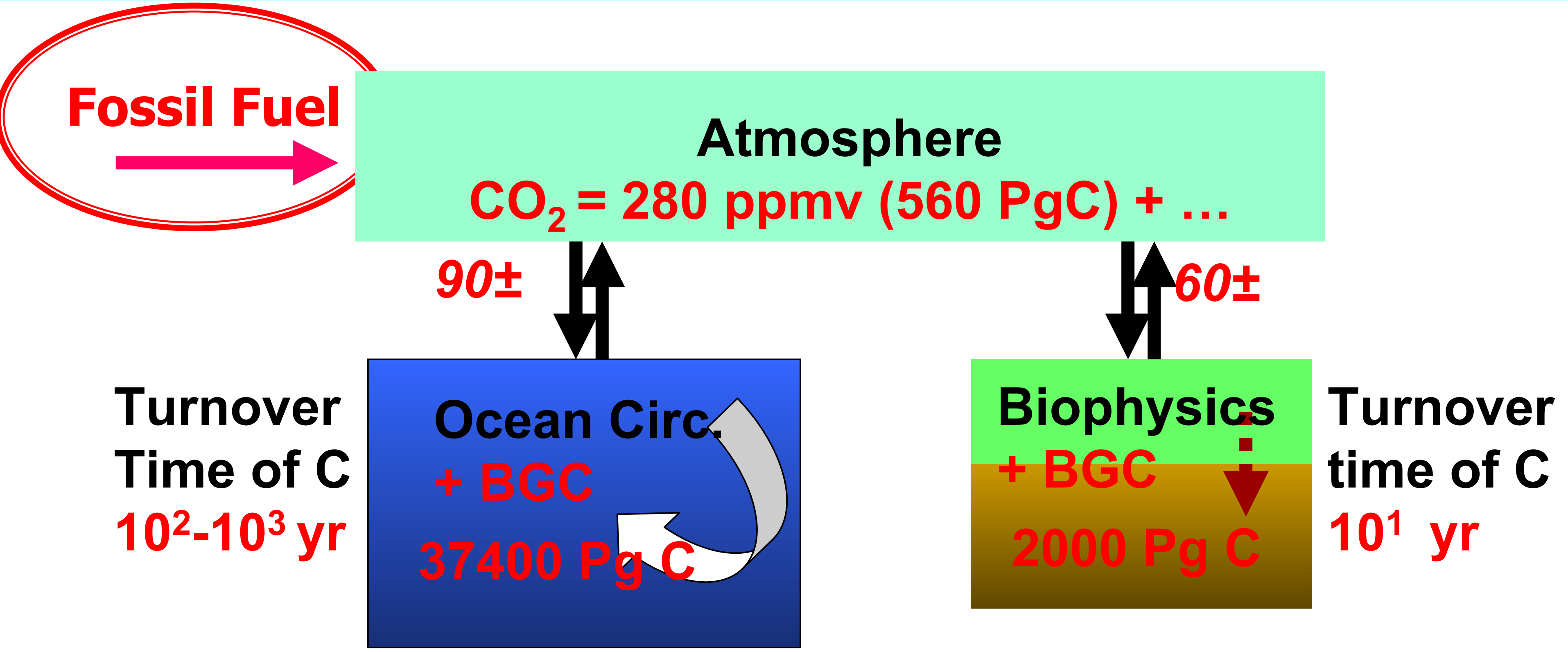
Challenges in Projecting Carbon-Climate Feedbacks in the 21st Century

Inez Fung

UC Berkeley

Coupled Carbon Cycle-Climate Experiments

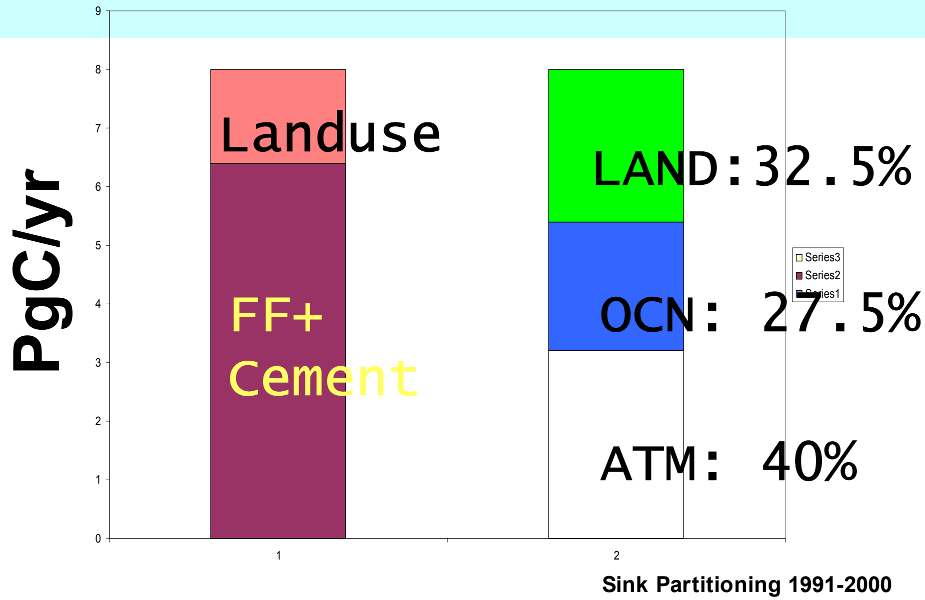


- Specify emissions from FF combustion and landuse modification
  - 19th-20th century – historical emissions
  - 21st century – SRES A2 and A1B
- Prognostic CO_2 in atm
- Model Expts:
  - Coupled: radiatively active CO2 = prognostic CO2
  - Uncoupled: radiatively active CO2 = 282 ppmv (control climate)

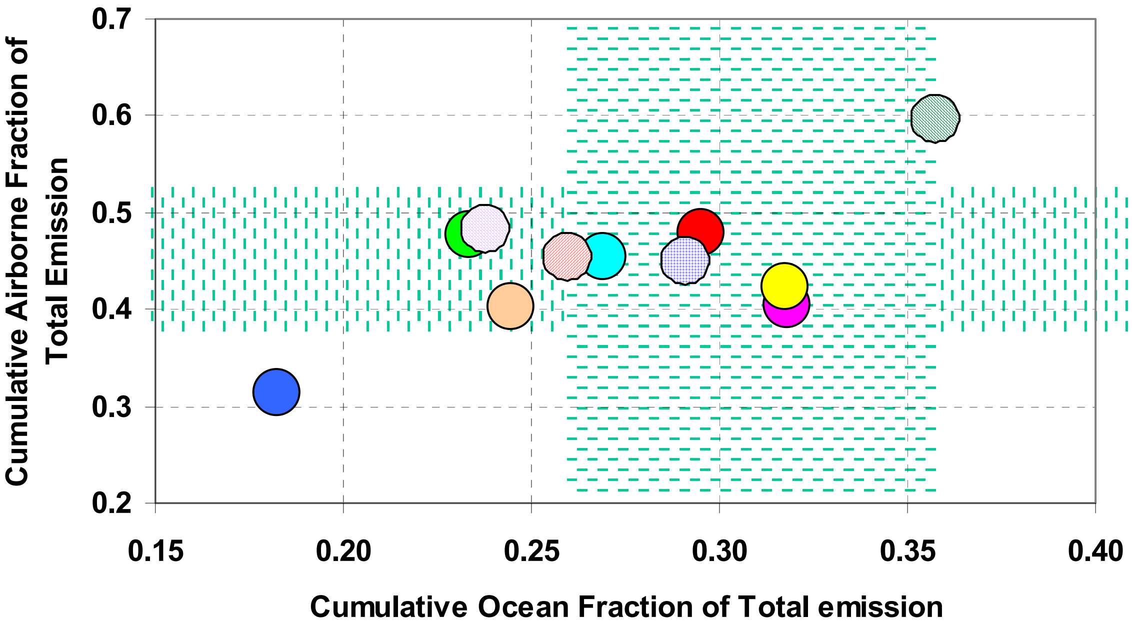
C4MIP: BYOModel

	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

Global Carbon Budget, 1990's

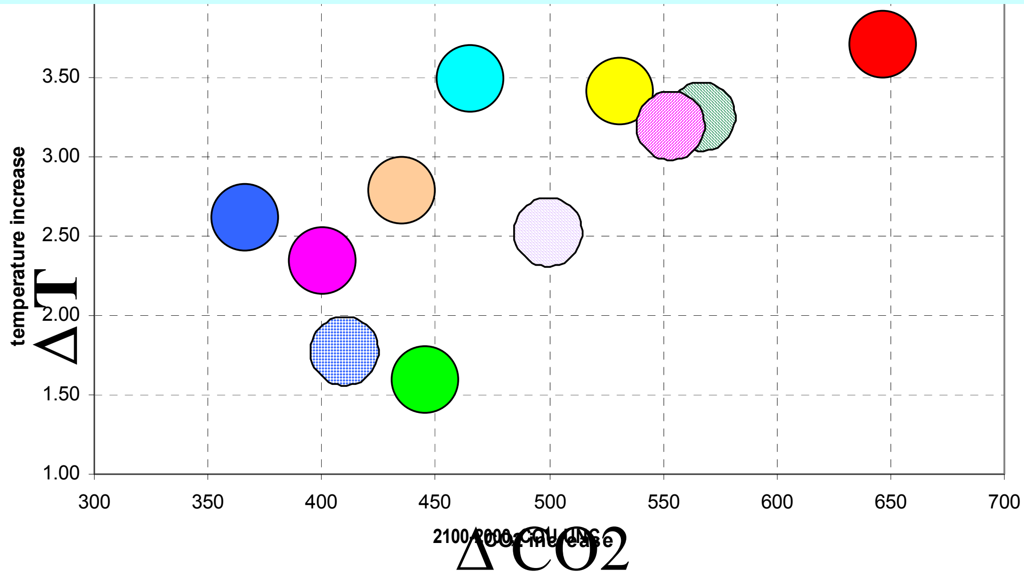


Apparent Airborne fraction =
Atm incr / FF emission
~50-60%



6 models OK

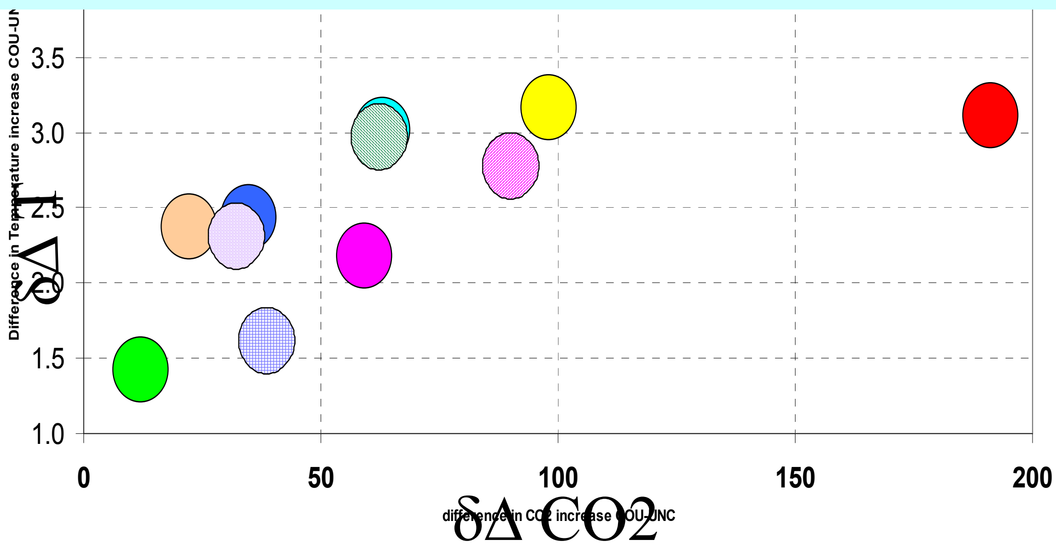
2091-2100 cou minus 1991-2000 cou:
$\Delta CO2 > 0$; $\Delta T > 0$



$21^{st}C - 20^{th}C$

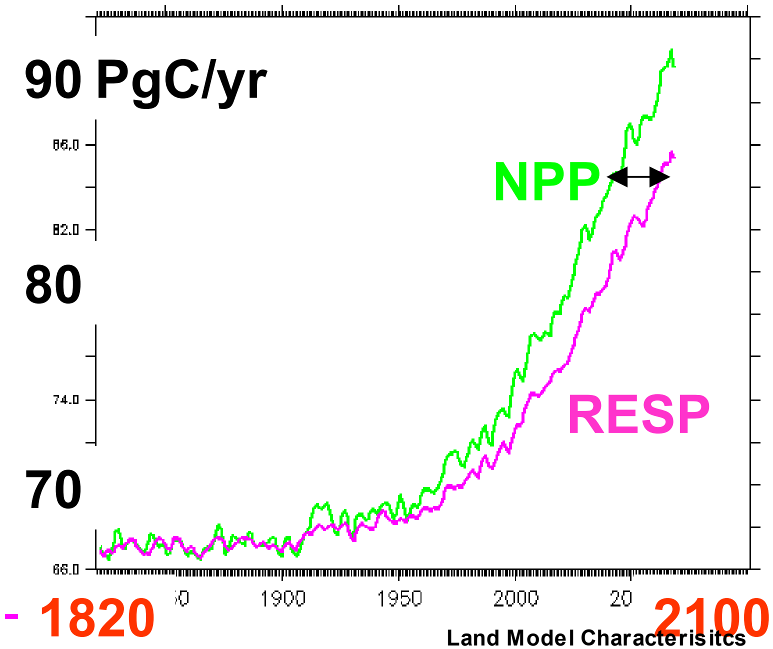
At the end of the 21st C
$\Delta CO2$: 350-650 ppmv
Warming: 1.5->3.5C

(2100s-2000s) cou minus (2100s-2000s) unc
$\delta\Delta CO2 > 0$; $\delta\Delta T > 0$

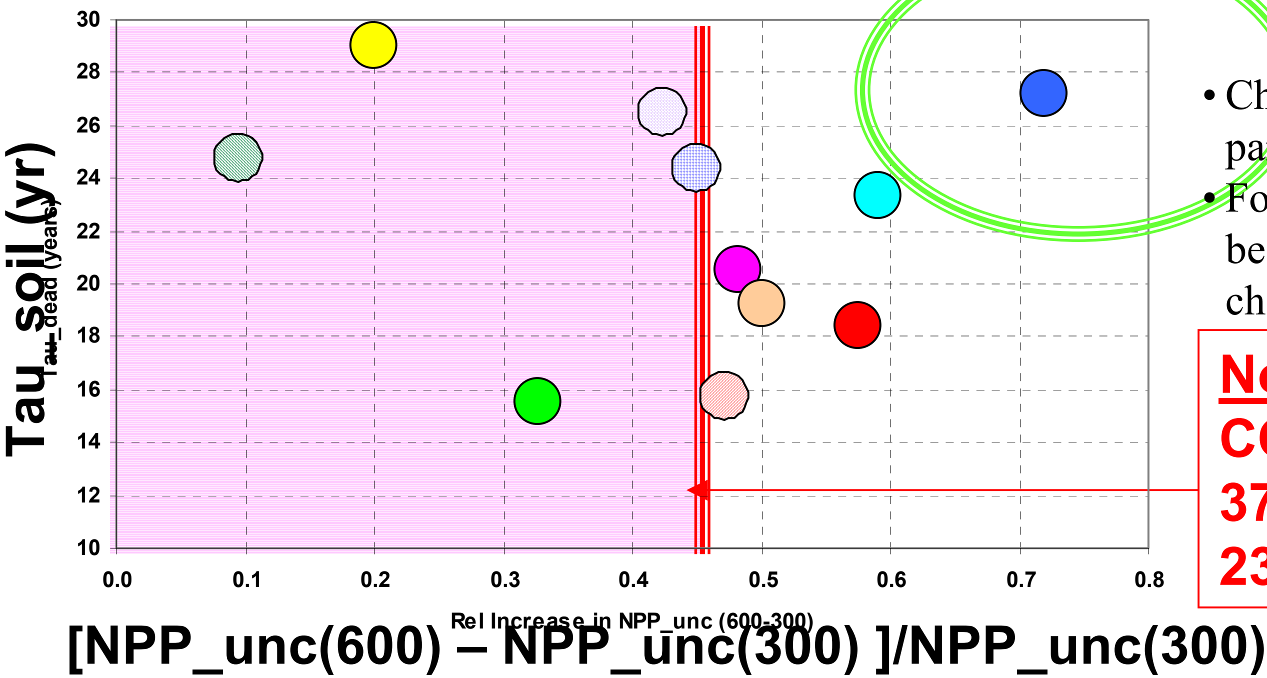


Carbon-climate feedback
- Positive
- Magnitude not proportional to actual increase

Land Carbon Storage Capacity



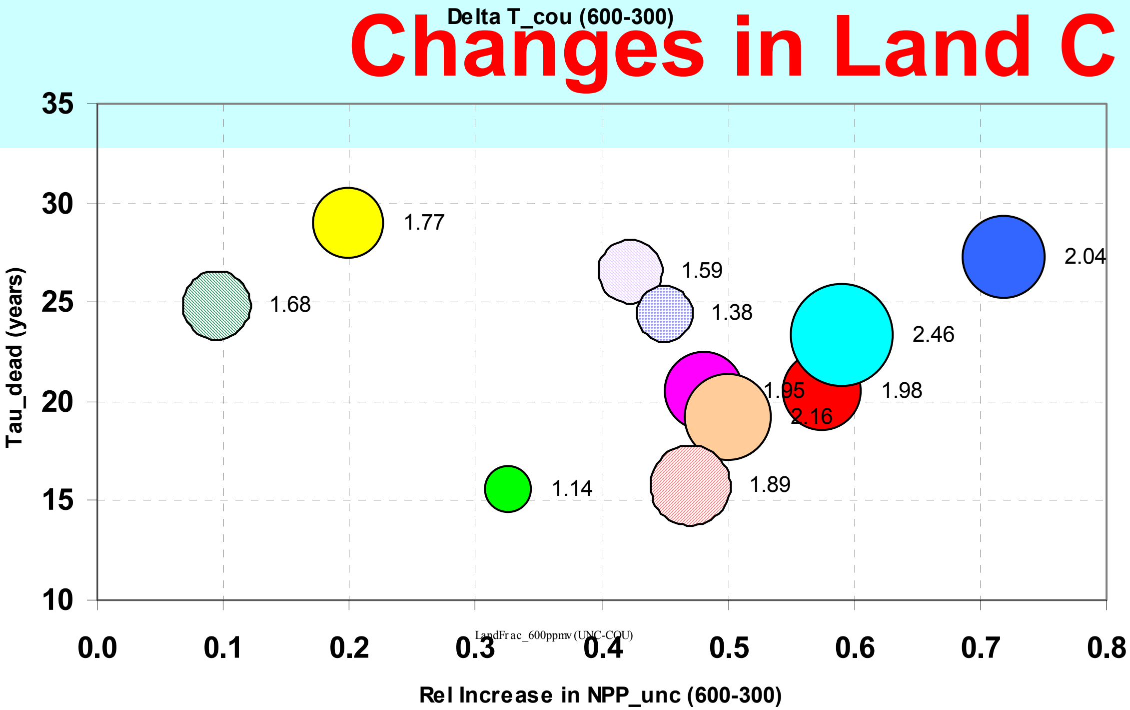
Increases with
- Rapid NPP increase
- Longer lag between NPP and Respiration



- Characterize models with two parameters
- Focus on 300-600 ppmv before significant dyn veg changes

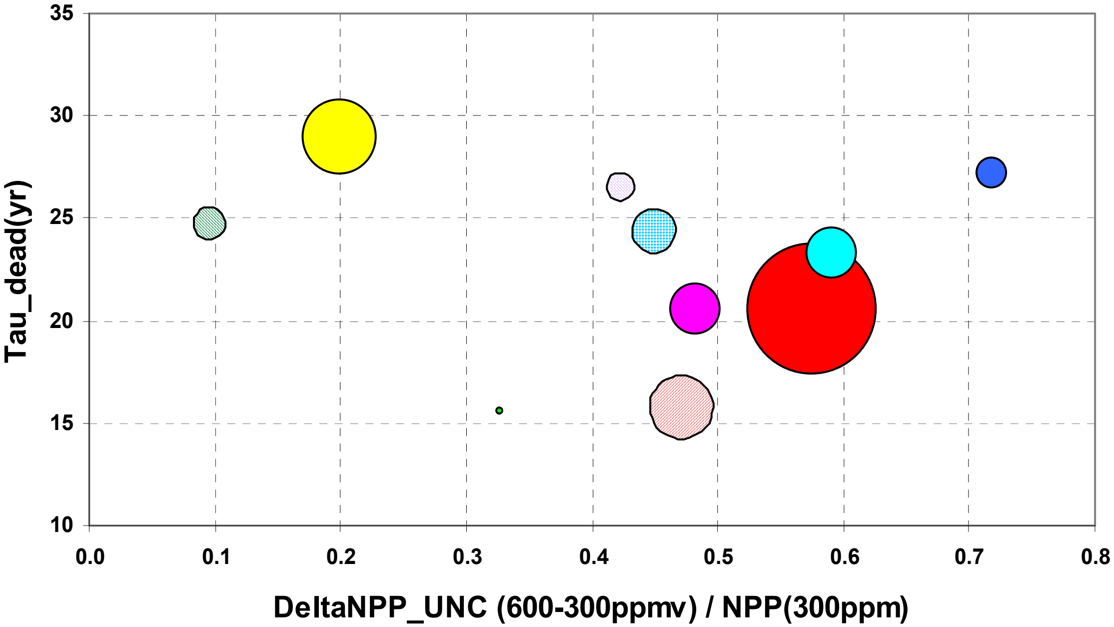
Norby et al (2005)
CO2 step increase
375→550 ppmv
23% increase in NPP

Changes in Land C storage



<u>Climate forcing of land C</u>

Size of bubble: Climate sensitivity ΔT_cou (600-300ppmv)



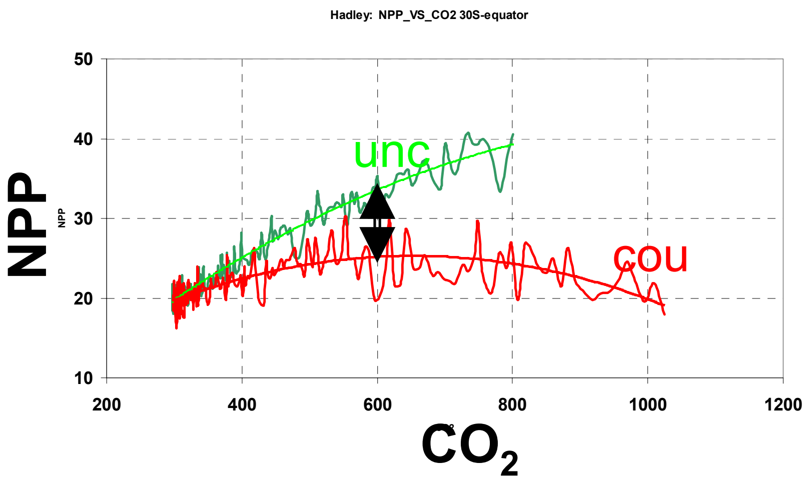
<u>Carbon-Climate Feedback</u>

Size of bubble: δΔ Land fraction of emission UNC(600-300)-COU(600-300)

(decr in land frac from 300-600)

reduction in land storage due to climate feedback not proportional to sink capacity or to climate sensitivity of model

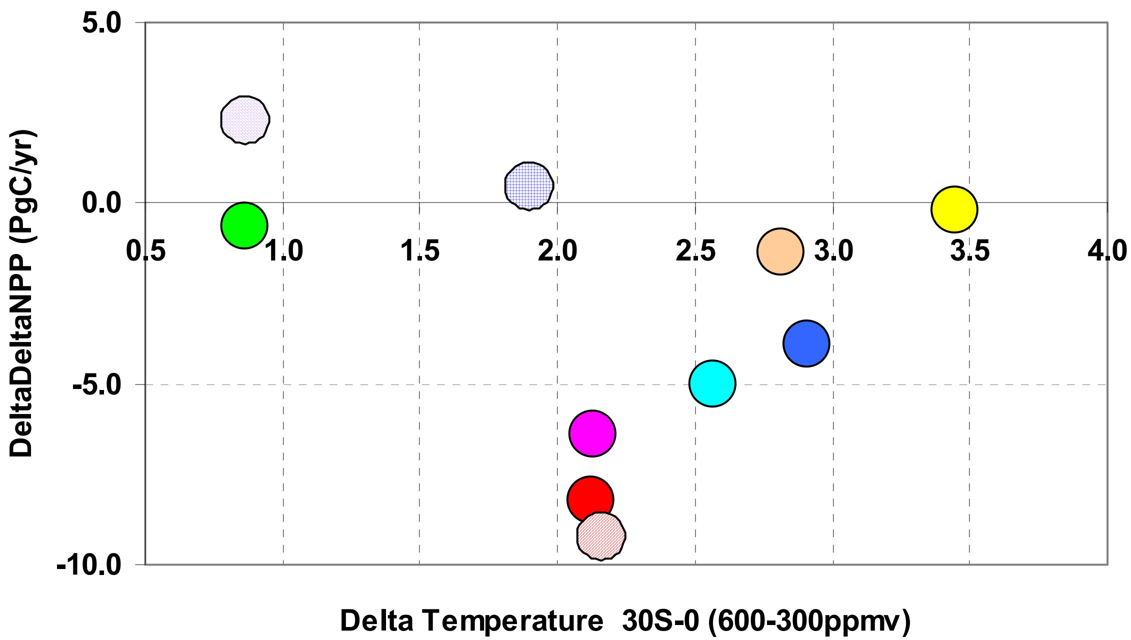
NPP in the tropics (30S-Equator)



Carbon-climate feedbacks → NPP

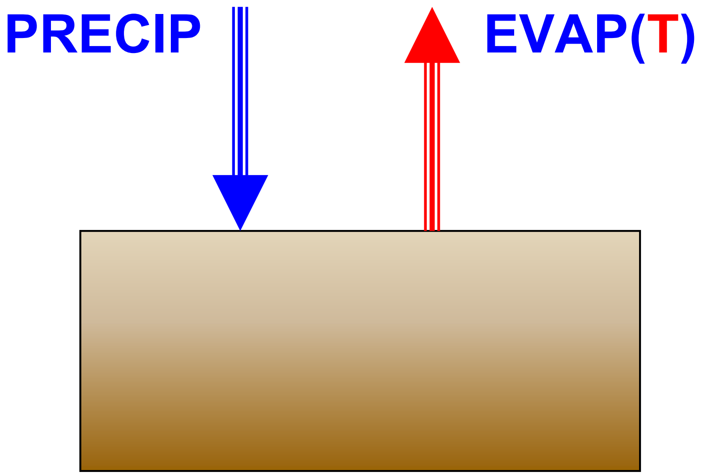
- decreases in 6 models
- Little change in 3 models
- Increases in 2 models

Delta Delta NPP (600-300ppmv)



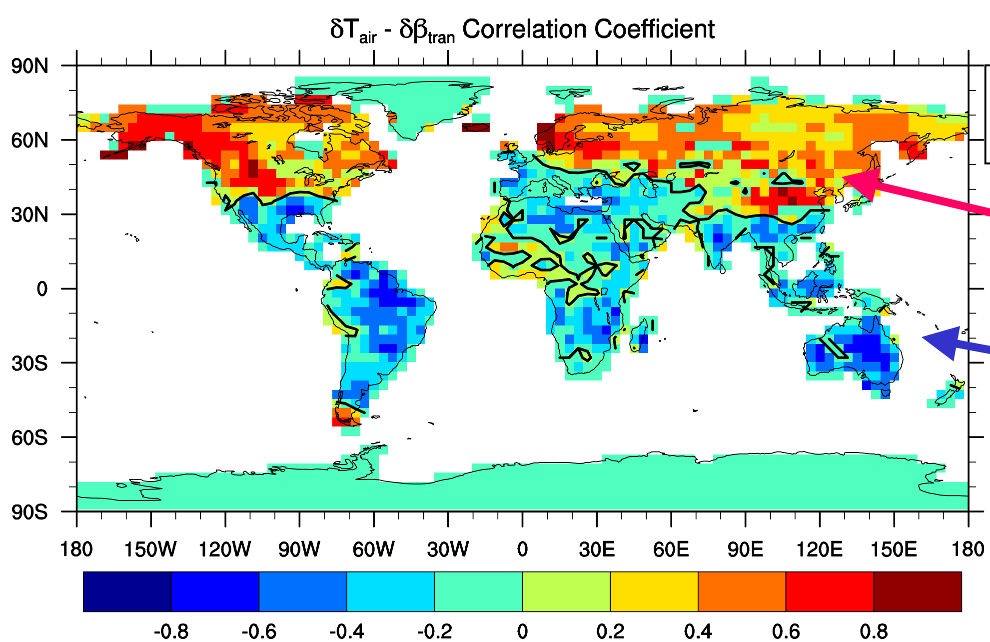
Climate feedback on NPP in the tropics shows no obvious relationship with ΔT

Hydrologic Cycle



With warming, EVAP(T)>Precip

Soil moisture decreases even though precip increasing

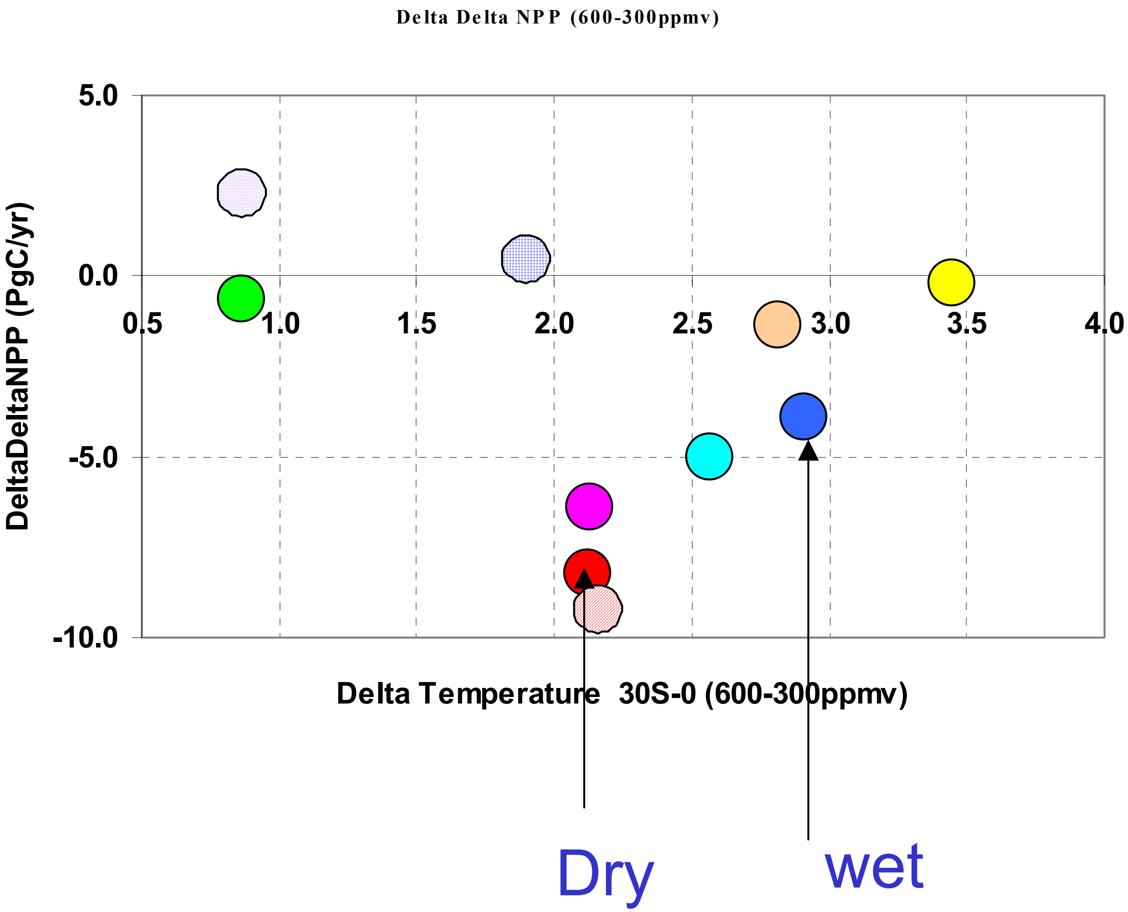


{δT, δSoil Moisture Index}

Warm-wet

Warm-dry

Carbon-Water Coupling



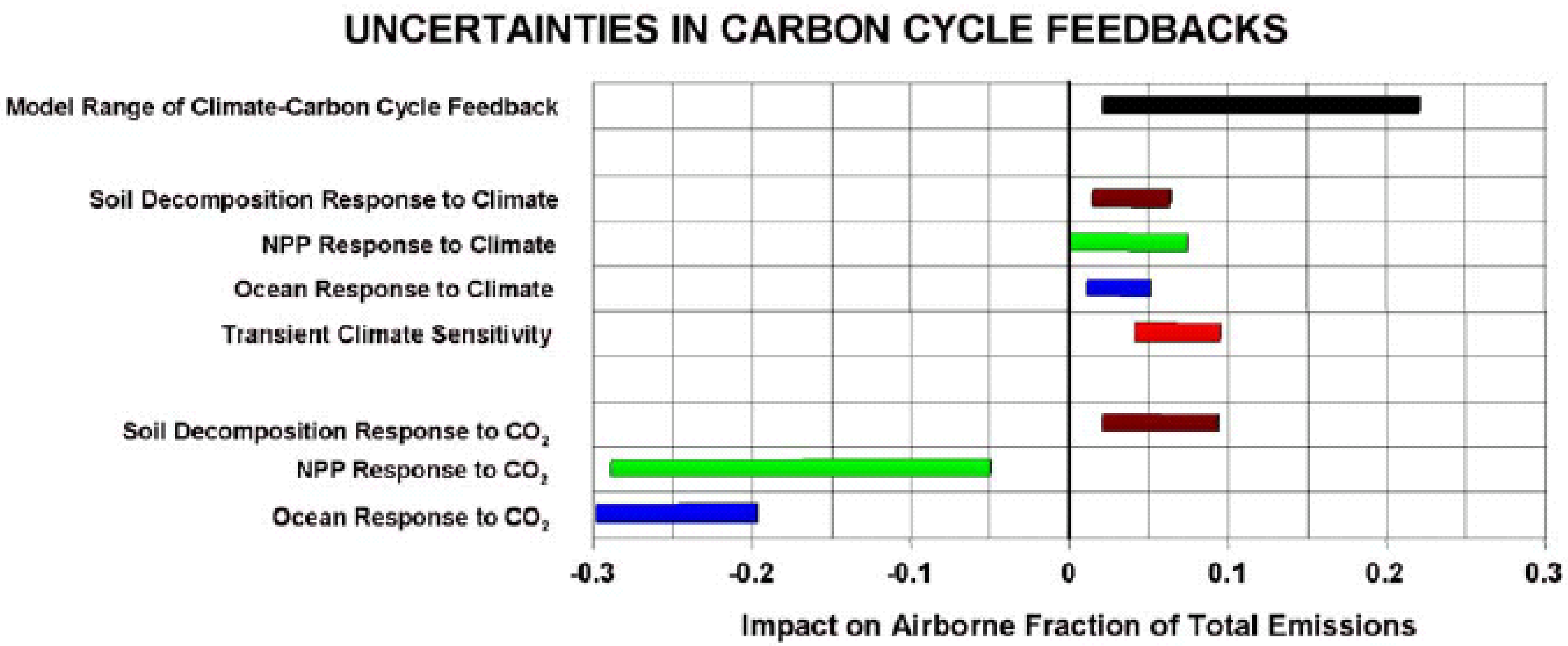
Models differ in degrees of

- **Soil water-rainfall coupling**
- **Soil water-evap coupling**
- **Evap-rainfall coupling**

(Koster et al. 2004)

Hypothesis: magnitude of carbon-climate feedback depends on bias in precip and soil moisture in control runs

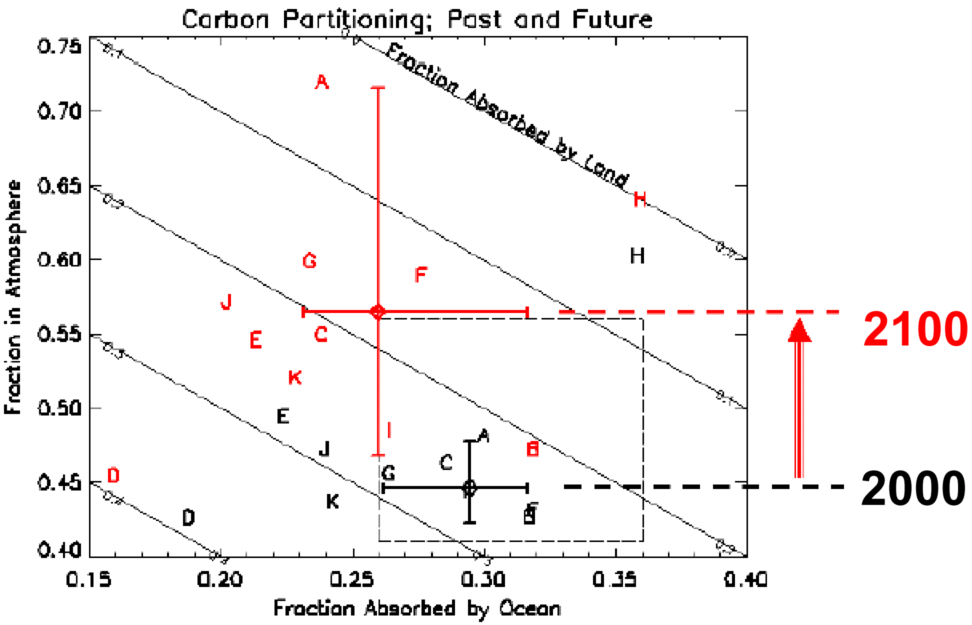
Summary: C4MIP: Model Uncertainties



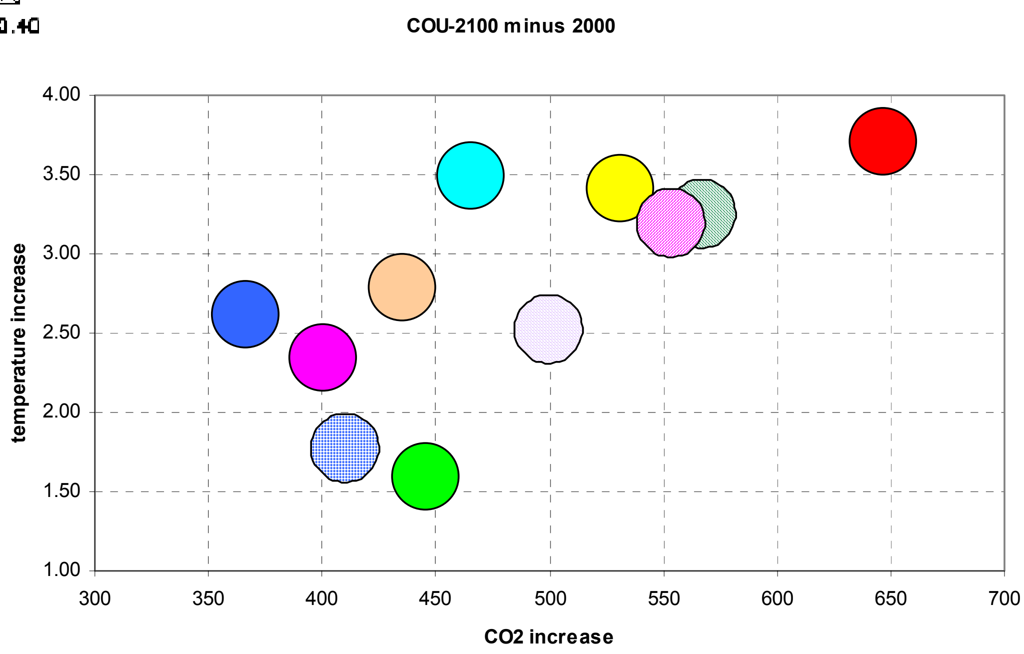
N.B. Uncertainties due to

- **representation of BGC processes as well as**
- **propagation of biases in control climate and uncertainties in climate projection**

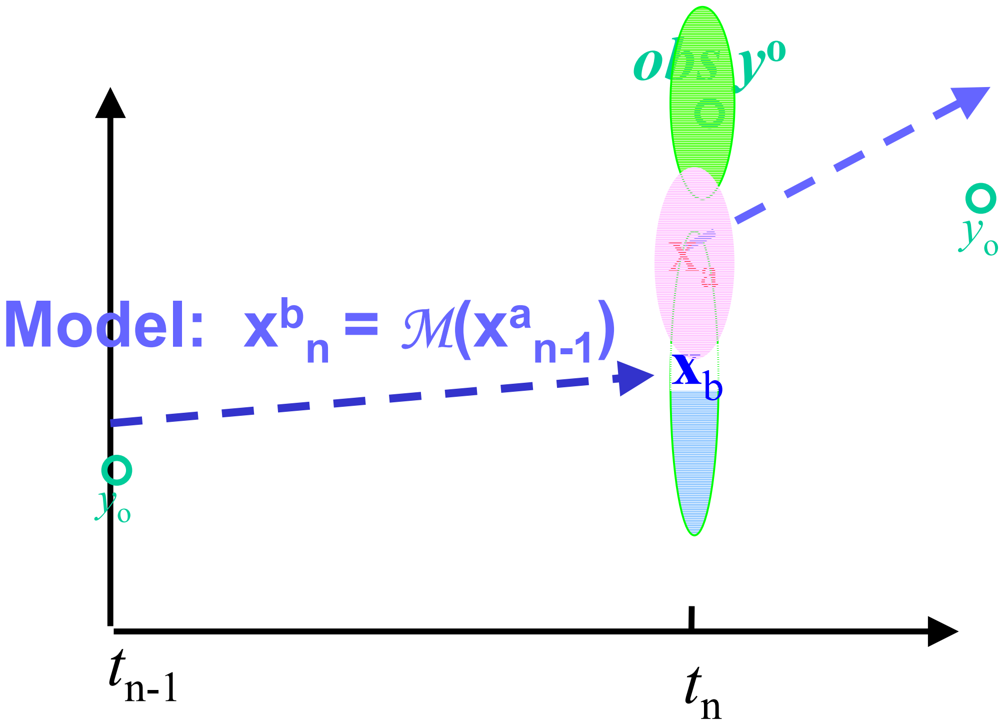
Summary: C^4MIP Robust Result



Carbon-climate feedback accelerates warming



Carbon Data Assimilation



x=[CO2,
fluxes,
EcoParameters..]

Find best estimate of x (x^a_n) given imperfect model (x^b_n) and incomplete obs (y^o)

3D Var

$$J(\mathbf{x}) = (\mathbf{x}-\mathbf{x}^b)^T \mathbf{B}^{-1} (\mathbf{x}-\mathbf{x}^b) + [\mathbf{y}^o - H(\mathbf{x})]^T \mathbf{R}^{-1} [\mathbf{y}^o - H(\mathbf{x})]$$

Distance to forecast **Distance to obs**

Minimize J(x): $\nabla J(\mathbf{x}^a)=0$ at $J(\mathbf{x}^a)=J_{min}$

Kalman filter $\boxed{\mathbf{x}^a = \mathbf{x}^b + \mathbf{K}[\mathbf{y}^o - H(\mathbf{x}^b)]}$

and other more sophisticated methods

Currently: a Relay Effort

- Global Inversion M=atm transport:
  - CO_2 → fluxes
  - CO_2 → LightUseEff, Q10 QED [e.g. Kaminiski et al. GBC 2002; Still et al. GCB 2005]
- Local Data assim
  - x=[C stock, fluxes, EcoParam]
  - M=forest dynamics model
  - Oregon, EnKF, e.g. Williams et al. GCB 2005
- Towards C Data assim
  - x=[CO_2, fluxes]
  - M=atm transport; persistence of fluxes (no Eco model)
  - e.g. Peters et al. JGR 2005
- NEED JOINT SCIENCE: INTEGRATE ATM and ECO systems into a single framework

Challenges

- **Model enhancement – multiple resource competition, disturbances, …**
- **Need data assimilation system**
  - **to synthesize atm, eco obs <u>in the same framework</u>**
  - **to improve the representation of carbon-climate models for the current climate**
- **Need new class of obs to formulate model representation of ecosystem function in the climate-CO2 space of the 21st century**
- **IPCC5! Carbon-climate models a "standard" contribution**