

Land-cover Change in Earth System Models

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With thanks to:

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Richard Betts, Navin Ramankutty**

Some Definitions

- Earth System Model (ESM) – a climate model typically coupled to carbon cycle and/or atmospheric chemistry models. Encompasses General Circulation Model (GCMs) and EMICs.
- Earth System Model of Intermediate Complexity (EMIC) – an ESM where one or more the components (e.g. atmosphere) takes a simplified or “reduced” form

Outline

- Motivation
- Relevant Work to date on Land-use Change in ESMs
- Plans for Land-use Change in ESMs
- Land-use Data Requirements for ESMs
- Conclusions and Outstanding Questions

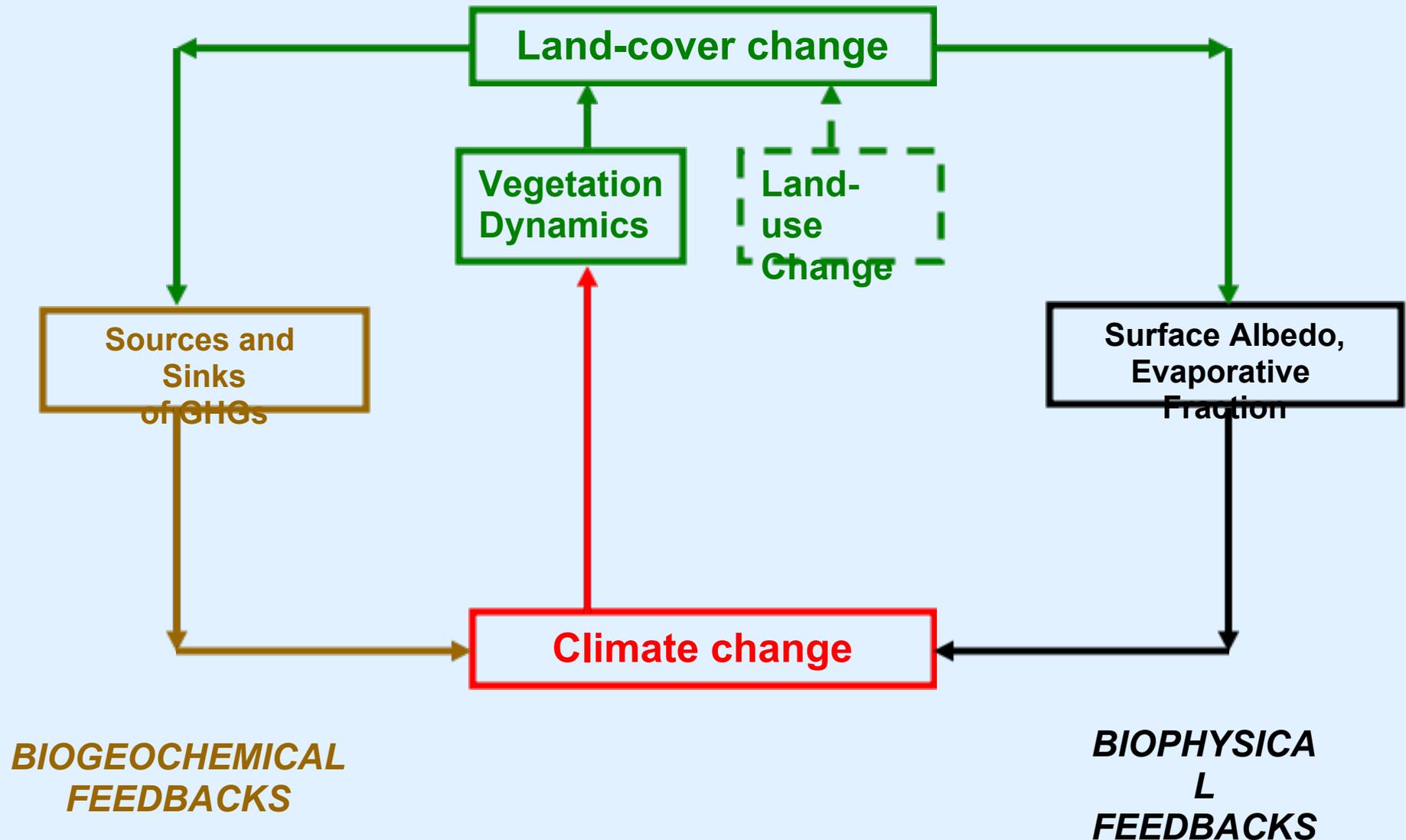
Motivation

- The focus of climate modelling is now moving from answering the question “how will the climate look if we carry-on the way we are going?” to “what do we need to do to minimize the risk of dangerous climate change, and to adapt to the changes that are now inevitable?”
- This requires the adoption of much more realistic and consistent scenarios by the ESM/climate modelling community, and therefore better communication with the IAM community (..hence this meeting.. ☺)
- Consistency between the drivers of climate change is key if we are to provide useful guidance on policy options.
- Land-use change and GHG emissions scenarios are intimately linked under many mitigation scenarios (e.g. use of land for biofuels or solar energy generation)

Importance of Including Land-use Change in AR5 Runs

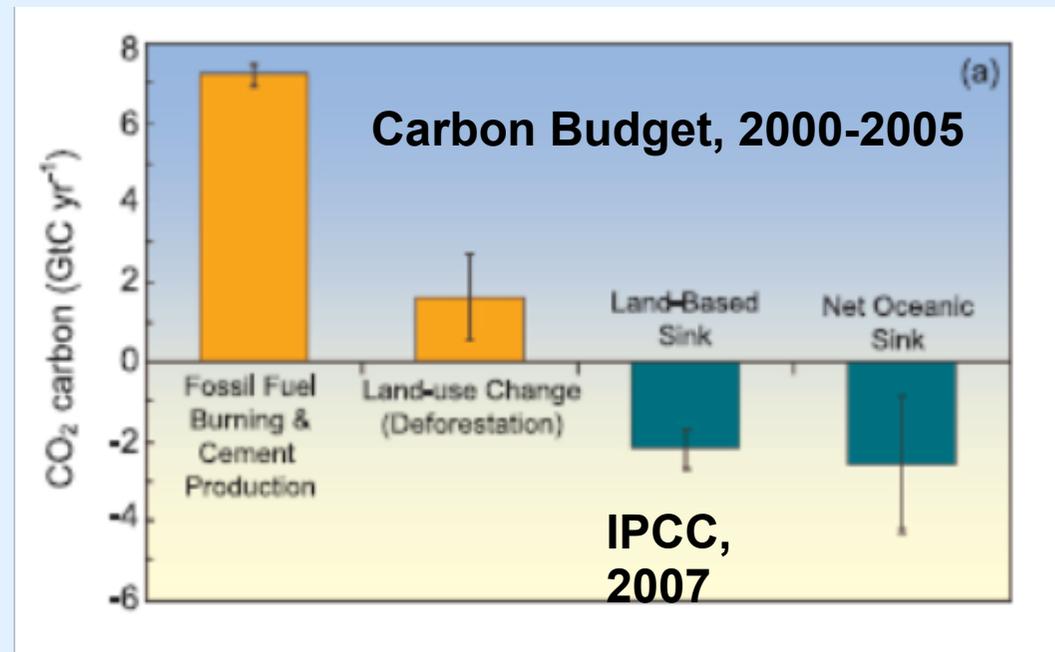
- Land-cover change can arise from either human land-use change or “natural” vegetation dynamics.
- Land-cover change can influence climate through both biogeochemical (e.g. GHG emissions) or biophysical effects (e.g. changes in surface albedo).
- Climate Models have typically assumed fixed land-cover and prescribed GHG concentrations therefore ignoring both biophysical and biogeochemical feedbacks.
- First generation Dynamic Global Vegetation Models (Cramer et al., 2001) and first generation Coupled Climate Carbon Cycle Models (C4MIP, Friedlingstein et al., 2006) both focused on natural vegetation and therefore did not consistently treat the effects of land-use change.
- Land-cover change in the 20th century has almost certainly been more heavily influenced by land-use change than by natural vegetation dynamics, and the same is likely to be true under most scenarios of the 21st century.

Land-cover and Climate



CO₂ Emissions from Land-Use Change

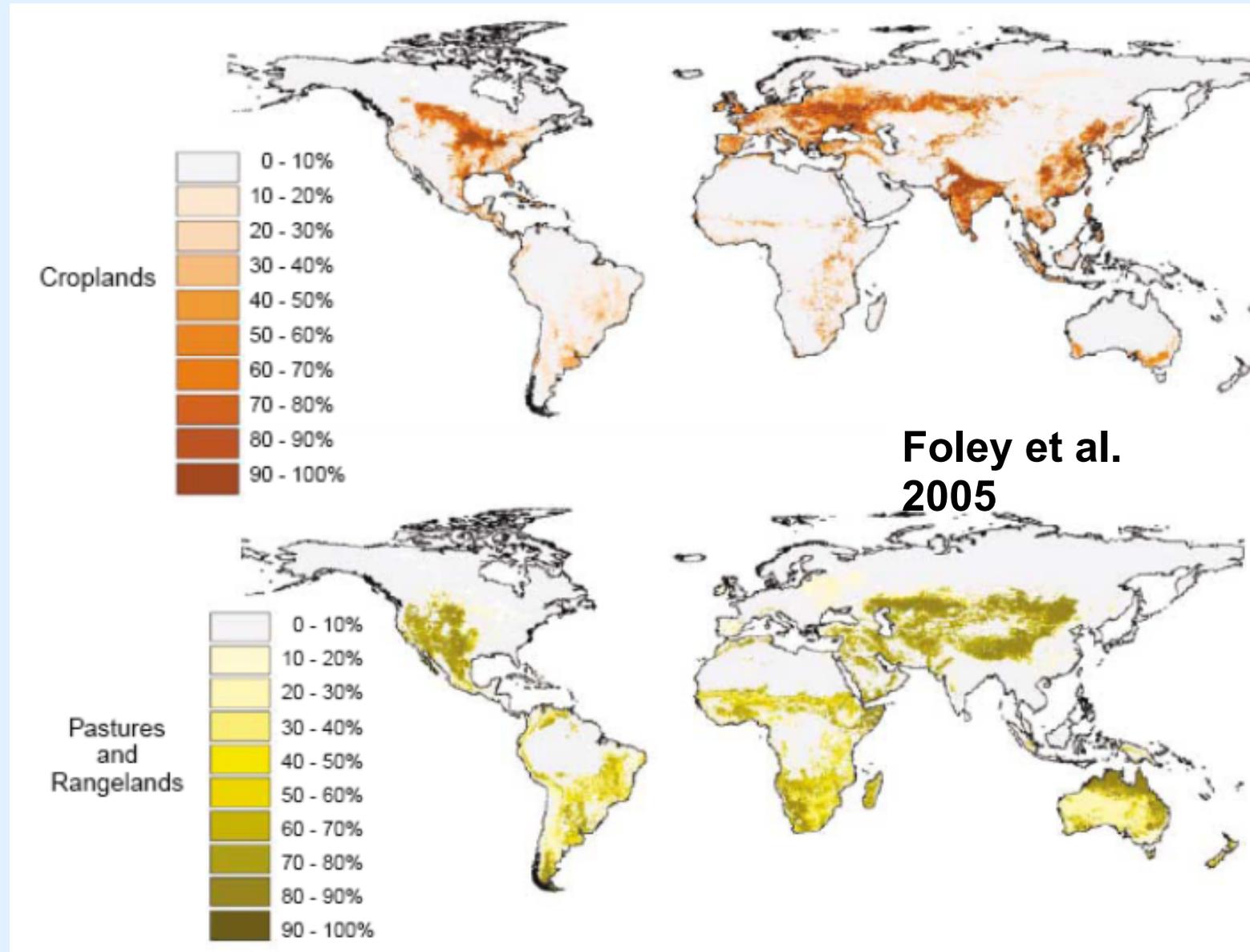
- Land-use change has accounted for about 35% of historical human CO₂ emissions (Foley et al., 2005)
- Land-use change currently accounts for about 20% of current CO₂ emissions (IPCC, 2007).



Relevant Work to date on Land-use Change in ESMs

- Historical datasets of croplands and pasture are now available to drive global models (e.g. Ramankutty and Foley, 1999; Goldewijk, 2001).

Human Land-Use (1990s)

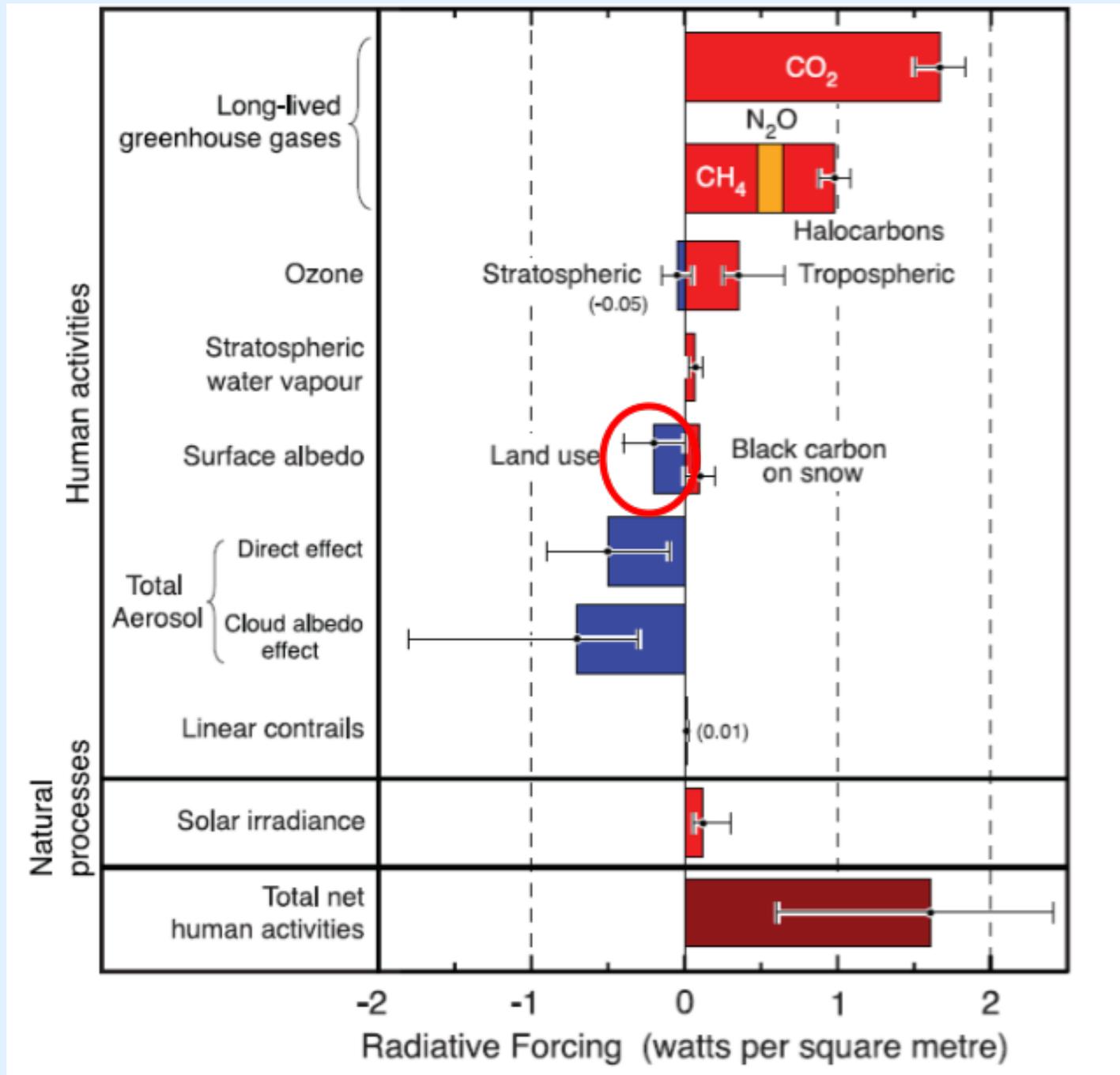


~ 40 % global land area

Relevant Work to date on Land-use Change in ESMS

- Historical datasets of croplands and pasture are now available to drive global models (e.g. Ramankutty and Foley, 1999; Goldewijk, 2001).
- The IPCC (2007) estimate a global mean radiative forcing of $0.2 \pm 0.2 \text{ W m}^{-2}$ due to surface albedo changes associated with historical land-use changes.

Radiative Forcing of Climate 1750-2005

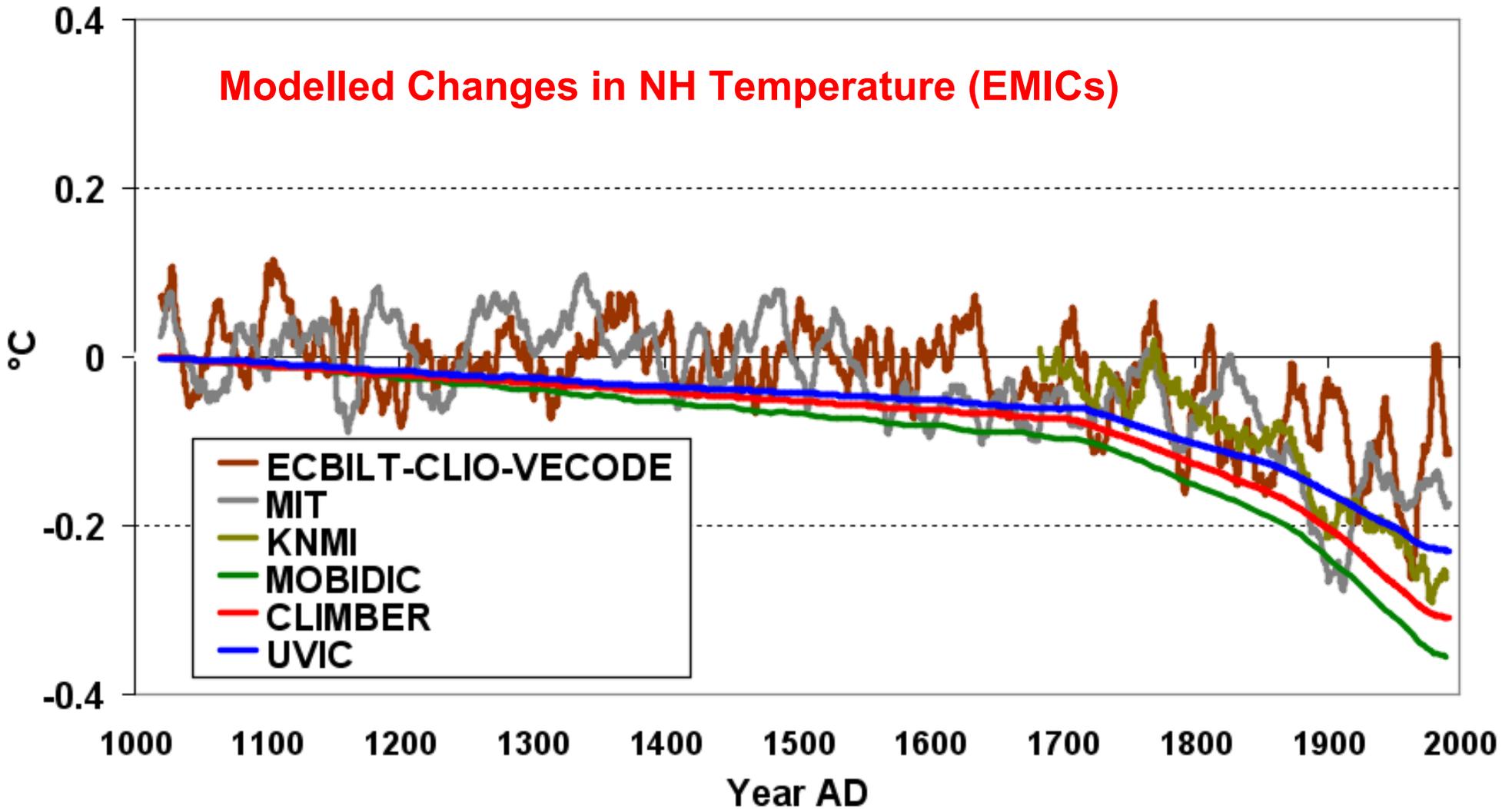


Land-use

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- GCMs (Betts et al. 2007) and EMICs (Brovkin et al. 2004) have been used to estimate the biophysical impacts of land-use change on climate.

Biophysical Effects on Global Climate (1000-2000)

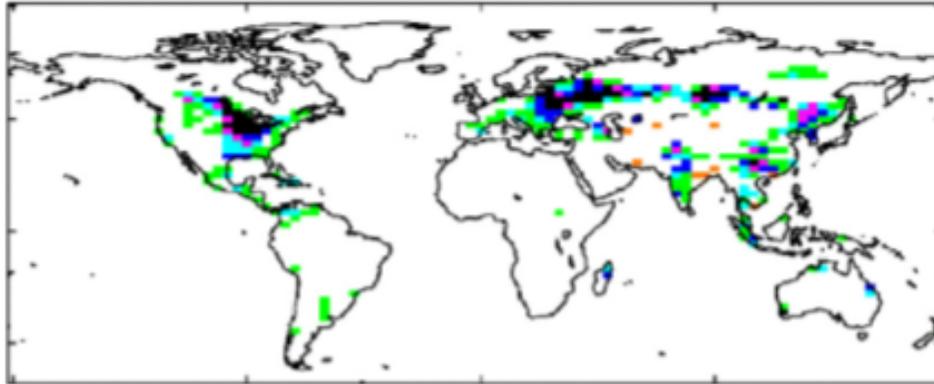


Relevant Work to date on Land-use Change in ESMs

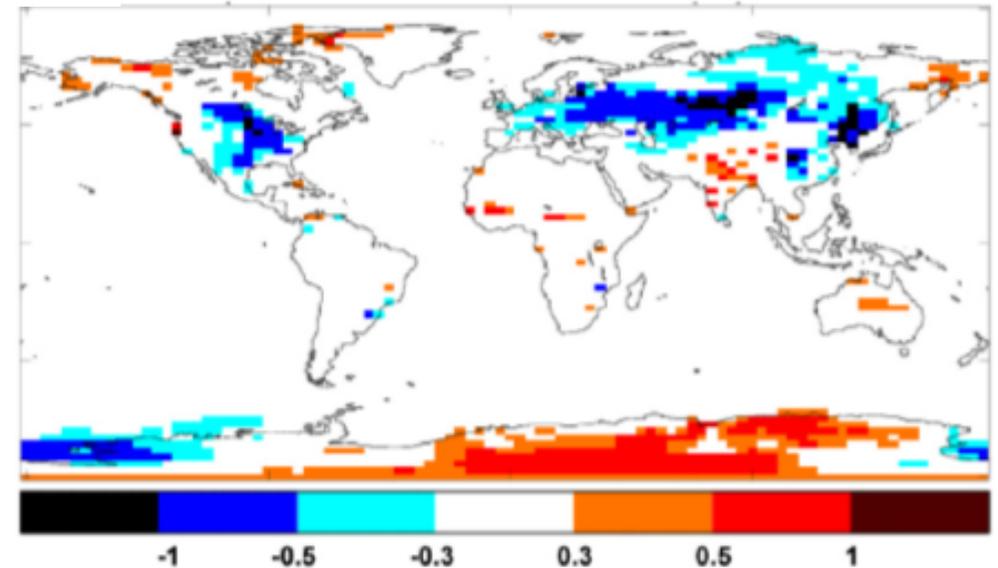
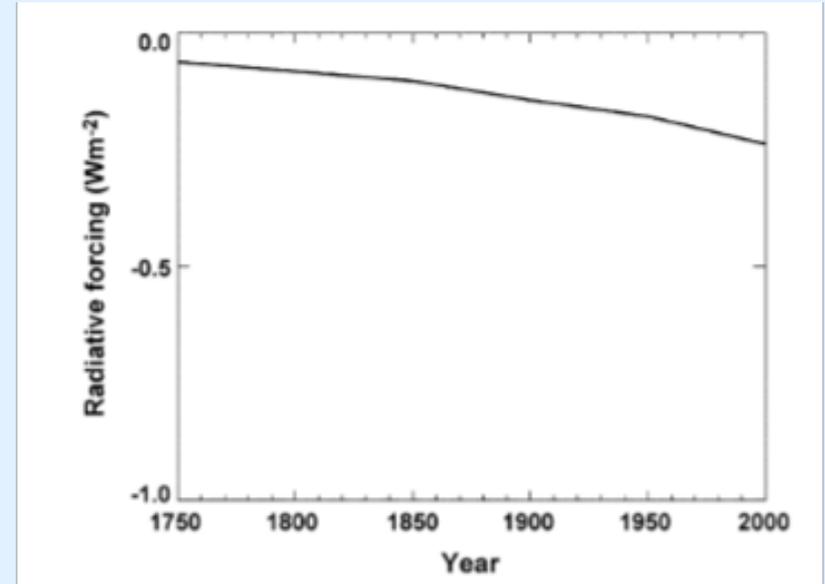
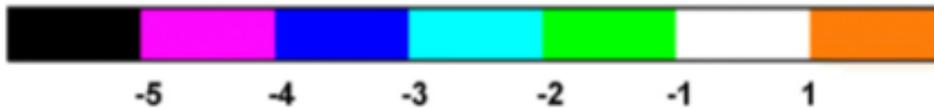
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- GCMs (Betts et al. 2007) and EMICs (Brovkin et al. 2004) have been used to estimate the biophysical impacts of land-use change on climate.
- Although the global mean temperature change due to land-use change is relatively small ($\sim -0.2 \text{ K}$ from 1750 to 1990), local effects can be very significant (up to -1K).

Biophysical Effects of Historical Land-use on Climate

1990-1750



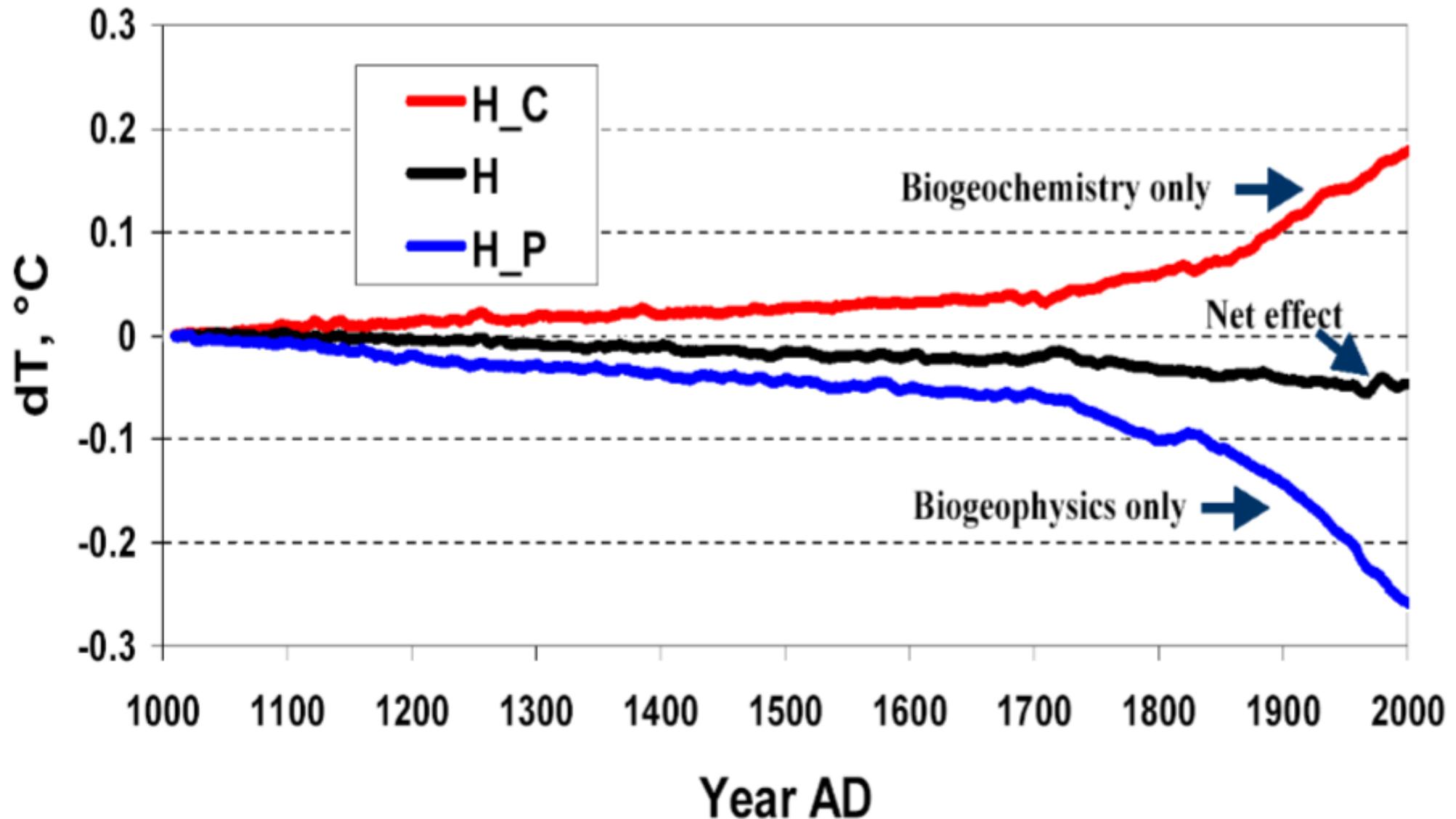
Radiative forcing (Wm^{-2})



Temperature Change (K)

Betts et al.,
2006

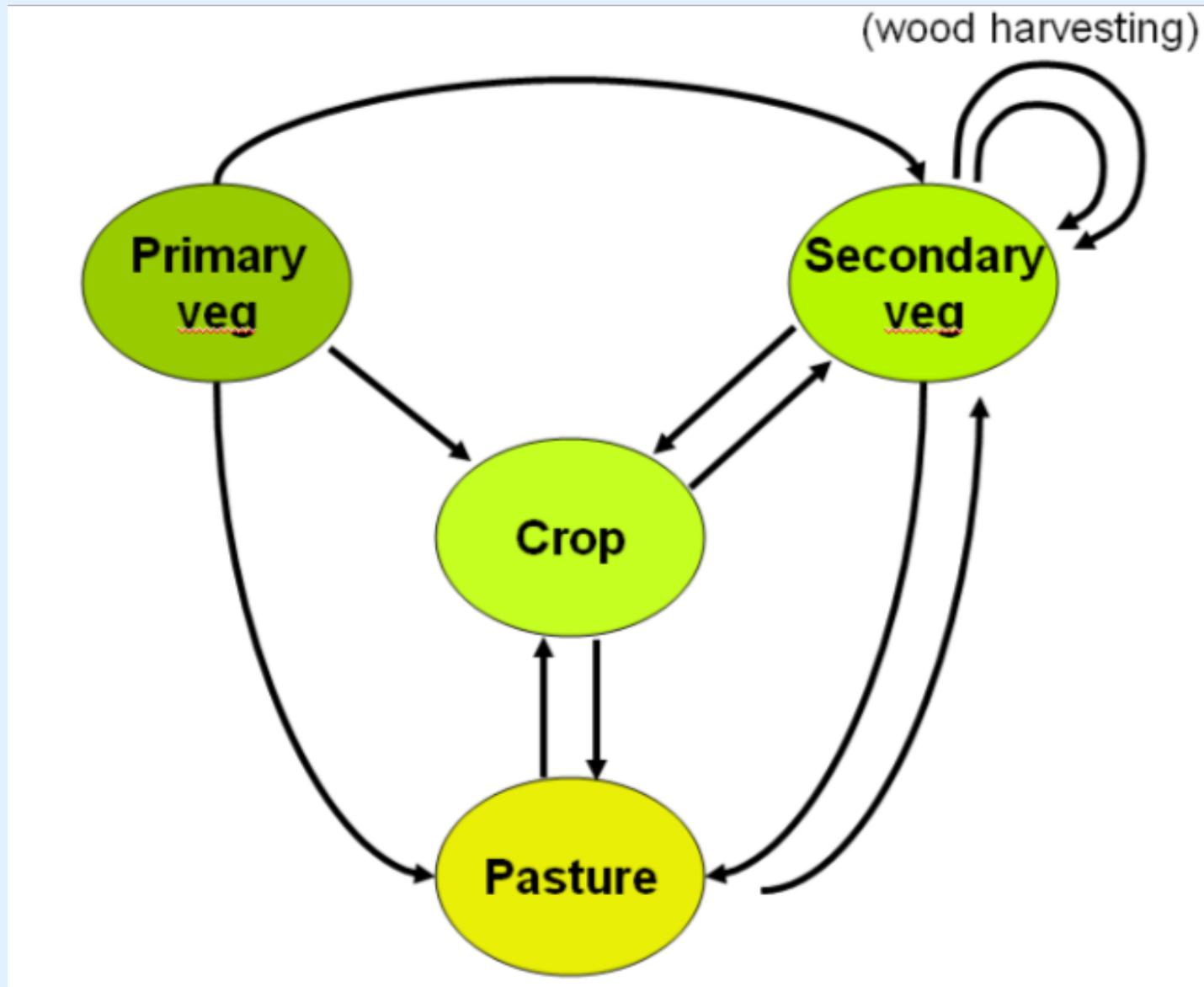
Land-cover Effects on Climate



Plans for Land-use Change in ESMs

- Many modelling groups are planning to include more sophisticated representations of the impacts of land-use change (especially for C₄MIP).

Increasing Sophistication of Land-use in ESMs (e.g. CLM-CN)



Plans for Land-use Change in ESMs

- Many modelling groups are planning to include more sophisticated representations of the impacts of land-use change (especially for C₄MIP).
- Some groups will prescribe time-evolving global vegetation cover taking account of land-use changes.

Land use change treatment in CCCma CanESM1 using Canadian Terrestrial Ecosystem Model (CTEM)

- Driven with historical (1850-1992) and future (1992-2100) fractional coverages of 9 PFTs (including C₃ and C₄ crops) from *Wang et al.* (2006) since competition is not yet explicitly modelled in CTEM 1.0.
- Historical increase in crop area is based on Ramankutty and Foley (1999).
- Future changes in crop area and other PFTs from the IMAGE model (but this will change when new land cover data consistent with RCPs will become available).

CTEM 1.0 Plant Functional Types	
1	Needleleaf Evergreen
2	Needleleaf Deciduous
3	Broadleaf Evergreen
4	Broadleaf Cold Deciduous
5	Broadleaf Dry Deciduous
6	C ₃ Crop
7	C ₄ Crop
8	C ₃ Grass
9	C ₄ Grass

Wang et al., 2006



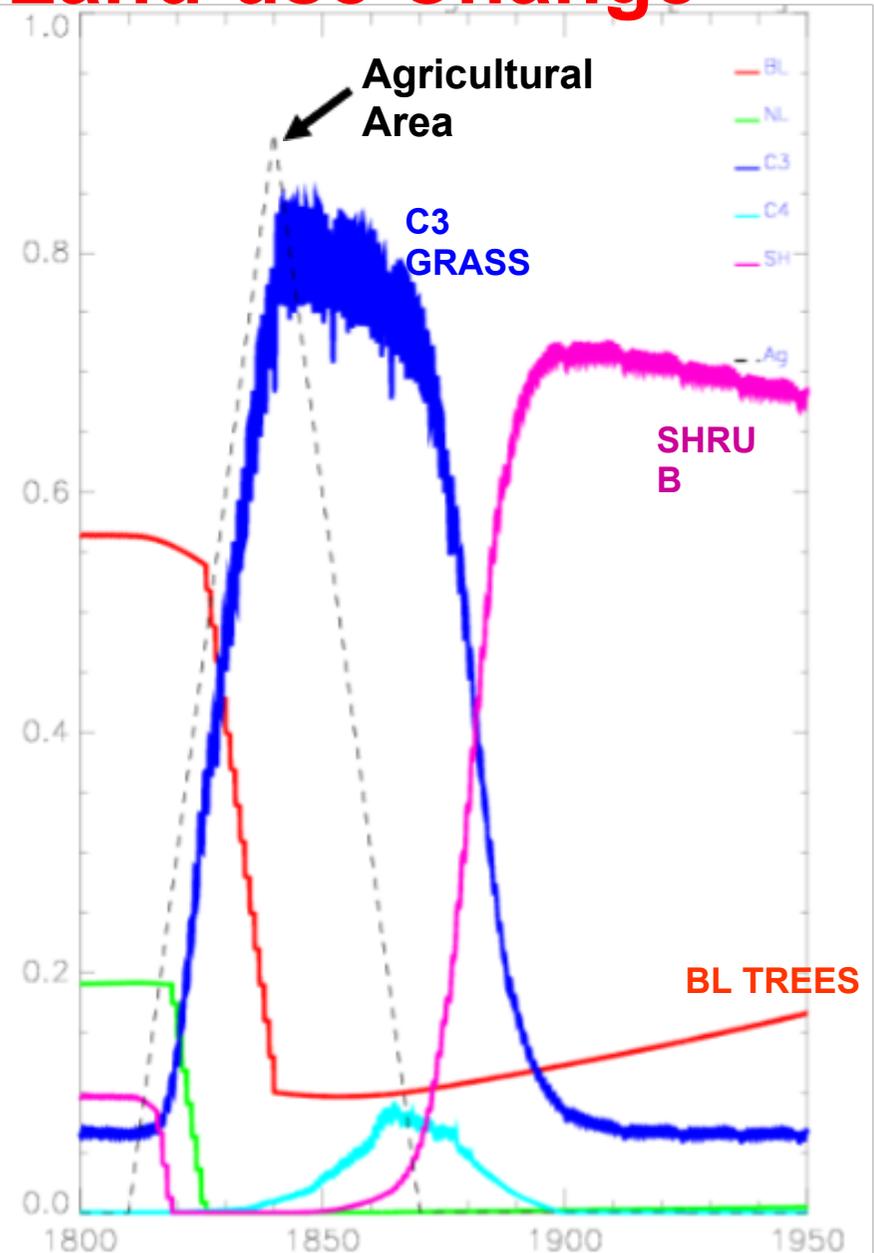
Plans for Land-use Change in ESMs

- Many modelling groups are planning to include more sophisticated representations of the impacts of land-use change (especially for C₄MIP).
- Some groups will prescribe time-evolving global vegetation cover taking account of land-use changes.
- Other groups will introduce representations of land-use change into existing Dynamic Global Vegetation Models.

Modelling Interaction between Vegetation Dynamics and Land-use Change

Example simulation:

- Initially a forest region, land use fraction increases from 0% to 90% and back to 0%.
- Trees (red and green) and shrub (pink) are displaced, allowing C3 type grass to dominate.
- After abandonment shrubs initially invade, and broadleaf tree starts to recover.

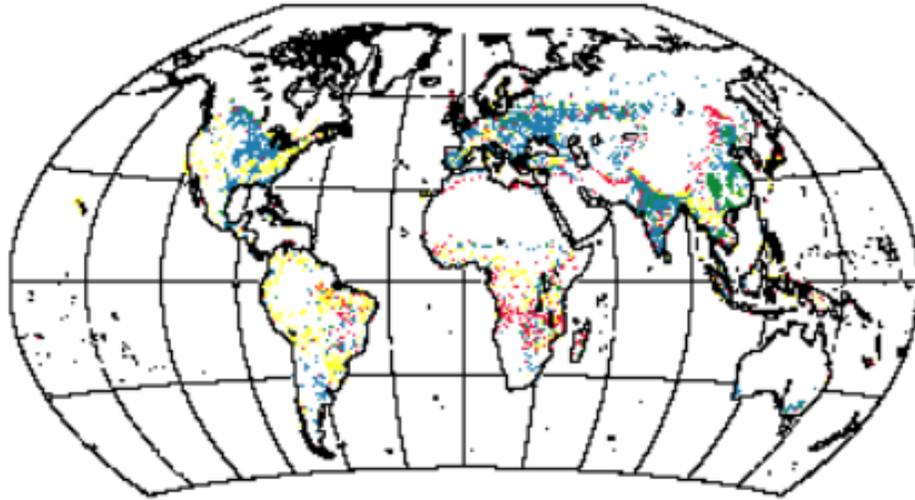


Land-use Data Requirements for ESMs

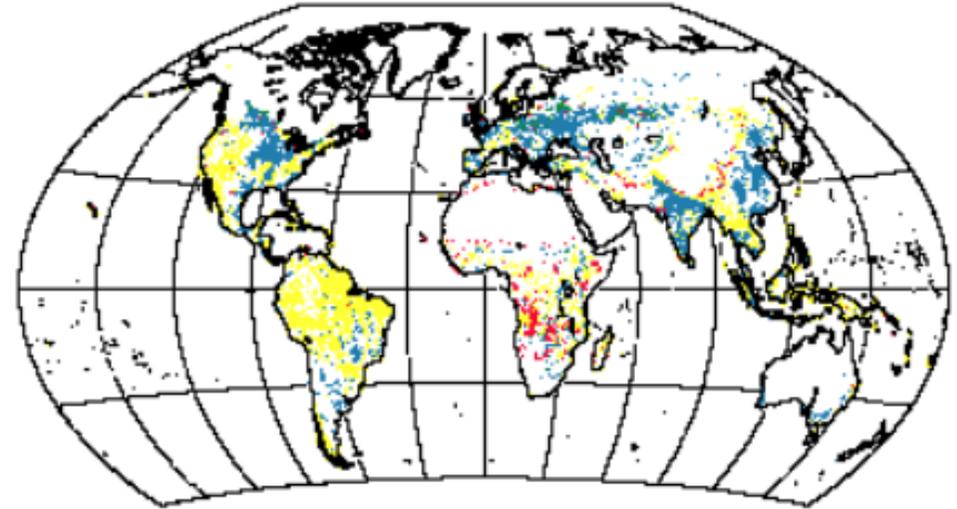
- Scenarios of land-use change *consistent* with Emissions Scenarios and/or Representative Concentration Pathways (RCPs).
- Minimum : decadal mean maps of crop and pasture fraction for 1850-2100 at GCM resolution ($\sim 0.5^\circ \times 0.5^\circ$)
- Ideal : annual mean maps of transition of one land-use type to another for 1850-2300 at GCM resolution ($\sim 0.5^\circ \times 0.5^\circ$).

RIVM Land-cover Scenarios

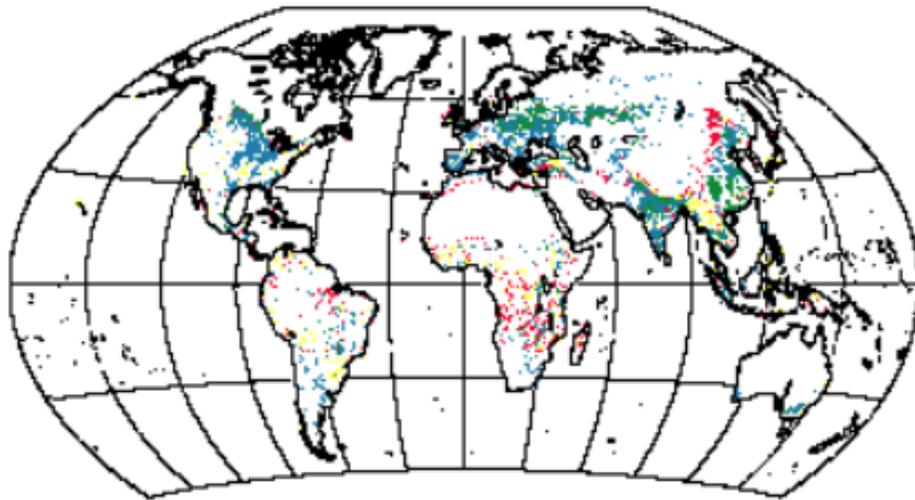
A1B



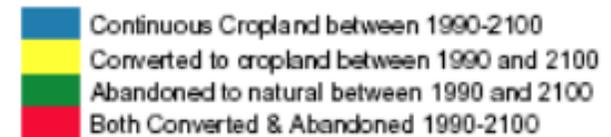
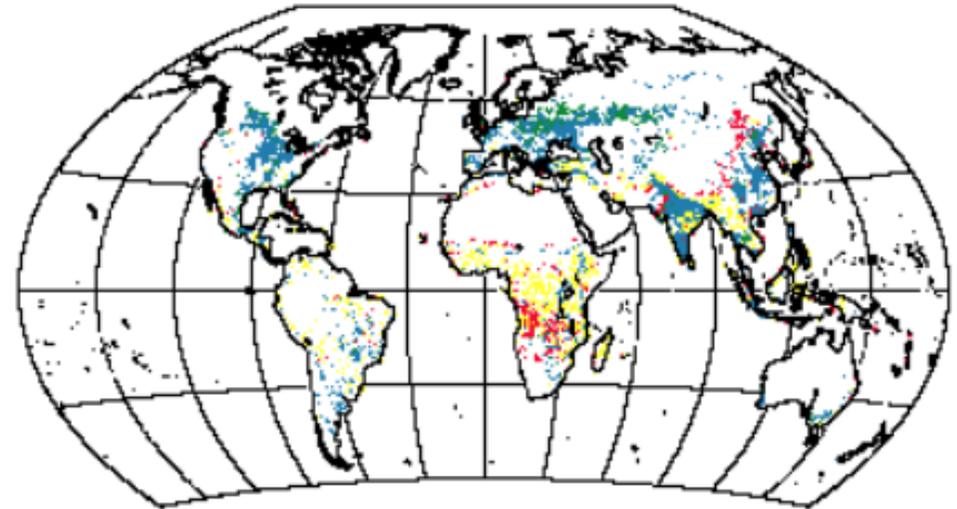
A2



B1



B2

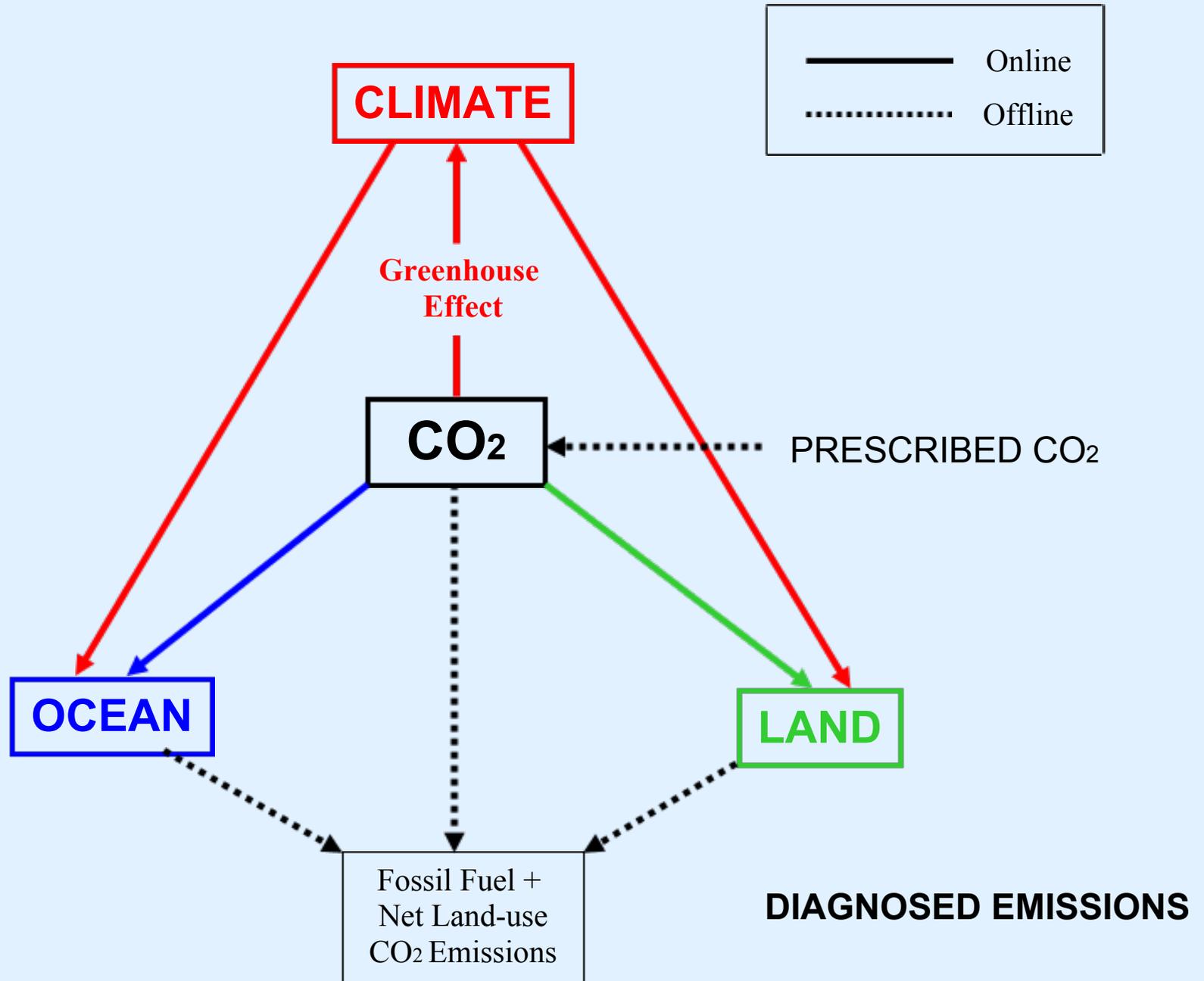


Conclusions and Outstanding Questions

- The climate modelling community must now begin to study more realistic scenarios, with greater consistency between the drivers of climate change such as GHG emissions and land-cover change.
- Many Earth System Modelling groups are working on including the biophysical and biogeochemical effects of land-use change.
- This requires data on human land-use change to be provided by the Integrated Assessment Modellers for each *Representative Concentration Pathway*
- Key outstanding questions include:
 - How do we ensure consistency between IAM and ESM representations of land-use ?
 - How do we ensure consistency between historical land-cover and IAM land-cover scenarios?
 - How do we deal with differing spatial and temporal scales of ESMs and IAMs?
 - How do the needs of groups running with prescribed and dynamic vegetation differ ?

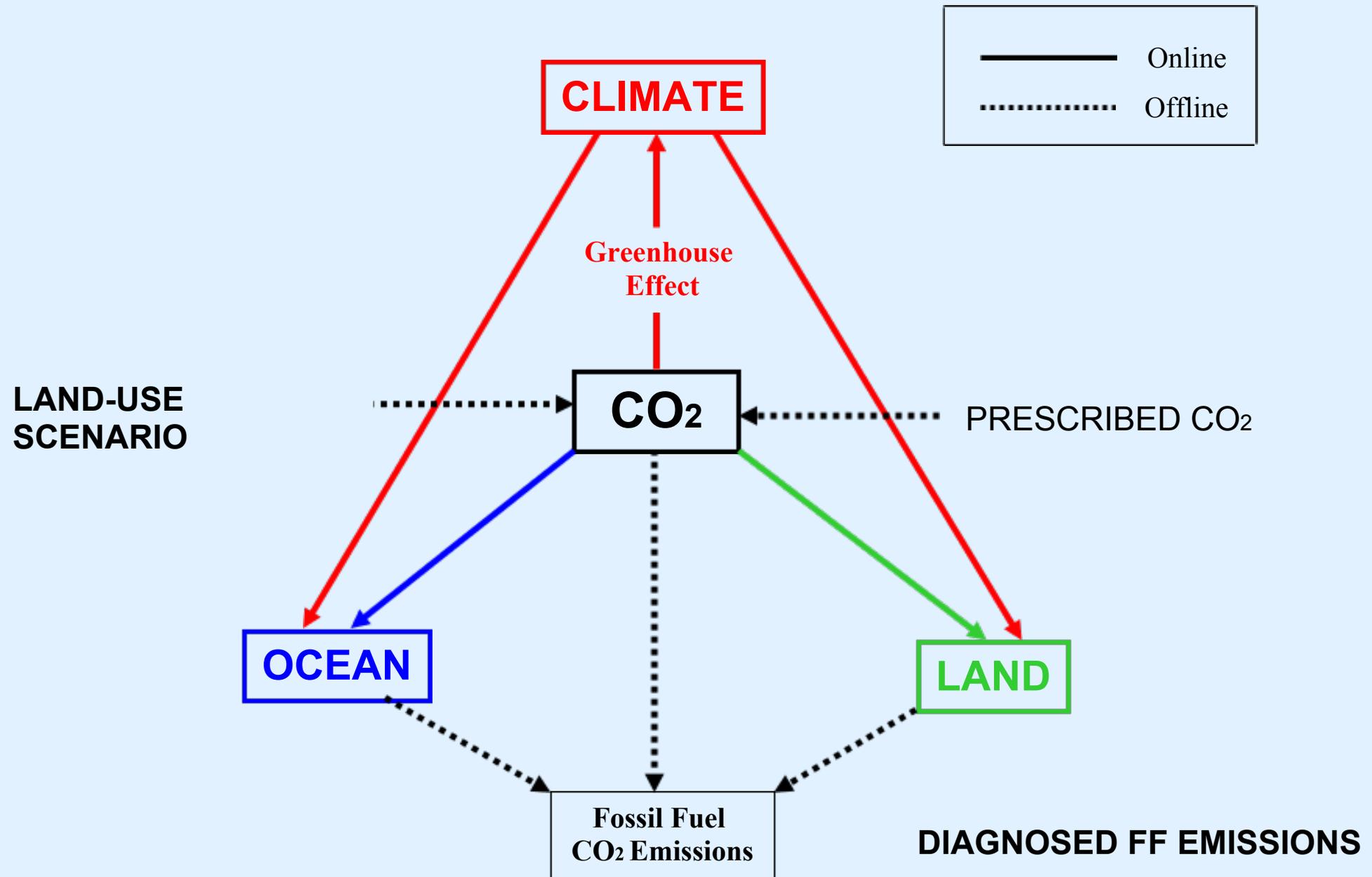
Original Aspen Proposal

“RCP”

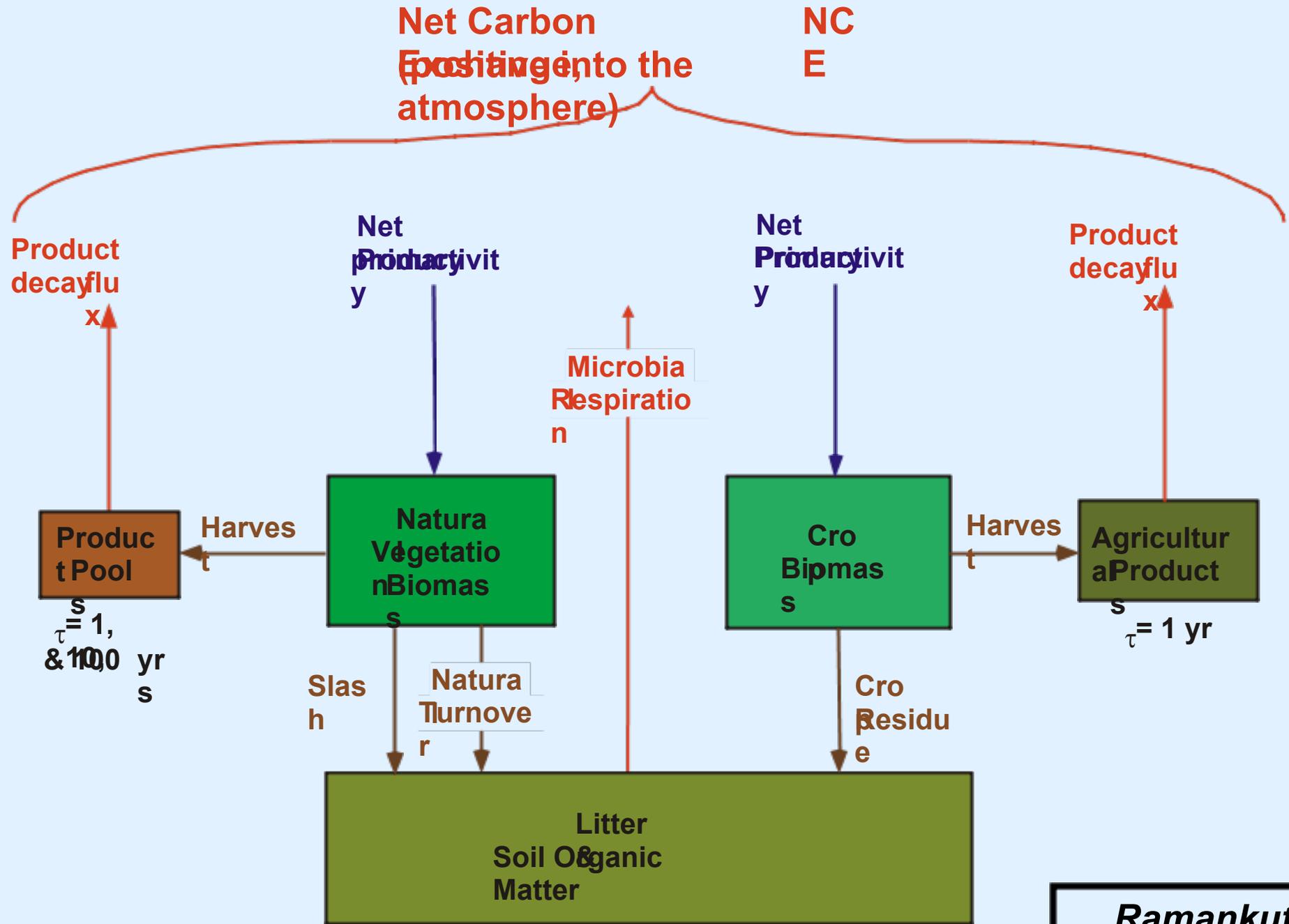


Revised Aspen Proposal

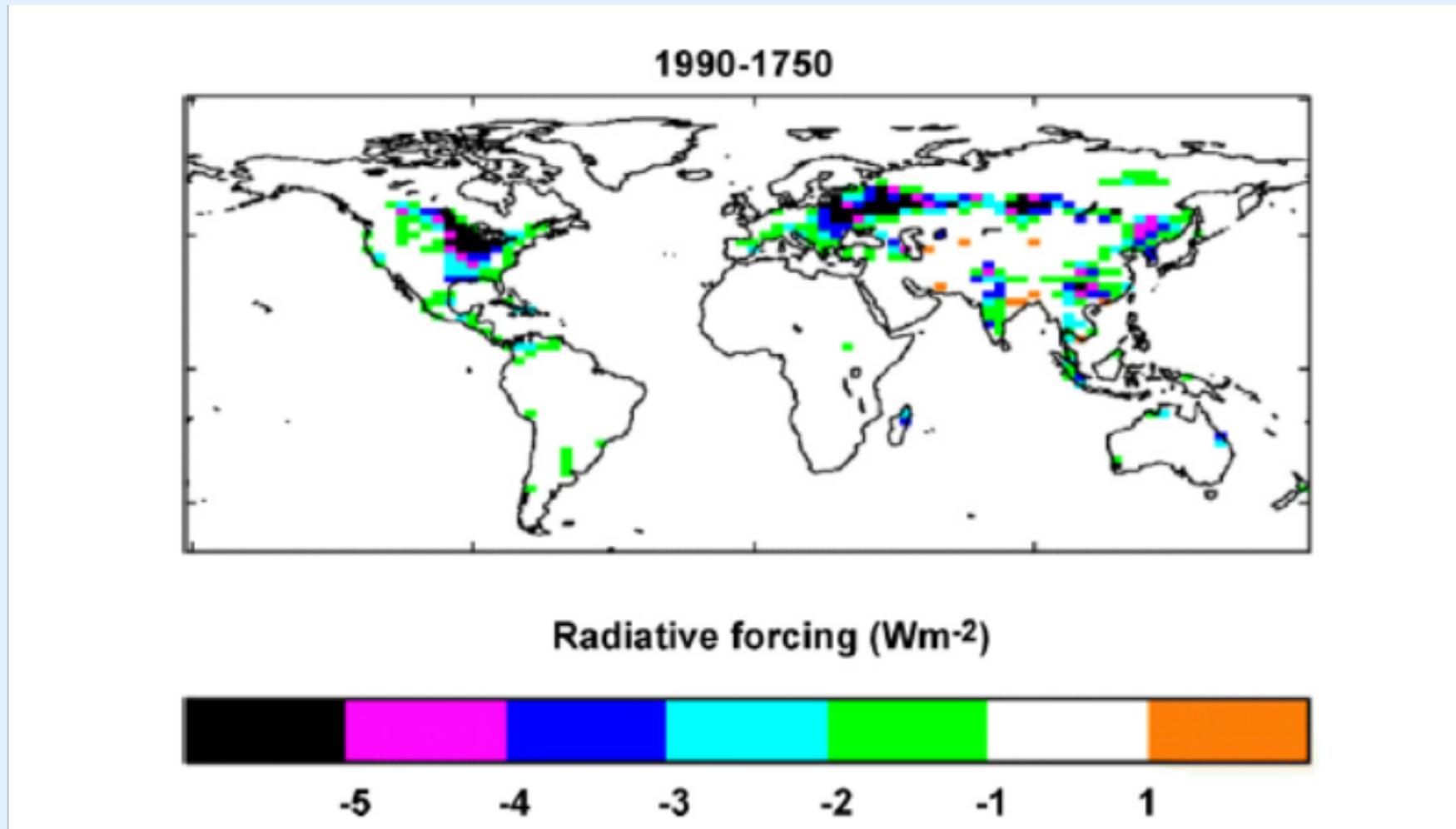
“RCP, with Land-use Change”



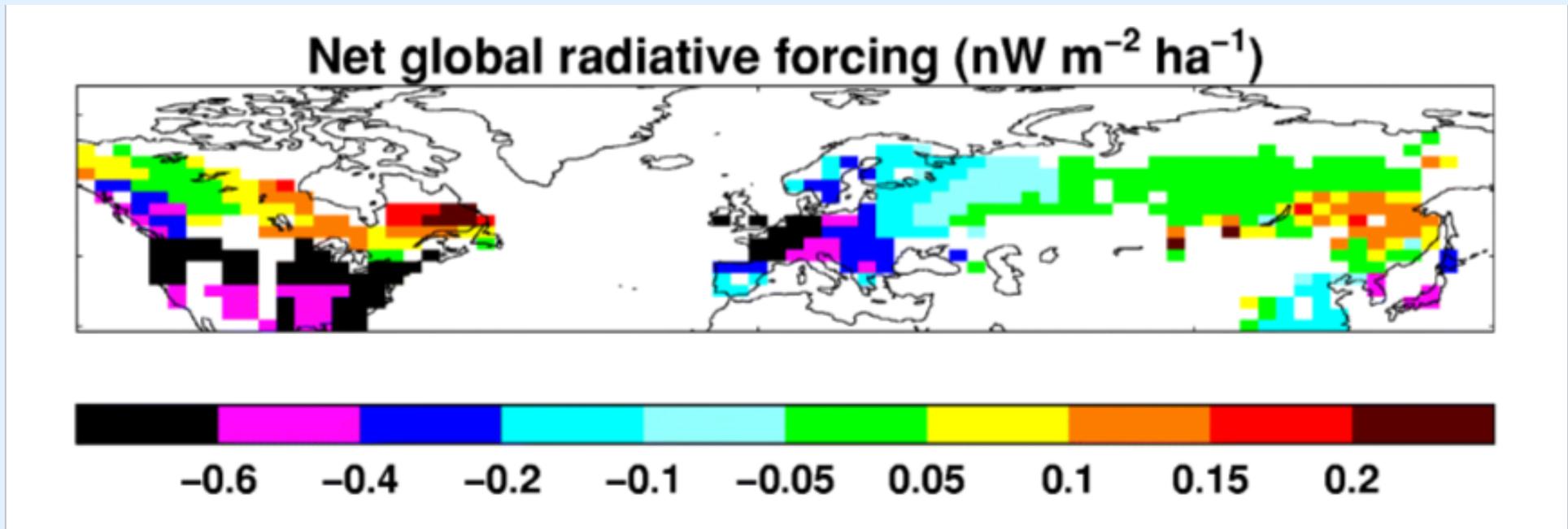
Land-use in CCMLP Expts.



Estimated SW Radiative Forcing due to Land-Use Change



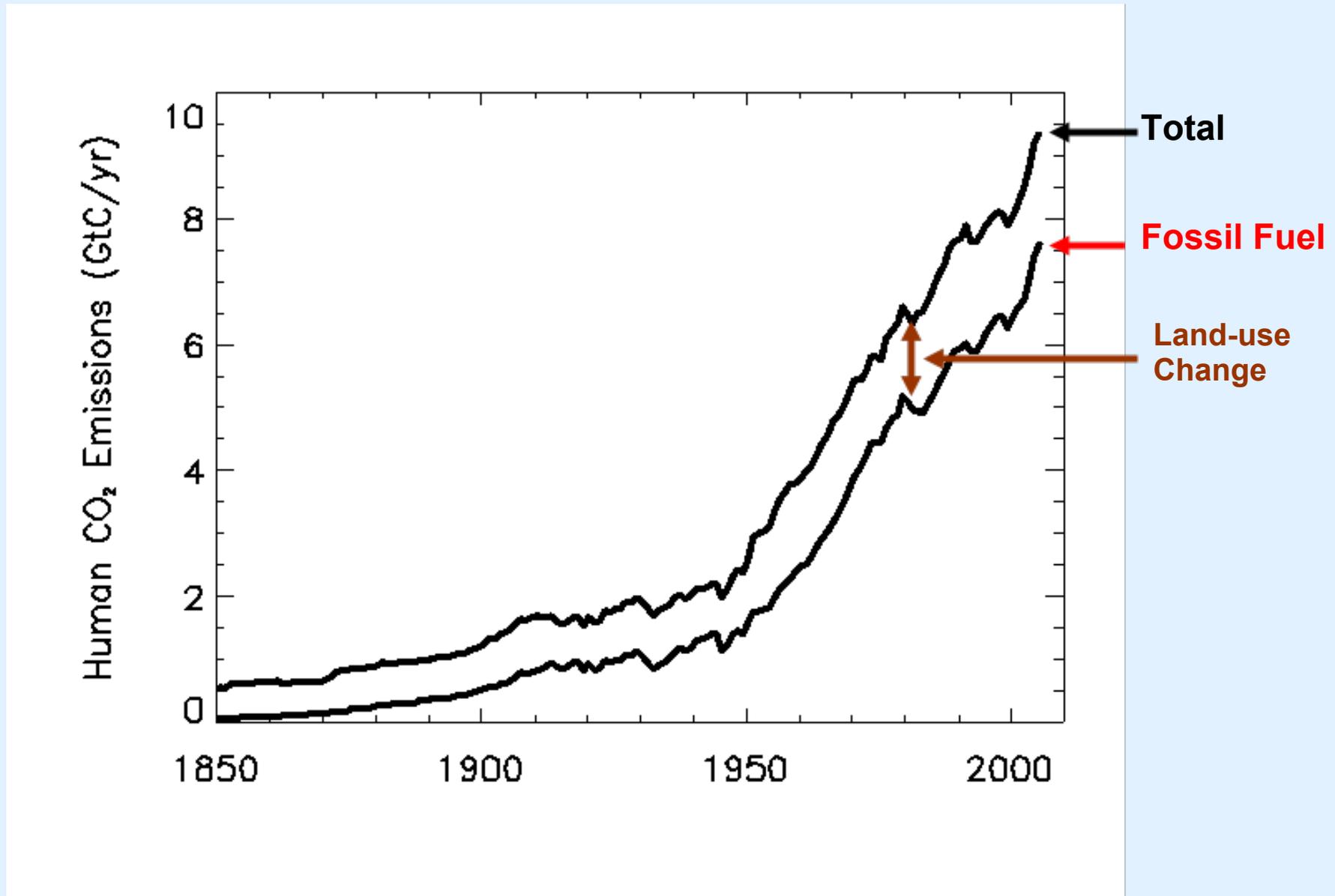
Net effect of “carbon sink” plantations



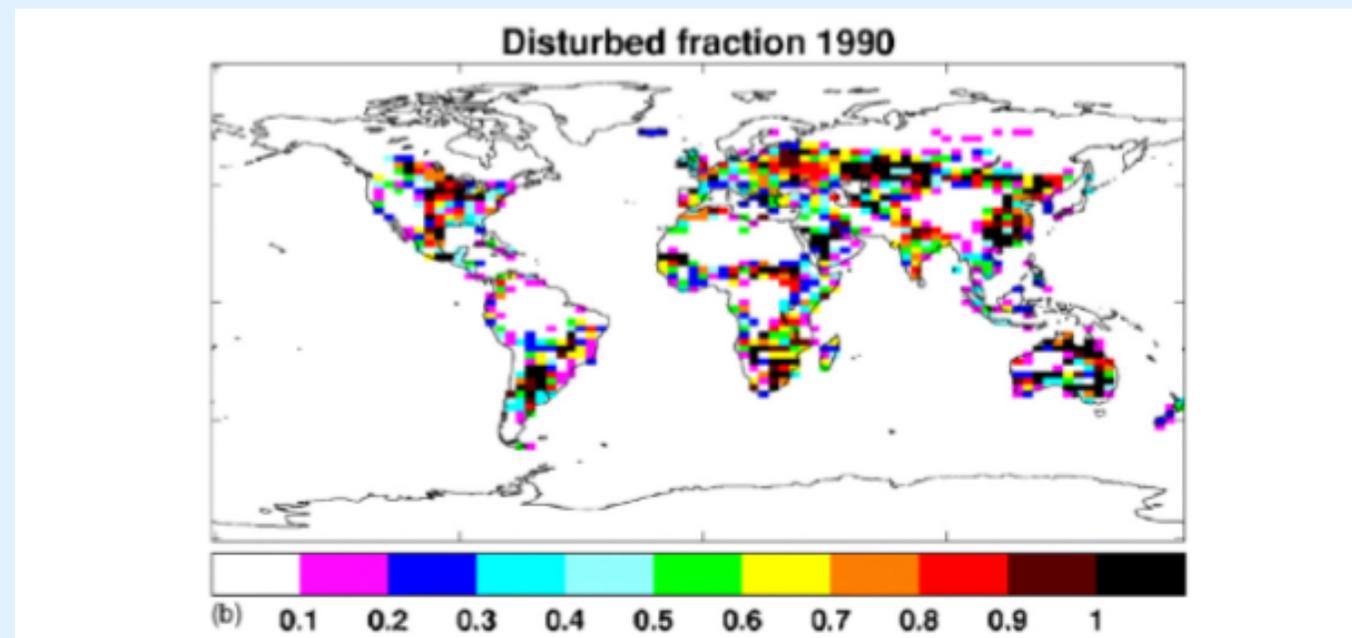
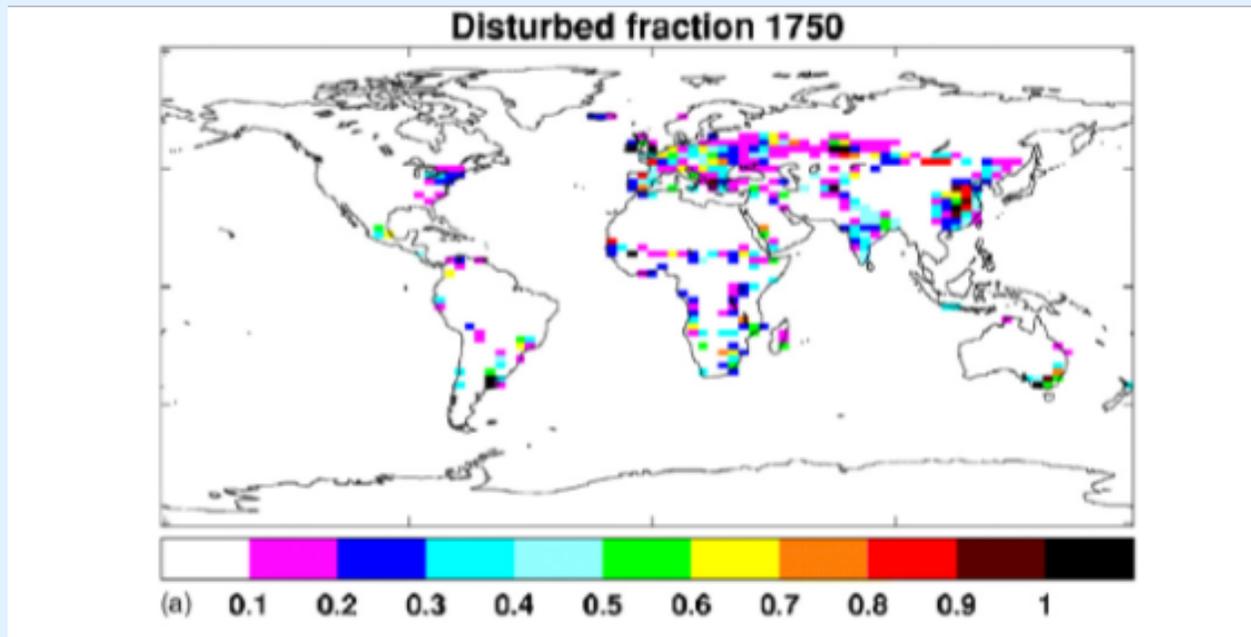
Positive numbers = warming effect

Betts,
2000

Anthropogenic CO₂ Emissions



Representation of Land-cover Change in GCMs



Betts et al.,
2006

Land-use Effects dominate Climate Effects on Land Carbon Storage

