Role of Land Use in Past and Future Carbon Response

Presented by
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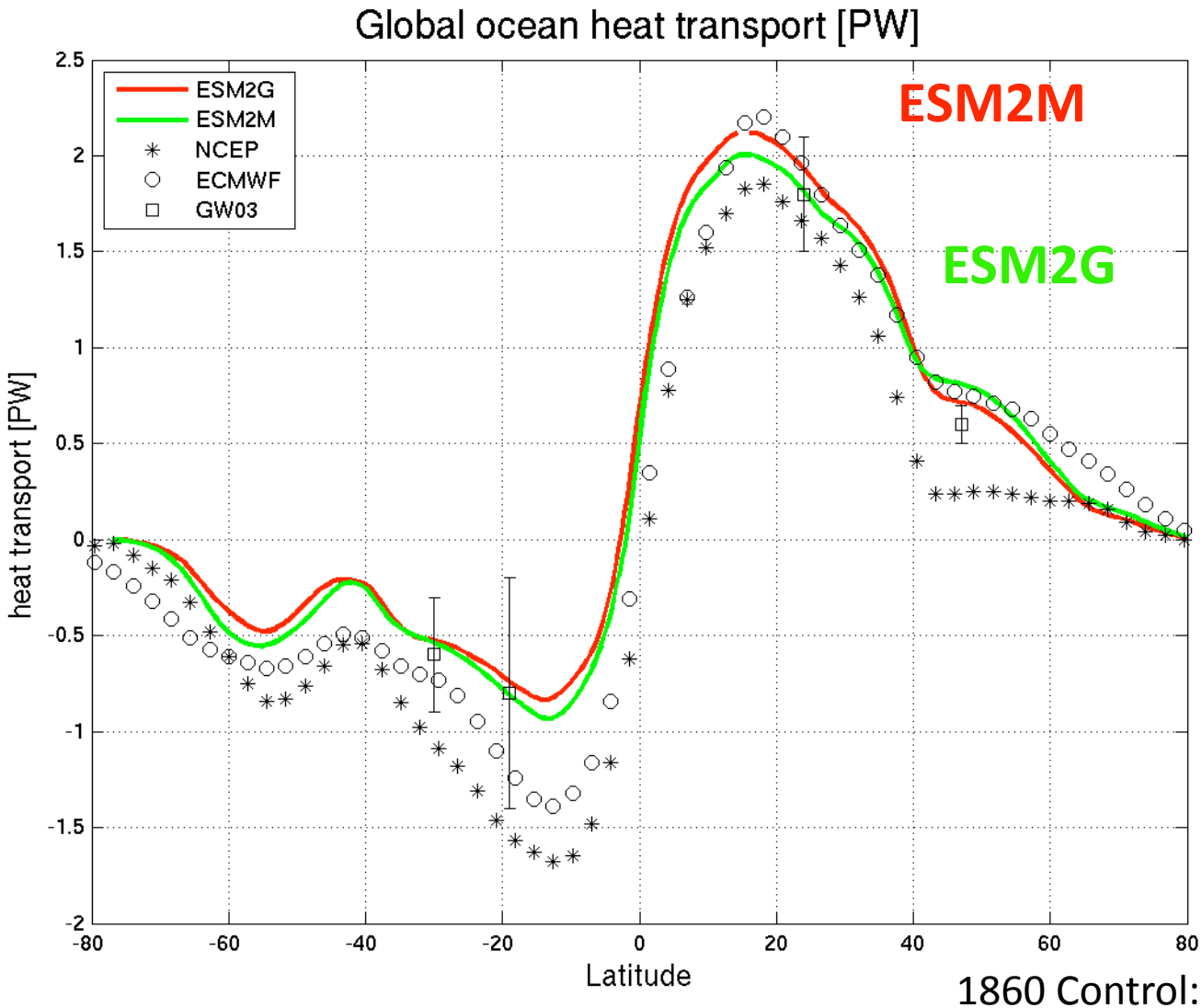
Summary: Context and Outline

- Major challenges in climate-carbon interactions
  - The role of ocean in the uptake of heat and carbon
  - The role of land use and management for carbon
  - The uncertainty of CO_2 fertilization in the future
- GFDL has built successful ESMs
  - Comprehensive Carbon component description
  - Internally consistent, coupled carbon-climate interactions
- These ESMs allow:
  - Simulation of past global temperature and carbon changes
  - Increased understanding of the physical mechanisms
  - Detection and attribution of causes
  - Increased confidence in projections

GFDL Earth System Models

- Atmosphere and sea ice components similar to CM2.1
  - 2 deg atmospheric model with 24 levels
- 2 different Ocean models
  - ESM2M – MOM based (z-type vertical coordinate – 50 levels)
  - ESM2G – GOLD based (isopycnal vertical coordinate – 63 layers)
  - Both models use a 1 deg tripolar grid
- New Land component (LM3) – more later

ESMs do a credible job simulating today's climate

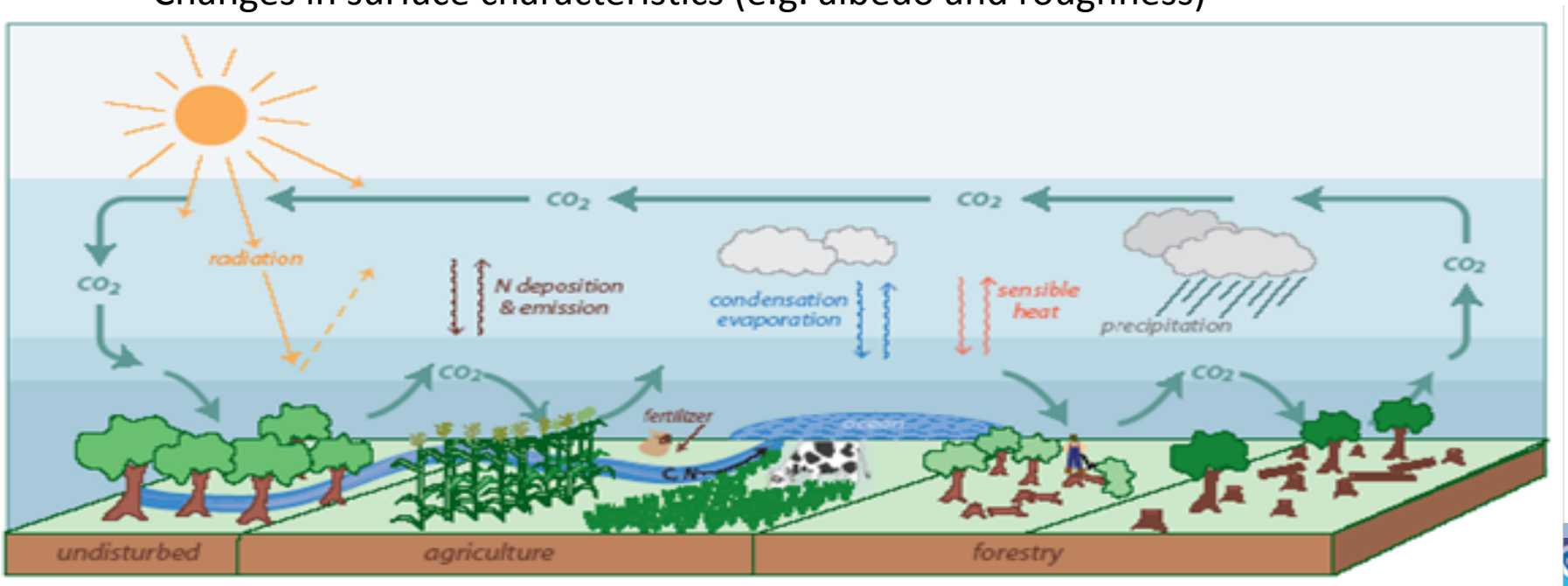


- ESM2M and ESM2G surface climates are very similar
- Some notable differences – e.g. ENSO

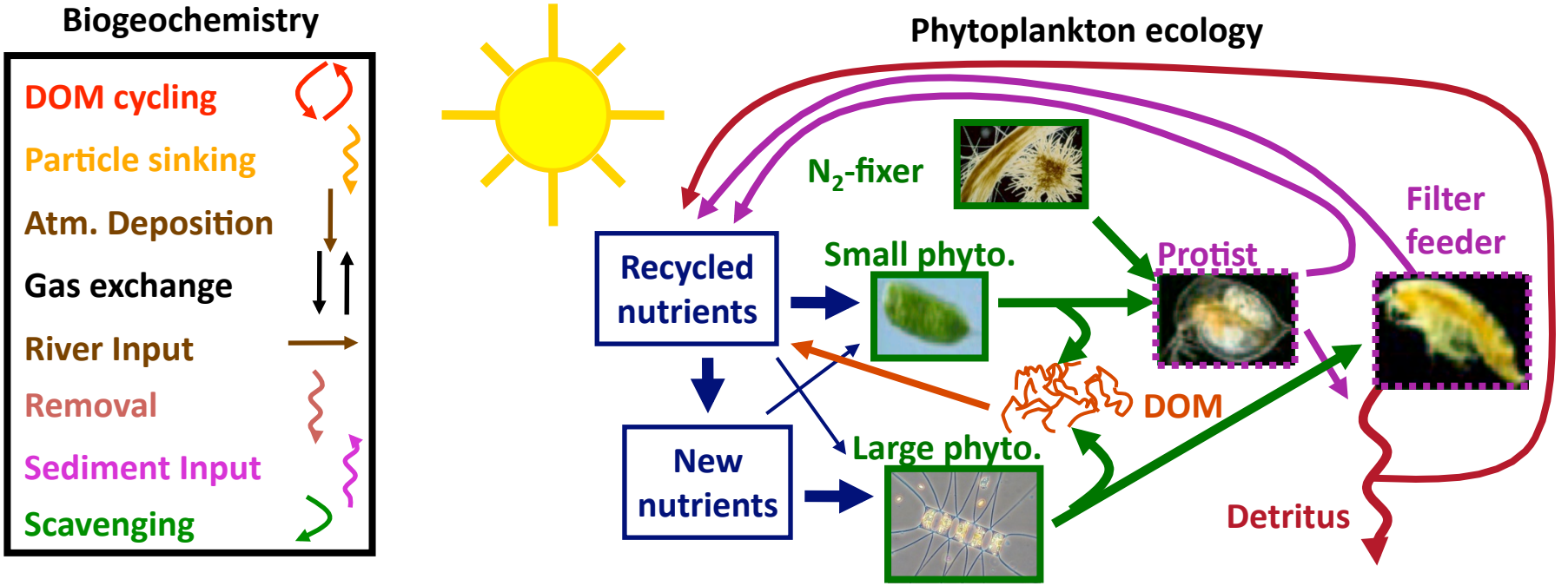
1860 Control: century time averages

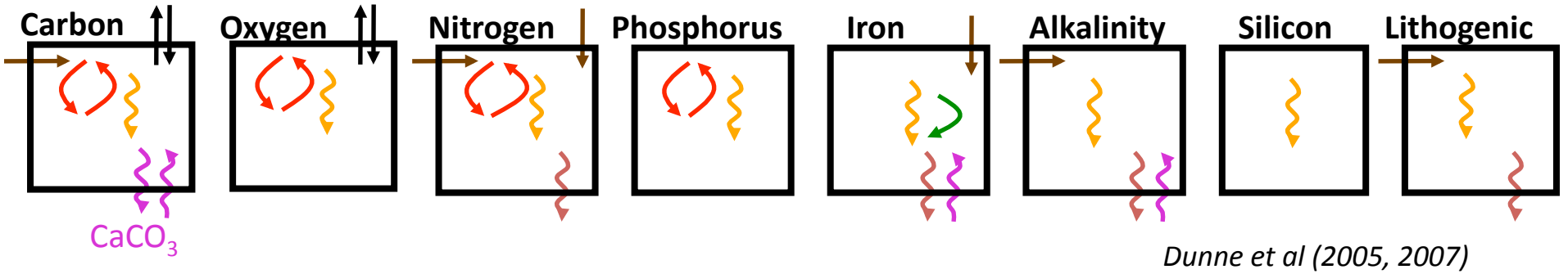
LM3 land model

- Land surface parameterization and hydrological processes
  - energy and water exchange between land, atmosphere and ocean
  - Liquid/frozen water dynamics, rivers and lakes
- Ecological processes and BGC cycling
  - Vegetation succession and growth
  - Carbon cycles
- Land use and management (works with AR5 LU scenarios)
  - Deforestation, wood harvesting and re-growth
  - Changes in surface characteristics (e.g. albedo and roughness)



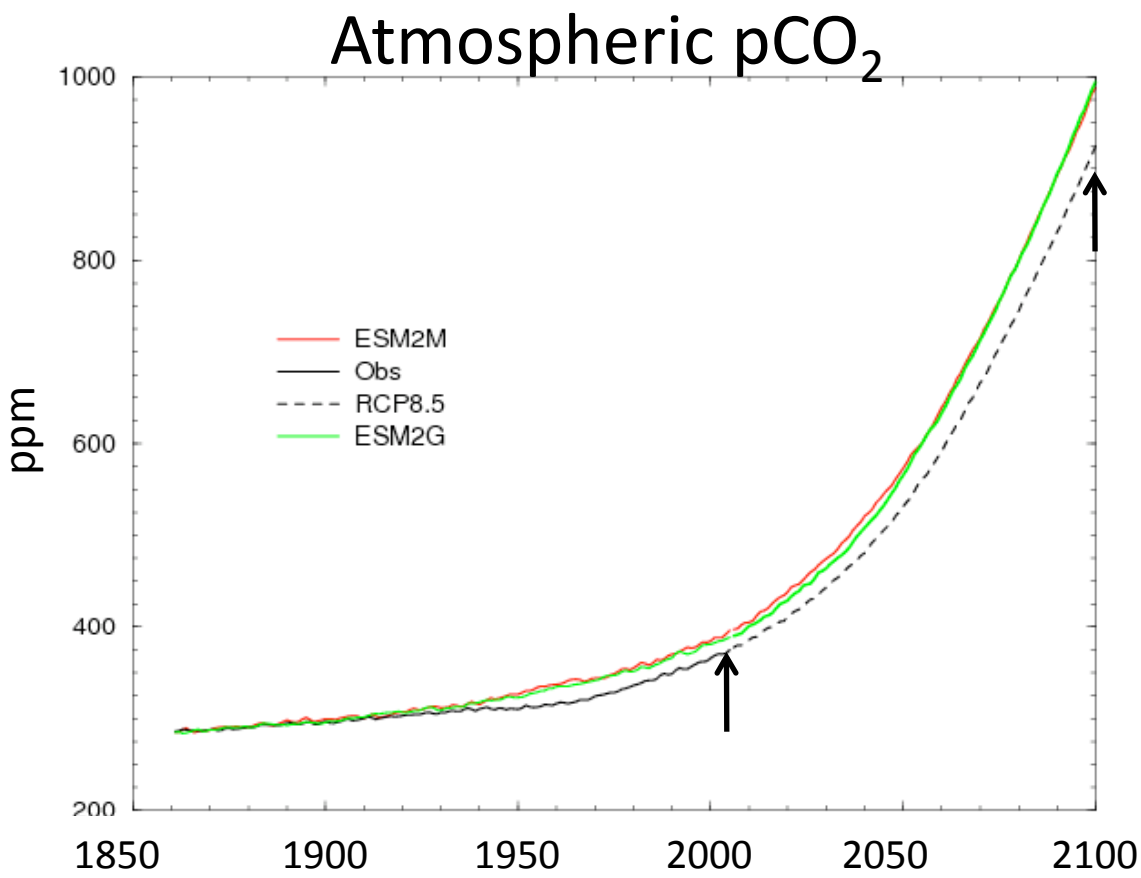
Tracers Of Phytoplankton with Allometric Zooplankton (TOPAZ) simulates the mechanisms that control the ocean carbon cycle





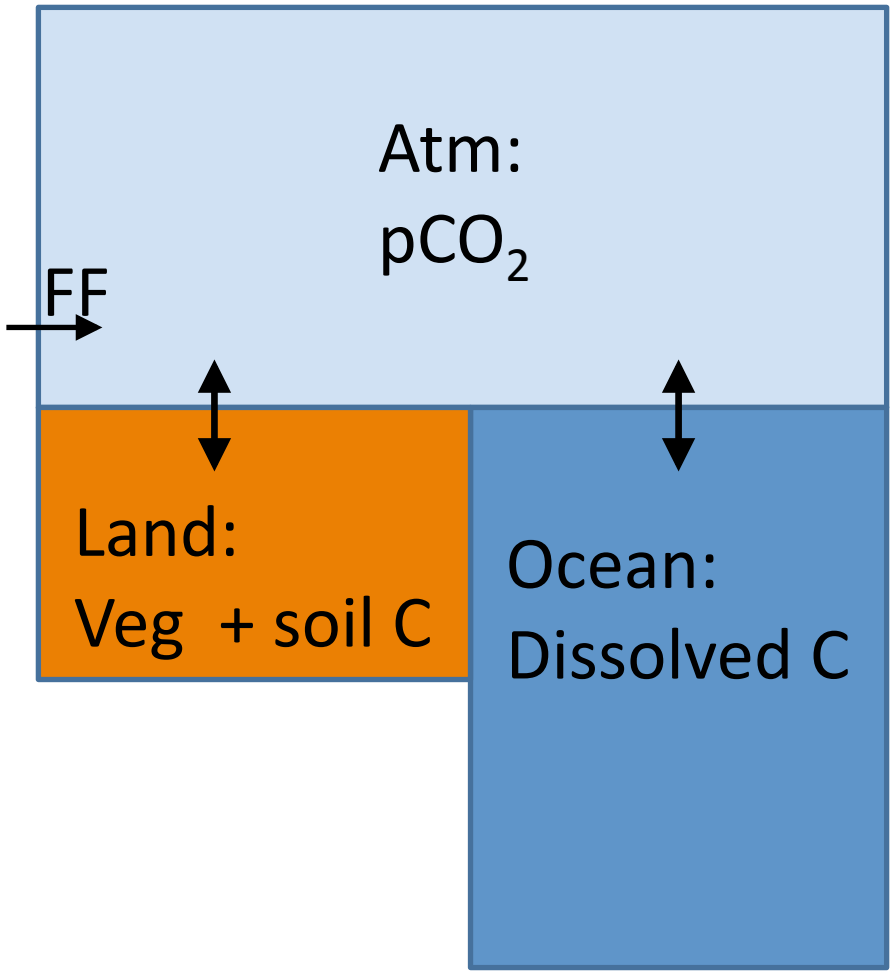
Dunne et al (2005, 2007)

ESM emissions driven runs show similar atmospheric pCO_2 response to each other and observations



- Emission driven runs have concentrations similar to observed
- ESMs about 20ppm high in 2005 versus observations
- ESMs about 70ppm higher than RCP8.5 by 2100

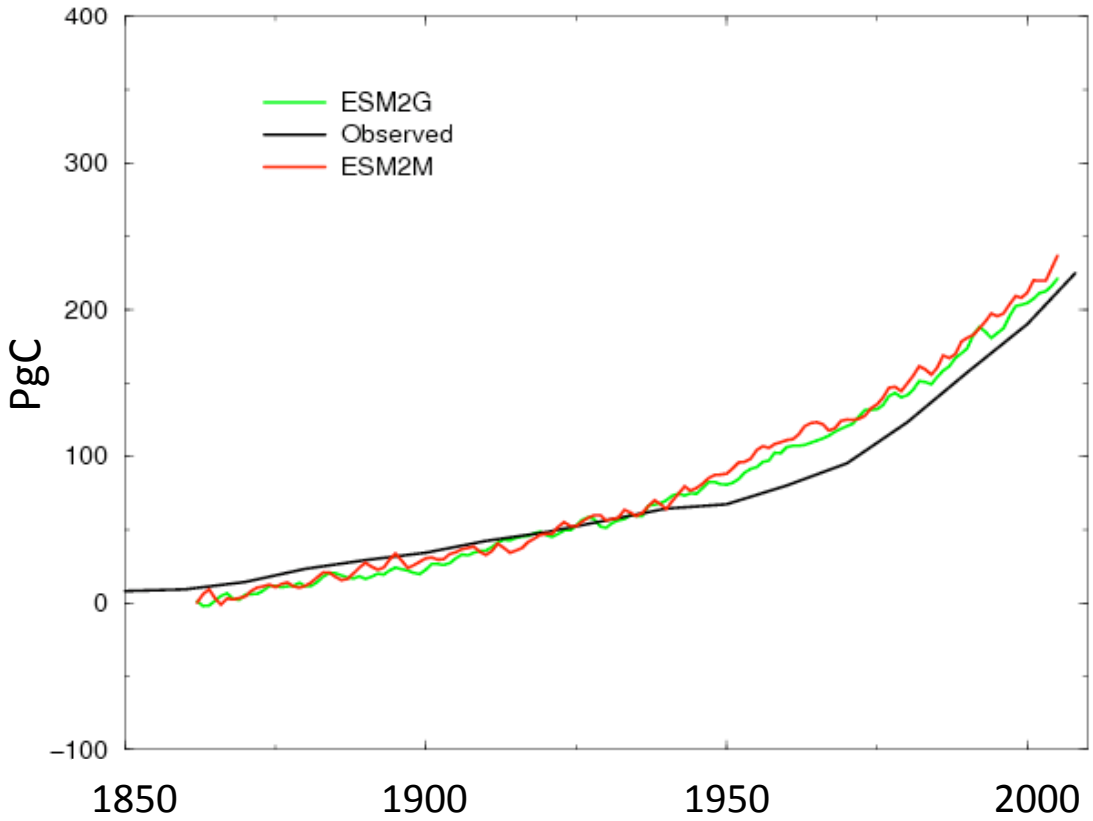
Model Evaluation: Carbon



- Fossil Fuel C emissions (FF) are stored in atm, land and ocean.
- Net Land C changes = FF – atm C changes – ocean C changes

ESMs' atmospheres accumulate slightly more Carbon than observed

Change in Atmosphere Carbon Inventory

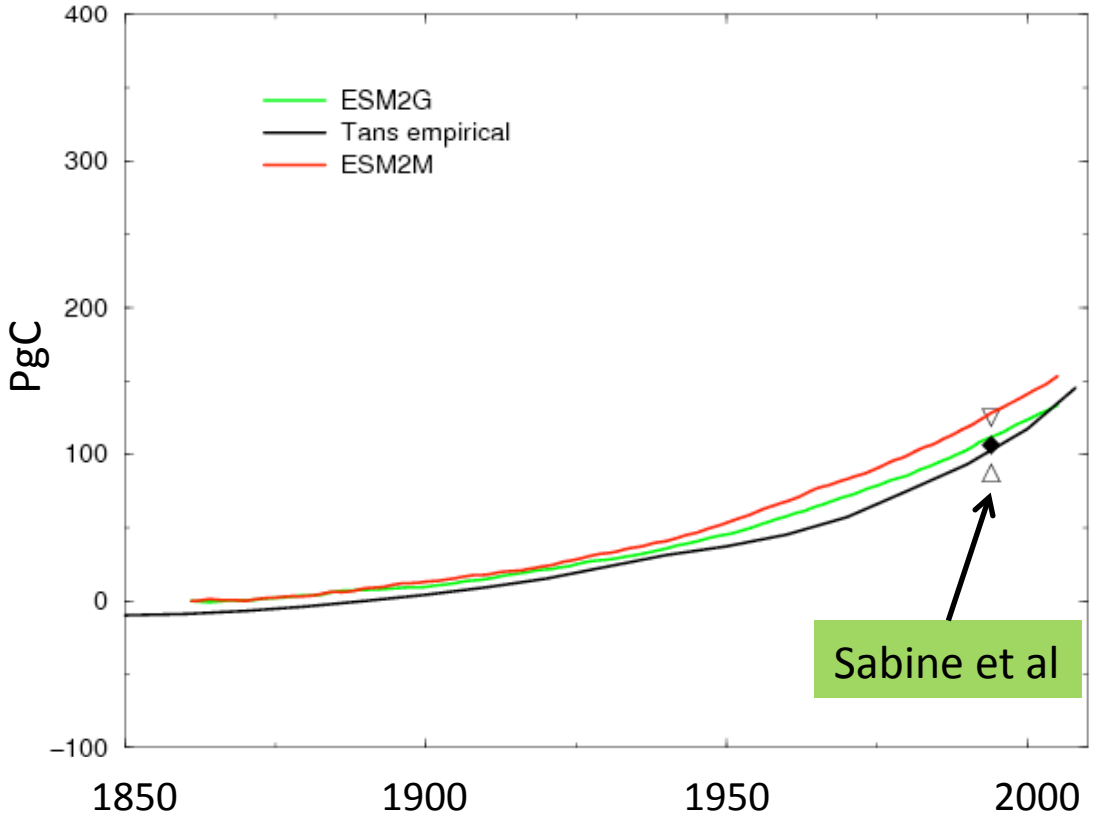


Observed = derived from pCO2 changes

- ESM2M about 10-20 PgC too high by 2005.
- ESM2G slightly smaller than ESM2M by 2005.

ESM ocean does a good job of simulating the observed carbon uptake

Ocean Anthropogenic Carbon Inventory Change

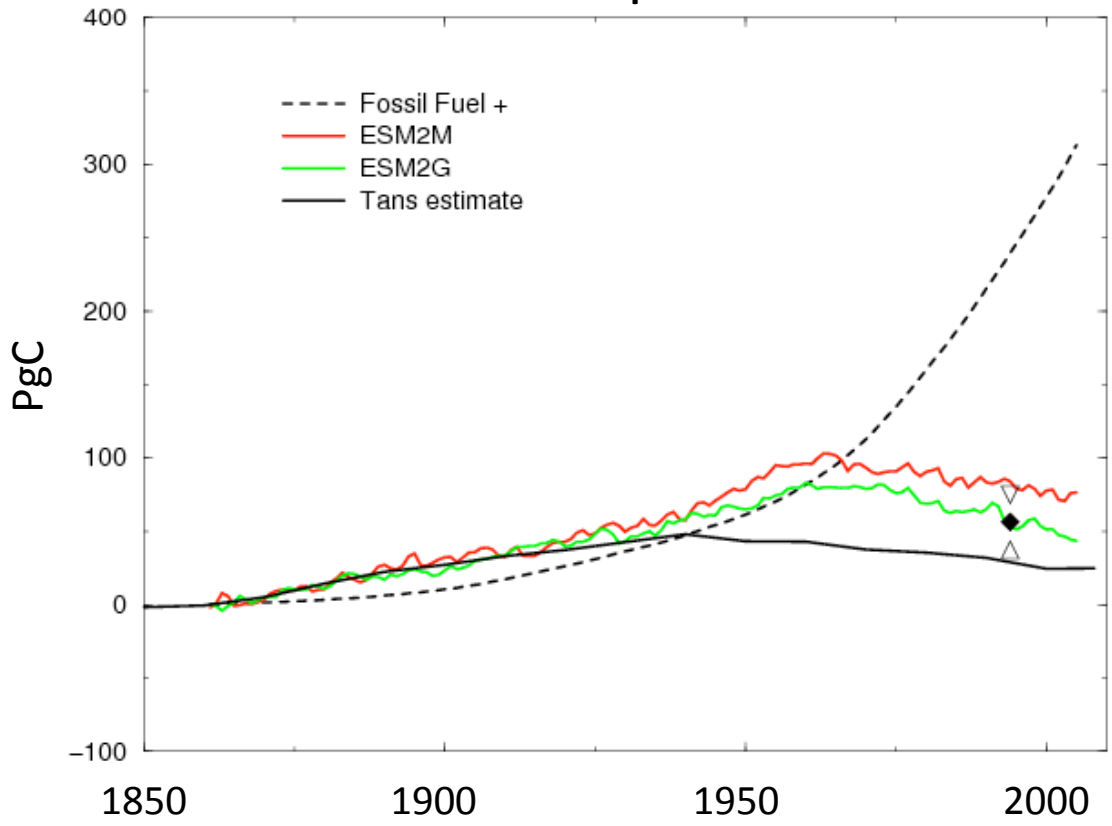


Empirical = Tans 2009 ocean estimate

- Ocean uptake proportional to atmospheric pCO_2 amount
- ESM2G smaller than ESM2M
- Both ESMs within uncertainty of Sabine et al. 2004

ESMs represent the quantitative character of the global land response

Cumulative Change in Land Carbon Flux into Atmosphere



Tans = Tans 2009 estimate

Fossil fuel + = FF+cement = Boden et al. (ORNL)

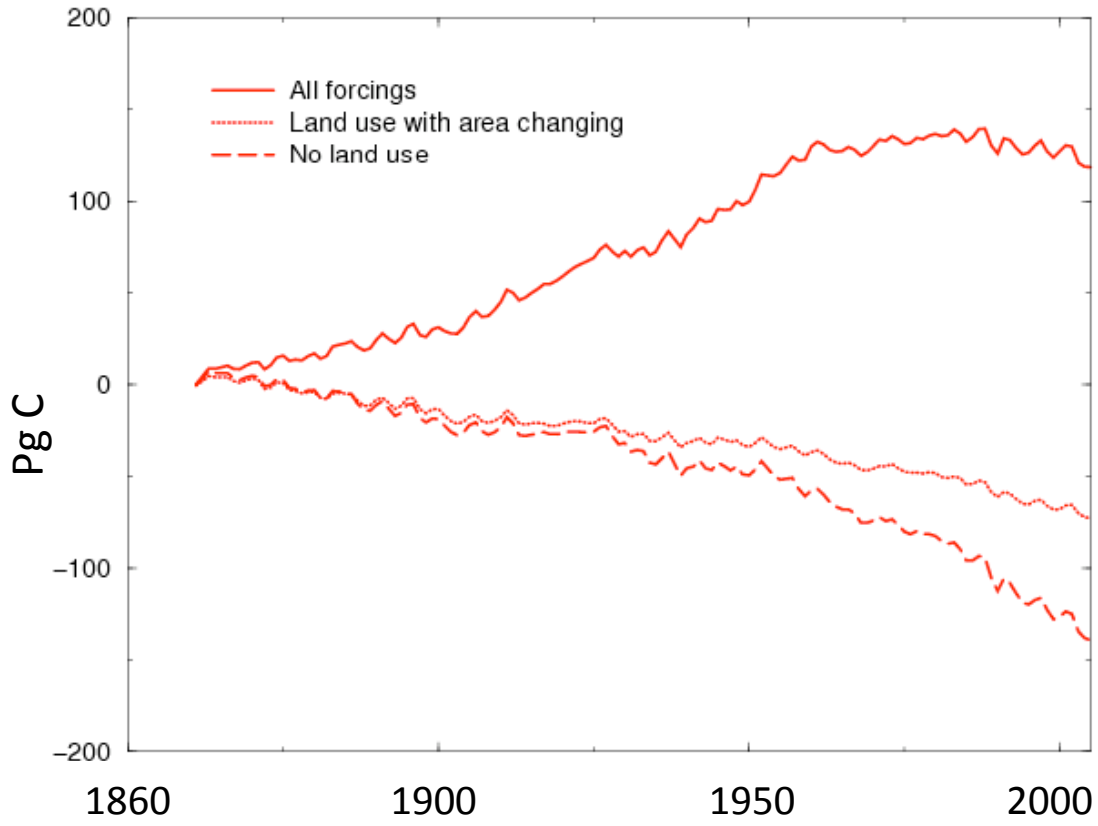
- Land carbon fluxes change sign over 20th C
- Cumulative land fluxes larger than Fossil Fuel + fluxes until ~1940's
- Both models get the observed decrease in past few decades but both miss the timing of the maximum

Important Causes of Land Carbon Flux Changes

- Increasing atm pCO_2 (CO_2 fertilization)
  - Decrease in land carbon flux to atmosphere
    - More biomass - More carbon stored in land plants
  - Magnitude uncertain – nutrient limitations (N, P,…)
- Climate change
  - Warming => changes of both signs
  - Drying => plants stressed => mainly increase in land carbon flux to atmosphere

Land use has a large impact on carbon changes over 20th Century

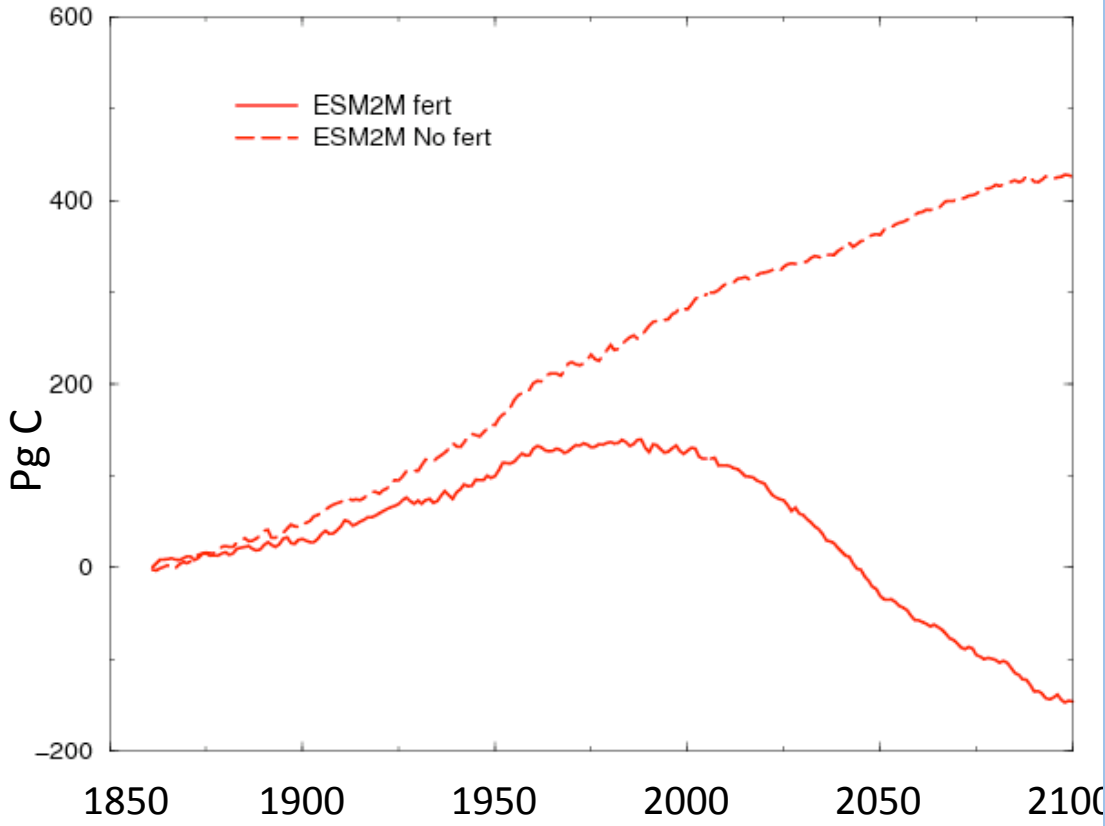
ESM2M - Cumulative Change in Land Carbon Flux into Atmosphere



- Land use yielded a large carbon flux to the atmosphere in 20th C
- Potential vegetation flux decrease mainly due to increased CO_2 fertilization
- Land use impacts carbon flux before 1860

Large Uncertainty in Future Land C Changes Associated with CO_2 Fertilization

ESM2M - Cumulative Change in Land Carbon Flux into Atmosphere



- Uncertainty associated CO_2 fertilization of plants increasing over 20th century
- CO_2 fertilization land C flux curve looks more like observational estimates
- In future, CO_2 fertilization of plants a large uncertainty
- ~600PgC => more than 300 ppm uncertainty over this century

Summary

- Major challenges in climate-carbon interactions
  - The role of ocean in the uptake of heat and carbon
  - The role of land use and management for carbon
  - The uncertainty of CO_2 fertilization in the future
- GFDL has built successful ESMs
  - Comprehensive Carbon component description
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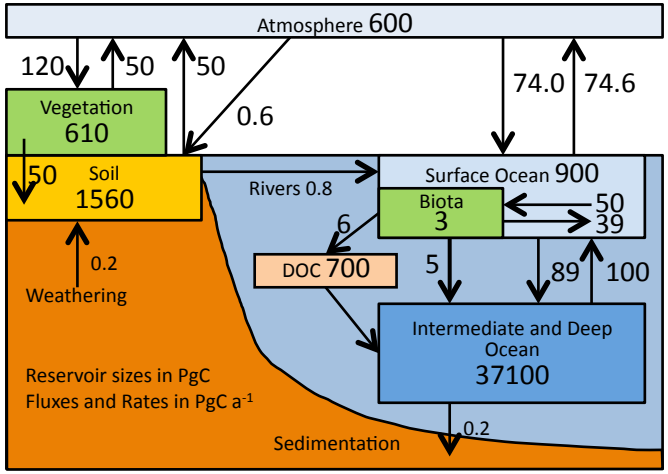
Questions?

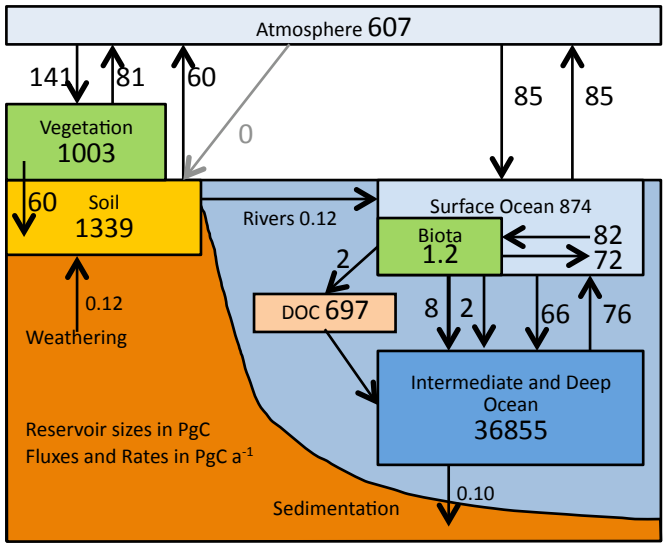
The ESMs represent the major component and interactions of the carbon cycle

A) Siegenthaler and Sarmiento (1993)*

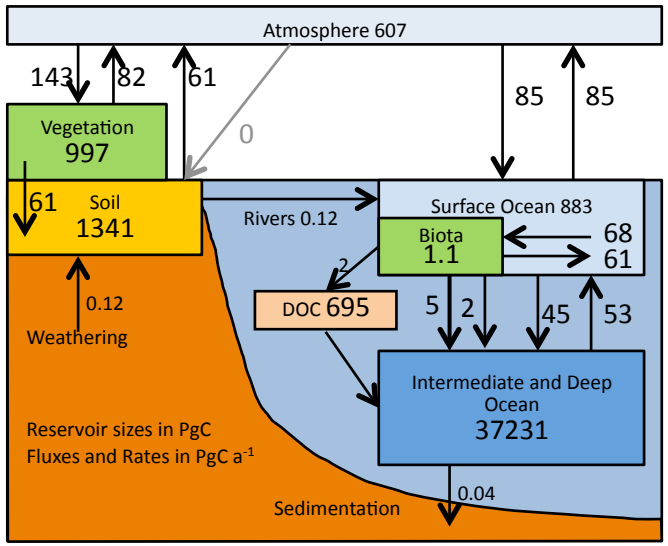


Preindustrial Carbon Cycle in ESM2M and ESM2G

B) ESM2M



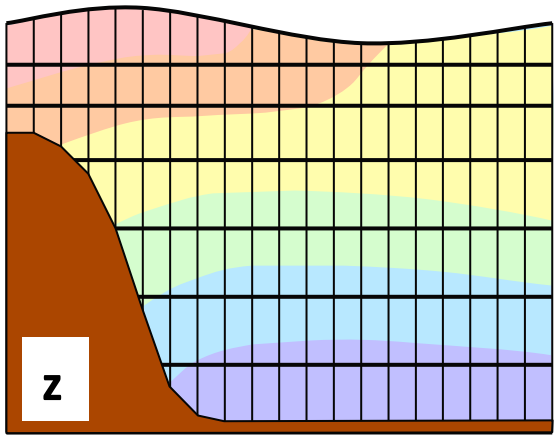
C) ESM2G

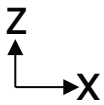


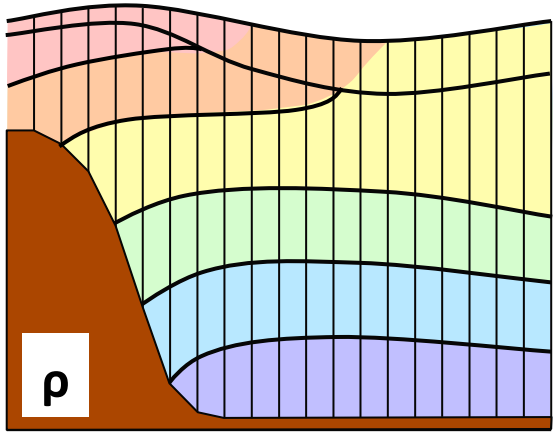
*includes modified ocean pools and fluxes (Sarmiento and Gruber, 2006; Sabine et al., 2004)

ESM2M and ESM2G differ only in ocean physics

Goal: Comparison of implications of ocean vertical coordinate choice







z* (MOM4.1):

- Laterally adjacent pressures interact
- Good representation of near surface
- Eulerian framework relatively straightforward to interpret
- Over 40 years of experience with it

ρ (GOLD):

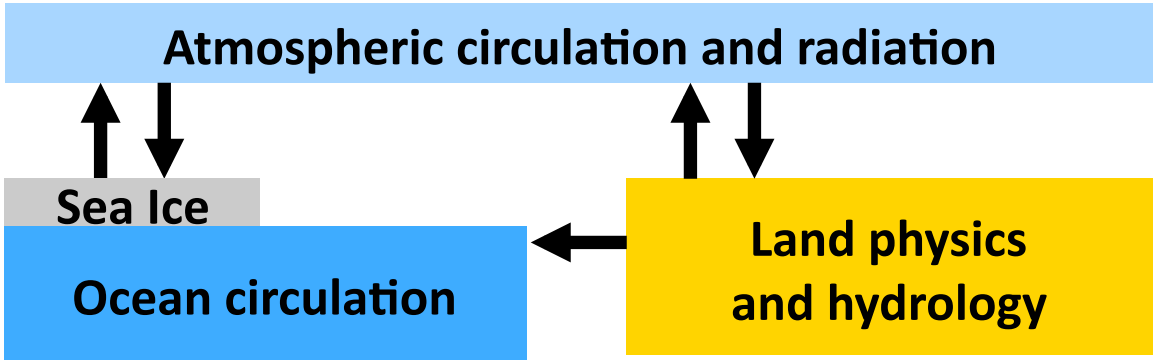
- Laterally adjacent densities interact.
- Bulk mixed layer allows continuously varying mixed layer properties
- Good representation of overflows
- No numerical diapycnal mixing

Question 1: Can they both give credible climates?

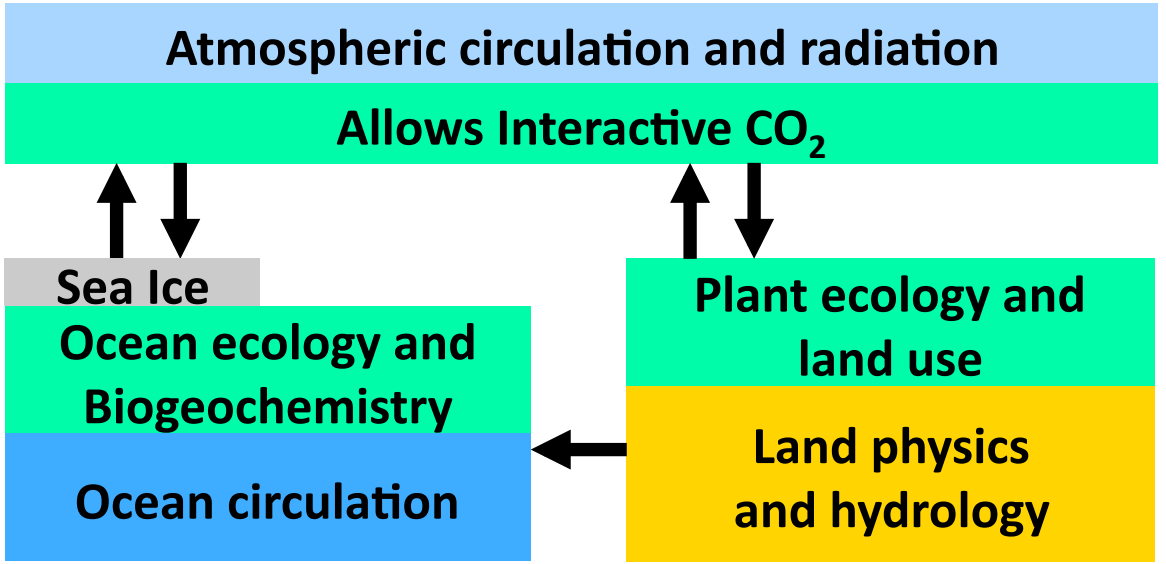
Question 2: How similar are the climate responses?

Earth System Models* close the carbon cycle

Climate Model

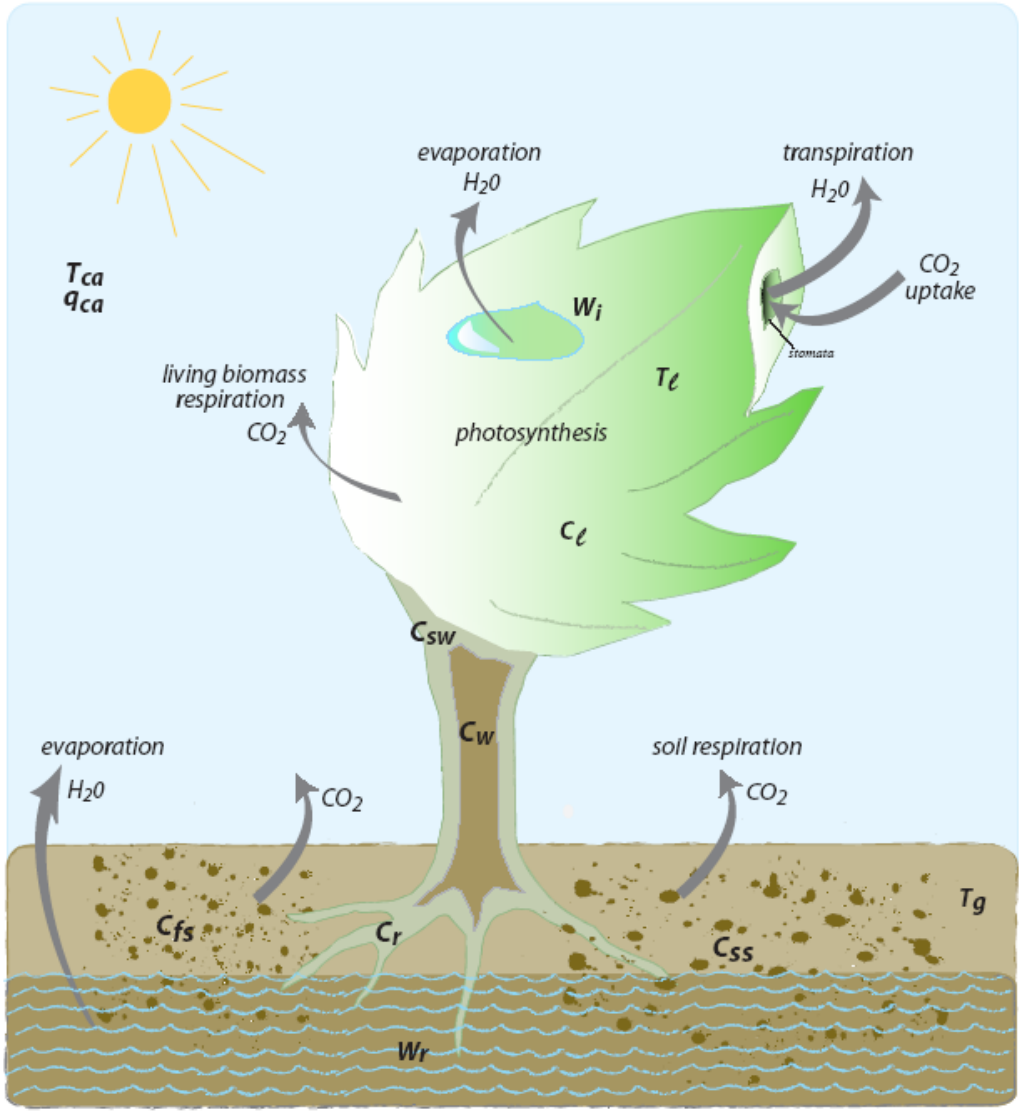


Earth System Model *



*CMIP5 definition; many other definitions of an ESM possible

Vegetation structure in the LM3 land model



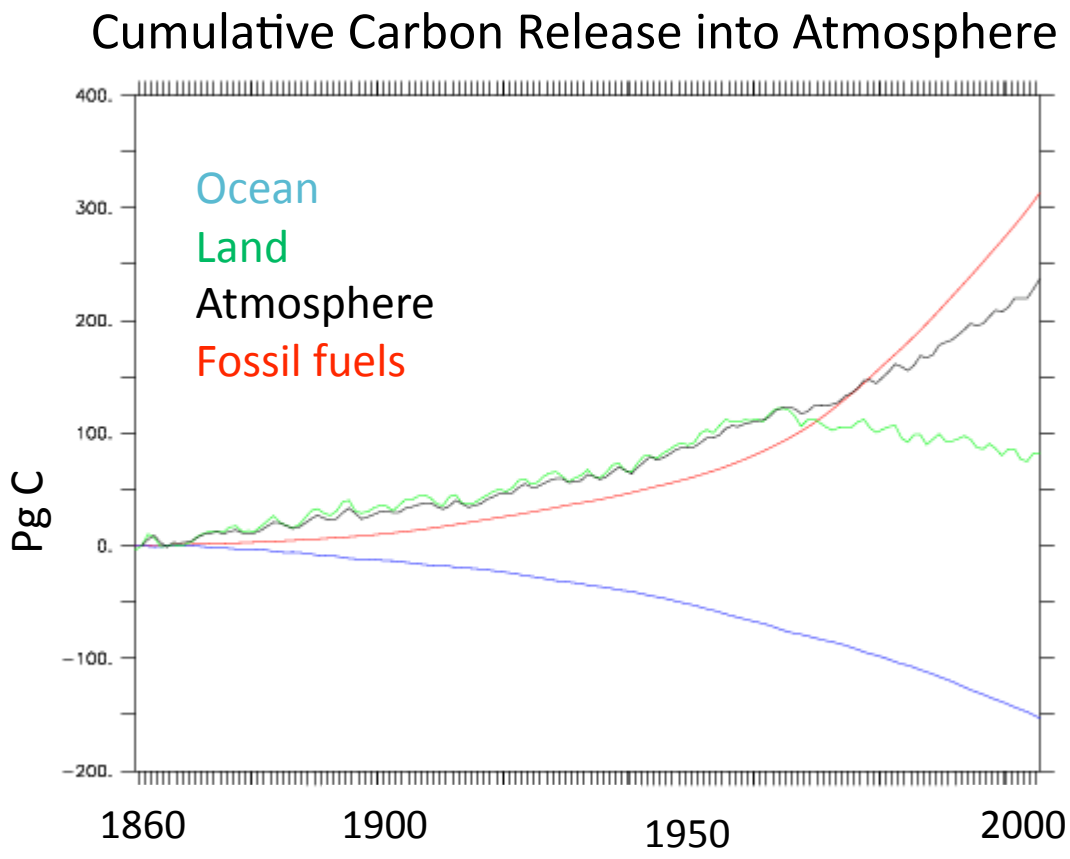
- 5 vegetation types
- 5 vegetation C pools
- 2 soil C pools
- 4 land-use types
- Sub-grid heterogeneity to represent forest ages
- Natural mortality and fire

Shevliakova et al., 2009

ESMs Allow Two Types of Experiments

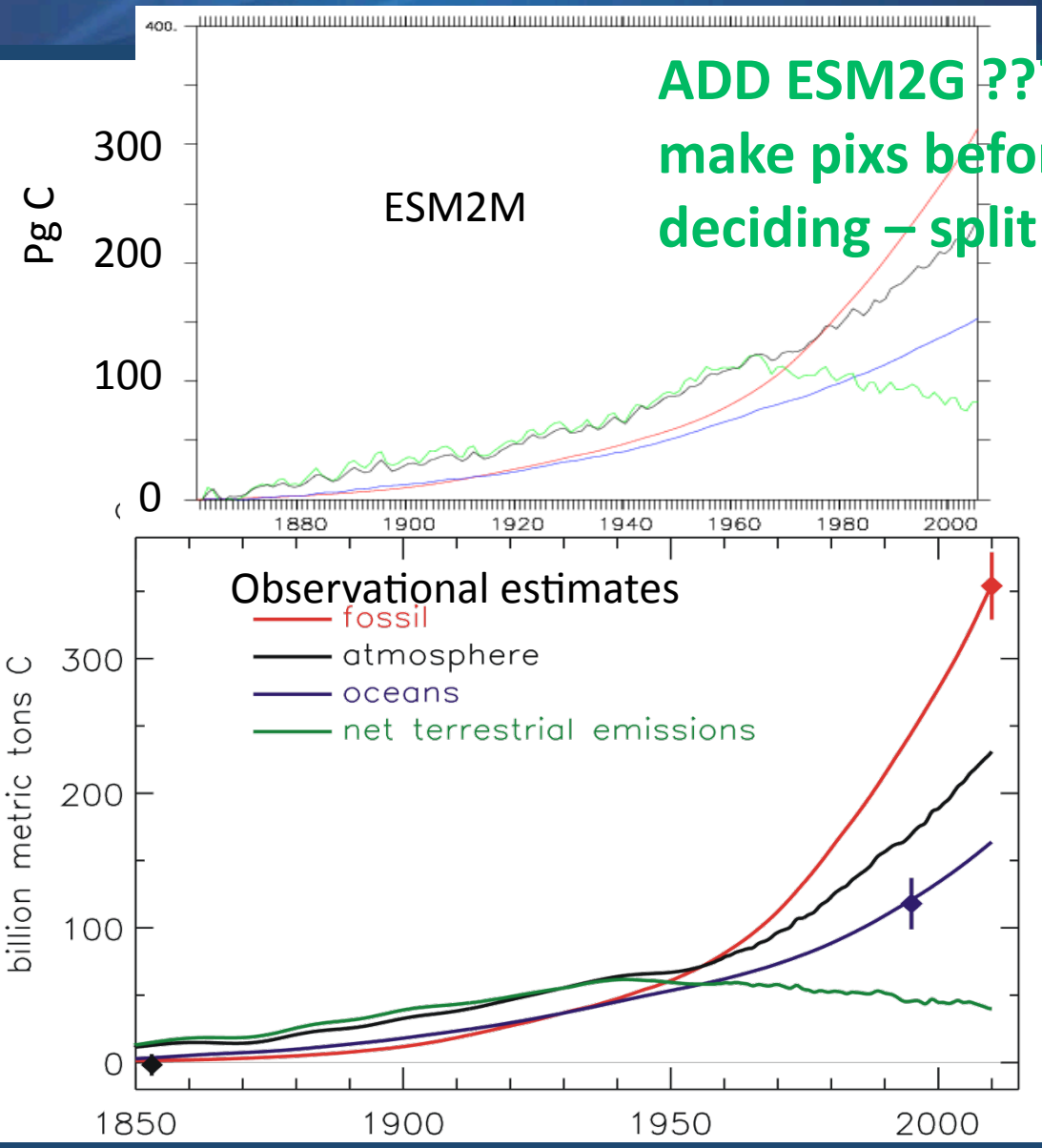
- Concentration driven
  - Atmospheric pCO_2 restored towards some specified value (time constant of 1 year)
  - Since concentration same in runs, allows comparison of physical response
- Emission driven
  - Model predicts atmospheric pCO_2 from various fluxes and human emissions (if used in run)
  - Allows full feedbacks between carbon and climate

Land largest source to atmosphere before ~1960



- Fossil fuel emissions *currently* largest carbon source to atm
- Ocean uptake proportional to atm pCO_2 amount
- Land carbon fluxes change sign over 20th C

Model Land Carbon fluxes similar to Obs Estimates

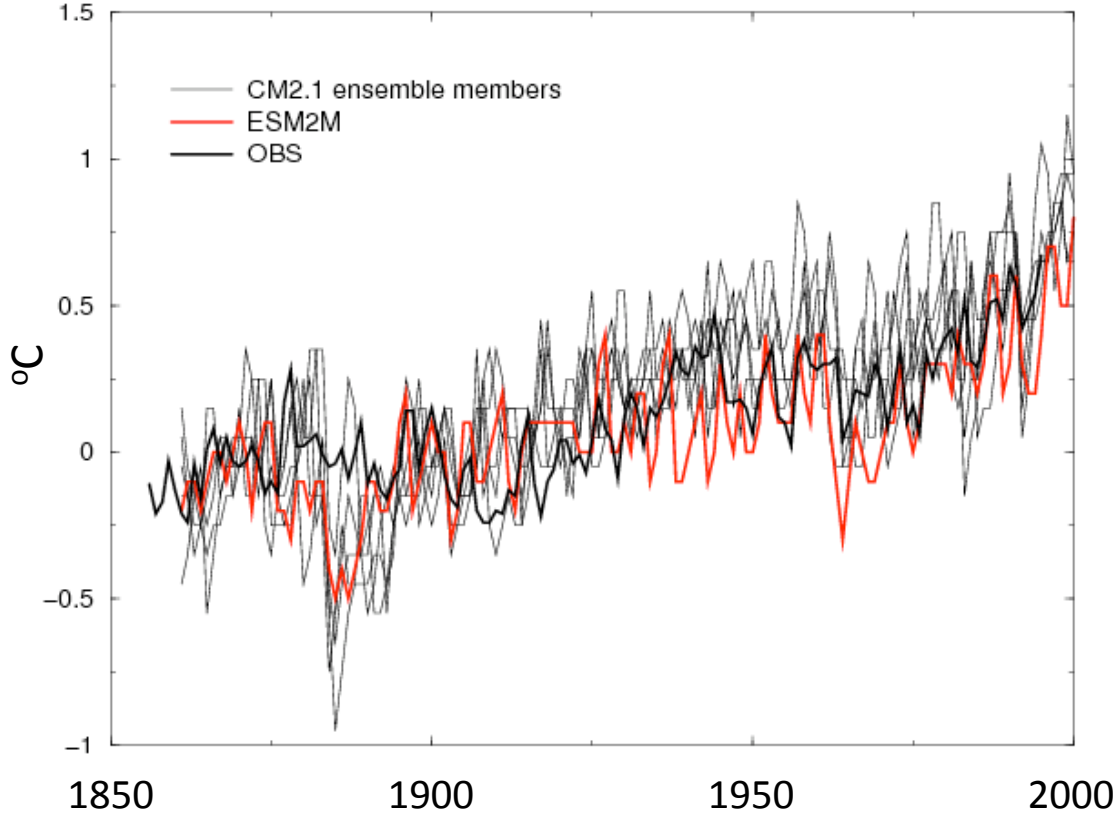


ADD ESM2G ??? Need to make pixs before deciding – split into parts

- Model and Tans estimates very similar in magnitude
- Land flux changes sign near 1950

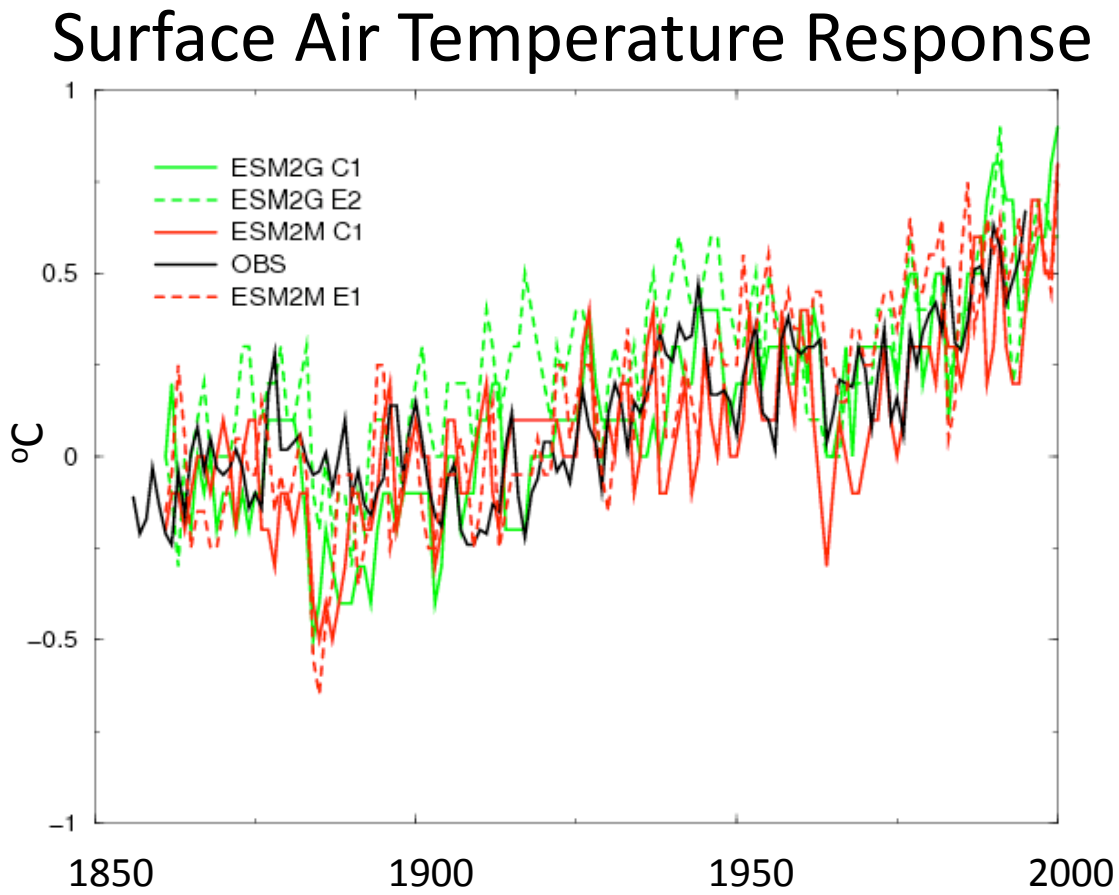
ESM2M (conc driven) Shows Similar Global Surface Air Temperature Response to CM2.1

Surface Air Temperature Response



- ESM2M C1 response may be slightly smaller than CM2.1 in historical period
- Both models do good job of simulating observed trend

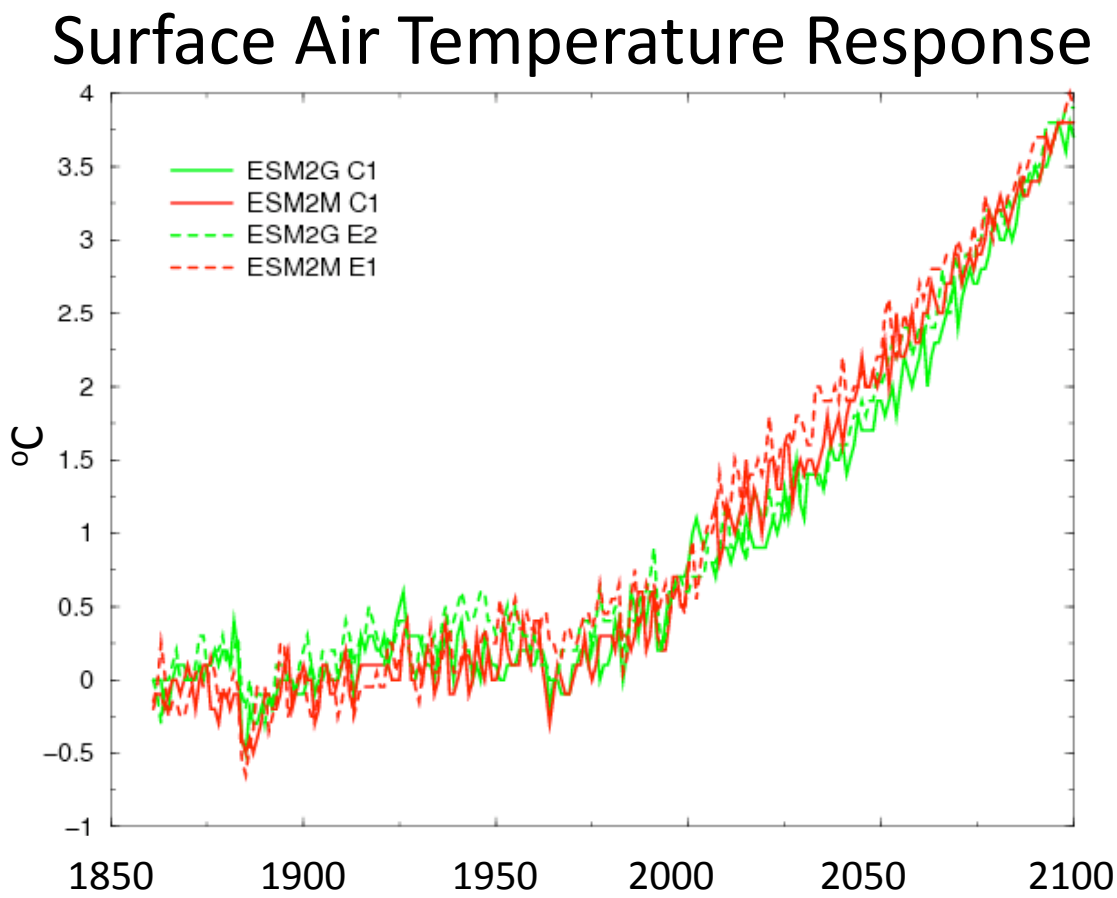
ESMs concentration (C1) and emission (E1) driven runs show similar Global Surface Air Temperature Response



- Two different forcings (C & E) give very similar responses
- Both models (M&G) do good job of simulating observed trend using emissions and concentrations.

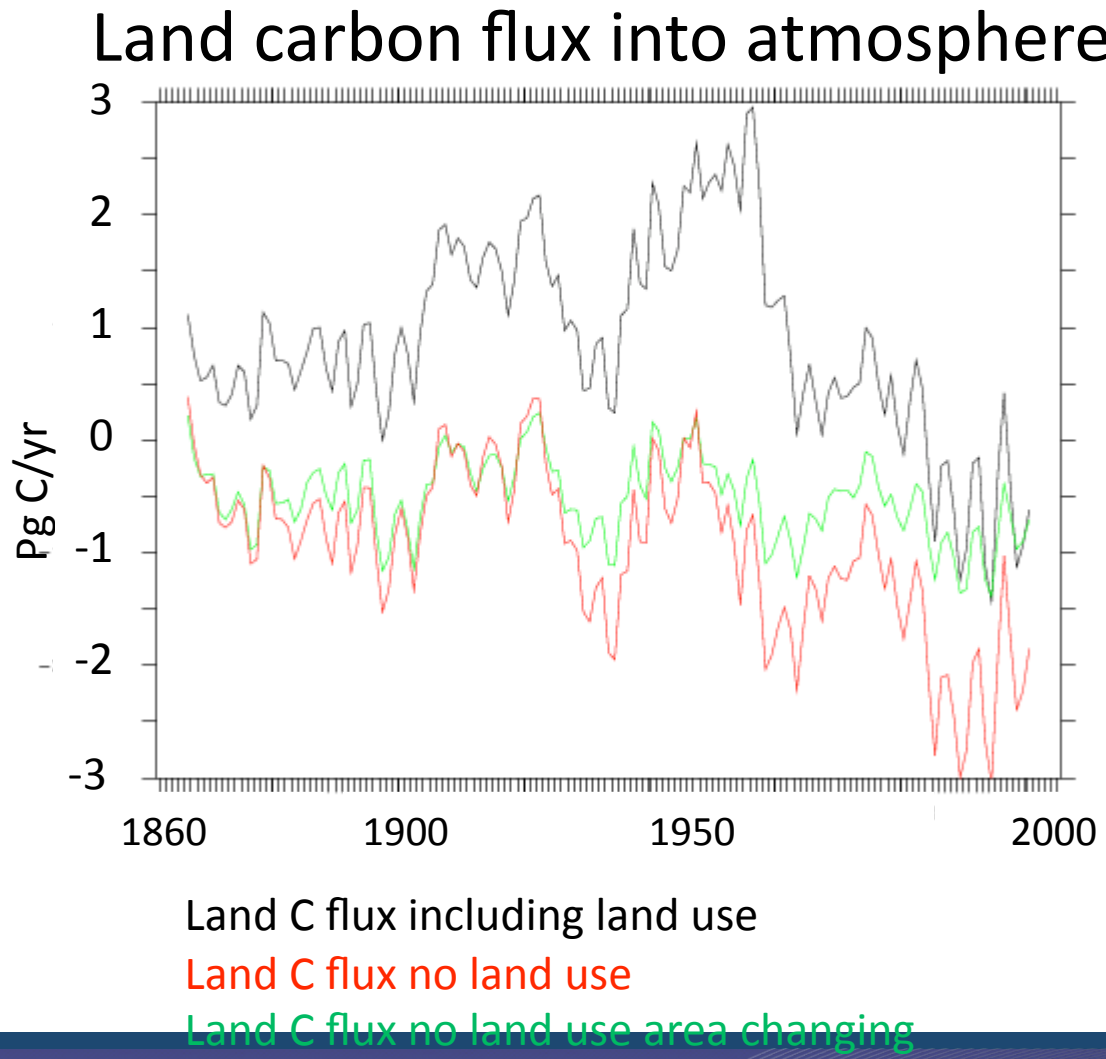
ESMs C1 and E1 also Similar in Future (RCP8.5)

C1=concentration; E1=emission



- Two different forcings give very similar responses
- ESM2M: Emission driven run slightly warmer than concentration run
- ESM2G: Slightly cooler than 2M in middle of this century

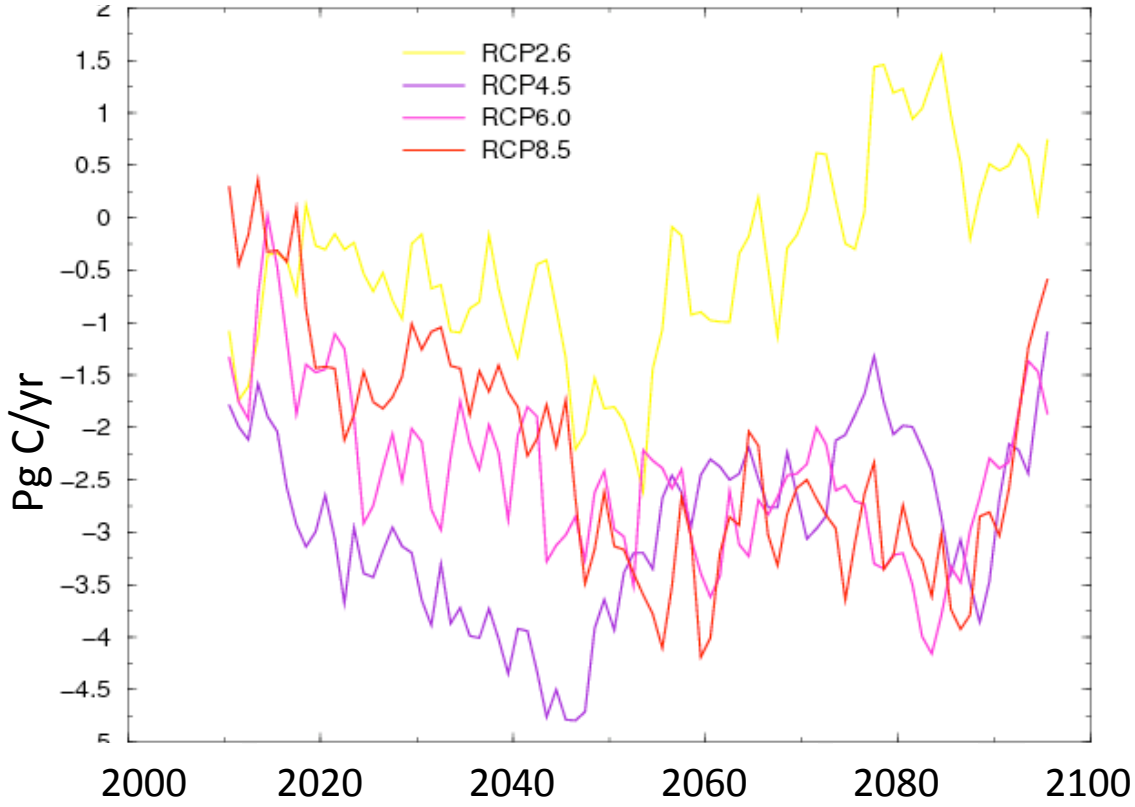
Land use has huge impact on carbon changes over 20th C



- Land use yielded 1-2 PgC/yr (0.5-1 ppm/yr pCO_2) to atmosphere
- Potential vegetation flux decrease due to increased CO_2 fert
- Land use impacts carbon flux before 1860

What happens to land fluxes in the Future?

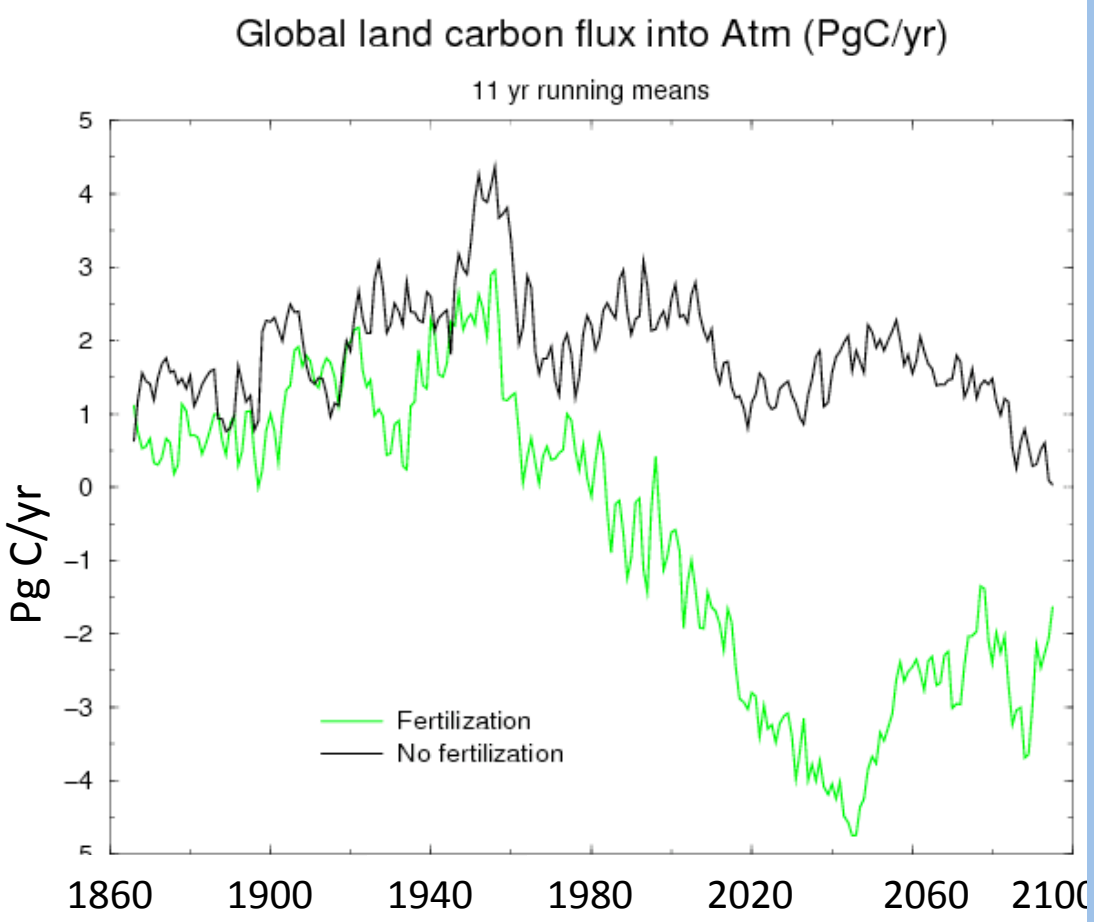
Land Carbon Flux into Atmosphere



Note: 11 yr running means used

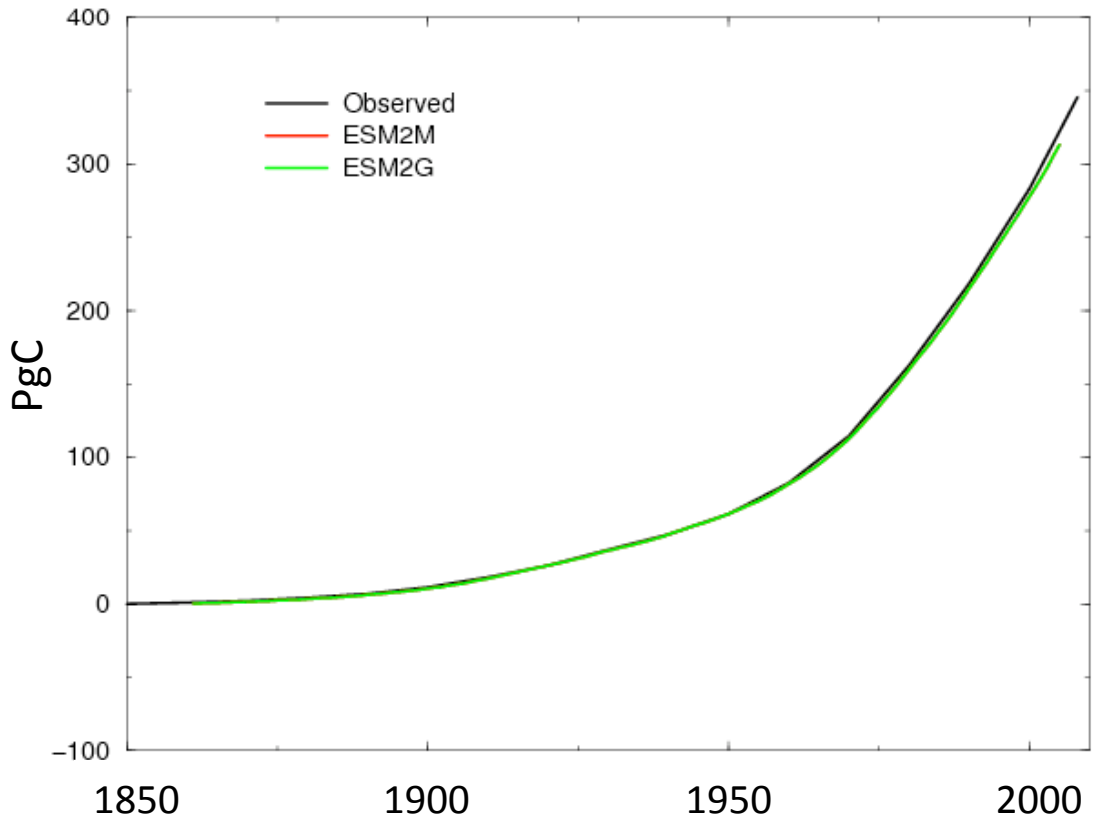
- RCPs have land taking up carbon in early part of this century
- All RCPs have LU stop changing near 2100 (land C flux goes toward zero)
- Interactions of climate change and CO_2 fert among RCPs

Uncertainty Associated with CO_2 Fertilization



- Uncertainty associated CO_2 fertilization of plants increasing over 20th century
- CO_2 fertilization land C flux curve looks more like observational estimates
- In future, CO_2 fertilization of plants a large uncertainty
- 2-4 Pg/yr => 1-2 ppm/yr => more than 150 ppm over this century

Cumulative Emission Flux into atmosphere



Observed = Boden et al. (ORNL)

- Fossil fuel emissions *currently* largest carbon source to atmosphere
- Model and observed agree – we input the emissions correctly…

Future Directions

- CMIP5
  - ESM2M runs complete; ESM2G running
  - Several 10's TB are appearing on our server now
- New Experiments
  - Exploring various science questions with ESM2M and ESM2G
- Model Development (e.g.):
  - Comprehensive land biogeochemistry (dust, CH_4, N, P, …)
  - Higher trophic levels in ocean (connection to fish)
- Exploring Higher Resolution – ESM2.5
  - CM2.5 based – 1/2 deg atmosphere, 0.25 deg ocean
  - Status: just running
  - Investigating potential for decadal ecosystem prediction