Natural and Anthropogenic Carbon-Climate System Feedbacks

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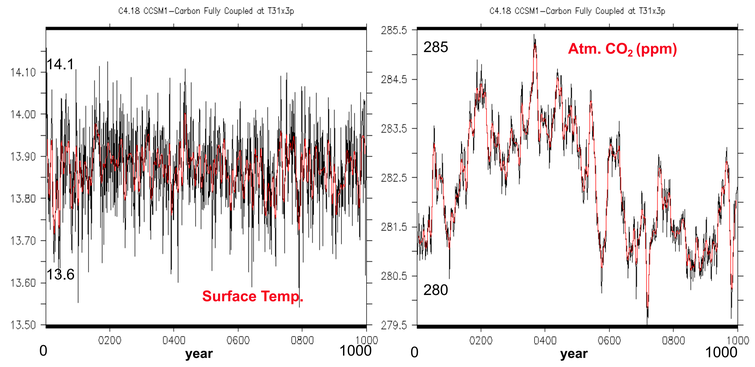
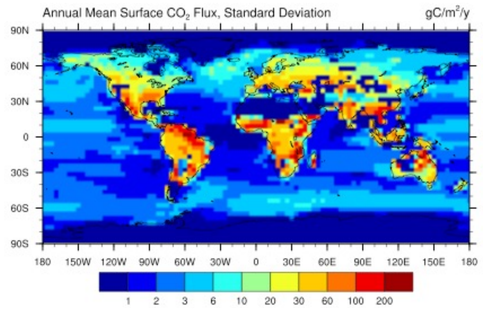
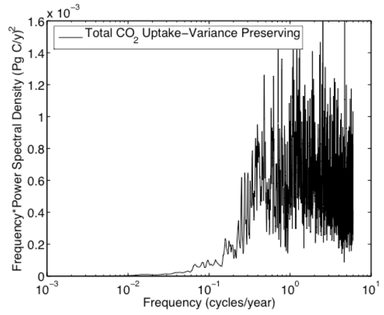
Abstract: A new three-dimensional global coupled carbon-climate model is presented in the framework of the Community Climate System Model (CSM-1.4). A 1000-year control simulation has stable global annual mean surface temperature and atmospheric CO_2 with no flux adjustment in either physics or biogeochemistry. At low frequencies (timescale > 20 years), the ocean tends to damp (20-25%) slow, natural variations in atmospheric CO_2 generated by the terrestrial biosphere. Transient experiments (1820-2100) show that carbon sink strengths are inversely related to the rate of fossil fuel emissions, so that carbon storage capacities of the land and oceans decrease and climate warming accelerates with faster CO_2 emissions. There is a positive feedback between the carbon and climate systems, so that climate warming acts to increase the airborne fraction of anthropogenic CO_2 and amplify the climate change itself. Globally, the amplification is small at the end of the 21st century in our model because of its low transient climate response and the near-cancellation between large regional changes in the hydrologic and ecosystem responses.

Natural Variability in Stable 1000 Year Control

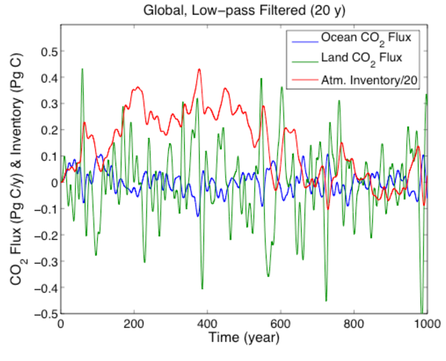


- Net Land+ocean inventory: ±2 PgC
- Natural climate modes (detection/attribution)
- Baseline for climate projections/fossil fuel perturbations



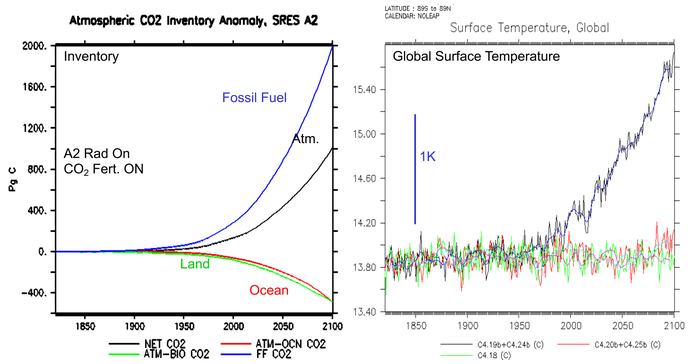


- Response of land/ocean to climate modes (ENSO, etc.)
- Land dominates signal; driven by soil moisture/NEP correlation
- Ocean mechanisms differ by region (T, S, winds, export)
- Time-scales < ~4 years but significant low-frequency variability

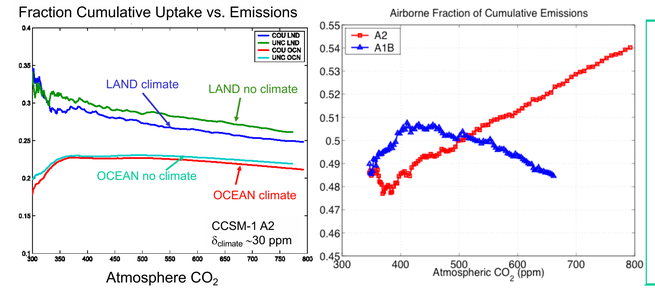


Ocean and land fluxes out of phase on low frequencies
land outgassing => atm. CO_2 increase => ocean uptake
ocean damps ~20-25% on multi-decade

Anthropogenic Climate Change (1820-2100)



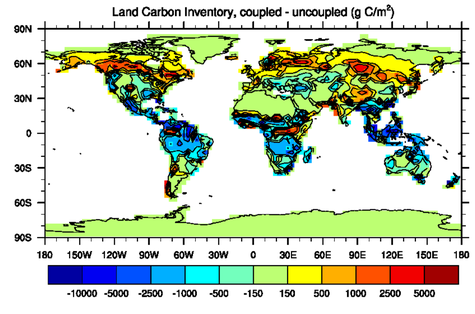
- Prescribed fossil fuel CO_2 emissions (historical + IPCC scenarios)
- Full coupling of climate and carbon system
- Experiments with and without land CO_2 fertilization

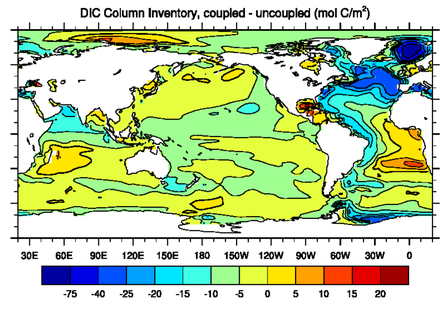


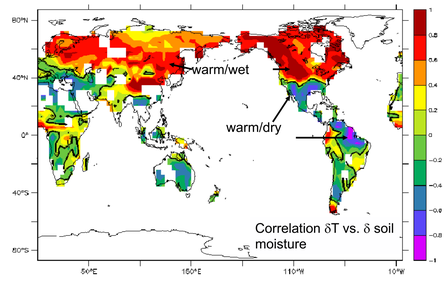
g="gain"
Carbon + feedback increases w/:

-large	×	CCSM-1 small +1.5-1.8K
-large	×	CCSM-1 land small ocean avg.
-small	×	CCSM-1 land & ocean avg.

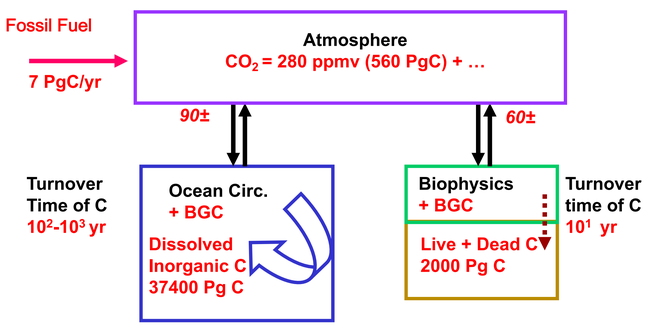
- Positive carbon-climate feedbacks reduce land and ocean sinks
- Carbon sink efficiency decreases with increasing fossil fuel emission rate







- Less land uptake in tropics & more uptake at mid./high latitudes
- NPP response to soil moisture
- Reduced ocean uptake in subpolar N. Atlantic,tropical Indo-Pac & Southern Ocean
- Slower thermohaline circulation, higher SST, stratified upper ocean & lower export



Community Climate System Model (1.4) Physics:

- Fully coupled ocean-atmosphere-land-sea ice simulation
- No heat/freshwater flux adjustment
- Low climate sensitivity (ΔT=1.4K for transient 2xCO_2)

Modified CASA Terrestrial Biogeochemistry Module:

- Dynamic leaf phenology and allocation
- Rapid soil turnover (60% with τ<5 years)

Modified OCMIP-2 Marine Biogeochemistry Module:

- Prognostic export as function of light, Fe, PO_4, temp.
- Dynamic iron cycle

3-D Atmosphere CO_2 Tracer Transport:

- Feedback of tracer CO_2 on radiation/climate

References:

- Fung, I., S.C. Doney, K. Lindsay, and J. John, 2005: Evolution of carbon sinks in a changing climate, *Proc. Nat. Acad. Sci. (USA),* **102**, 11201-11206, doi:10.1073/pnas.0504949102.
- Doney, S.C., K. Lindsay, I. Fung and J. John, Natural variability in a stable 1000 year coupled climate-carbon cycle simulation, *J. Climate, submitted.*