Prediction of Future Carbon Sink dynamics in the North America

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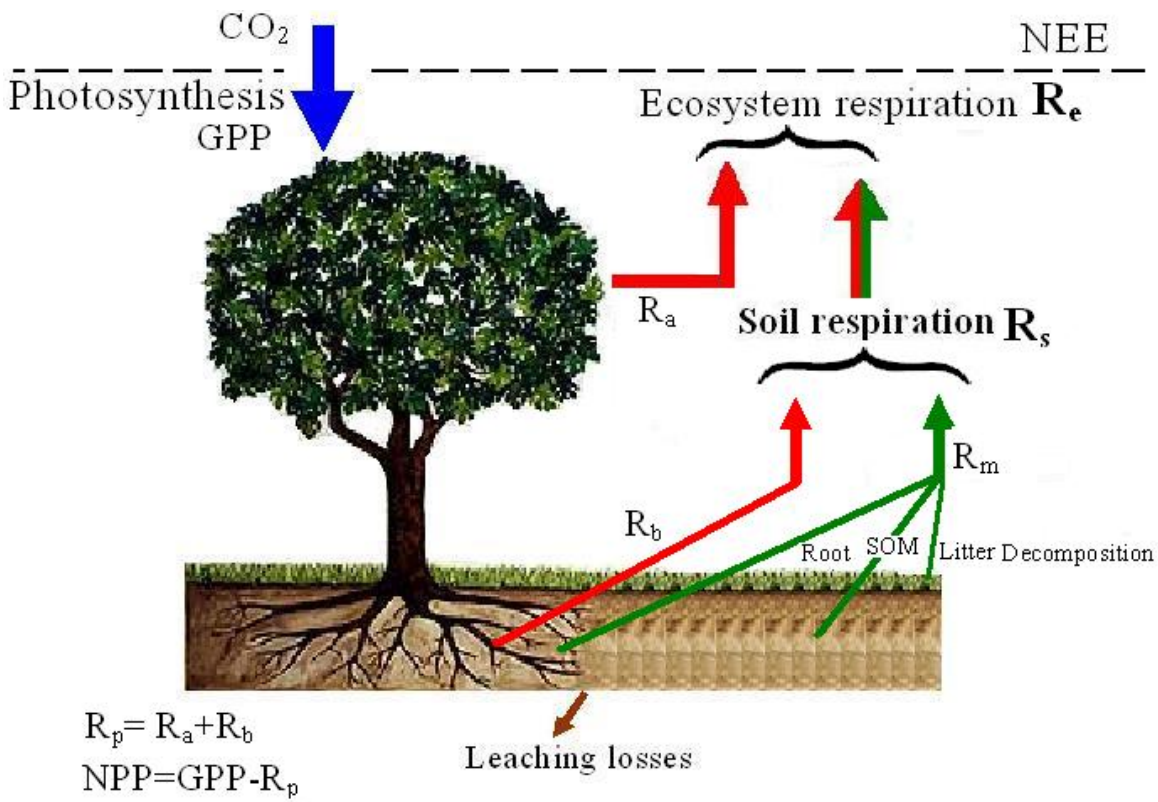
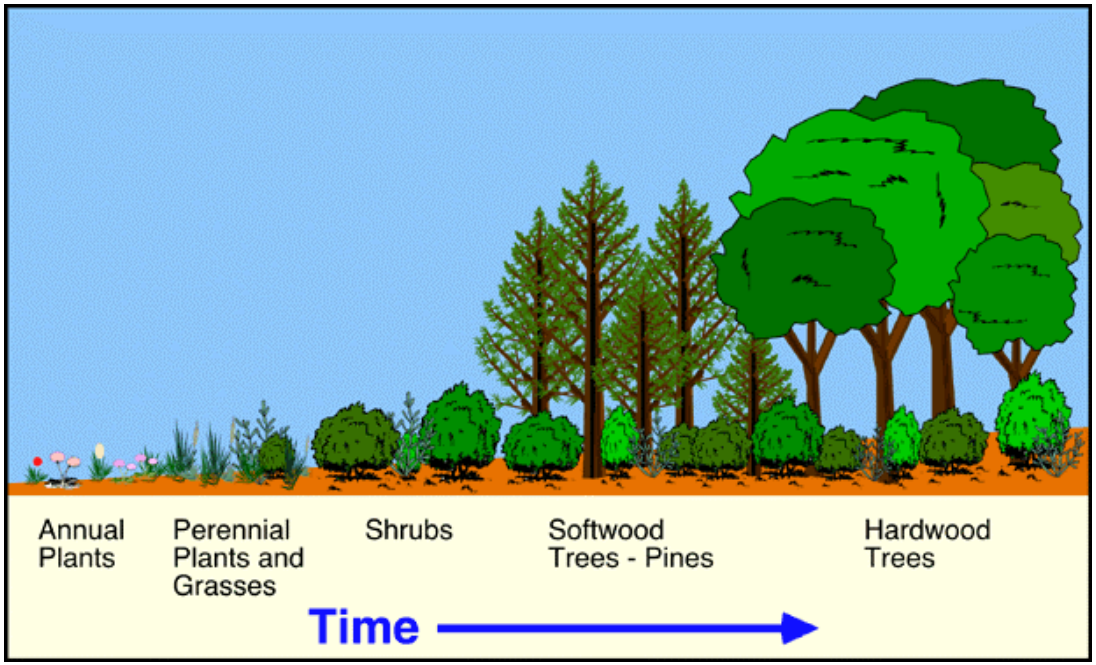
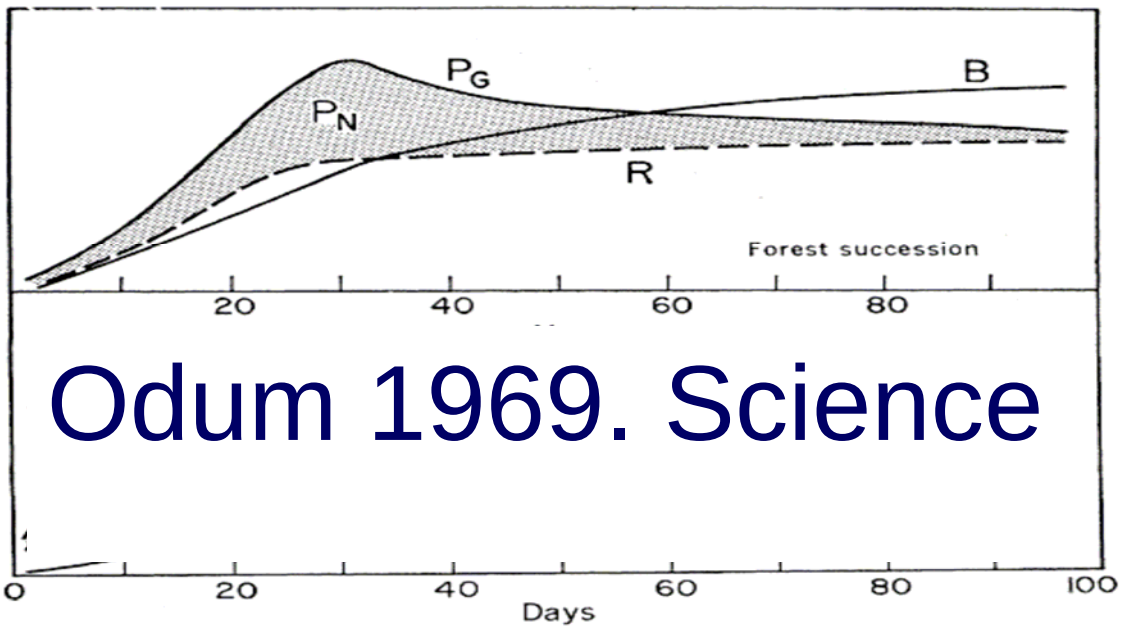
What processes determine future carbon sink?



Disequilibrium

Carbon sequestration occurs
only when influx > efflux





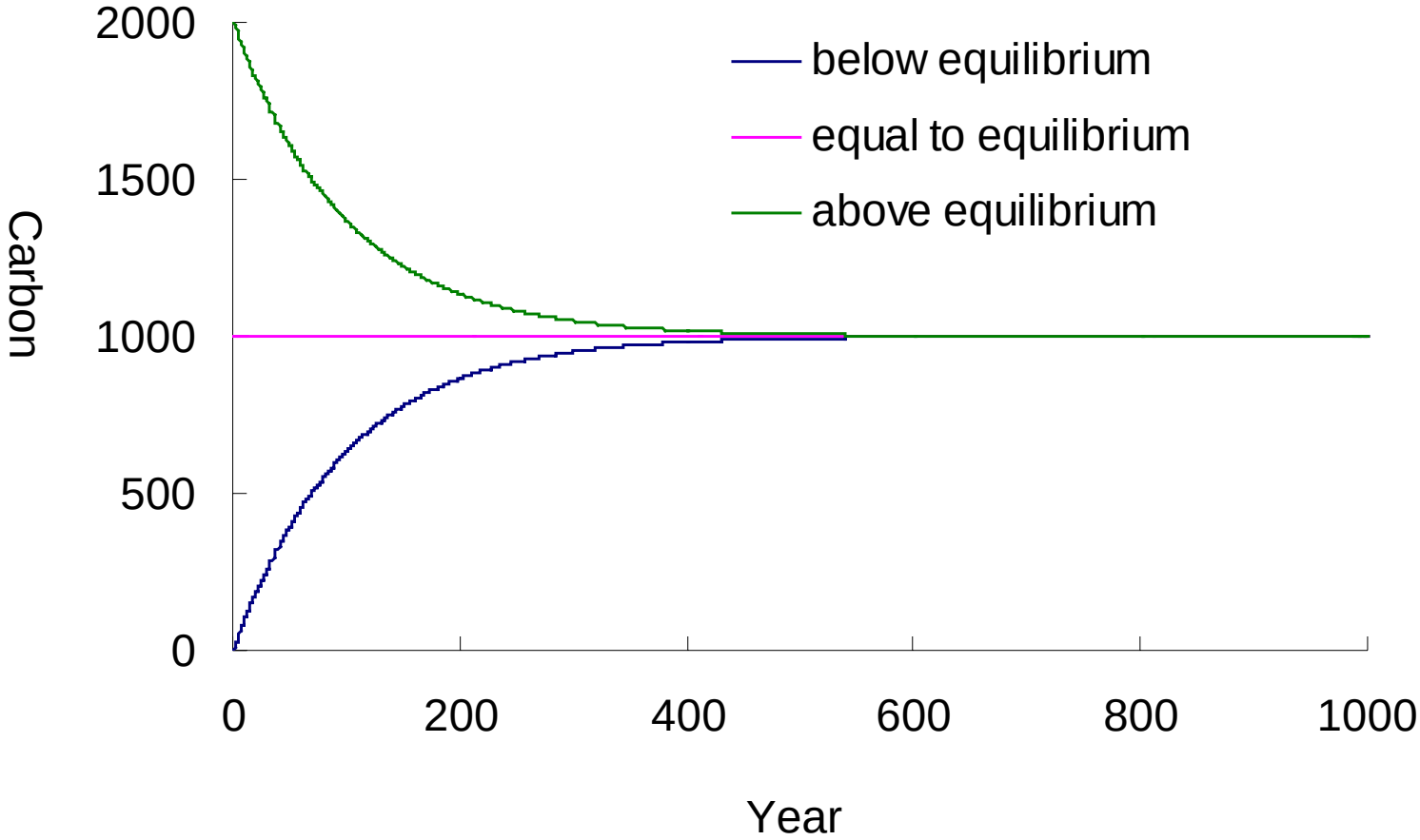
Odum 1969. Science

Fig. 1. Comparison of the energetics of succession in a forest and a laboratory microcosm. P_G, gross production; P_N, net production; R, total community respiration; B, total biomass.

1. Internal processes to equilibrate efflux with influx

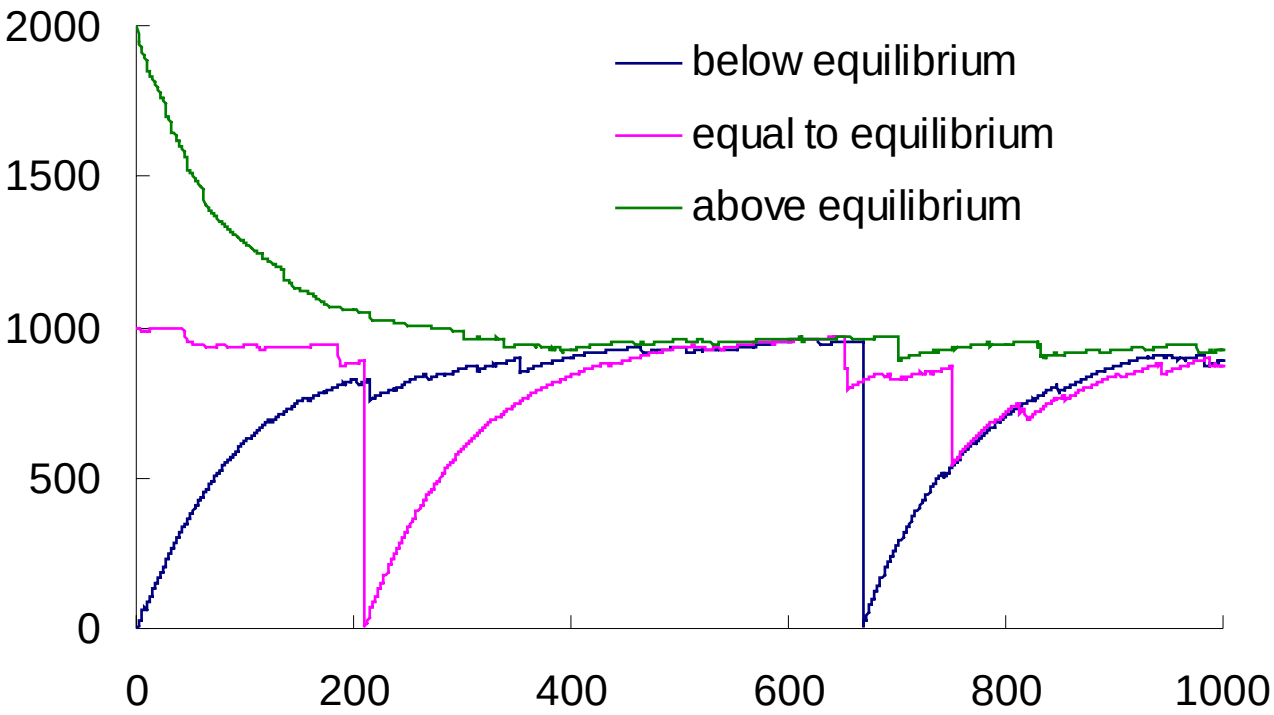
2. C sink strength becomes smaller as efflux is equalized with influx

Internal processes to equilibrate C processes without disturbances



Disturbances

Carbon dynamics with disturbances



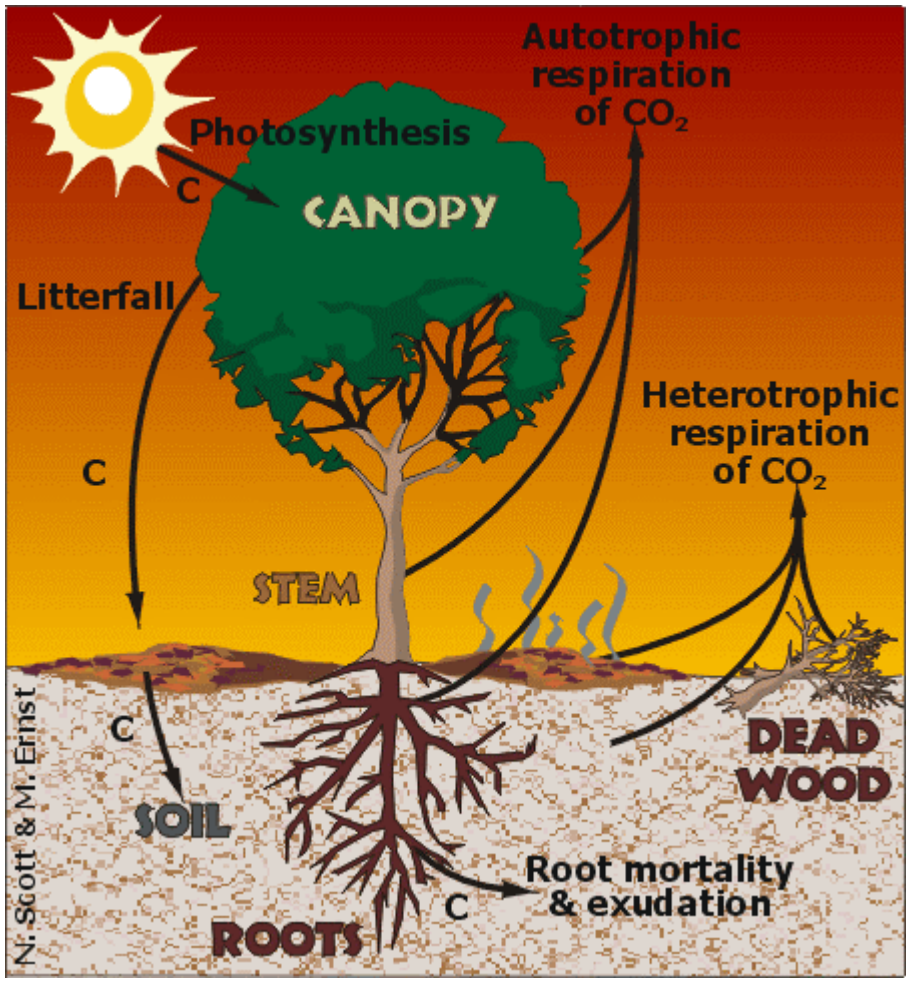
Disturbances create disequilibrium

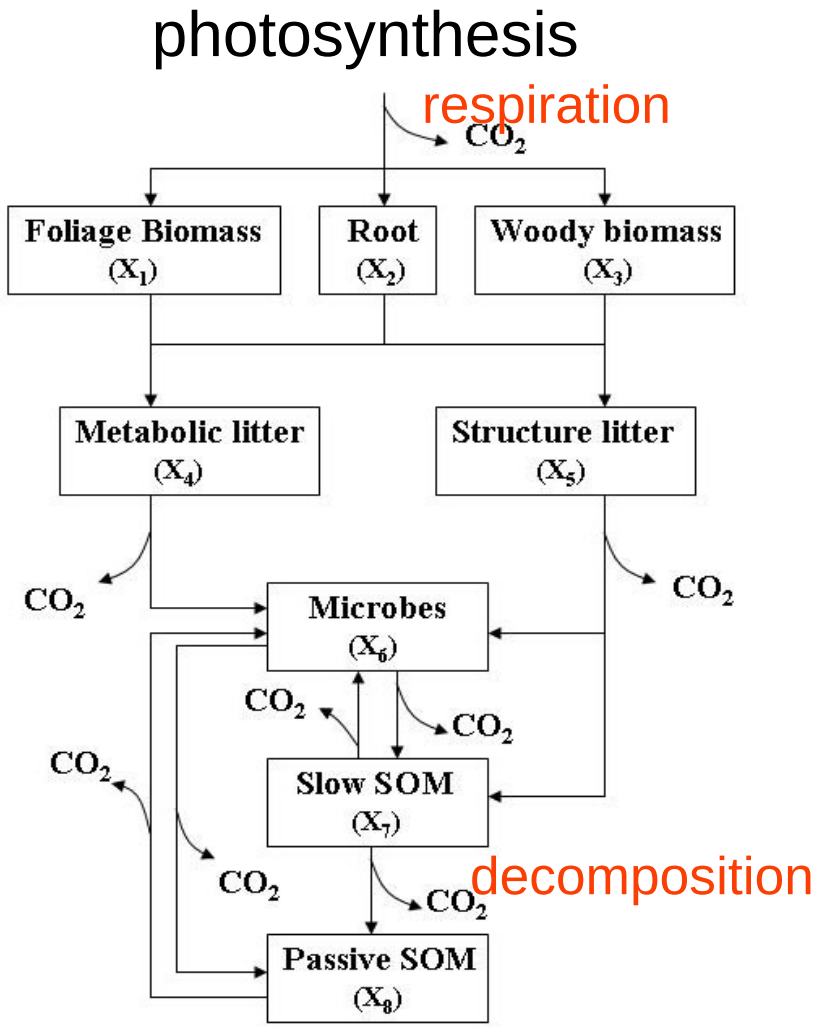
After disturbance, carbon sinks become smaller over time.

Dynamic Disequilibrium (DD)

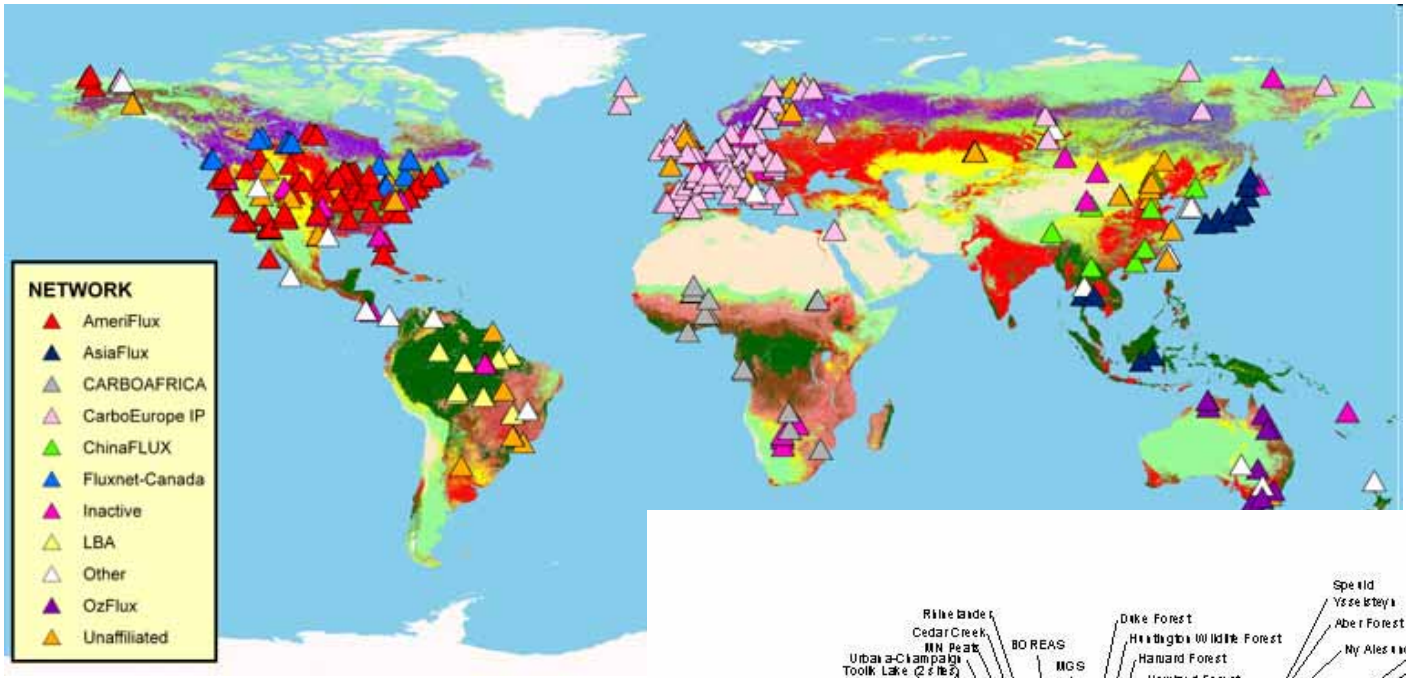
1. Carbon sequestration occurs when C influx and efflux are at disequilirbium.
2. Ecosystems have internal processes to gradually equalize C efflux to influx. Thus, C sink becomes smaller over time without disturbances,
3. Disturbances and/or environmental change create disequlibrium.
4. Future C sink dynamics will be determined by relative strengths between the internal equilibration forces and external disturbance forces

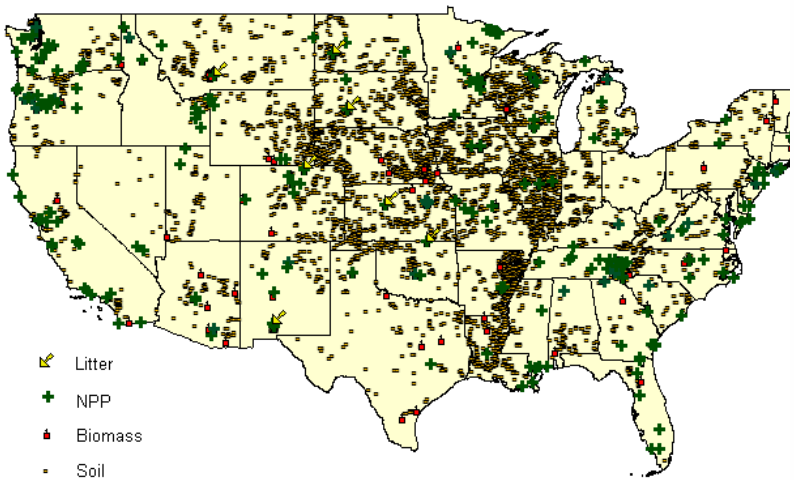
Terrestrial Ecosystem Carbon Cycle

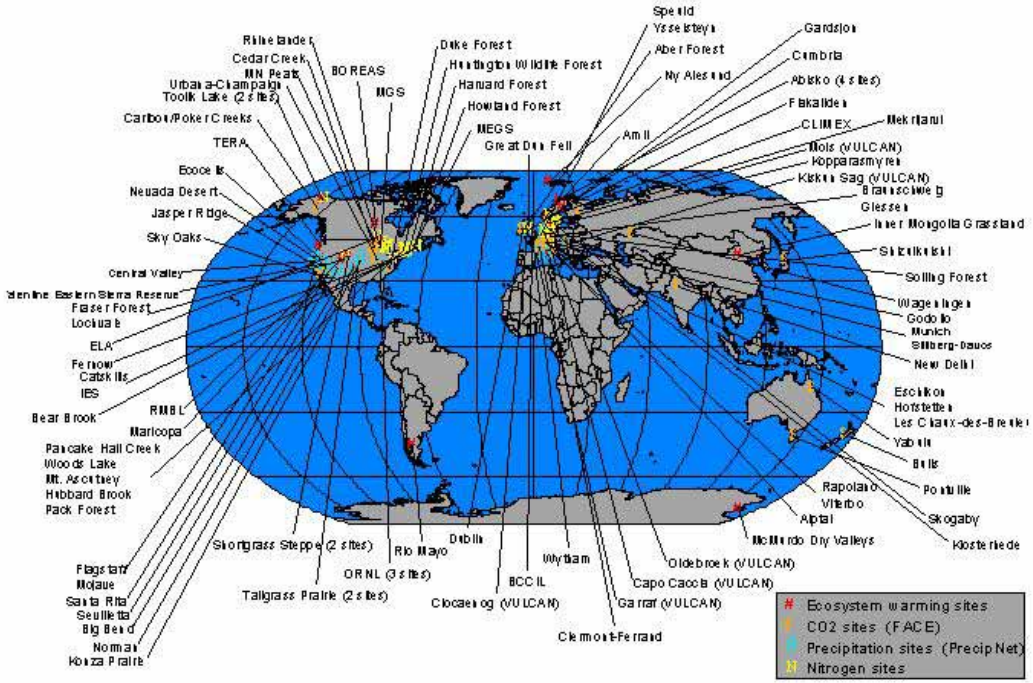




Data assimilation







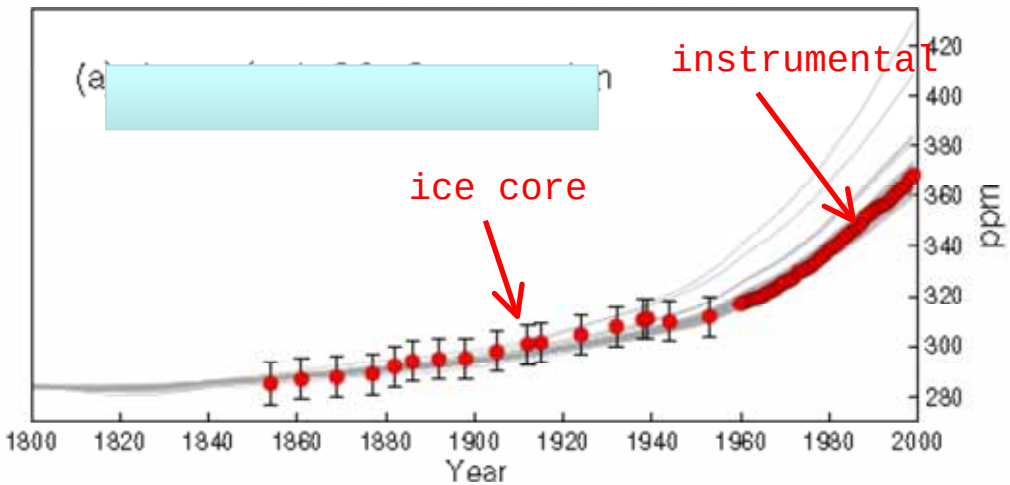
Estimating carbon cycle parameters from global observations using an Earth system model

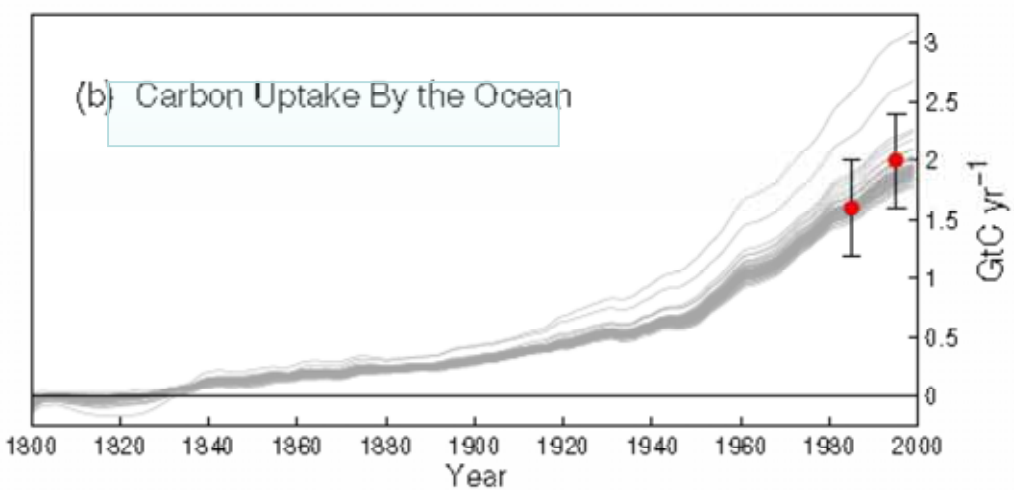
based on work presented in Ricciutio, Tonkonojenkov, Urban, Wilkinson, Matthews, Davis, and Keller, submitted to *Global Biogeochemical Cycles* (2008)

- Parameters: soil respiration (Q_{10}), photosynthetic rate constant (Kc_{25})
- Observations: annual atmospheric CO_2 (instrumental & ice core),decadal air-sea CO_2 fluxes
- Model: UVic Earth System Model (TRIFFID for terrestrial carbon)
  (ensemble of 48 runs in 2-dimensional parameter space)
- Assimilation: Bayesian parameter estimation (via Monte Carlo) + statistical emulation (fast approximation to UVic)

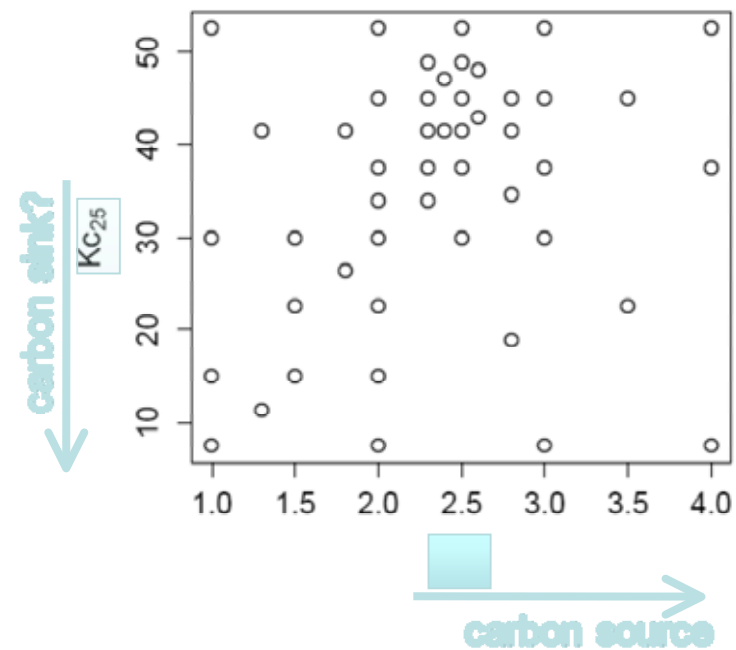
Ensemble output and observational constraints

hindcasts





ensemble design
(48 runs)



model parameters

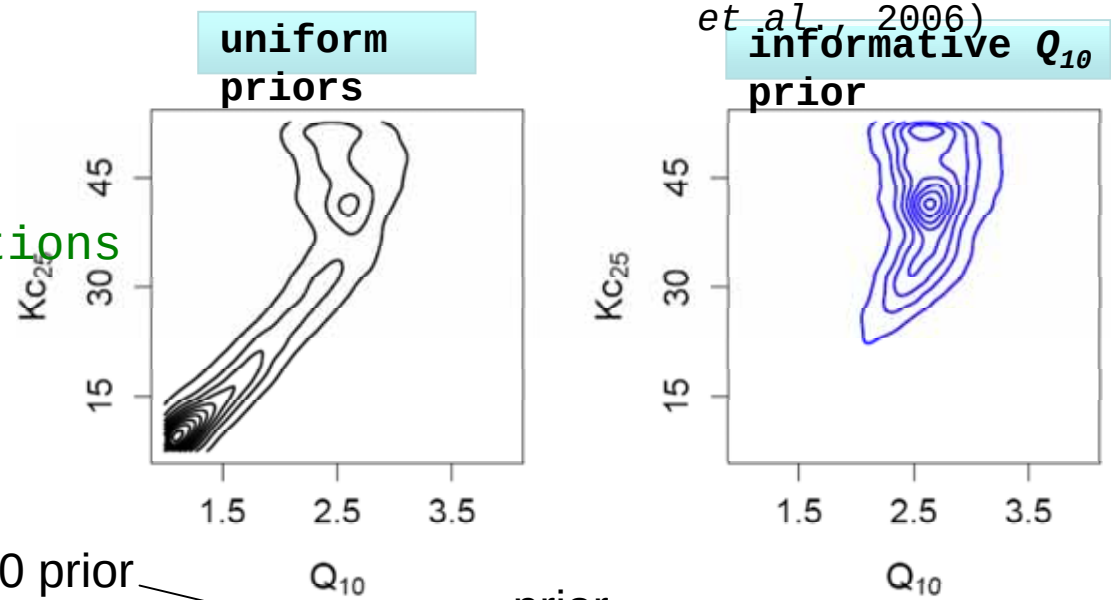
Q_{10}: temperature sensitivity of soil CO_2 respiration

Kc_{25}: photosynthetic rate constant (w/ CO_2 fertilization)

Assimilation results

(prior from lab measurements, Fierer *et al.*, 2006)

joint parameter probability distributions

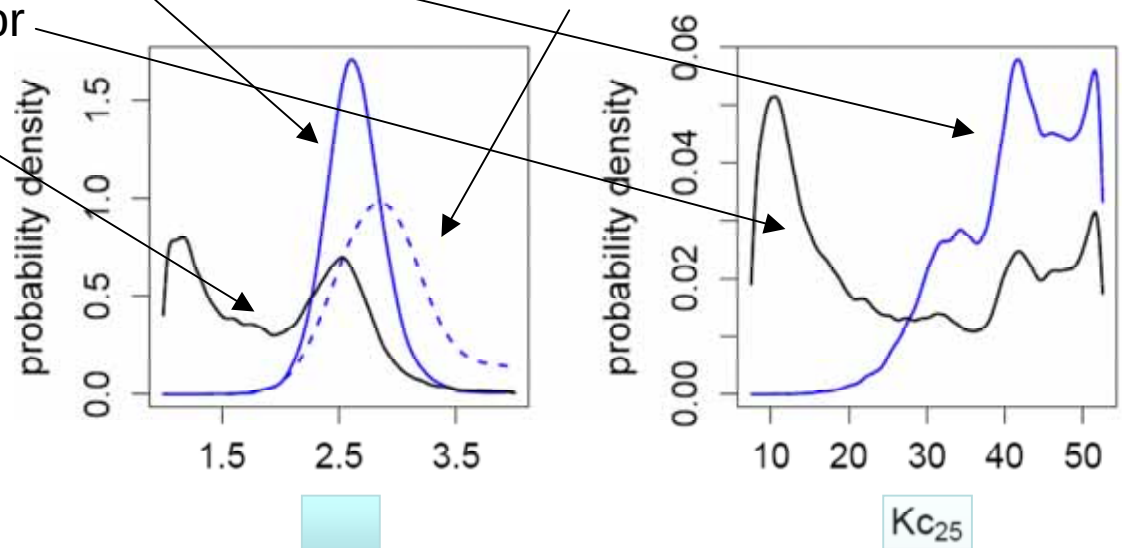


Posterior with Q10 prior

prior

Posterior without Q10 prior

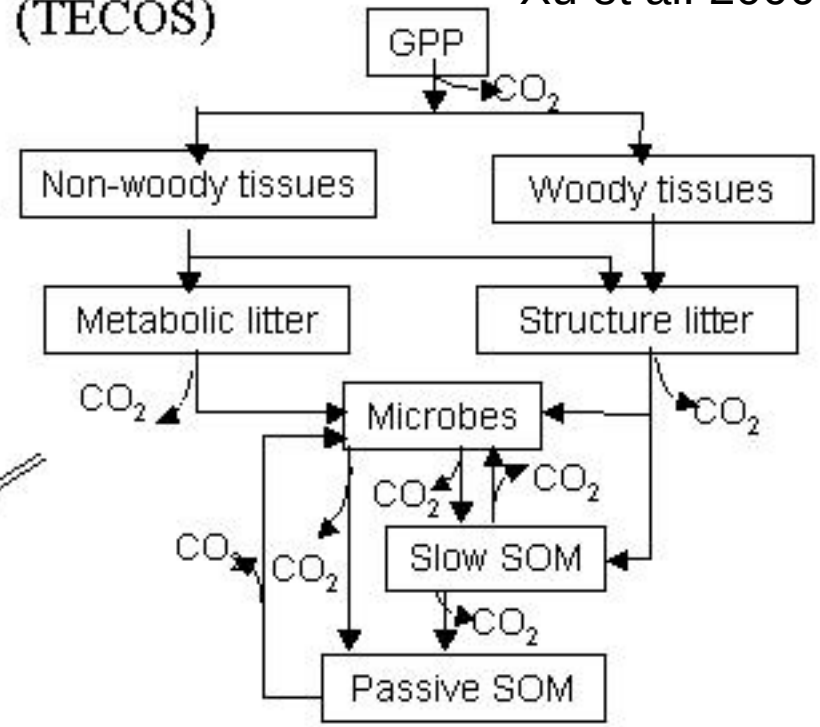
single-parameter (marginal) probability distributions



Luo et al. 2003
Xu et al. 2006

Multiple data sets

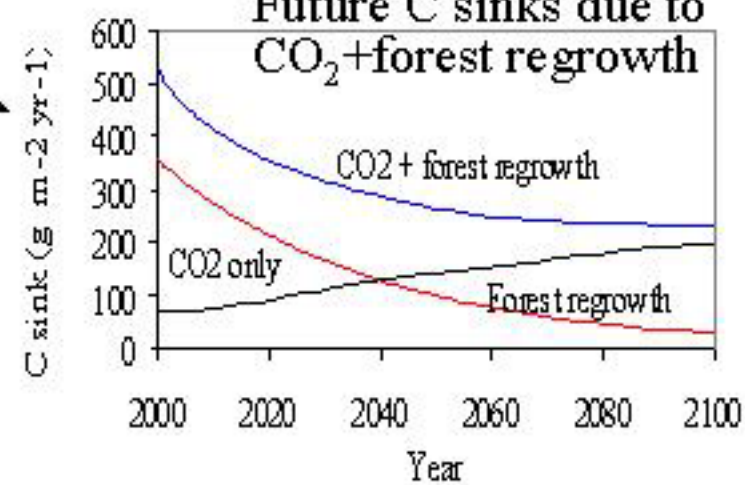
Multi-pool model (TECOS)



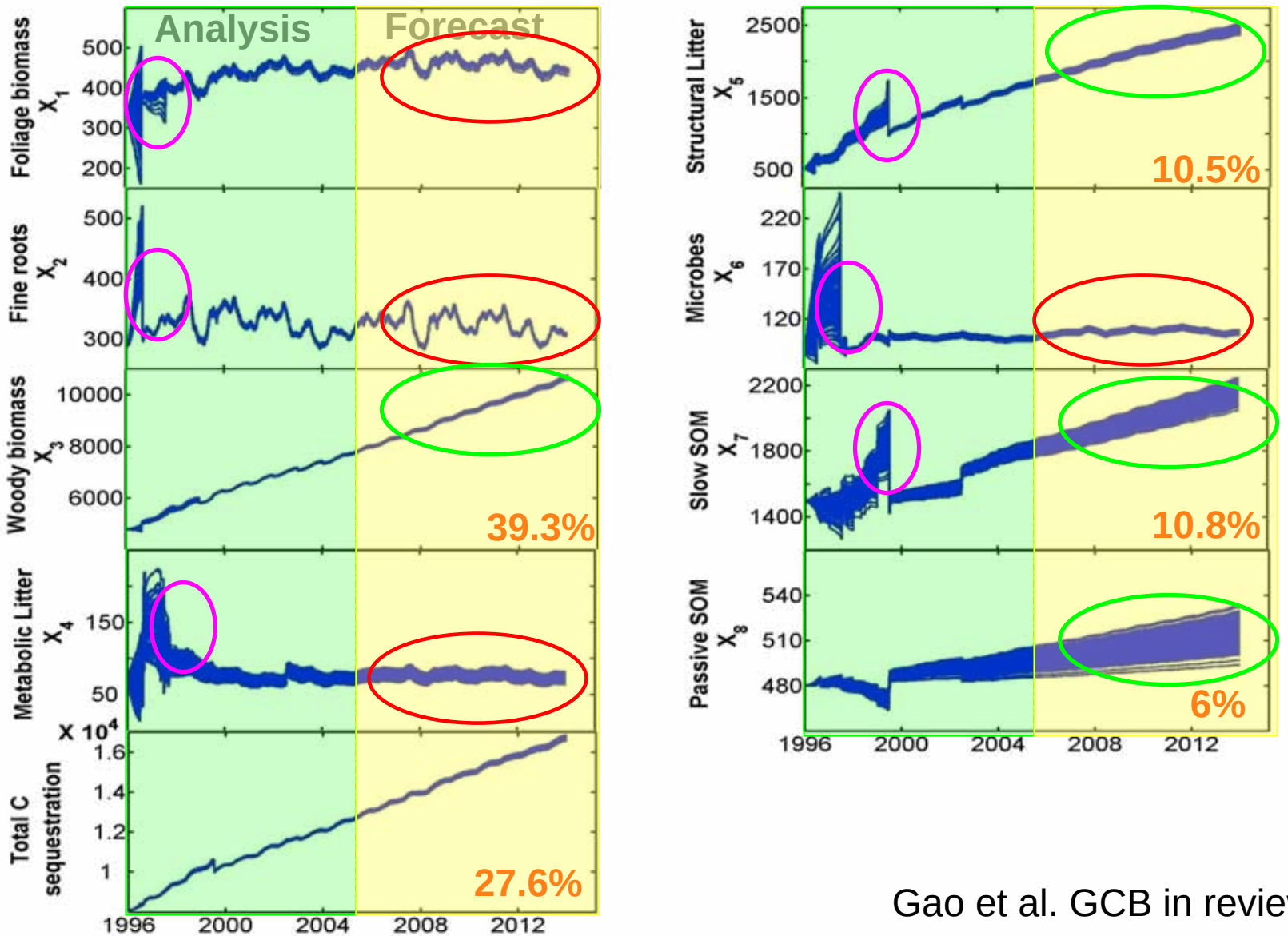
Multiple parameter values

Pool	Residence time (yr)	
	- CO_2	+ CO_2
Nonwoody biomass	1.557	1.263
Woody biomass	27.369	19.429
Metabolic litter	0.128	0.121
Structural litter	3.242	2.839
Microbial biomass	0.321	1.081
Slow SOM	30.523	49.134
Passive SOM	885.027	1031.368

Future C sinks due to CO_2+forest regrowth



Carbon pools daily analysis (lines) from 1996-2004 and carbon pools daily forecast from 2004-2012 using 100 ensembles.



Gao et al. GCB in review

Regional applications

NPP
Biomass
Litter
SOC

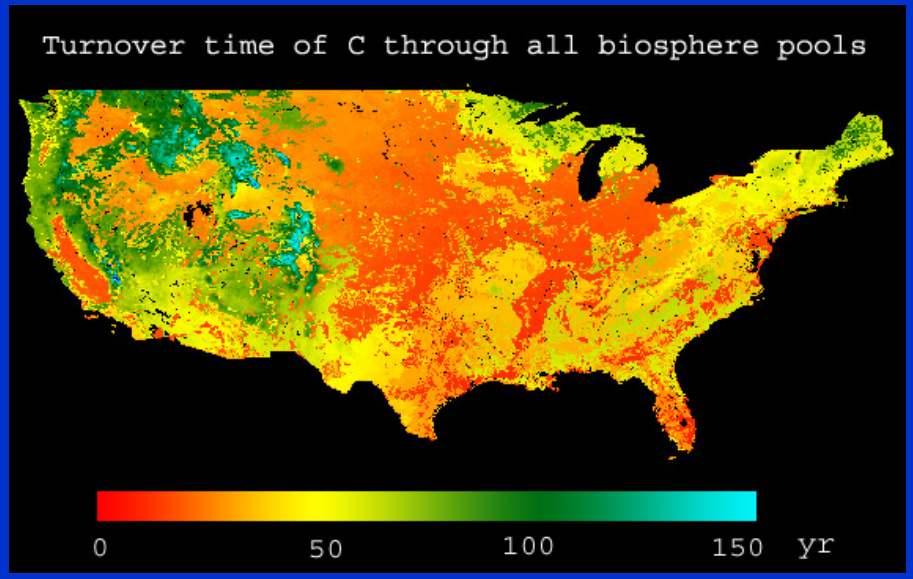
NDVI
Radiation
Land cover
Soil texture
Precipitation
Soil moisture
temperature

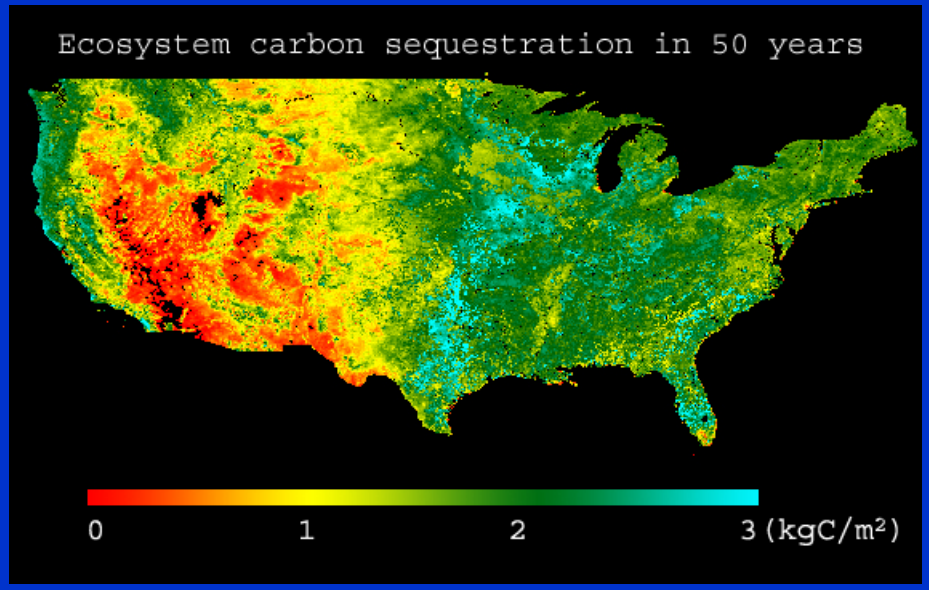
→ TECO → parameters

Partitioning coefficients
Transfer coefficients

Global change scenarios

→ TECO → Regional carbon sinks and its variability

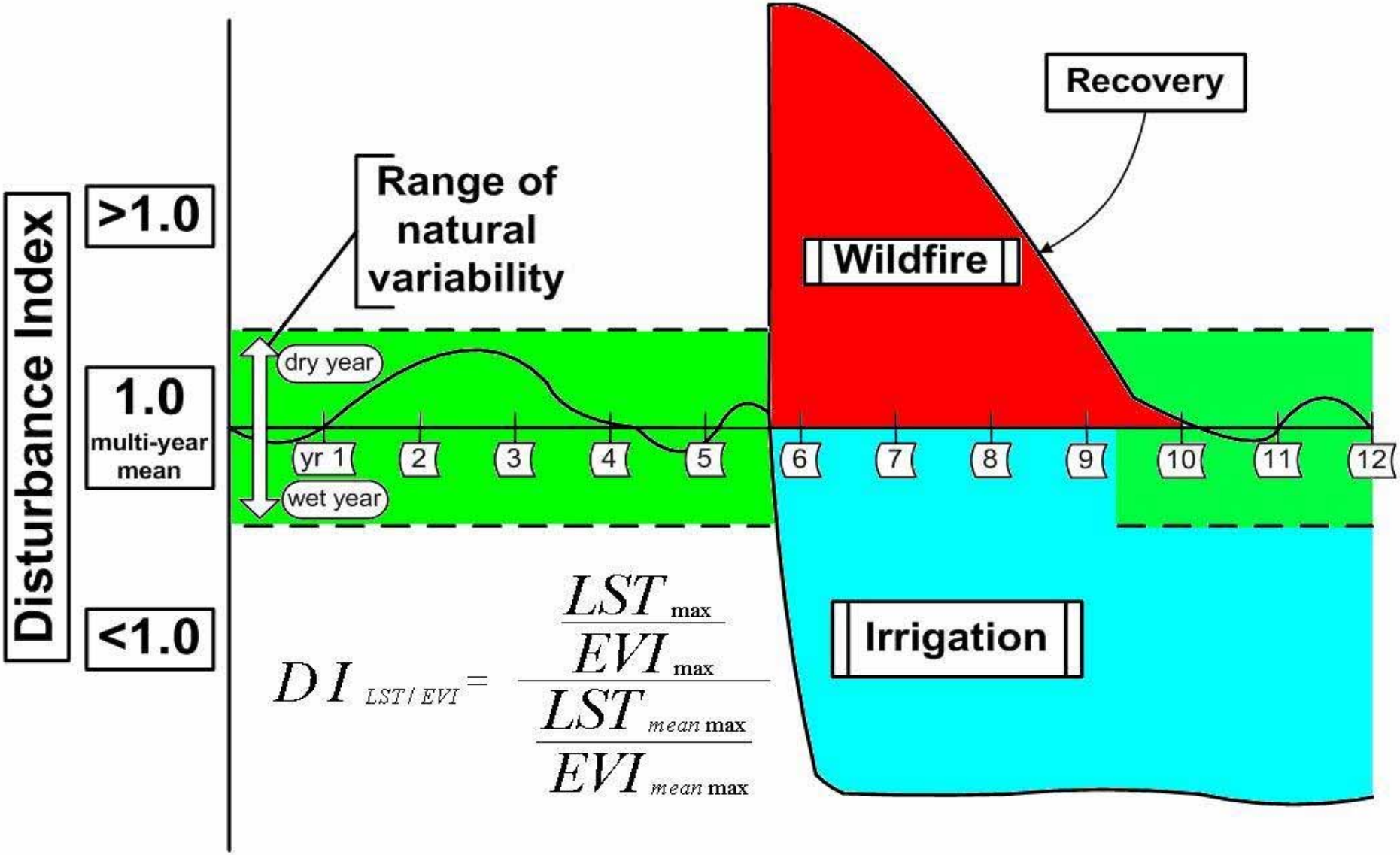




Zhou and Luo 2008 GBC

Disturbances

GLOBAL Generalized Disturbance Index



$$DI_{LST/EVI} = \frac{\frac{LST_{max}}{EVI_{max}}}{\frac{LST_{mean\,max}}{EVI_{mean\,max}}}$$

Mildrexler et al 2006

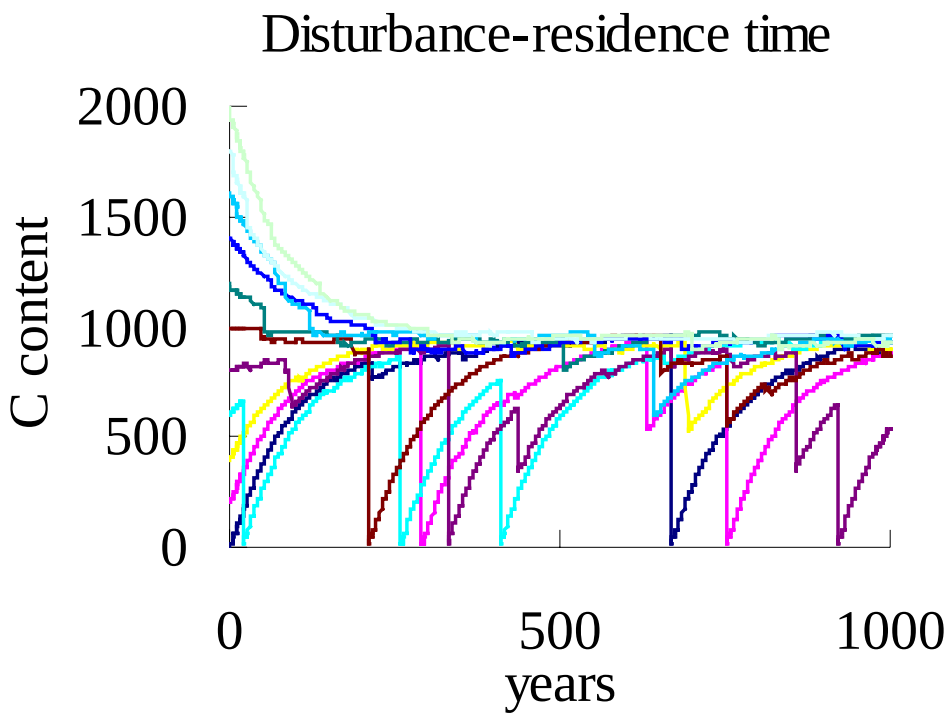
Effects of disturbances on C cycles

Types	**Effects on ecosystems**	**Occurrence**	**Distribution of Intensity**	**Disturbances**
I	Fluctuation of carbon influx	Always	Uniform	Changes in temperature
II	Fluctuation of residence time	Always	Uniform	Changes in temperature
III	Decreases in carbon influx	Poisson	Normal	Diseases, drought
IV	Decreases in residence time	Poisson	Normal	Storms, extreme weather events
V	Decreases in carbon content	Poisson	Normal	Fire, harvest

E. S. Weng and Y.Q. Luo, unpublished

Disturbances reducing residence time (Type IV)

$$Exp(X) = \frac{U}{Exp(1/\tau)}$$



E. S. Weng and Y.Q. Luo, unpublished

Future research directions

1. Data assimilation to improve models for forecasting future C sink dynamics
2. Disturbance regimes
3. Effects of global change on carbon processes and disturbance regimes
4. Frameworks to integrate disturbances with carbon cycle models

Dynamic Disequilibrium (DD)

- Internal mechanism of equilibration
- External forces to cause disequilibrium
- The two forces are opposite and act against each other to maintain dynamic disequilibrium
- Future land carbon sink capacity depends on relative magnitudes of the two forces