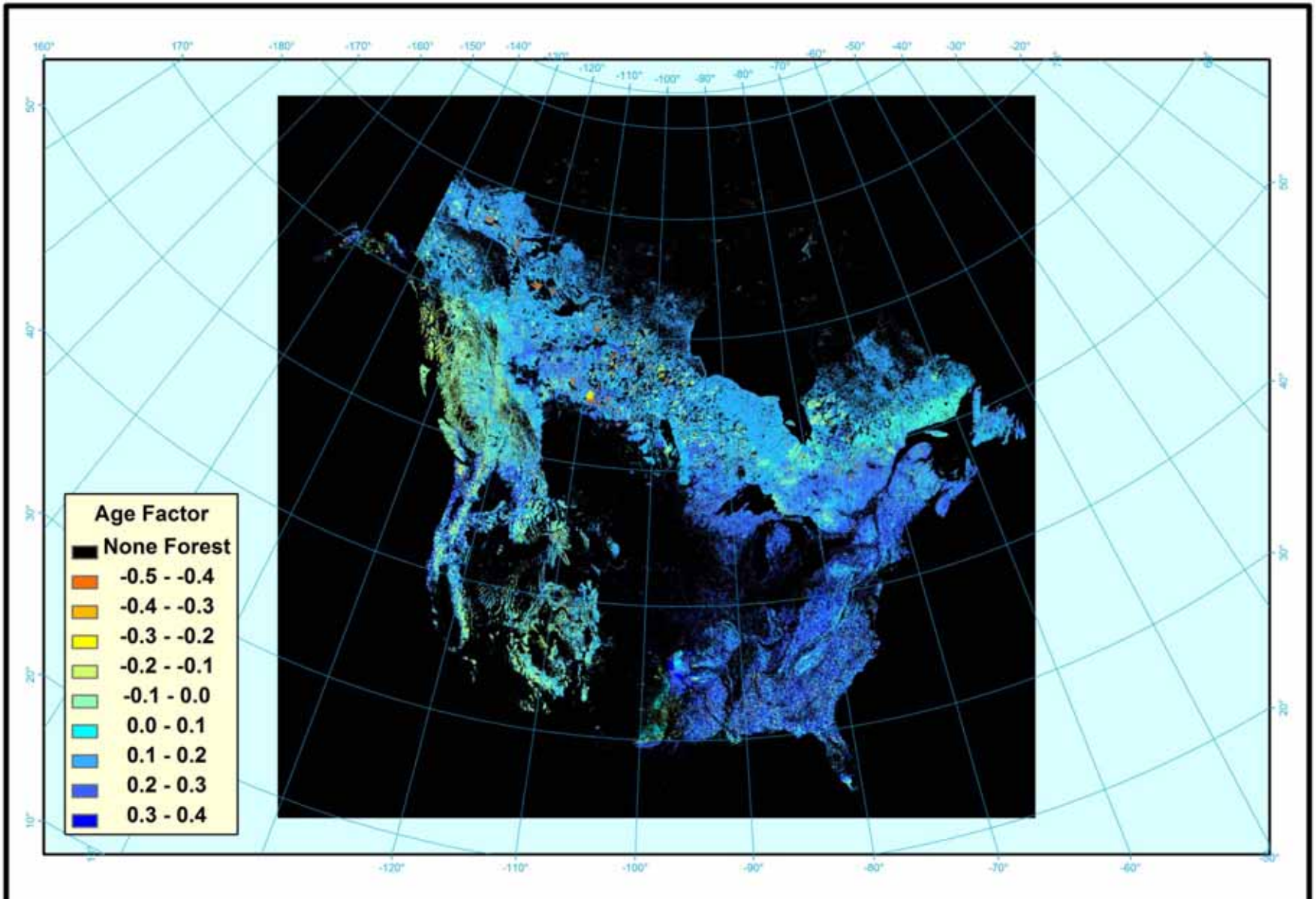
Age Factor:

$$\Lambda = NPP(age) / \overline{NPP} - 1$$

Adjustment of the neutral biosphere flux (annual NEP=0) using the age factor:

$$NEP = NPP - (1 - \Lambda) R_h \approx \Lambda NPP$$

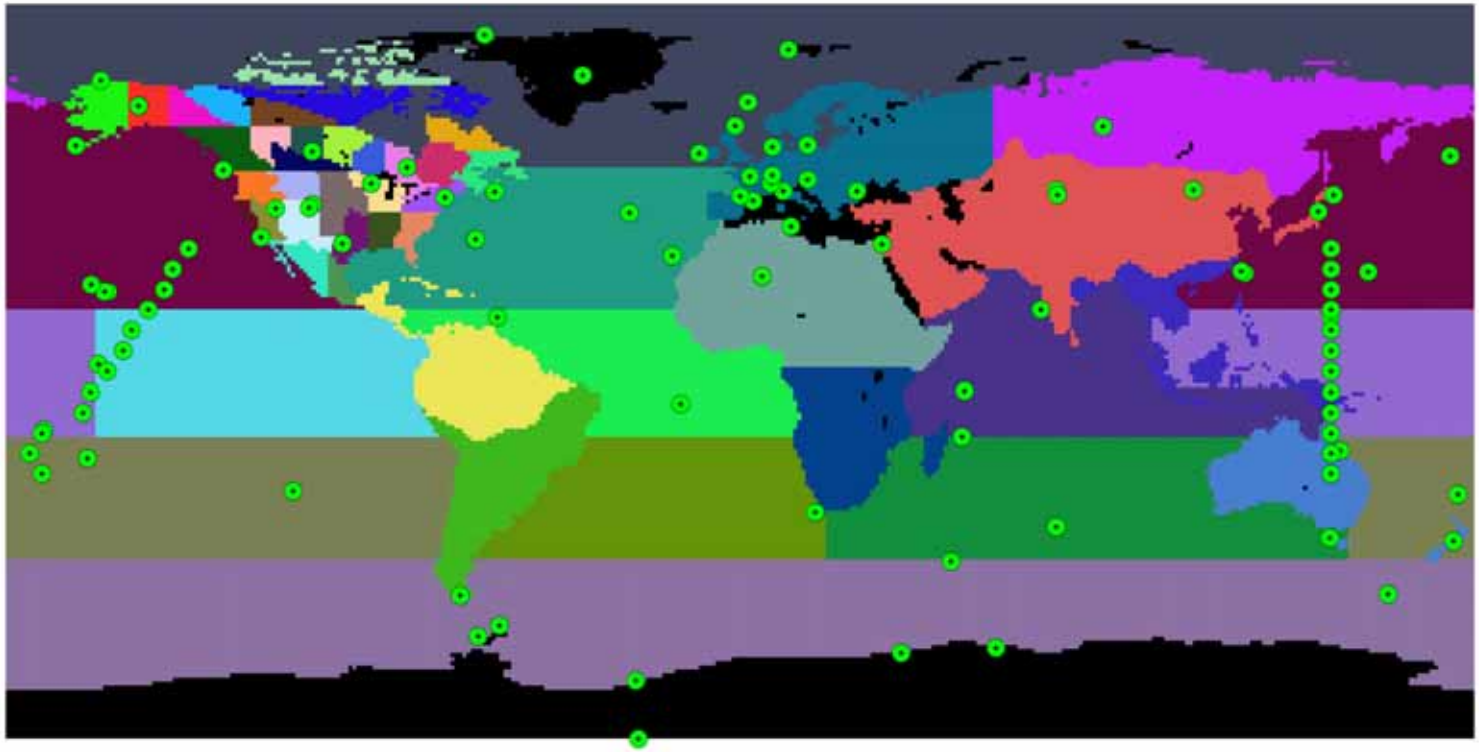
Forest Age Factor for Adjusting NEP *A Priori*



Top-down

Nested Global Inversion System

30 small regions in North America, 20 large regions for the rest of the globe (Transcom 3), and 88 CO_2 stations (GlobalView)



Deng et al. (2007, *Tellus*)

Key Datasets Used in Inversion

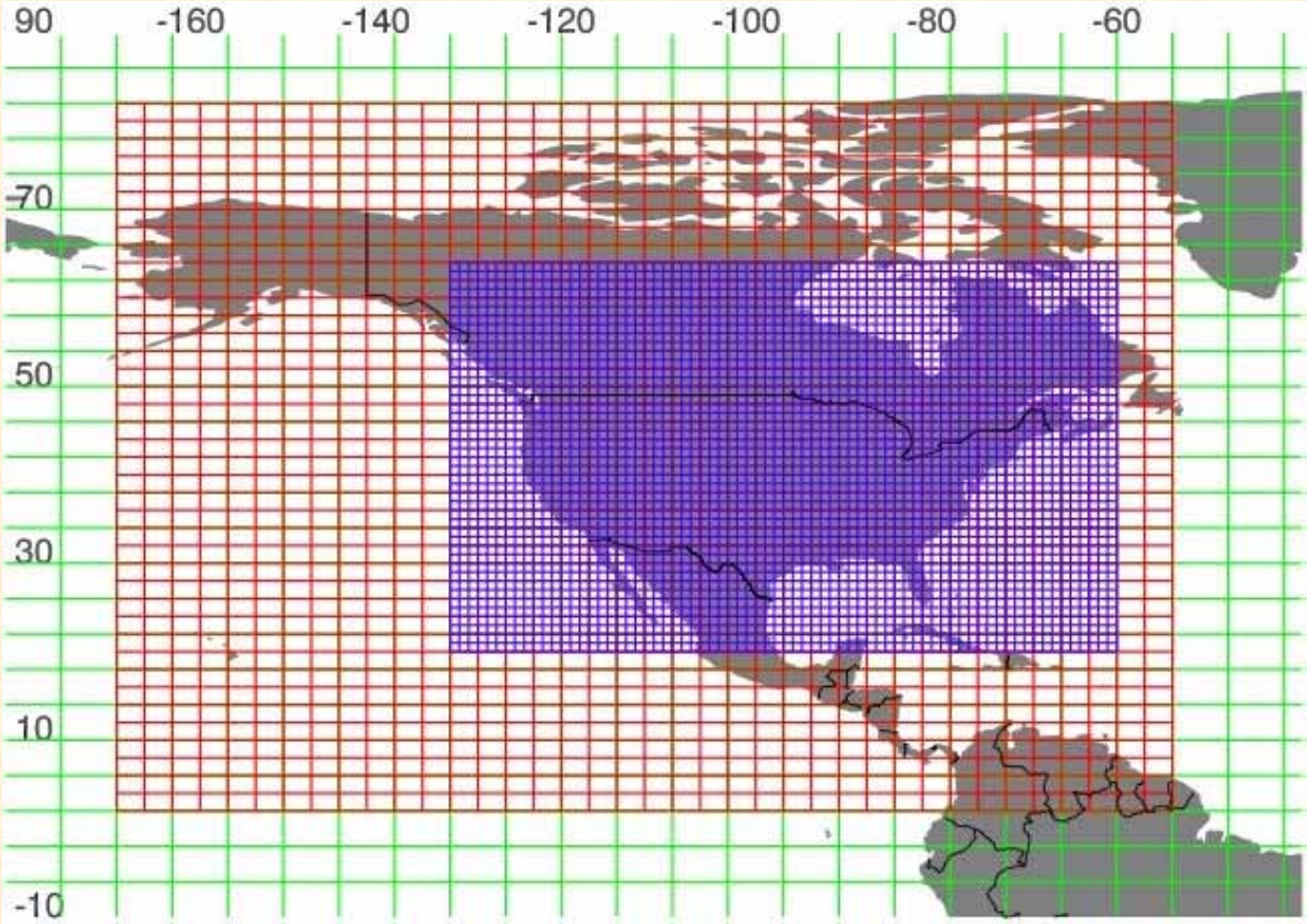
Meteorology: ECMWF (European Center for Medium-range Weather Forecast) and NCEP (National Center for Environmental Prediction) meteorology datasets are used TM5 and BEPS modeling, respectively.

CO_2 emission from fossil fuels: The following relevant datasets were used to construct the temporal and spatial distributions of global CO2 emissions from fossil-fuel burning and industrial processes.
1). The global, regional and national fossil-fuel CO2 emission from 1871 to 2004 (CIDAC) (Marland, Boden, and Andres, 2007);
2). The EDGAR 3.2 database provides global annual CO2 emission on a 1x1 degree grid for 1990 and 1995 (http://www.mnp.nl/edgar/model/)

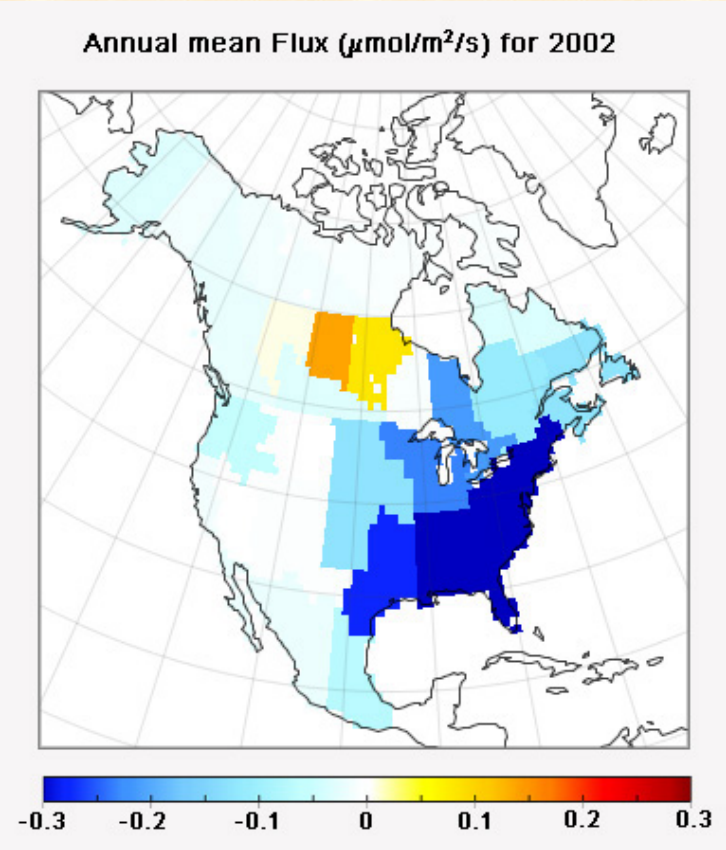
CO_2 emission from vegetation fires: The fire emission was based on the Global Emissions Fire Database version 2 (GFED v2). (van der Werf et al., 2003; Giglio et al., 2006).

Ocean surface flux: The flux of CO2 across the air-water interface are constructed based on five ocean inversion flux (OIF) estimates, and optimized in Carbon Tracker (Peters et al. 2007)

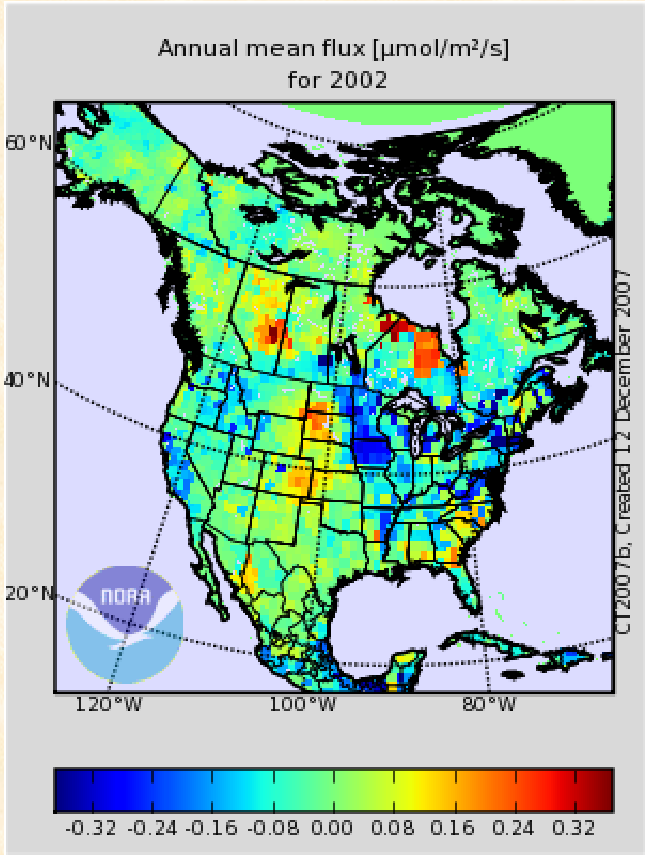
Nested Grid System Used by the Transport Model TM5 (Krol et al., 2005; Peters et al., 2007)



Comparison of Inversion Results

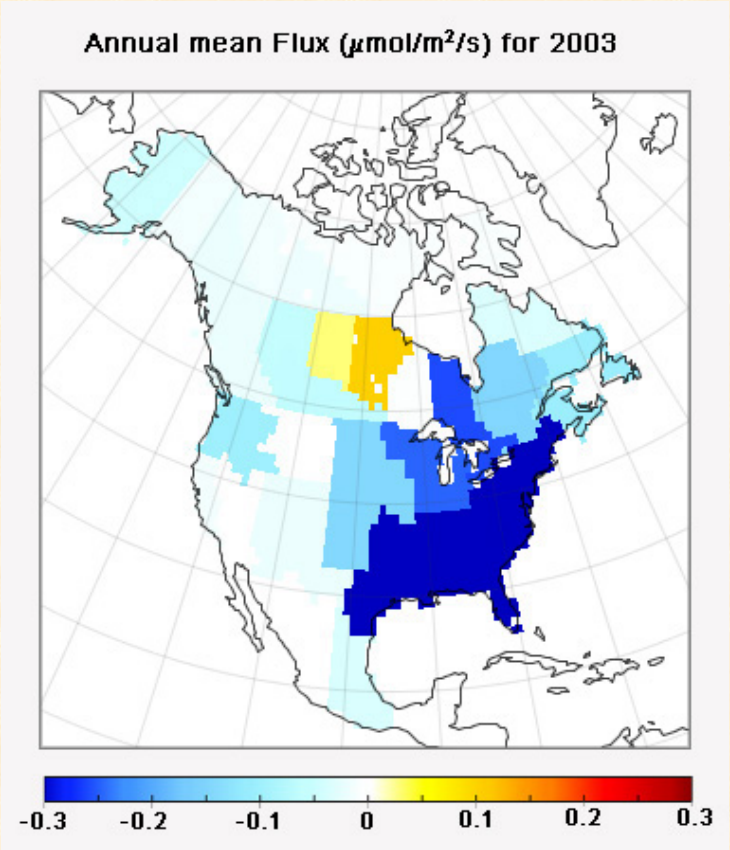


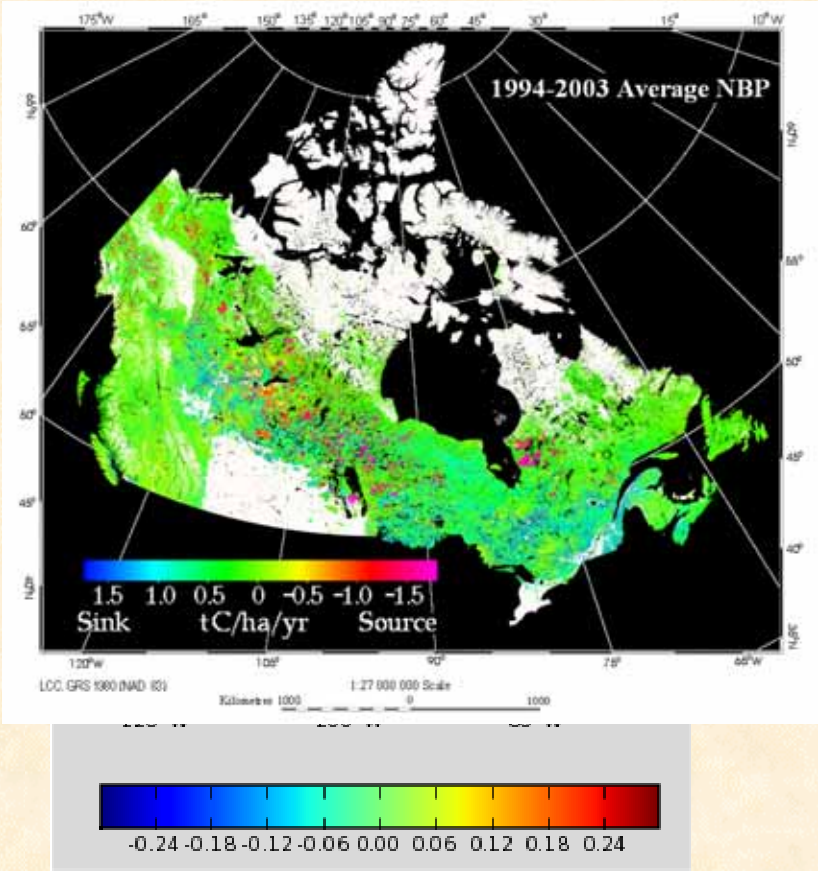
Nested Inversion (U of T)



Carbon Tracker (NOAA)

Comparison of Inversion Results





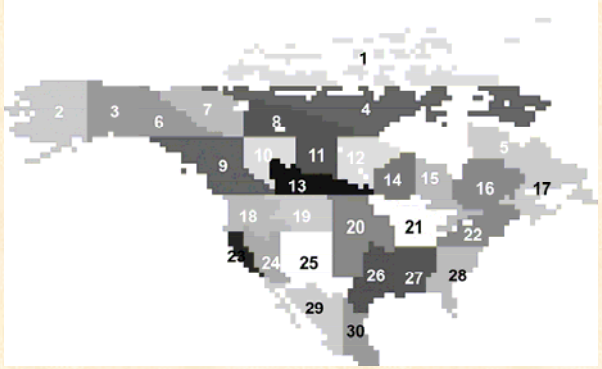
Nested Inversion (U of T)

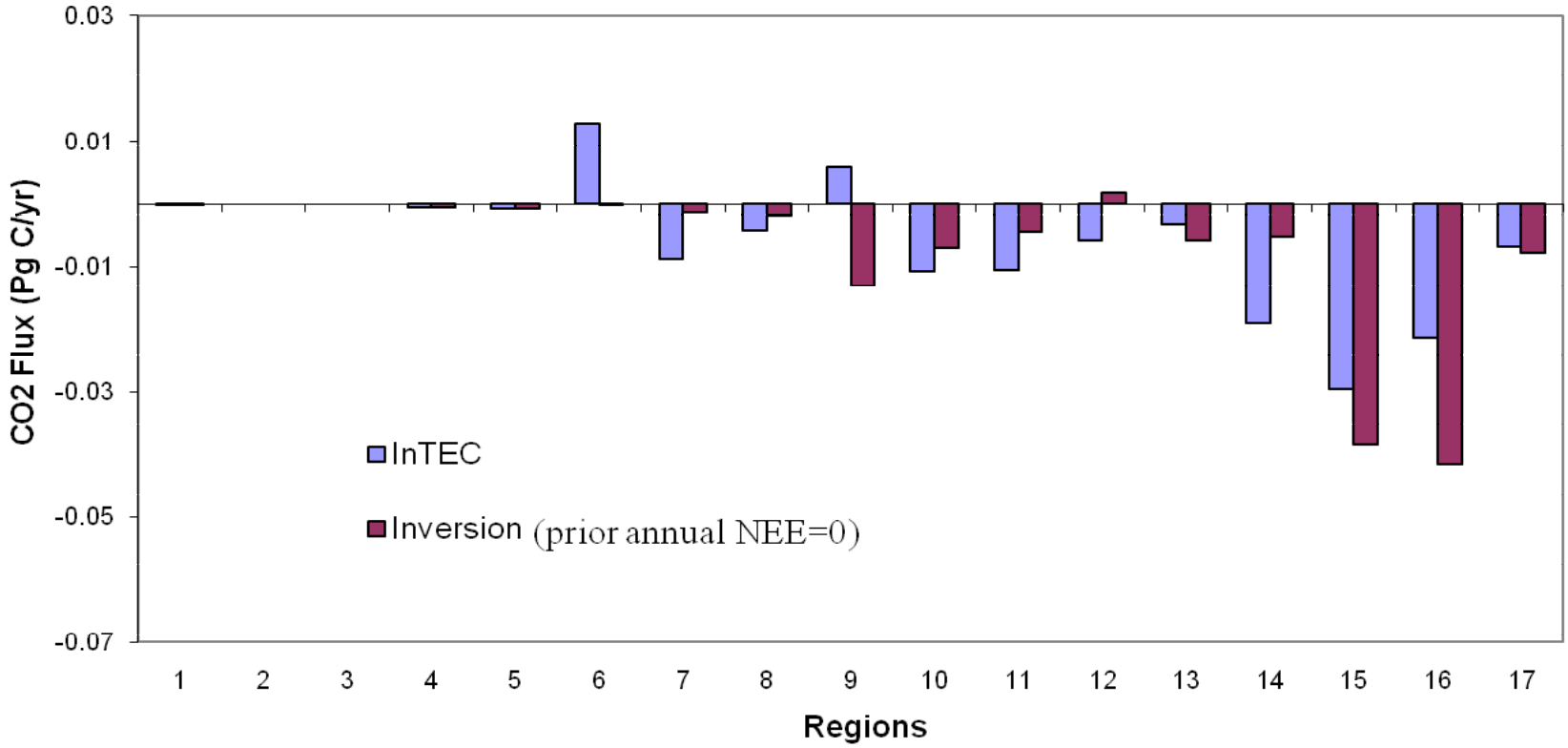
Carbon Tracker (NOAA)

Comparison with Carbon Tracker

	NBP 2002	NBP 2003	NBP 2004
Carbon Tracker			
NA-Boreal	0.07 ± 0.41	-0.22 ± 0.40	-0.07 ± 0.33
NA-Temperate	-0.19 ± 0.51	-0.74 ± 0.42	-0.75 ± 0.39
Nested Inversion (U of T)			
NA-Boreal	-0.067 ± 0.18	-0.060 ± 0.18	-0.201 ± 0.18
NA-Temperate	-0.715 ± 0.23	-0.883 ± 0.23	-1.048 ± 0.23

Bottom-up and Top-down Results for NA Boreal Regions in 2003





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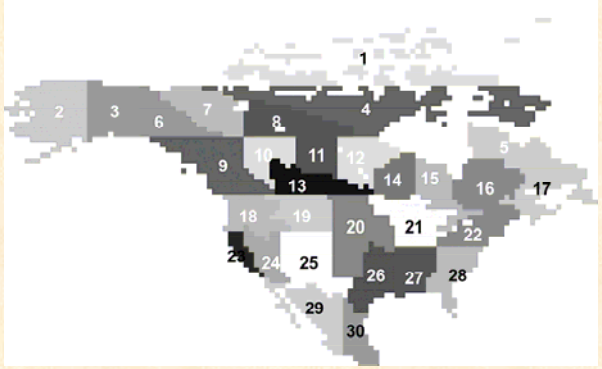
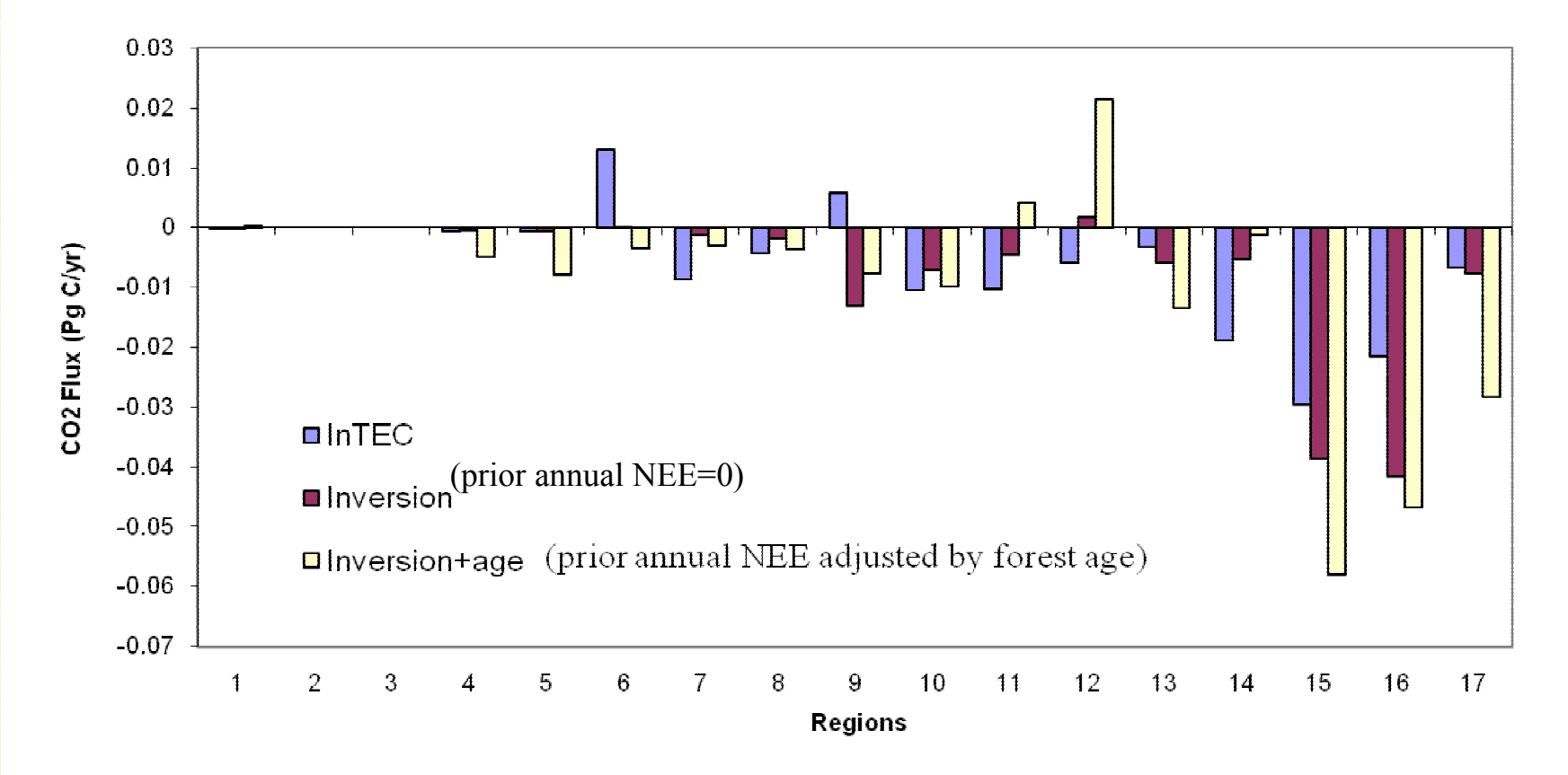
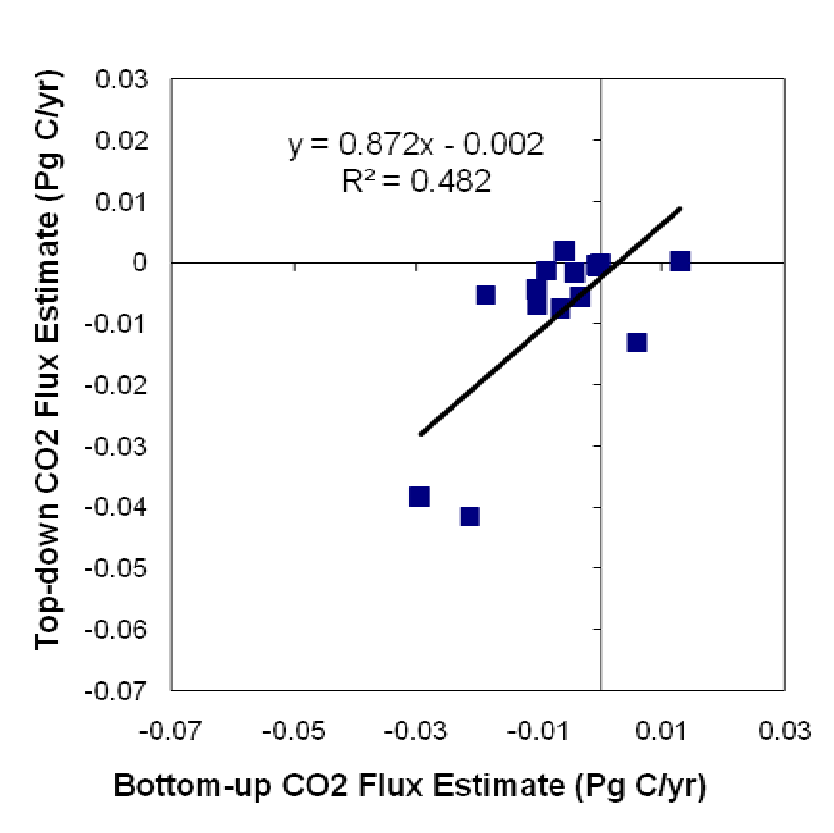
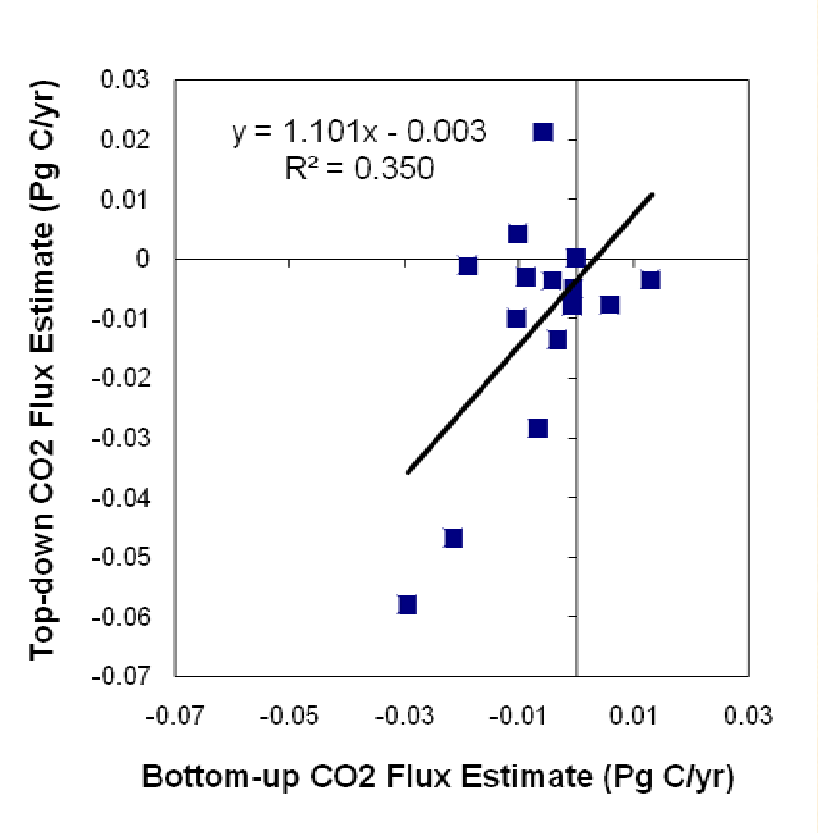




Bottom-up and Top-down Results for NA Boreal Regions in 2003

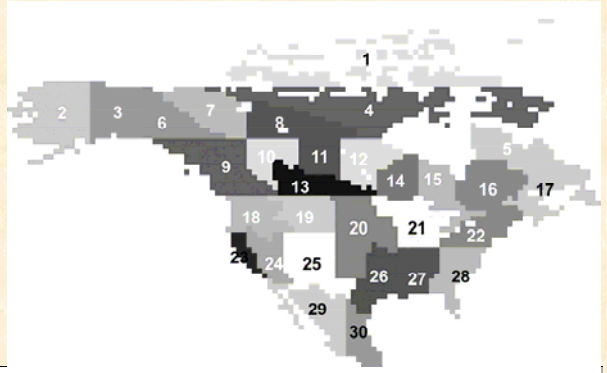


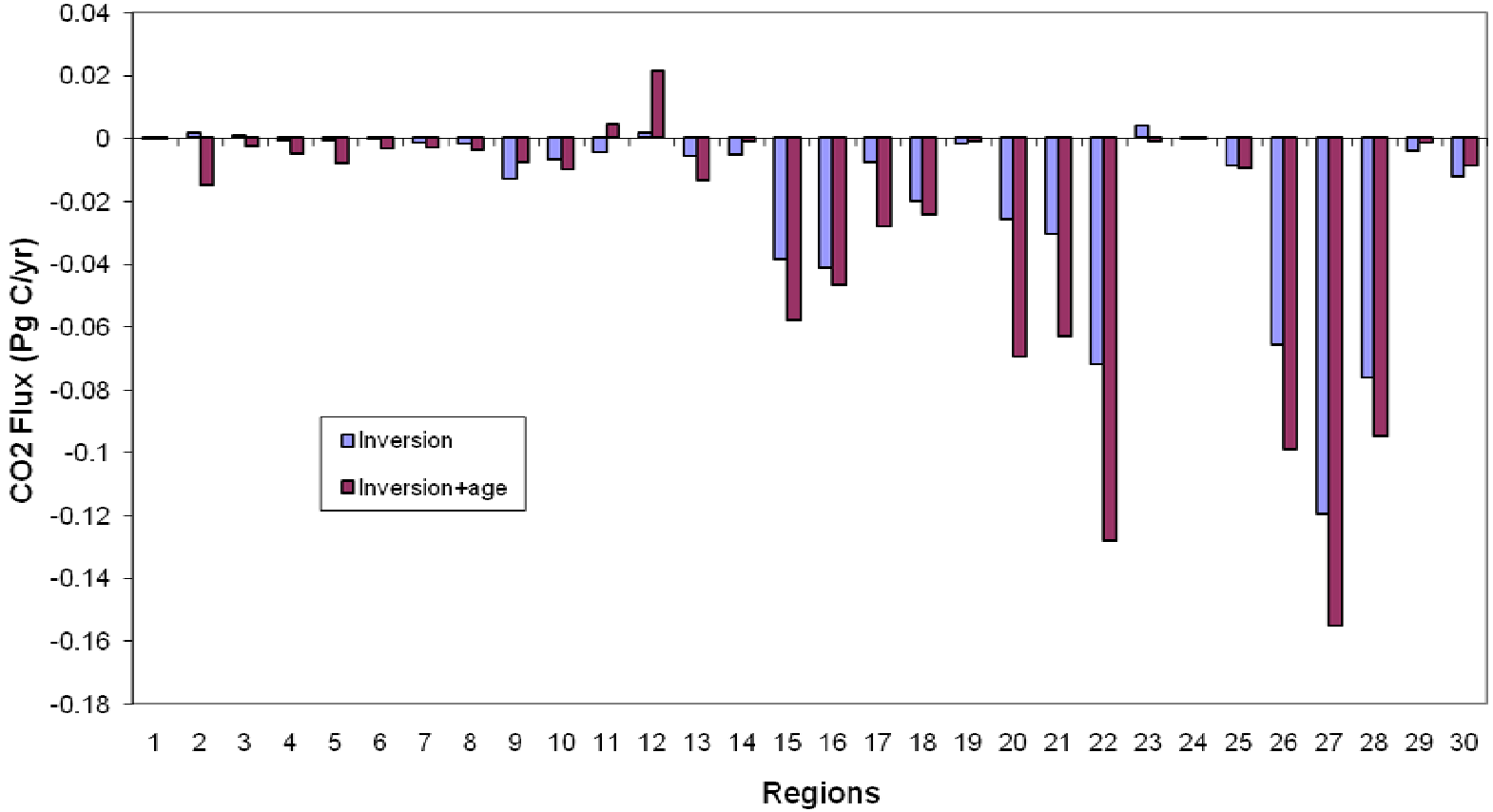
Prior annual NEE=0



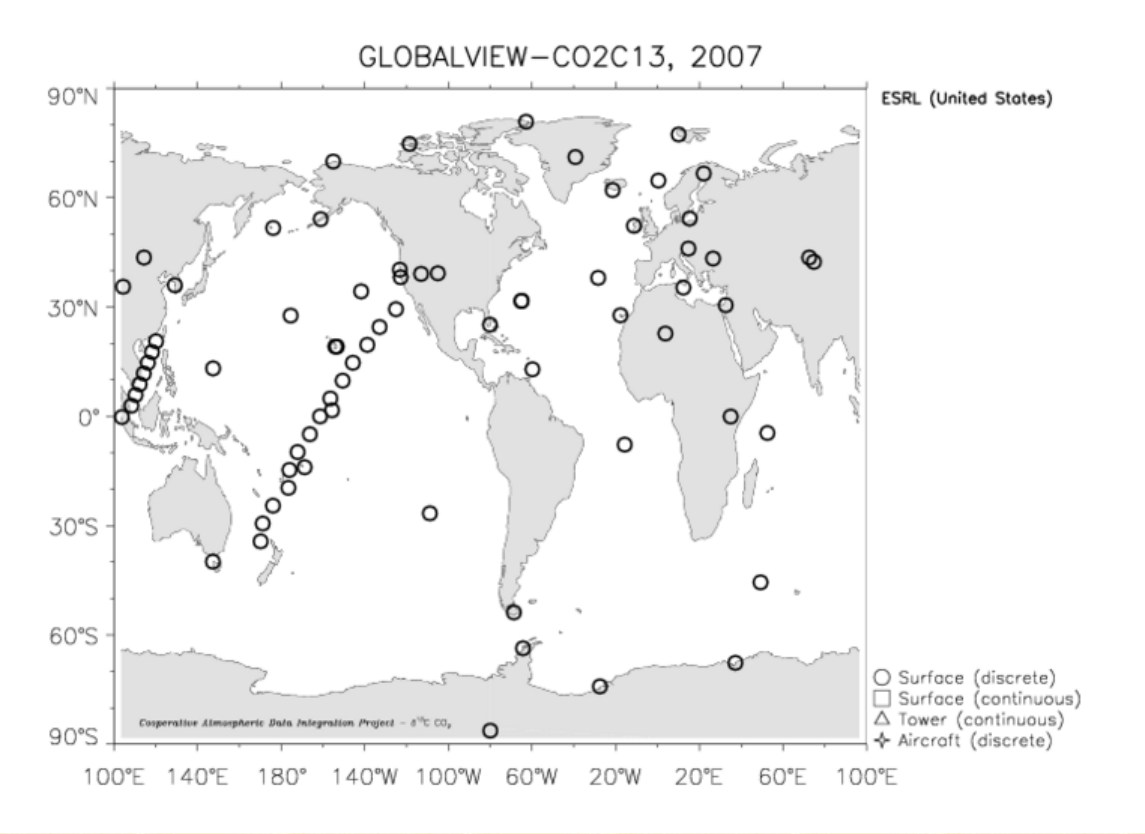
Prior NEE adjusted by age

The influence of the age factor on the inversion of 30 regions in NA



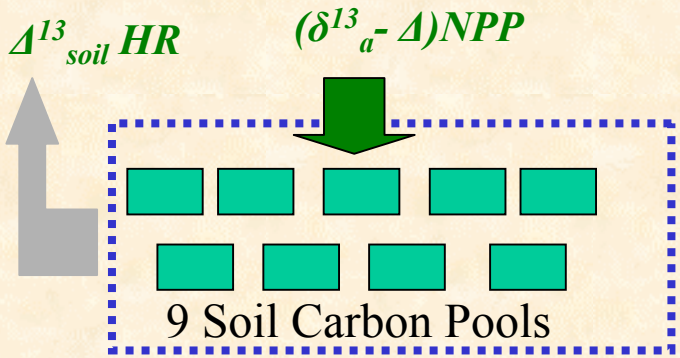


Usefulness of $\delta^{13}C$ in CO_2 Inverse Modeling

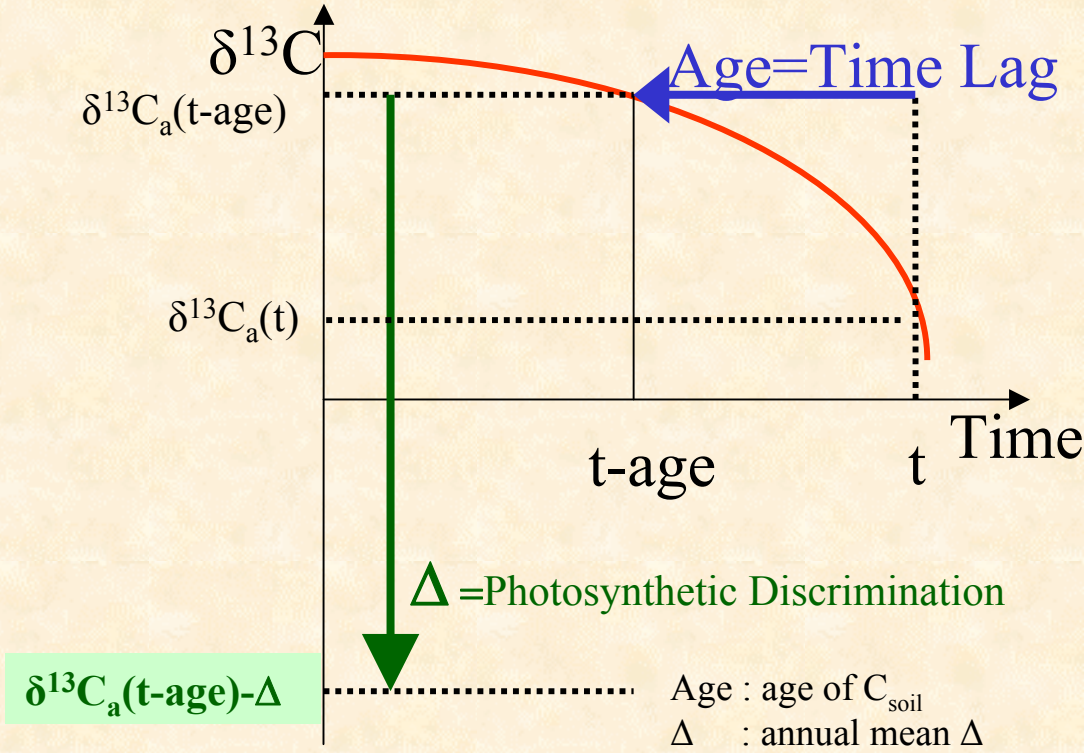


- Differentiating between land (~17.5‰) and ocean (~2‰) sinks
- Differentiating between photosynthesis and respiration

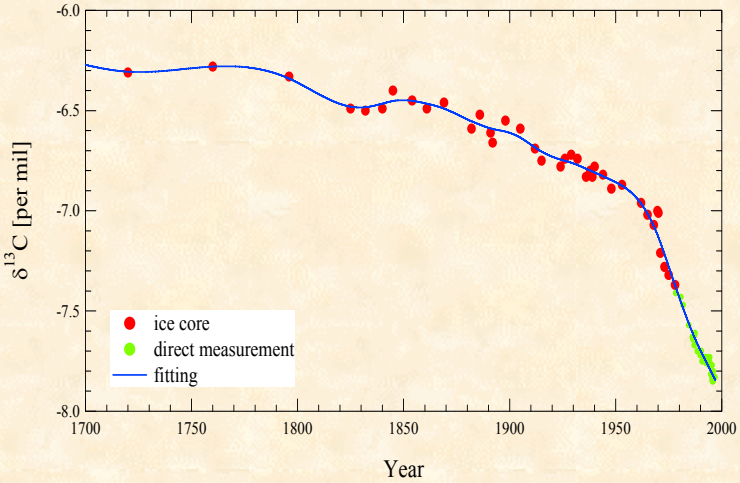
$\delta^{13}C$ in Carbon Pools in BEPS



$$\delta^{13}C_{soil} = \delta^{13}C_a(t\text{-age}) - \Delta$$



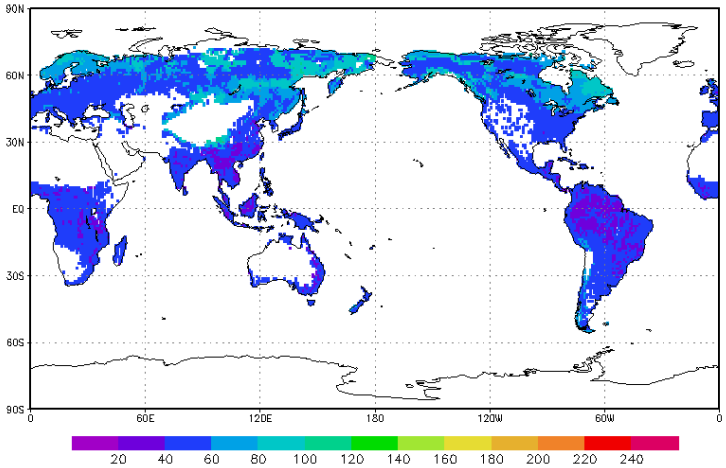
Time Trends of Global $\delta^{13}C$ in atmospheric CO_2



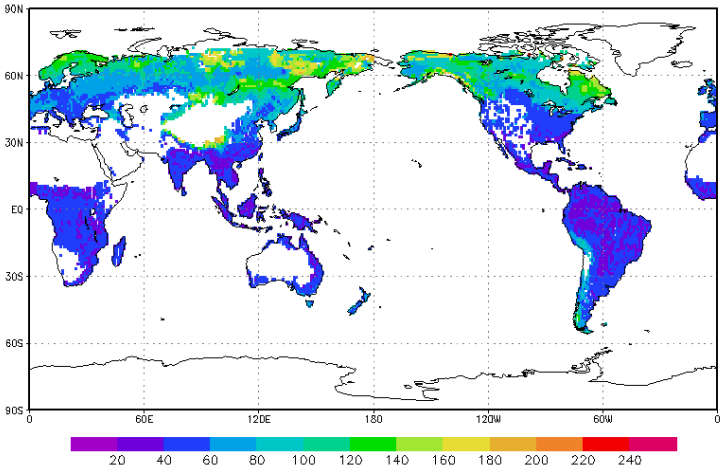
Soil Carbon Age

For Deciduous

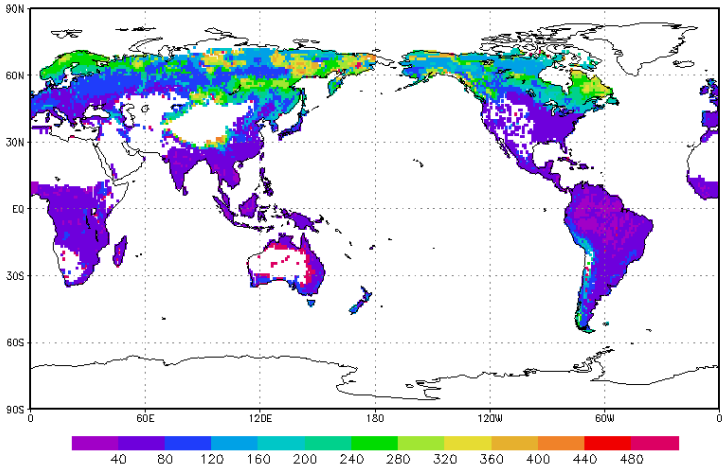
Detritus



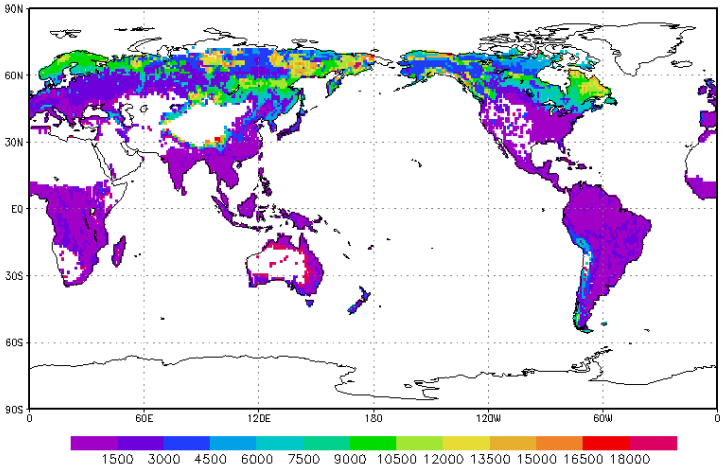
Microbes



Slow

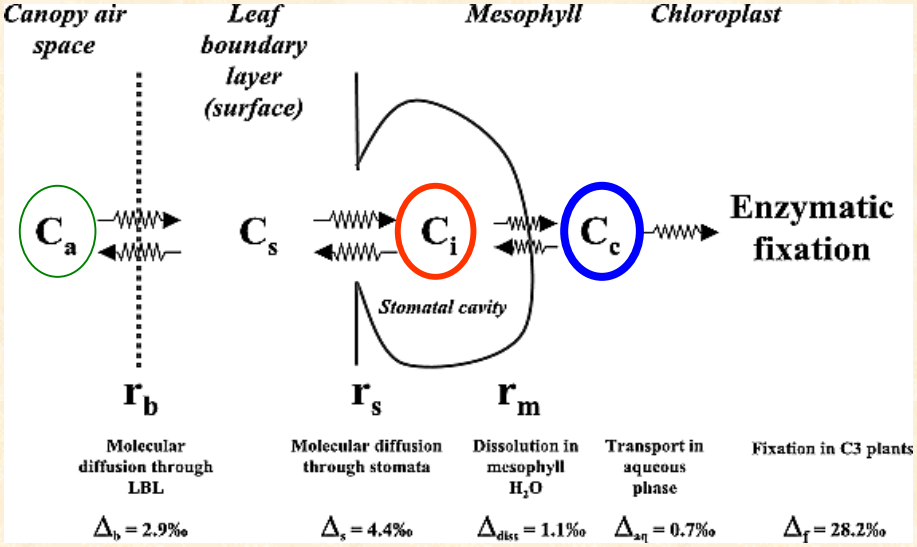


Passive



Photosynthetic Isotope Dissemination

One-stage and Multi-stage



One-stage (Farquhar et al., 1989)

$$\Delta = a + (b - a)\frac{C_i}{C_a}$$

Multi-stage (Farquhar et al., 1989; Fung et al., 1997; Suits et al., 2005)

$$\Delta_{C_3} = \Delta_b\left(\frac{C_a - C_s}{C_a}\right) + \Delta_s\left(\frac{C_s - C_i}{C_a}\right) + \left(\Delta_{diss} + \Delta_{aq}\right)\left(\frac{C_i - C_c}{C_a}\right) + \Delta_f\left(\frac{C_c}{C_a}\right)$$

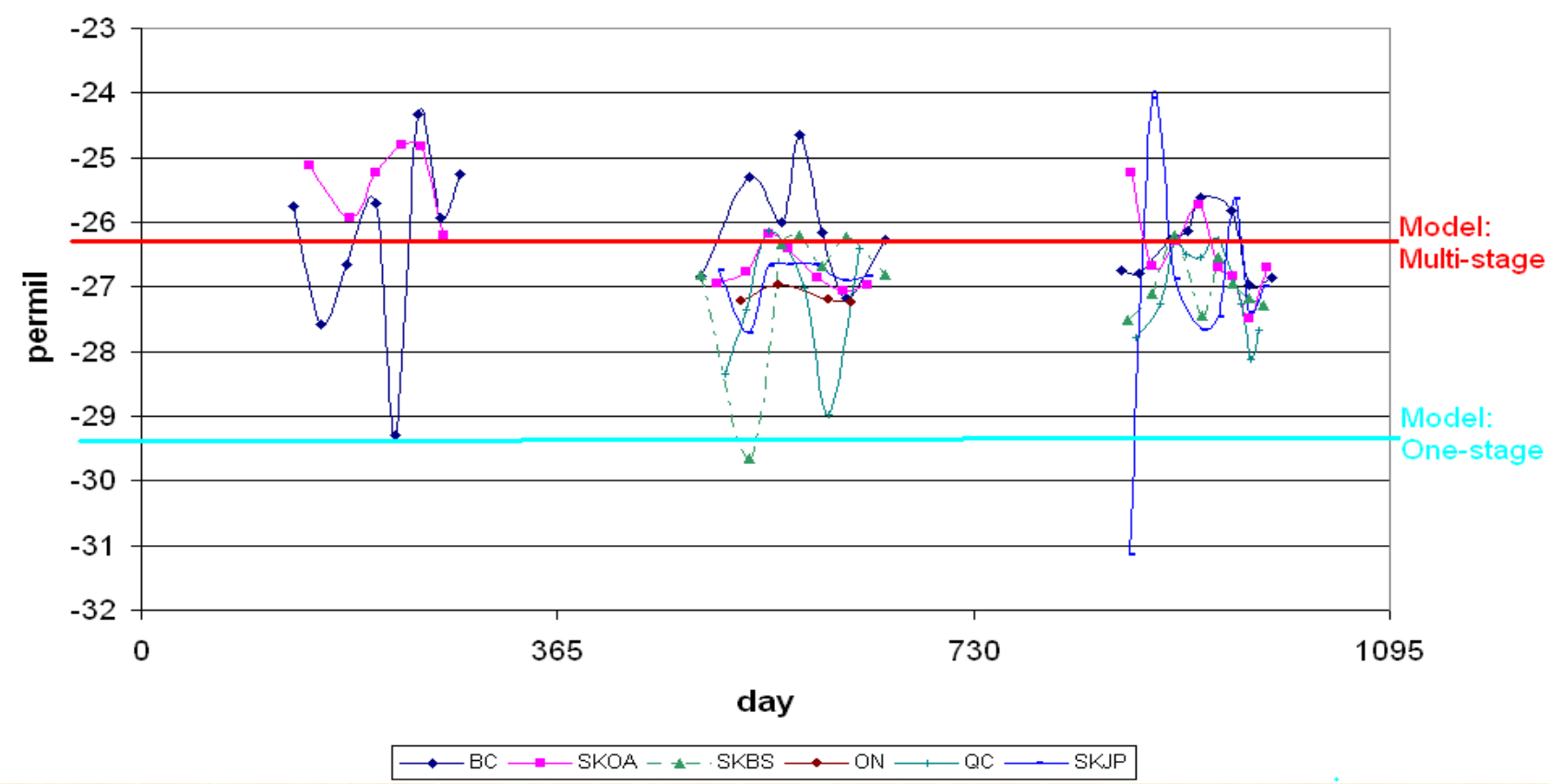
$$\begin{cases} C_s = C_a - r_b A_n \\ C_i = C_s - r_s A_n \\ C_c = C_i - r_m A_n \end{cases}$$

Comparison with Observations

Observations:

$\delta^{13}C$ of Ecosystem Respiration (ER) was estimated from the intercept of Keeling plot with $\delta^{13}C$ and CO_2 at 6 Canadian sites.

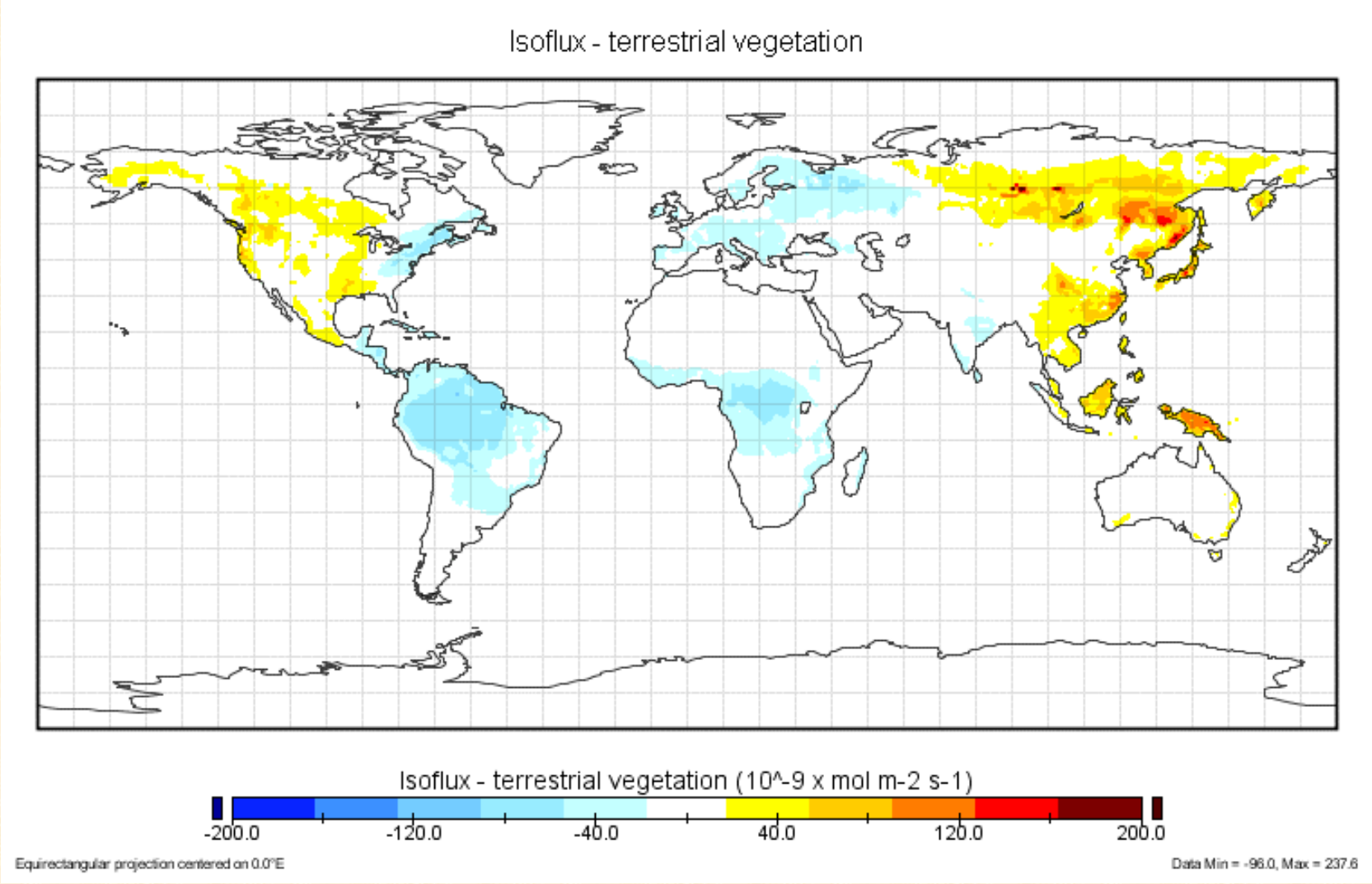
Model: $$\delta^{13}{}_{ER_model} = \frac{(\delta_a - \Delta) * AR + \delta_{soil} * HR}{AR + HR}$$



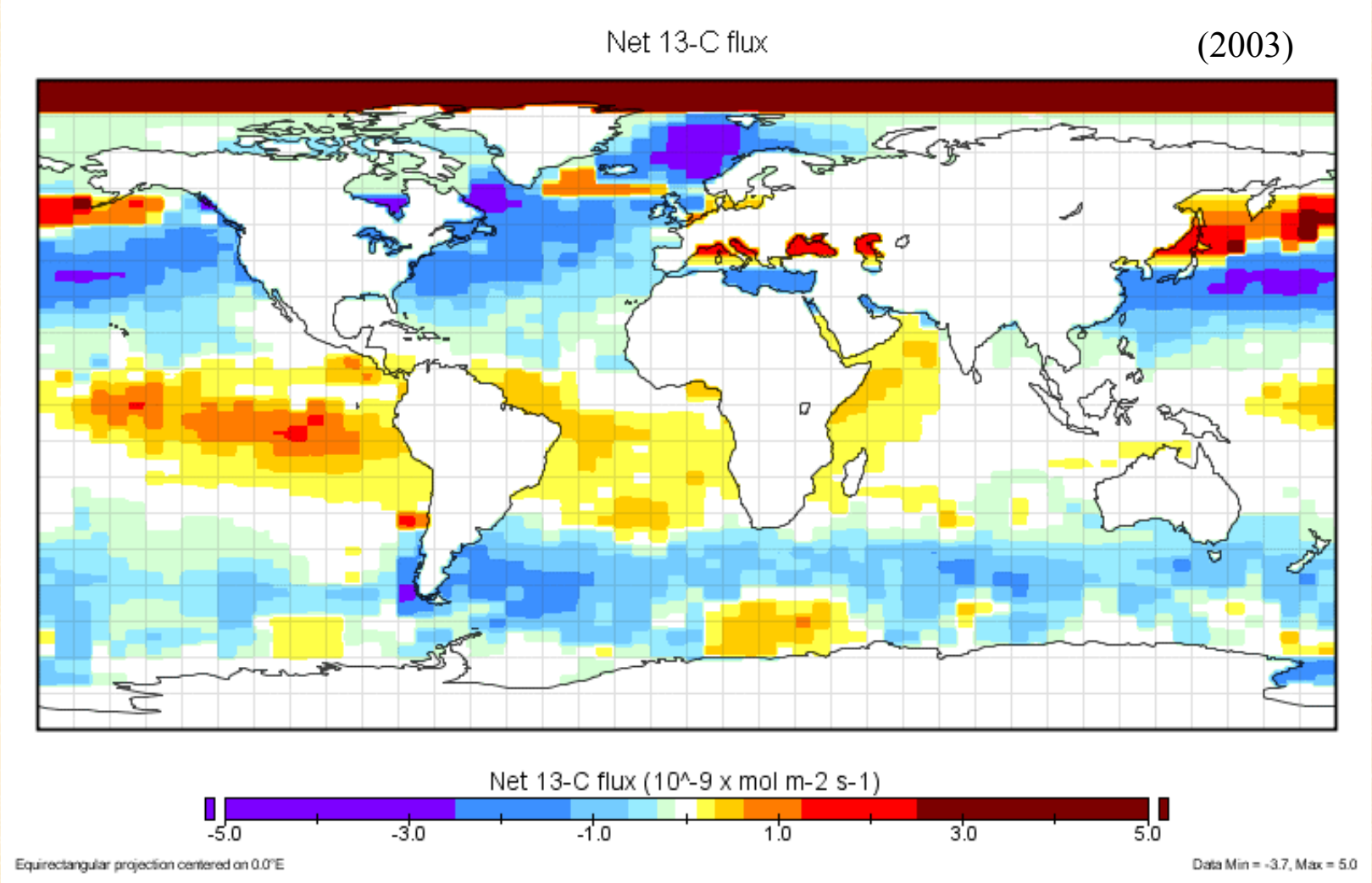
(Data source: Larry Flanagan)

Hourly ^{13}C Flux Simulated by BEPS

(Example, July 1-3, 2003)



Simulated Monthly Ocean ^{13}C Flux



Summary

- The spatial distribution of the CO2 flux in forests is closely related to the forest age distribution. The first order estimation based on a continent-wide forest age map indicates that the forest age structure in North America is in favor of carbon uptake.

- Atmospheric inversion with a neutral annual *a priori* surface flux produces a carbon source and sink distribution compatible with the forest age map in Canada. Using the continent-wide forest age information as an additional constraint in the inversion, the carbon sink increased significantly for most regions in NA.

- We are still exploring the possibility of using GlobalView ^{13}C data in the inversion to improve the differentiation between land and ocean carbon fluxes and between photosynthesis and respiration.

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