Land use, disturbance, and the coupled carbon-climate system

http://earthobservatory.nasa.gov/Features/BlueMarble/

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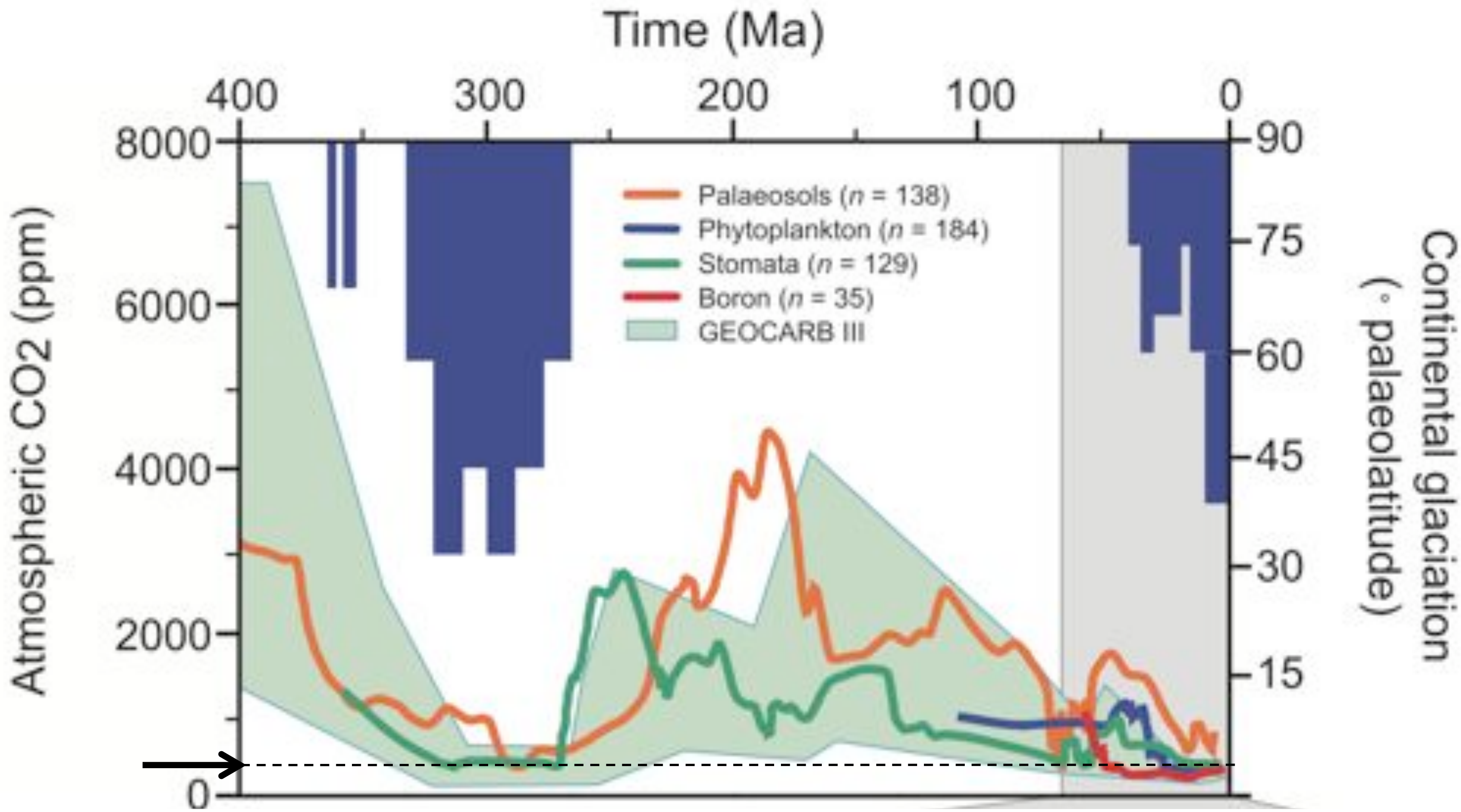
UNH & Princeton/GFDL NASA EOS IDS research group

'*Advancing our Understanding of the Earth System through Coupled Carbon-Climate Modeling and Observations*'; NNX07AH32G

2010 MODIS/VIIRS SCIENCE TEAM MEETING, Washington DC

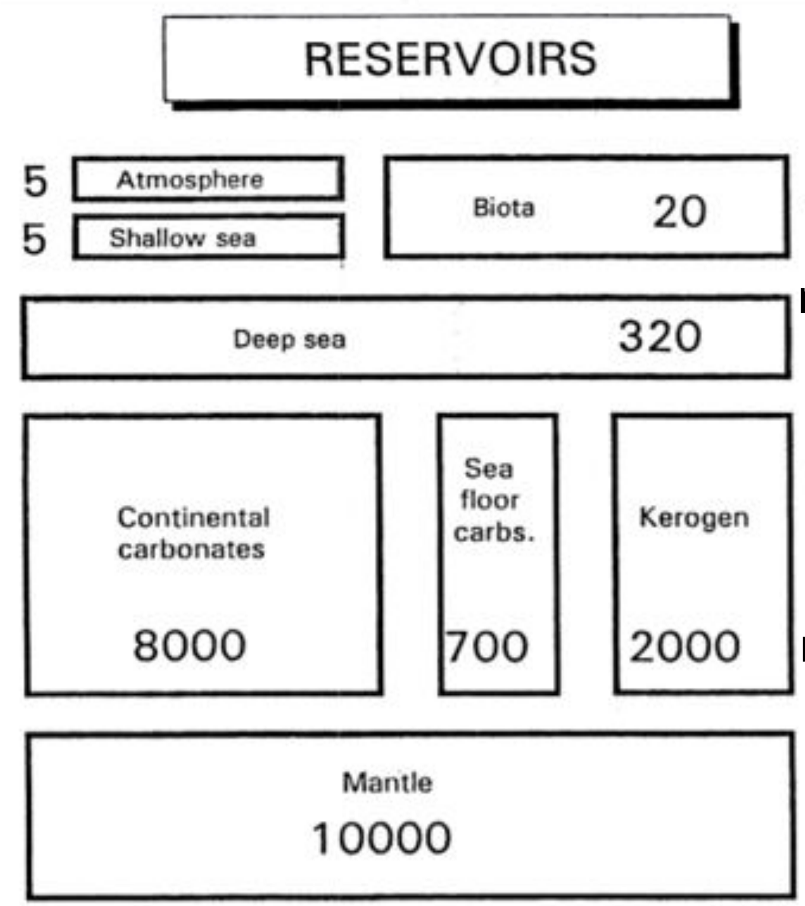
CO_2 and land ice over the past 400 million years



IPCC 2007; Ch. 6

AGU Fall 2009 - Bjerknes Lecture
RB Alley: *The Biggest Control Knob: Carbon Dioxide in Earth's Climate History*
http://www.agu.org/meetings/fm09/lectures/videos.ph

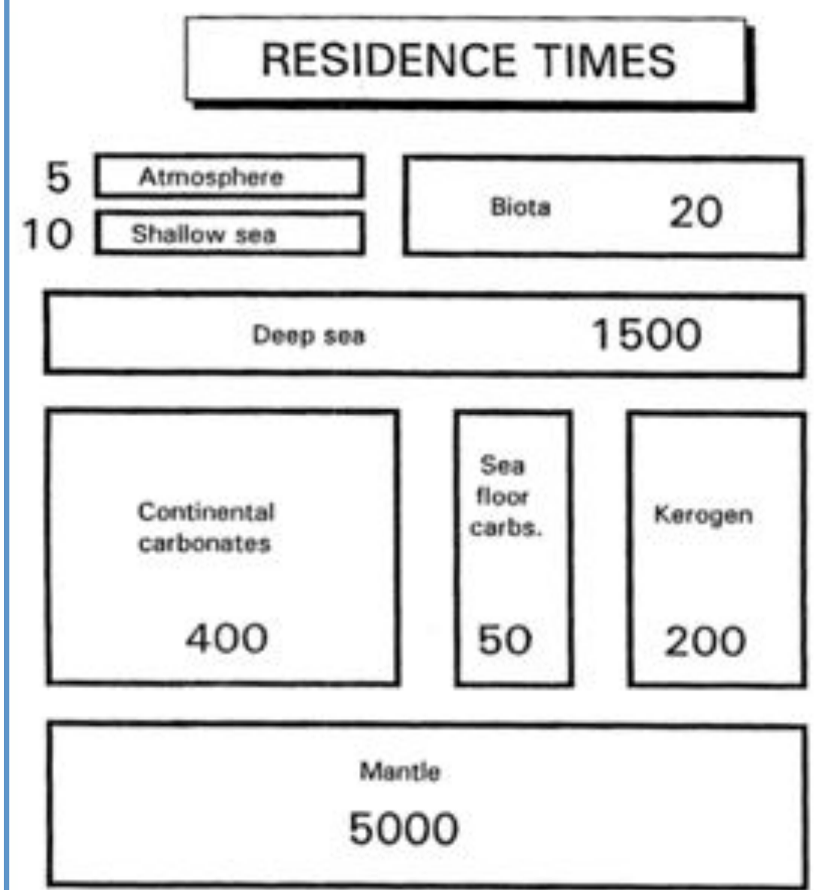
Global Carbon Cycle – reservoirs and time scales



10^{16} moles

10^{18} moles

10^{16} moles C = 120 Pg C



years

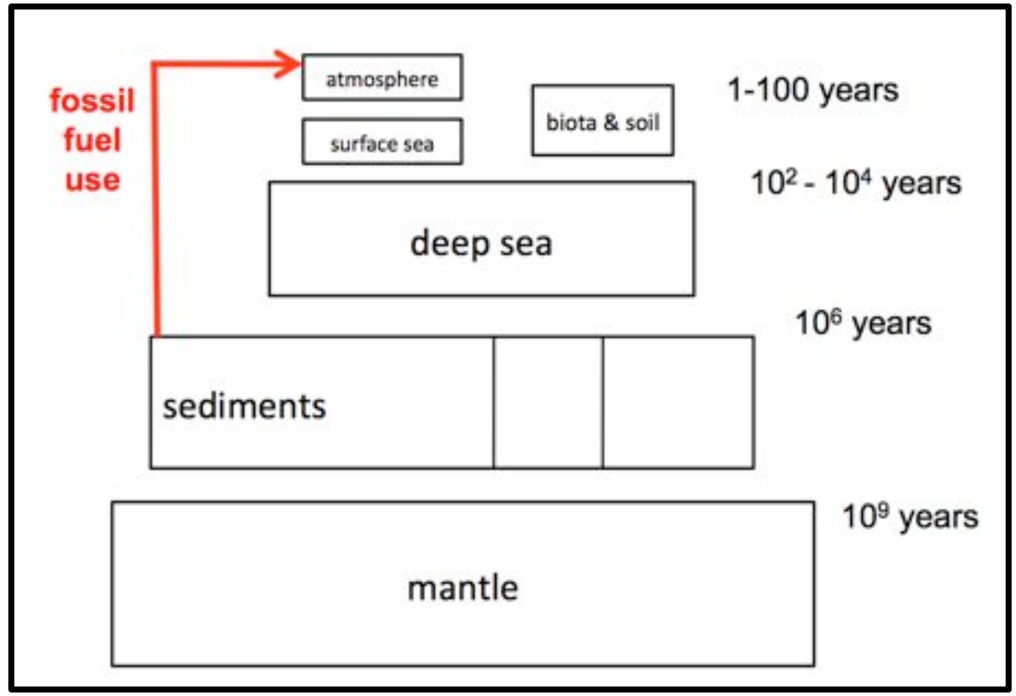
million years

mean residence time of a C atom

not necessarily perturbation timescale

Walker (1991)

Fate of fossil fuel CO_2 over 40,000 yrs



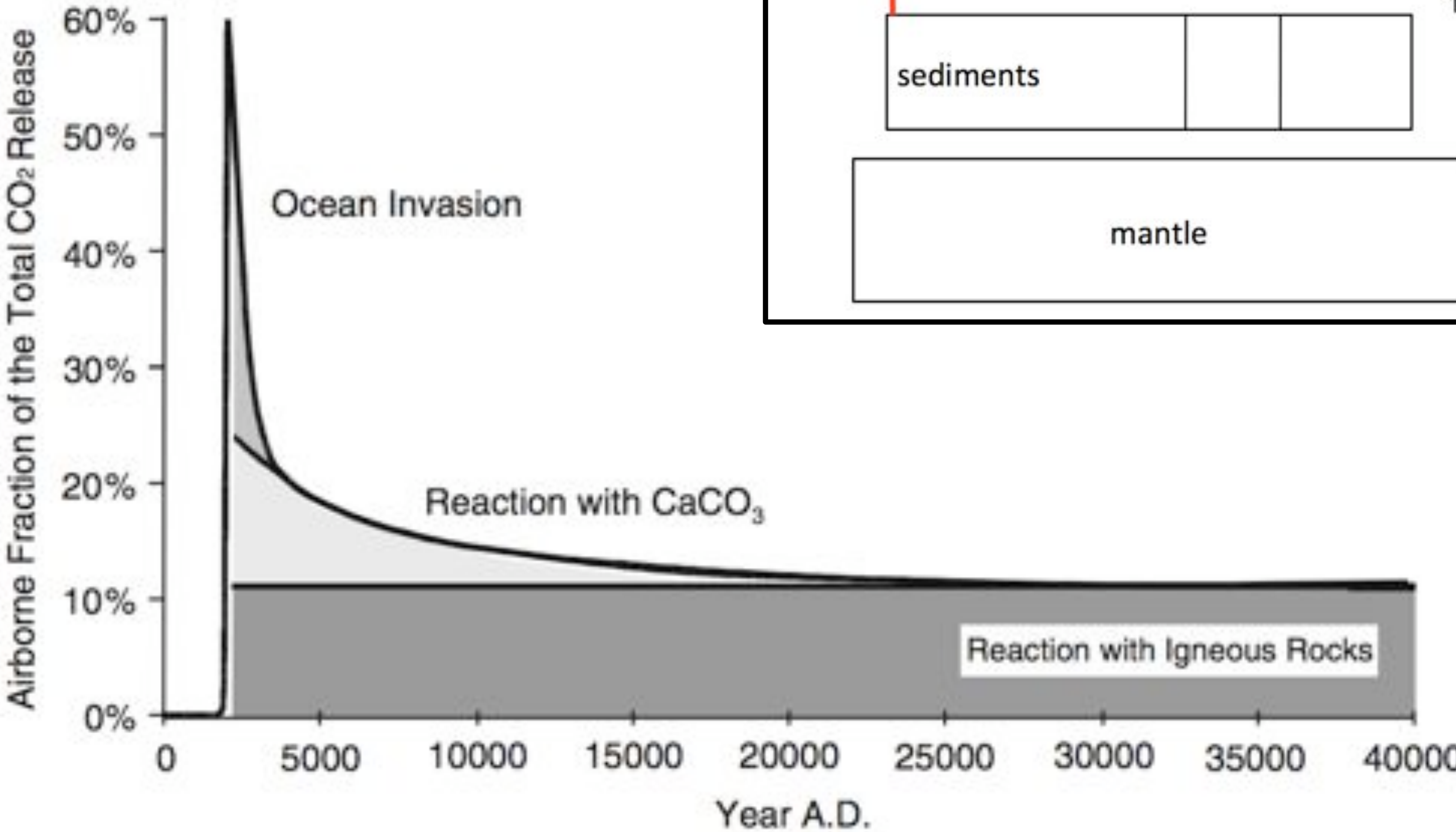


Fig. 1 Schematic breakdown of the atmospheric lifetime of fossil fuel CO_2 into various long-term natural sinks. Model results from Archer (2005)

Archer and Brovkin (2008)

Fate and impact of emitted CO_2 over 1000 yrs

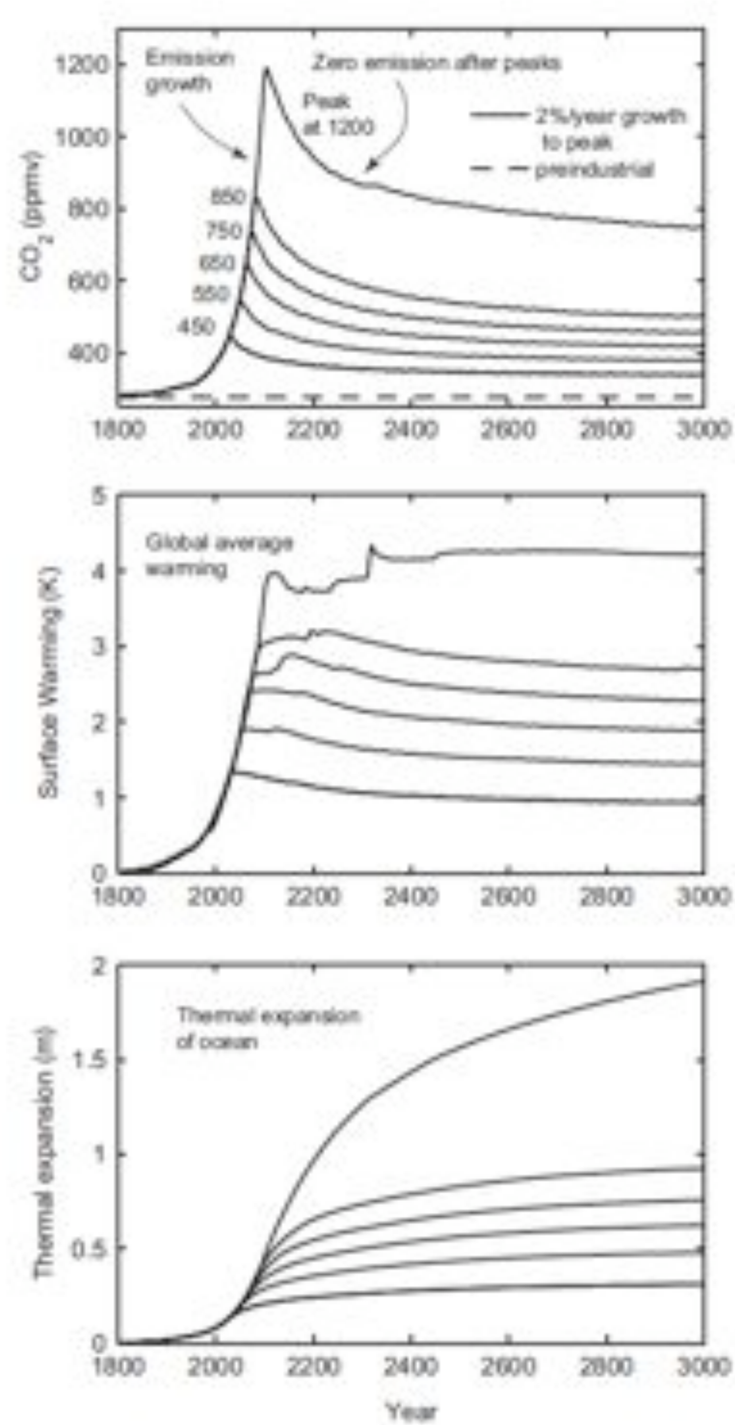
climate model: Bern 2.5CC EMIC

- model sensitivity = 3.2°C for $2xCO_2$
- warming greater over land

  and at high latitude

not including effect of loss of land ice

Solomon et al, PNAS, 2009
'irreversible climate change'



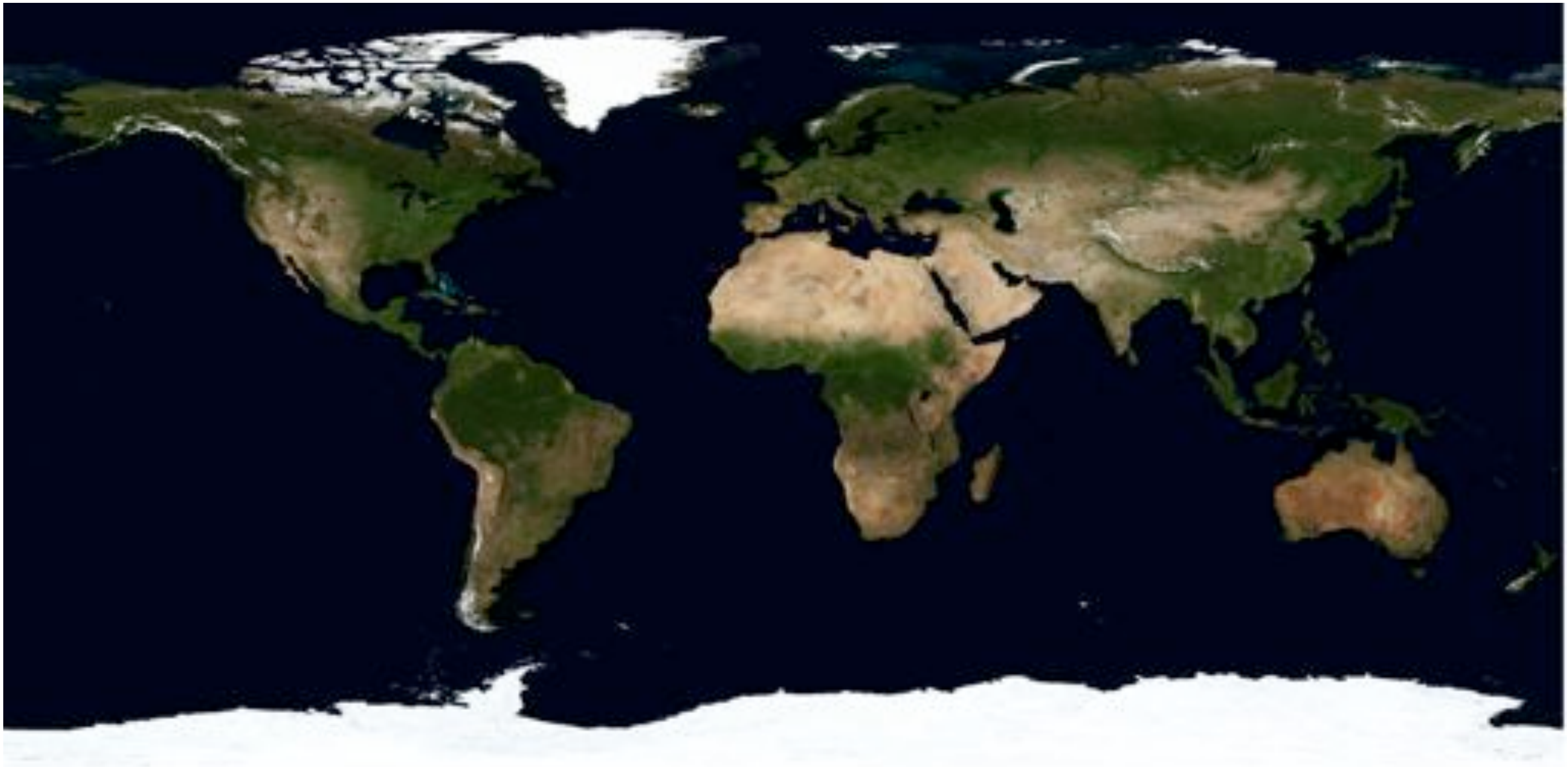
CO_2 ppmv

~20% in air

mean global surface warming

ocean thermal expansion

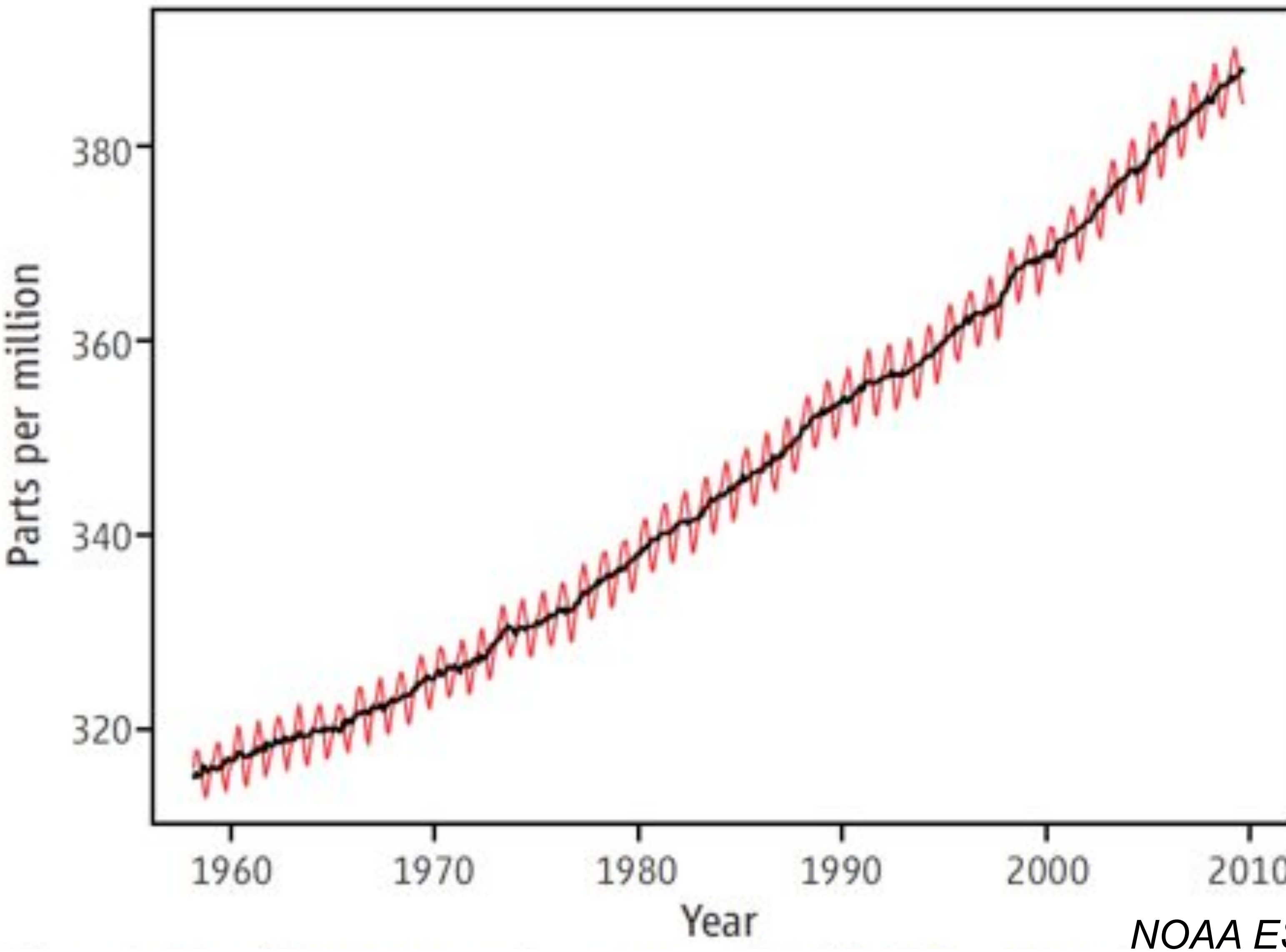
MODIS July composite



http://earthobservatory.nasa.gov/Features/BlueMarble/

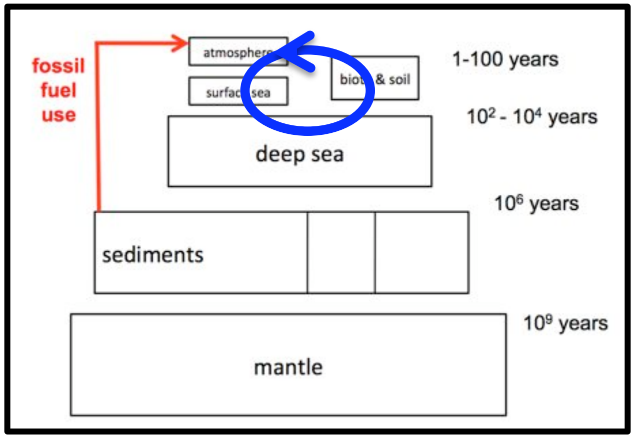
what happens as the ice melts?

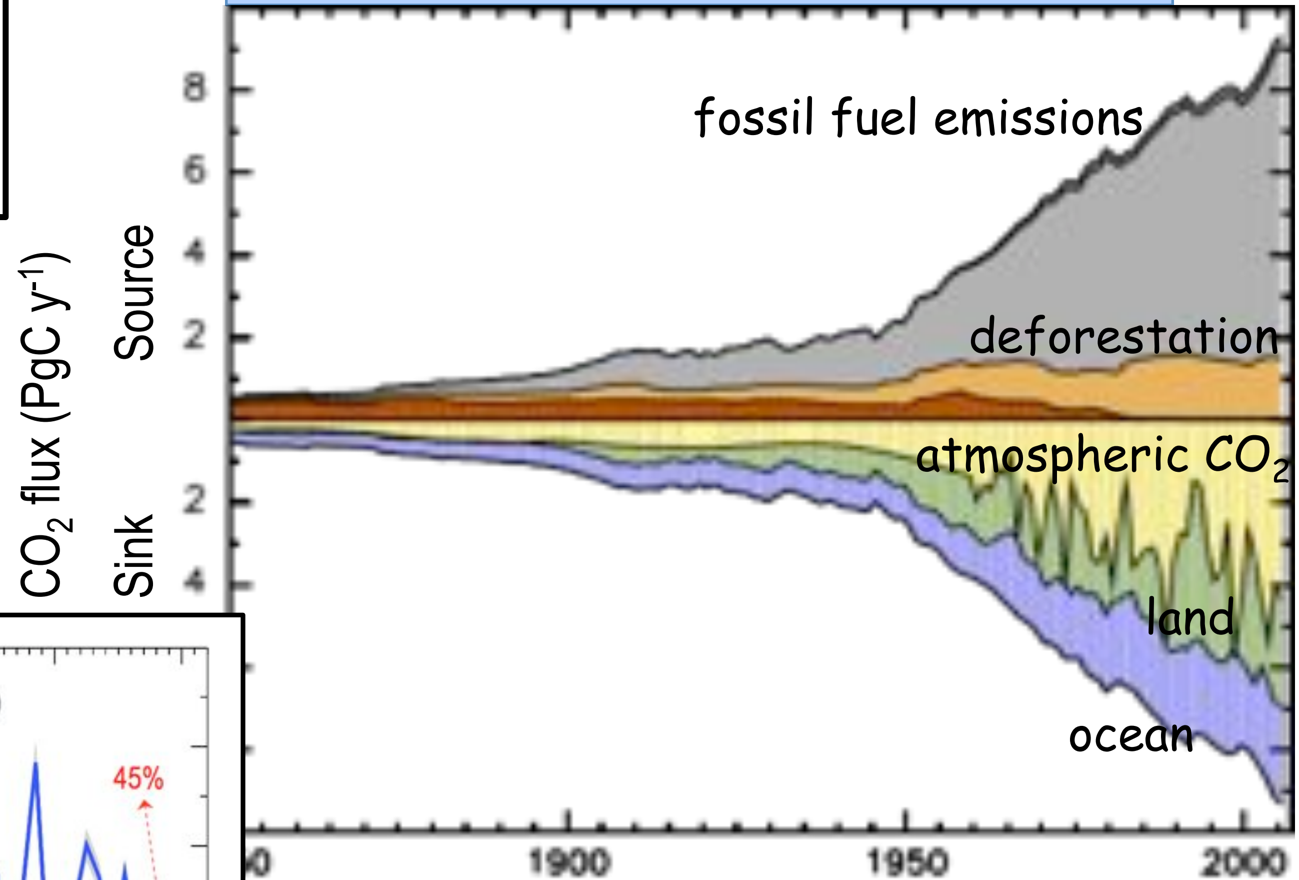
Atmospheric CO_2 data from Mauna Loa iconic global change environmental data record

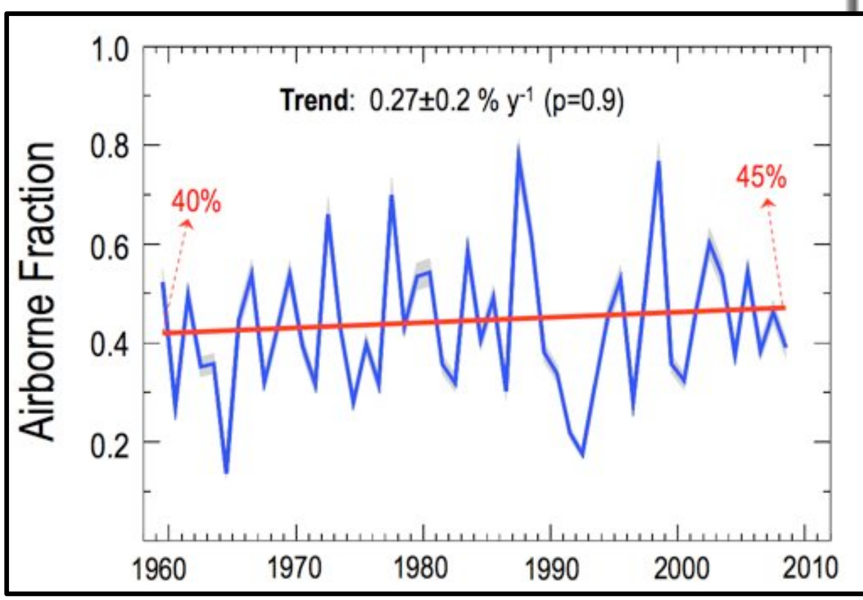


NOAA ESRL; SIO

Human Perturbation of the Global Carbon Budget







Global Carbon Project 2009

Le Quéré et al. 2009, Nature-geoscience

Why is the airborne CO_2 fraction increasing?

- Emissions are rising faster than the time scales regulating the rate of uptake by sinks.

- Sinks are becoming less efficient at elevated CO_2 (***<u>their favorite</u>***)
  - Land: saturation of the CO_2 fertilization effect
  - Ocean: decrease in [carbonate] which buffers CO_2

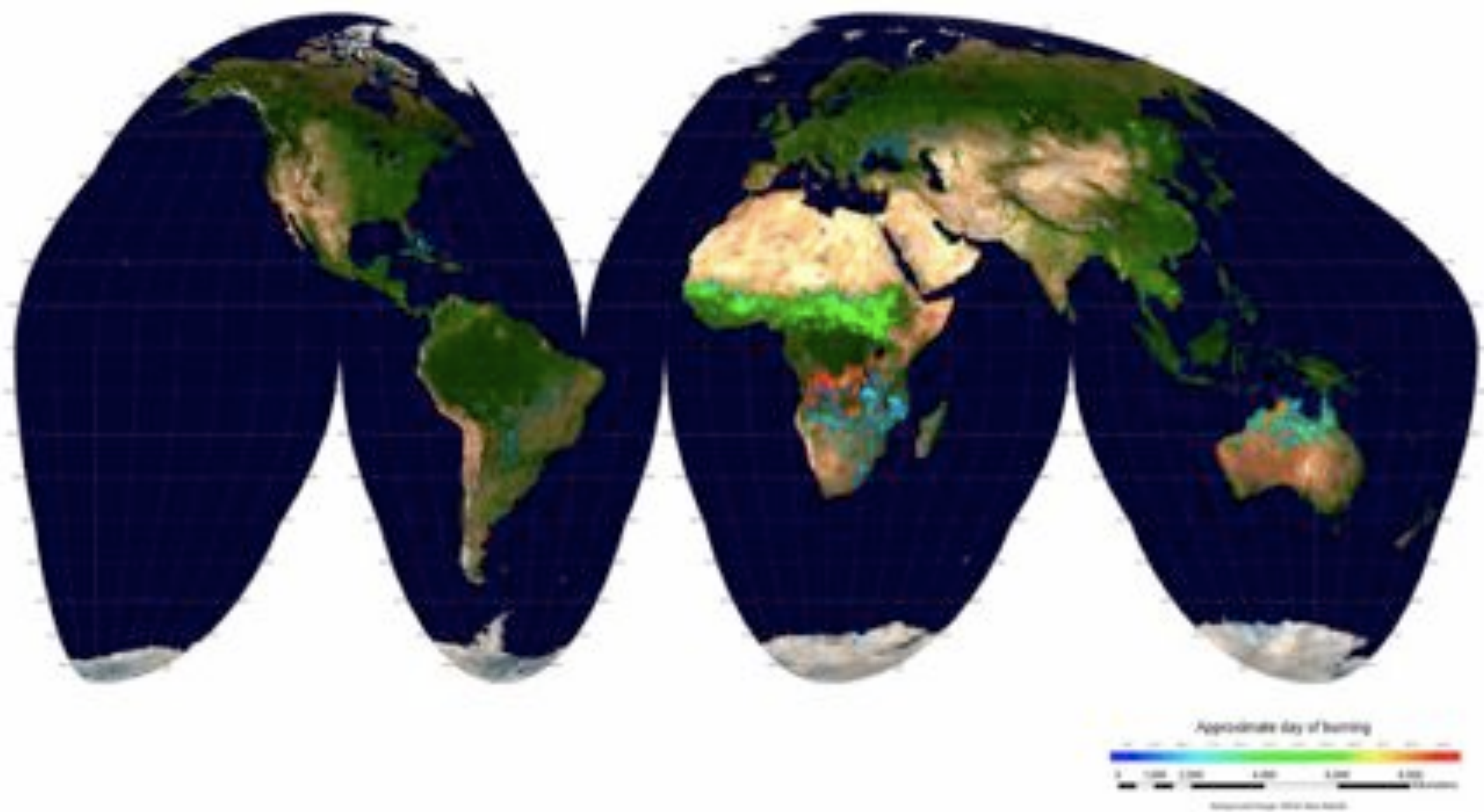
- Land and/or ocean sinks are responding to climate change and variability.

- models are missing sink processes that are contributing to the observed changes.
  (partly related to disturbance and land use)

Global Carbon Project 2009
Le Quéré et al. 2009, Nature-geoscience

Land surface disturbance
fire, wind, humans, …

MODIS-derived global burned areas



Land disturbance (including land use)

- abrupt or chronic – (e.g., fire vs. pollution loading)
- large or small footprint – (e.g., clear cut vs. selective logging)

→ forest: abrupt and large (>0.1 ha) ~ 500,000 km^2/year (~1%)

- widespread or restricted – (e.g., fire vs. avalanches)

- natural or anthropogenic – (e.g., hurricane vs. logging)
- temporary or permanent – (e.g., tornado vs. land conversion)
- rapid or slow C flux – (e.g., fuelwood harvest vs. landslide)

impacts of disturbances on atmospheric CO_2

- net flux likely smaller than *current* fossil fuel use…
  but there are alternatives to fossil fuel use

- likely to be small and temporary if
  > there is recovery - e.g., not land conversion
  > there is ‘full’ recovery – e.g., not severe land degradation
  > disturbance rates are relatively constant (interannual var.)

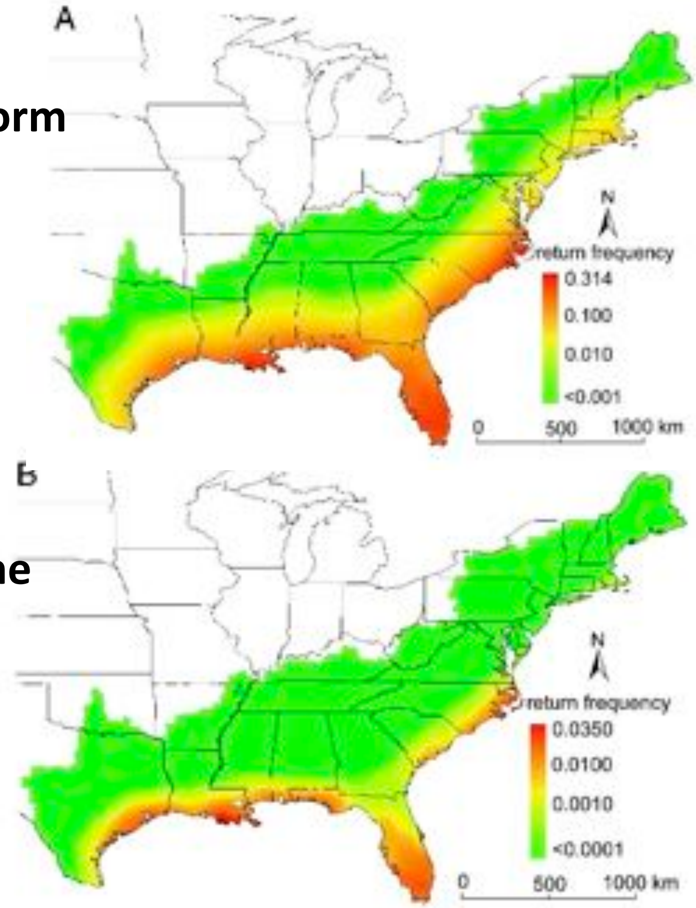
- changing disturbance/recovery rates will cause net land-atmosphere C flux, could lead to change in airborne fraction
  > still likely less than current fossil fuel use
  > but relevant to
    - understanding precise [CO_2] measurements
    - making accurate climate predictions
    - the business of carbon trading

Hurricane Tracks 1851-2005

Return Frequency

Tropical Storm

Hurricane

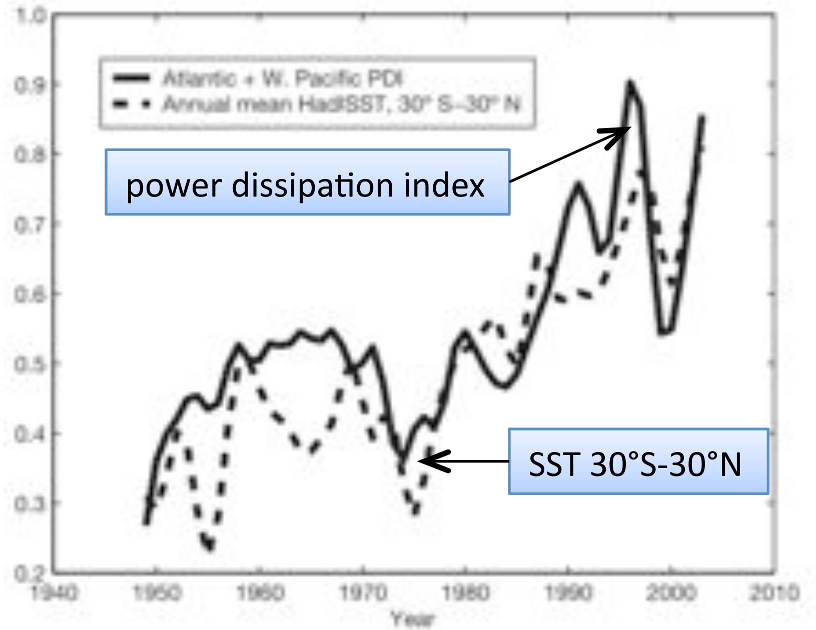


Tg C y^{-1}

Zeng et al. 2009

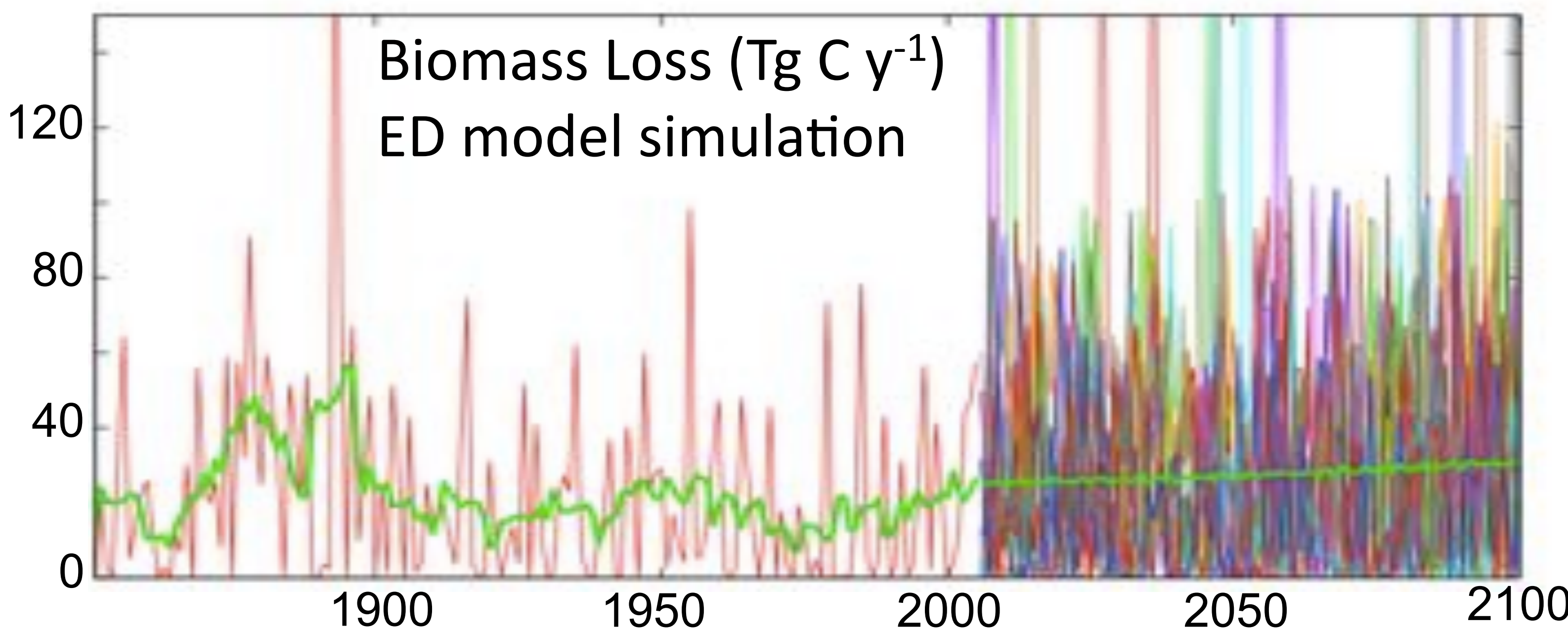
Future?

Emanuel 2005



power dissipated (damage) increases with SST

ensemble runs – random year draw from hurricane history,
SST increase → damage increase



storm damage ↑ ~35%

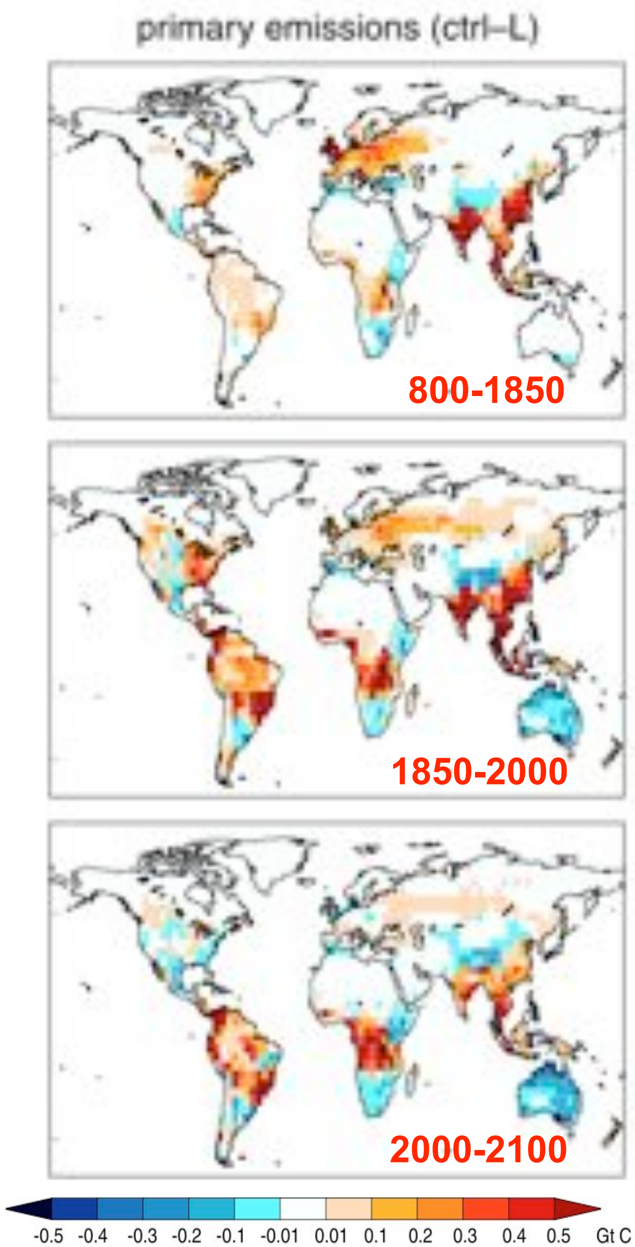
C-loss ↑ ~20%

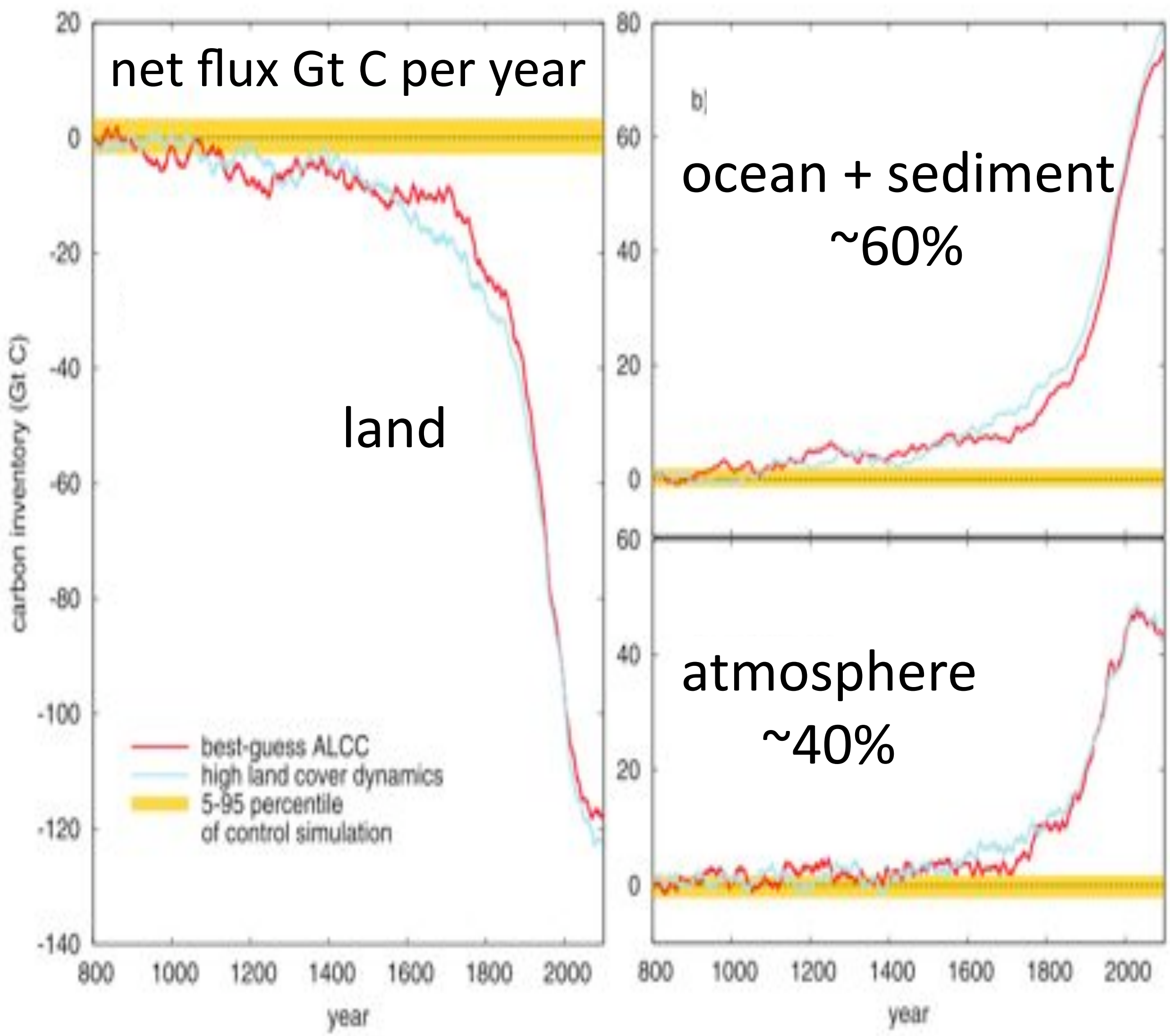
Fisk et al 2009

The Scale of Land-use

- >50% of the land surface has been transformed by direct human action, >25% of forests cleared, >30% in agriculture.
- Land-use/Land-cover change affect regional and global carbon balance and weather/climate.
- Habitat destruction is the primary cause of species extinctions.
- The demand for food, feed, fiber, and fuel are increasing and future land-use decisions (and options) will have consequences for the carbon/climate system.

The carbon impact of land-use, 800-2100





Pongratz et al. GBC 2009

IPCC AR4 climate change simulations

- included land-use greenhouse gas emissions
- no change in land surface properties
- no change in land surface energy balance

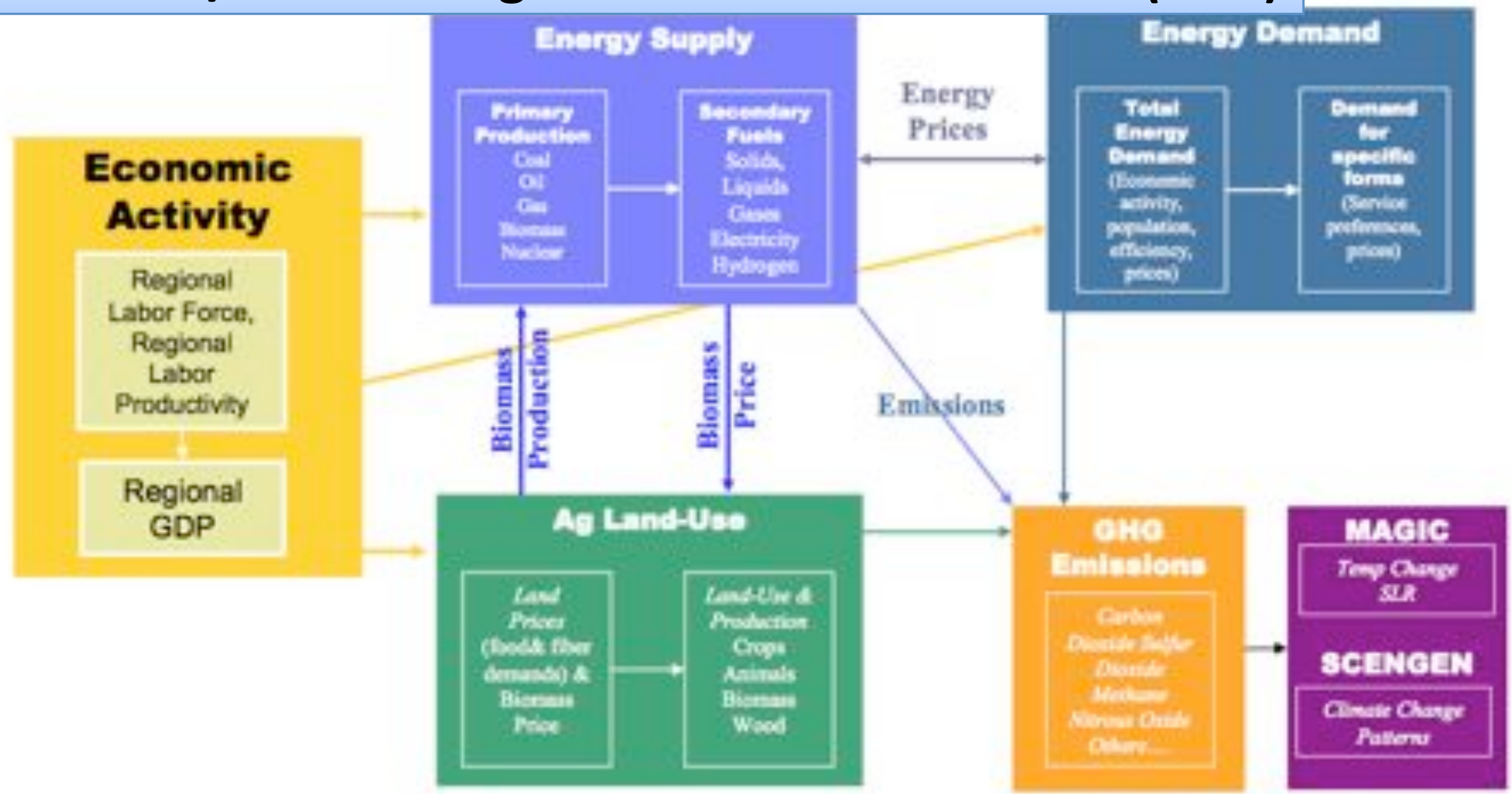
IPCC AR5 will include land-use – future from IAMs

IPCC AR5 Representative Concentration Pathways (RCPs)

Integrated Assessment Model	RCP	Radiative Forcing in 2100	Concentration in 2100	Pathway Shape
MESSAGE	8.5	>8.5 W/m^2	~1370 ppmv CO_2-eq	Rising
AIM	6	~6 W/m^2 (stabilization after 2100)	~850 ppmv CO_2-eq (at stabilization after 2100)	Stabilization without overshoot
MiniCAM	4.5	~4.5 W/m^2 (stabilization after 2100)	~650 ppmv CO_2-eq (at stabilization after 2100)	Stabilization without overshoot
IMAGE	2.6	~2.6 W/m^2 (declining from peak at ~3 W/m^2 before 2100)	Peak ~490 ppmv CO_2-eq (before 2100)	Peak and decline

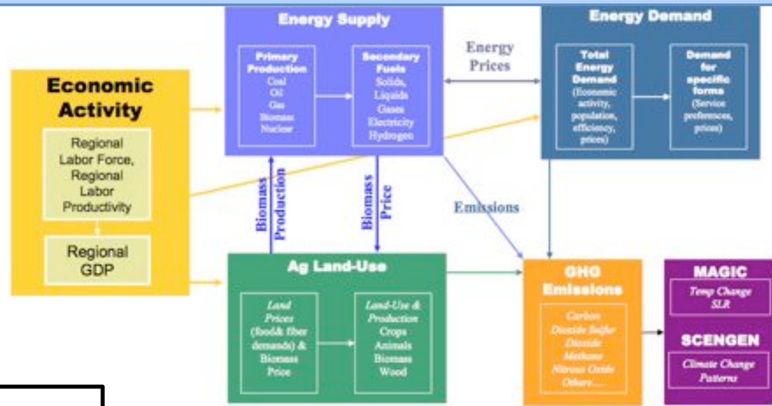
Moss et al. 2008 "*Towards New Scenarios for Analysis of Emissions, Climate Change, Impacts, and Response Strategies*". IPCC, Geneva.

MiniCAM/GCAM Integrated Assessment Model (IAM)



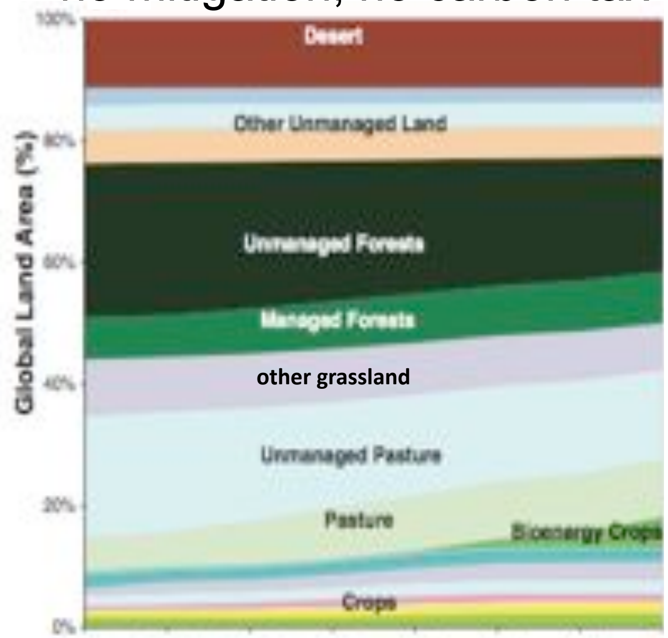
Wise et al. Science, 2009

MiniCAM/GCAM Integrated Assessment Model (IAM)



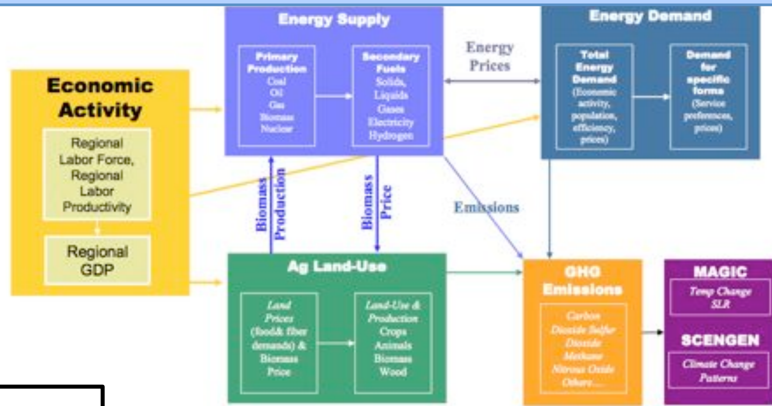
Wise et al. Science, 2009

reference scenario:
no mitigation, no carbon tax



1990 2050

MiniCAM/GCAM Integrated Assessment Model (IAM)

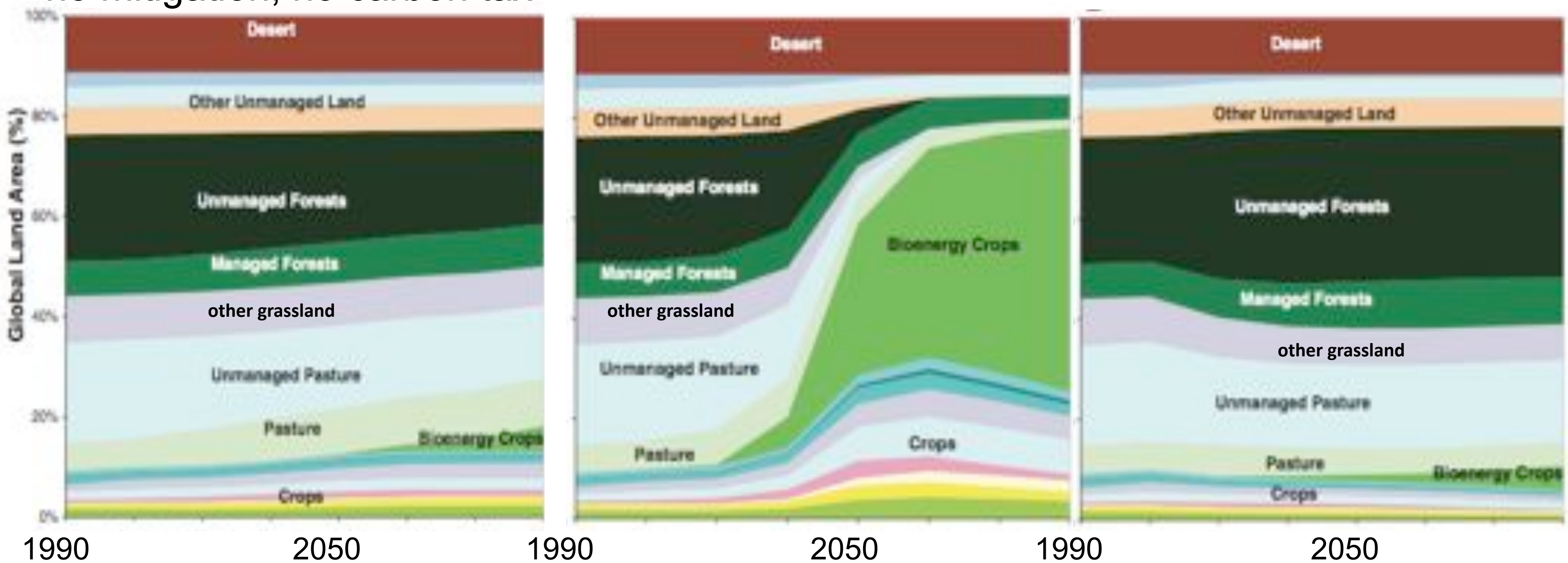


Wise et al. Science, 2009

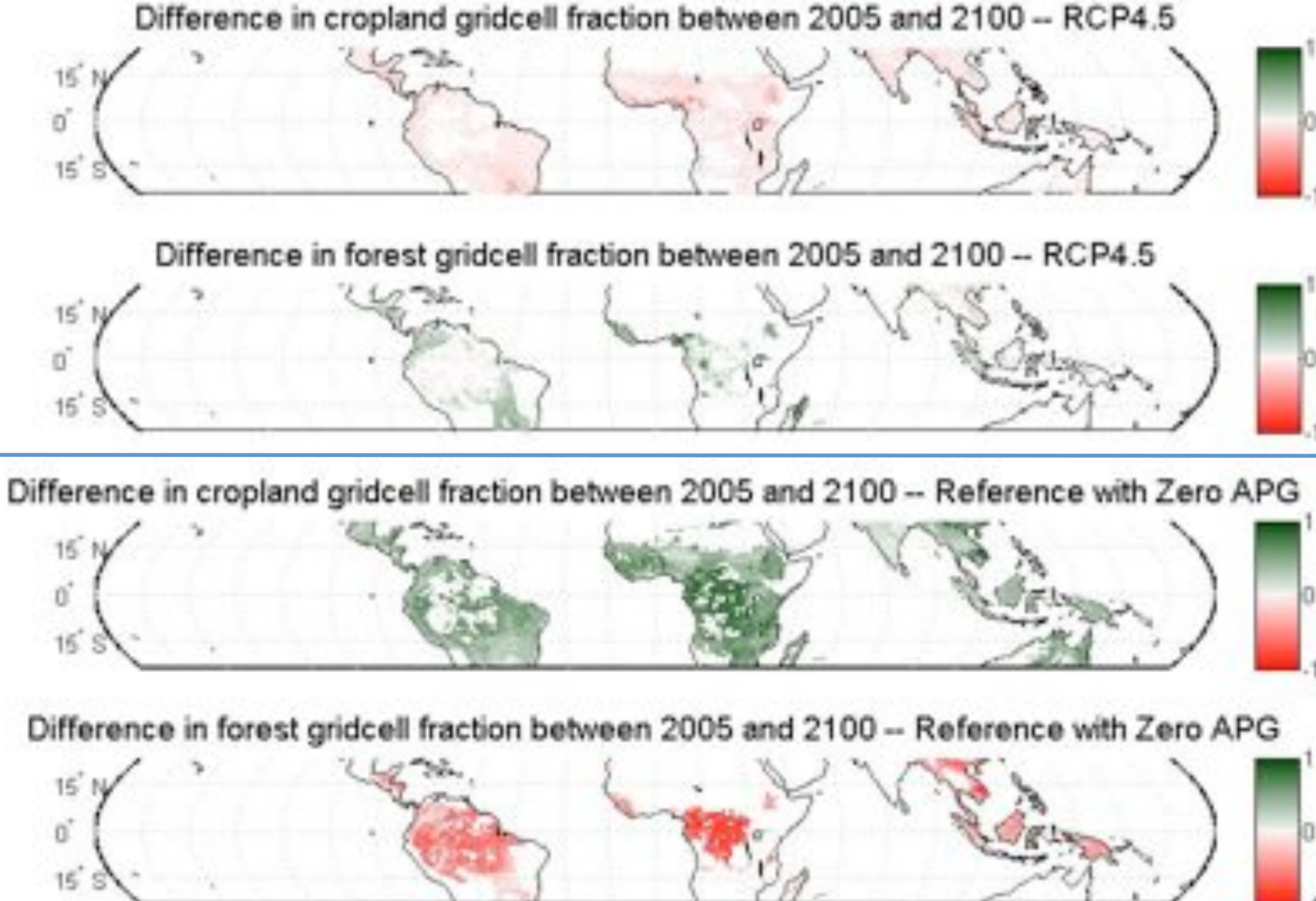
reference scenario: no mitigation, no carbon tax

RCP4.5: fossil fuel C tax

RCP4.5: universal C tax



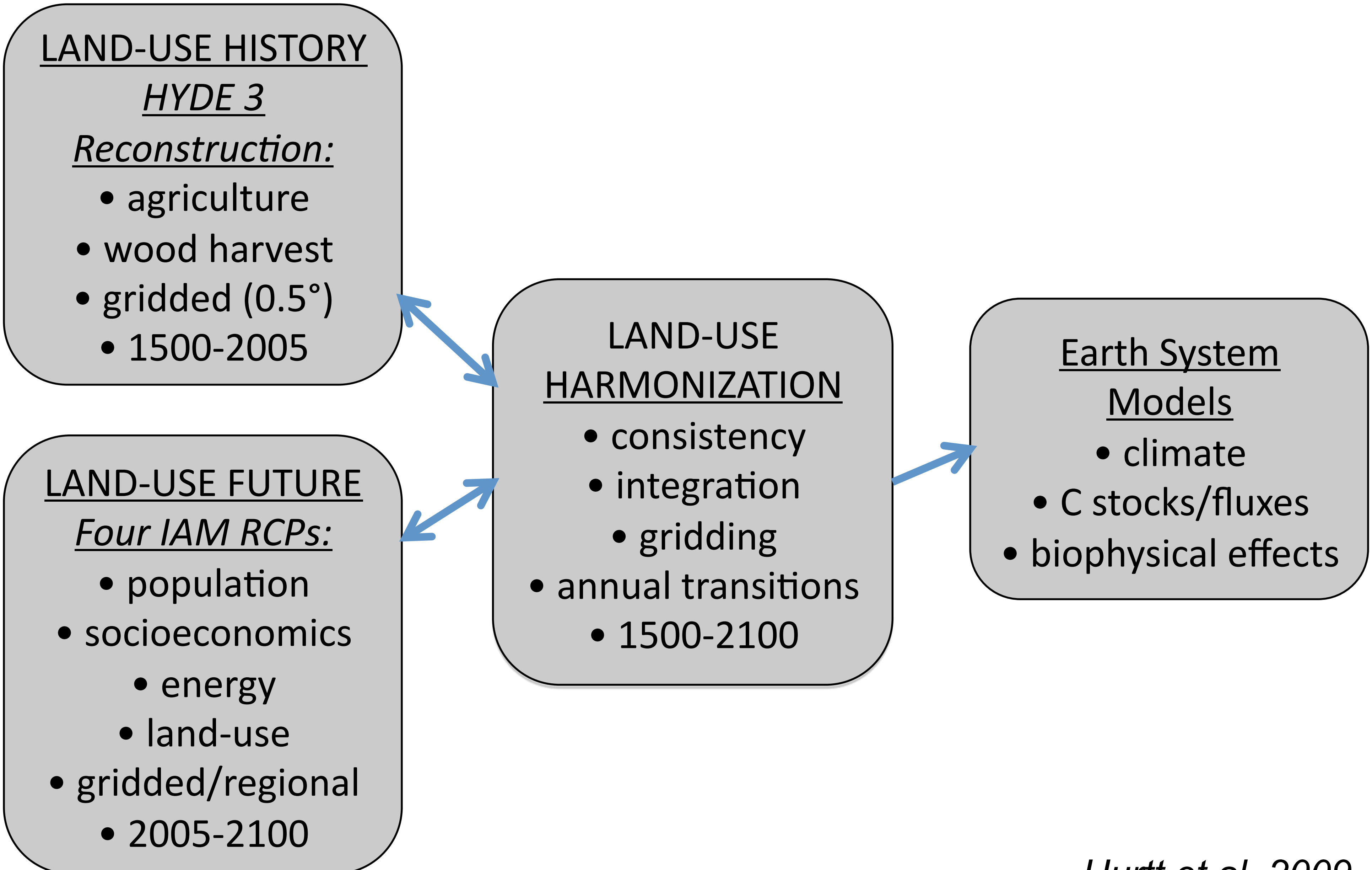
Importance of continued improvements in agricultural productivity



GCAM IAM simulations

Thompson et al. in review

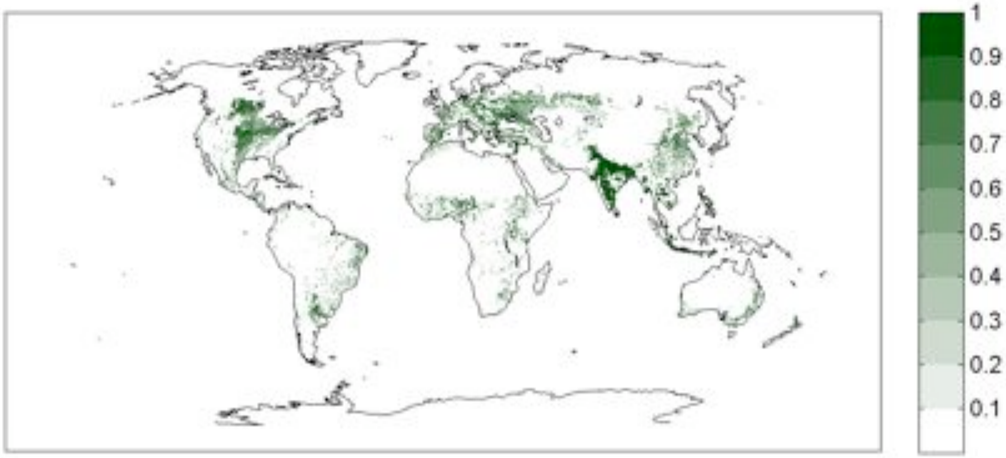
IPCC AR5 scheme for land-use

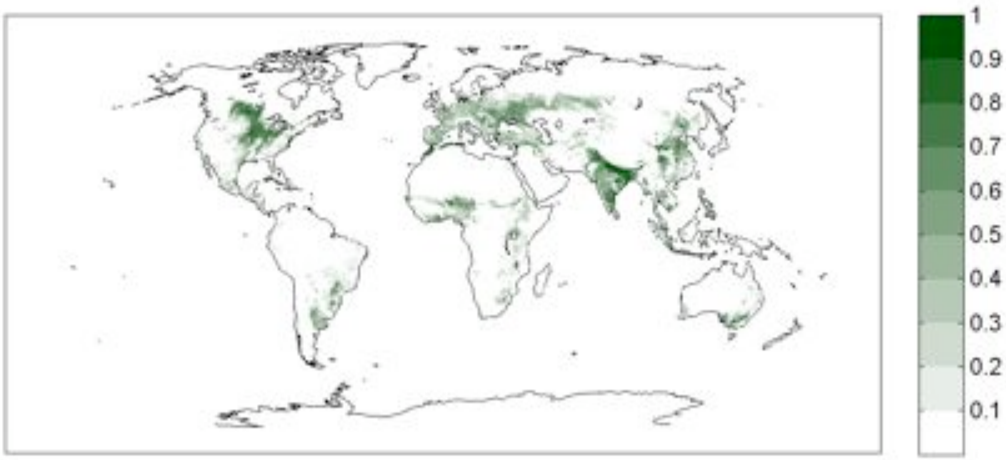


Hurtt et al. 2009

Matching cropland distribution in 2005

IMAGE – IAM future for RCP2.6

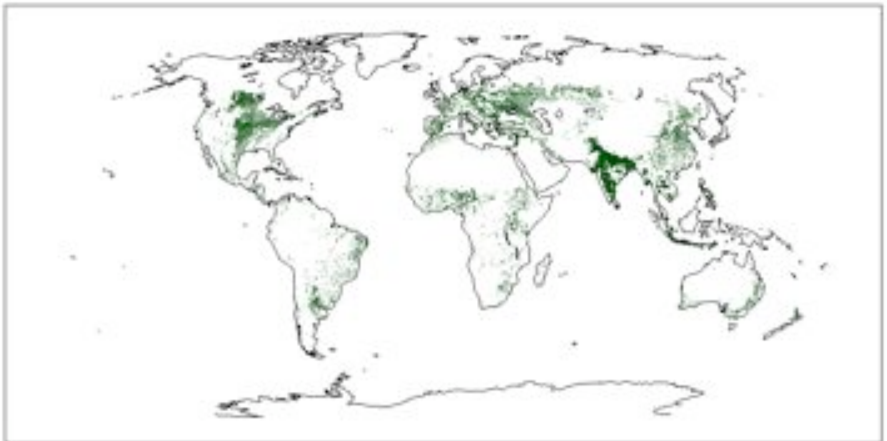


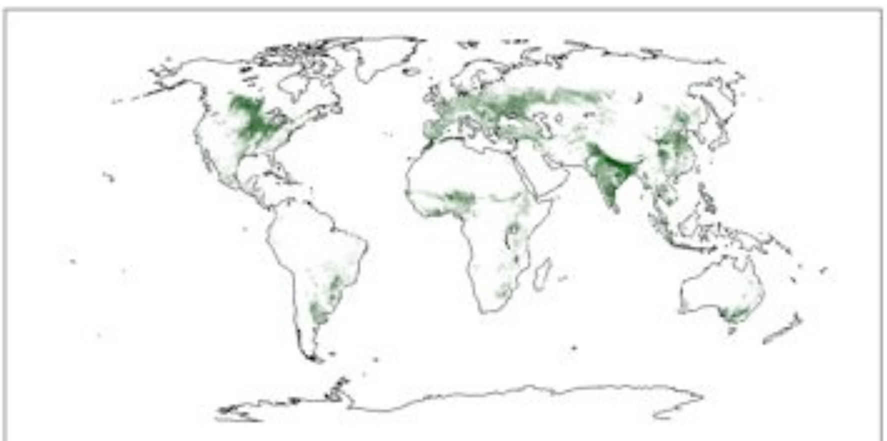


HYDE 3 – historical reconstruction

Matching cropland distribution in 2005

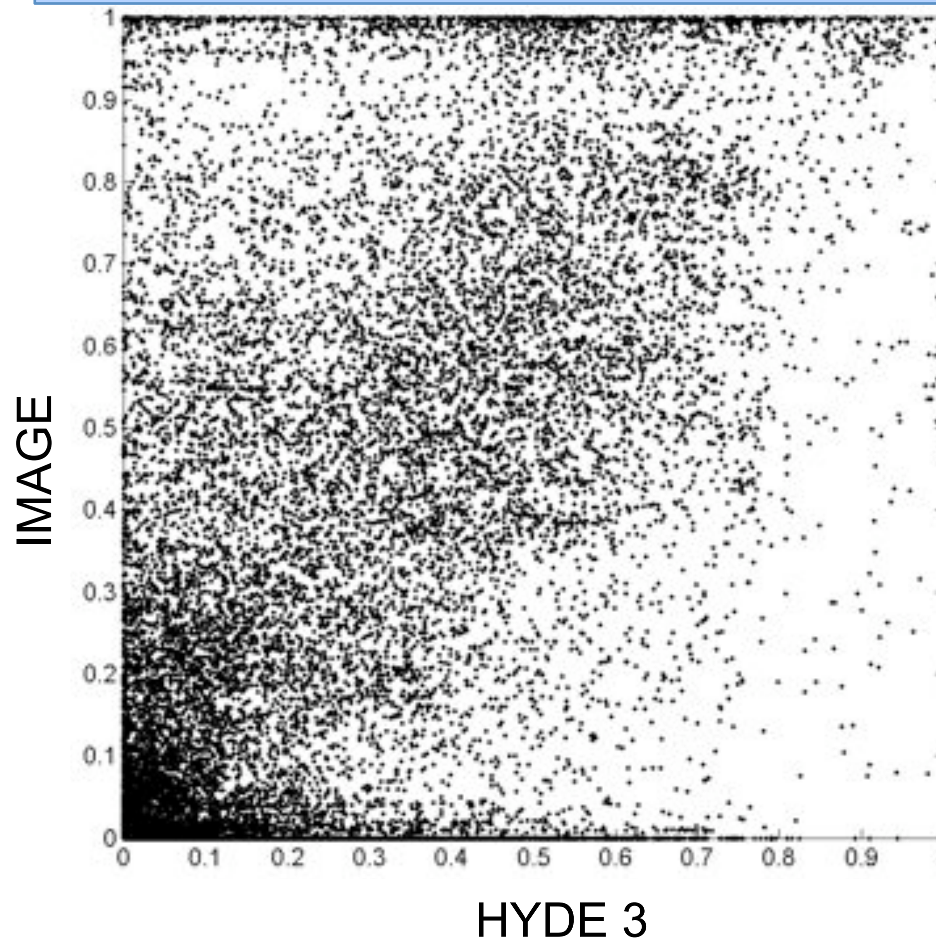
IMAGE – IAM future for RCP2.6



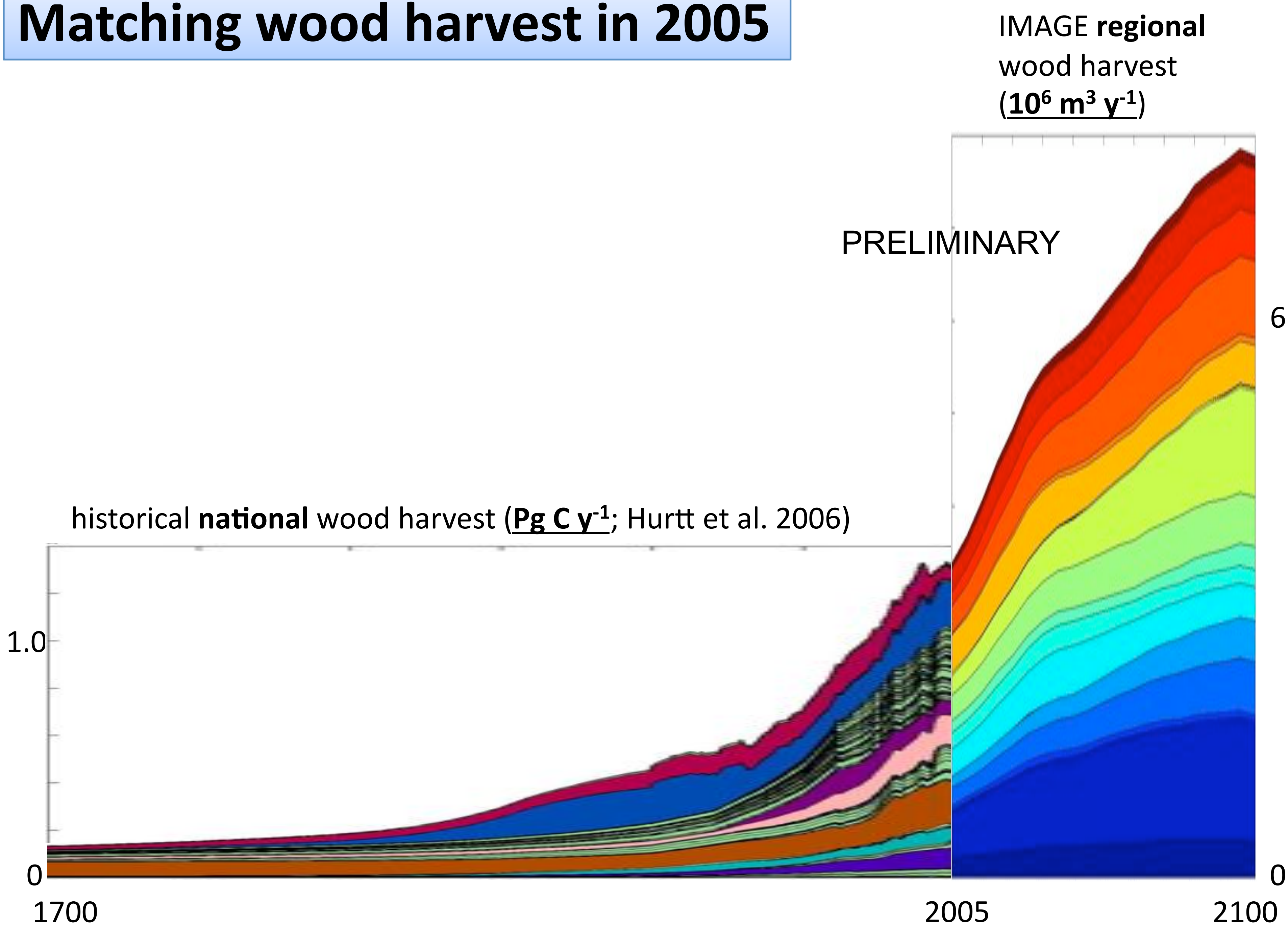


HYDE 3 – historical reconstruction

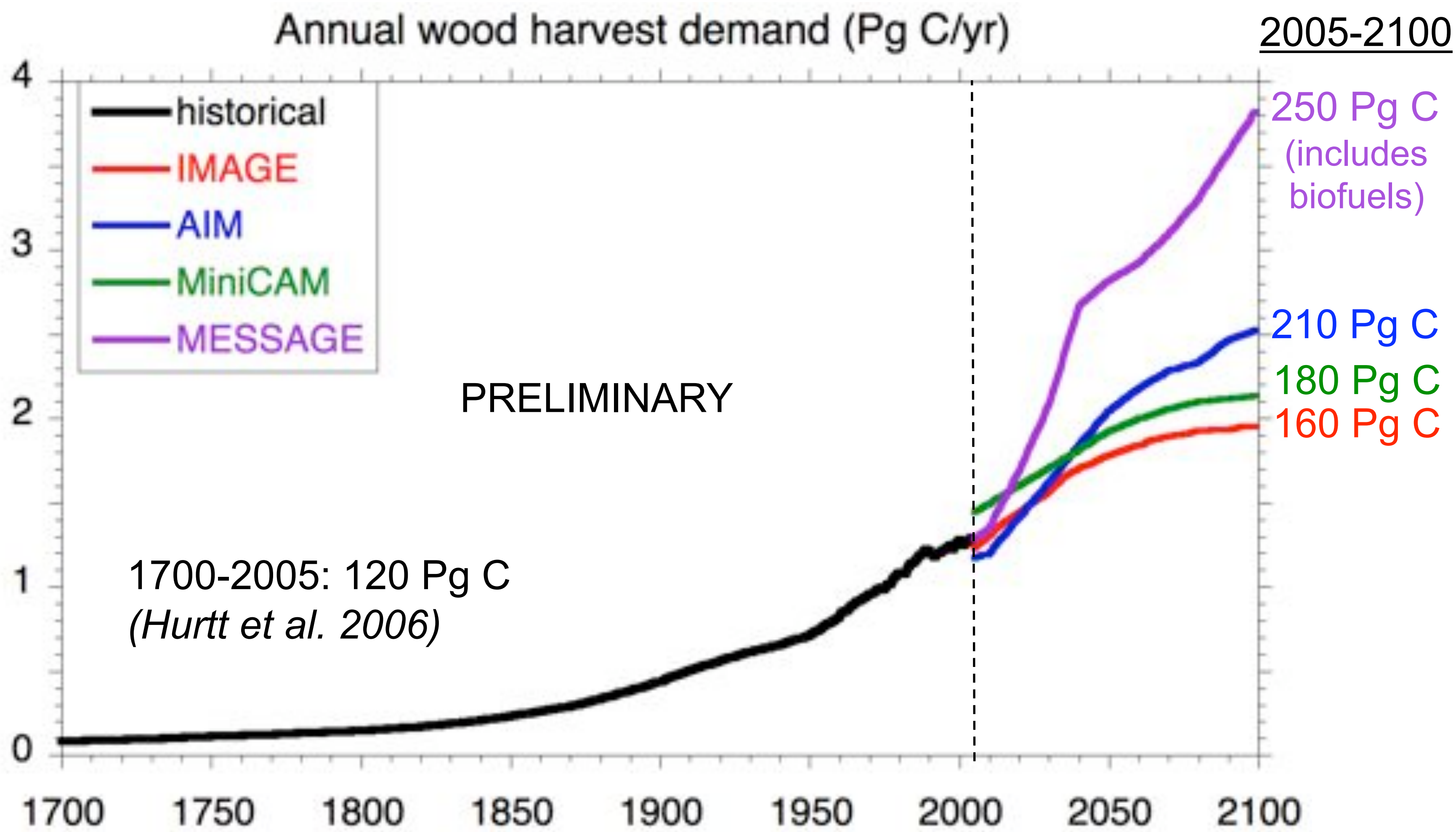
Cropland fraction by 0.5° grid cell in 2005



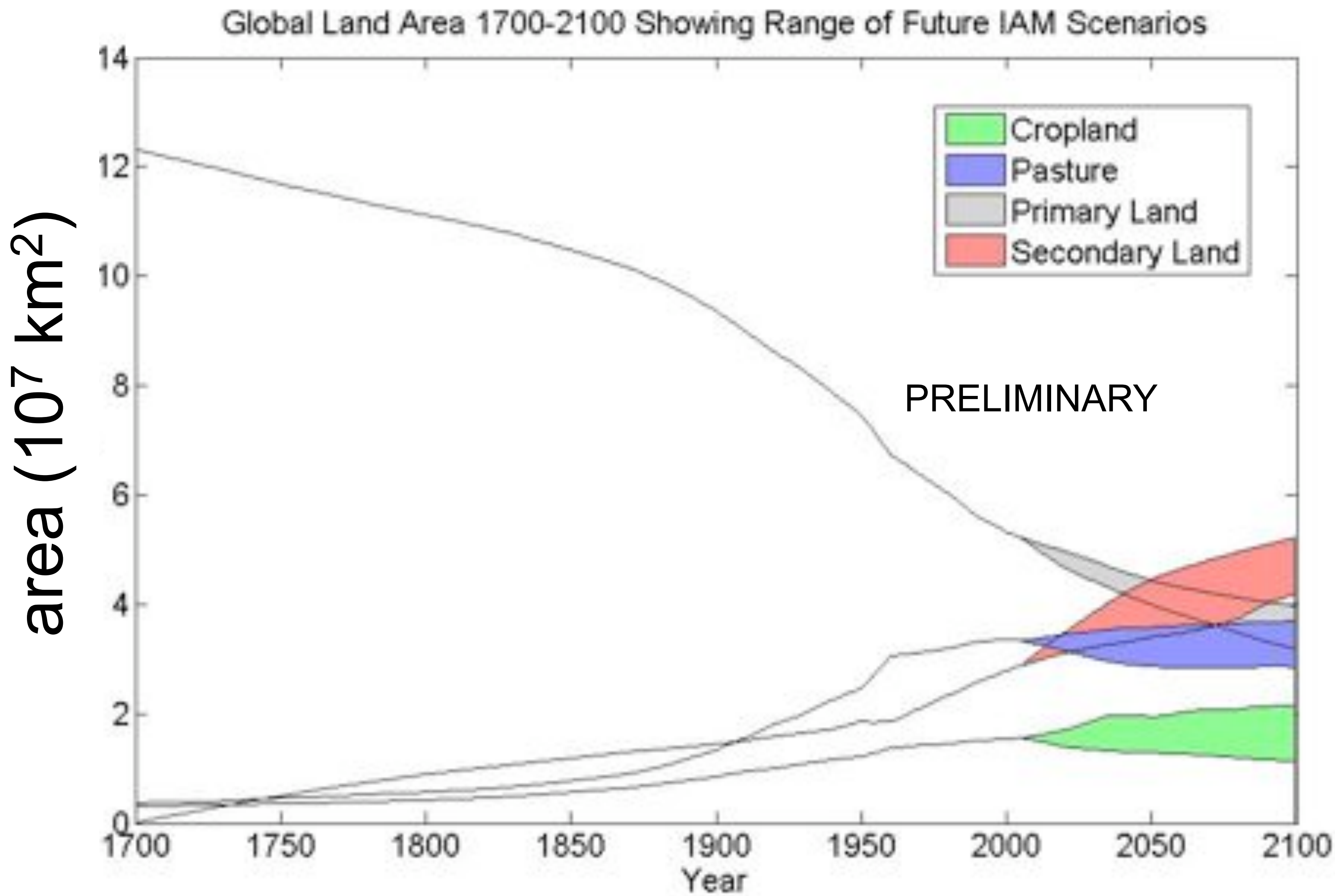
Matching wood harvest in 2005



IPCC AR5 wood harvest 1700-2100

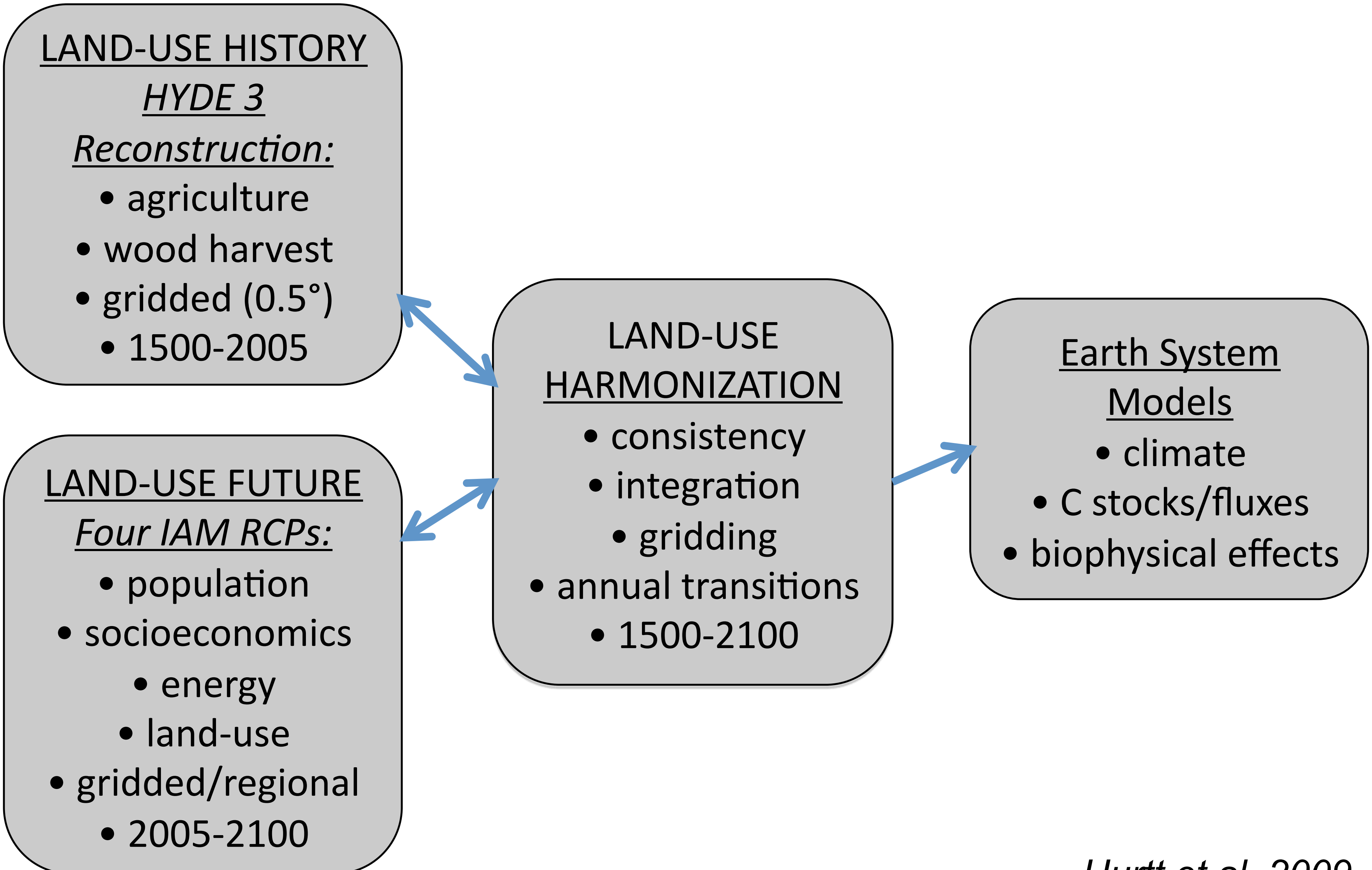


IPCC AR5 Land Use 1700-2100



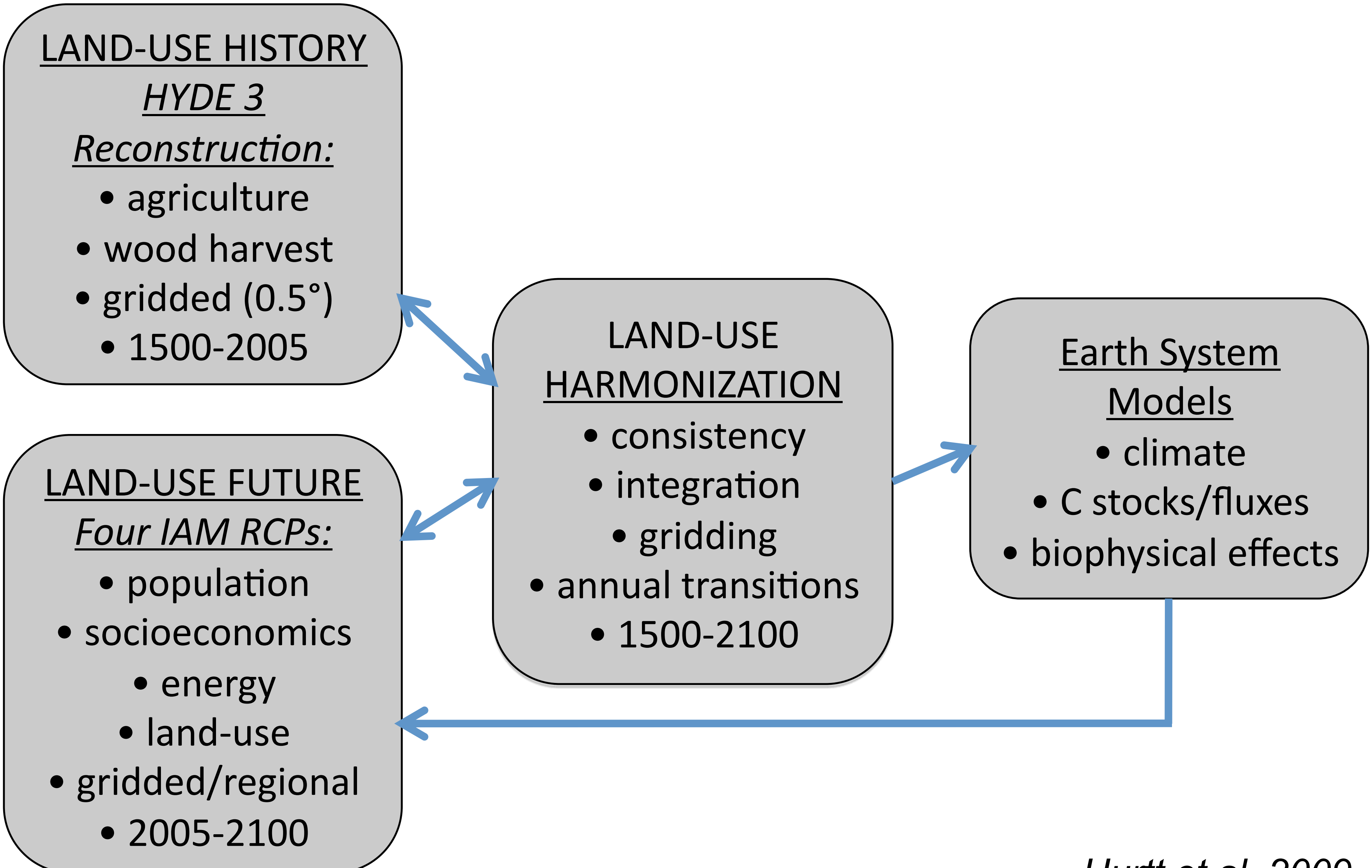
http://luh.unh.edu

Conclusions 1: Land use in IPCC AR5



Hurtt et al. 2009

Conclusions 2: still a missing feedback



Hurtt et al. 2009

Conclusions 3

- most disturbance rates will probably increase in 21st Century
- land use extent may, and intensity will, increase in 21st Century
- Improving detection & mapping of disturbance and land use

Disturbance: impacts/severity, heterogeneity
quantify changes in rates
recovery – rate and towards what final state

Land Use: management – e.g., multiple cropping, irrigation

Degradation: impoverishment – erosion, desertification, salinization