Biosphere Atmosphere Interactions: Ingredients for Toy Models

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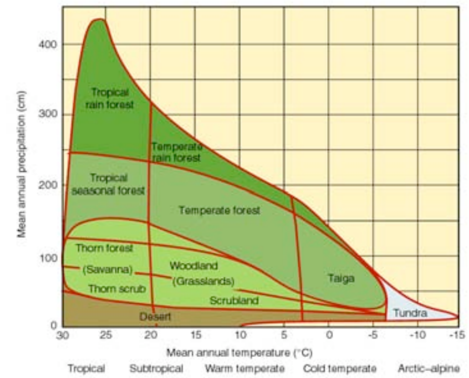
(1) Who: Name Calling

1. Taxa/Species

2. **Physionomic/structural**: Biomes e.g. desert, rainforest - albedo, roughness



3. **Bioclimatic + CO2 +…**

4. **Functional:** based on satellite photosynthesis index:

$$\{\%tree/shrub\} \times \begin{Bmatrix} deciduous \\ evergreen \end{Bmatrix} \times \begin{Bmatrix} broadleaved \\ needleleaved \end{Bmatrix}$$

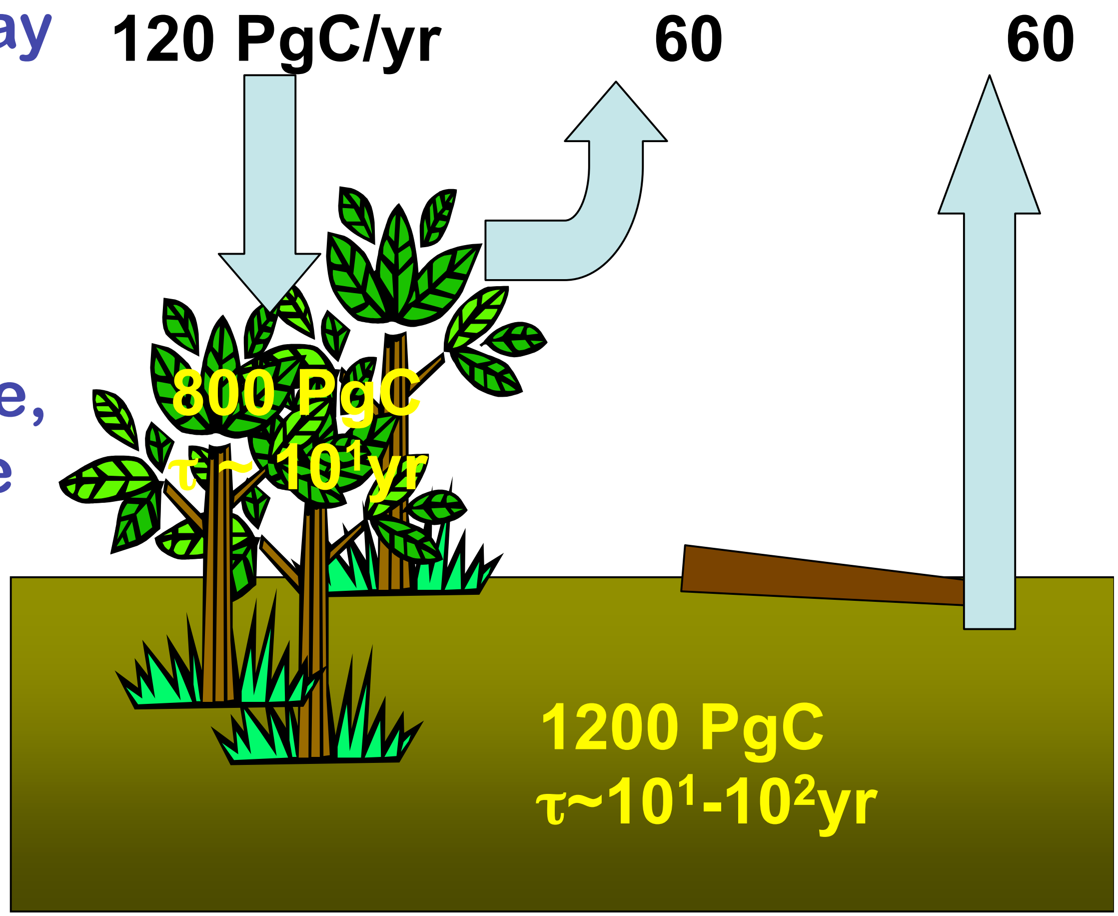
$$\{\%herbaceous/crops\} \times \begin{Bmatrix} C3 \\ C4 \end{Bmatrix}$$

$$\{\%bare\}$$

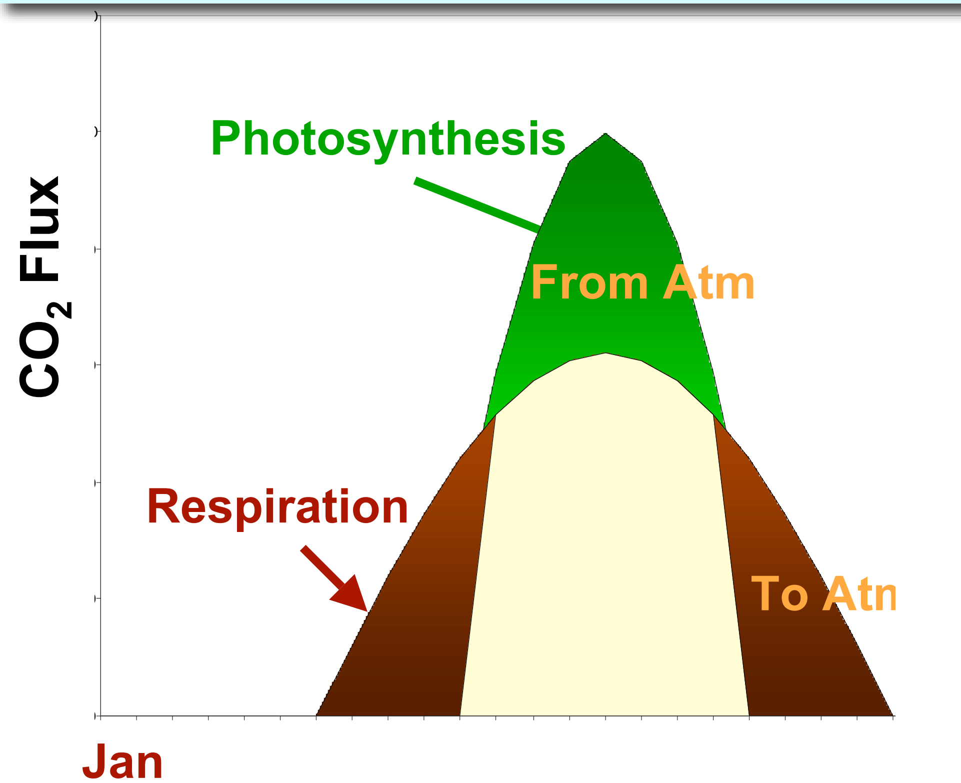
Static land cover: typically 4 --> lookup table of structural properties and BGC chacteristics. Prognostic land cover: 3+

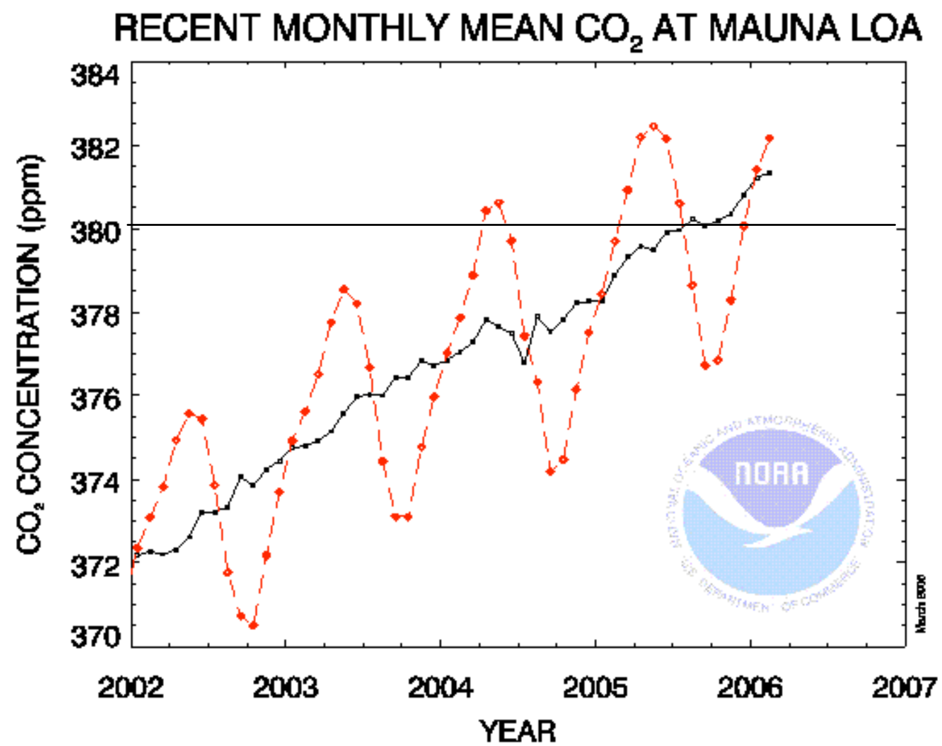
(2) What? [lifecycle traced by C cycle]

- Growth, mortality, decay
- Population: {ages}
- Photosynthesis (climate, CO_2, soil H_2O, resource limitation)
- Decay (T, soil H_2O,..)



Two major fluxes - seasonal cycle





- **Seasonal asynchrony between photosynthesis and decomposition**

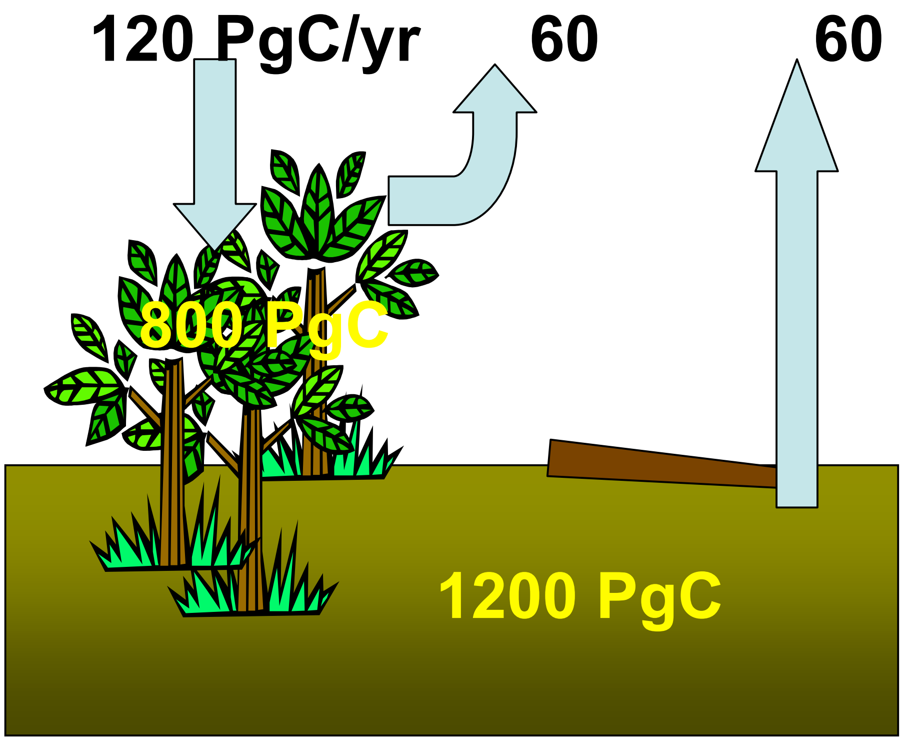
→ net fluxes of CO_2 to and from atm
→ seasonal cycle of CO_2 in atm

- **Annual imbalance → carbon source/sink**

Fung et al JGR 1983, 1987:

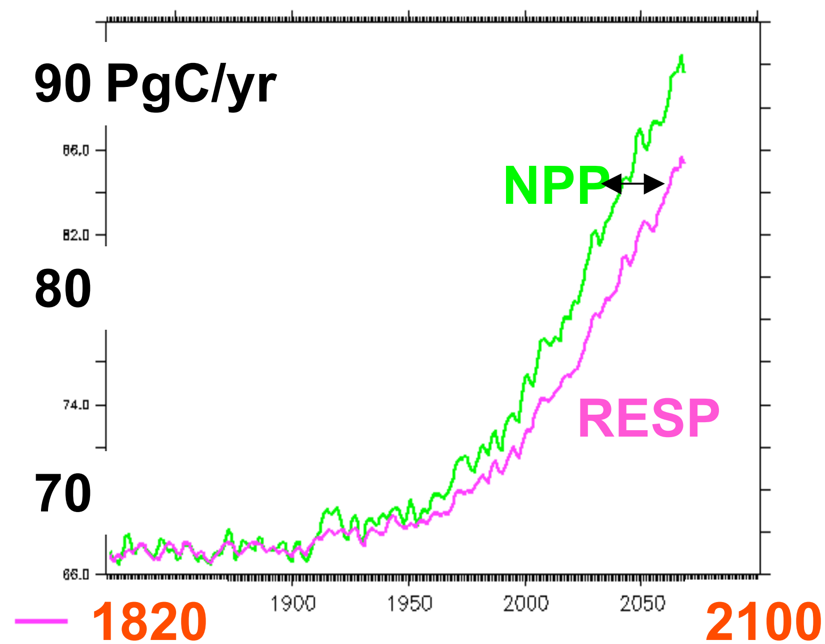
Simple prescriptions of seasonality. 1987 based on satellite obs + temperature

(3.1) How?
First simple toy model: carbon only



$$\frac{\partial M_{veg}}{\partial t} = NPP - \frac{M_{veg}}{\tau_{veg}}$$

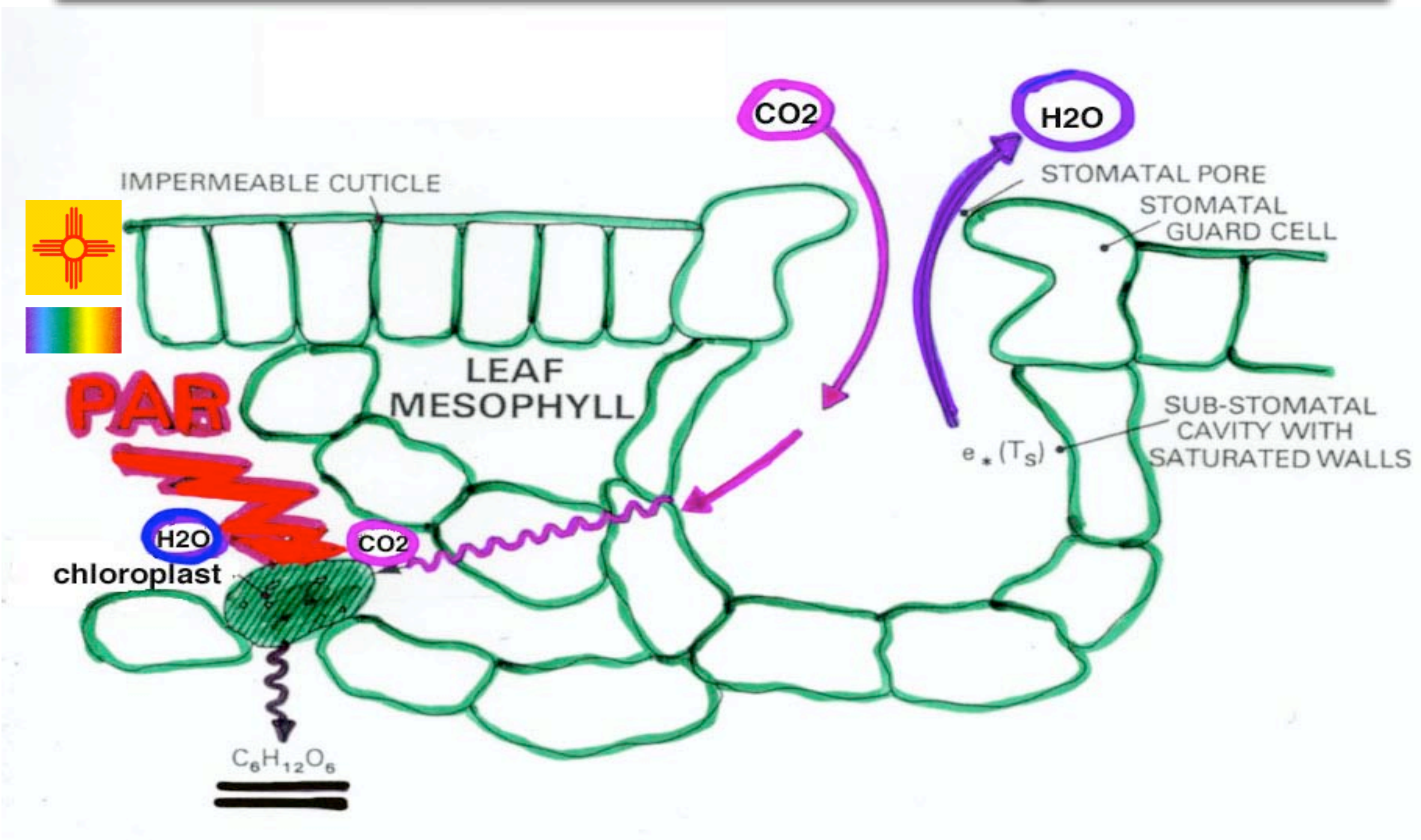
$$\frac{\partial M_{soil}}{\partial t} = \frac{M_{veg}}{\tau_{veg}} - \frac{M_{soil}}{\tau_{soil}}$$



τ_{veg} ~ 15 yr

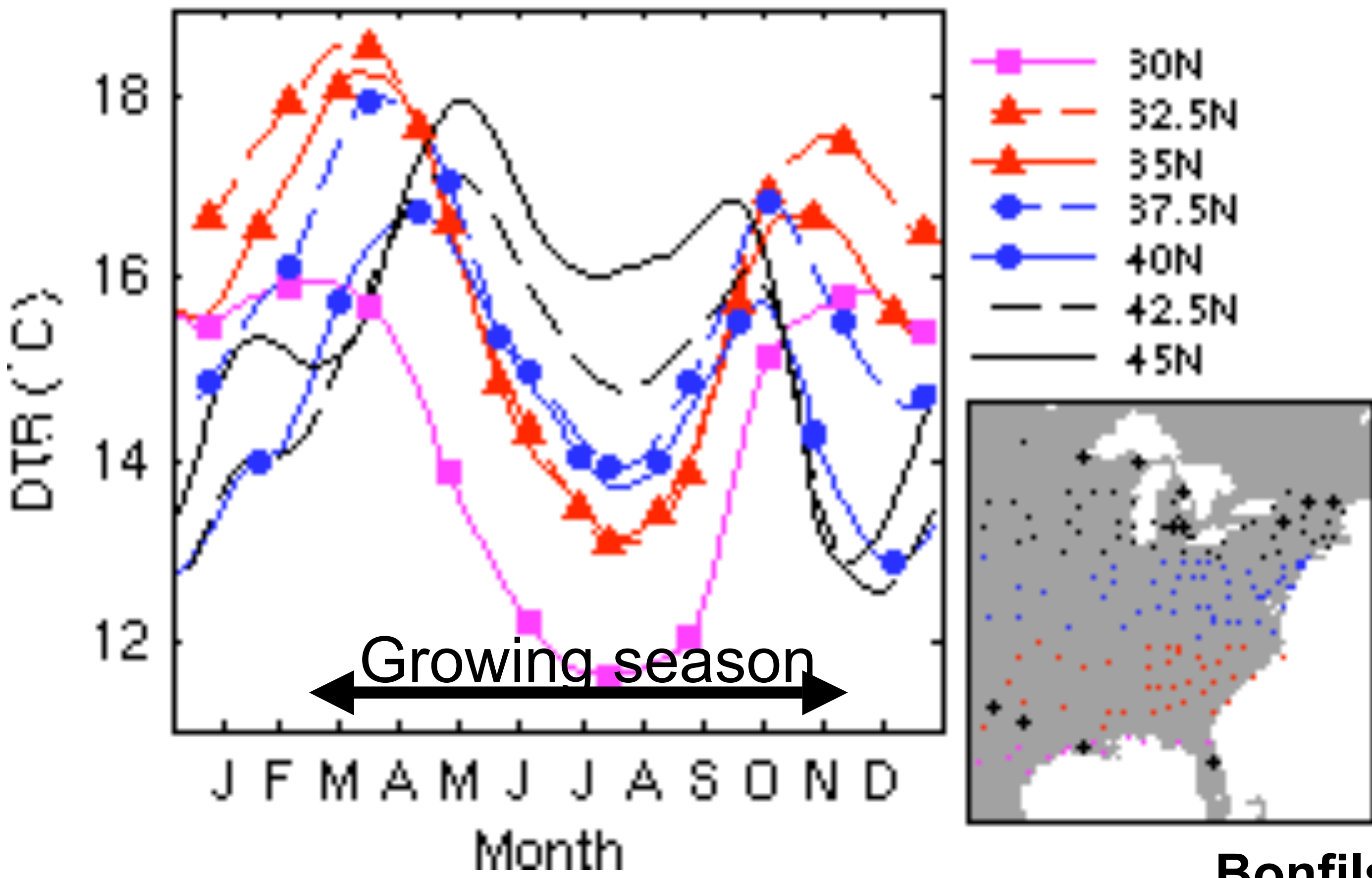
τ_{soil} ~ 25 yr

(3.2.1) Leaf Photosynthesis Piers Seller's PAR Diagram



Diurnal Temperature Range: coupling of energy-water-carbon fluxes

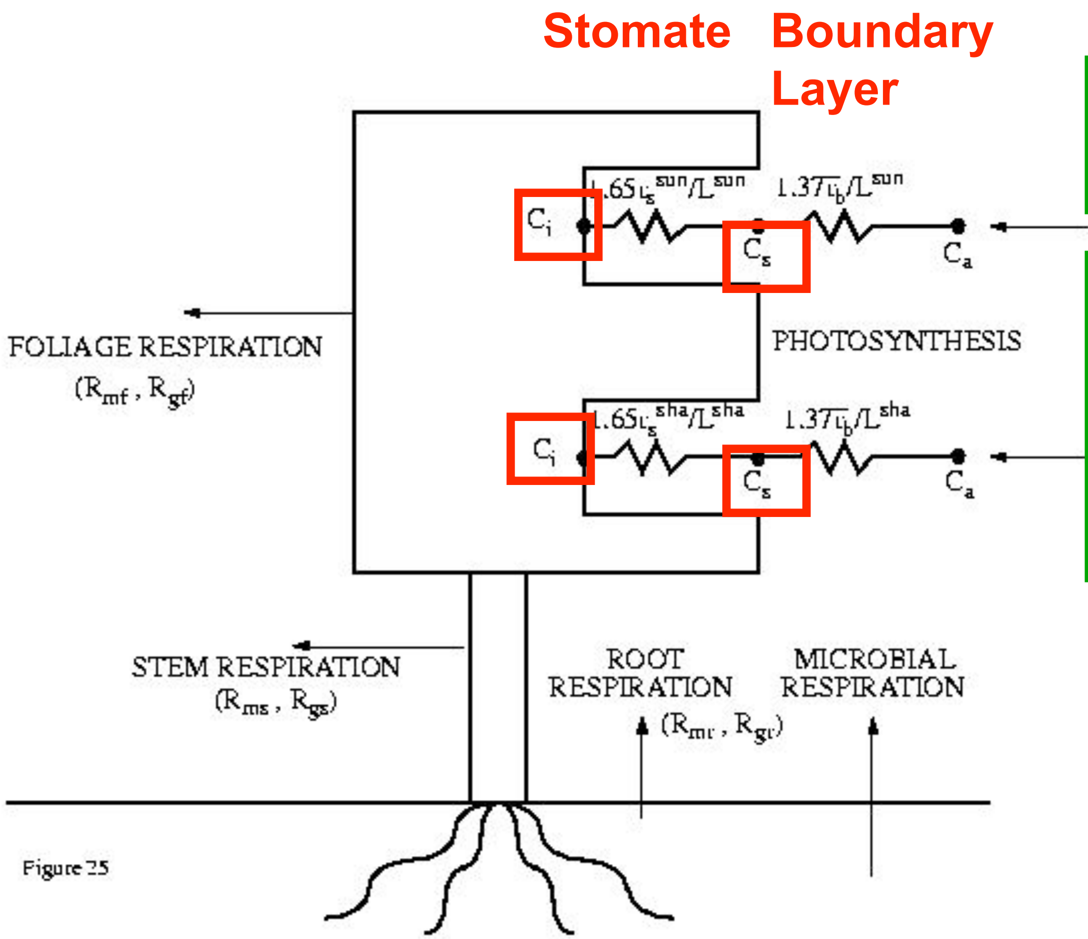
$$C\frac{\partial T_g}{\partial t} = SW \updownarrow + LW \updownarrow \underbrace{-SH}_{\textit{warms PBL}} - \underbrace{LH}_{\textit{cools PBL}}$$



Spring chill when growing season starts

Bonfils et al. GRL 2005

(3.2.1) Rates of Carbon Assimilation and Transpiration



Farquhar:

$A = g\_s\ (C_a - C_i)$

Collatz: leaf boundary layer

$A = g\_l\ (C_a - C_s)$

$= g\_s\ (C_s - C_i)$

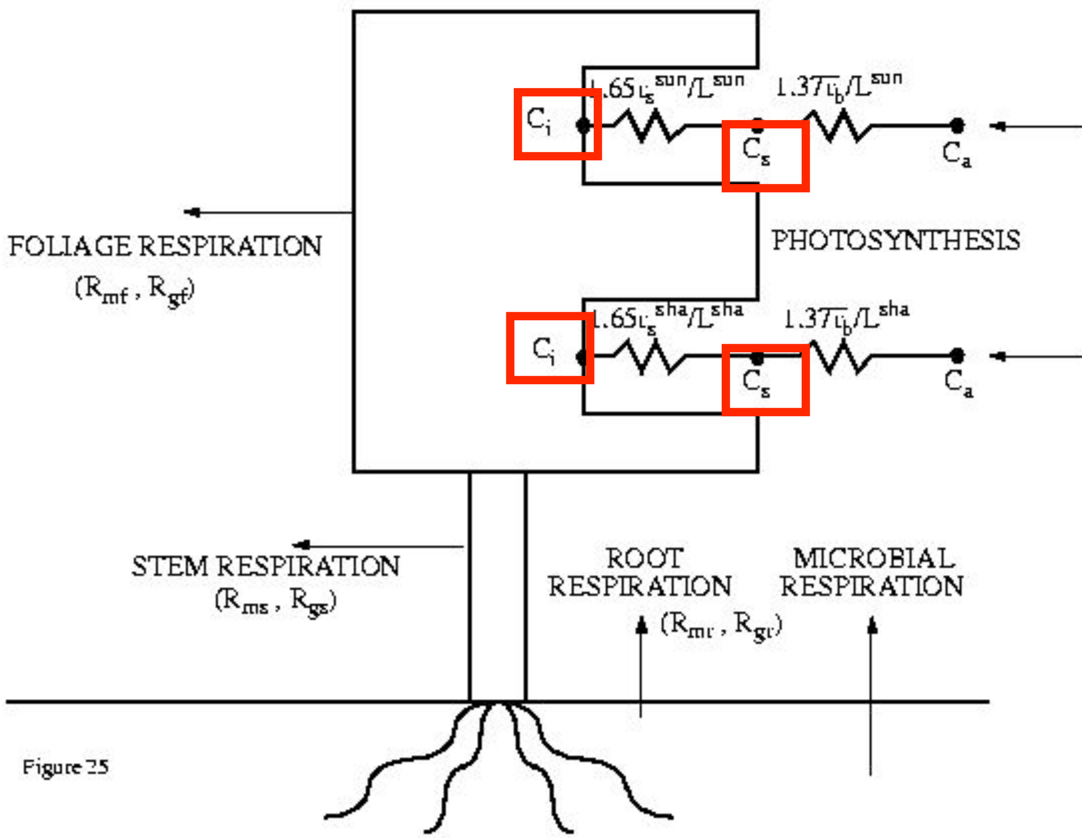
Need to determine stomatal conductances g_s and C_i

Transpiration

Tr = g_w (1-RH_a)

Assimilation Rates of Sun and Shade Leaves

(Sellers et al. J Climate 1996)



Per area of leaf sfc:

A_*sun,shade* = min {

PEP-Carboxylase

Light_*sun,shade*

Export/utilization }

limited rates of assimilation

Varies with plant functional types

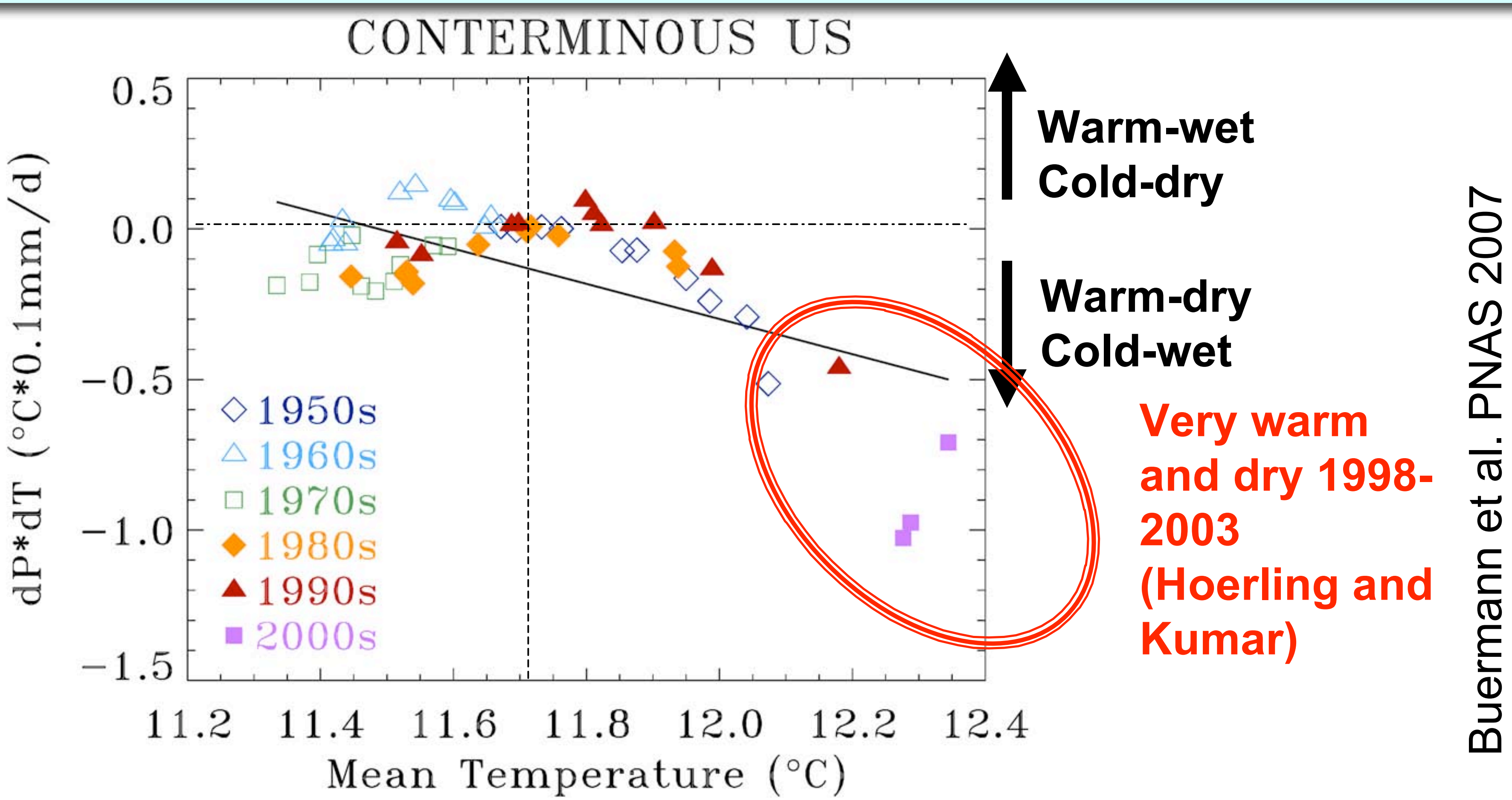
Normalize canopy

GPP =

A_*sun* * f_sun*LAI

\+ A_*shade* * f_*shade* * LAI

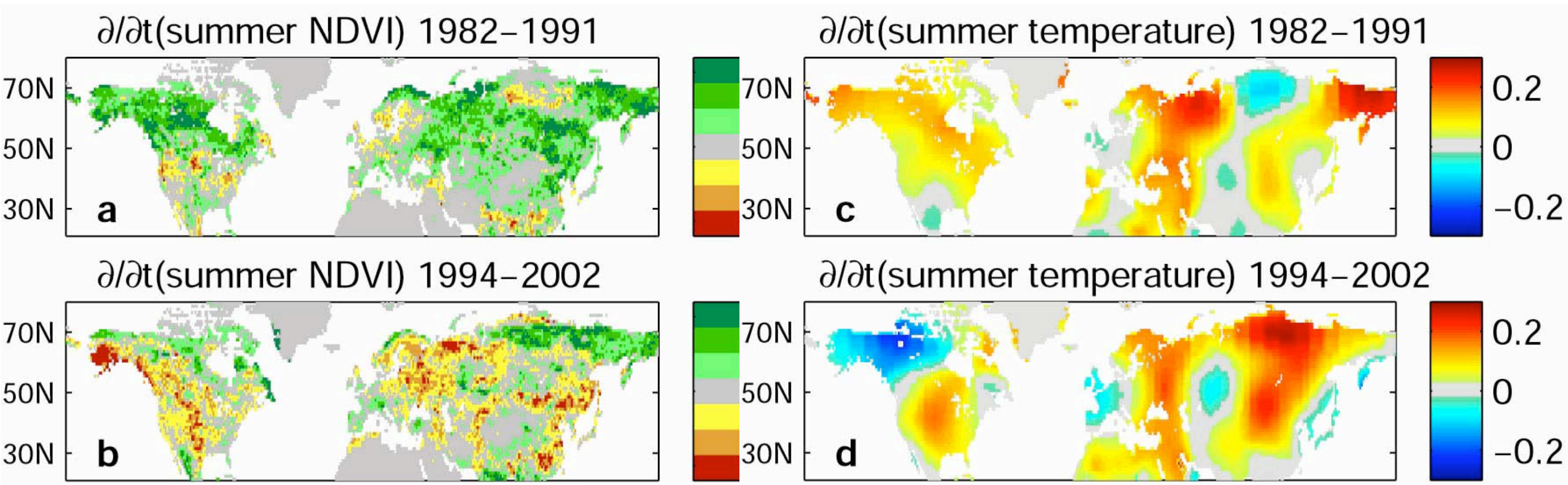
Recent Drought: Co-Variations of ΔT and ΔPrecip

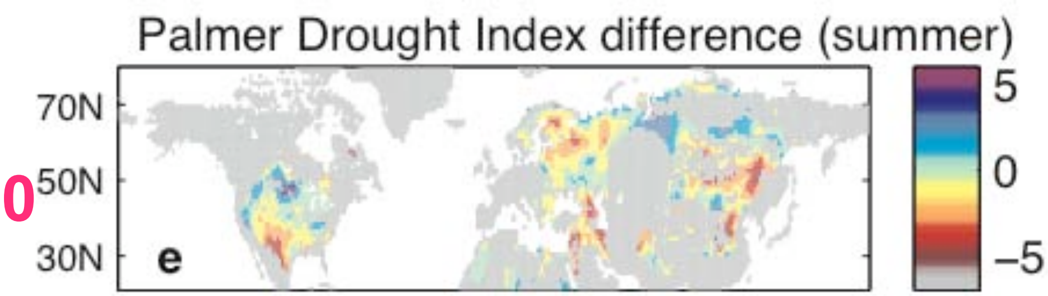


Global distribution of droughts:

Dai, A., K. E. Trenberth, and T. Qian "A global data set of Palmer Drought Severity Index for 1870-2002: Relationship with soil moisture and effects of surface warming" *J. Hydrometeorology,* 2005.

Halting of the Summer Greening Trend: slowing of northern hemisphere land sink





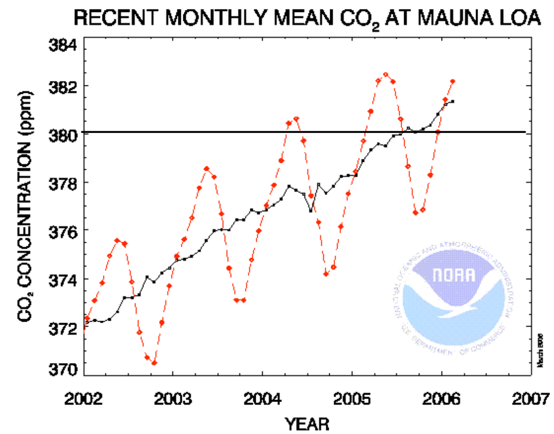
Where

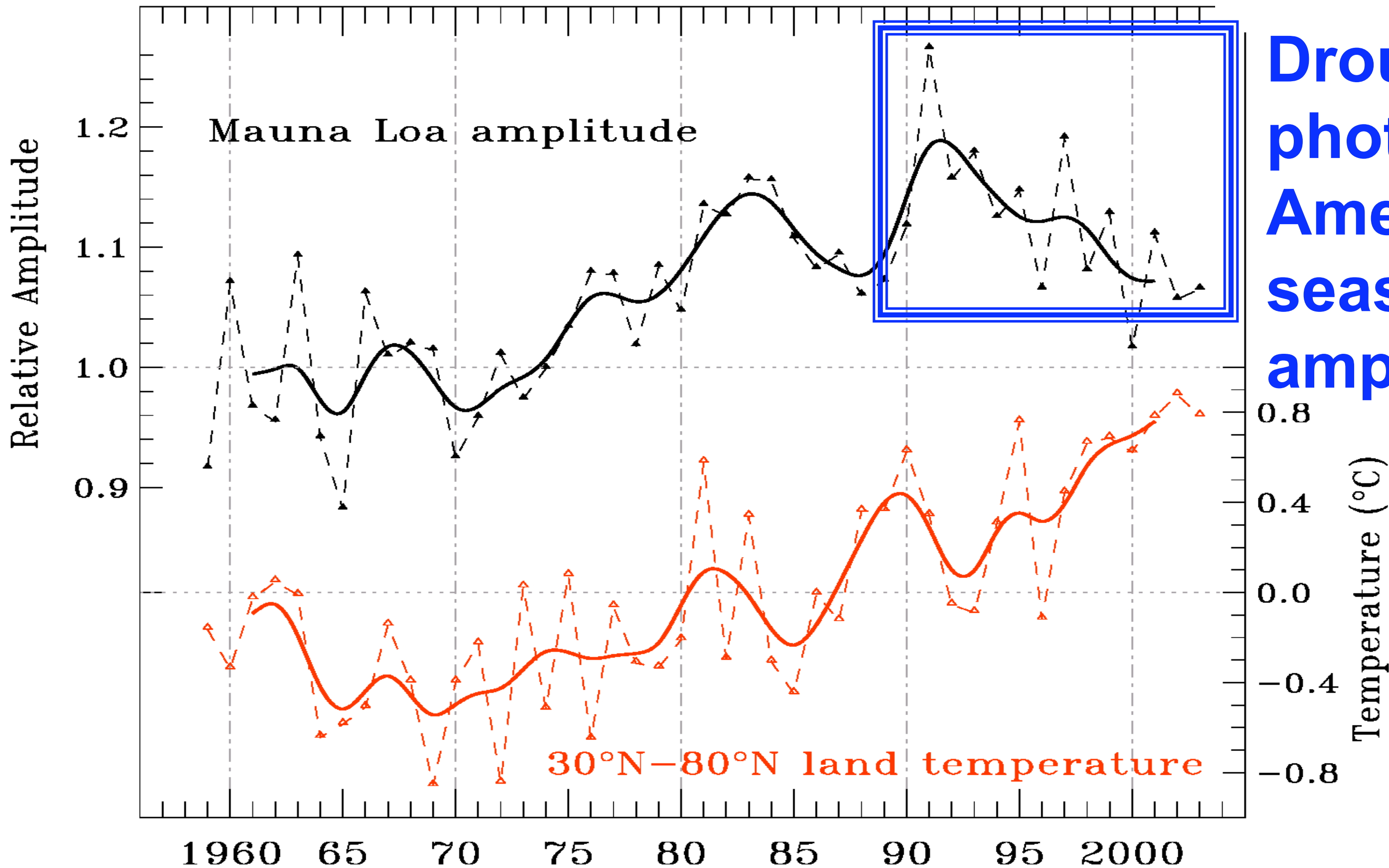
∂/∂t(NDVI)<0 and ∂/∂t(T)>0

water stress

Angert et al., PNAS 2005

Evidence for slowing NH land sink: Changes in MLO Amplitude since 1990

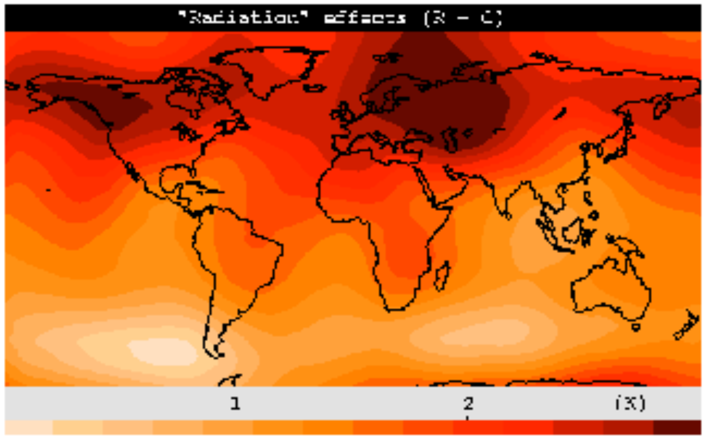




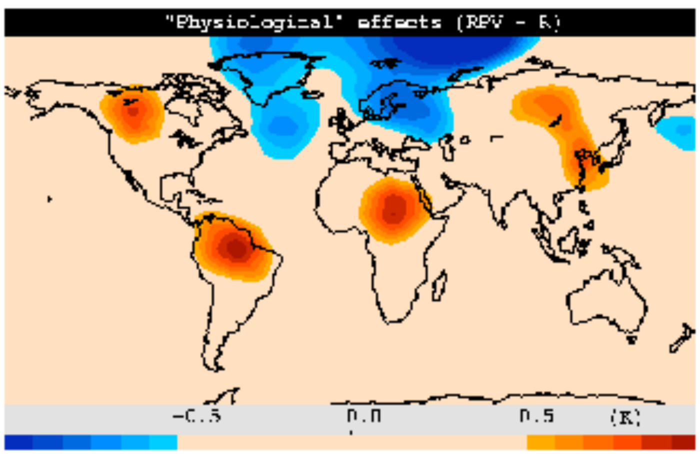
Droughts reduced photosyn in N America and seasonal CO2 amplitude at MLO

Buermann et al. PNAS 2007

2xCO2: Additional Feedbacks due to Plant Physiology in GCM with biophysics.



Warming due to radiation



Additional Warming due to plant physiology

In the tropics:

- Nutrient limitation of photosynthesis
- Stomatal closure at high water stress
- Reduces transpiration and
- Causes net radiation to be balanced by sensible rather than latent heating

Sellers et al. Science 1996

Stomatal Suicide

$$C\frac{\partial T_g}{\partial t} = SW\updownarrow + LW\updownarrow \underbrace{-SH}_{warms\ PBL} - \underbrace{LH}_{cools\ PBL}$$

+Δ CO_2

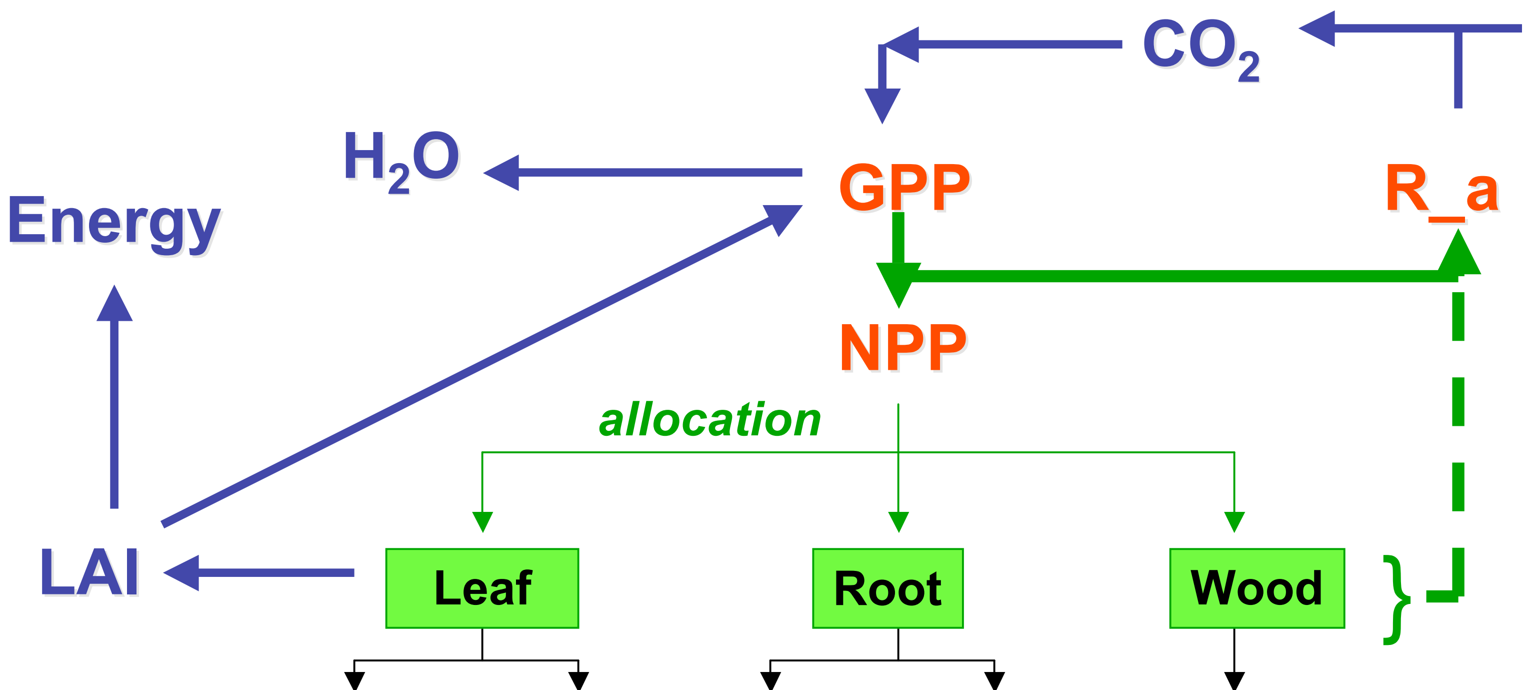
+Δ T

→ stomatal closure

→ less evaporation

→ shift to sensible heating to balance net radiation

(3.2.2) Photosynthesis --> Growth



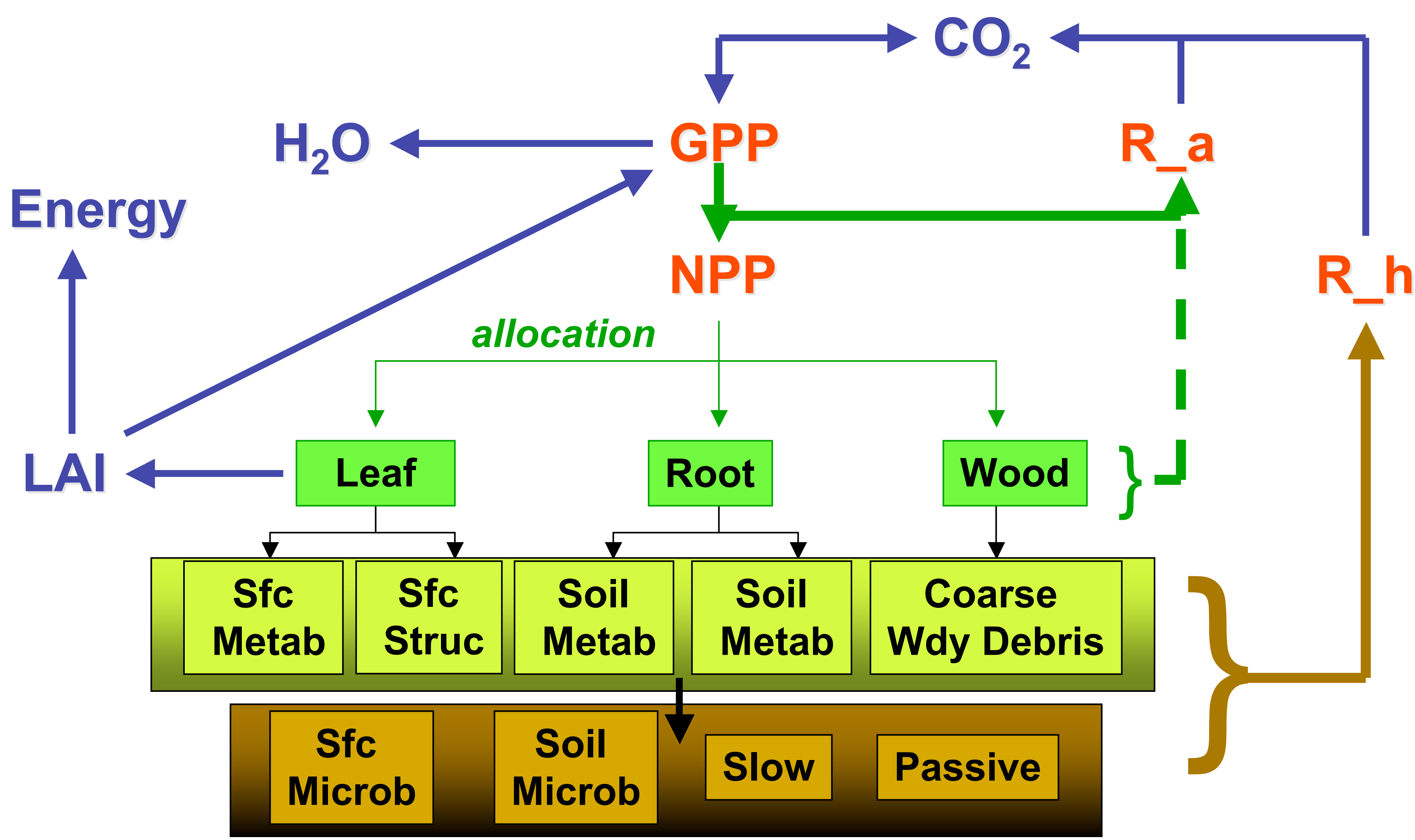
<u>Strategy for survival</u>: allocate new C to

Roots when water and nutrient limited

Wood when light limited

Friedlingstein et al. GCB 1995

(3.2.3) Photosynthesis, Growth, Mortality & Decay



(3.2) Prognostic Carbon Cycle (with transpiration and dynamic albedo)

Atm

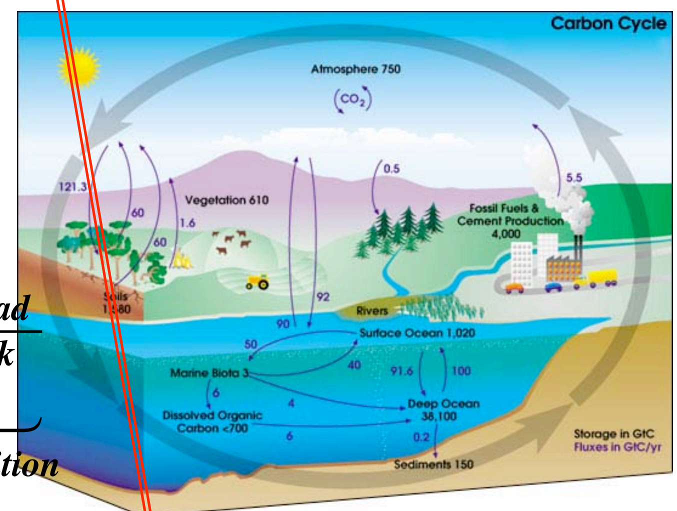
$$\frac{DC_a}{Dt} = (FF + Def + \underbrace{F_{oa}\Updownarrow}_{air-sea\_flux} + \underbrace{F_{ba}\Updownarrow}_{atm-land\_flux})\Big|_0 + \Im(C_a)$$

Land-live

$$\frac{\partial C^k_{b\_live}}{\partial t} = -\alpha^k \underbrace{F_{ab}\downarrow}_{photosynthesis}\Big|_0 - \underbrace{\frac{C^k_{b\_live}}{\tau^k_{live}}}_{mortality}$$

Land-dead

$$\frac{\partial C^k_{b\_dead}}{\partial t} = \underbrace{\frac{C^k_{b\_live}}{\tau^k_{live}}}_{mortality} + \sum_j F_{jk} - \underbrace{\frac{C^k_{b\_dead}}{\tau^k_{dead}}}_{decomposition}$$

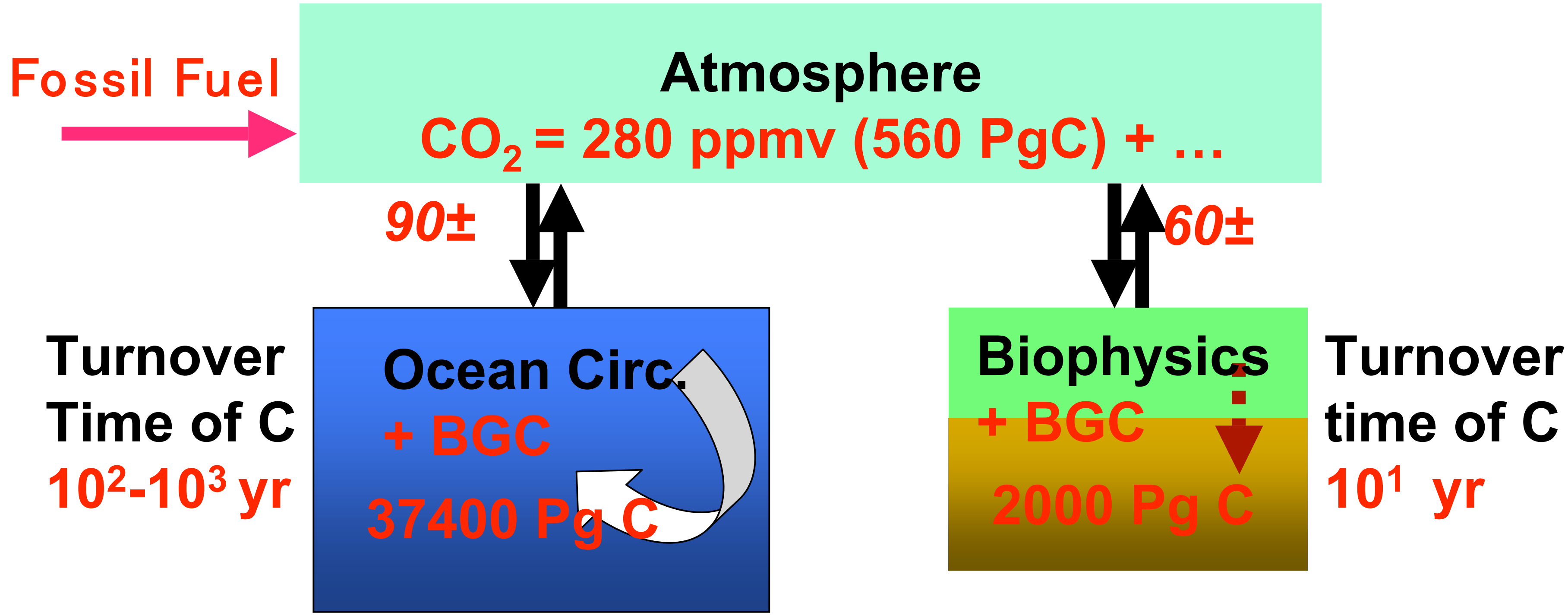


Changes climate

Responds to climate change

(4) Will the warming accelerate the warming?
CO2-Climate Feedbacks

Technical Goal: include interactive carbon dynamics in the climate model. Specify Emission (t), not atm CO_2 (t)



Challenge: validation of model

How would CO_2 and climate co-vary?

Suppose there is warming…

Atm CO_2 would increase because:

- Warming may enhance decomposition
- Increased ocean stratification → more carbon in mixed layer → reduced air-to-sea flux
- ….

Atm CO_2 would decrease because:

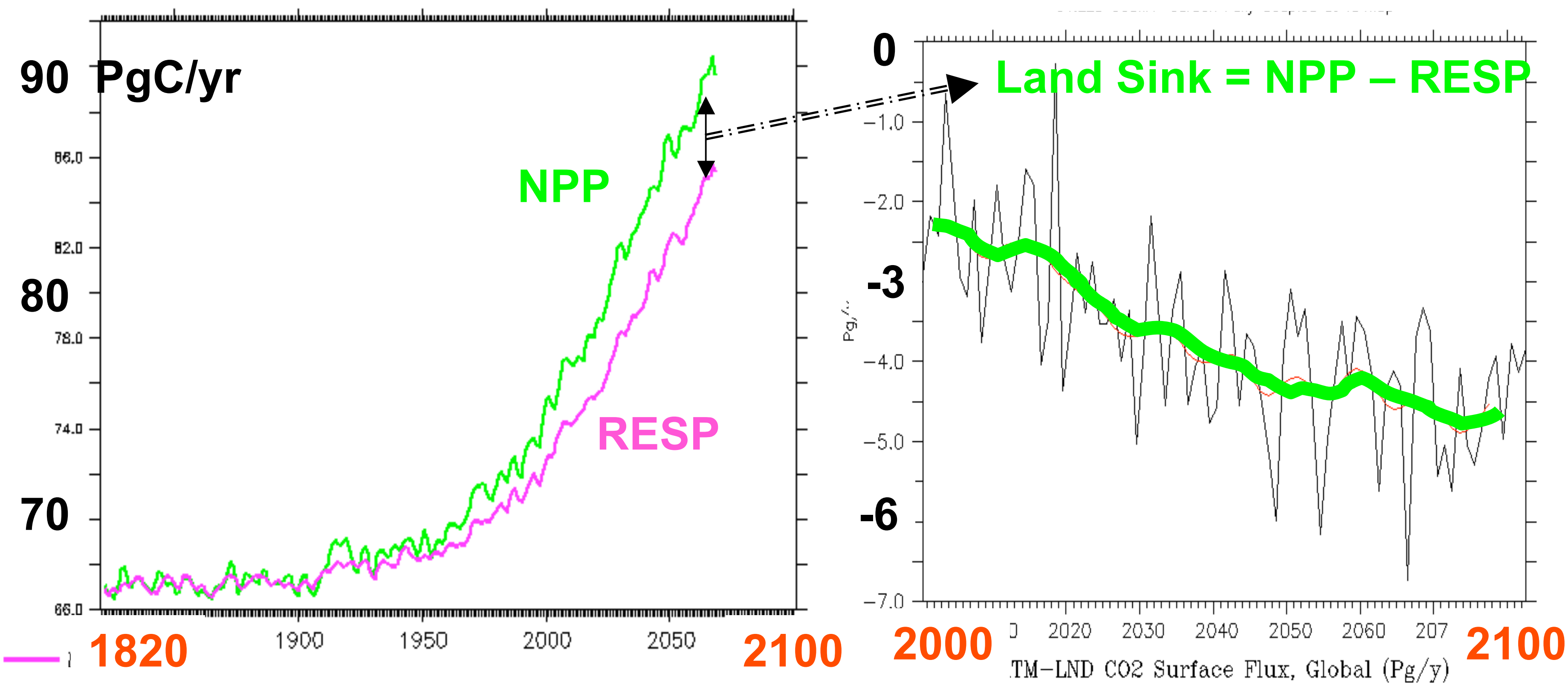
- warming may enhance photosynthesis
- Enhanced marine productivity and export

In model, three flavors of CO2:

- CO2_tracer(x,y,z,t)
- CO2_bgc=CO2_tracer(x,y,lowest layer,t)
- CO2_rad=CO2_tracer(x,y,column,t)

Models expts:
BGC coupling,
Radiative coupling

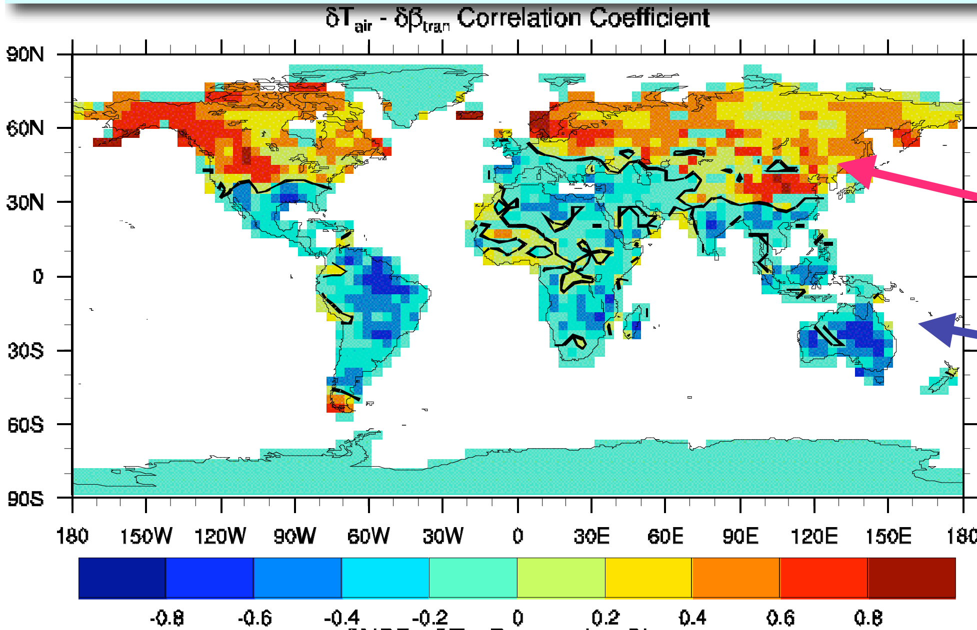
Land-Atm Fluxes
NCAR CCSM1-Carbon: FF



NPP incr with atm CO2 + ΔT
RESP incr with incr biomass + ΔT

Slowing down of land sink around 2050 despite continued increase in atm CO_2 and temperature

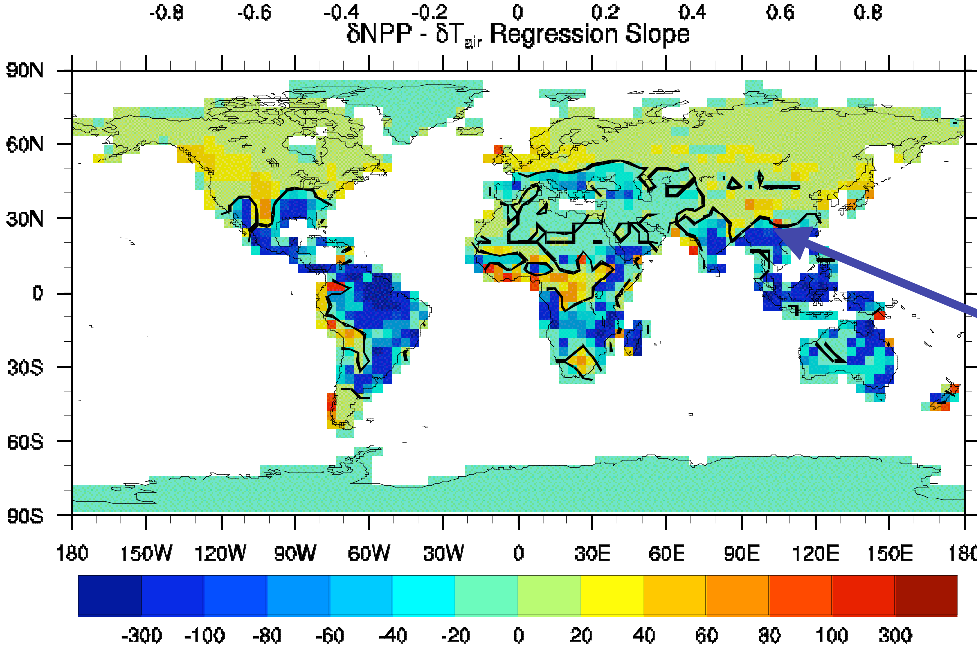
21st Century Correlations & Regressions: FF= SRES A2 ; δ = Coupled minus Uncoupled



{δT, δSoil Moisture Index}

Warm-wet

Warm-dry



Regression of δNPP vs δT

NPP decreases with carbon-climate coupling

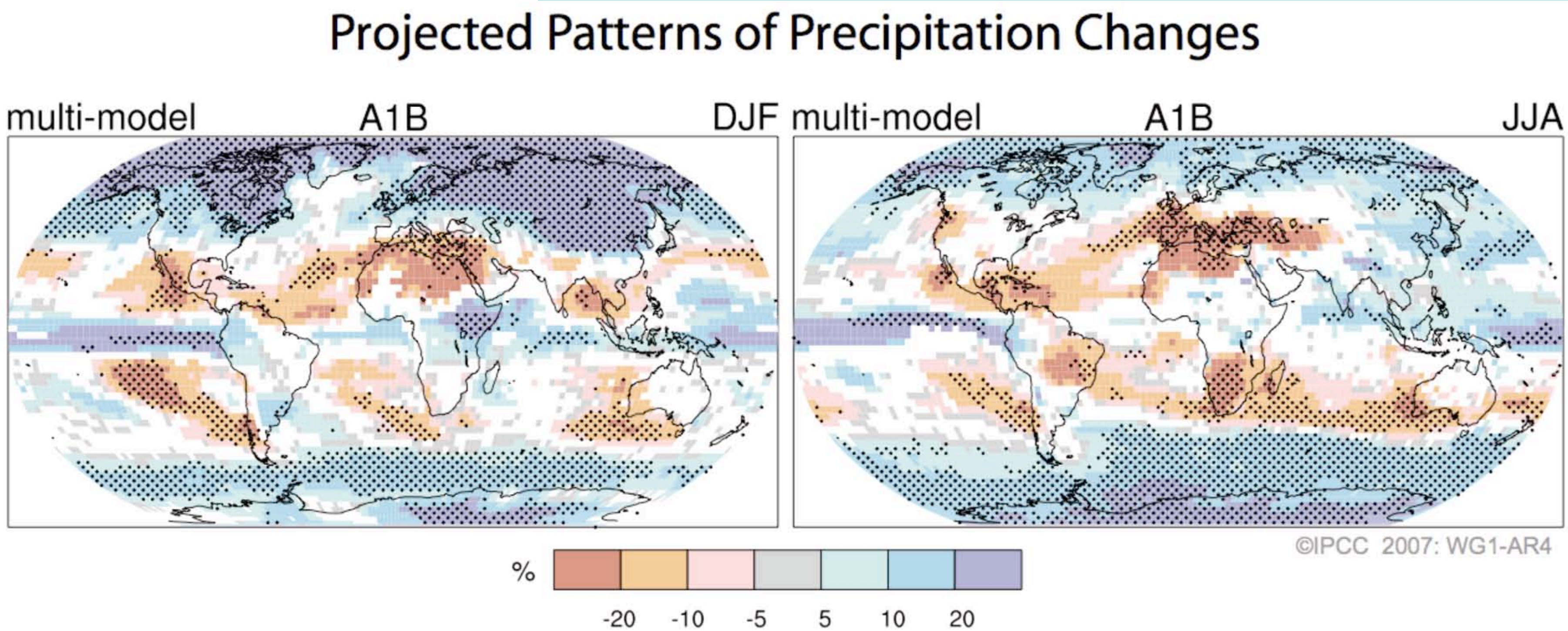
Fung et al. Evolution of carbon sinks in a changing climate. PNAS 2005

C4MIP: BYOModel

	Atm	Ocean		Land C	Ocn C
Hadley	HADCM3 2.5°×3.75°,L19	2.5°×3.75°, L20 flux-adjusted		MOSES/TRIFFID – **DynVeg, stomates,** GCM soil moisture, 1 soil pool	HadOCC: NPZD, DIC, TALK
IPSL-CM2	LMD5 64x50, L19	OPA, no flux-adj		LUE*APAR, **4 soil pool, 1 water bucket**	OCMIP'
LLNL	PCM, 2.8°×2.8°, L18	POP 0.6 ° x0.6°, L40		**DynVeg,** IBIS- **CENTURY**	OCMIP'
NCAR-CSM1.4	CSM1, T31 L18	NCOM3.6x3		**Stomates, 9 soil pools, LSM 6-layer water**	OCMIP'+Fe patch
MPI	ECHAM	MPI-OM		JSBACH	HAMOCC5
FRCGC	CCSR/NIES/ FRCGC T42L20	COCO; No flux-adj, (0.5-1.4)x1.4		Sim-CYCLE	NPZD
UVIC	1-layer Energy Balance	MOM-2.2		TRIFFID **DynVeg, stomates,** 1 soil bucket	DIC-abiotic
UMD	QTCM	Mixed layer-Qflux		VEGAS **DynVeg, 3 soil pools**	OCMIP-abiotic
CLIMBER	2.5D stat-dynam 10°x51°	X-avg,2.5° lat, 3 basins		LPJ	NPZD
Bern-CC	EBM 2.5°x3.75°	HILDA box-diffusion model		LPJ	perturbation

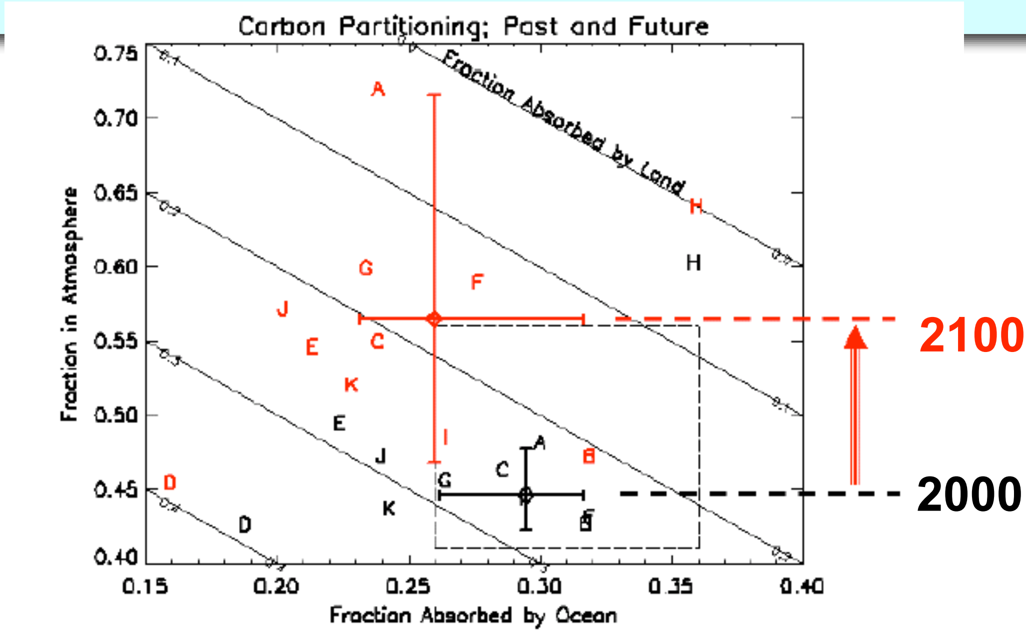
IPCC WG1-AR4:
regional differences in precipitation change

White area: < 66% of models agree in the sign of change
Stippled area: > 90% of models agree in the sign of change



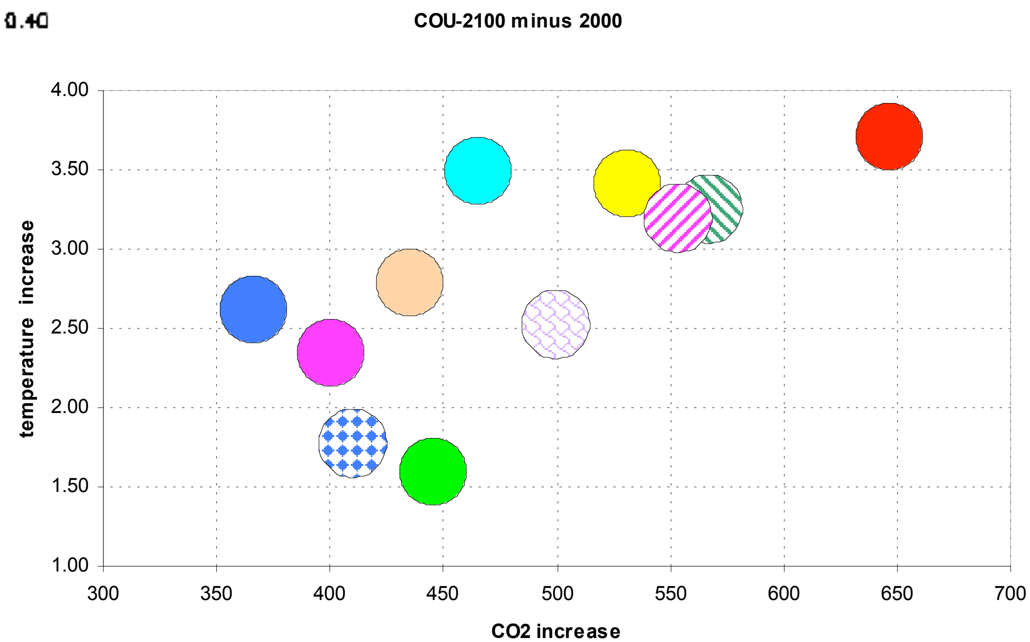
- **Moistening at high lat,**
- **??? N American summer,**
- **??? In tropics**

Summary: C[4]MIP Robust Result



IPCC AR4 WG1 CH7

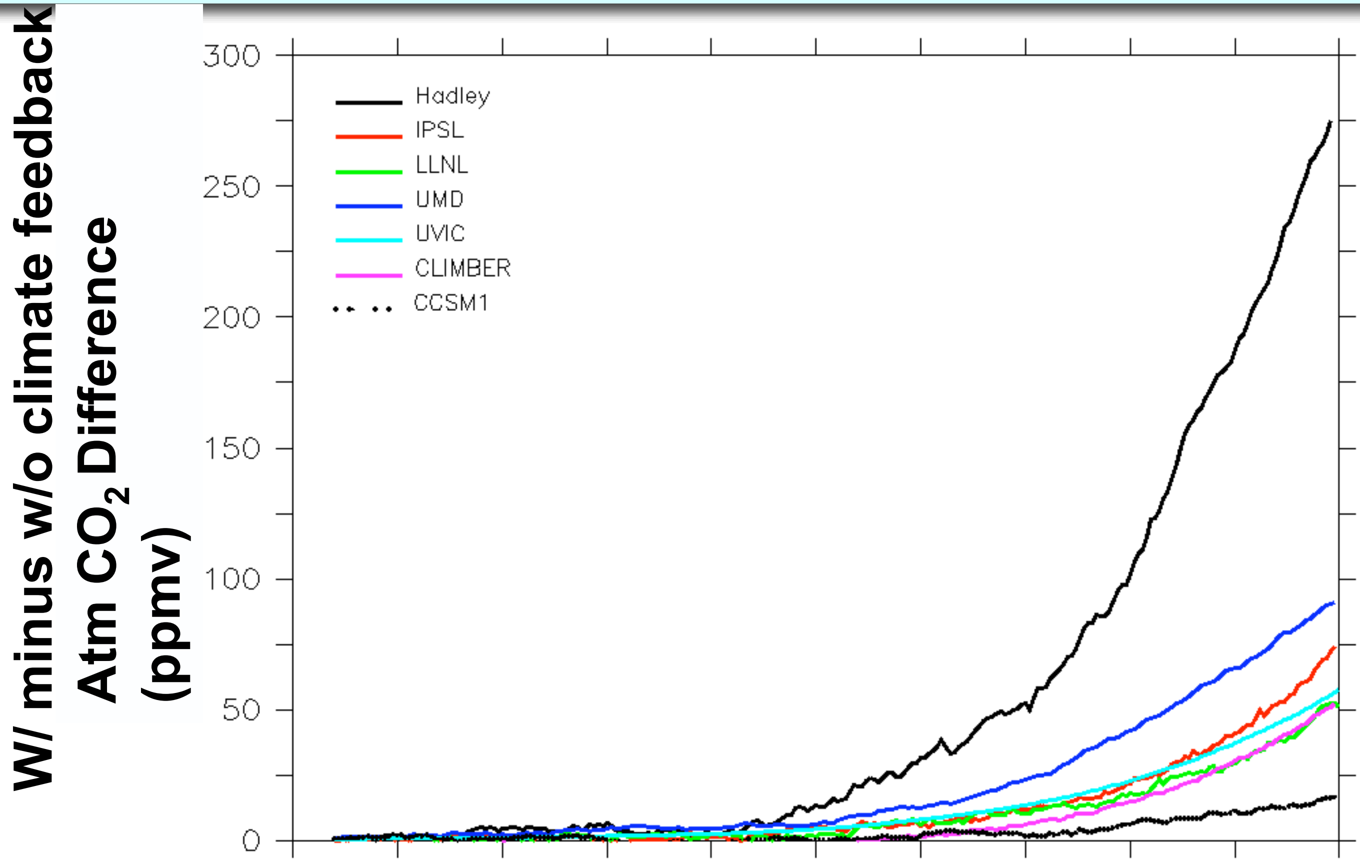
Carbon-climate feedback accelerates warming



Coupled Carbon-climate models: 2100 minus 2000:

350-650 ppmv increase in CO2

WCRP-IGBP Coupled Carbon Cycle Climate (C^4MIP): FF=historical + SRES A2, BYOM



Cox et al (2000) - High climate sensitivity; Rainforest crashed

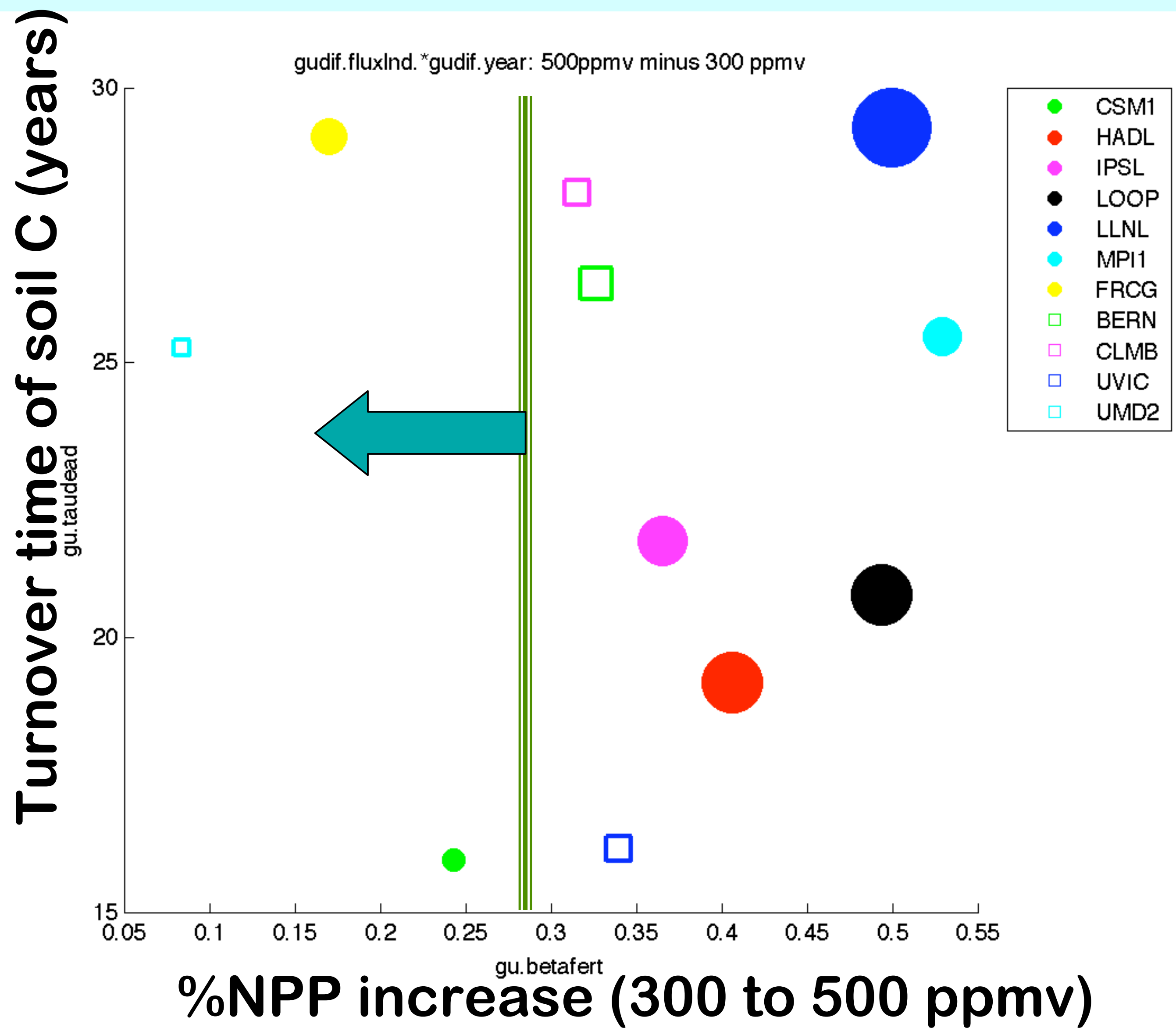
No danger of consensus

Fung et al. (2005) Low climate sensitivity

All models: with C-climate feedback → higher CO_2, warmer

Friedlingstein et al. (J Clim, 2006)

Control Climate: Land Uptake (300-500 ppmv) as a function of land parameters



Challenge

- C4MIP - ecosystem function dependent on plant-soil moisture coupling -
  - soil moisture(z);
  - how do plants access soil moisture(z) (deep roots, tap roots…) [Lee et al. PNAS 2005]
- Resource limitation (N, P,…) on CO2 fertilization
- No clue about time constants for ecosystem dieback and recovery [Moorcroft et al. - ED]
- No clue about soil microbe population in new climate +biogeochem space [Treseder]
- No clue about ecosystem function in a new climate + biogeochem space