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Land-Use Change and Associated Changes in Biogeochemical and Biophysical Processes in Monsoon Asian Region (MAR)

Atul Jain
University of Illinois, Urbana, IL 61801, USA
Email: jain1@uiuc.edu

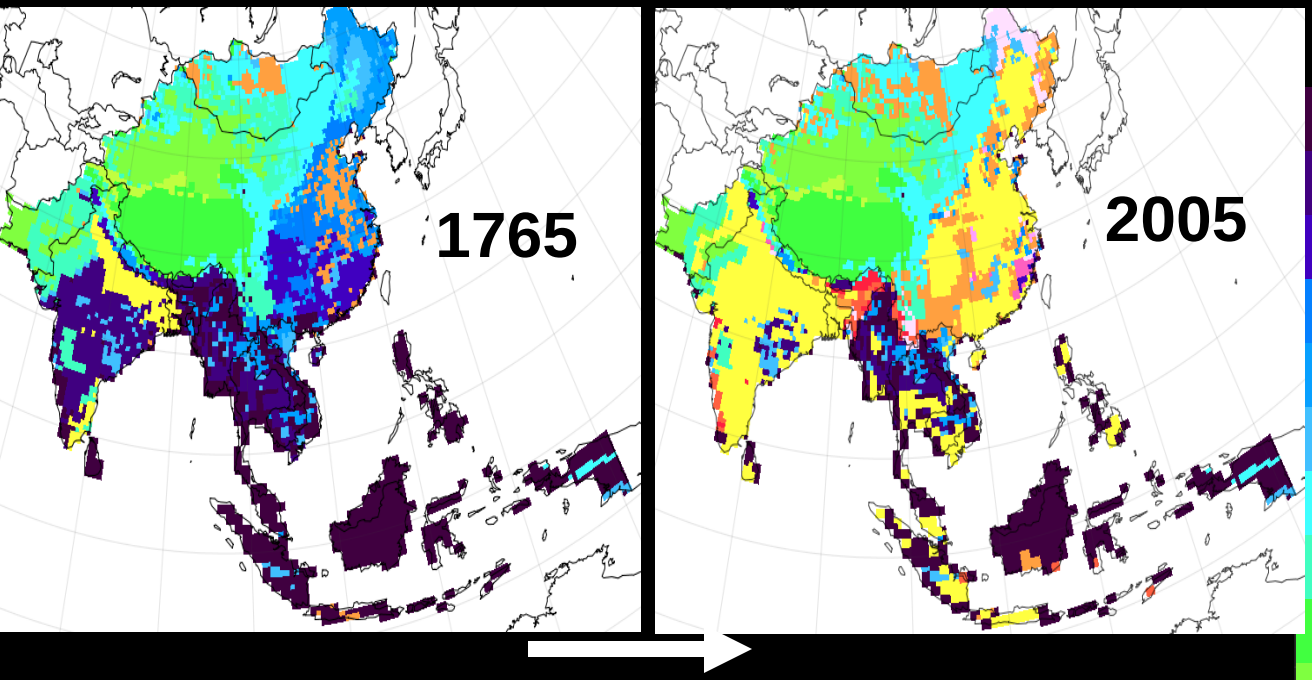
Team Members

Ramakrishna Nemani, NASA Ames

David Skole, Michigan State University

Brian O'Neill, NCAR

Land Cover Change in MAR



Biome Types

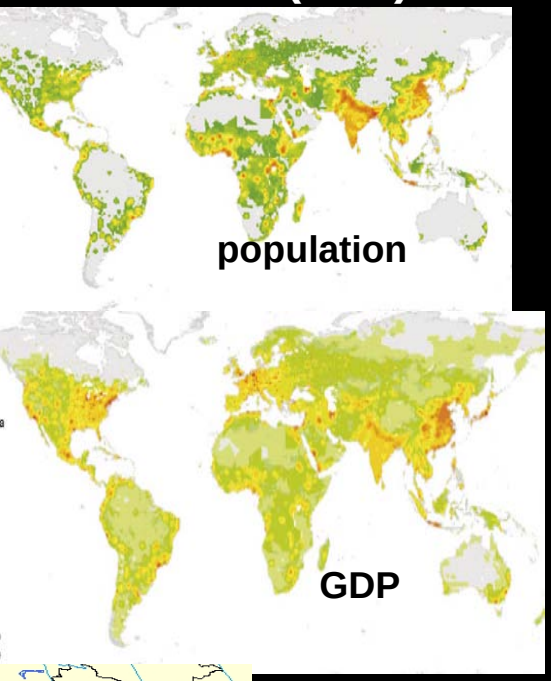
- Tropical Evergreen
- Tropical Deciduous
- Temperate Evergreen
- Temperate Deciduous
- Boreal Forest
- Savanna
- Grassland
- Shrubland
- Tundra
- Desert
- Polar Desert
- Cropland
- Pastureland
- Sec. Tropical Evergreen
- Sec. Tropical Deciduous
- Sec. Temperate Evergreen
- Sec. Temperate Deciduous
- Sec. Boreal Forest

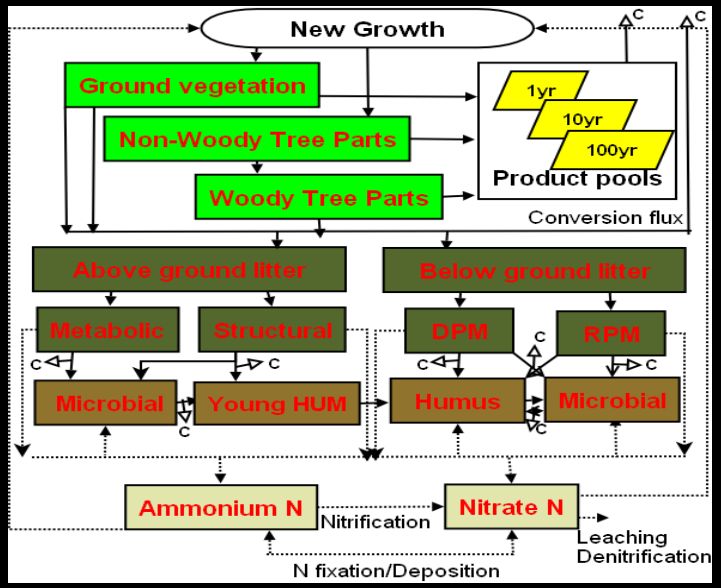
- Less primary land, more secondary land, more cropland and pastureland
- Land use alters : *Atmospheric CO_2, N cycle, albedo, runoff, soil water holding capacity, dust*

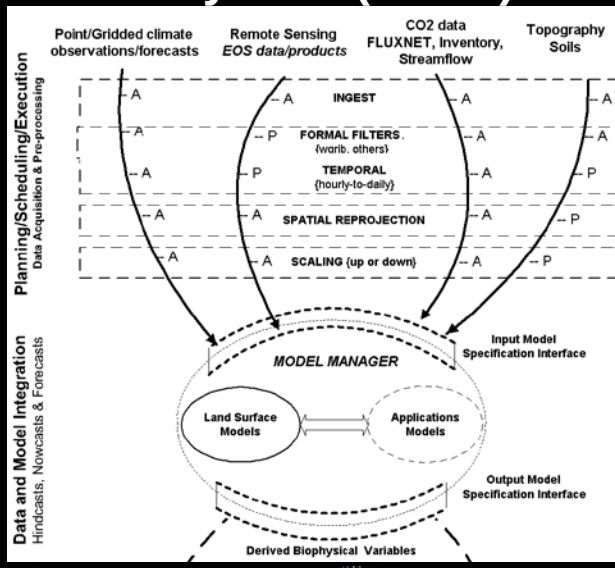
Jain and Yang (2005, GBC); Jain et al. (2009, GBC); Yang et al. (2009, GBC); Yang et al. (2010, Biogeoscience)

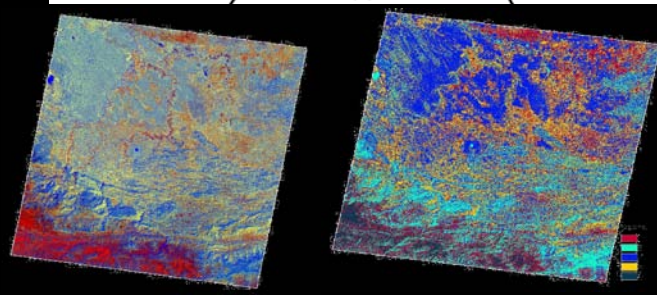
Terrestrial Ecosystems, Land Use Changes and Carbon Dynamics

Socio-Economic Model (PET) ⟷ ISAM Model ⟷ The Terrestrial Observation and Prediction System (TOPS)





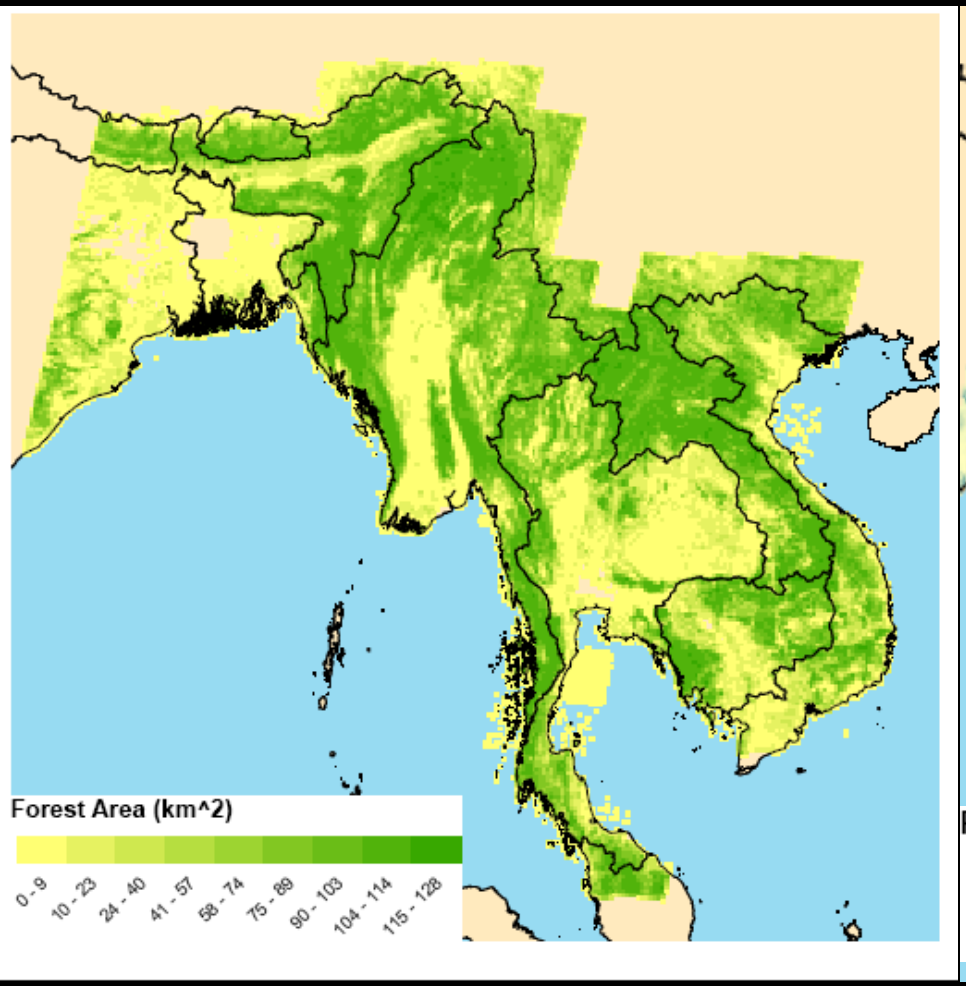




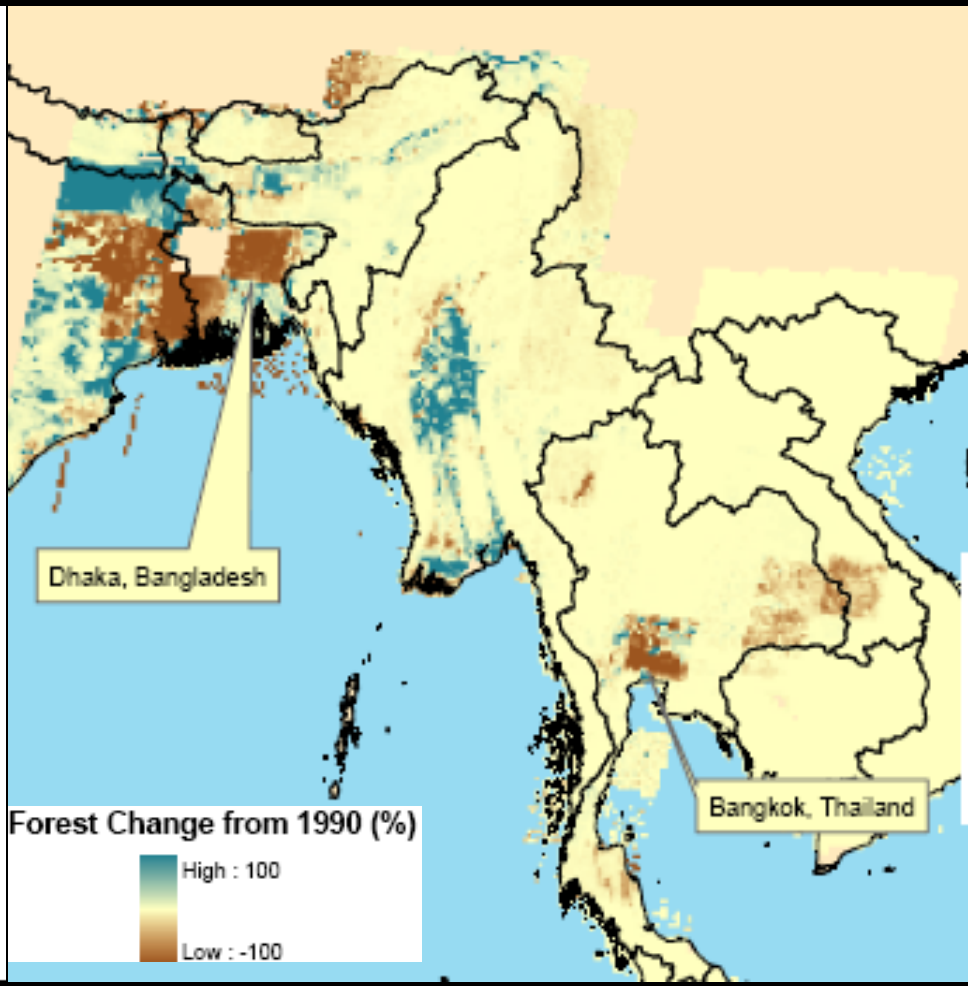
Satellite Measurements

Satellite Measurements

Landset Satellite Data 1990 & 2000



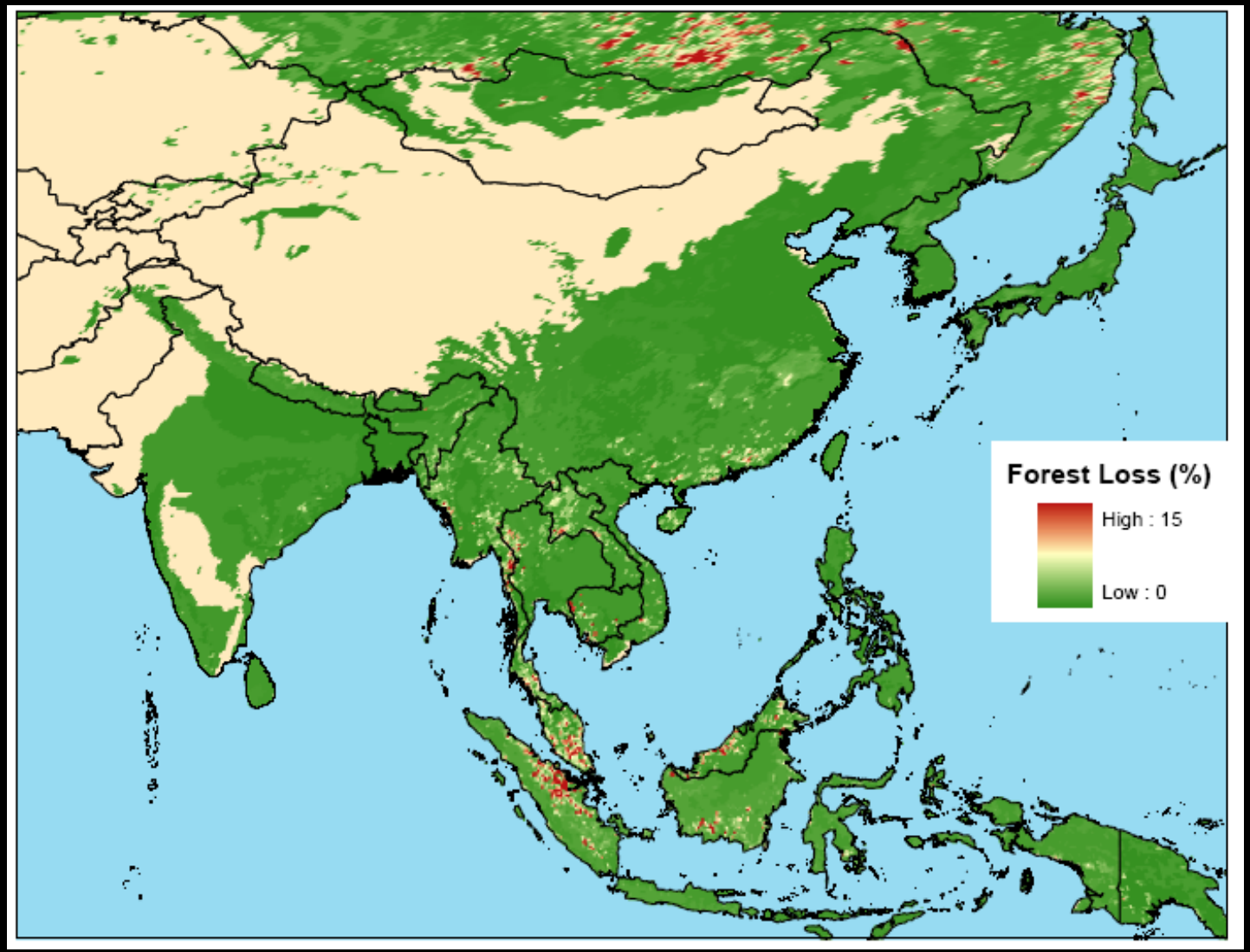
2000



Area change (%) from 1990

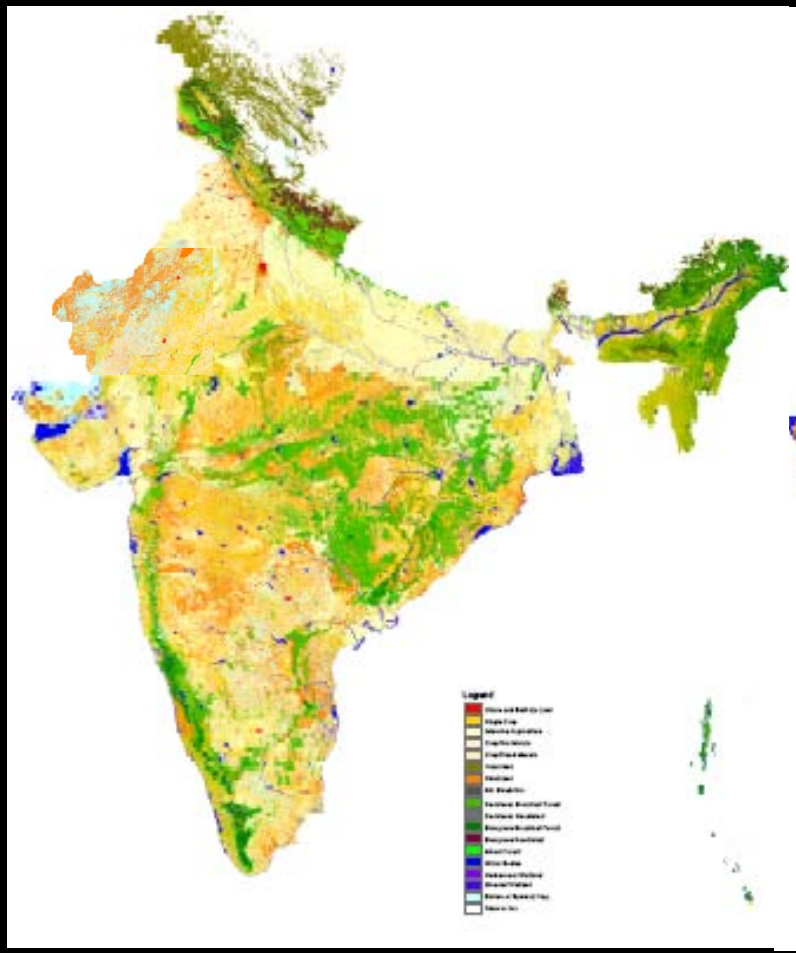
Courtesy: David Skole (MSU)

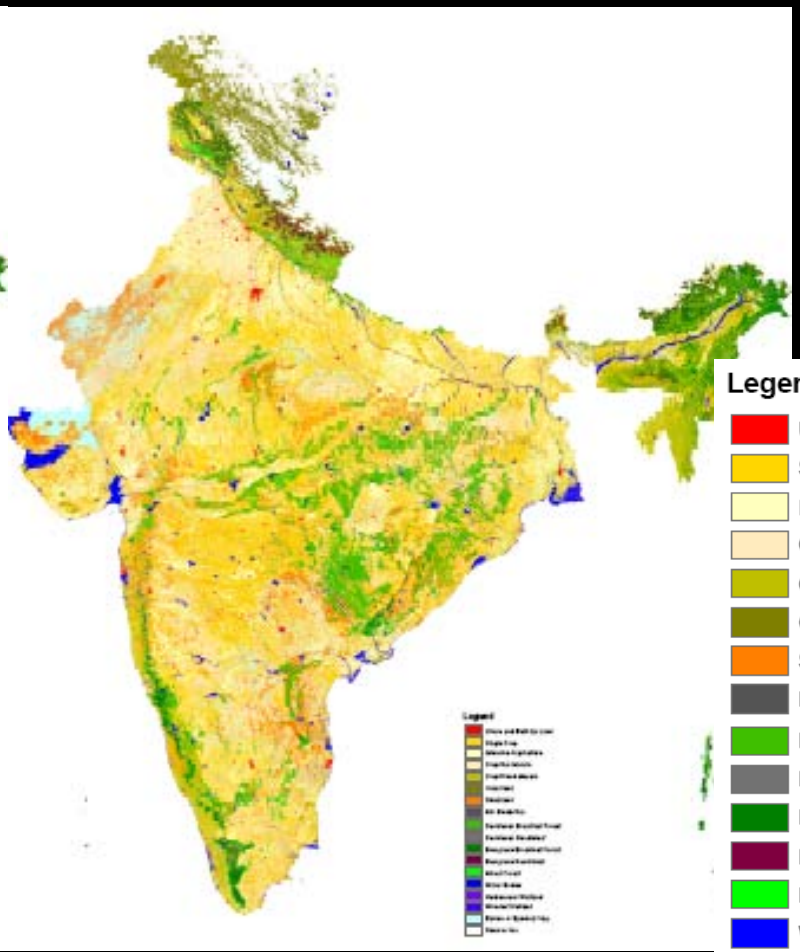
Forest Area Change Based on MODIS Data (2000-2005)



Courtesy: Matt Hansen (South Dakota State University)

Land Use and Land Cover of India





Year 2000

Sensor: IRS 1D -WiFS

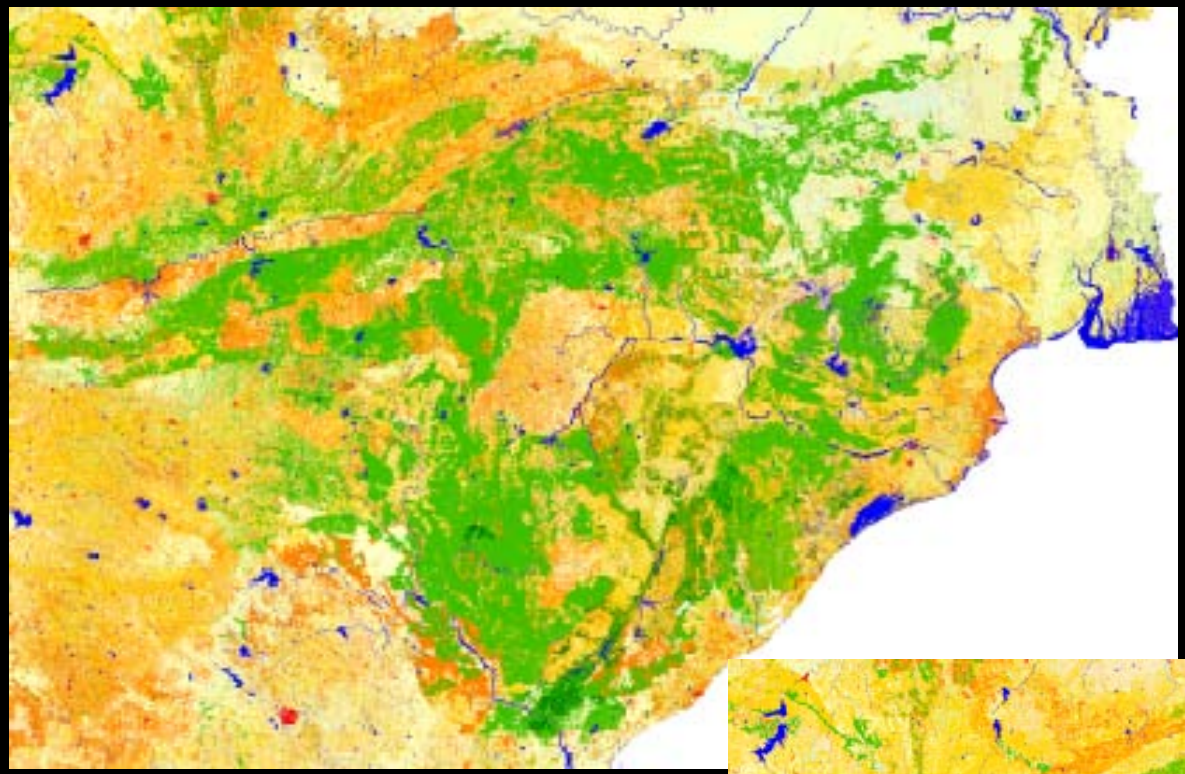
Resolution: 180 m

Year 2007-2008

Sensor: IRS P6 – AWiFS

Resolution: 56 m

Courtesy: P. S. Roy (IRS)

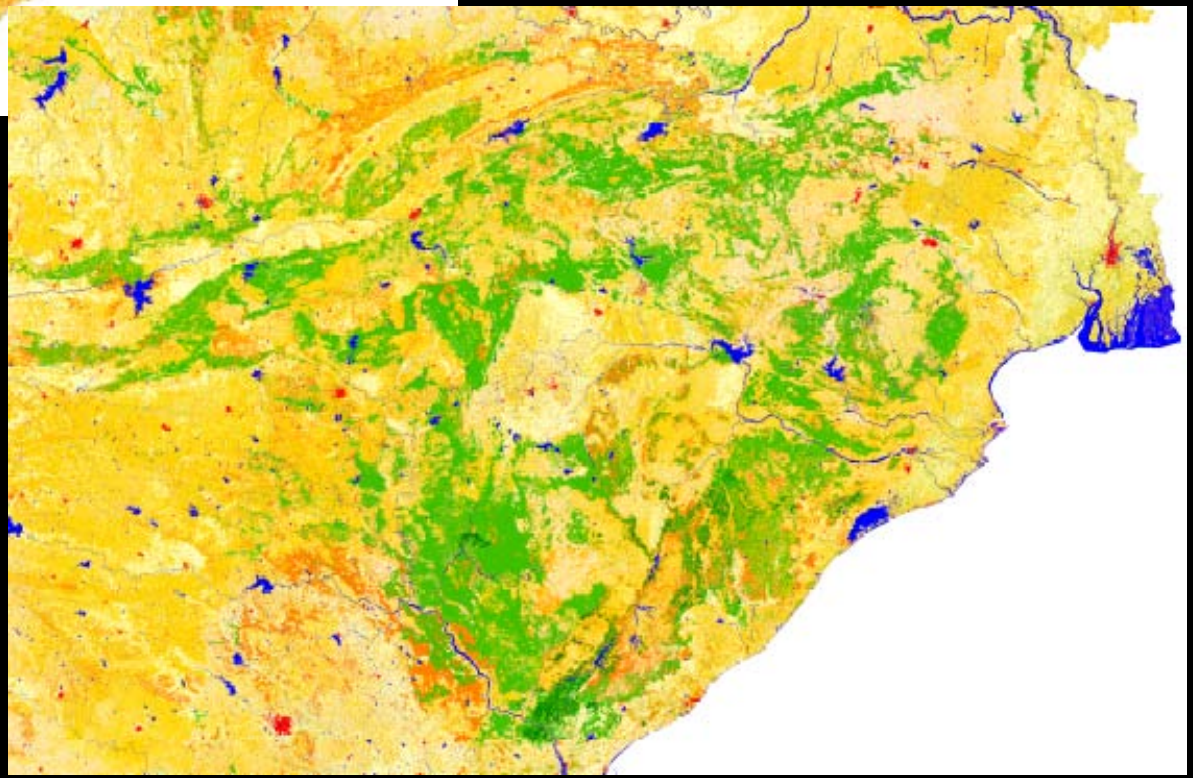


Year 2000

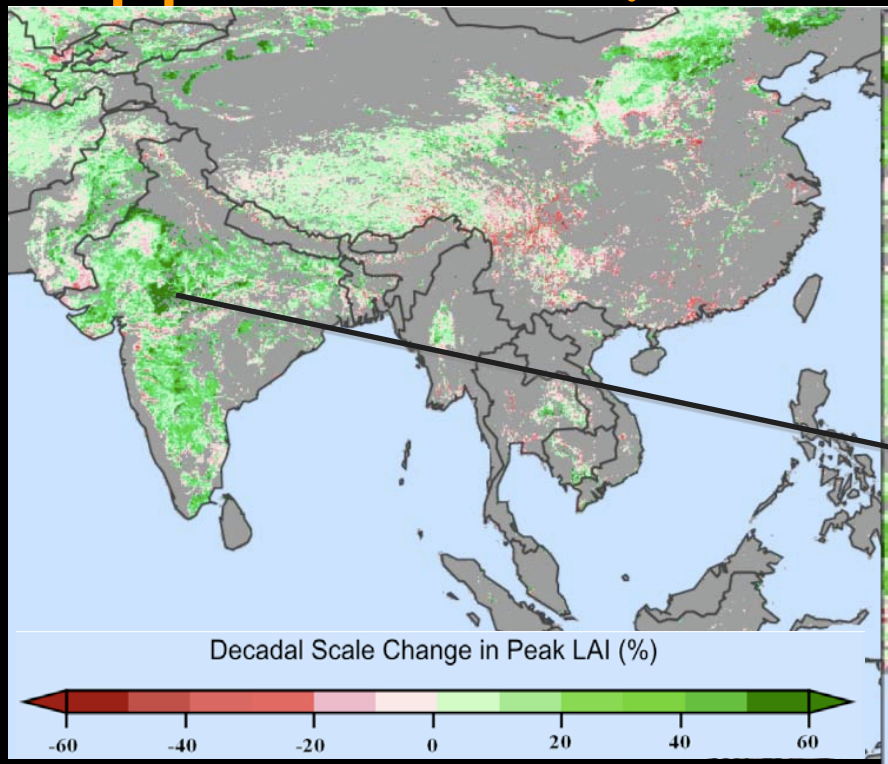
Sensor: IRS 1D -WiFS

Year 2007-2008

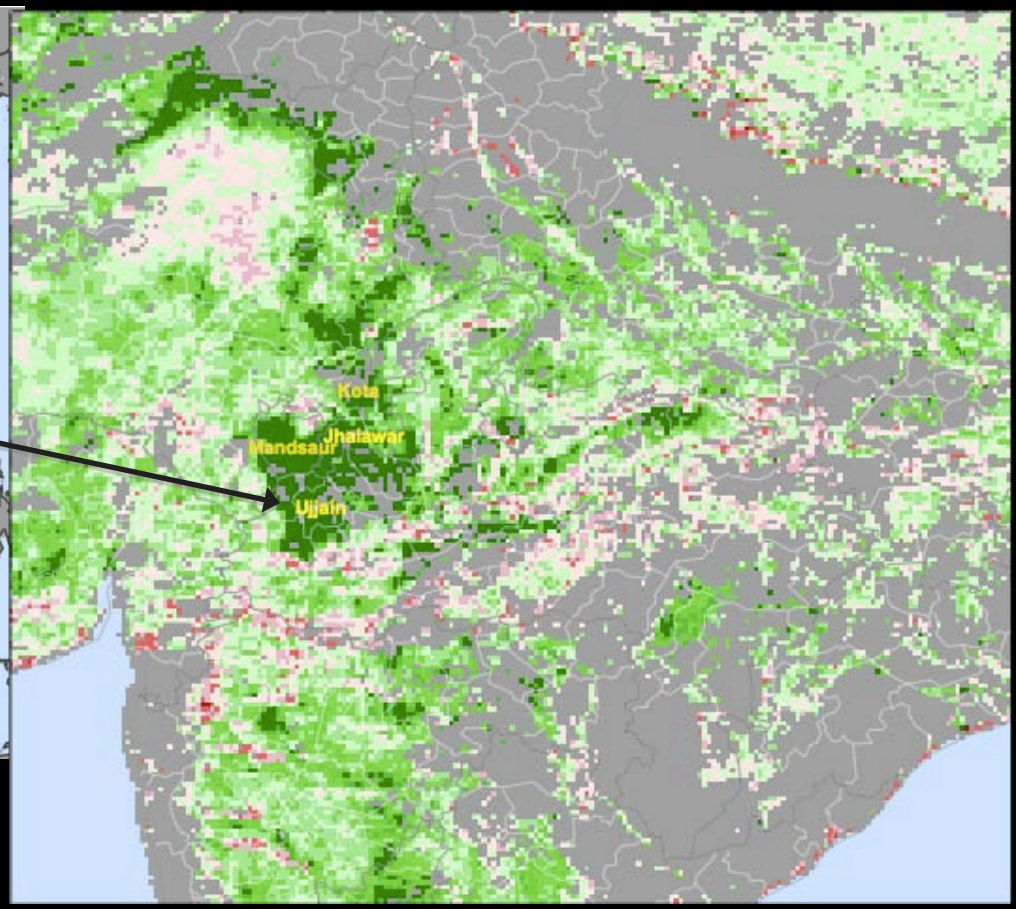
Sensor: IRS P6 – AWiFS



Biophysical Products - LAI
Application of AVHRR and MODIS Data



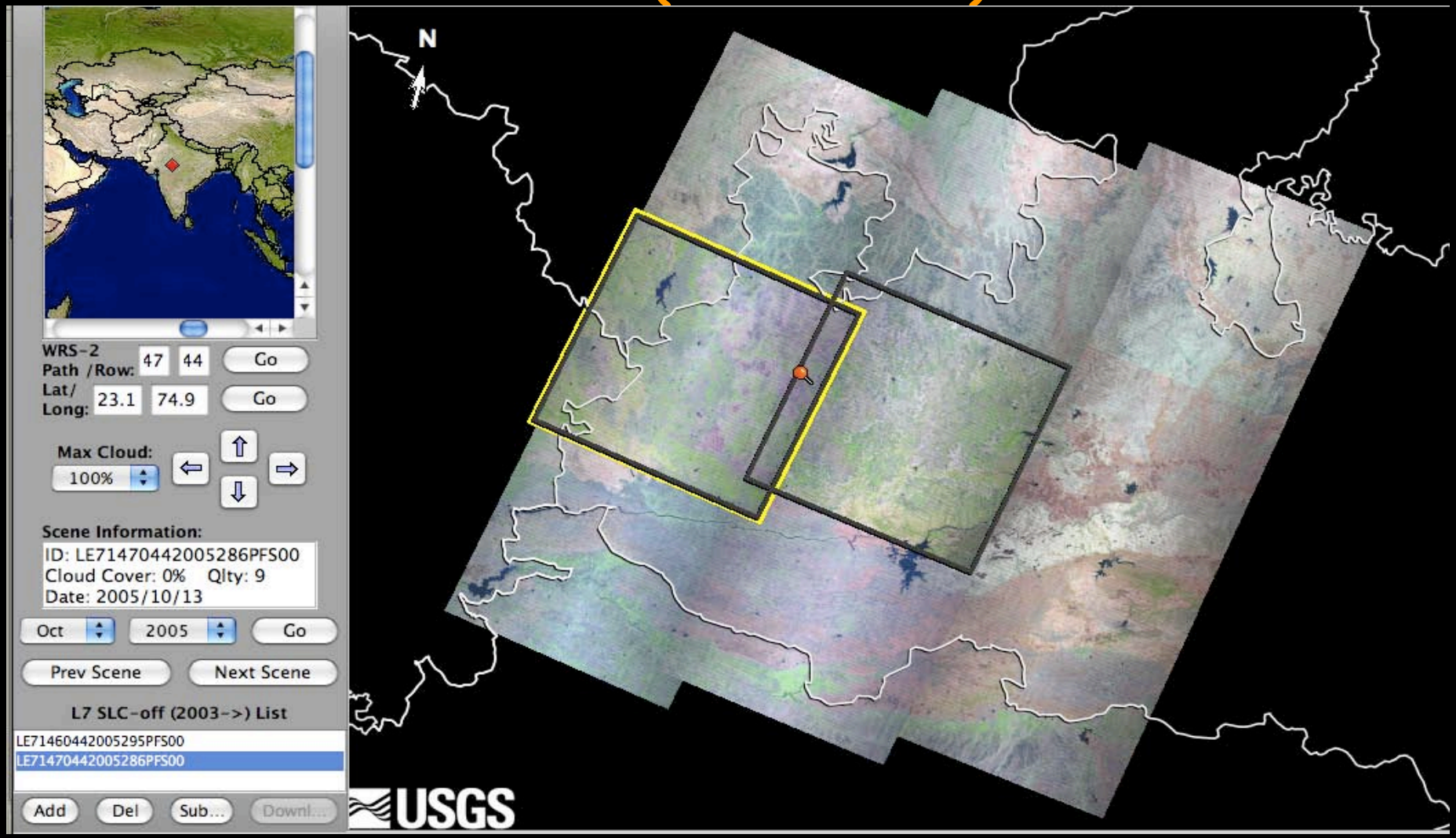
Resolution: 8 km



- Correspond to the region covering parts of Rajasthan and Madhya Pradesh, where there has been significant changes in LAI.
- Percent change in mean peak annual LAI between decade 1 (1981-1990) and decade 2 (1995-2006)

Courtesy: R. Nemani & S. Ganguly (NASA Ames)

LAI Derived from Landsat Global Land Survey 2005 (GLS2005)

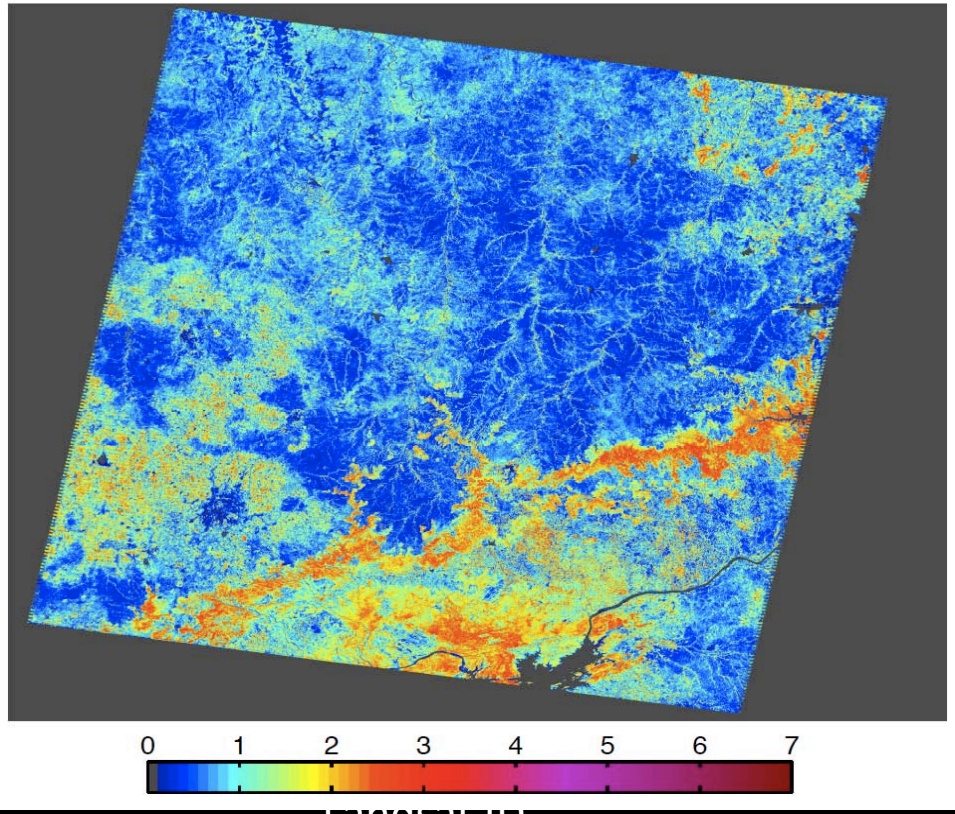


Two scenes (path-147,row-44 & path-146,row-44) correspond to the region shown in previous Slide.

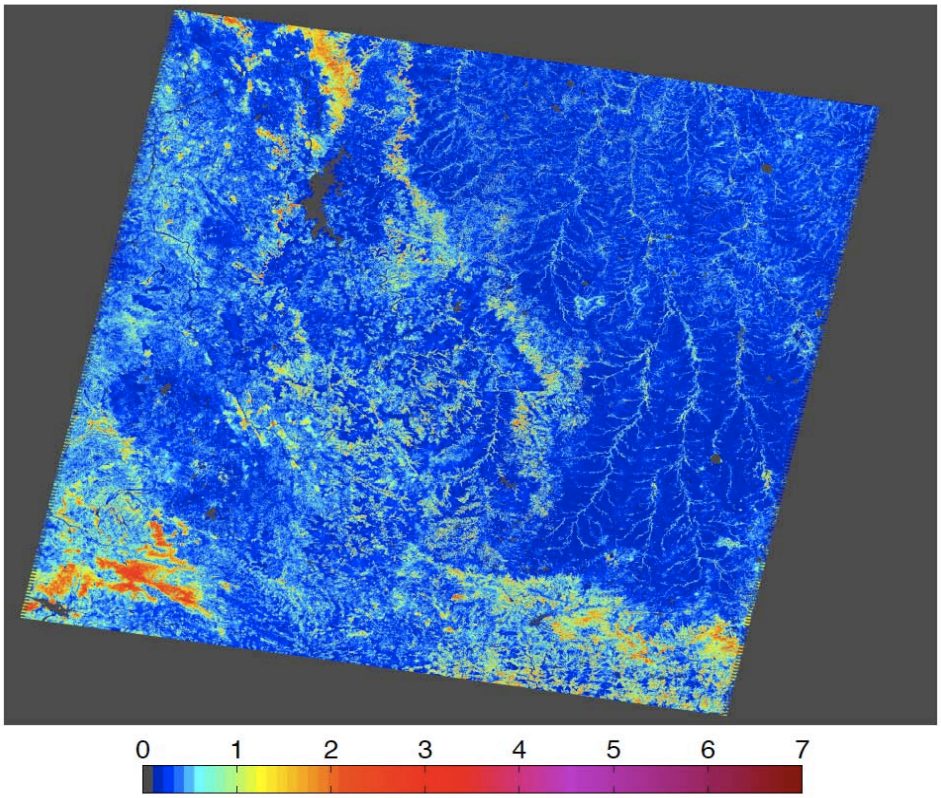
(*courtesy*: USGS Landsat Global Visualization Viewer)

LAI Derived from the GLS2005

Scenes are performed using Landset Ecosystem Disturbance Adaptive Processes System (LEDAPS) for radiometric calibration



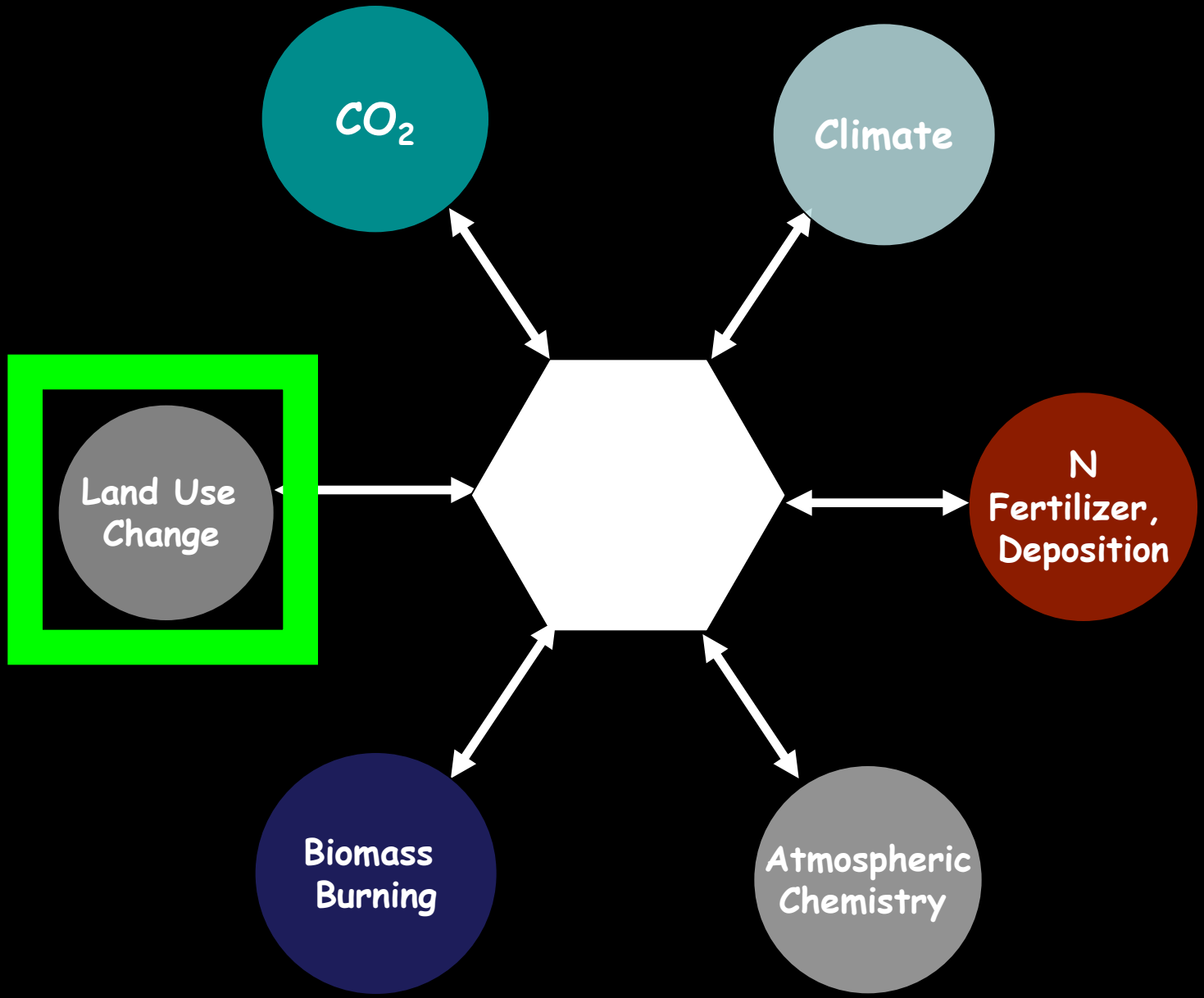
Landsat ID
Path: 146
Row: 44
Acquisition Date:
6th Oct, 2005



Landsat ID
Path: 147
Row: 44
Acquisition Date:
1st Nov, 2006

Impact of LCLUC on Biogeochemistry: Carbon and Nitrogen Dynamics & Emissions

LUC, Terrestrial Ecosystems and Environmental Factors

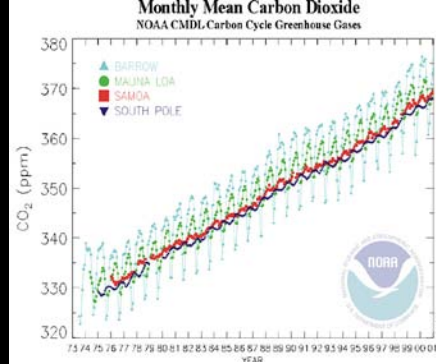


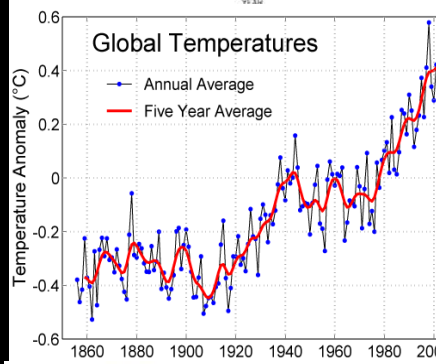
Questions?

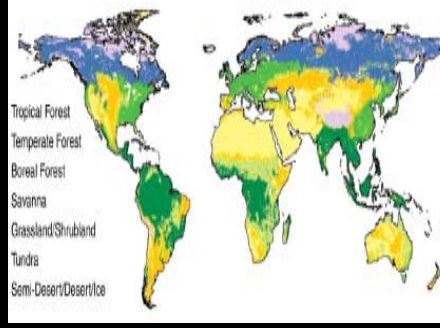
- What are the relative contributions of
  - LCLUCs for cropland, pastureland and wood harvest
  - Secondary forests
  - N deposition and fertilizer
  - agriculture management
  - Fire

  on
  - Biogeochemistry (ecosystems and carbon and nitrogen dynamics)
  - Biophysical Processes (LH, SH, Albedo)

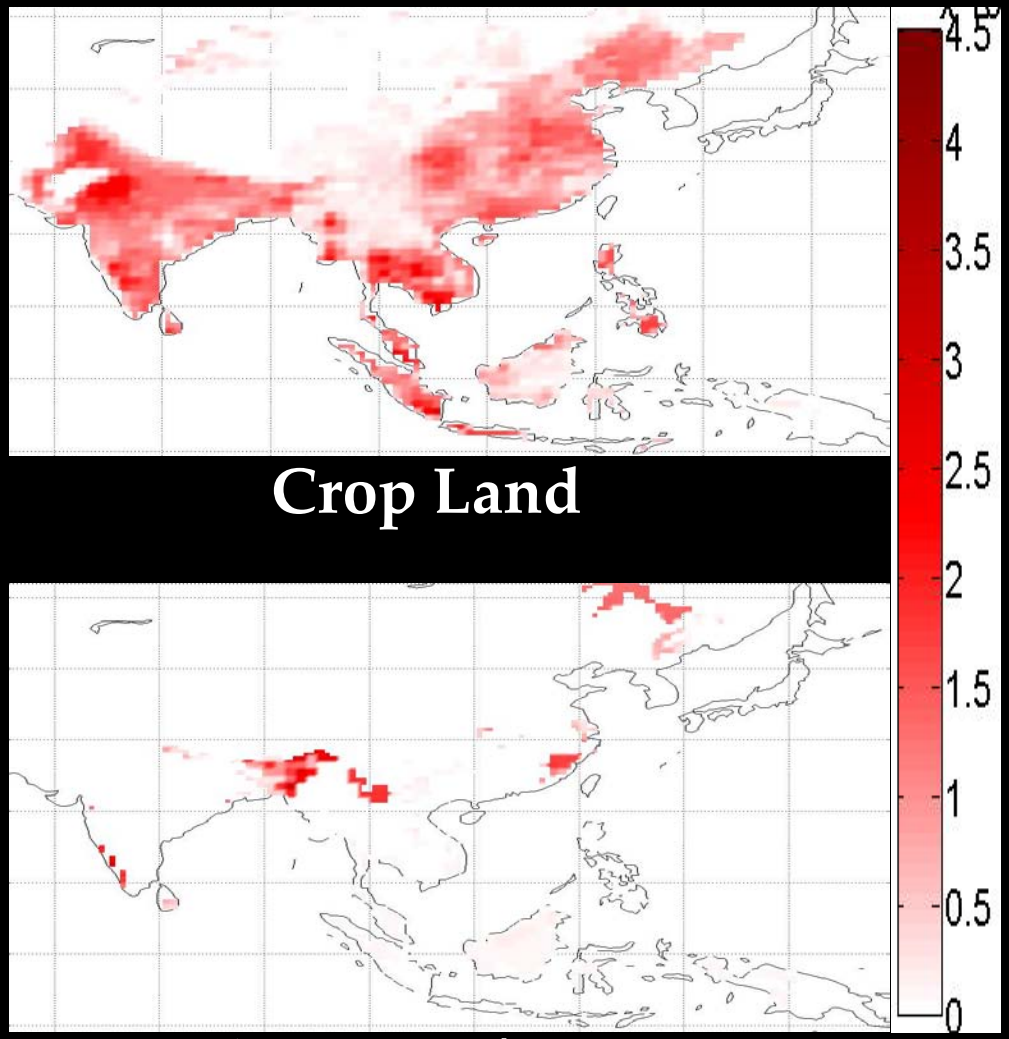
  in and South and South East Asia (SSEA) ?
- What are their synergistic effects?







Land Use Changes due to Different Activities (10^9 m^2)



Crop Land

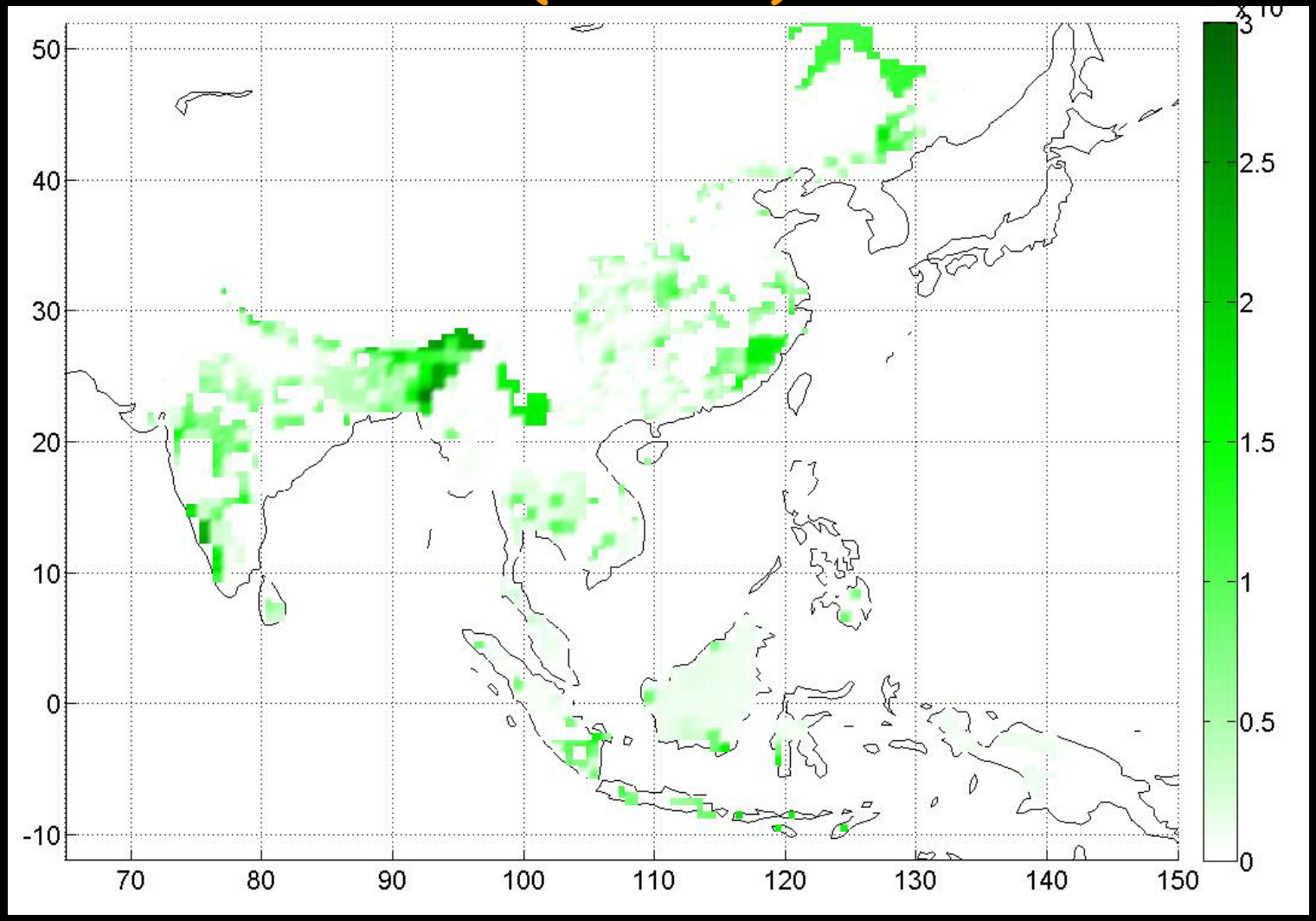
Pasture Land

Wood Harvest/Forest Fires

Total

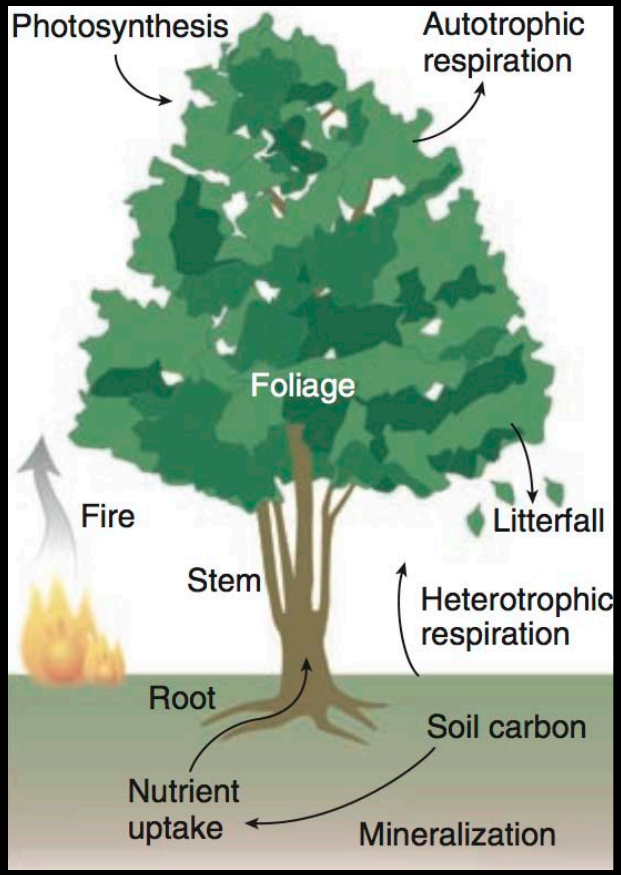
Sources: Hurtt et al. (2006), Ramanlutty and Foley (1999), FAO (2008), MODIS Satellite

Secondary Forest Area from Cropland, Pastureland, and Wood Harvest Activities (10^9 m^2)

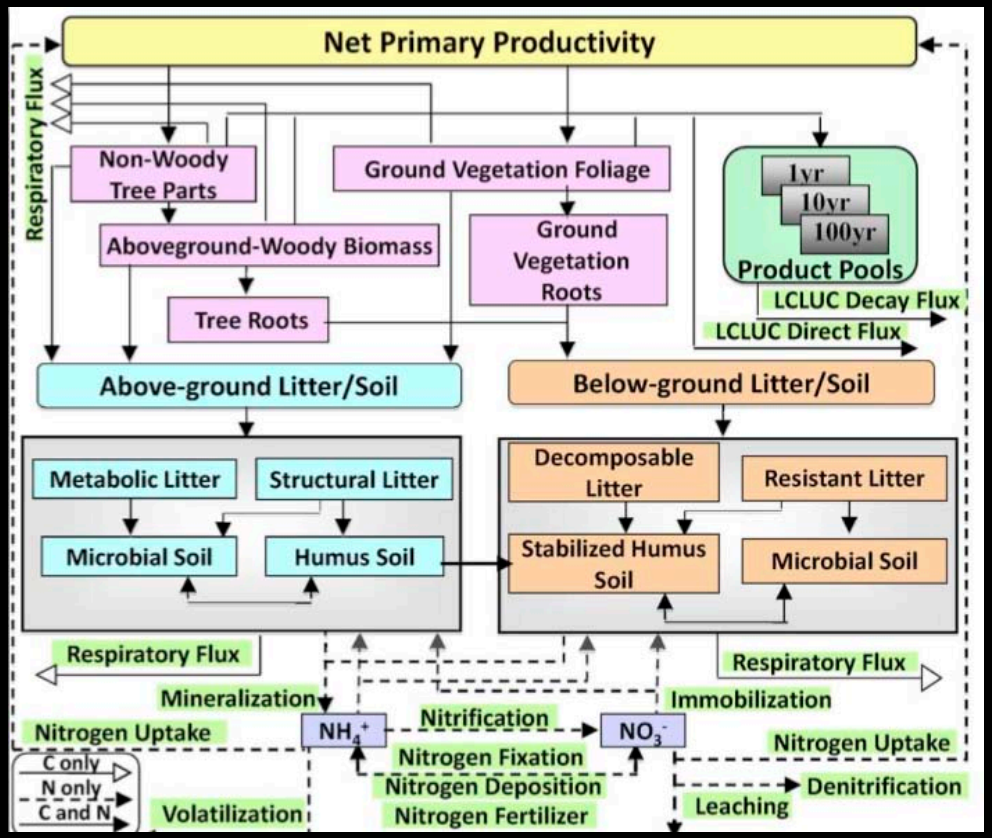


Yang et. al. (2010, Biogeosciences)

ISAM Land-Surface Model



Carbon and Nitrogen Cycling



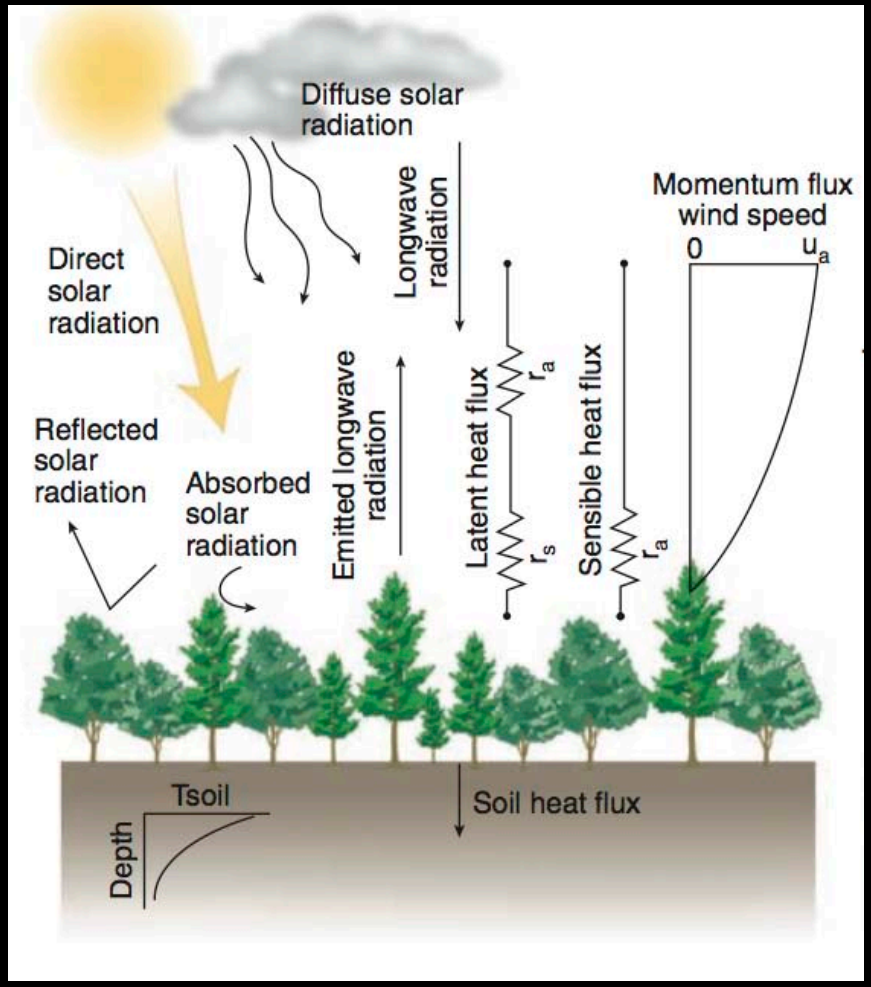
Jain and Yang (2005, GBC)
Jain et al. (2005, GRL)
Jain et al. (2006, JGR)
Jain et al. (2009, GBC)
Yang et al (2009, GBC)
Yang et al.(2010, Biogeoscience)

Calculate fluxes of carbon, nitrogen, energy, water, and the dynamical processes that alter these fluxes

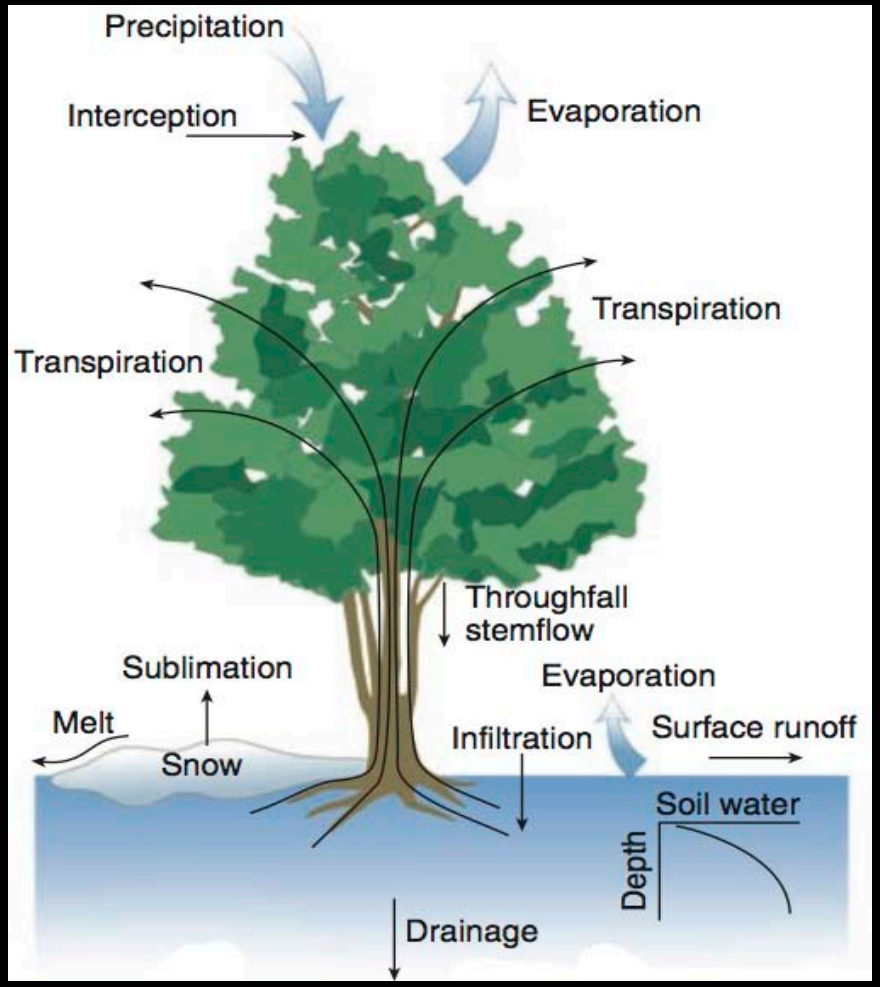
- 18 Biome types
- 0.5 x 0.5 degree resolution
- 30 minutes temporal scale
- Season-to-interannual variability (penology)

ISAM Land-Surface Model

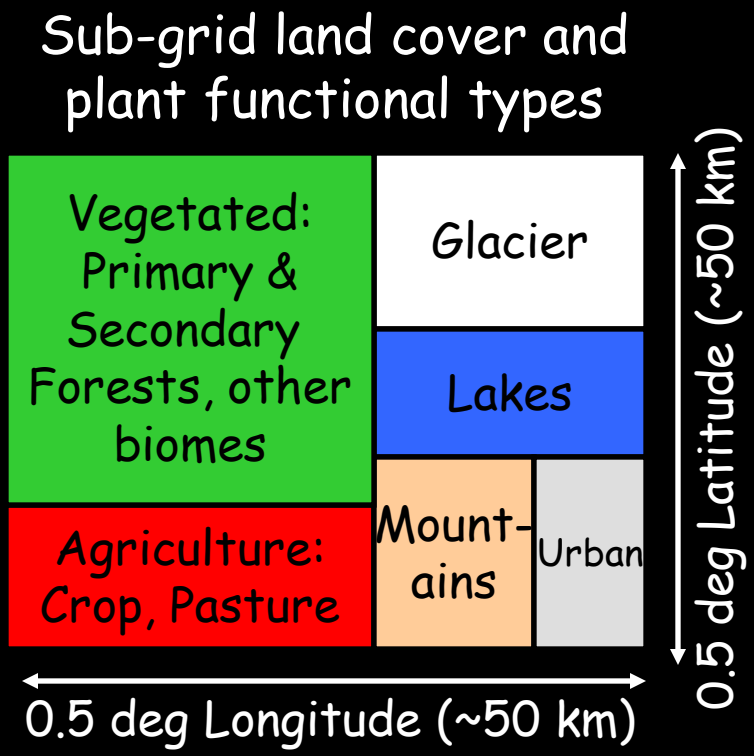
ENERGY



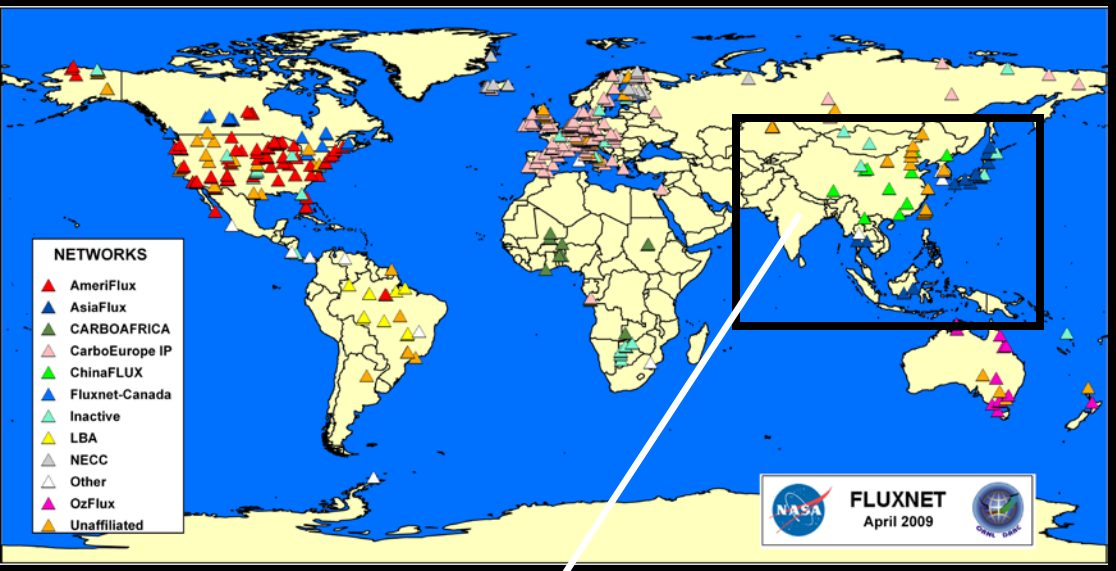
HYDROLOGY



Land Surface Heterogeneity in the ISAM



ISAM represents a model grid cell as a mix of different land cover types.



Use of FLUXNET and Other Ground-Based Data in the ISAM Land Surface Model Development

The Indian Institute of Remote Sensing (IIRS) has undertaken a National Carbon Project (NCP) to establish 6 carbon flux measurement towers using eddy covariance techniques:

(1) Haldwani (mixed forest plantation)

(2) Pauri (oak forest)

(3) Barkot (sal forest) in Uttarakhand

(4) Betul (teak forest) in Madhya Pradesh

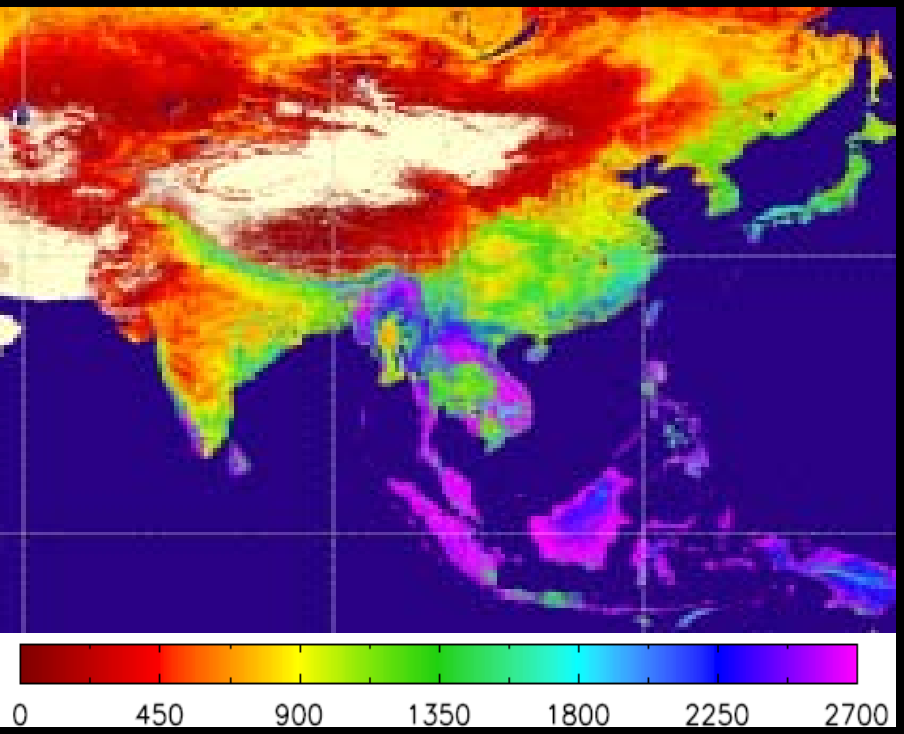
(5) Dandeli (tea plantation) and

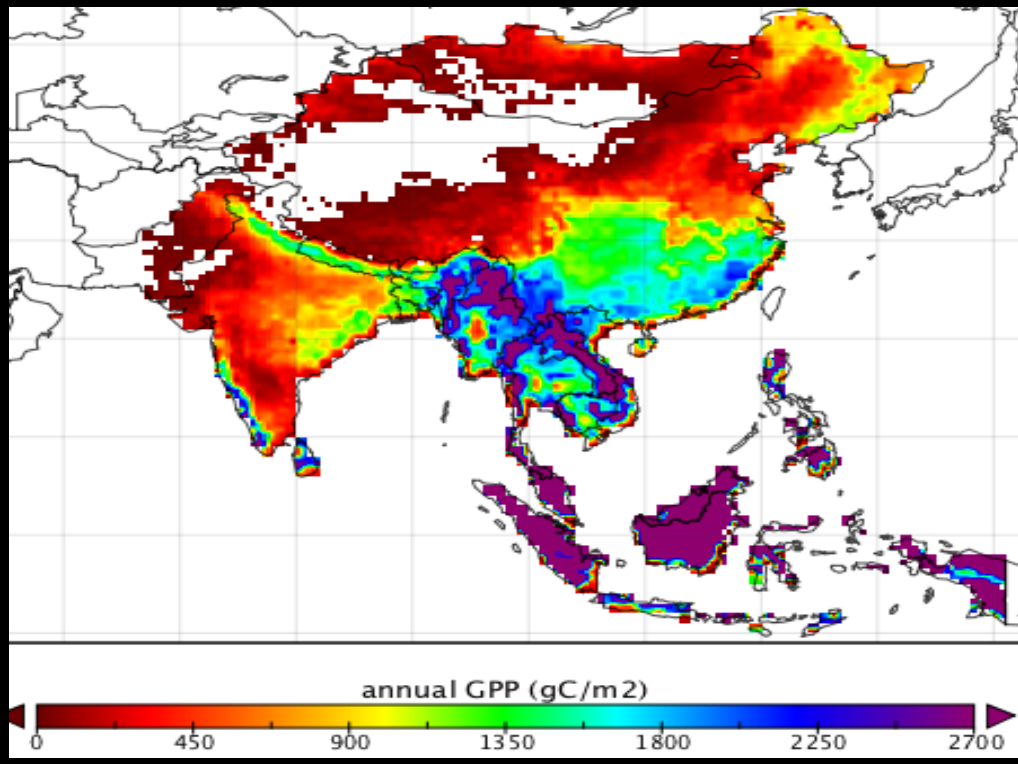
(6) Nagarhole (moist deciduous forest) in Karnataka.

Model Evaluation Using Satellite Data

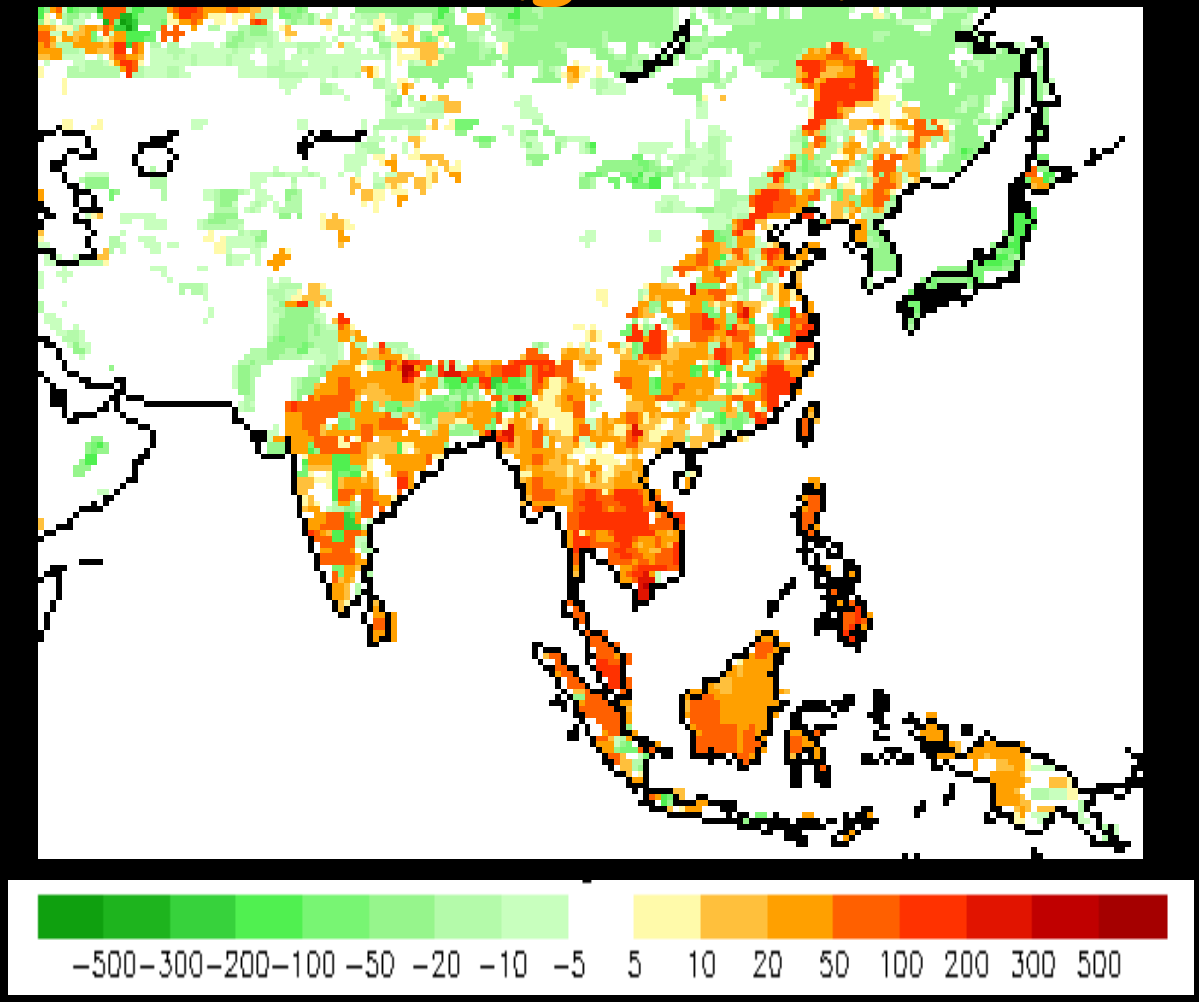
ANNUAL GPP Averaged for 2000-2006

MODIS vs. ISAM





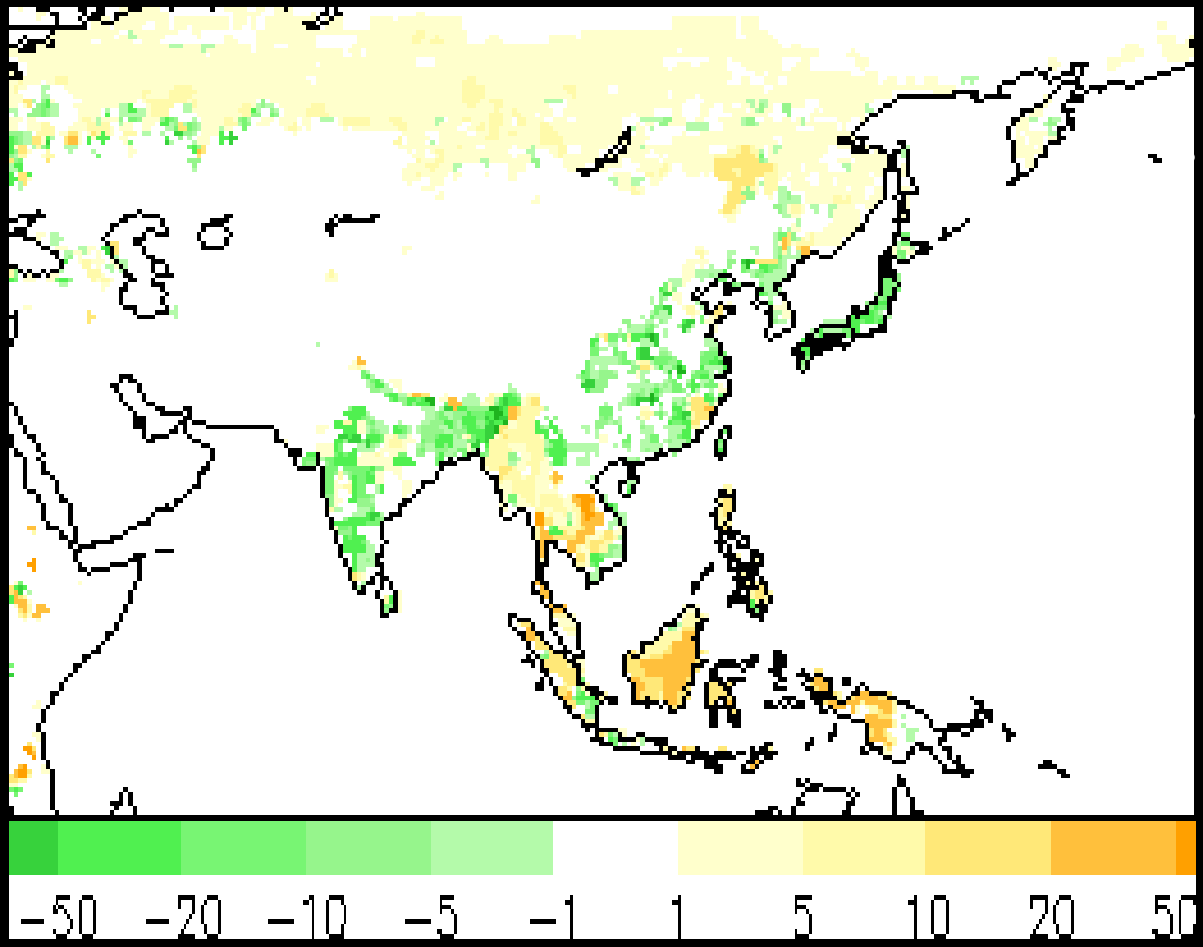
1990s Net Terrestrial C Flux due to LUCs (gC/m^2)



SSEA forests were releasing more C than absorbing

Yang et. al. (2010, Biogeosciences)

Estimated Net Exchange of C ($gC/m^2/yr$) for the 1990s in Secondary Forests



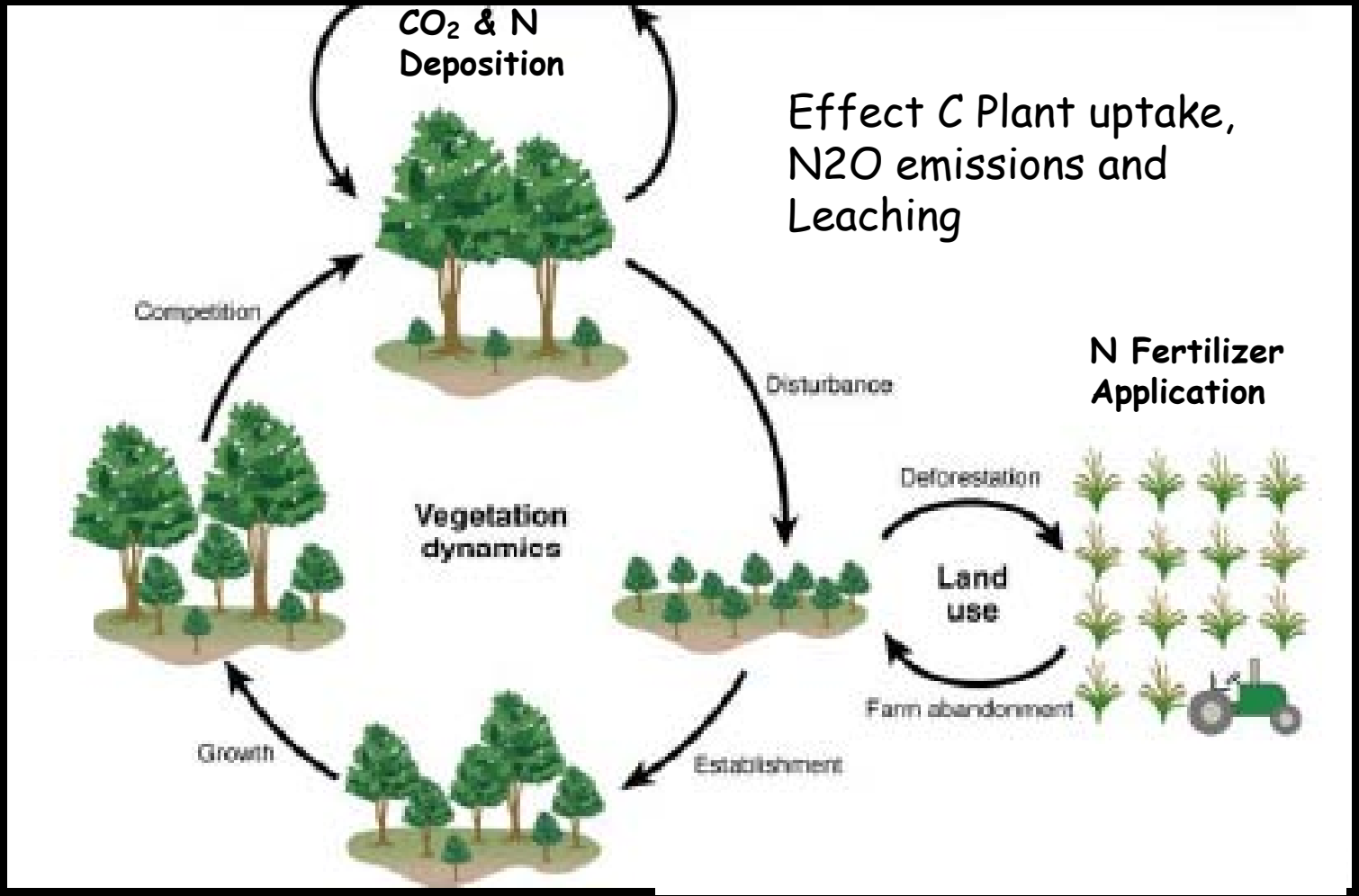
Carbon stocks in forests are increasing in recent years due to reforestation and afforestation

In some regions accumulation of carbon is reduced where nitrogen is a limiting nutrient or enhanced if the additional N is deposited in the forest regrowing regions

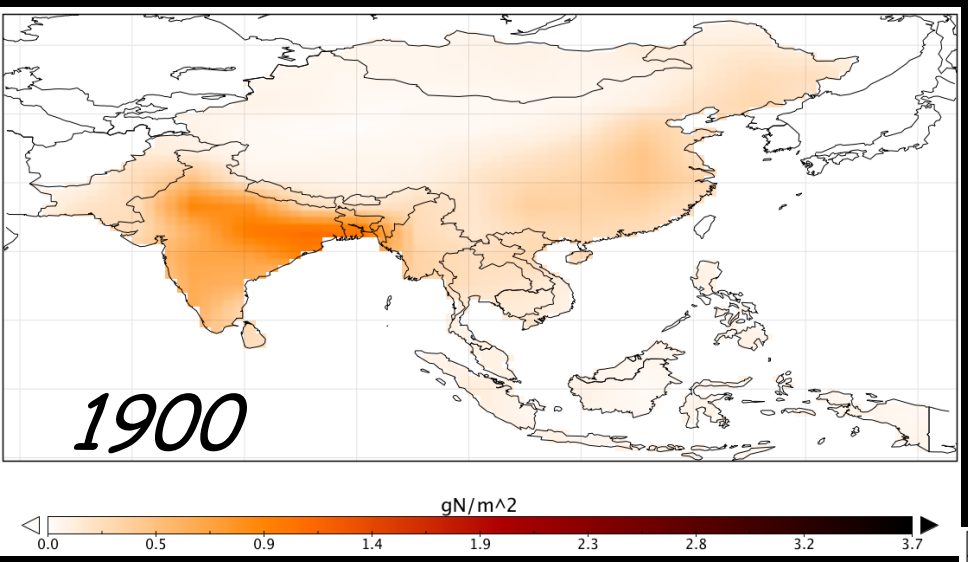
Positive values represent net C release to the atmosphere and negative values represent net C storage in terrestrial biosphere

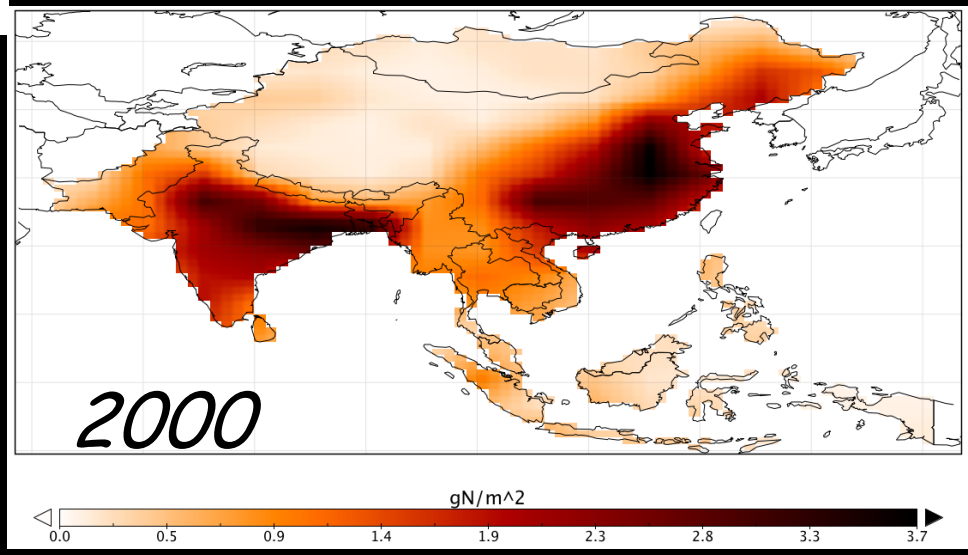
Yang et. al. (2010, Biogeosciences)

The Impact of N Deposition and Fertilizer



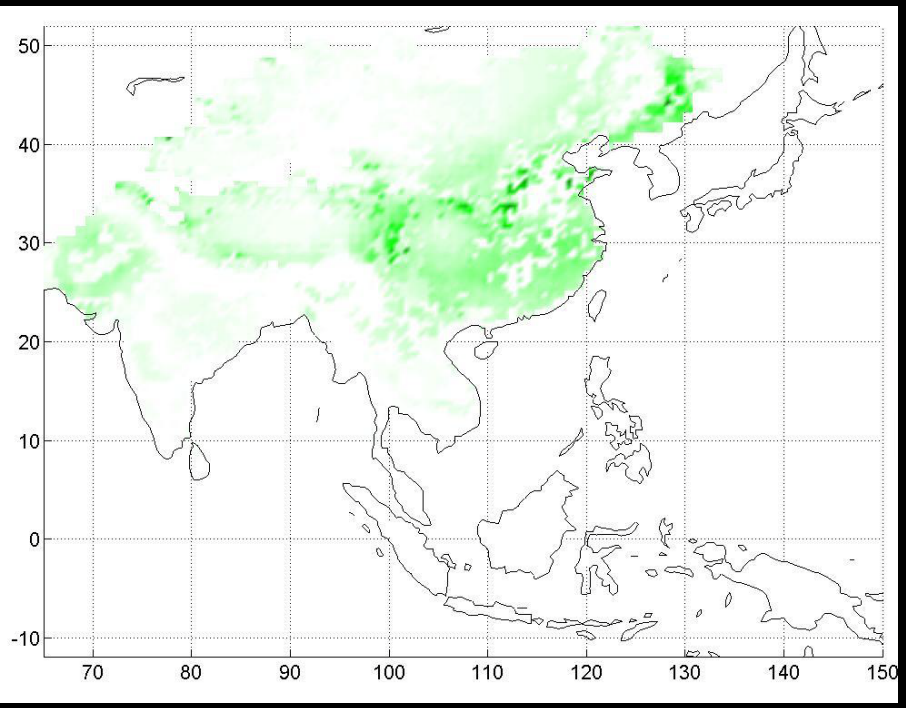
Nitrogen Deposition - Fossil Fuel Burning



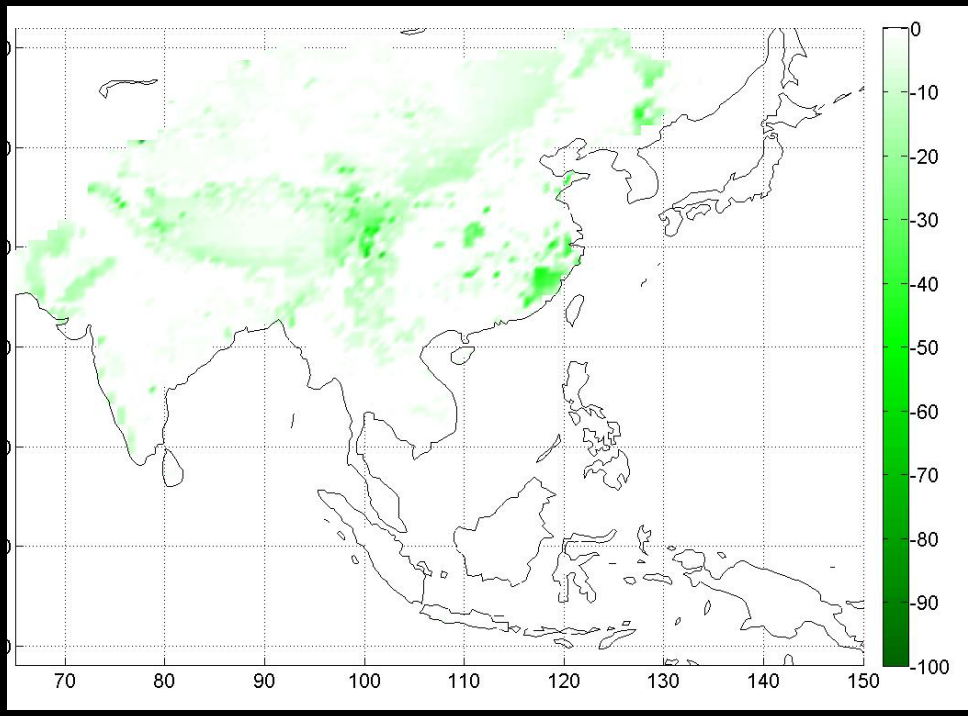


Galloway et al. (2004)

1990s N Deposition Effect on Carbon Uptake (gC/m^2)



Without LUCs

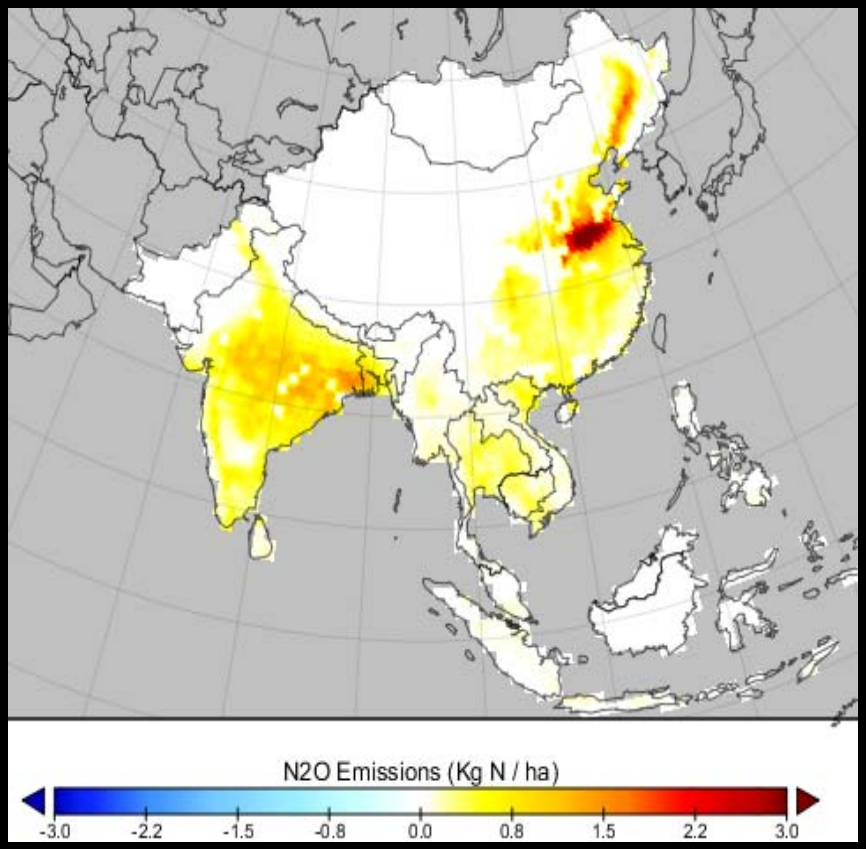


With LUCs

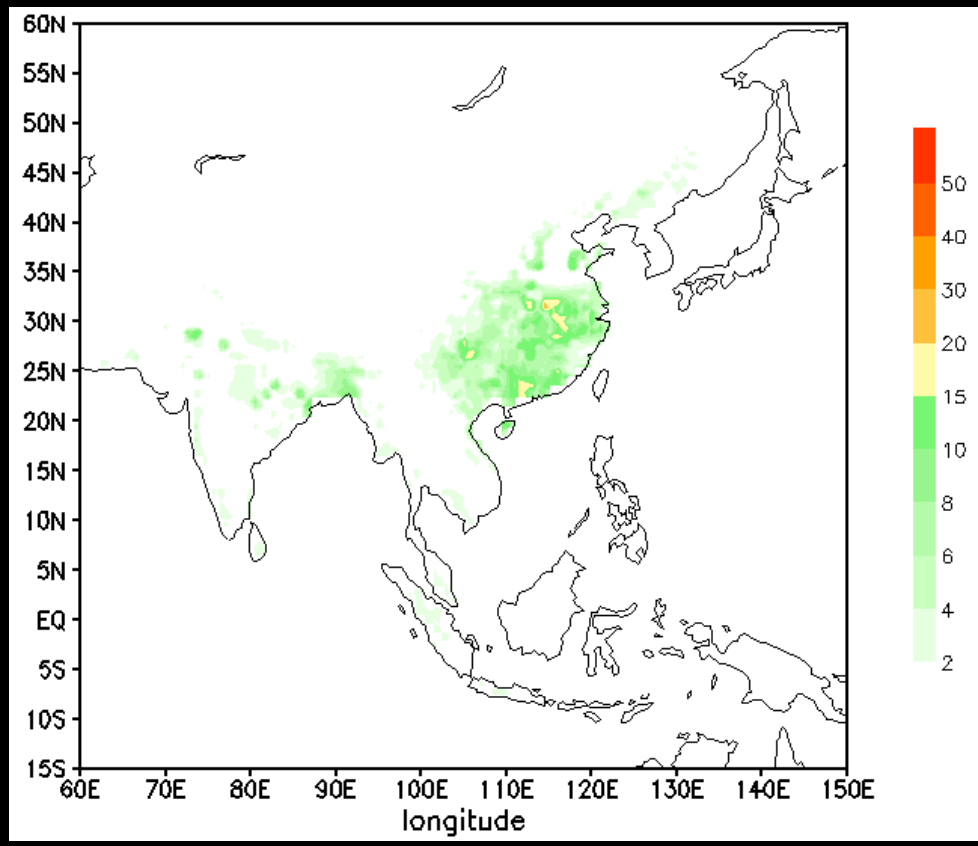
N deposition leads to additional terrestrial carbon sink

Yang et. al. (2010, Biogeosciences)

1990s N Deposition Effect on N2O Emissions and Leaching



N2O Emissions (Kg N/ha)



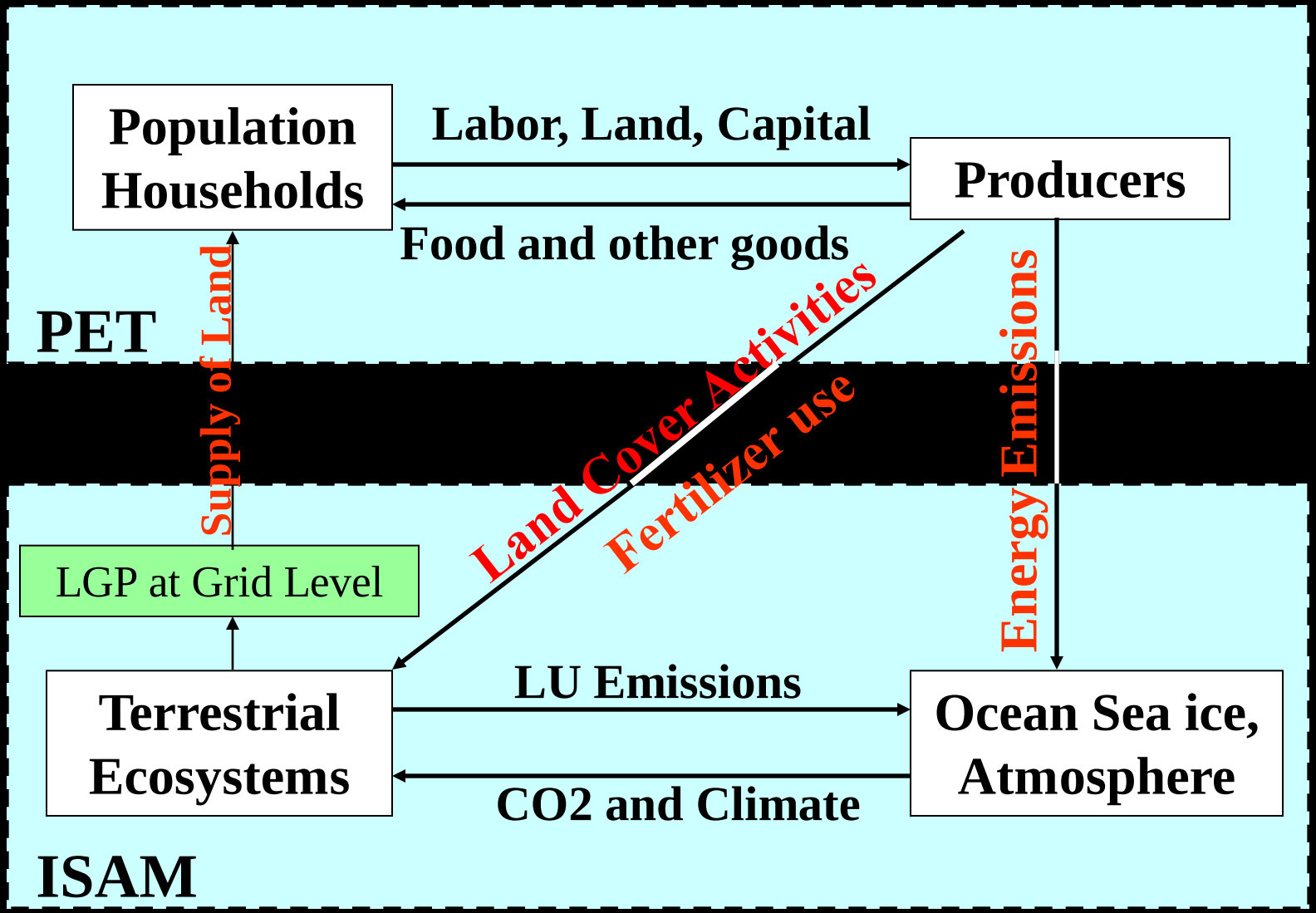
Leaching (gC/m2)

Yang et. al. (2010, Biogeosciences)

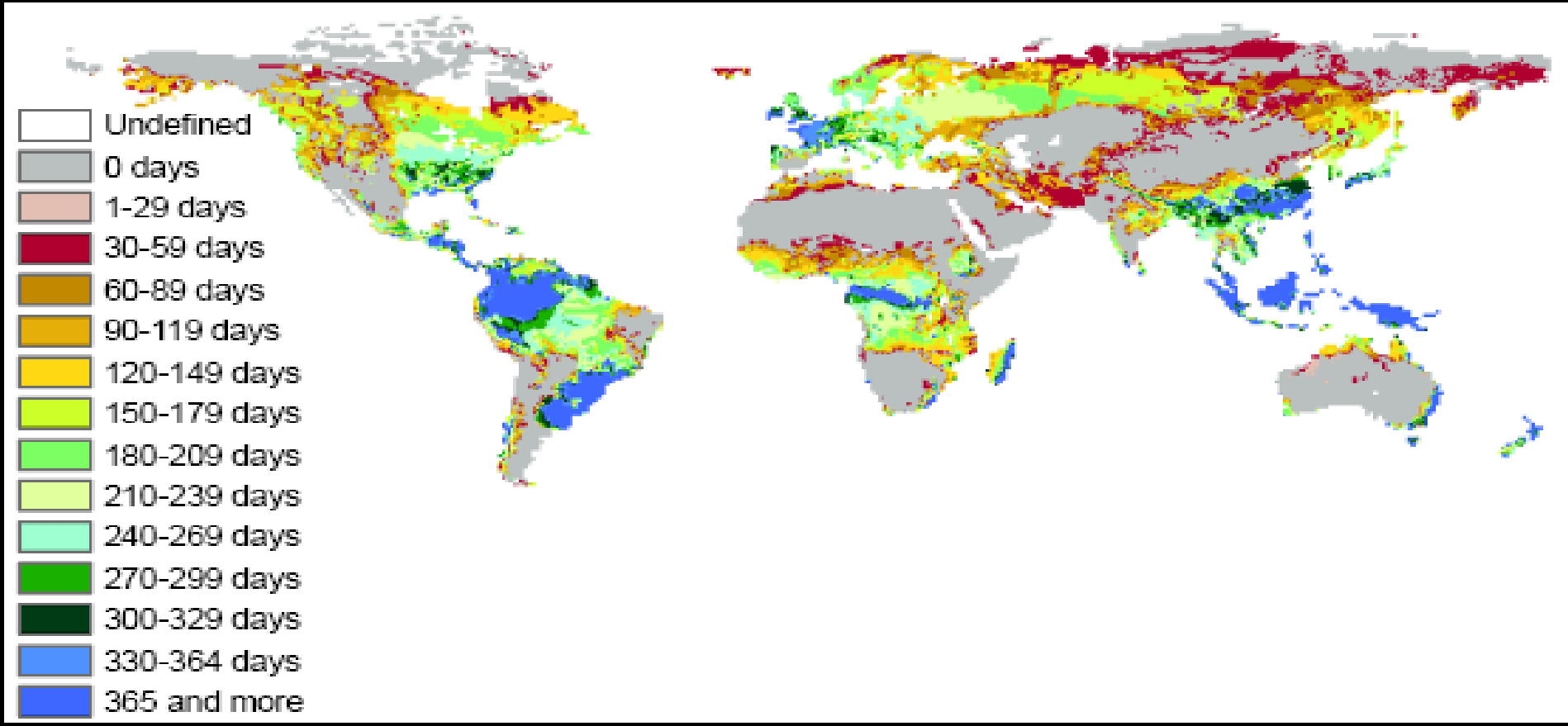
Linking Socio-Economic and Biophysical Systems

- PET (Population-Economic-Technology) is a socio-economic dynamic system
  - the principle economic activities related to agriculture and raising livestock, forest sector, management practices such as fertilizer use.
- Terrestrial ecosystem component of Integrated Science Assessment Model (ISAM)
  - the biophysical potential of land for production, across and within regions

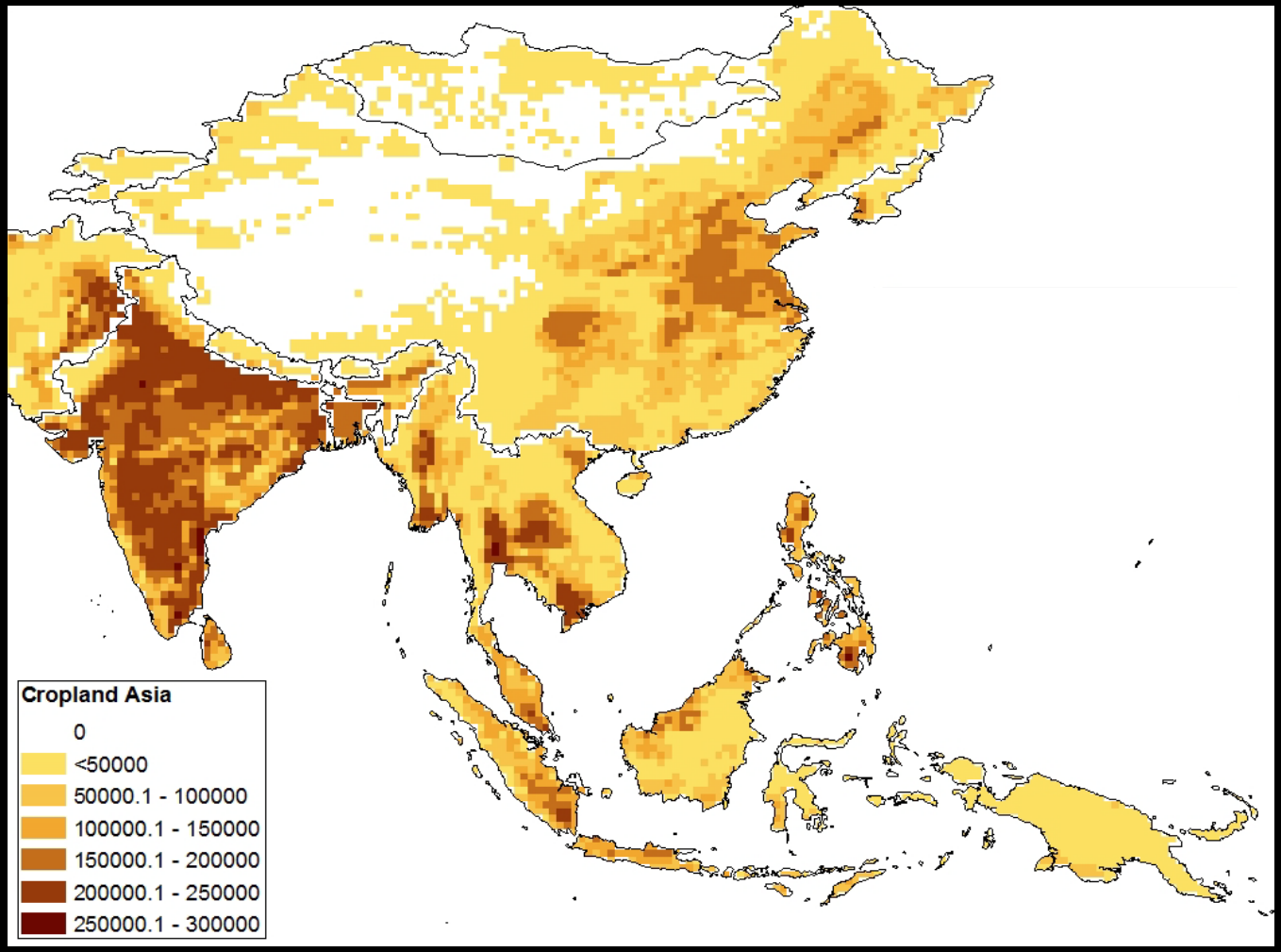
PET-ISAM Modeling Framework



Length of Growing Period - Year 2000

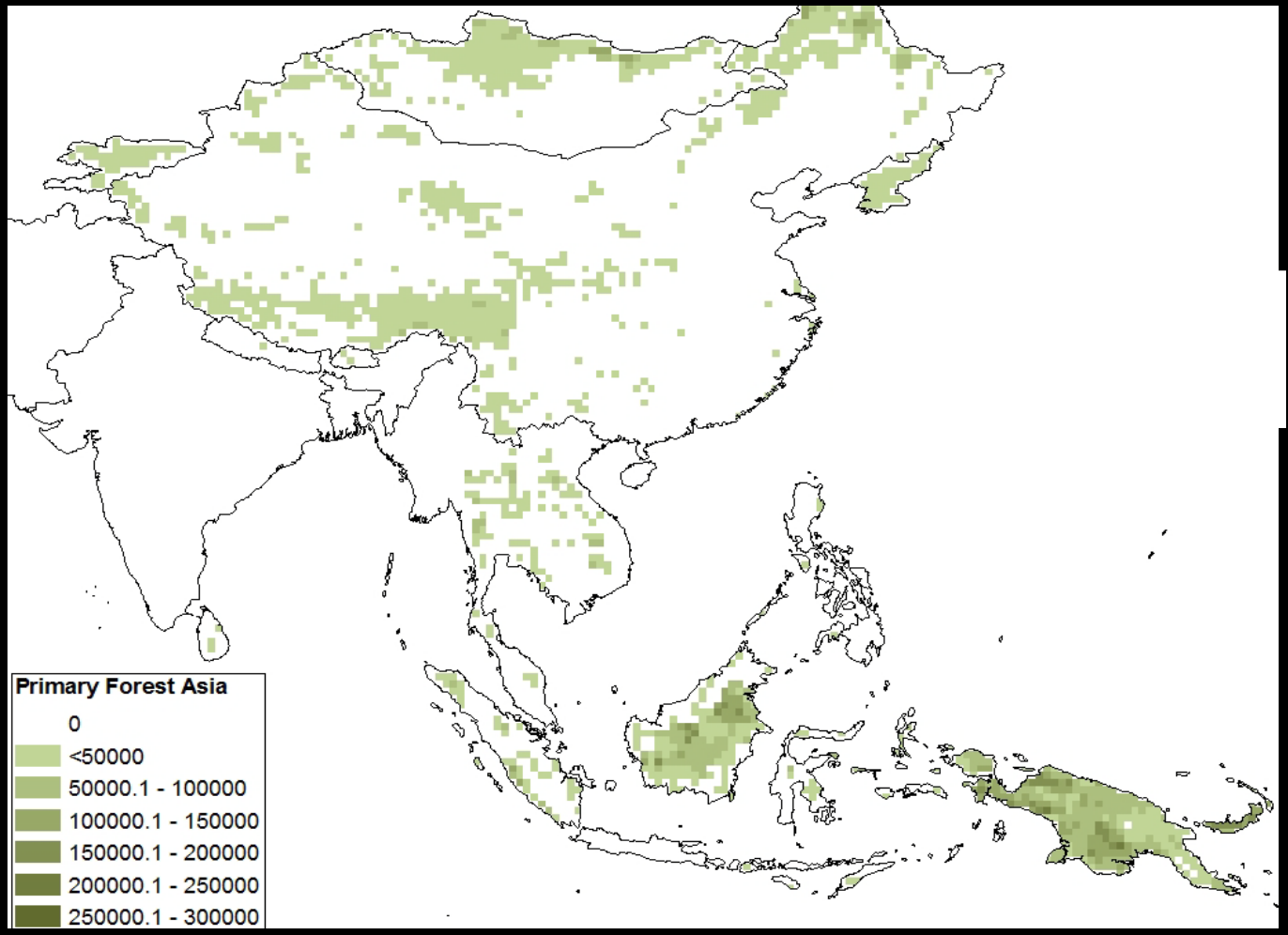


ISAM/PET Agriculture Land Area Based on IPCC A2 Scenario (in 2050)



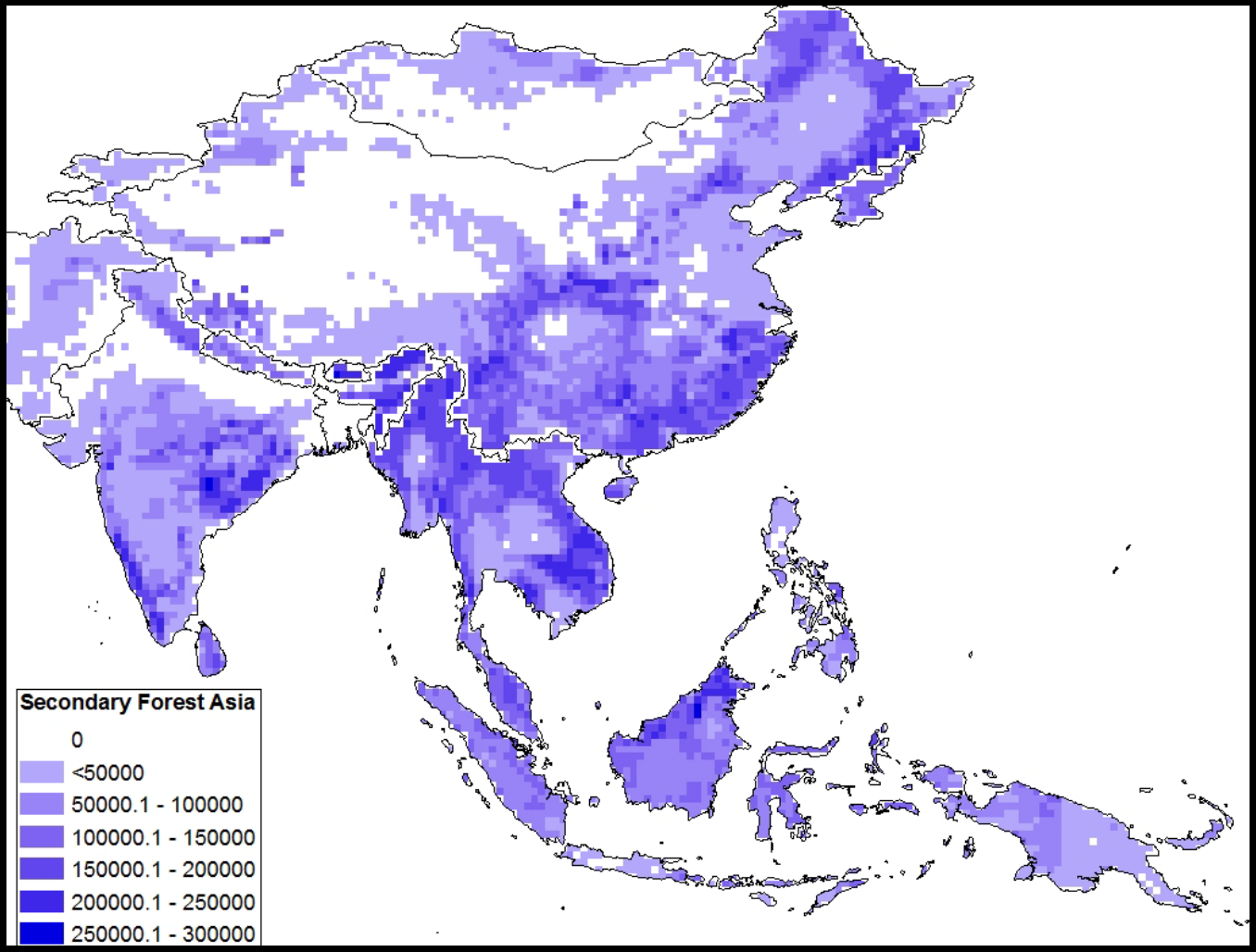
Courtesy: Brian O'Neill (NCAR)

ISAM/PET Primary Forest Area Based on IPCC A2 Scenario (in 2050)



Courtesy: Brian O'Neill (NCAR)

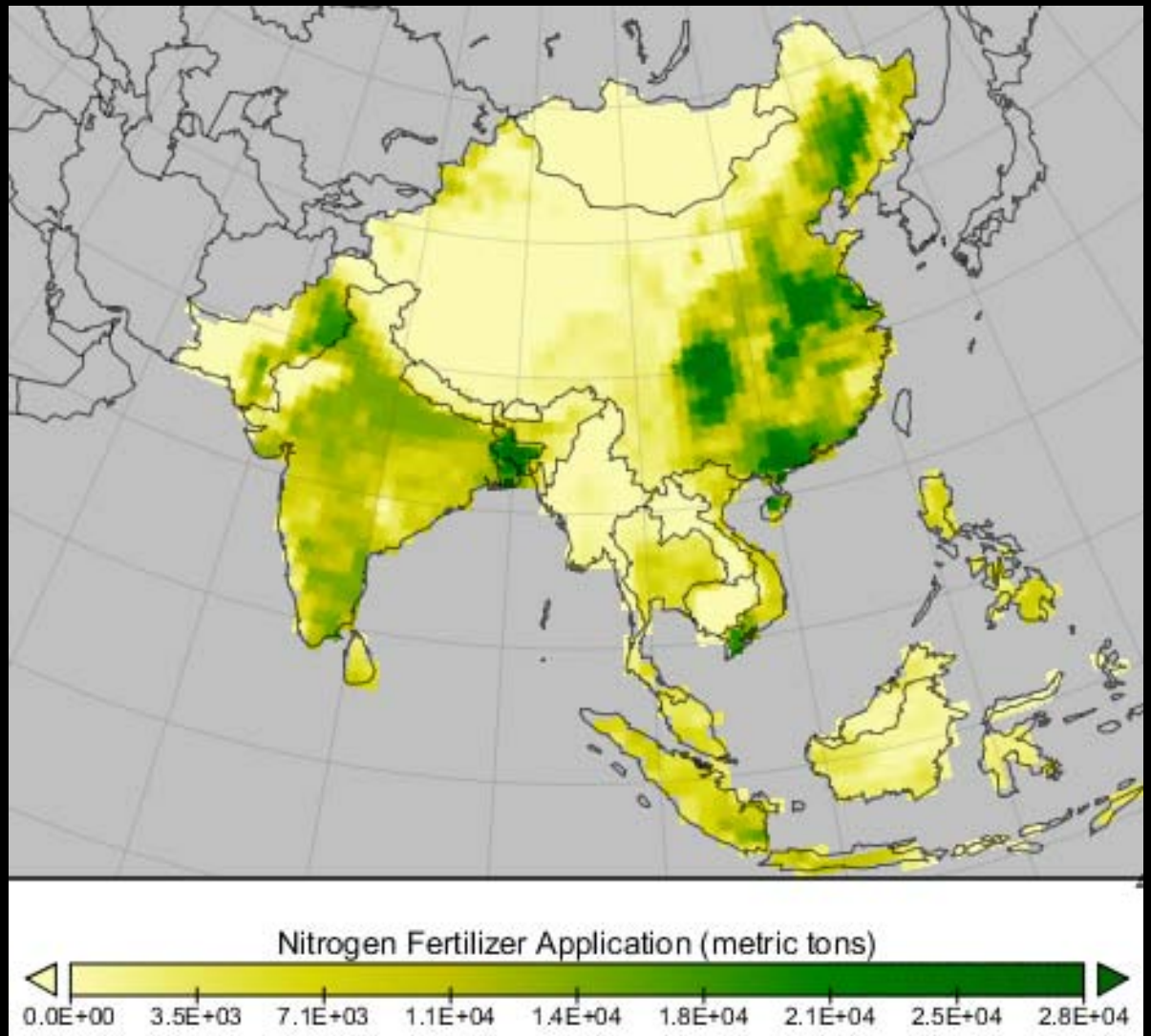
ISAM/PET Secondary Forest Area Based on IPCC A2 Scenario (2050)



Courtesy: Brian O'Neill (NCAR)

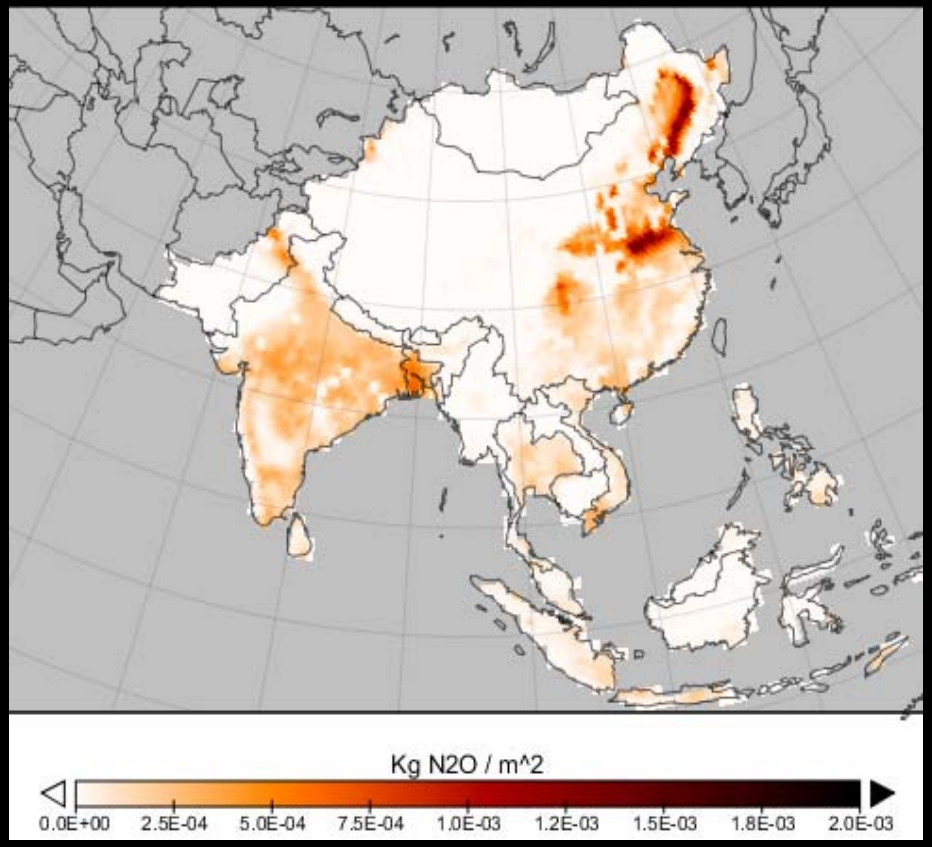
Thank you..

1990s Average Yearly Nitrogen Fertilizer Application (tons)

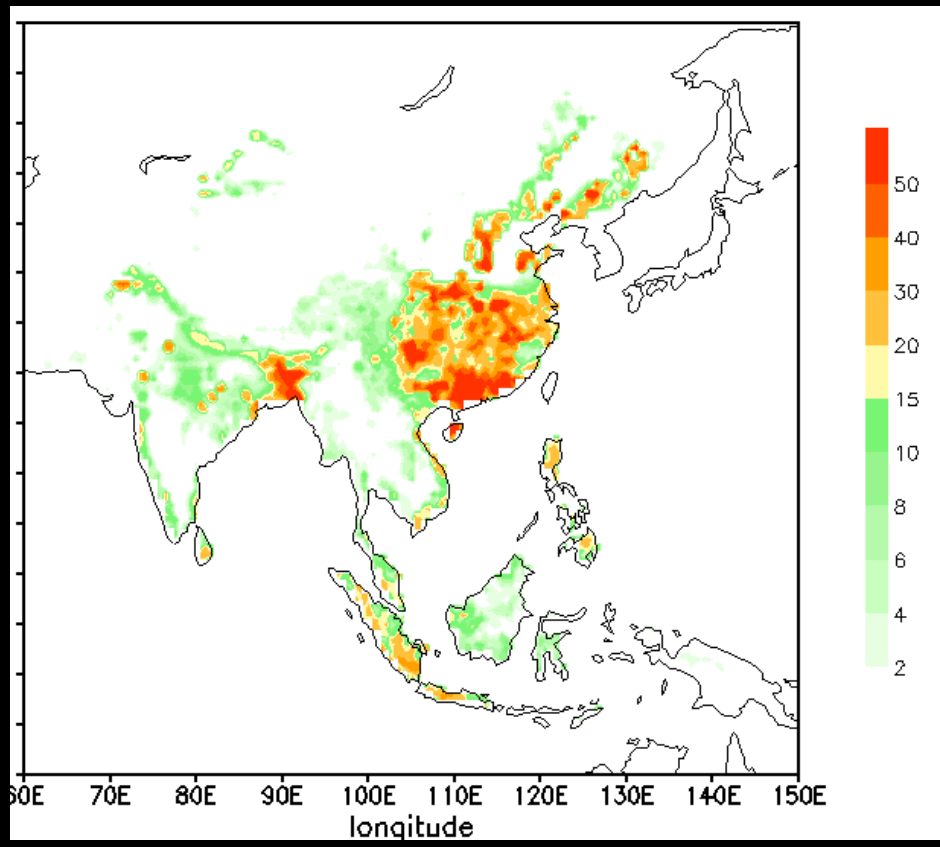


International Fertilizer Industry Association (2005)

Nitrogen Fertilizer Effect on 1990s N2O Emissions and Leaching



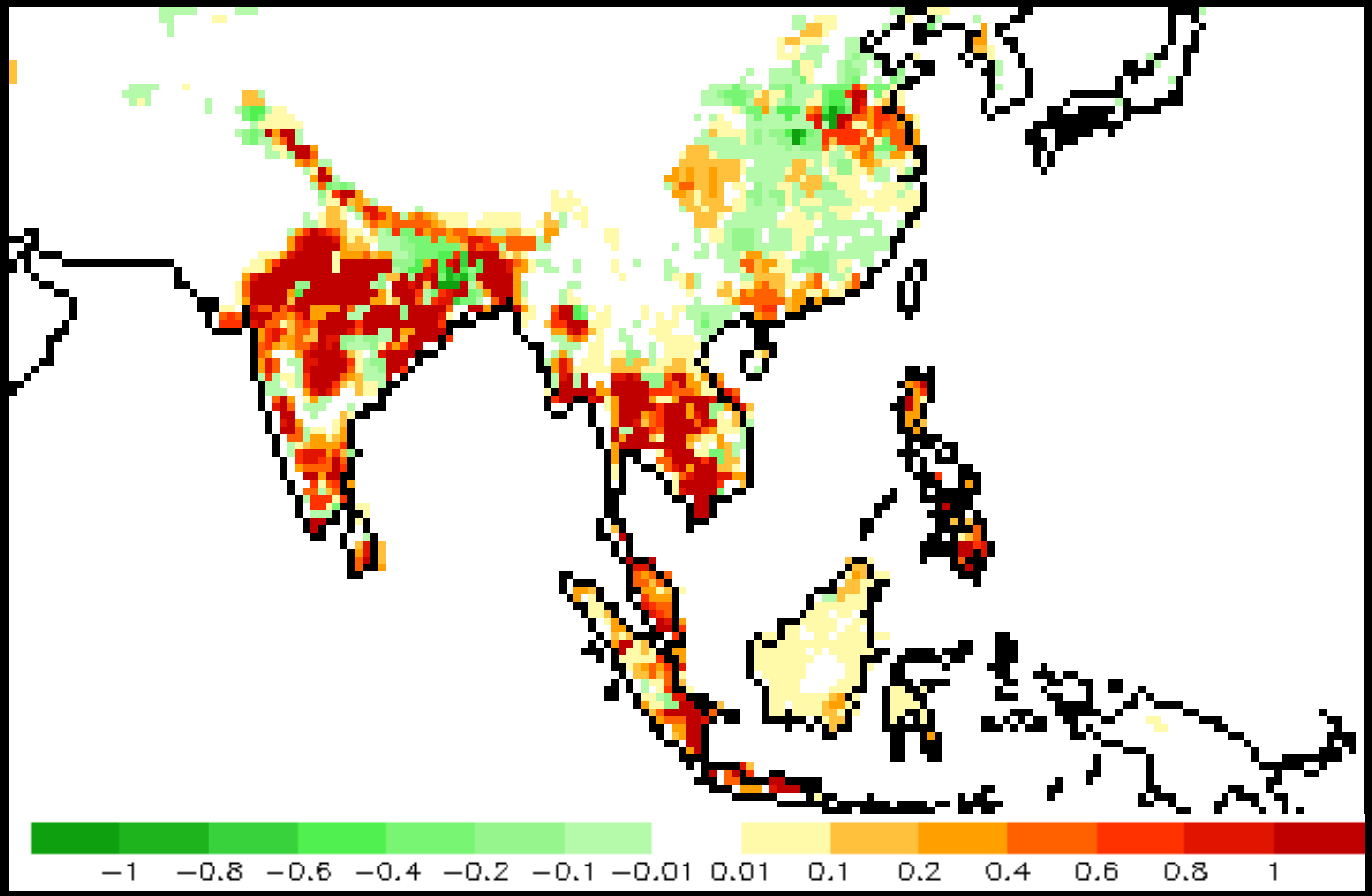
N2O Emissions (Kg N/ha)



Leaching (gN/m2)

Yang et. al. (2010, Biogeosciences)

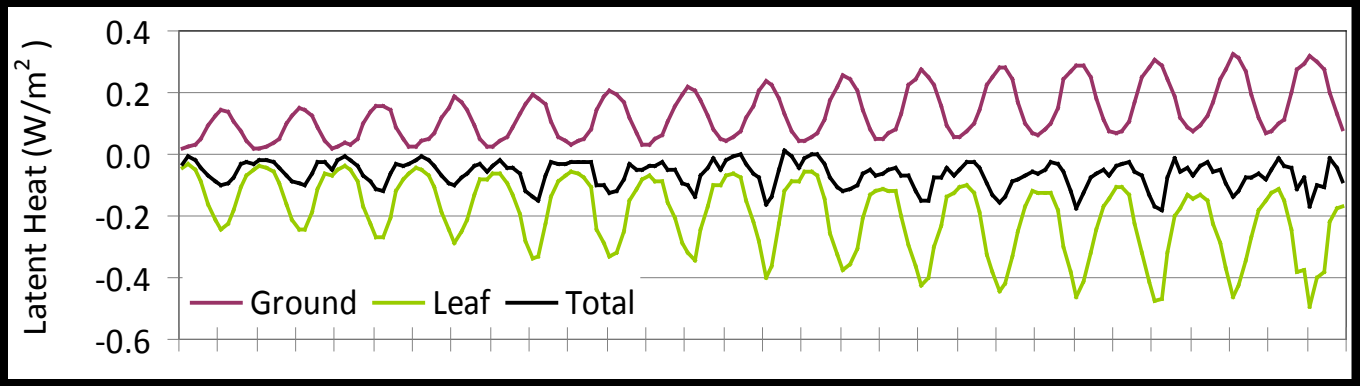
1990s Contribution of LCLUC to N2O Emissions (KgN/ha/yr)



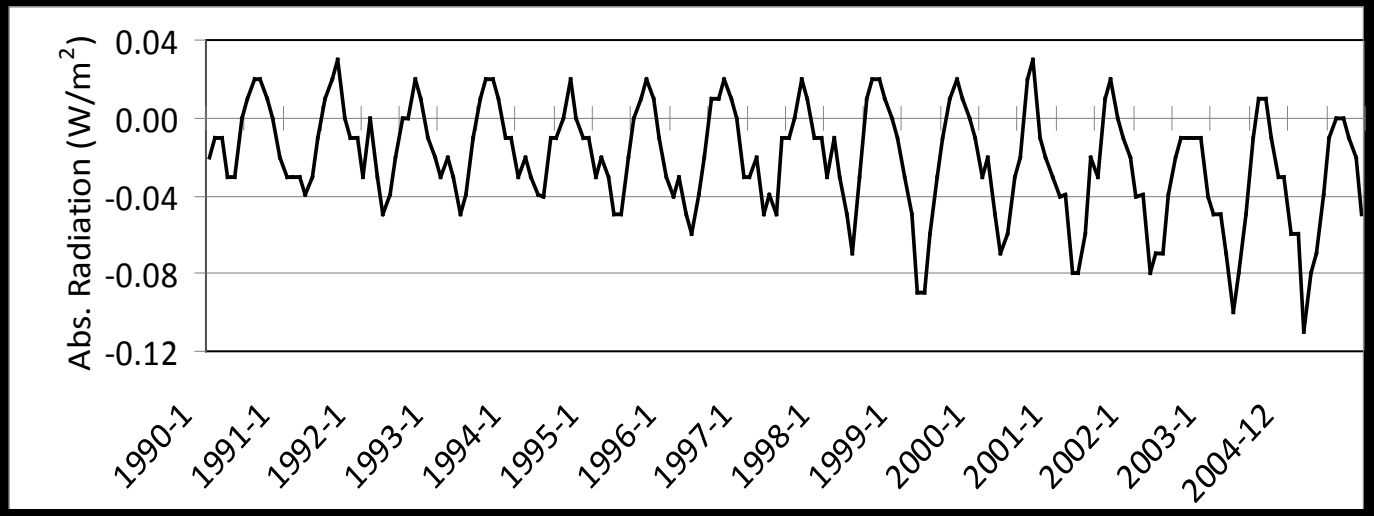
Impact of Land Cover and Land Use Changes on Biophysical Processes: Energy and Hydrology Fluxes

Experiments Performed for
the Period 1979-2004

Land Use Change Effect

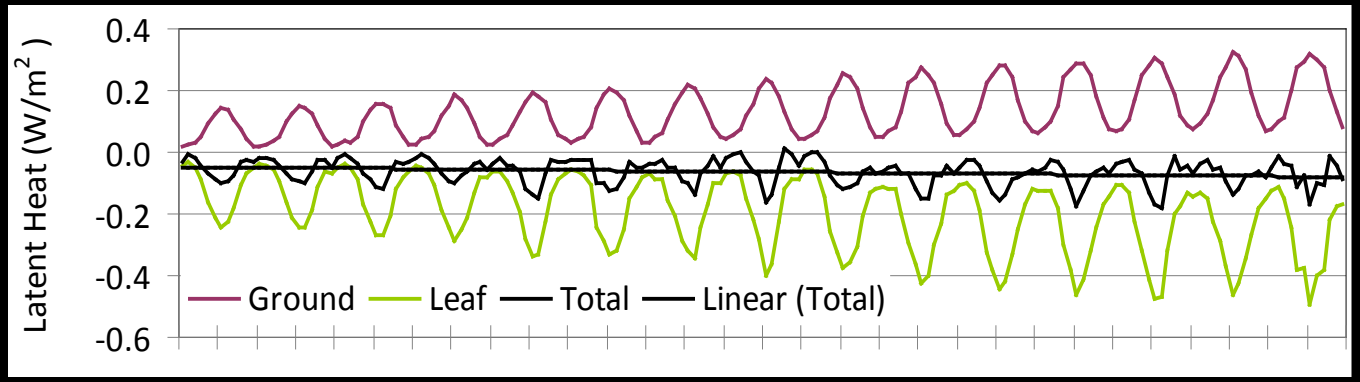


Latent Heat

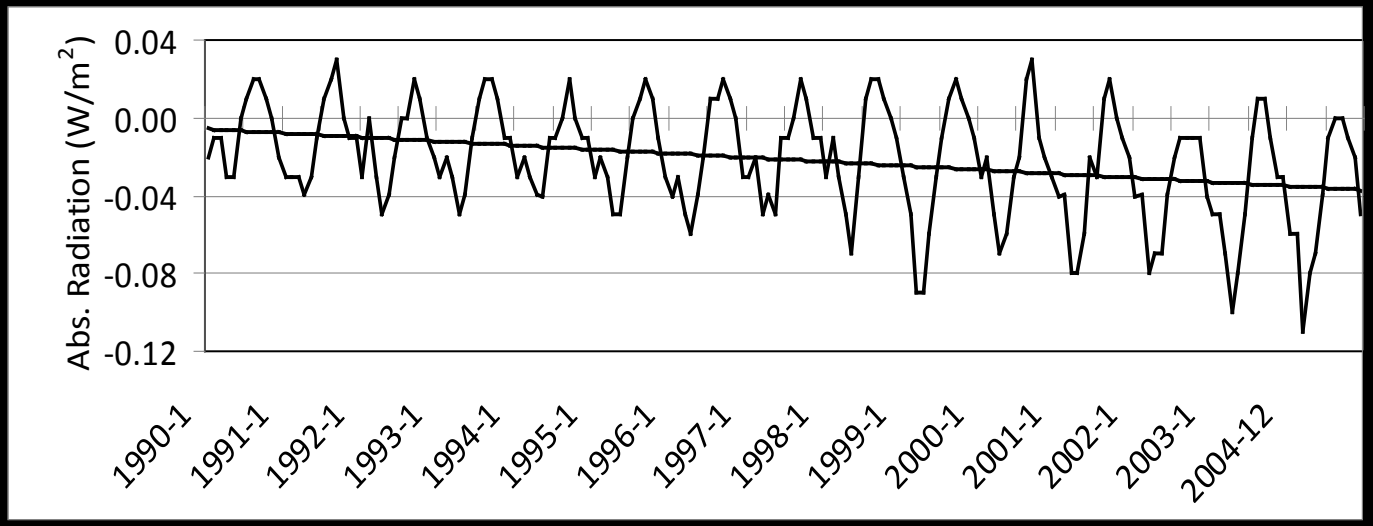


Absorbed Radiation

Land Use Change Effect

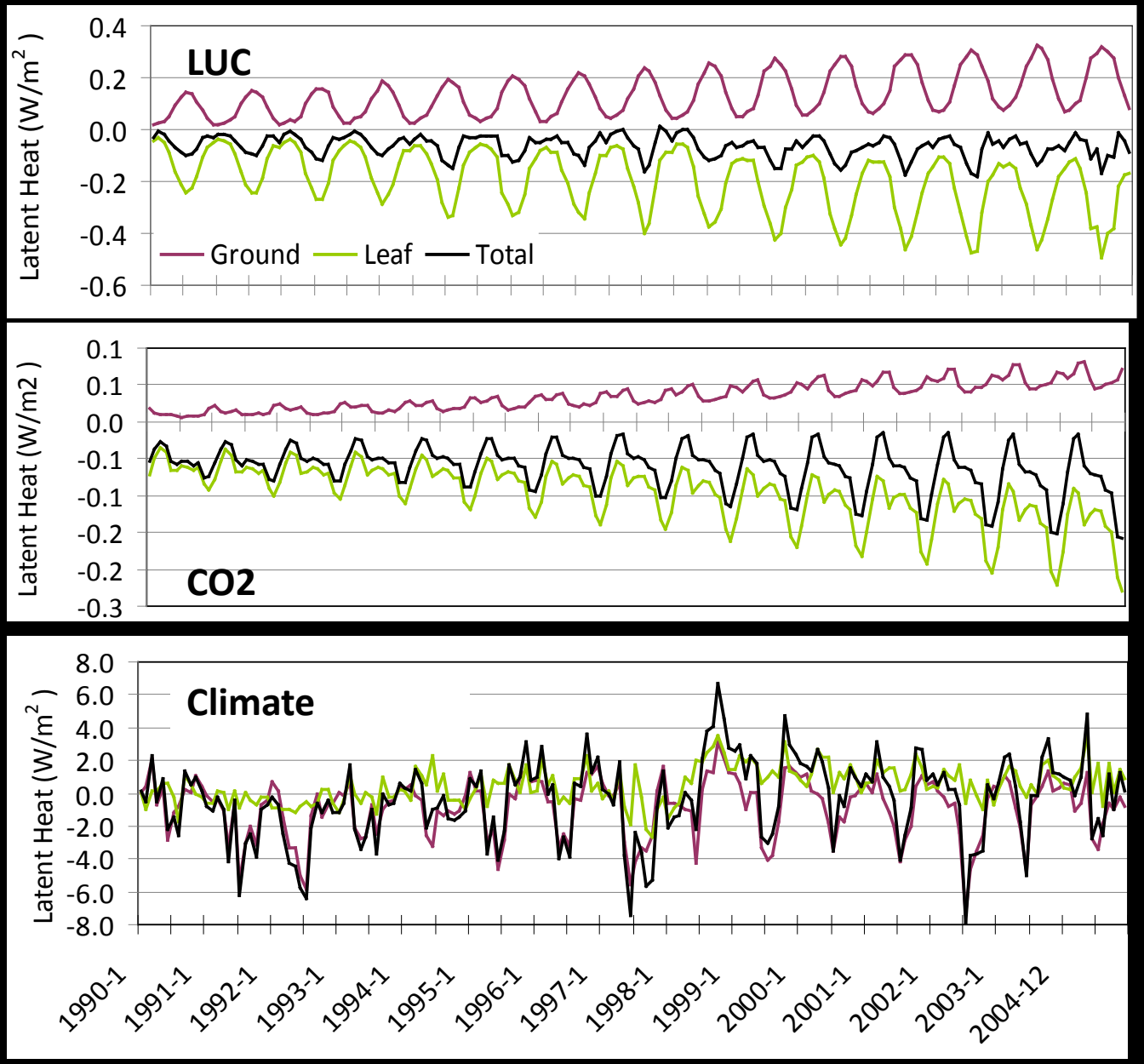


Latent Heat

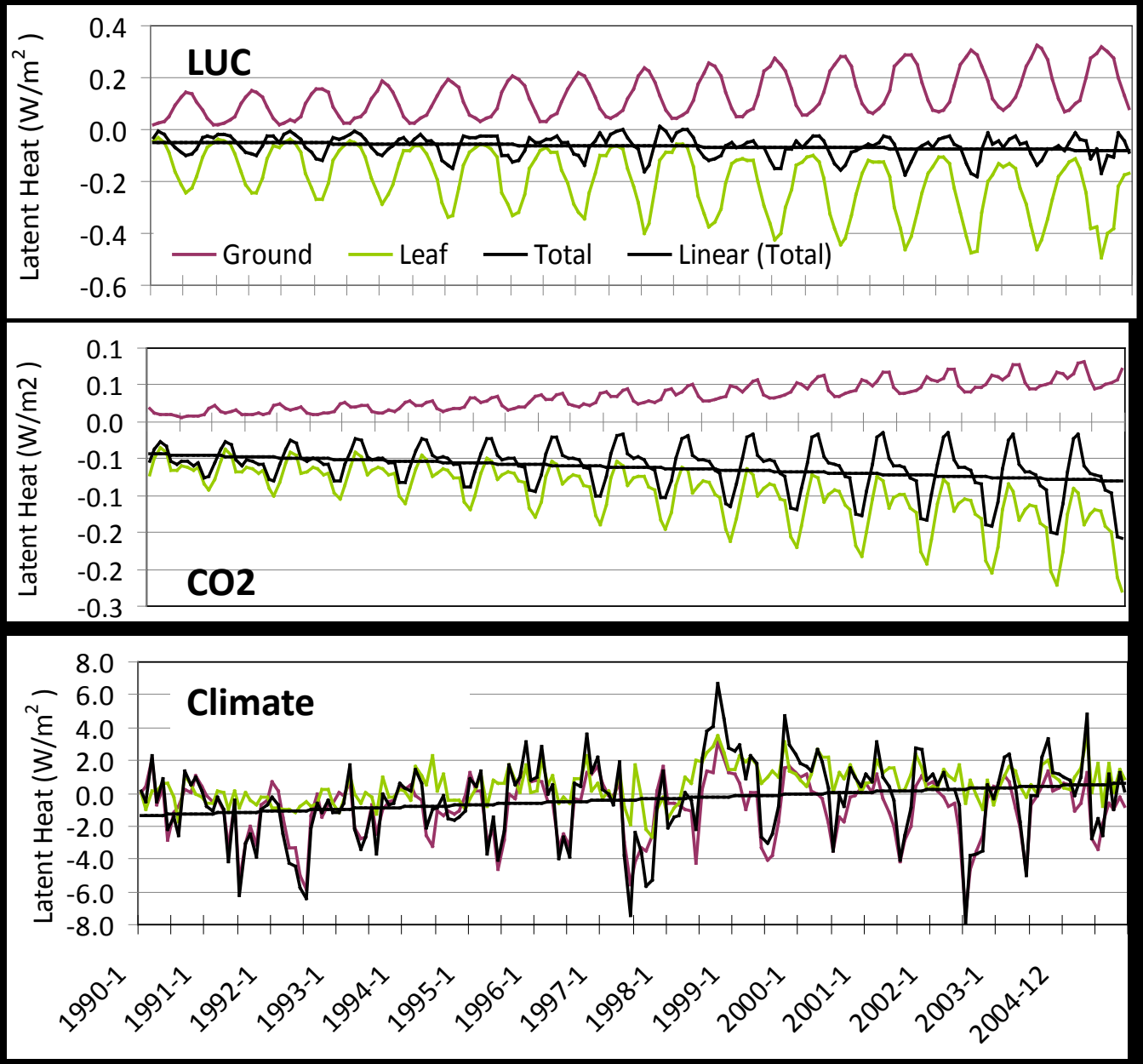


Absorbed Radiation

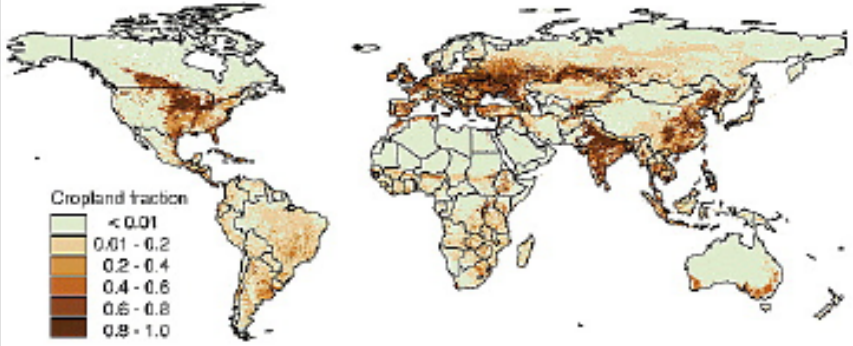
LH by Effect

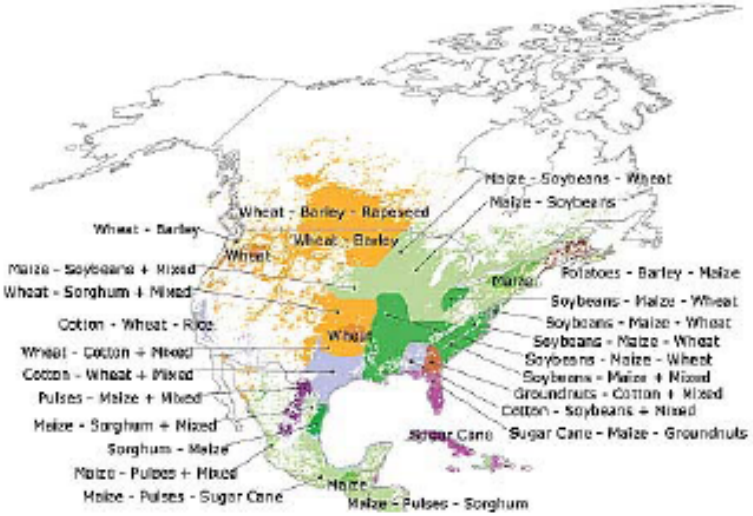

LUC
Latent Heat (W/m2)
0.4
0.2
0.0
-0.2
-0.4
-0.6
Ground
Leaf
Total
CO2
Latent Heat (W/m2)
0.1
0.1
0.0
-0.1
-0.1
-0.2
-0.2
-0.3
Climate
Latent Heat (W/m2)
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
1990-1
1991-1
1992-1
1993-1
1994-1
1995-1
1996-1
1997-1
1998-1
1999-1
2000-1
2001-1
2002-1
2003-1
2004-12

LH by Effect


LUC
Latent Heat (W/m2)
0.4
0.2
0.0
-0.2
-0.4
-0.6
Ground
Leaf
Total
Linear (Total)
CO2
Latent Heat (W/m2)
0.1
0.1
0.0
-0.1
-0.1
-0.2
-0.2
-0.3
Climate
Latent Heat (W/m2)
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
1990-1
1991-1
1992-1
1993-1
1994-1
1995-1
1996-1
1997-1
1998-1
1999-1
2000-1
2001-1
2002-1
2003-1
2004-12

Implementation of Broad Diversity of Crops in the ISAM

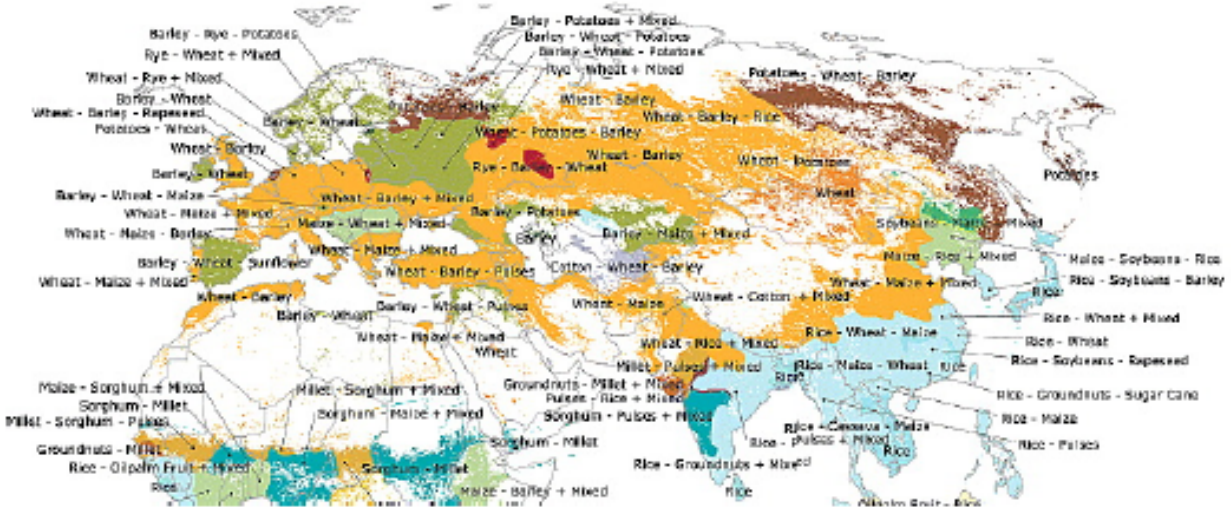




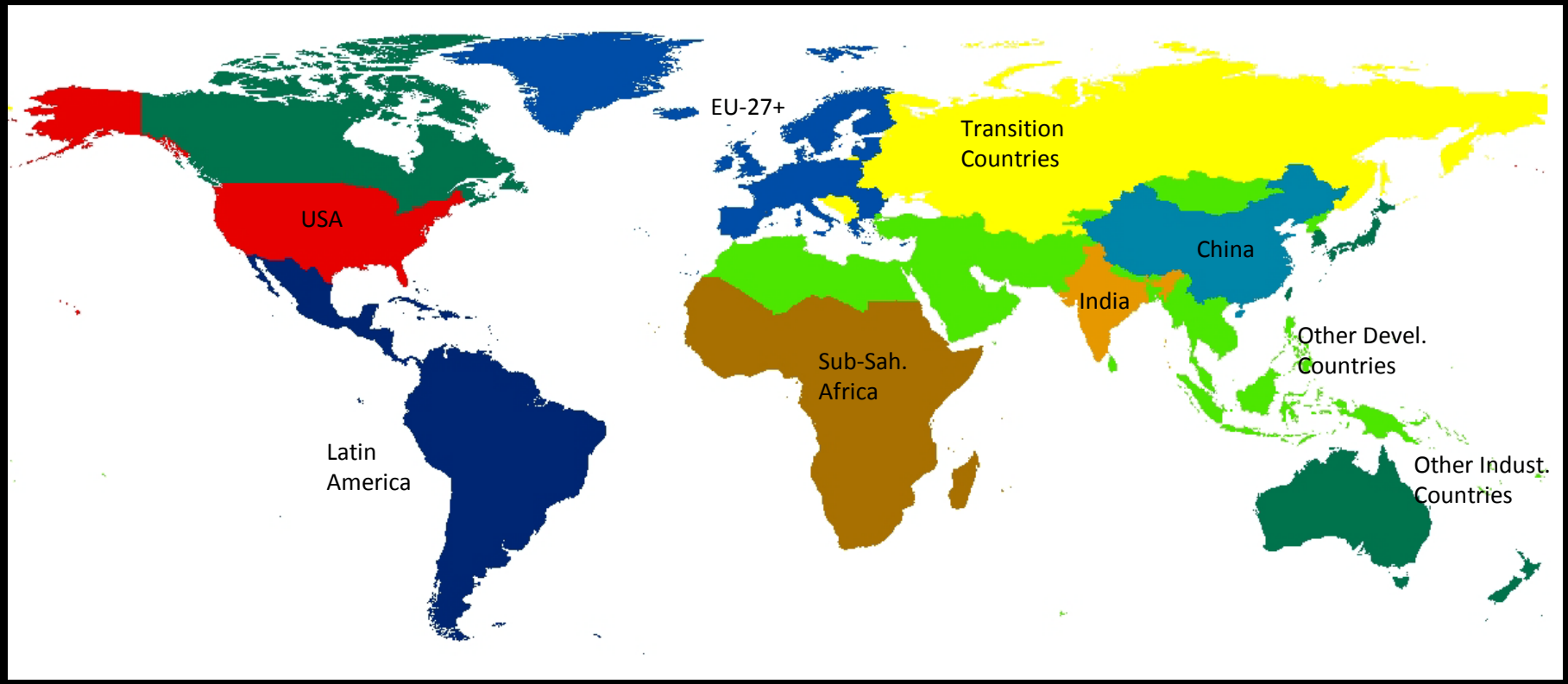
The type of land cover change matters:

Forest → winter crop
Forest → spring crop
Forest → summer crop

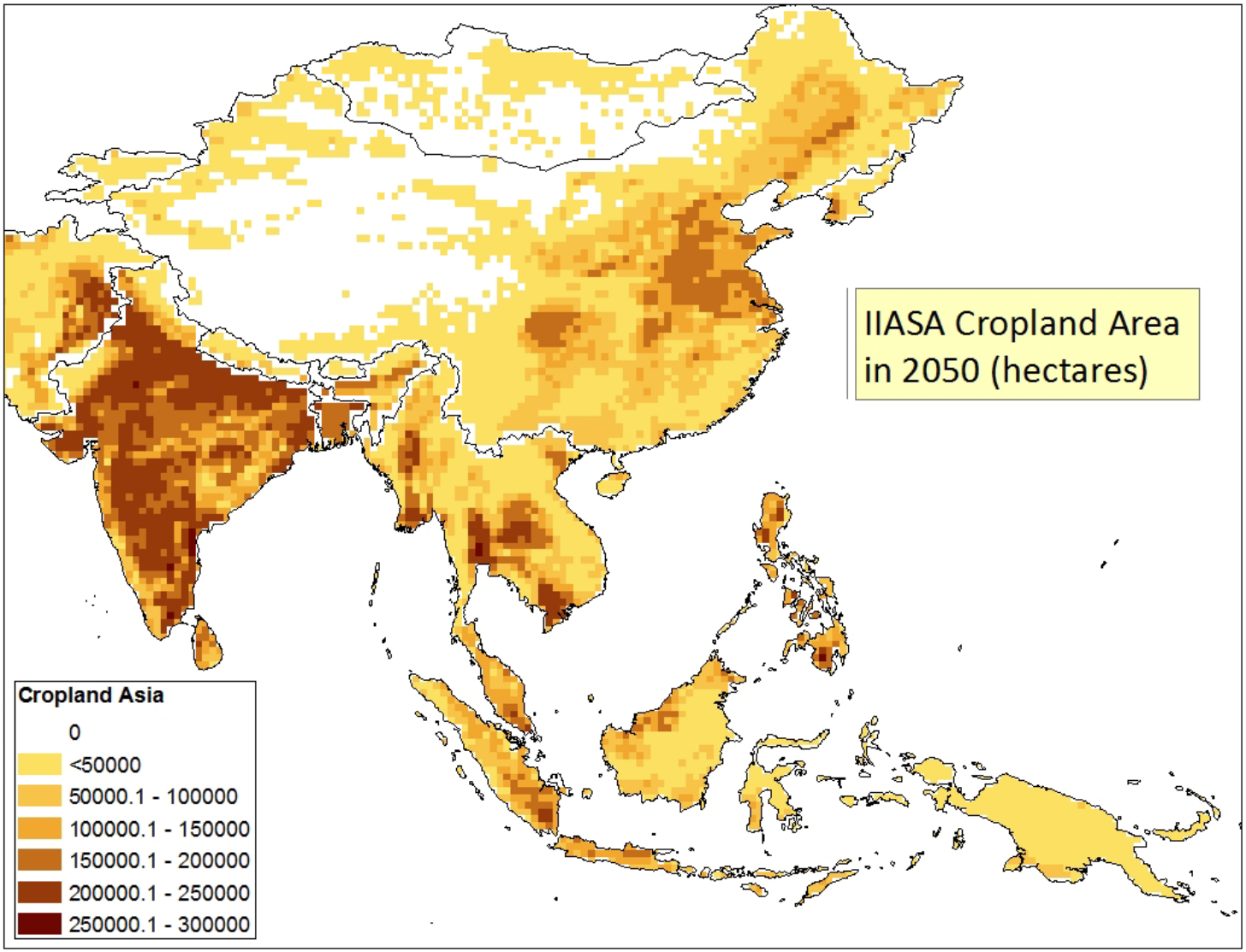
Forest vs grassland

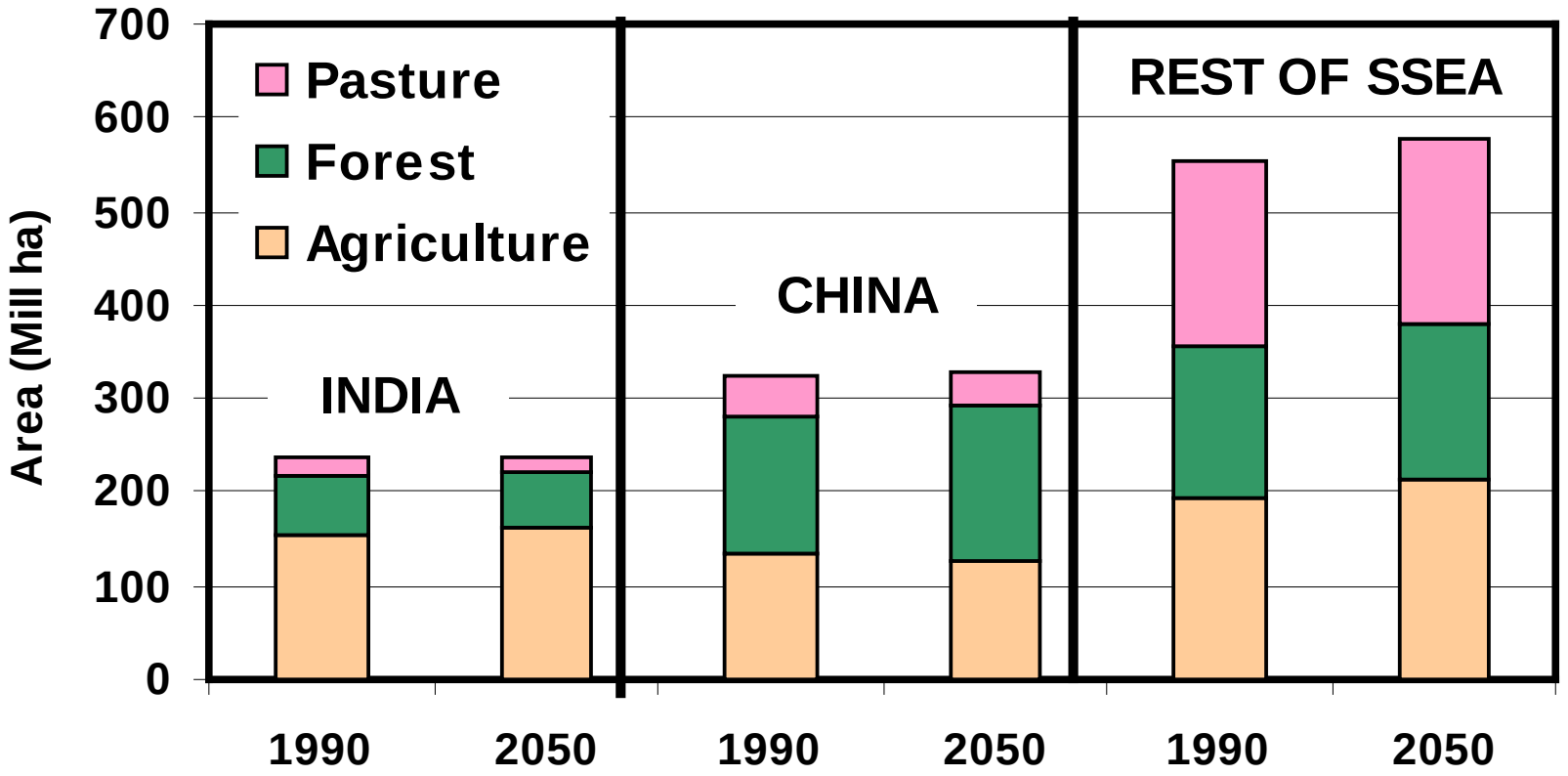


Population-Economy-Technology (PET) Model
9-Region CGE* Model, with Trade



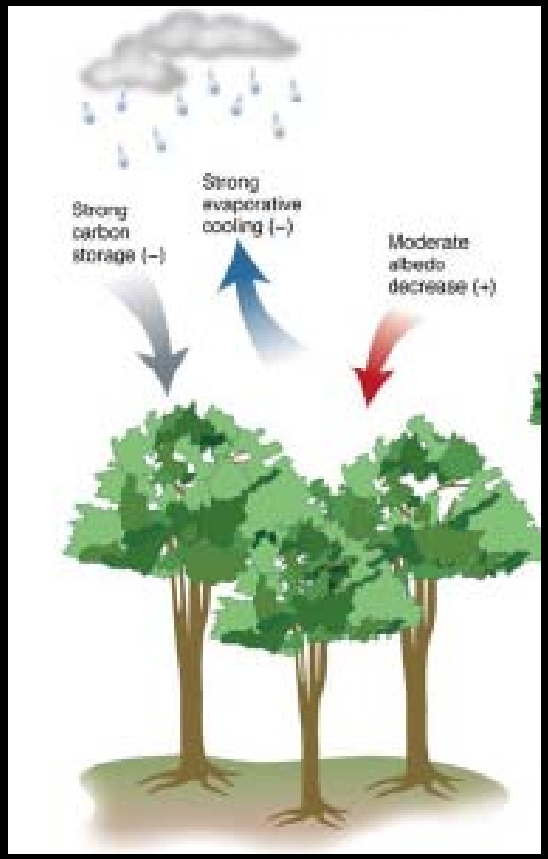
Computable general equilibrium (CGE) model is an economic model that use actual economic data to estimate how an economy might react to changes in policy, technology or other external factors.


IIASA Cropland Area in 2050 (hectares)
Cropland Asia
0
<50000
50000.1 - 100000
100000.1 - 150000
150000.1 - 200000
200000.1 - 250000
250000.1 - 300000


Area (Mill ha)
700
600
500
400
300
200
100
0
Pasture
Forest
Agriculture
INDIA
CHINA
REST OF SSEA
1990
2050
1990
2050
1990
2050

LUC and Biophysical Drivers on Land

- Latent heat (forests > crops > bare ground)
- Albedo (bare ground > crops > forests)
- In tropics, LH effects dominate over albedo effects.
- Conversion of forests to crops in tropics increases albedo (cooling effect), but this is overwhelmed by large decrease in latent heat flux to atmosphere (warming effect), resulting in a net warming in tropics.



The Dynamics of Irrigation

- The dynamics of irrigation in tropics can alter the relative importance of these biophysical drivers.
- The LH flux over well-watered crops may be more than that from forests.
- Globally, crop irrigation comprises of 70% of all human water withdrawals. India leads the world in total irrigated land where irrigation withdrawals represent 80-90% of all water use.
- Pre-monsoon season NDVI anomalies have increased in the Indian subcontinent. Increases are strongly correlated with increases in irrigated area, not preceding rainfall

LUC and Biophysical Drivers on Land

- Surface roughness (forests > crops > bare ground)
- Stronger mixing due to greater surface roughness of forests (over crops or bare ground, increasing supply of moisture from surface and the microscale circulations

Effects of Energy, Hydrology, Irrigation and vegetation activity on Indian Summer Monsoon Variability

- Vegetation cover, surface roughness, and stomatal resistance all imparted to the development of convection and monsoon rainfall activities
- Vegetation and soil moisture introduce differential heating, which enhances frontal activity
- Stronger Asian summer monsoon associated with lower surface albedo (i.e., forests), greater soil moisture, less snow cover, and greater land-sea thermal contrast.
- Irrigation increases LH over land, which decreases sea-land temperature contrast, which can thereby decrease summer monsoon.
- Indian monsoon was significantly weakened by increase in surface albedo (cropland) and by a reduction in surface roughness

LCLUC in MAR

LUC activities can be grouped into three main categories:

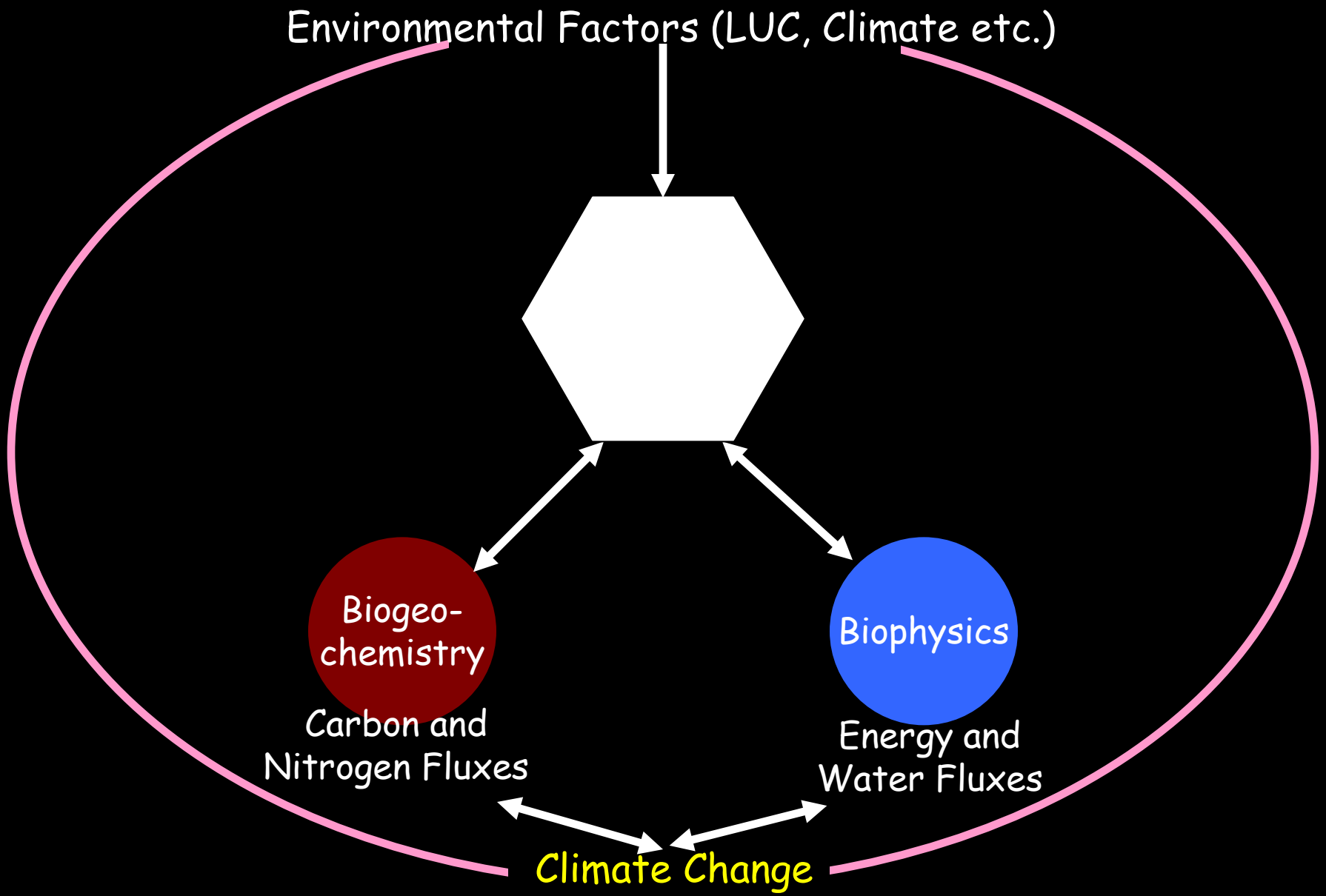
- agriculture (including crop growth and raising livestock)
- forestry (for the production of wood products such as timber or paper), and
- Production of biomass as an energy source (either commercial biomass or biomass fuels at the household level).

Tropical Forests – planetary savior – promote avoided deforestation, reforestation, or afforestation

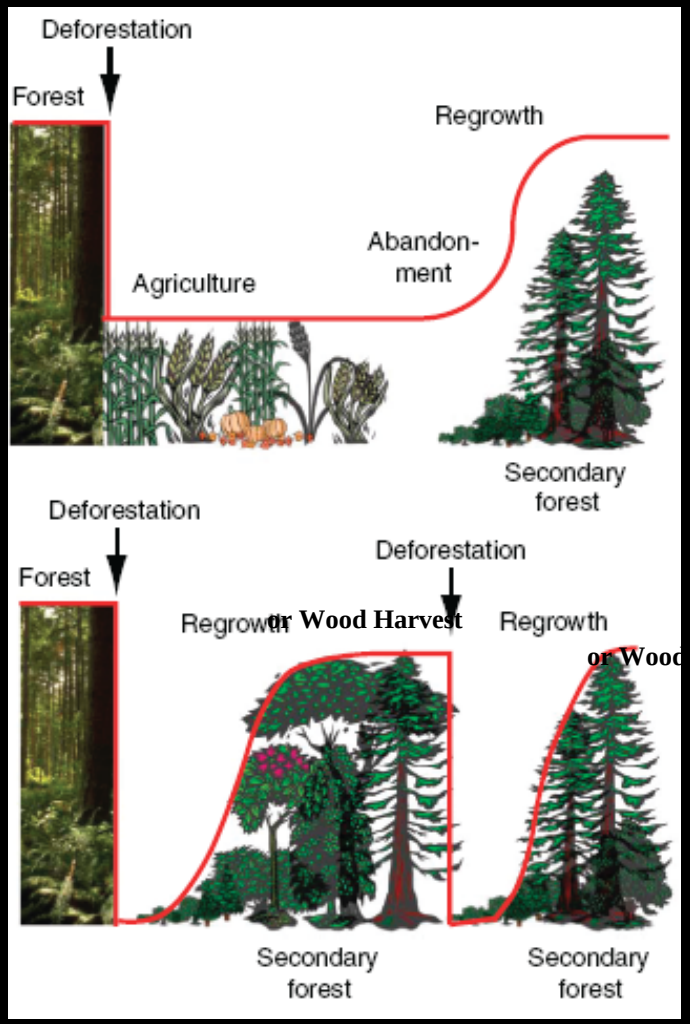
Biofuel plantations to lower albedo and reduce atmospheric CO_2

A last category – the management of land primarily as a carbon sink

Environmental Factors and Processes



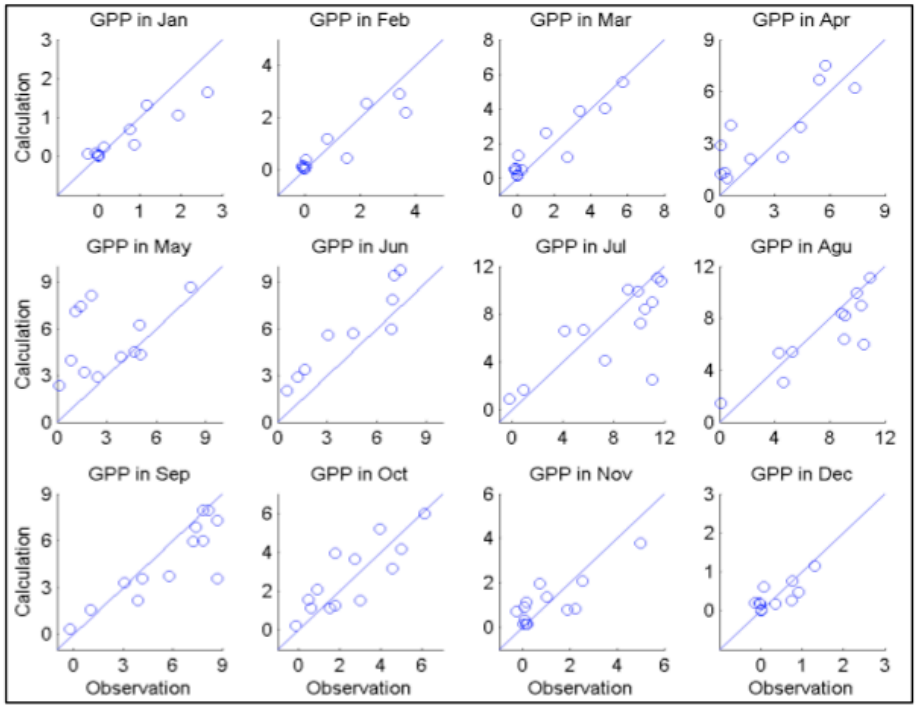
LUC and C and N Dynamics



- Instantaneous C and N release after deforestation
- After abandonment C stored in *secondary forest* (SF)
- Stored C in SF could be <u>enhanced</u> due to CO2 fertilization
- C accumulation in SF could be constrained due to nutrient (e.g., N) limitation
- N Deposition can enhanced the C accumulation
- After LUC soil C and N are increased for a short while

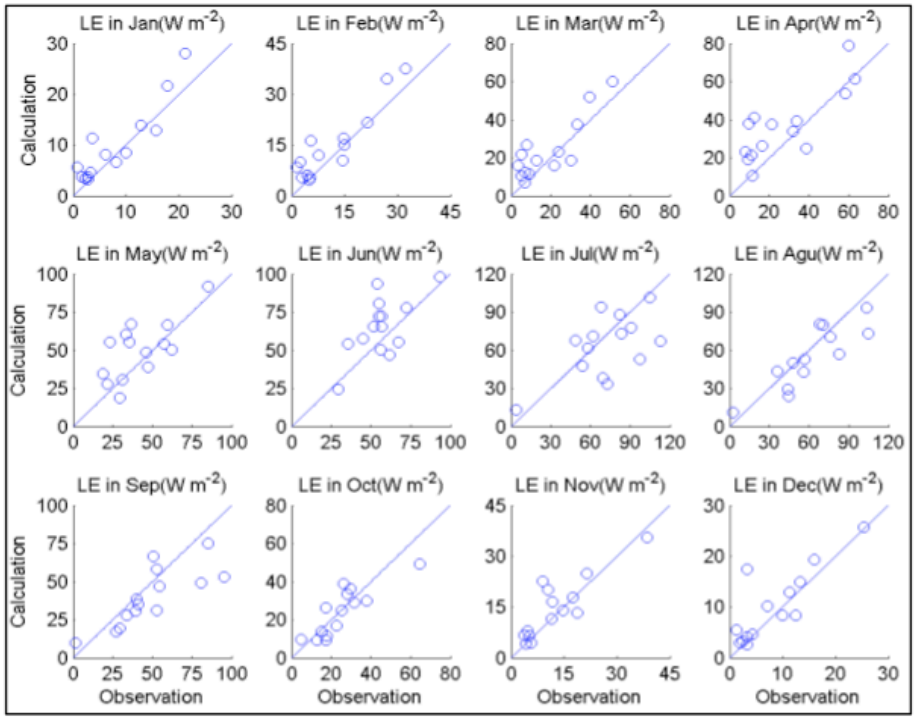
Model Evaluation Using Ground-Based Measurements

GPP



Gross Primary Production ($u$molCO$_2$ m^{-2} s^{-1}) for 12 months. Observation vs. Calculation for 14 sites

LH

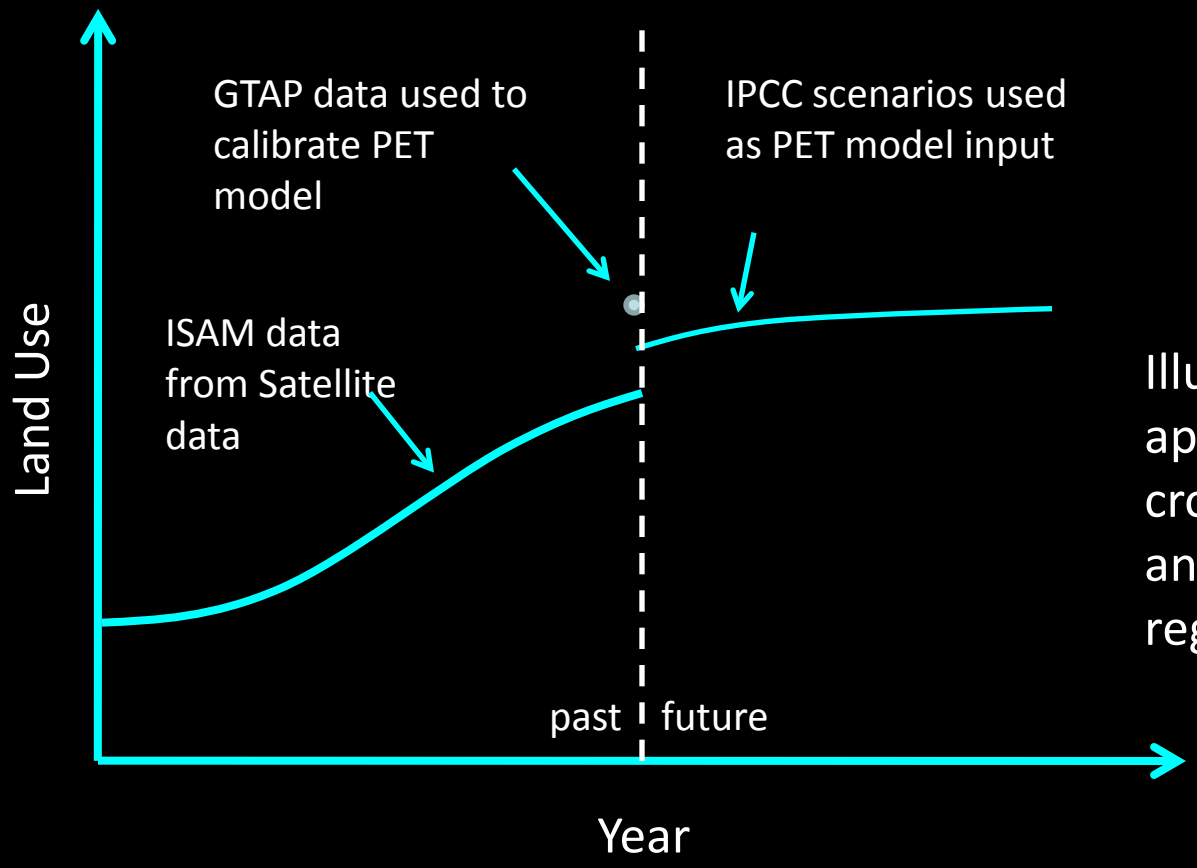


Latent Heat Flux (Wm^{-2}) for 12 months. Observation vs. Calculation for 14 sites

Revised PET Model Sectors

PET model	GTAP sectors
Rice	Paddy rice (pdr)
Other Crops	Wheat (wht); Cereal grains (gro); Vegetables, fruits, nuts (v_f); Oil seeds (osd); Sugar Cane, sugar beet (c_b); Plant based fibers (pfb); Crops nec (ocr)
Livestock	Cattle, sheep, goat, horses (ctl); Raw milk (rmk); Wool, silk worm, cocoons (wol); Animal products (oap)- This sector does not use land input in GTAP LU data set.
Forestry	Forestry (frs): Forestry was not included in traditional GTAP v data for land use.

Data Challenge



Illustrative case, applies to data for cropland, forest, and pasture by region and AEZ.