Interactions between climate and ecosystems

David W. Kicklighter
The Ecosystems Center
Marine Biological Laboratory
Woods Hole, MA USA

Climate Change Impacts and Integrated Assessment Workshop
Snowmass, CO
27-29 July, 2011

Effects of Climate on Ecosystems

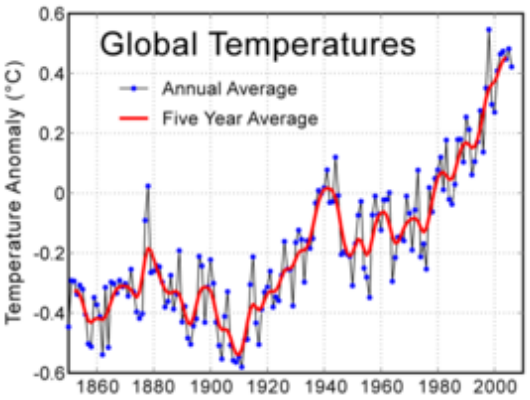
- Solar Radiation
- Temperature
- Water

Effects of Ecosystems on Climate

- Uptake and release of carbon dioxide (CO_2)
- Uptake and release of methane (CH_4)
- Uptake and release of nitrous oxide (N_2O)
- Evapotranspiration
- Albedo

Global Environmental Changes

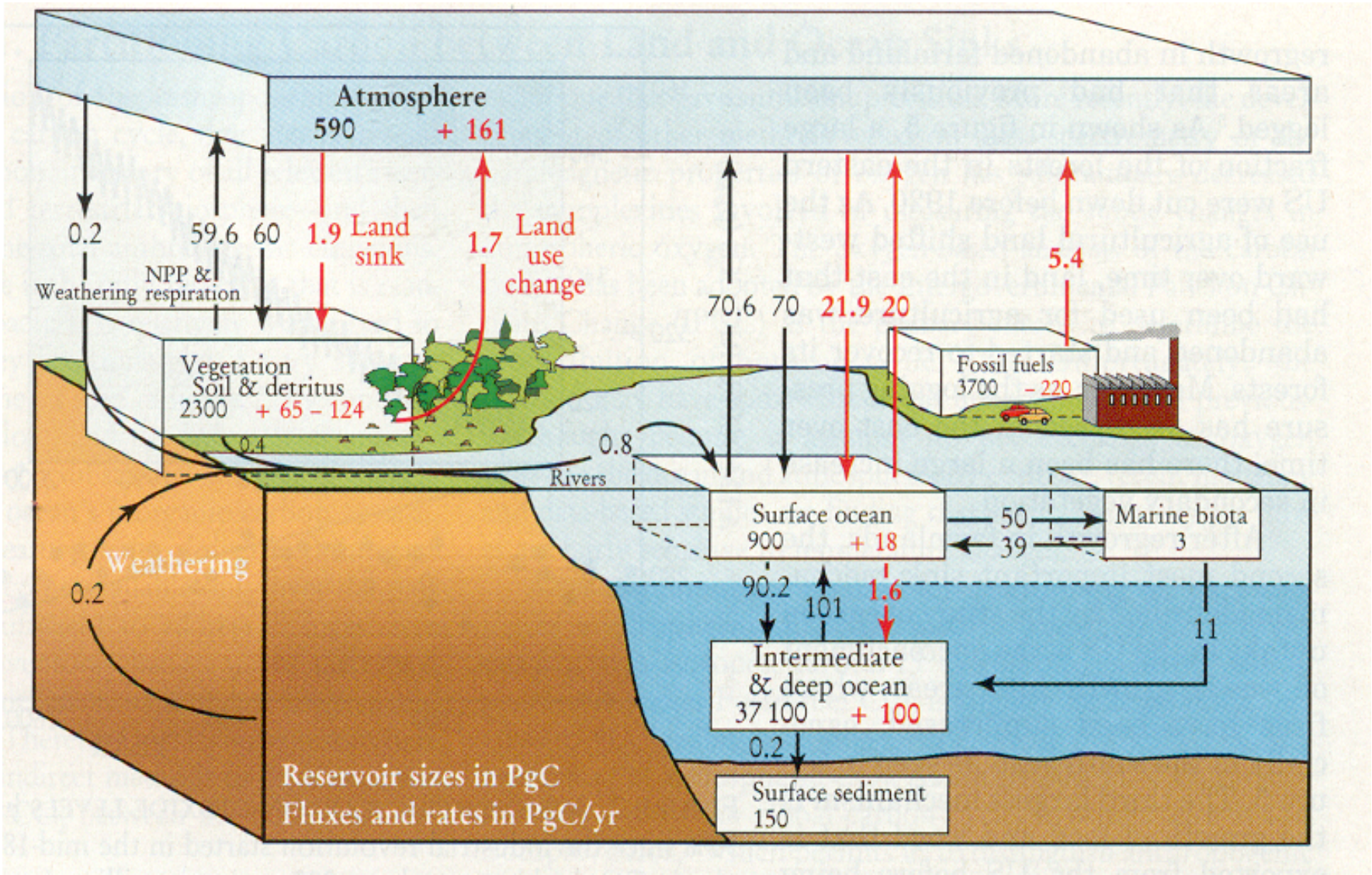
(a partial list)



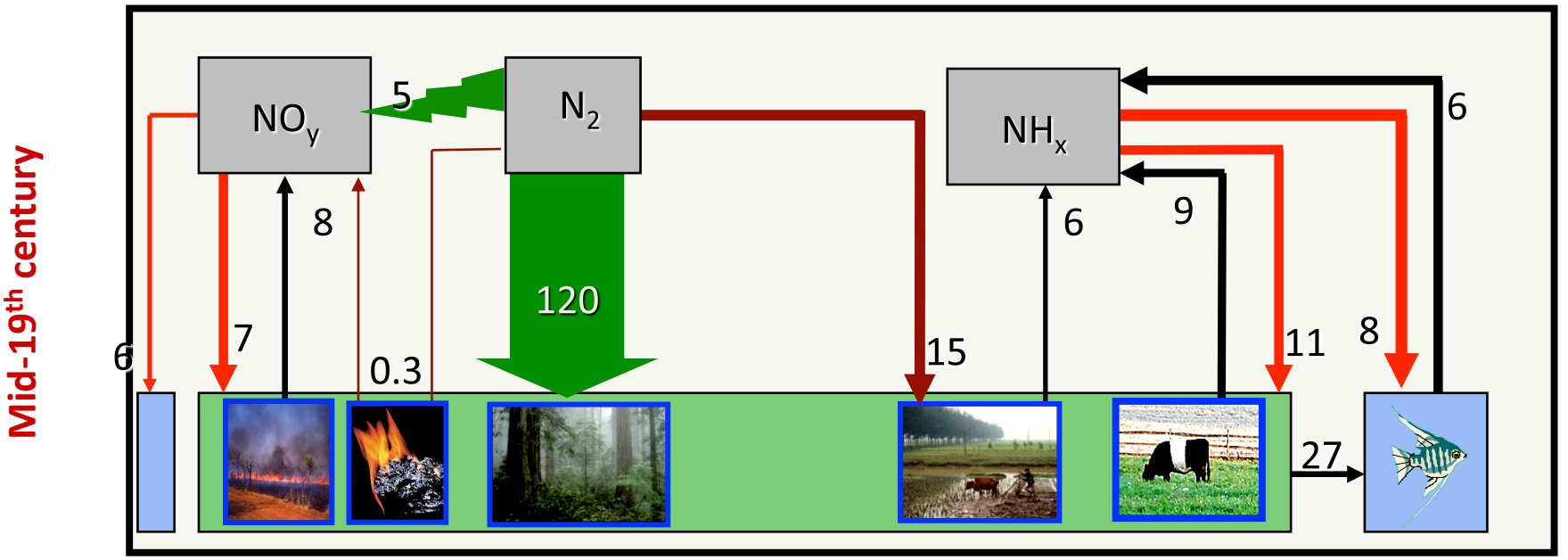
- Carbon cycle
- Nitrogen cycle
- Climate
- Land cover and land use
- Glacier & Permafrost degradation
- Air Quality
- Fire

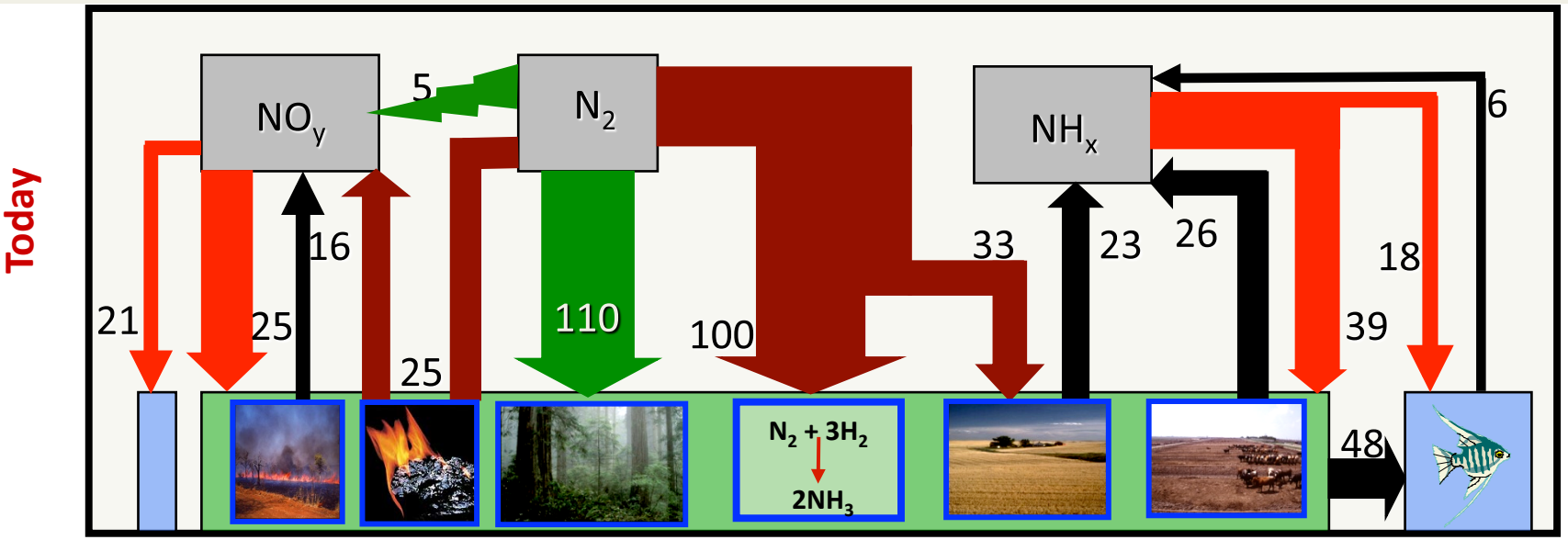
These changes co-occur in various combinations across the globe and they often interact in complex ways .

Global carbon budget – the late 20th century



Disruption of the nitrogen cycle - Global nitrogen budget in 1860 (baseline) and today, TgN/yr





Galloway et al., 2004. *Biogeochemistry* 70:153.

Questions:

1) Has disruption of the nitrogen cycle influenced global carbon cycling and its effect on climate?

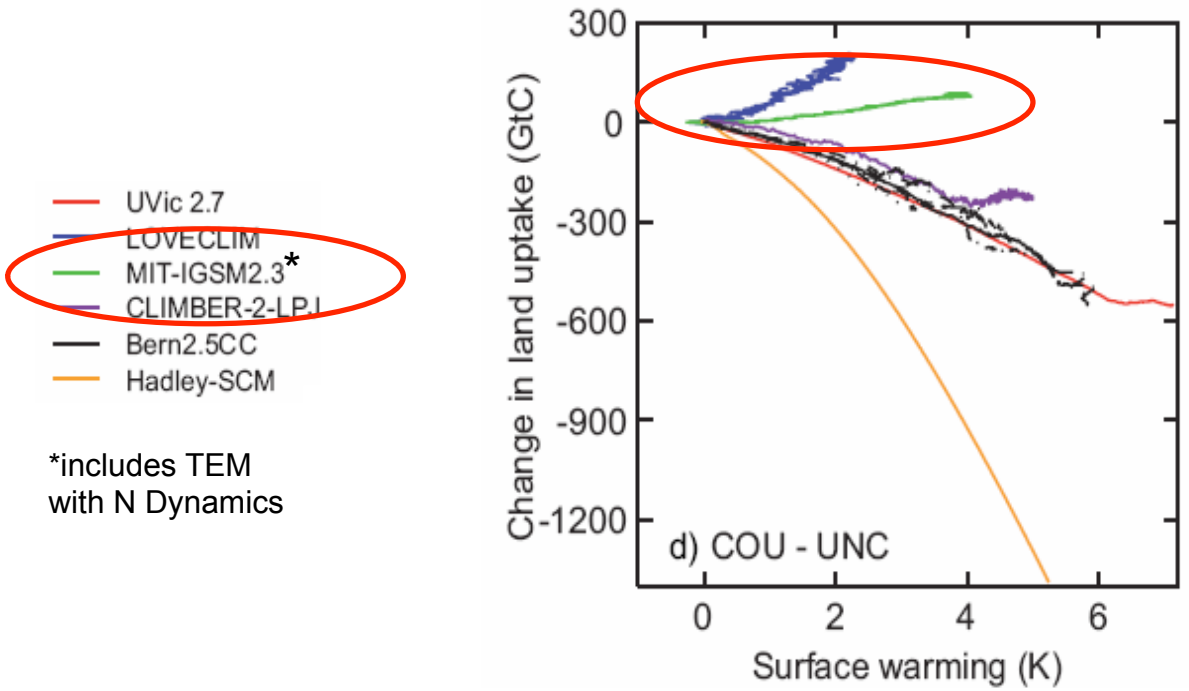
Energy-Land-Water-Nitrogen Nexus

2) Other than CO_2, how does this nexus influence interactions between ecosystems and climate?

3) Does consideration of multiple factors alter assessments of climate change impacts on ecosystems and their feedback to climate

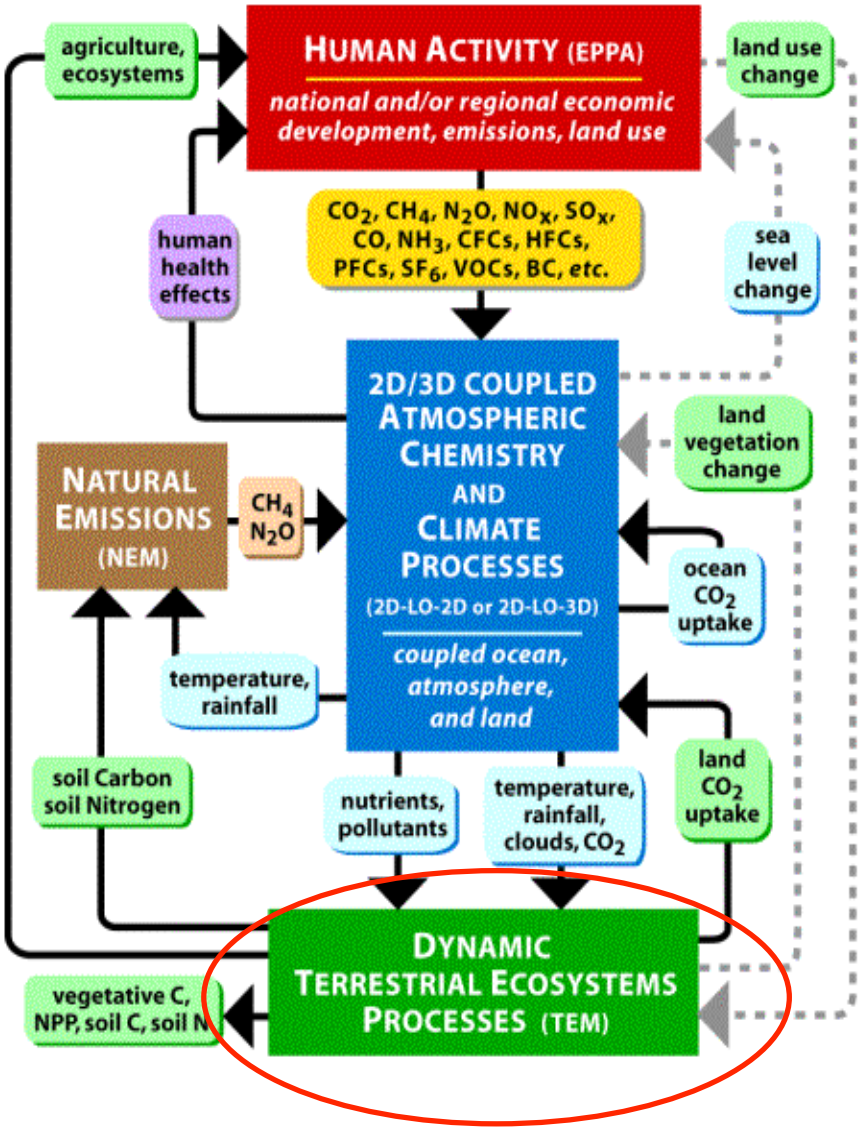
Response of Terrestrial Carbon to Surface Warming

Plattner et al. (2008)
J. Climate



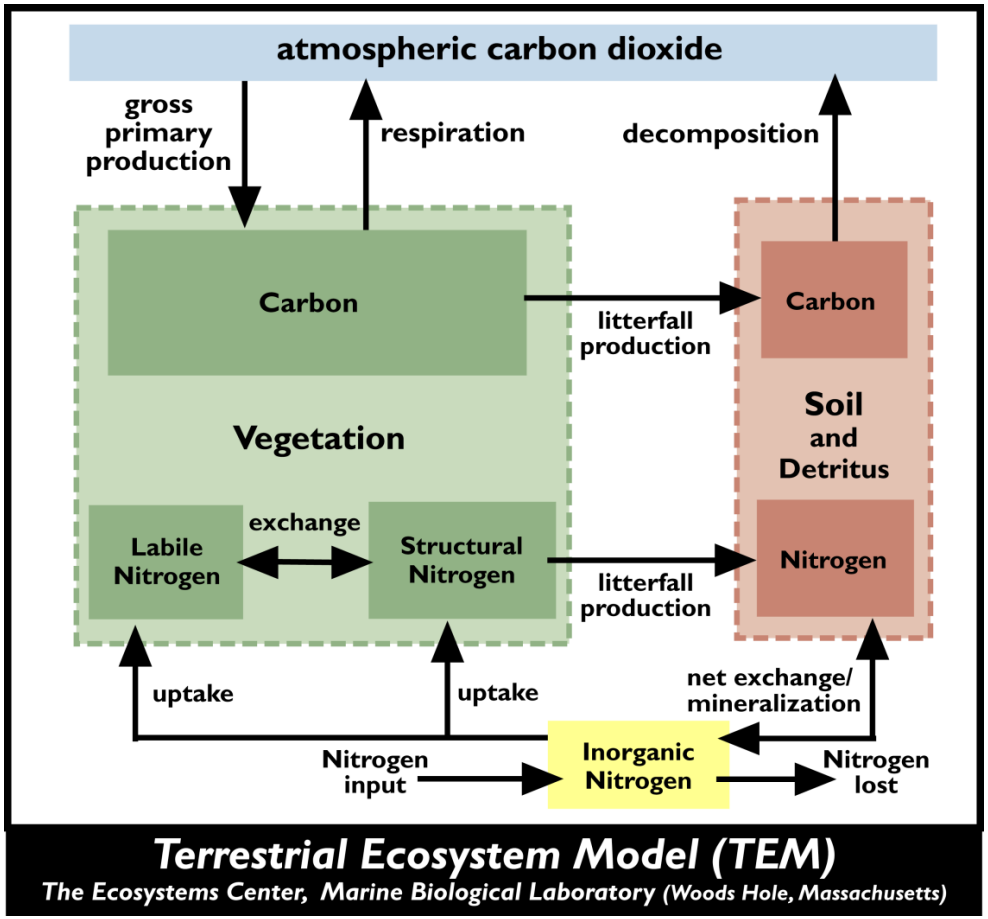
UNC – Climate uncoupled to atmospheric CO_2 concentrations
COU – Climate coupled to atmospheric CO_2 concentrations

MIT Integrated Assessment Modeling Framework



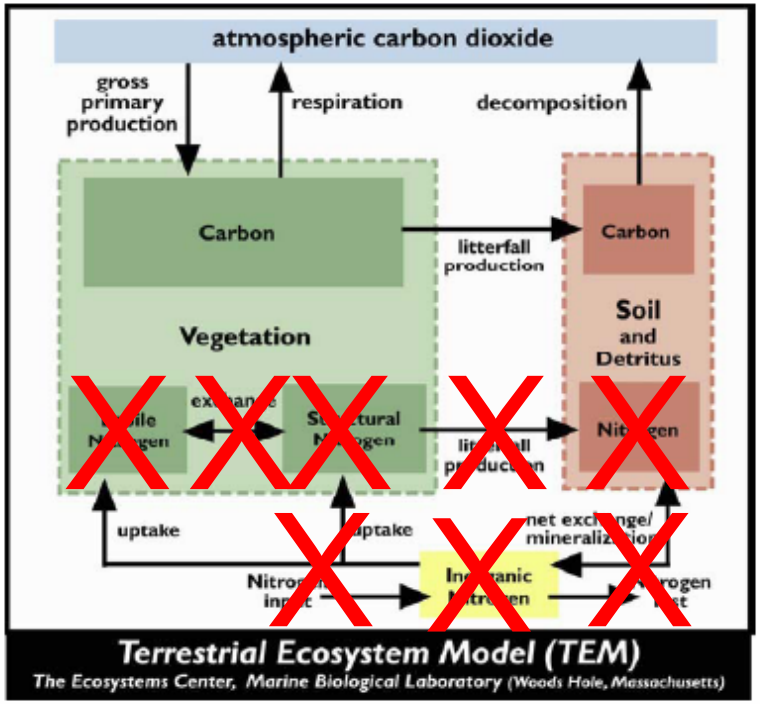
Terrestrial Ecosystem Model (TEM)

The Ecosystems Center, Marine Biological Laboratory (Woods Hole, Mass.)

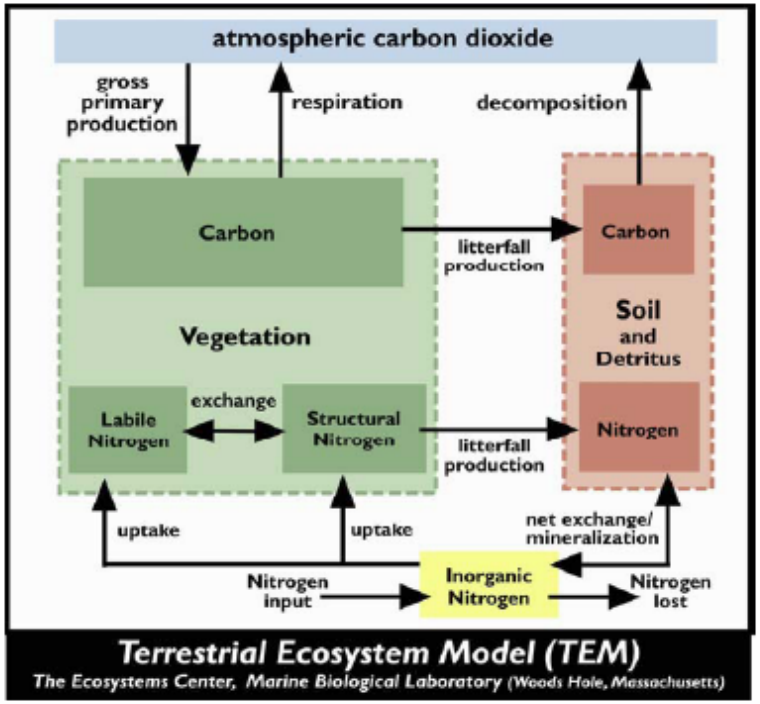


The Terrestrial Ecosystem Model of Ecosystem Impact (TEM) is used for predictions of the future state of ecosystems and the fluxes of CO_2 between the atmosphere and the land biosphere. TEM uses spatially-explicit data sets that represent land areas at a resolution of 0.5˚ x 0.5˚ (latitude x longitude).

C-TEM

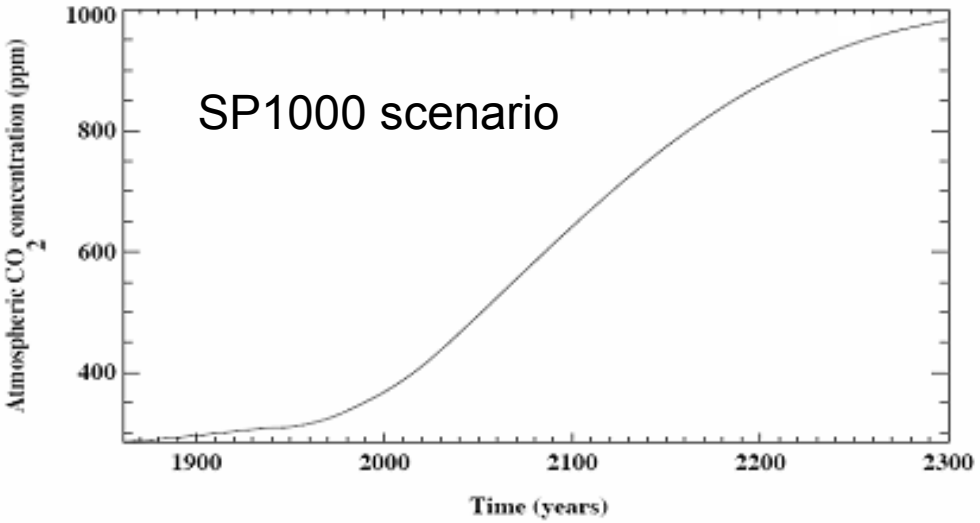

atmospheric carbon dioxide
gross primary production
respiration
decomposition
Carbon
litterfall production
Carbon
Soil and Detritus
Vegetation
uptake
uptake
Terrestrial Ecosystem Model (TEM)
The Ecosystems Center, Marine Biological Laboratory (Woods Hole, Massachusetts)

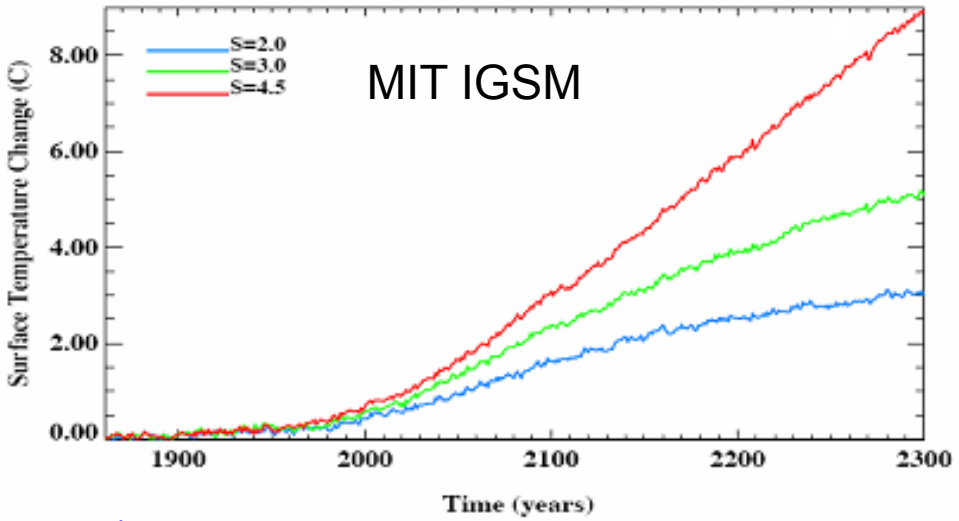
CN-TEM


atmospheric carbon dioxide
gross primary production
respiration
decomposition
Carbon
litterfall production
Carbon
Soil and Detritus
Vegetation
Labile Nitrogen
exchange
Structural Nitrogen
litterfall production
Nitrogen
uptake
uptake
net exchange/ mineralization
Nitrogen input
Inorganic Nitrogen
Nitrogen lost
Terrestrial Ecosystem Model (TEM)
The Ecosystems Center, Marine Biological Laboratory (Woods Hole, Massachusetts)

Simulation Experiment

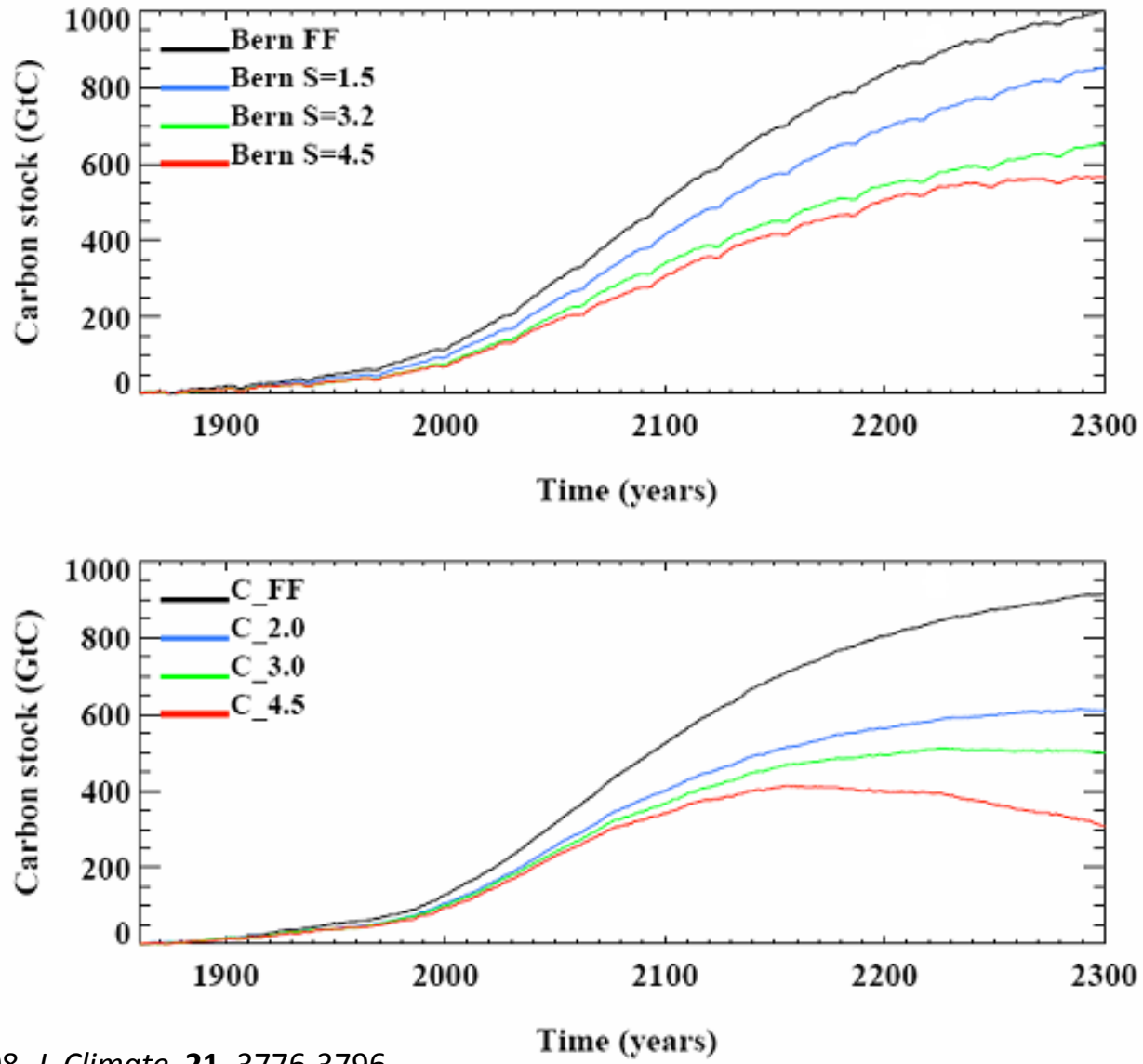
Run C-TEM and CN-TEM with prescribed atms. CO_2 uncoupled and coupled to climate -- no feedback of land carbon flux on climate





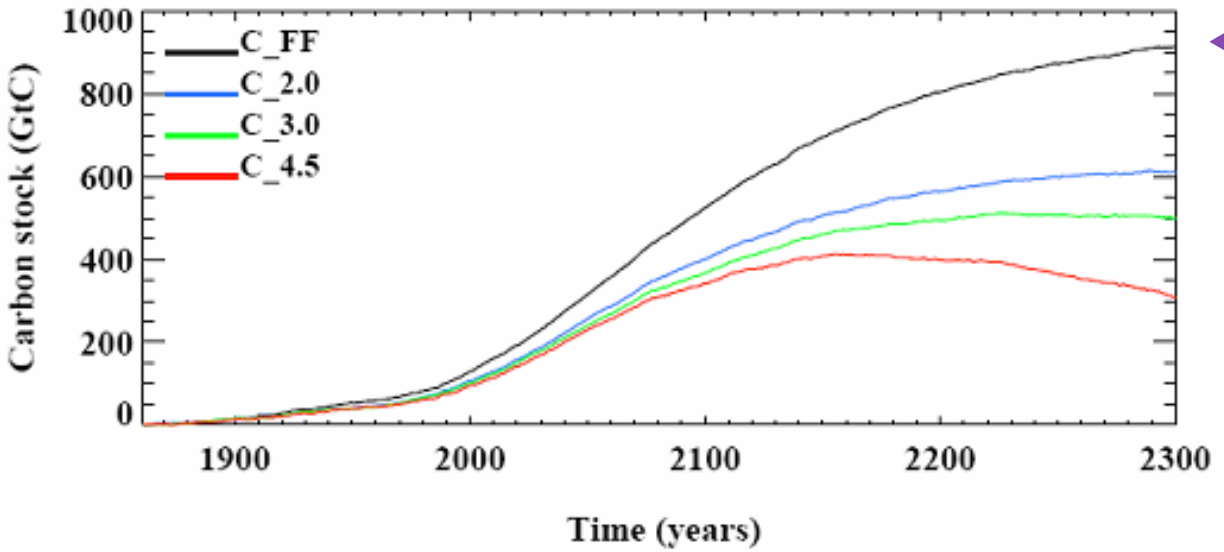
Sokolov et al. 2008, *J. Climate*, **21,** 3776-3796, doi: 10.1175/2008JCLI2038.1

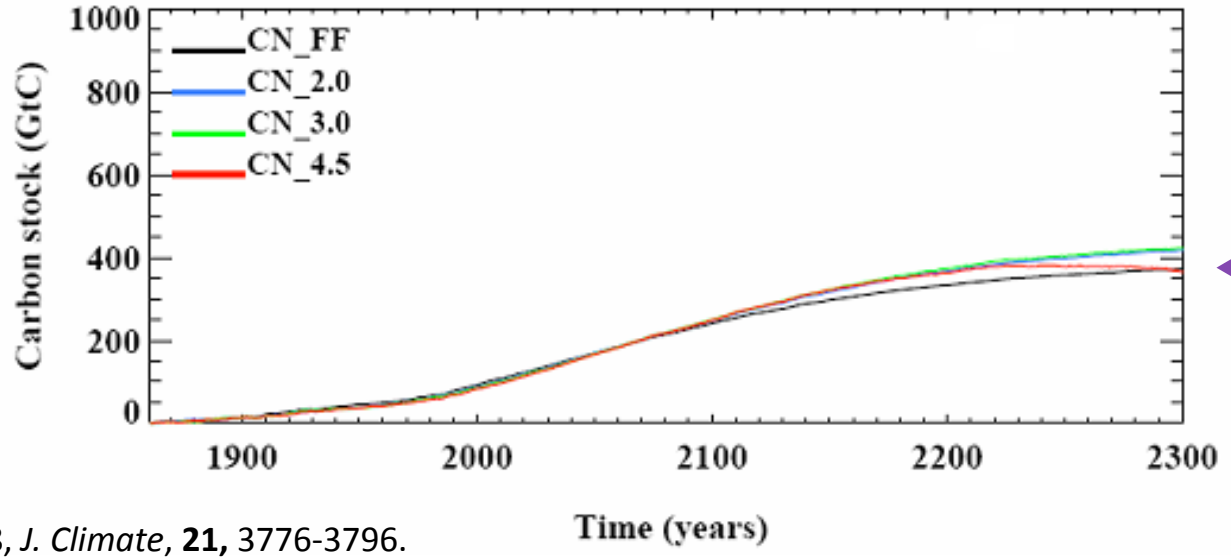
Comparison of Land Carbon Sequestration Estimated by the Bern Model and C-TEM



Sokolov et al. 2008, *J. Climate*, **21,** 3776-3796.

Comparison of Land Carbon Sequestration Estimated by C-TEM and CN-TEM

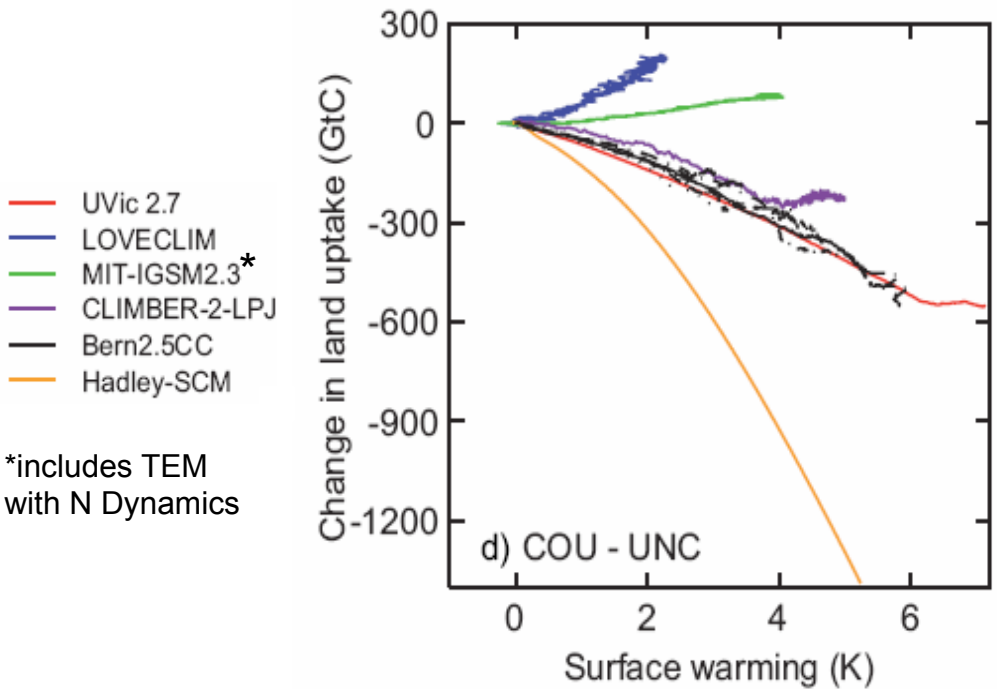




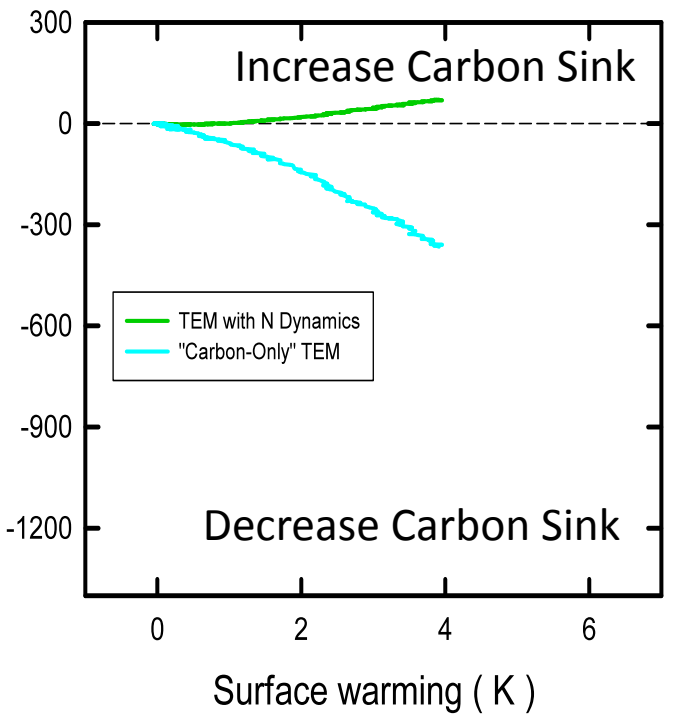
Sokolov et al. 2008, *J. Climate*, **21,** 3776-3796.

Response of Terrestrial Carbon to Surface Warming

Plattner et al. (2008)
J. Climate



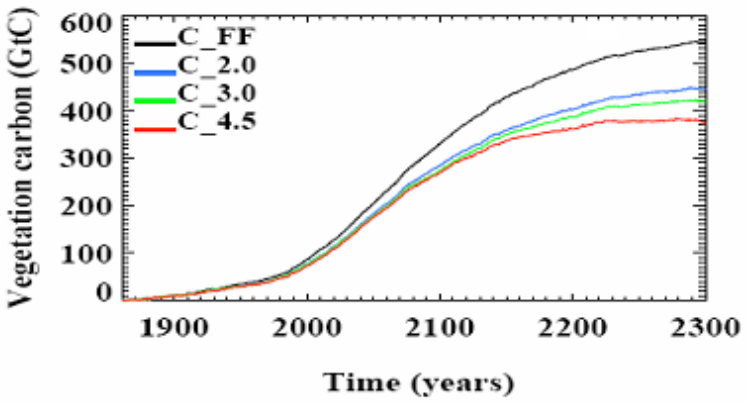
Sokolov et al. (2008)
J. Climate

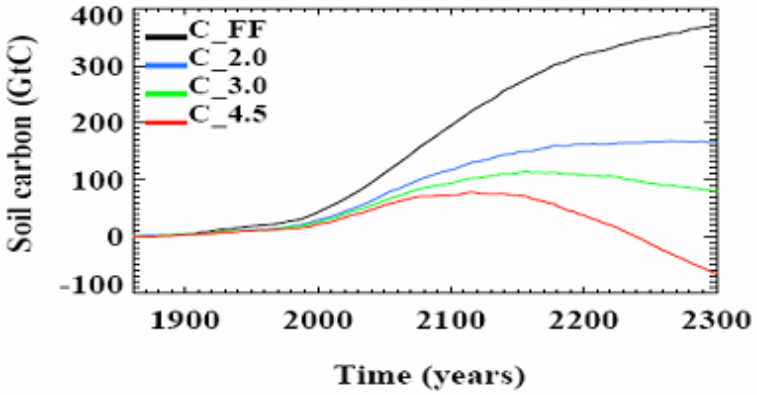


UNC – Climate uncoupled to atmospheric CO_2 concentrations
COU – Climate coupled to atmospheric CO_2 concentrations

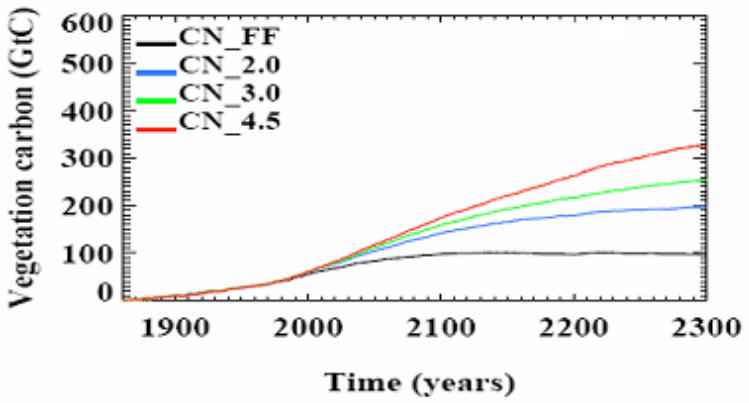
Changes in Global Vegetation and Soil Organic Carbon Stocks

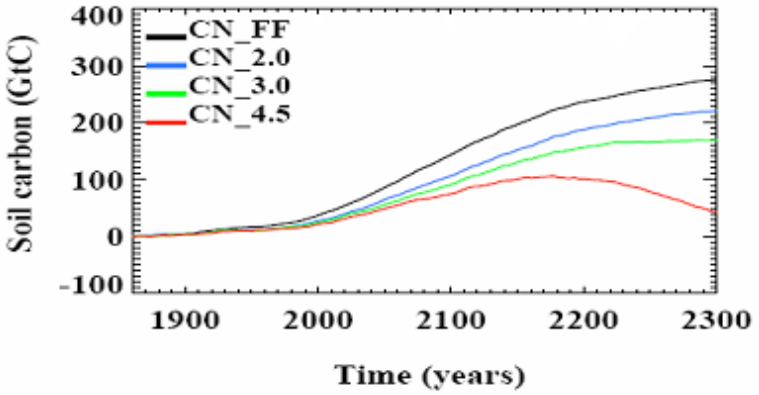
C-TEM





CN-TEM





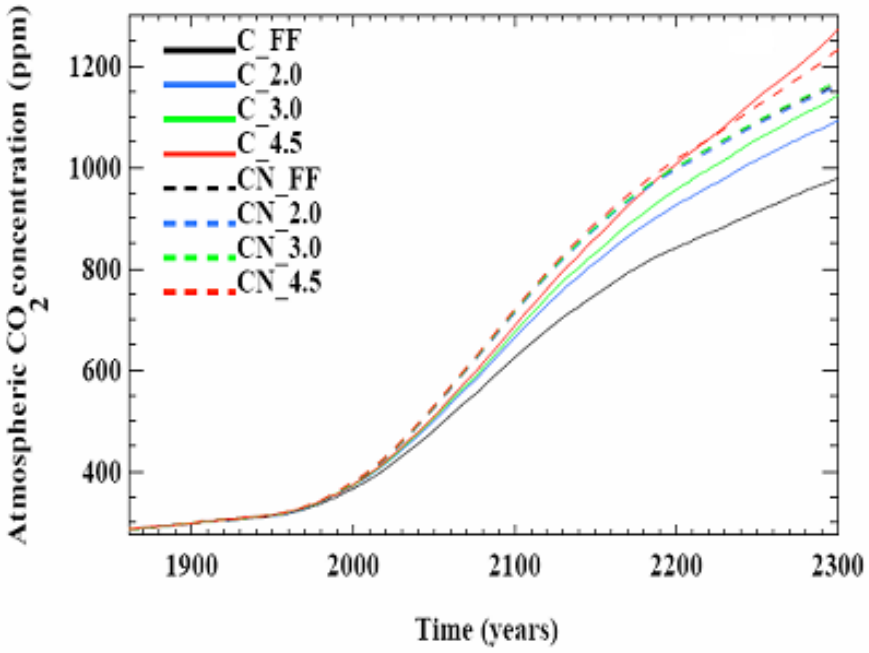
C:N

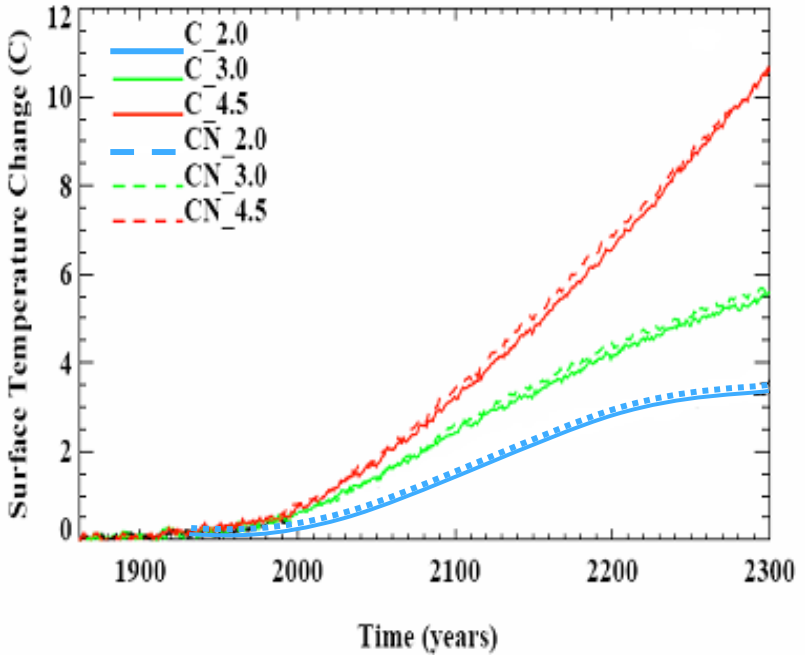
300:1

16:1

Sokolov et al. 2008, *J. Climate*, **21,** 3776-3796, doi: 10.1175/2008JCLI2038.1

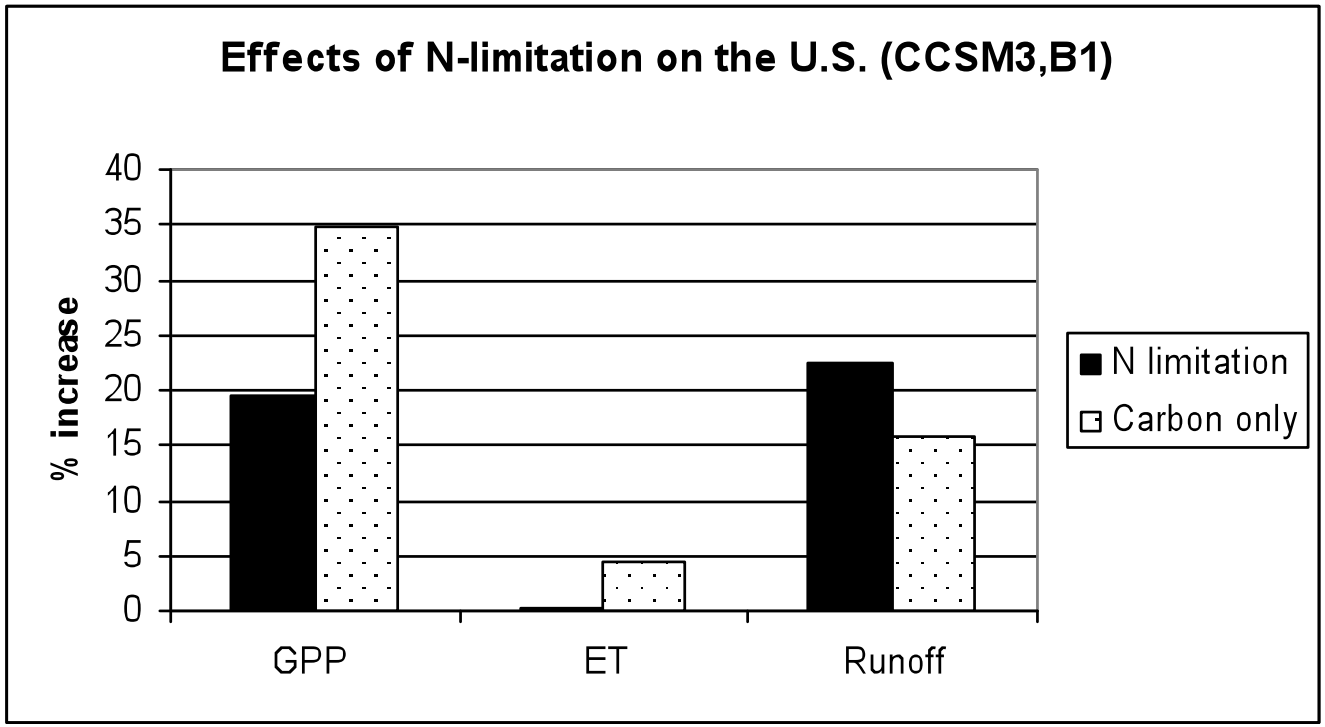
Consequences of Carbon-Nitrogen Interactions on the Feedback of Land Carbon Dynamics on Climate





Sokolov et al. 2008, *J. Climate*, **21,** 3776-3796, doi: 10.1175/2008JCLI2038.1

Evapotranspiration (ET)



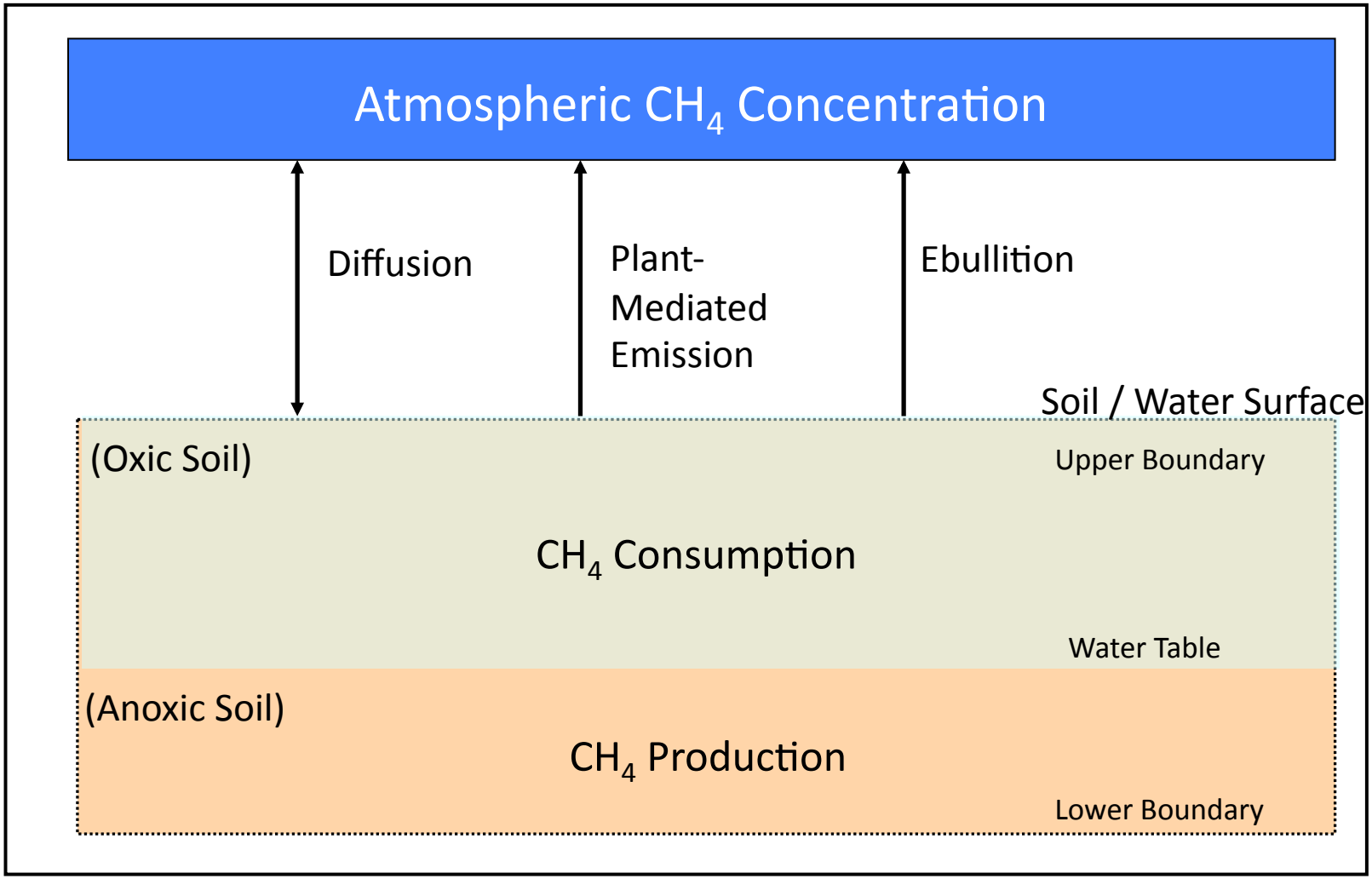
% increase based on 30 year means from 2070-2099 vs. 1970-1999

Felzer et al. 2009, *J. Geophysical Res.* **114**, G01020, doi: 10.1029/2008JG000826.

Methane (CH_4)

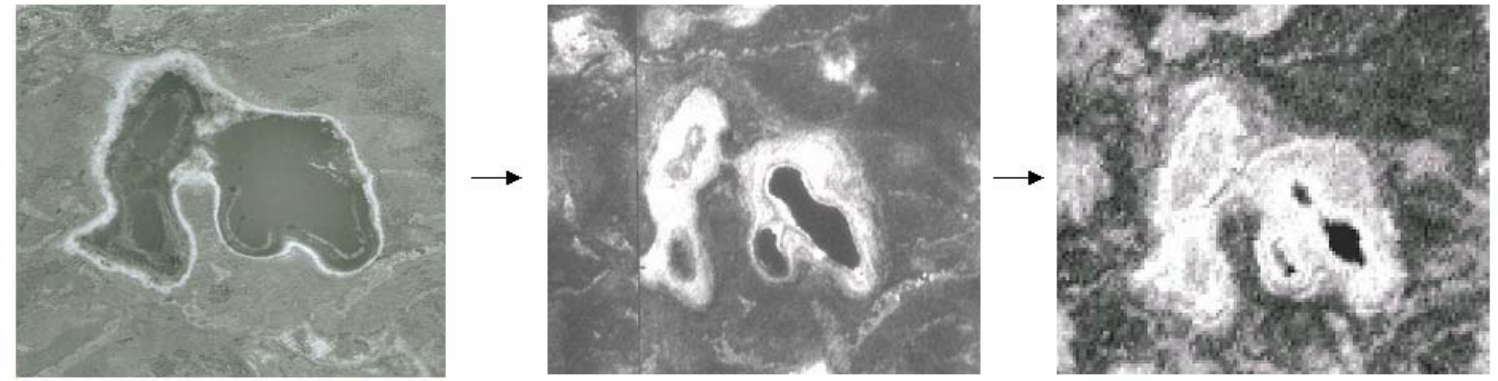
- Global emissions – ~500 to 600 Tg CH_4/year
- 100-yr GWP 25x CO_2
- Second largest radiative forcing (0.48 W m^{-2} in 2005)
- Land Sources
  - Wetlands, rice paddies
  - Fires
  - Ruminant animals

Interactions of Methane and Water

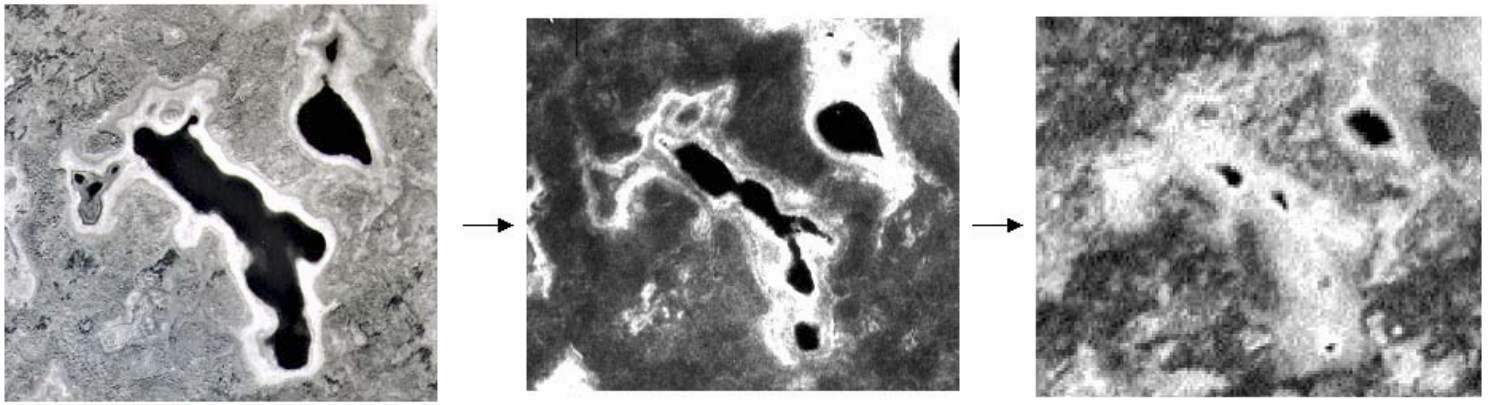


Zhuang et al., *2004 Global Biogeochem. Cycles,* **18**, GB3010, doi:10.1029/2004GB002239.

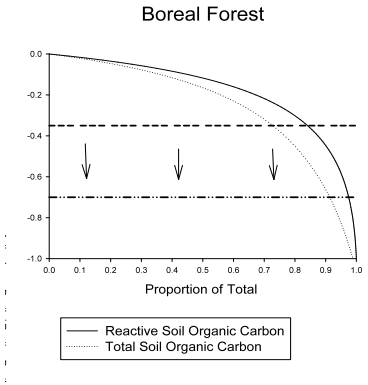
Shrinkage of open water
Yukon Flats National Wildlife Refuge, Alaska



1950s 1970s 2000



Influence of Permafrost on Availability of Soil Carbon

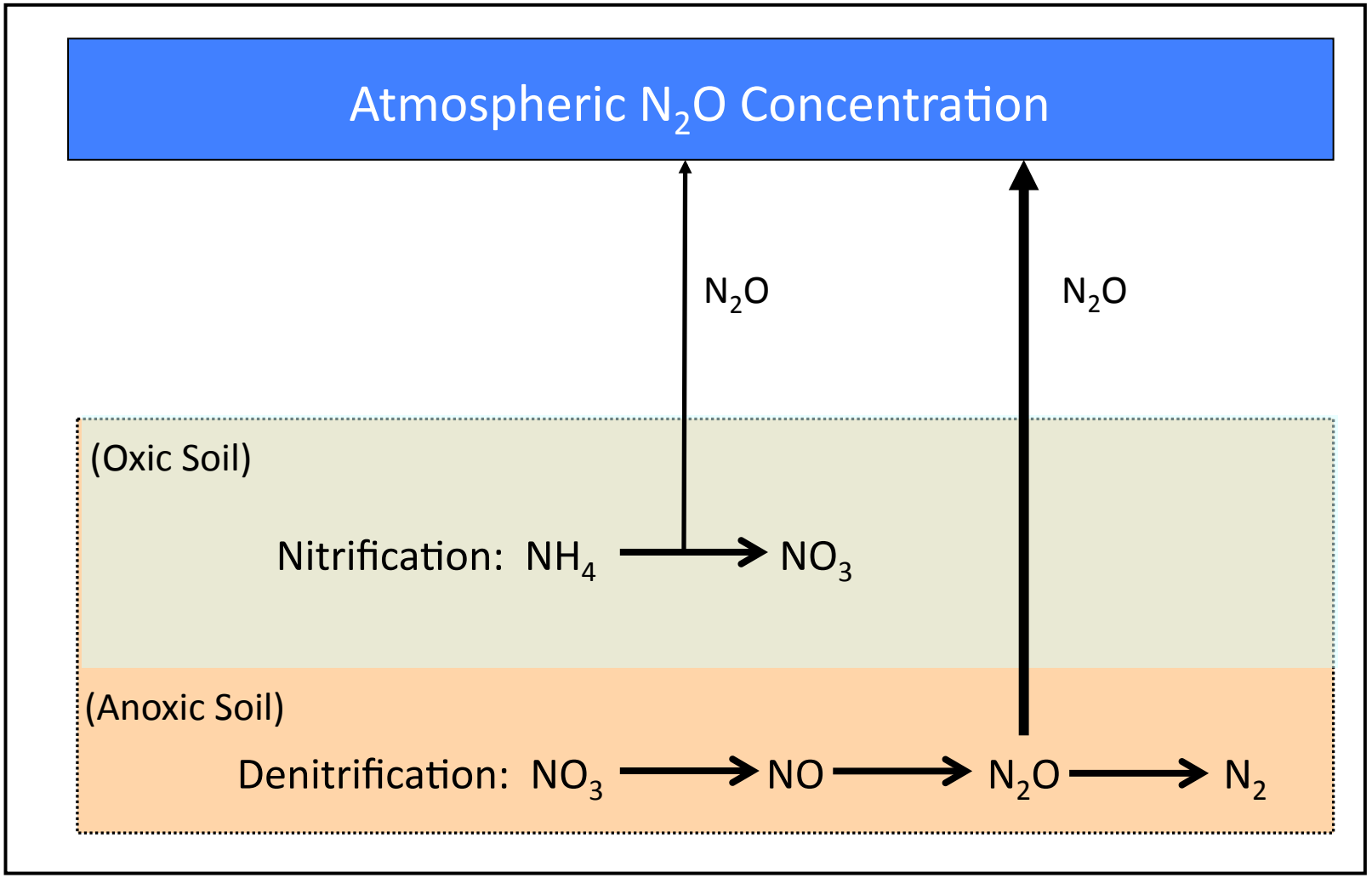


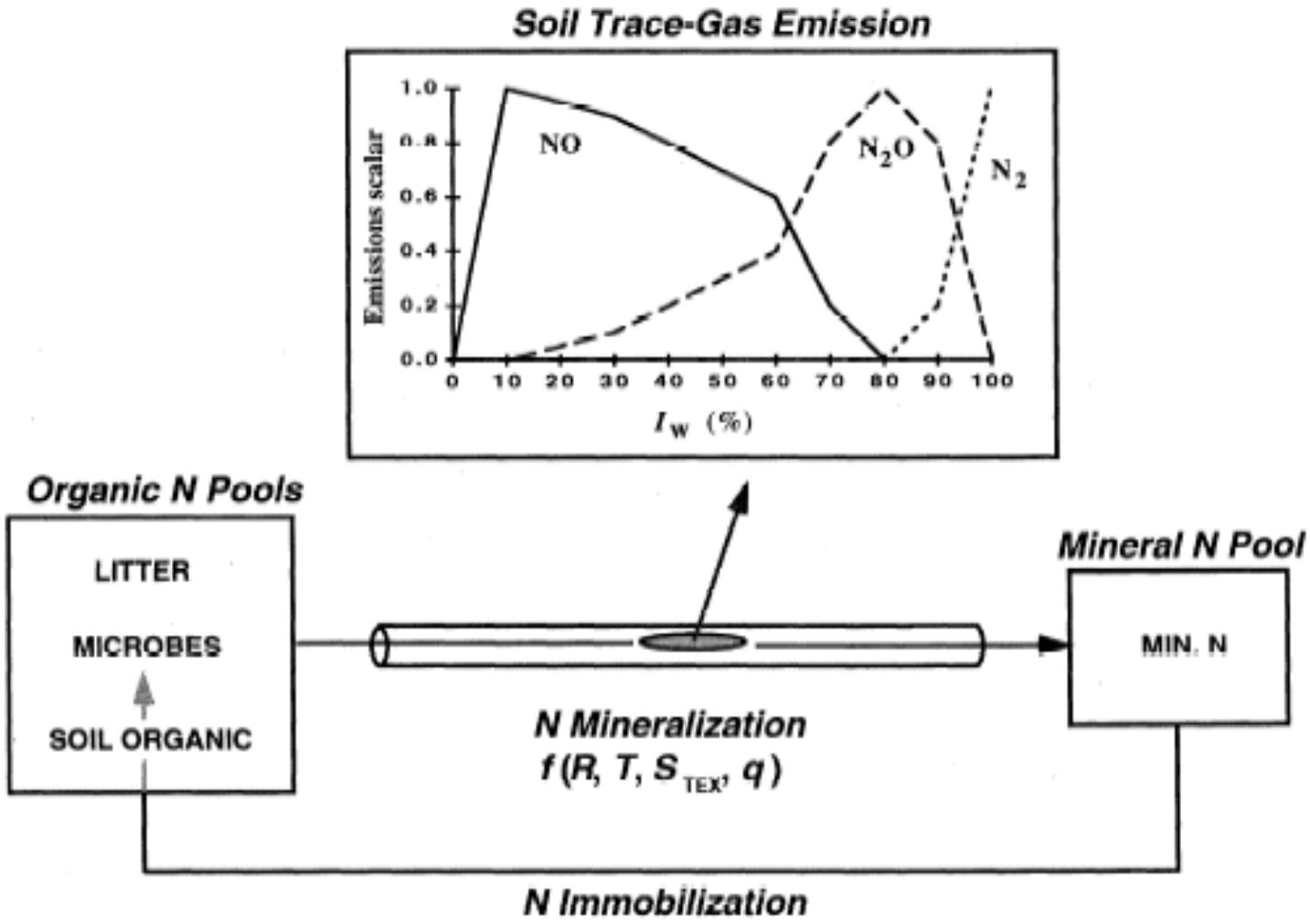
Hayes et al. (*in press*), *Global Biogeochem. Cycles*, doi: 10.1029/2010GB003813.

Nitrous Oxide (N_2O)

- Global emissions – 8.5 to 27.7 Tg N/year
- 100-yr GWP 298x CO_2
- Fourth largest radiative forcing (0.16 W m^{-2} in 2005)
- Land Sources
  - Fertilizer application (1.5-5% lost as N_2O)
  - Nitrification and denitrification

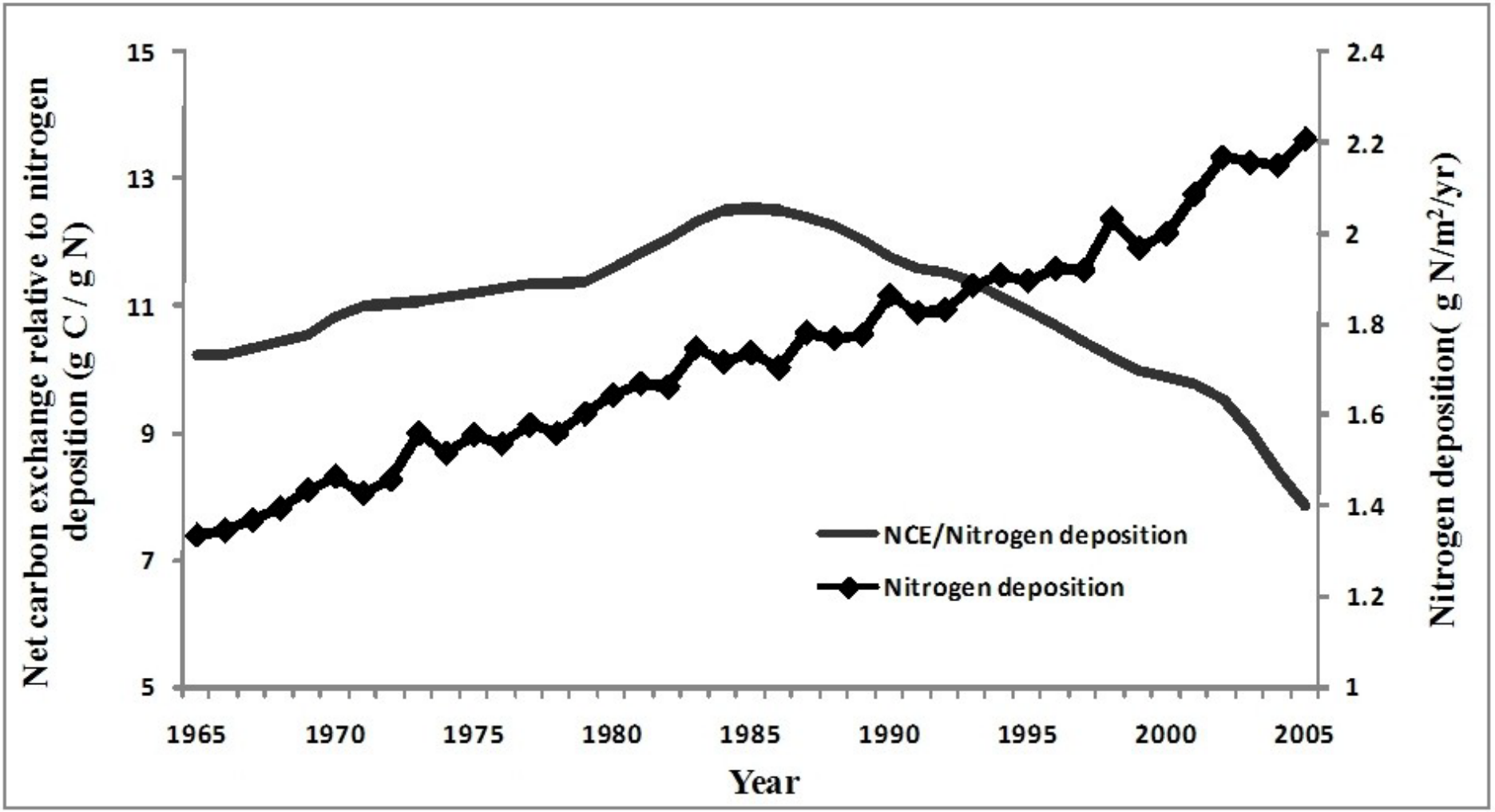
Interactions of Nitrous Oxide and Water





Potter et al. 1998, *Global Biogeochem. Cycles* **12(4),** 621-637.

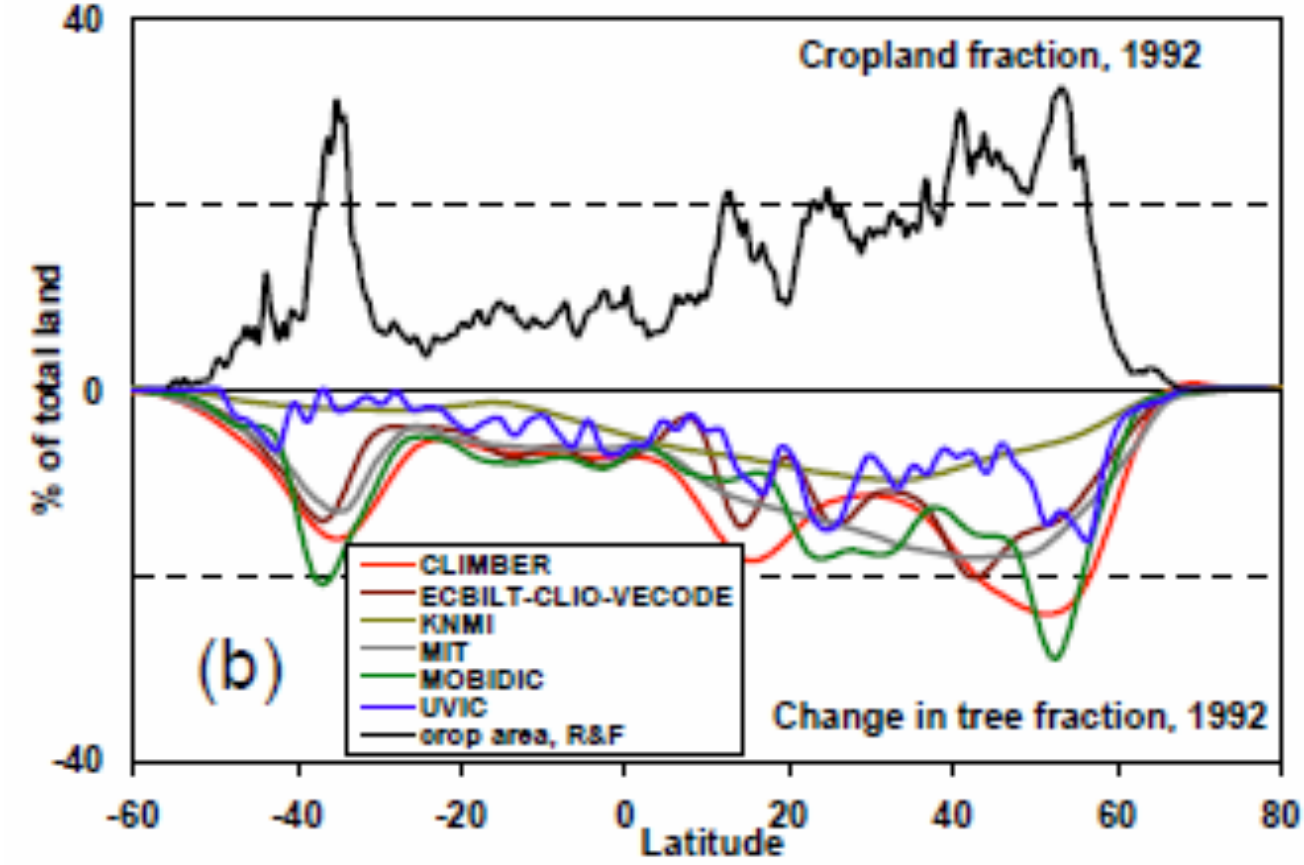
Simulated Nitrogen Saturation in China



Tian et al. 2011, *Global Biogeochem*. Cycles **25**, GB1007, doi: 10.1029/2010GB003838.

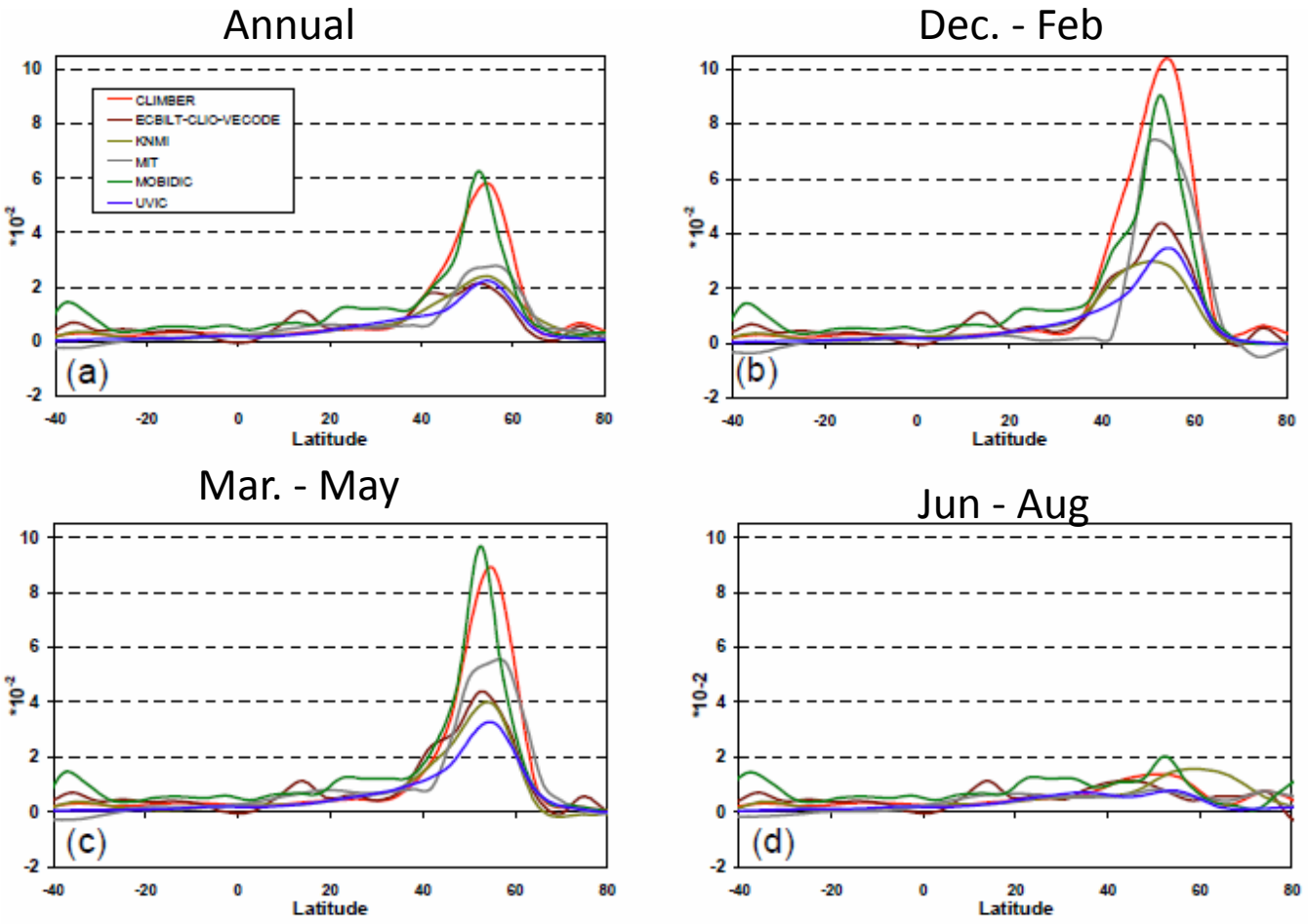
Albedo

Changes in Vegetation Cover, 1700-1992



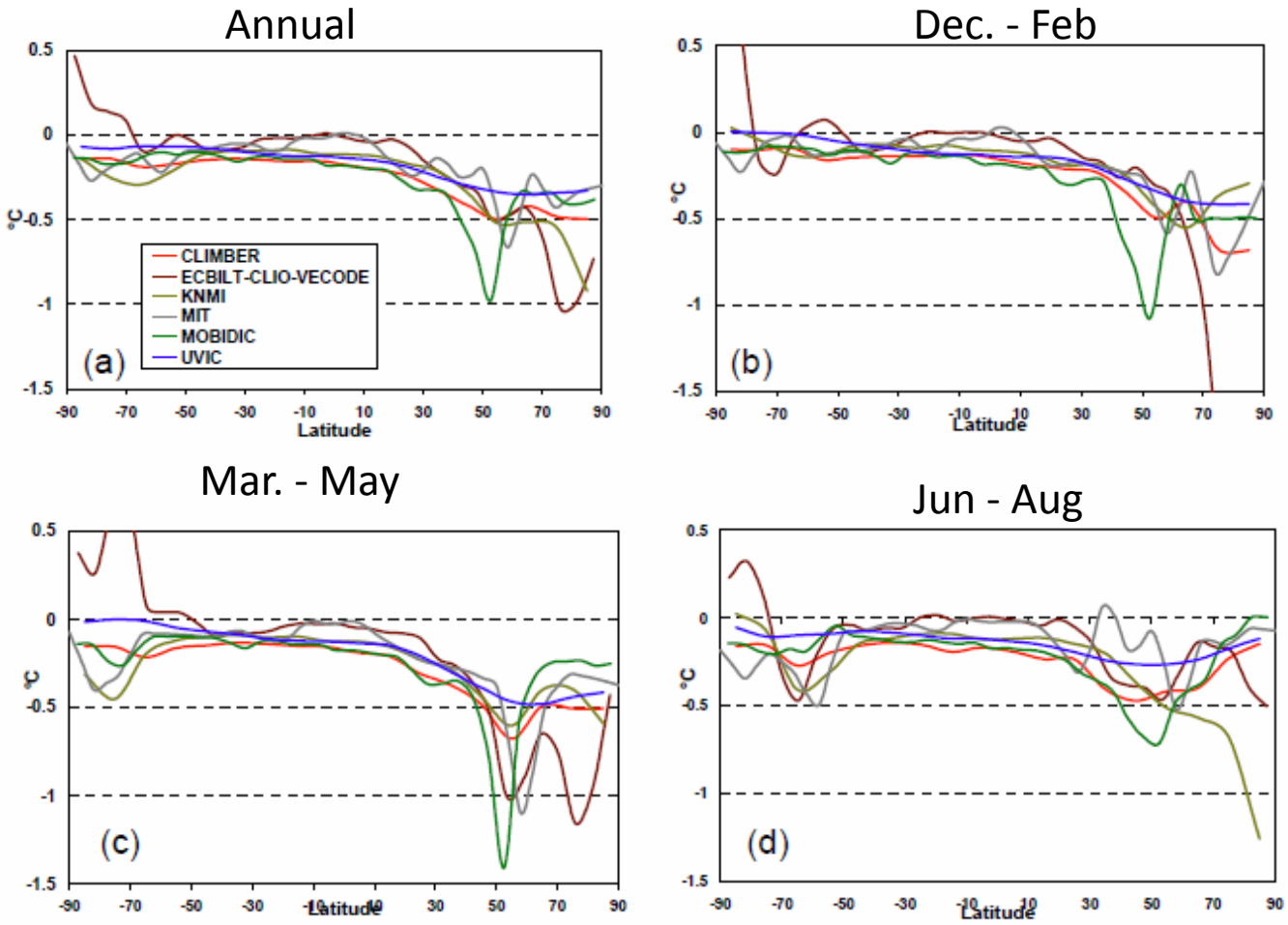
Brovkin et al. 2006, *Climate Dynamics* **26**, 587-600.

Changes in Zonally Averaged Albedo, 1700-1992



Brovkin et al. 2006, *Climate Dynamics* **26**, 587-600.

Changes in Zonally Averaged Land Surface Temperature, 1700-1992

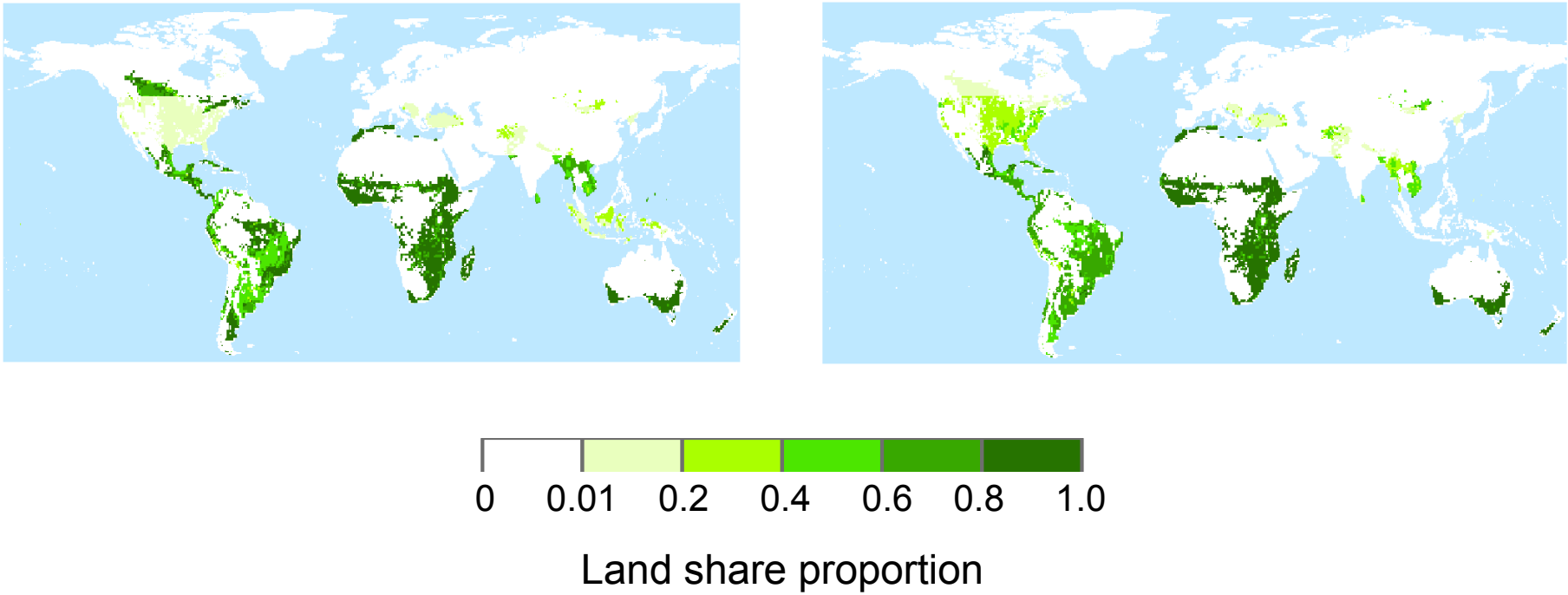


Brovkin et al. 2006, *Climate Dynamics* **26**, 587-600.

Distribution of Cellulosic Biofuels in 2100

Case 1 - Deforestation Scenario

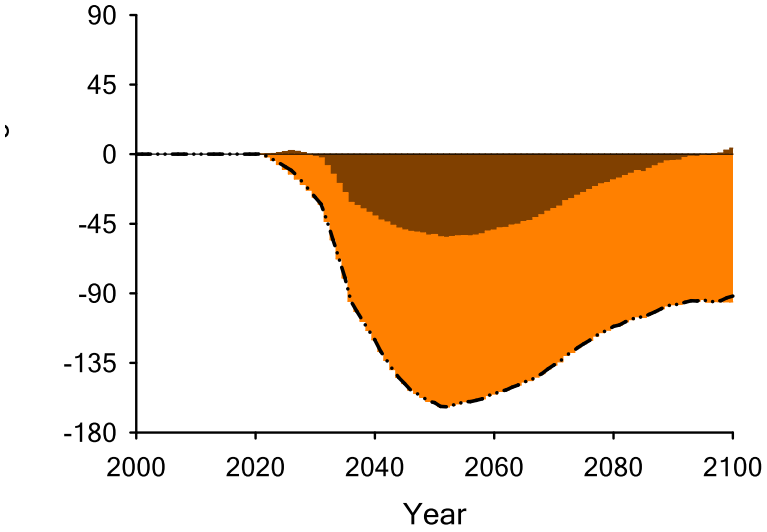
Case 2 - Intensification Scenario



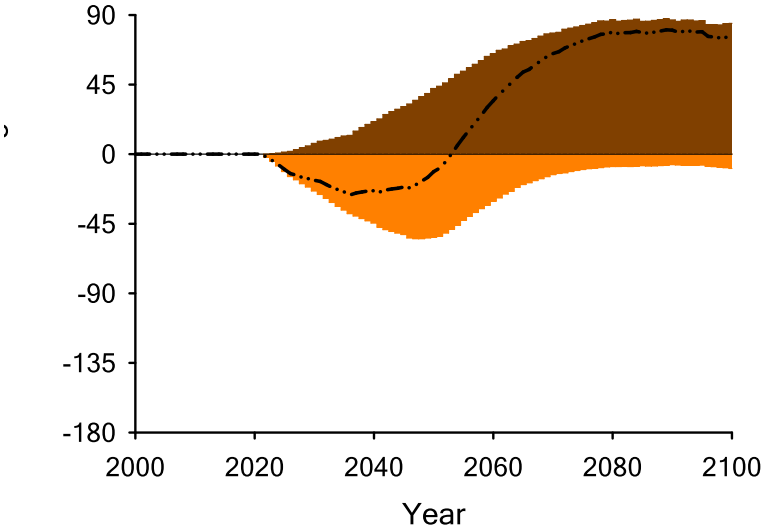
based on Melillo et al. 2009, *Science* **326**, 1397-1399

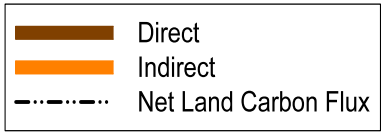
Net Land Carbon Flux - global

Case 1 - Deforestation Scenario



Case 2 - Intensification Scenario



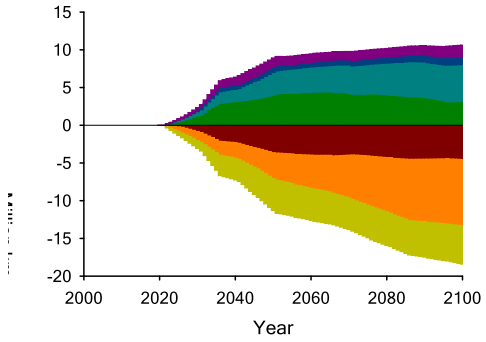


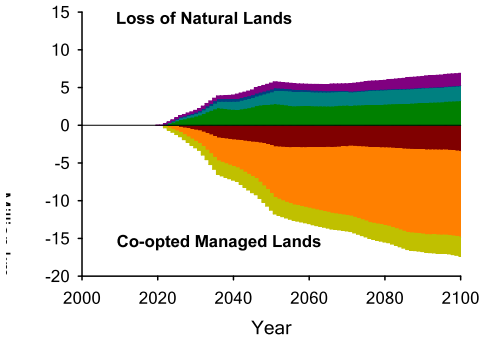
Melillo et al. 2009, *Science* **326**, 1397-1399

Case 1 - Deforestation Scenario

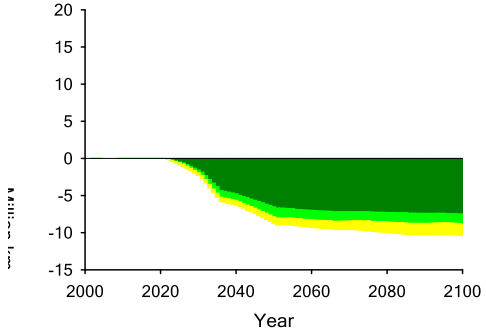
Case 2 - Intensification Scenario

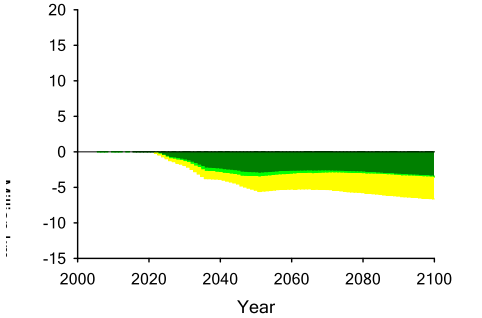
Co-opted Food Crops
Co-opted Pasture
Co-opted Managed Forests
Residual Biofuel
Displaced Food Crops
Displaced Pasture
Displaced Managed Forests



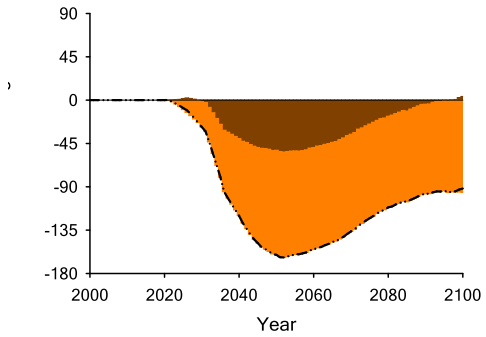


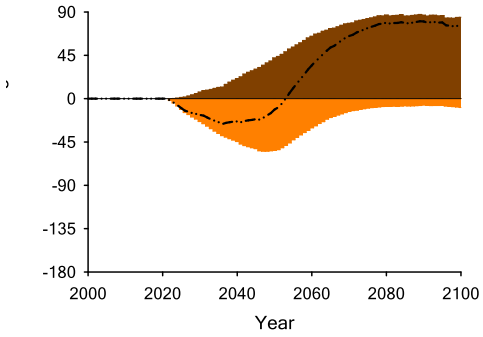
Natural Forests
Shrublands
Grasslands





Direct
Indirect
Net Land Carbon Flux



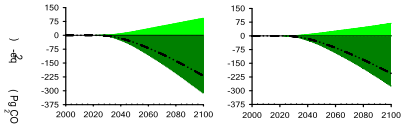


Kicklighter et al. MIT JP Report (in prep.)

Case 1 - Deforestation Scenario

Case 2 - Intensification Scenario

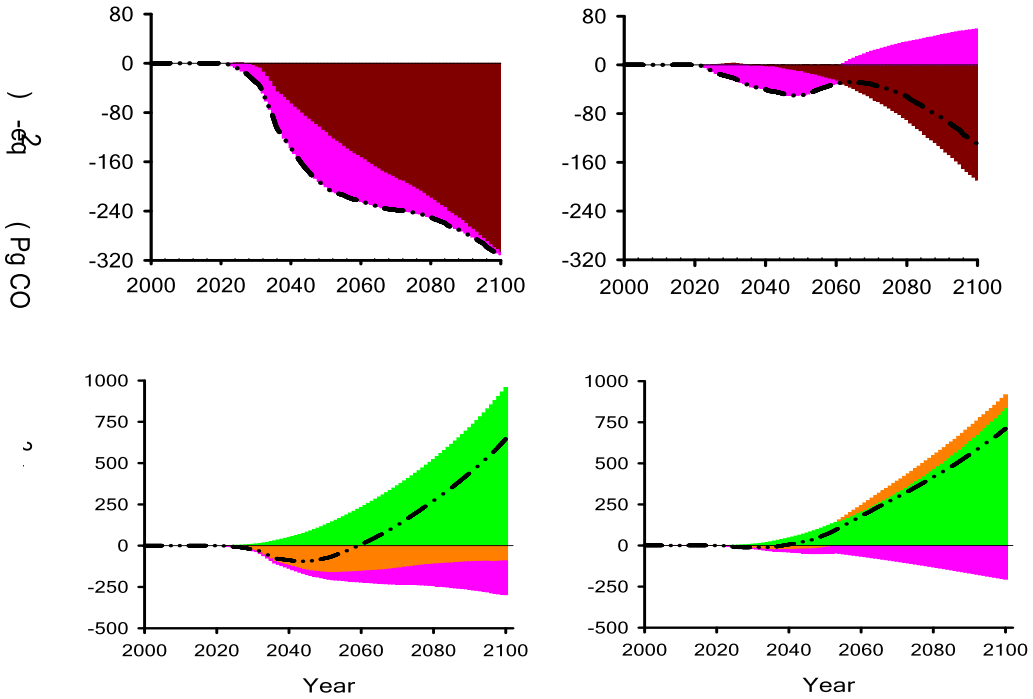
Case 2



Direct Effects
Indirect Effects
Net N_2O Abatement

Direct Effects
Indirect Effects
Net Land GHG Abatement

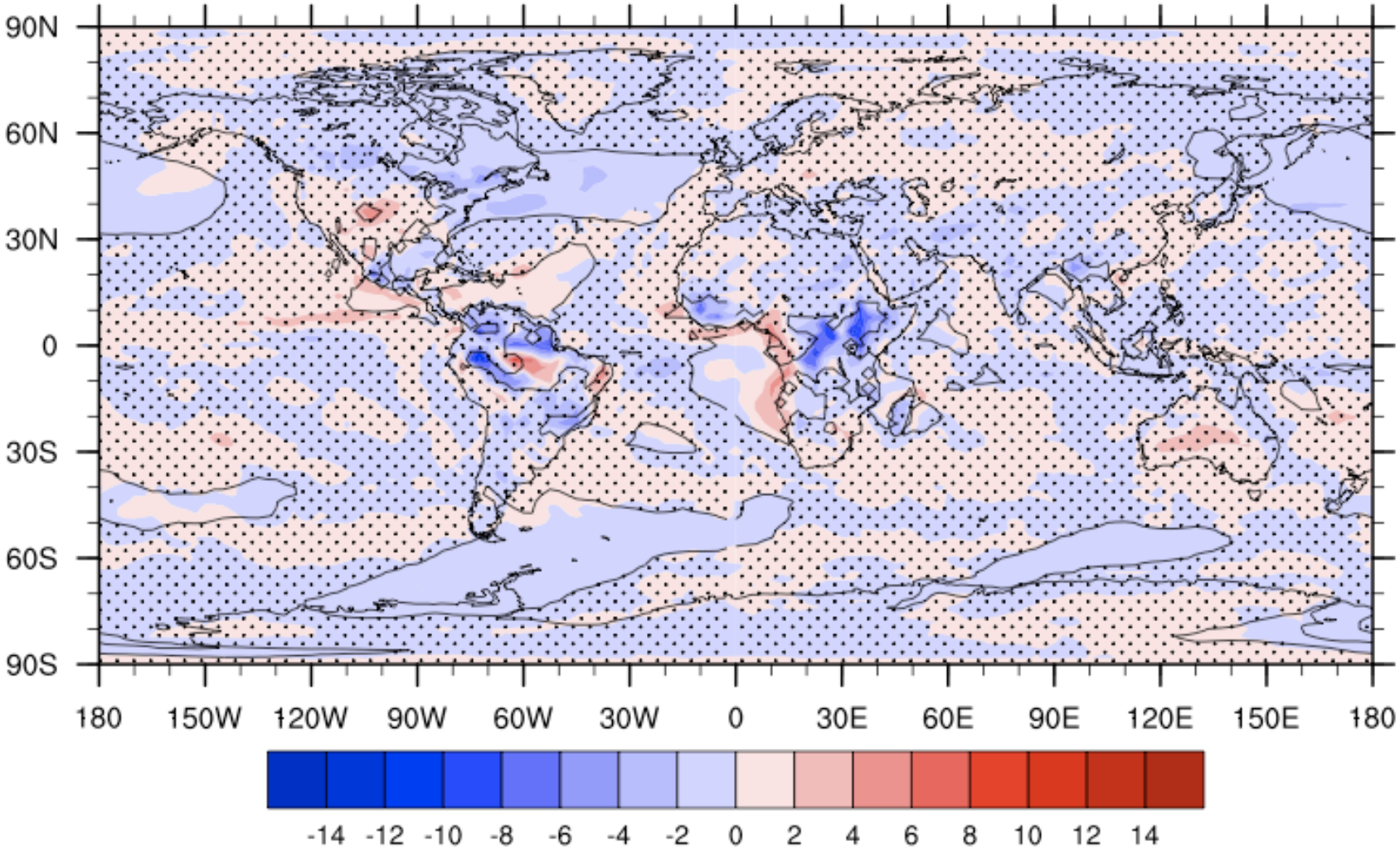
Fossil Fuel Abatement
Net Land Carbon Flux
Net N_2O Emissions
Net Abatement



Kicklighter et al. MIT JP Report (in prep.)

Changes in Latent Heat from Biofuels Production

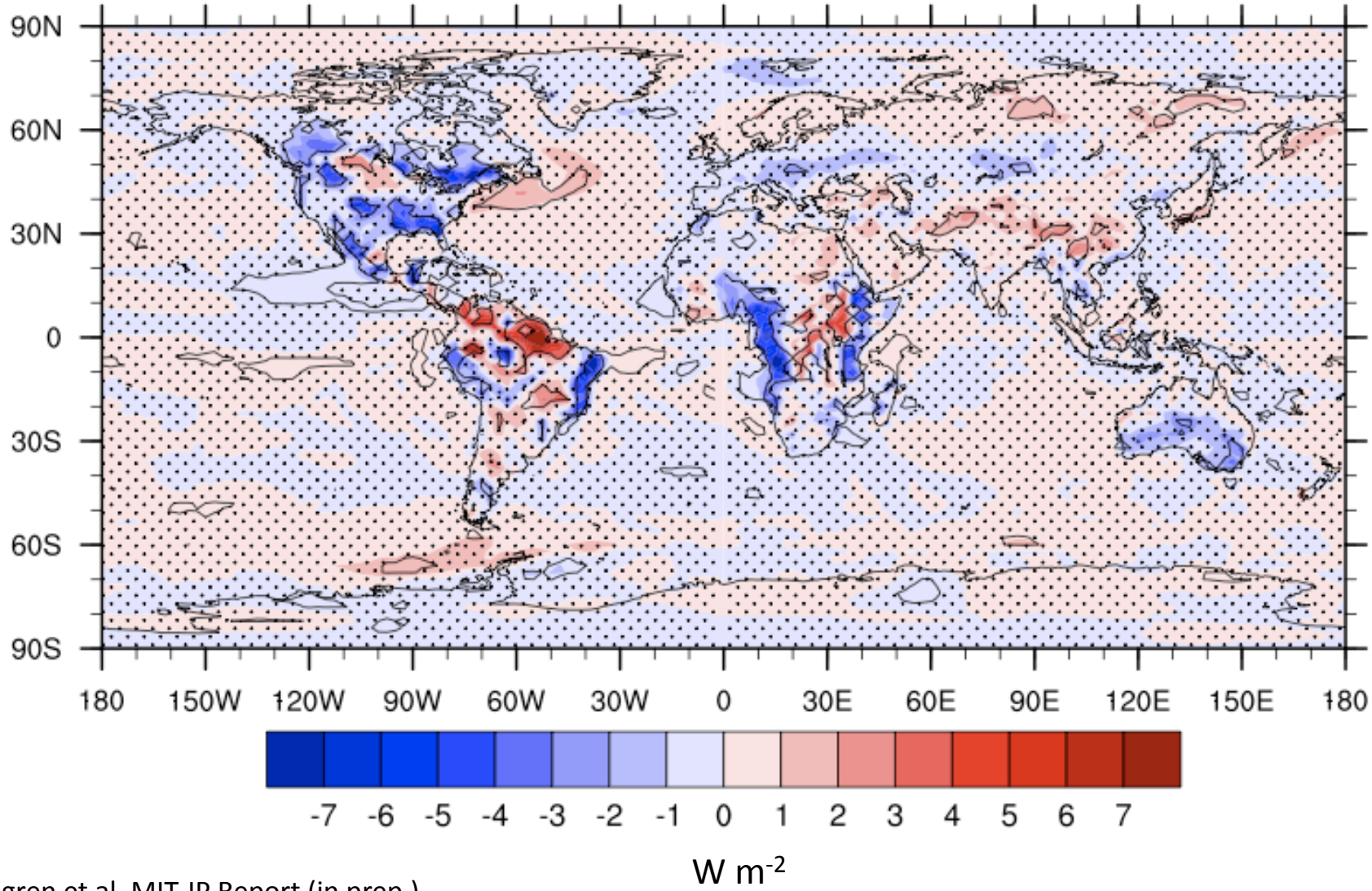
Case 1 – Deforestation Scenario , 1990-2050



Hallgren et al. MIT JP Report (in prep.)

Changes in Sensible Heat from Biofuels Production

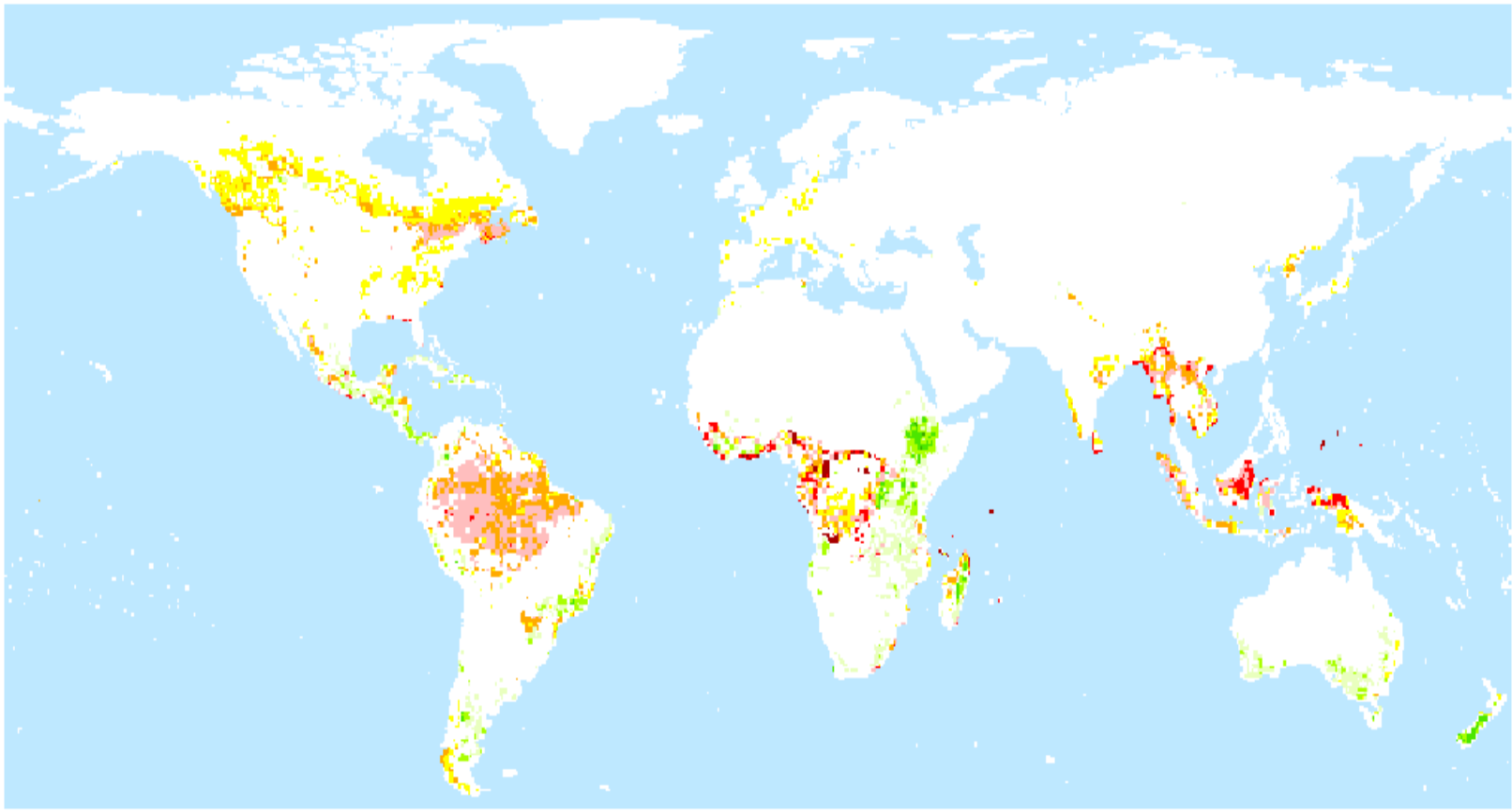
Case 1 – Deforestation Scenario, 1990-2050



Hallgren et al. MIT JP Report (in prep.)

Net Terrestrial Carbon Sequestration from Biofuels Production

Case 1 – Deforestation Scenario, 2001-2050

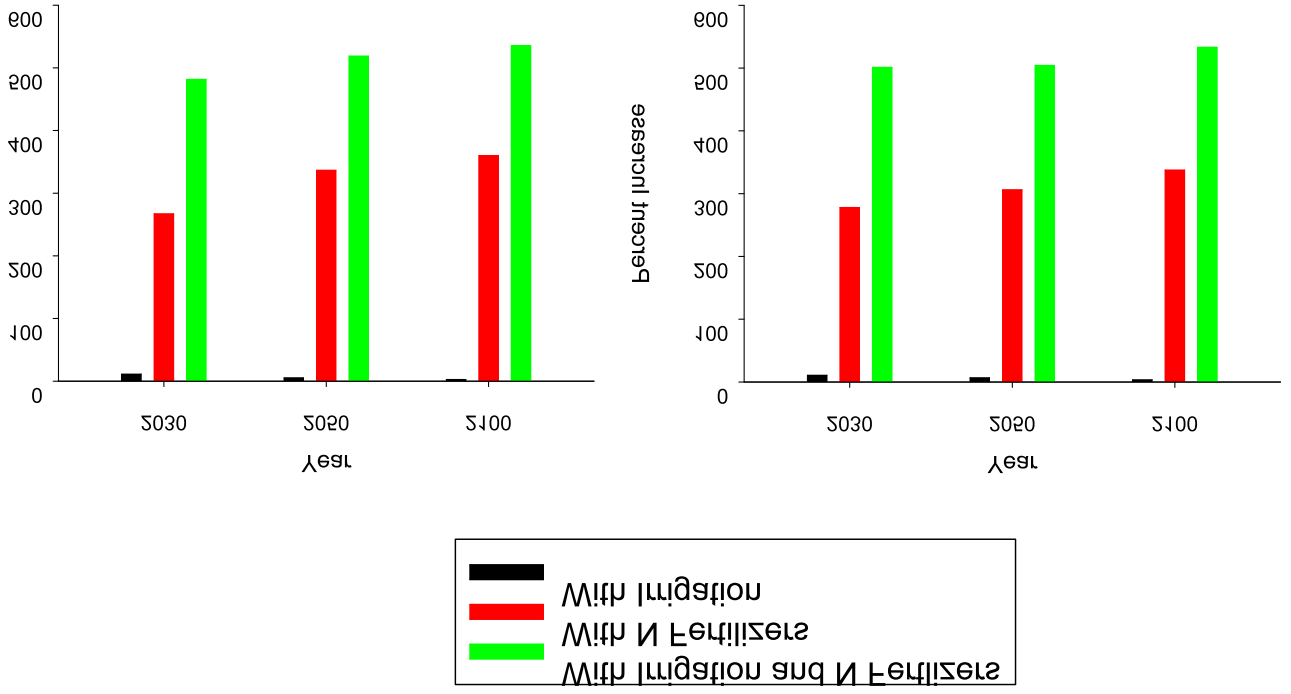


Kicklighter et al. MIT JP Report (in prep.)

Effect of Irrigation and N Fertilizer Applications on production of cellulosic biofuels over the 21st Century

Case 1 - Deforestation Scenario

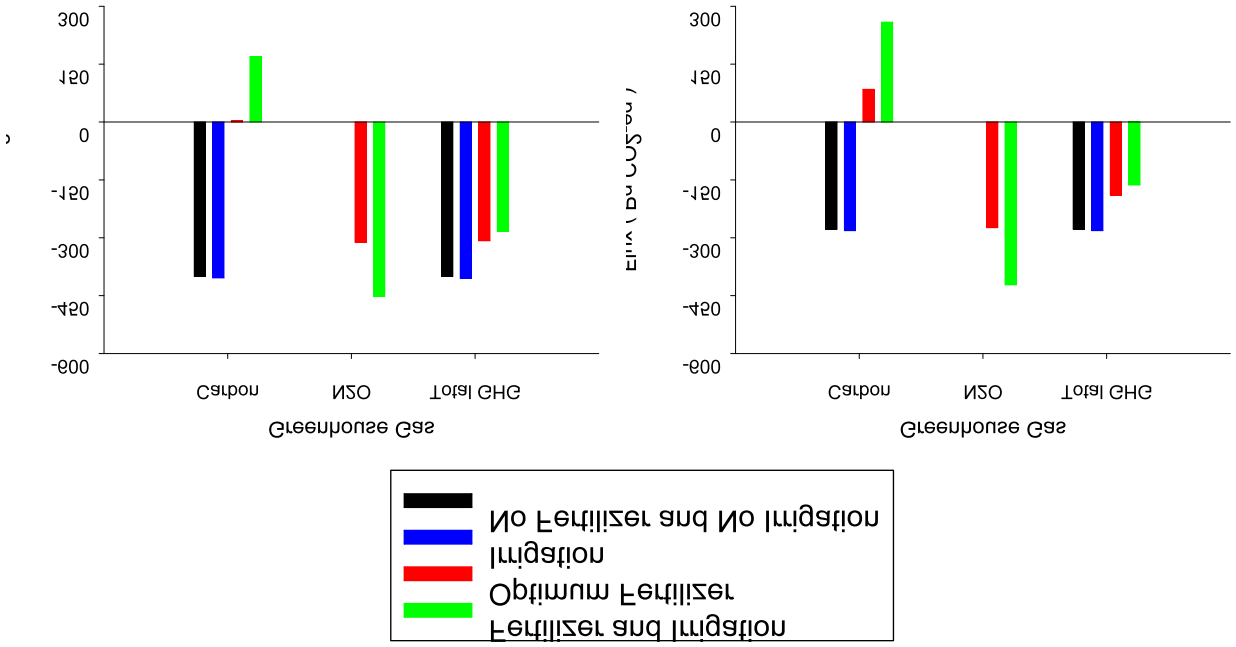
Case 2 - Intensification Scenario



Effect of Irrigation and N Fertilizer Applications on GHG fluxes from biofuels over the 21st Century

Case 1 - Deforestation Scenario

Case 2 - Intensification Scenario



Conclusions

- Carbon/nitrogen interactions should be included in future climate change assessments
- Land N_2O emissions could become a more important factor forcing climate change in the future
- The relative roles of ecosystem biophysics (ET, albedo) and biochemistry (CO_2, CH_4, N_2O) on future climate change need further study
- Further study is needed on the effect of disturbances on the energy-land-water-nitrogen nexus