Land Use – Ecosystem – Climate Interactions in Monsoon Asia:

Evaluating the impacts of current and projected LCLUC on climate, water and carbon cycling in the first half of 21st Century

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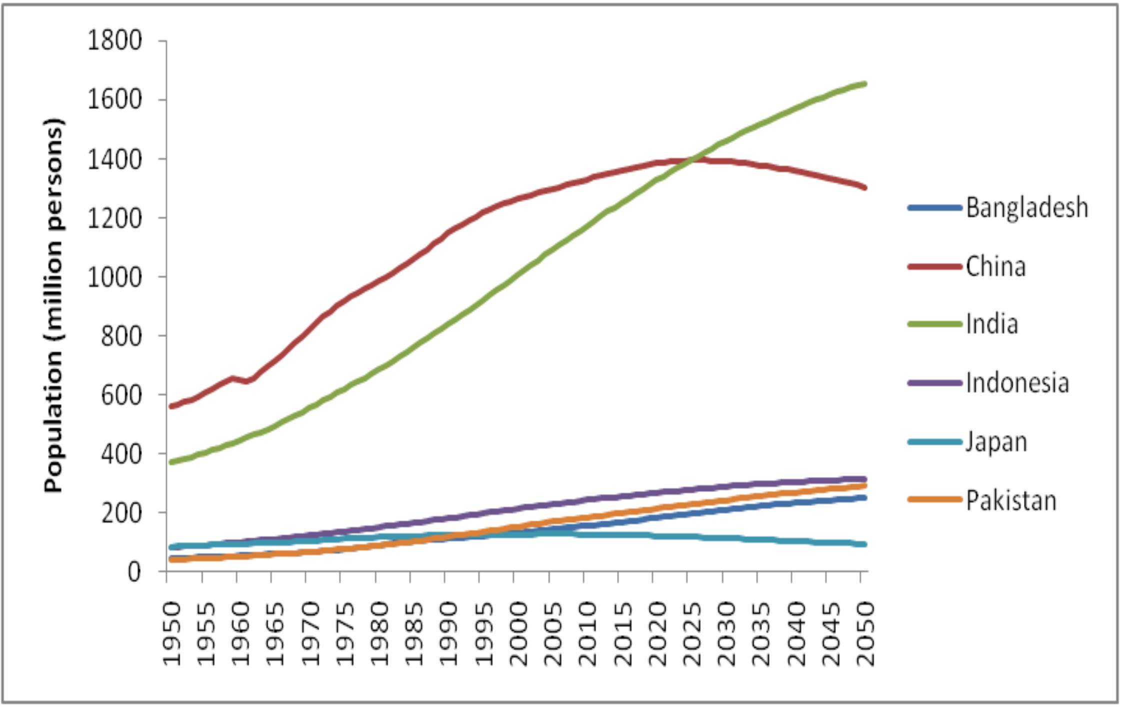
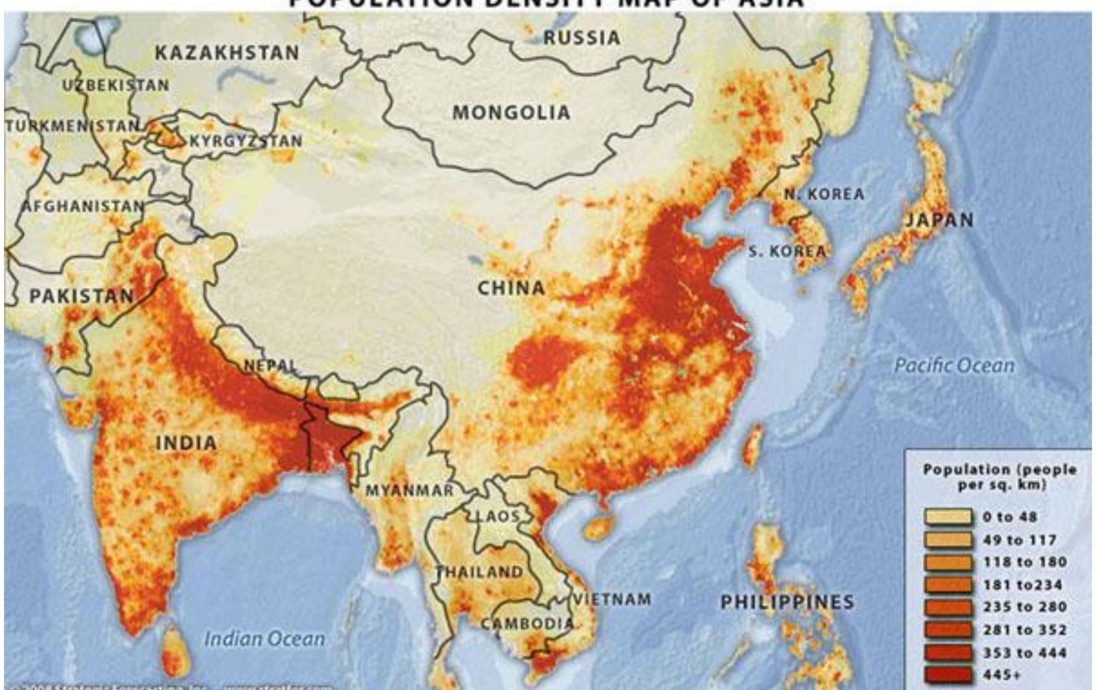


POPULATION DENSITY MAP OF ASIA

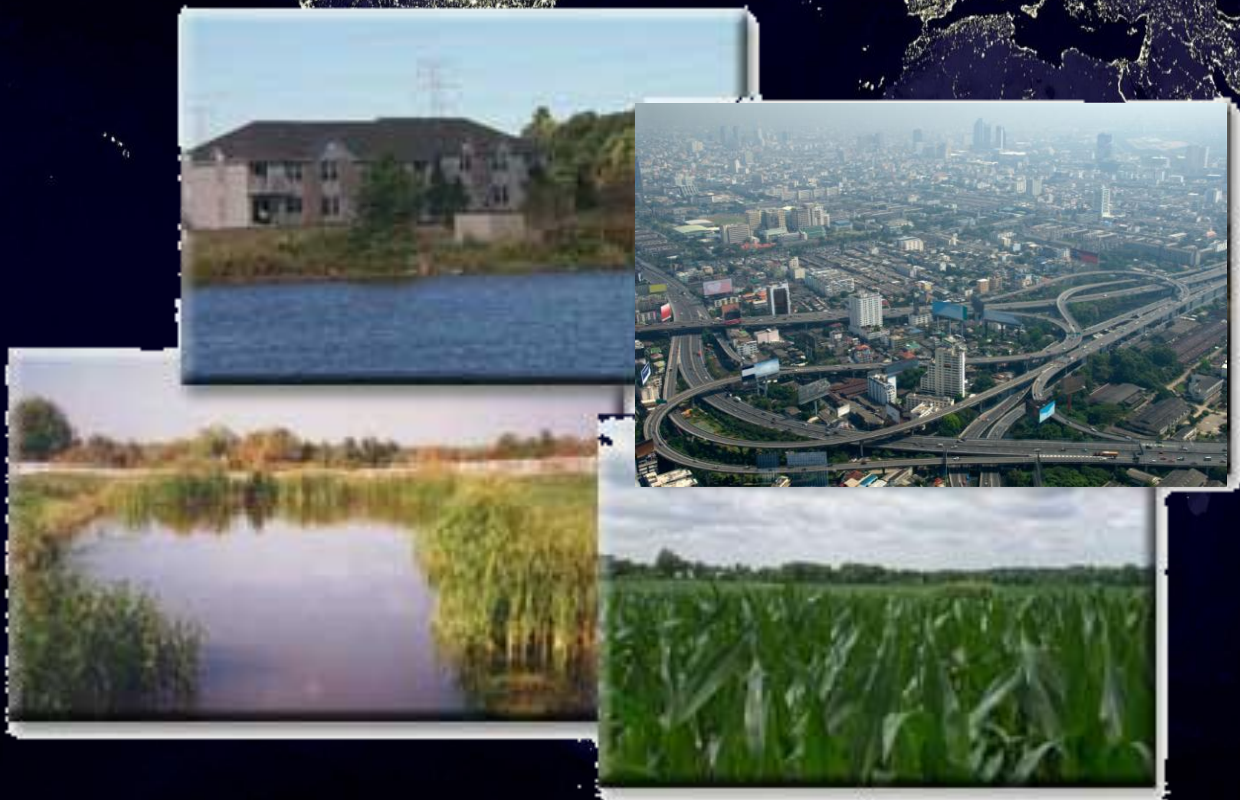


People want to use LAND for:

- **Food**
- **Energy**
- **Living**

So all compete for the LAND, which drives LCLUC.

Land cover/land use changes in Monsoon Asia



Earth at Night
More information available at:
http://apod.nasa.gov/ap081005.html

Astronomy Picture of the Day
2008 October 5
http://apod.nasa.gov/

Project Goals :

Understand complex interactions among land use, ecosystem and climate and evaluate the impacts of current and projected LCLUC on climate, water and carbon cycling in the region of monsoon Asia in the first half of 21^{st} century by using an integrated model of regional climate, ecosystem, land use and economy; remote sensing and field observations.

Key questions:

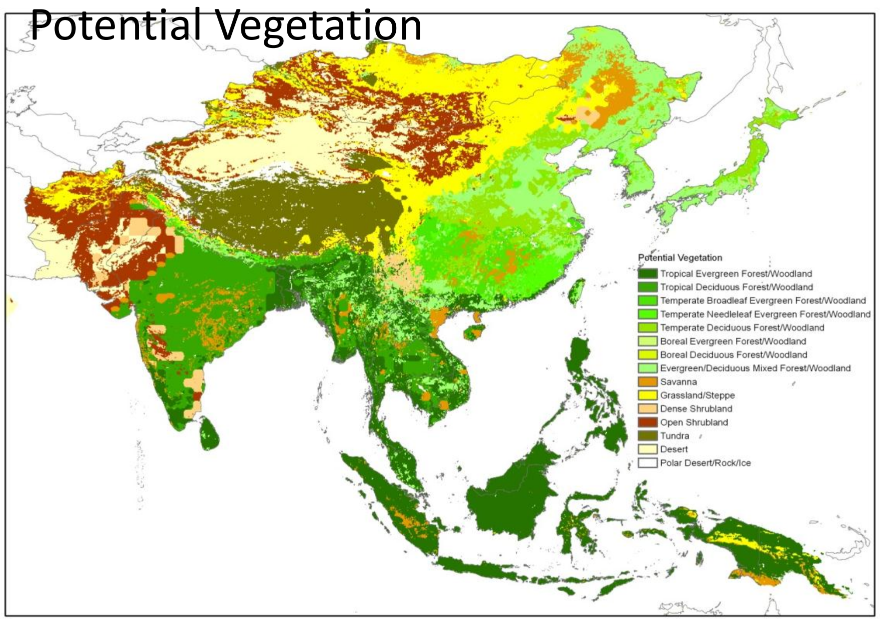
- **Question 1** – What are current patterns and projected changes in land use and land cover in the first half of 21^{st} century?
- **Question 2 -** How have the carbon and water cycles been changed by LCLUC in the region in the past and how will the carbon and water cycles be changed by LCLUC in Monsoon Asia in the first half of 21^{st} century?
- **Question 3 -** What are relative roles of LCLUC and non-LCLUC factors (e.g., climate variability/change, nitrogen deposition, troposhereic ozone concentration) on climate change, water and carbon cycling?
- **Question 4 -** To what extent do the LCLUC modulates the Asia monsoon climate and how will the changed monsoon climate impact LCLUC in Monsoon Asia in the first half of 21^{st} century?

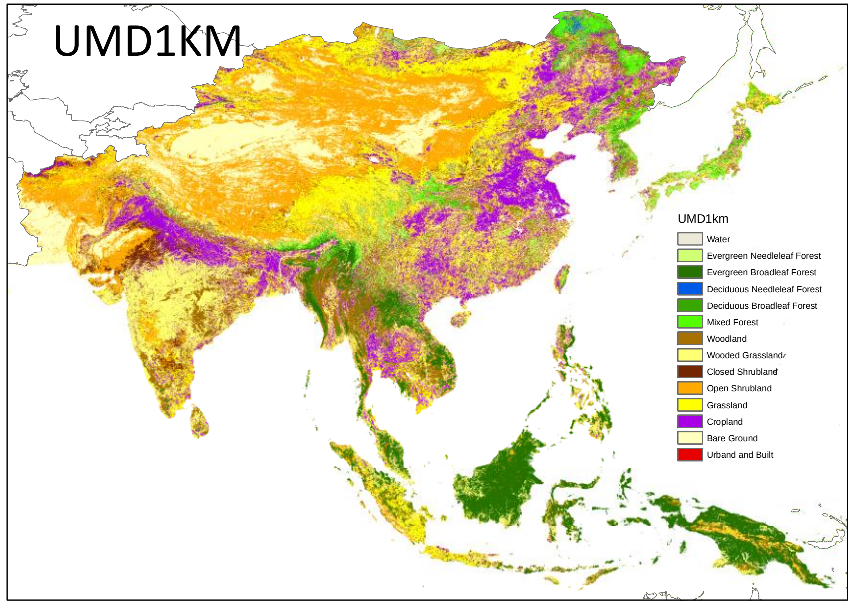
I

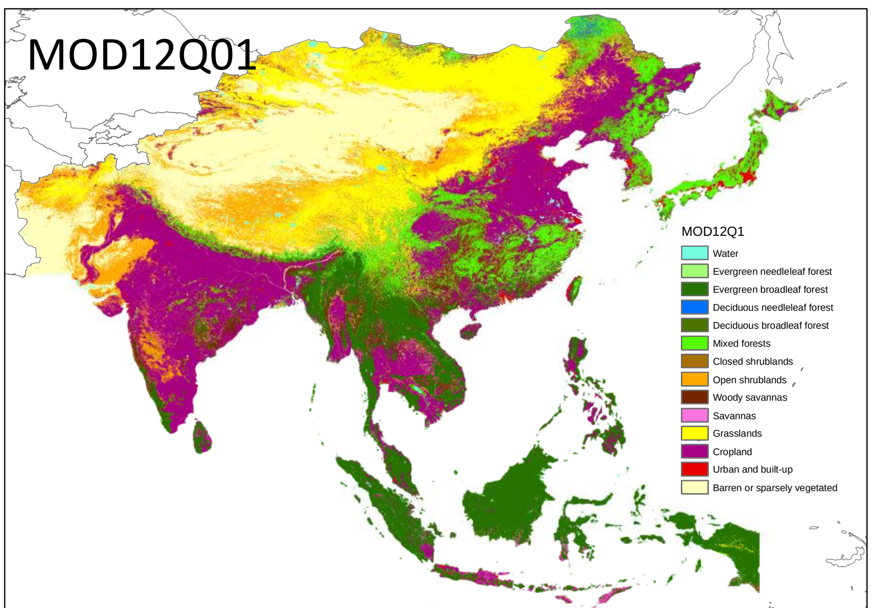
What are current patterns and projected changes in LCLUC during 1900-2050 and the changes in non-LCLUC factors?

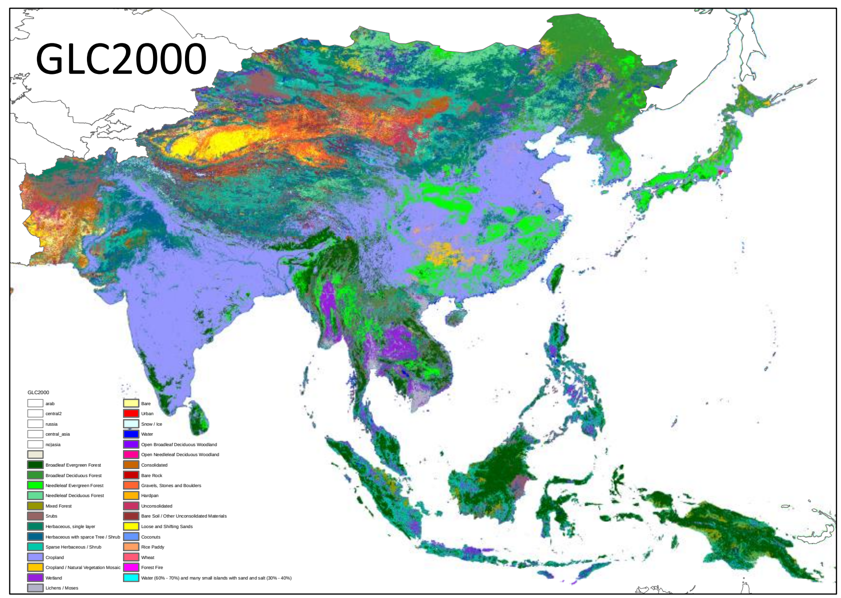
Global and regional land cover and land use data

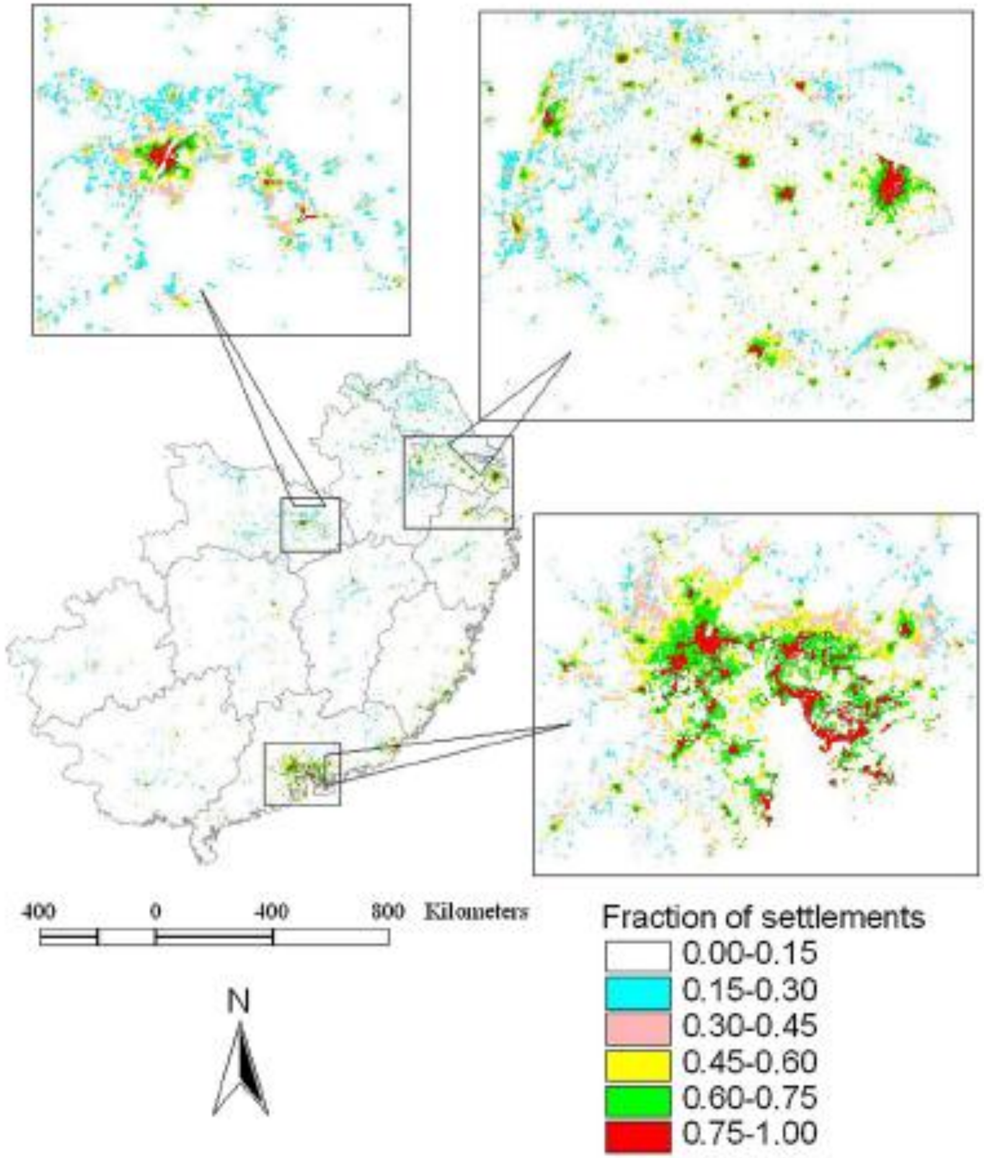
Data name	Time period	Resolution	Major character	Reference
Historical croplands Dataset	1700-1992	0.5 degree	Global Cropland distributions	Ramankutty and Foley, 1999
HYDE 3.1	1700-2005	5 minute	Global cropland, pasture and cultivated land use	Goldewijk and Ramankutty, 2004
The Global Landuse Modeling Data	1700-2000	1 degree	the fraction of crop, pasture, primary land, secondary land, water, and ice	Hurtt et al., 2006
1992 Major Crops Dataset	1992	5 minute	major crops	Leff et al., 2004
MODIS land cover	2001-present	1 km	multiple classification schemes describing land cover properties	http://modis-land.gsfc.nasa.gov/landcover.htm
GLC2000	2000	1 km	Base on SPOT 4 VEGETATION instrument	http://www-gvm.jrc.it/glc2000/defaultGLC2000.htm
Global Land Cover Characteristics Data Base	1992/1993	1 km	Based on IGBP AVHRR 10-day composites	Loveland et al., 2000
UMD 1km Global Land Cover	Between 1981-1994	1 km	AVHRR 1981-1994	Hansen et al, 2000
China's National Land Use/Cover Dataset	1990, 1995, 2000	30 meter	Landsat TM/ETM	Liu et al., 2003, 2005


Potential Vegetation
Potential Vegetation
Tropical Evergreen Forest/Woodland
Tropical Deciduous Forest/Woodland
Temperate Broadleaf Evergreen Forest/Woodland
Temperate Needleleaf Evergreen Forest/Woodland
Temperate Deciduous Forest/Woodland
Boreal Evergreen Forest/Woodland
Boreal Deciduous Forest/Woodland
Evergreen/Deciduous Mixed Forest/Woodland
Savanna
Grassland/Steppe
Dense Shrubland
Open Shrubland
Tundra
Desert
Polar Desert/Rock/Ice

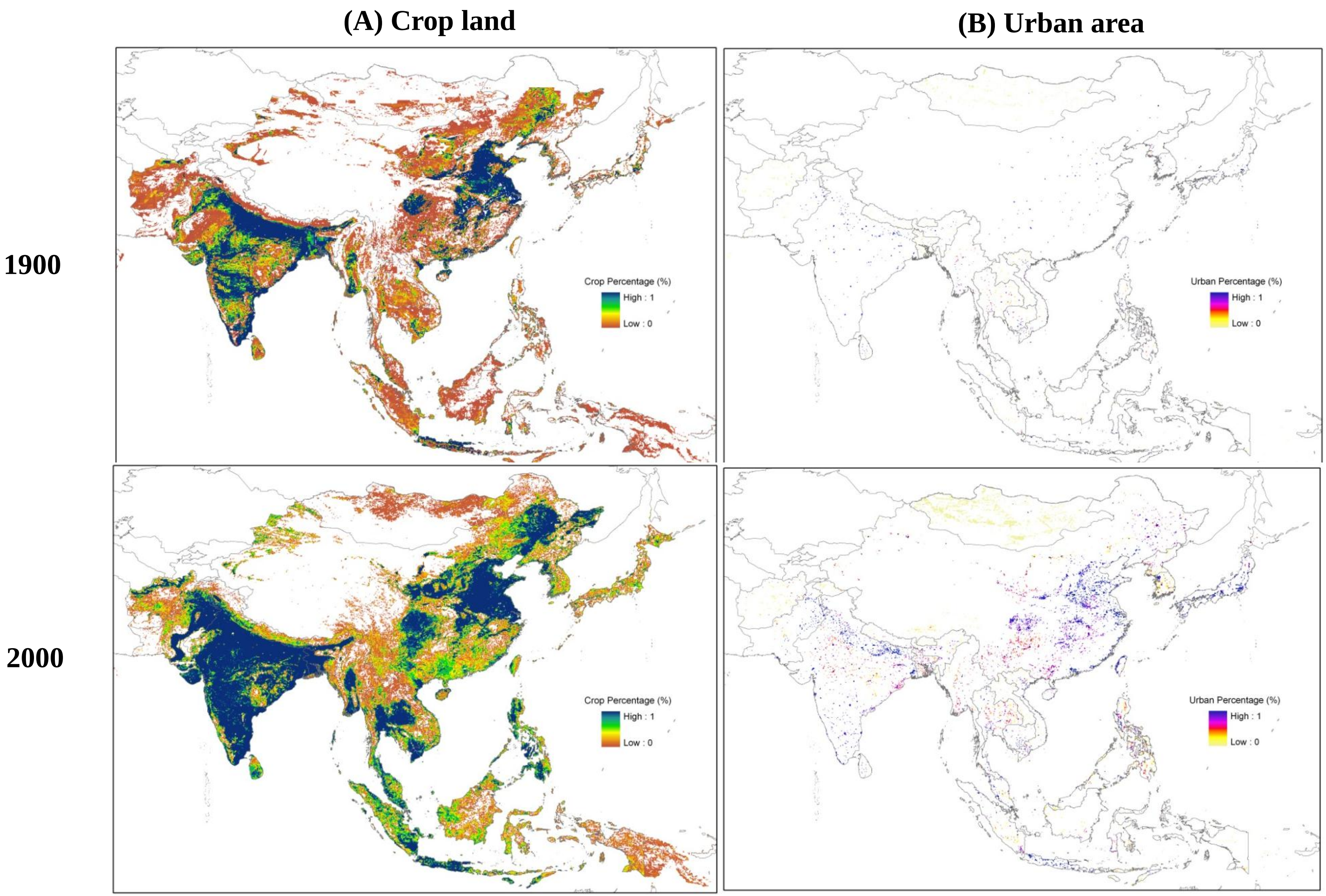

UMD1KM
UMD1km
Water
Evergreen Needleleaf Forest
Evergreen Broadleaf Forest
Deciduous Needleleaf Forest
Deciduous Broadleaf Forest
Mixed Forest
Woodland
Wooded Grassland
Closed Shrubland
Open Shrubland
Grassland
Cropland
Bare Ground
Urband and Built

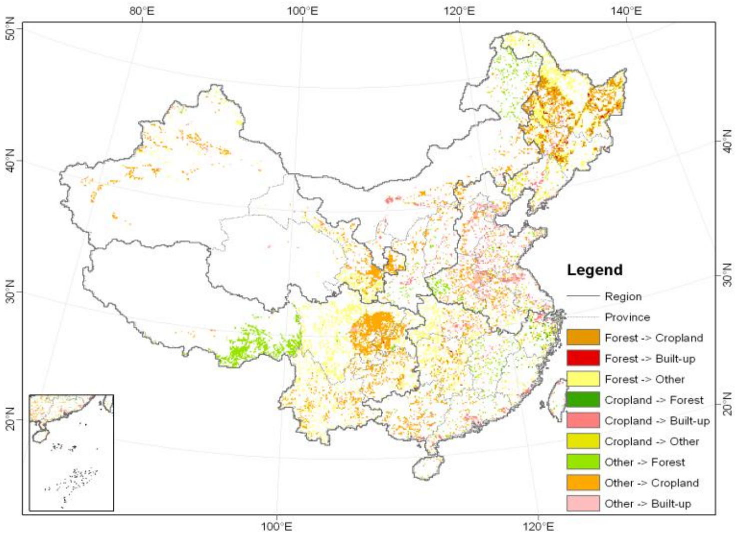

MOD12Q01
MOD12Q1
Water
Evergreen needleleaf forest
Evergreen broadleaf forest
Deciduous needleleaf forest
Deciduous broadleaf forest
Mixed forests
Closed shrublands
Open shrublands
Woody savannas
Savannas
Grasslands
Cropland
Urban and built-up
Barren or sparsely vegetated


GLC2000
GLC2000
arab
central2
russia
central_asia
no)asia
Broadleaf Evergreen Forest
Broadleaf Deciduous Forest
Needleleaf Evergreen Forest
Needleleaf Deciduous Forest
Mixed Forest
Srubs
Herbaceous, single layer
Herbaceous with sparce Tree / Shrub
Sparse Herbaceous / Shrub
Cropland
Cropland / Natural Vegetation Mosaic
Wetland
Lichens / Moses
Bare
Urban
Snow / Ice
Water
Open Broadleaf Deciduous Woodland
Open Needleleaf Deciduous Woodland
Consolidated
Bare Rock
Gravels, Stones and Boulders
Hardpan
Unconsolidated
Bare Soil / Other Unconsolidated Materials
Loose and Shifting Sands
Coconuts
Rice Paddy
Wheat
Forest Fire
Water (60% - 70%) and many small islands with sand and salt (30% - 40%)



Fractional settlements developed from a combination of DMSP-OLS, MODIS NDVImax, and Landsat ETM+ images in 2000 in southeastern China, highlighting three urban regions (the administrative boundary at the provincial level was overlaid on the human settlement image). *(Lu et al., 2008)*


(A) Crop land
(B) Urban area
1900
2000
Crop Percentage (%)
High : 1
Low : 0
Urban Percentage (%)
High : 1
Low : 0
Crop Percentage (%)
High : 1
Low : 0
Urban Percentage (%)
High : 1
Low : 0



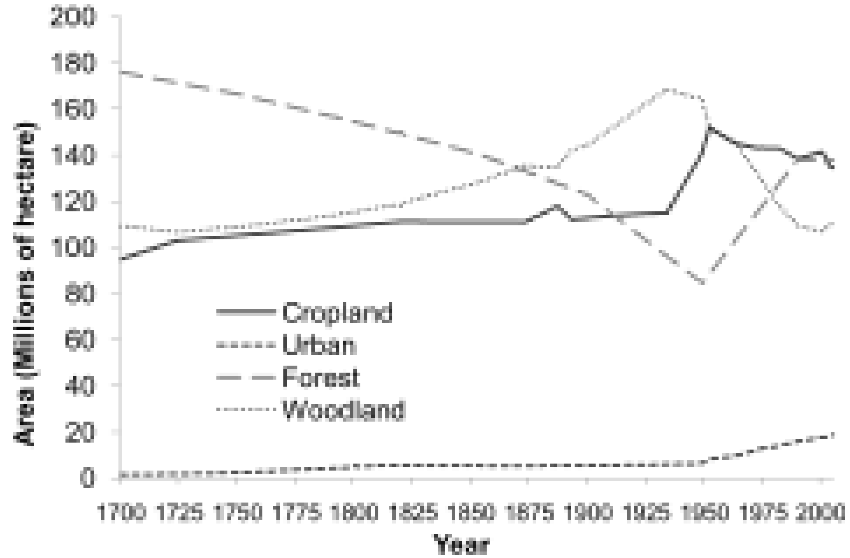
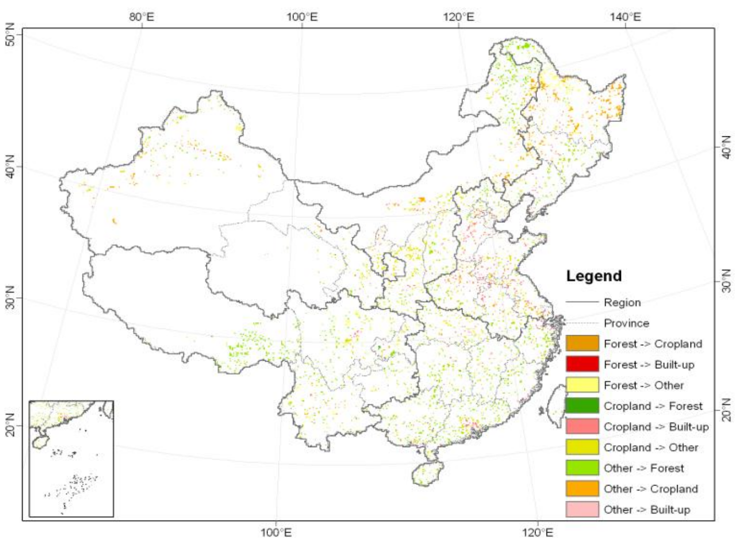
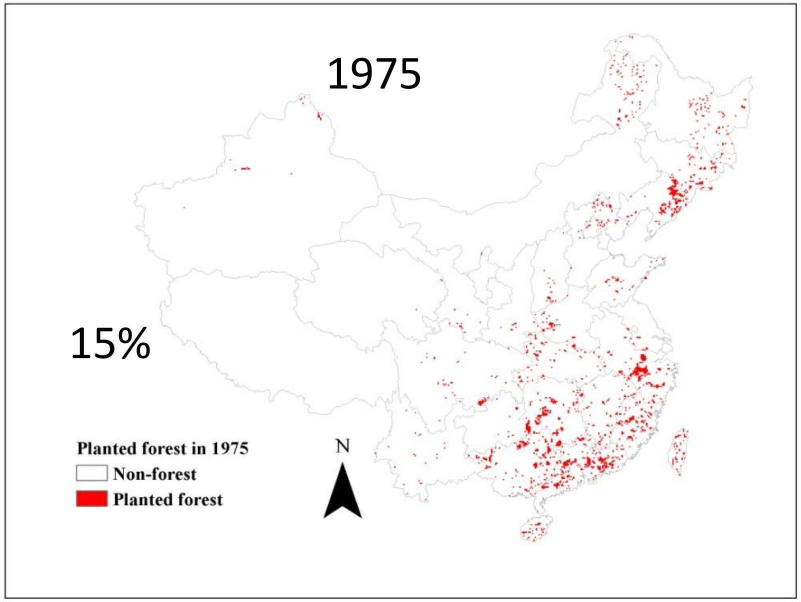


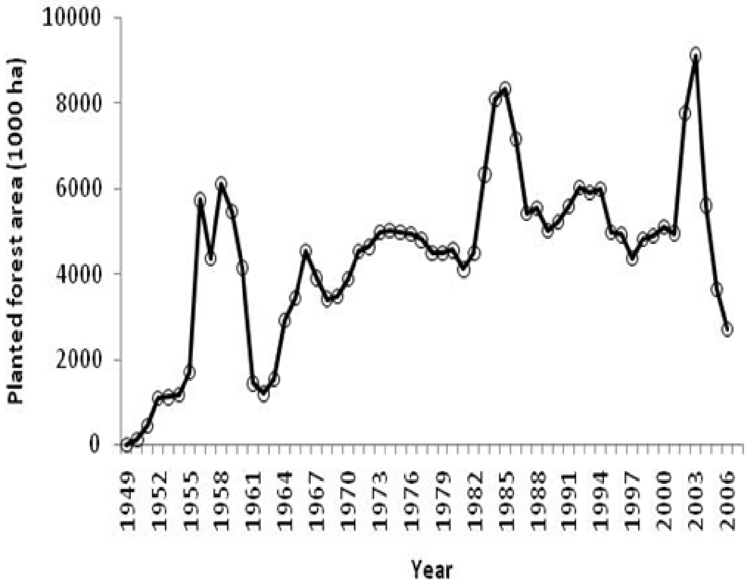
Figure 4. Changes in the area of forest, cropland, urban, and woodland during 1700–2005 (unit: million ha).

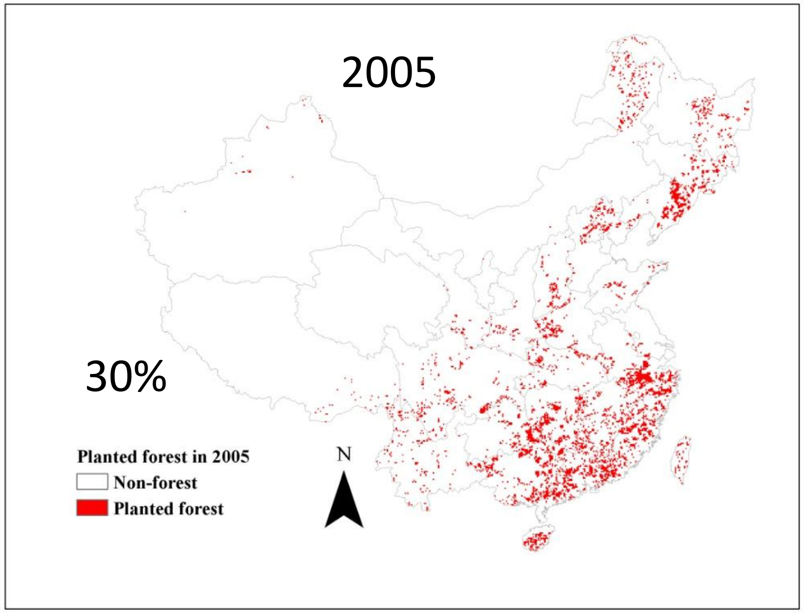


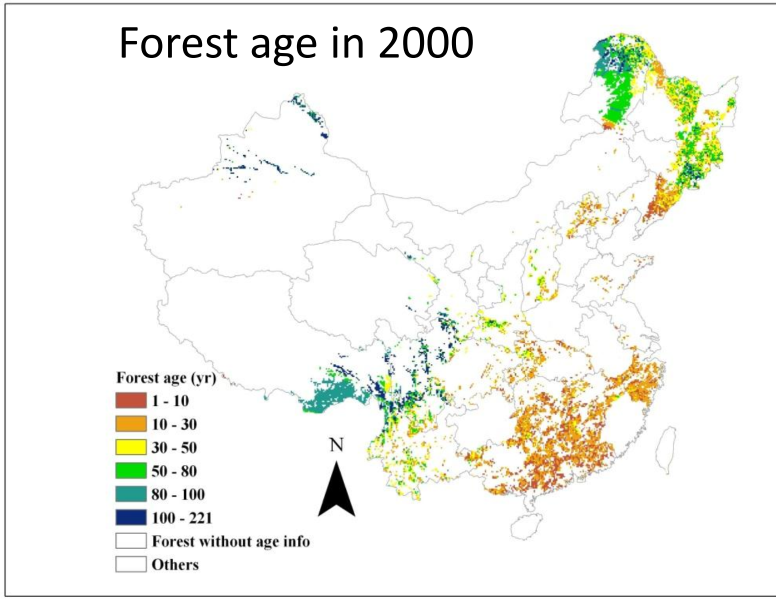
Land-use/Land-cover transitions during 1700-2005 (a) and during 1980-2005 (b) (*Liu & Tian, 2010*)

Increased Plantation forest area and forest age

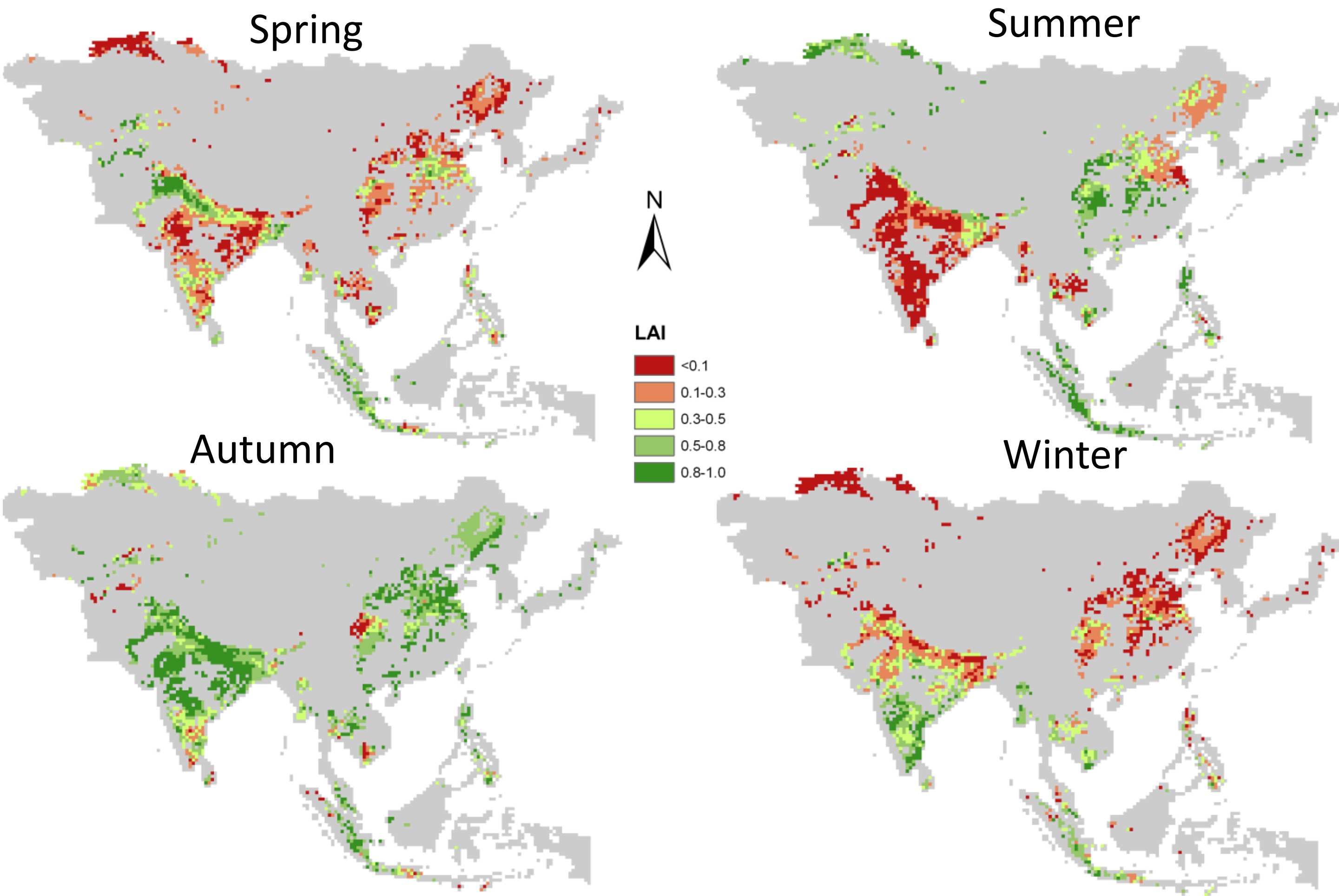






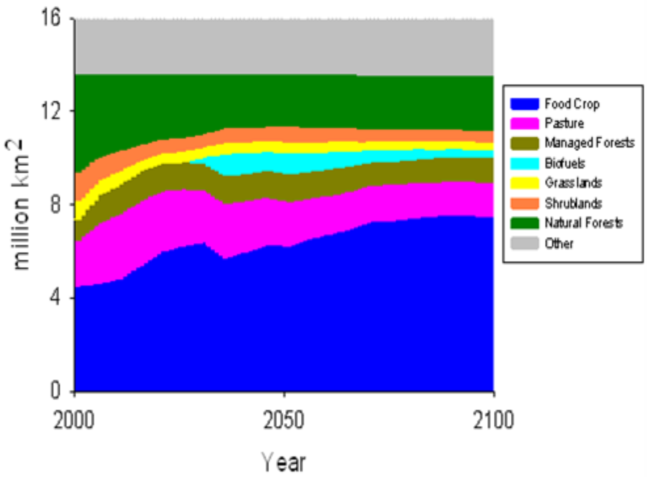


Seasonal pattern of Standardized LAI in Asia's cropland

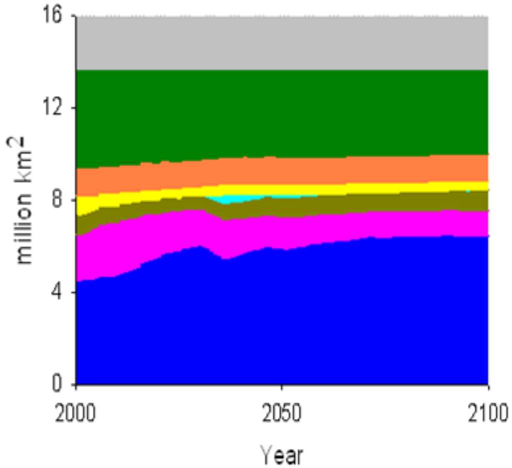


Future land cover/land use change induced by biofuel crop production during the 21st century

A

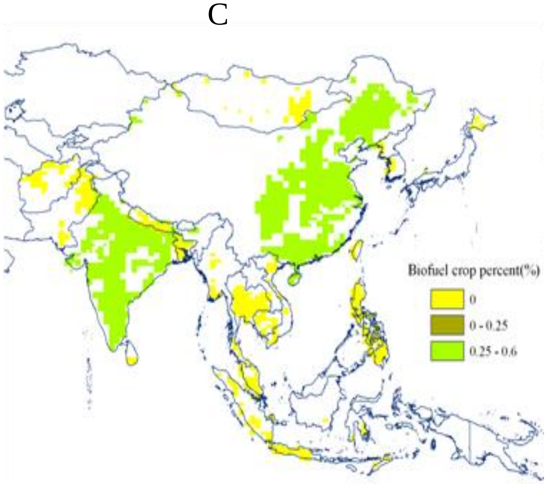


B

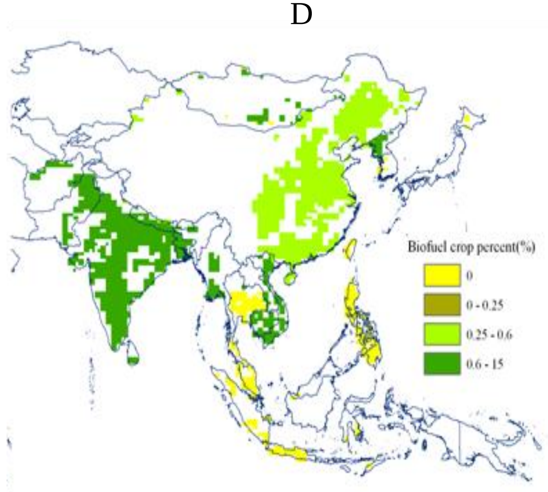


The area of biofuel crop would increase dramatically and account for 14% of total cropland area under the policy scenario by the year of 2100; while two major land types, natural forest and pasture, would be largely converted for biofuel production under both scenarios over MA region during 2000-2100.

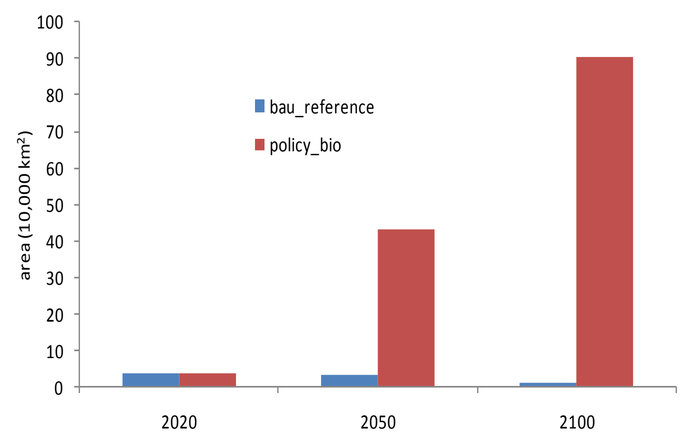
C



D



E



Future land use change under the reference scenario (A) and policy scenario (B); Spatial patterns of biofuel crop in Monsoon Asia in the 21st century under the reference scenario (C) and policy scenario (D); Changes in the area of biofuel crop in Monsoon Asia in the 21st century (reference scenario and policy scenario) (E), generated by the MIT Emissions Prediction and Policy Analysis (EPPA) model.

Other major environmental factors - Climate

Over the late half of 20th century, precipitation amount reduced by 15.1 mm per decade across MA region with a significant increase in drought area and drought duration.
Over the first half of 21st century, temperature will increase up to about 2 degree under three climate policy scenarios.

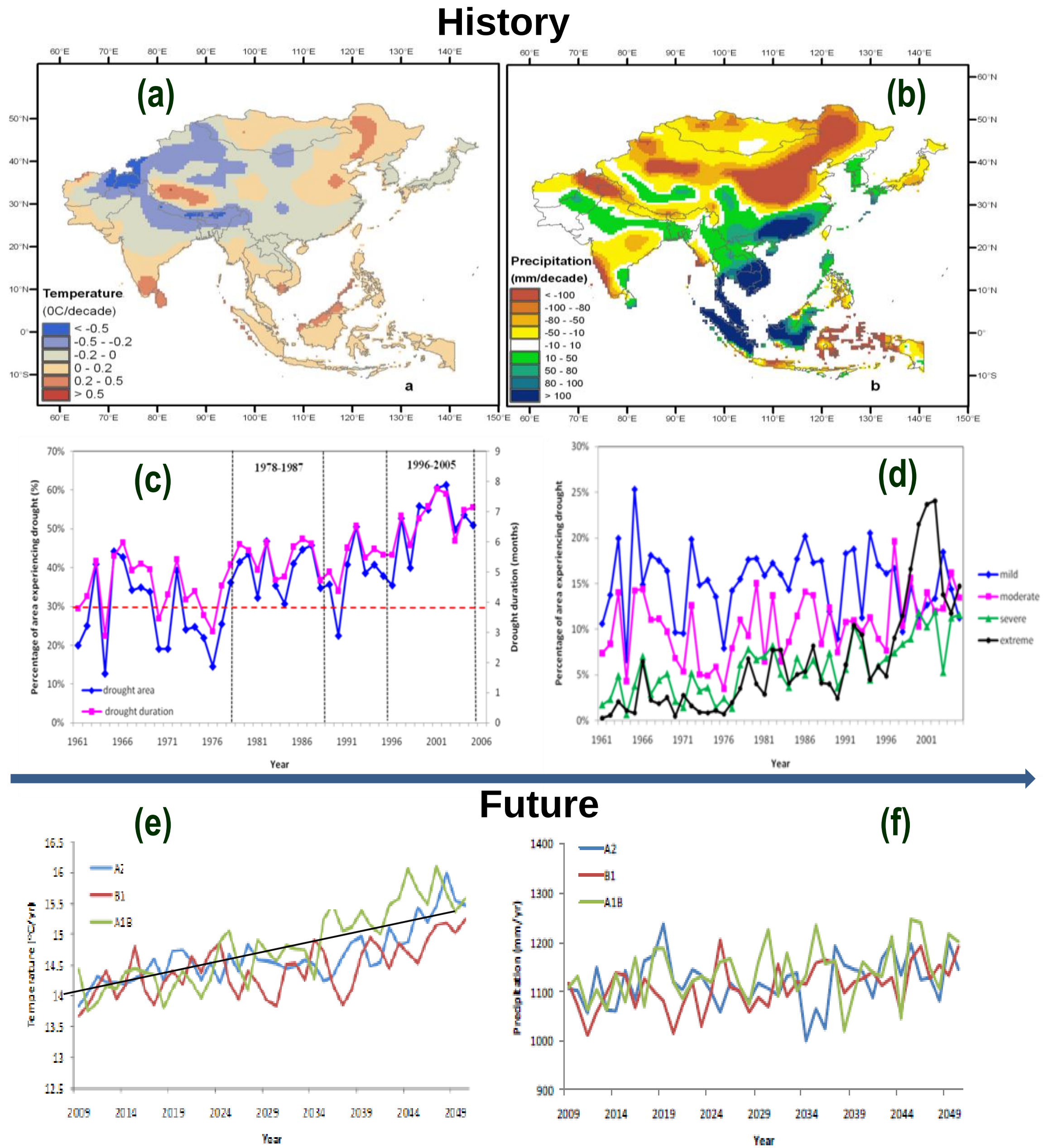
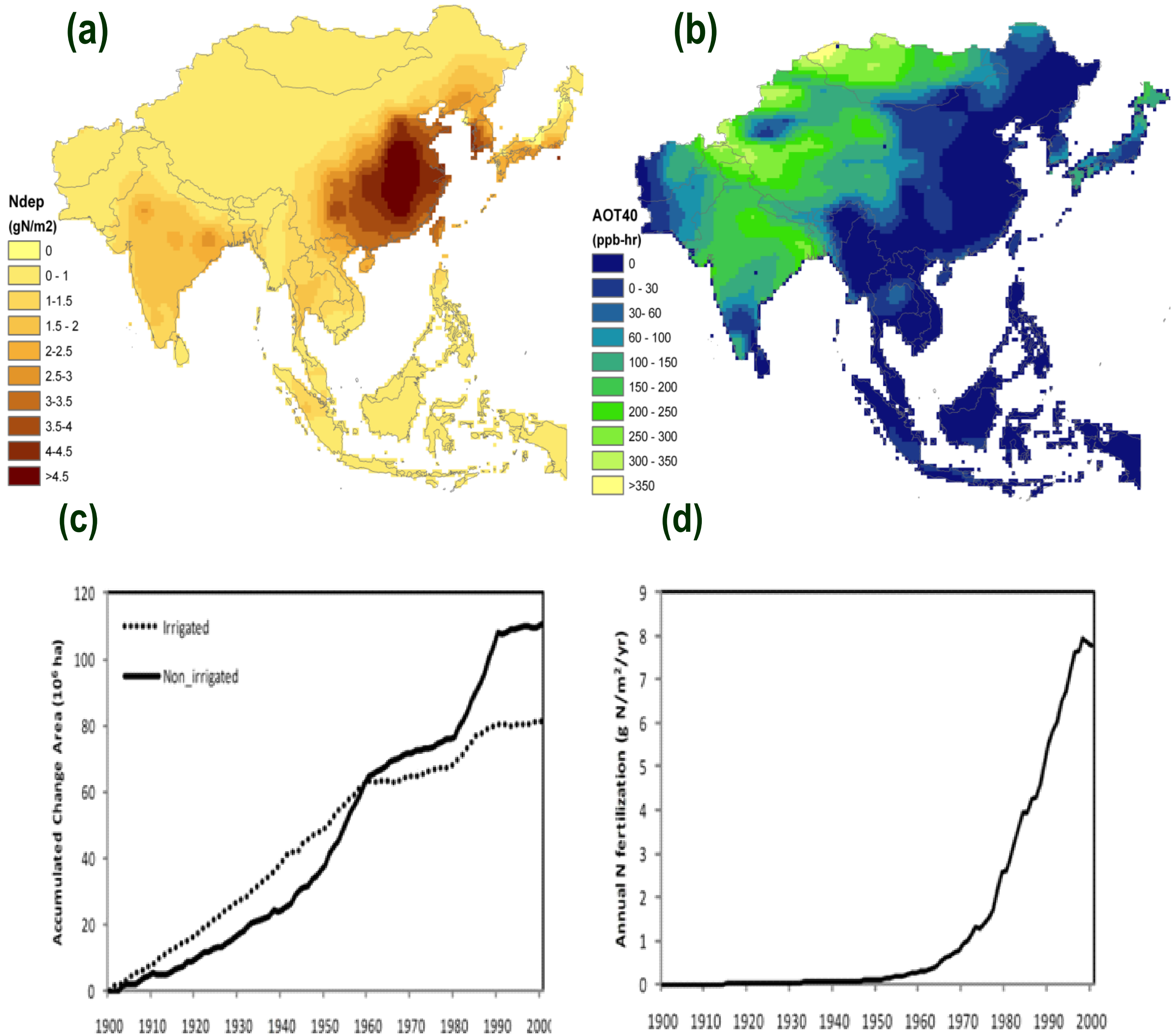


Figure: Spatial pattern of changing trend of (a) temperature (°C/decade) and (b) precipitation (mm/decade); Percentage of (c) dry area, drought duration and (d) area experiencing different drought levels in monsoon Asia during the period 1948-2000;
Projected interannual variations of mean temperature (e) and precipitation (f) under three climate policy scenarios over the first of the 21st century, averagely estimated by four GCMs results.

Other major environmental factors



During the 20th century, both nitrogen deposition and ozone pollution index elevated over MA region with the highest increase of Ndep and AOT40 in Southeast China and Northwest Outer Mongolia, respectively.
Since 1960, irrigated area almost doubled and fertilizer application rate dramatically increased by 8 times.

Figure: Spatial pattern of changes in nitrogen deposition (gN/m^2) (a) and Ozone AOT40 index (ppb-hr) (b); Annual average of irrigation/non-irrigation land area (c), and fertilizer application rate (d) over MA region during the 20th century.

Across MA region,

I: Land cover/land use patterns have been dramatically altered over the last 20th century with the significant expansion of agricultural land and urban land; and the conversion of natural to managed ecosystems will continuously take place as an increasing demand for biofuel production during the 21st century.

II: Land management practices (e.g. irrigation and fertilizer application) have been applied intensively/extensively with the expansion of managed cropland aiming to increase crop productivity during the late half of 20th century.

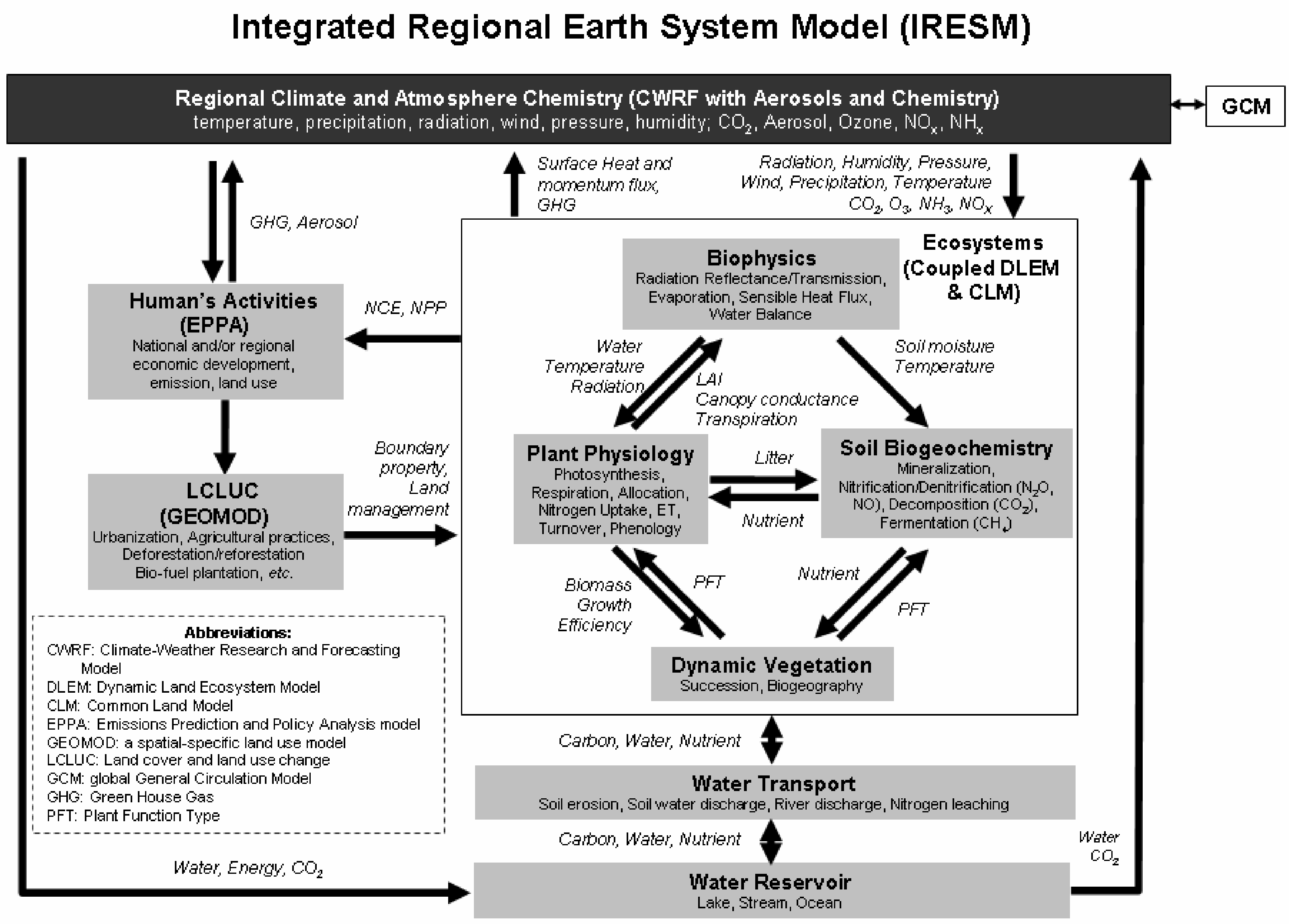
III: Changes in other environmental factors imply that MA region has experienced increased drought stress, elevated nitrogen deposition and ozone pollution. The MA region will face warming climates with significantly increasing temperature in the 21st century.

IV: Changes in land cover/land use, climate and atmospheric chemistry substantially varied from place to place.

II

How have the carbon and water cycles been changed by LCLUC in the past and how will the carbon and water cycles be changed by LCLUC in MA region in the first half of 21st century?

Integrated Regional Earth System Model (IRESM)



Ecosystem and hydrological models within IRESM

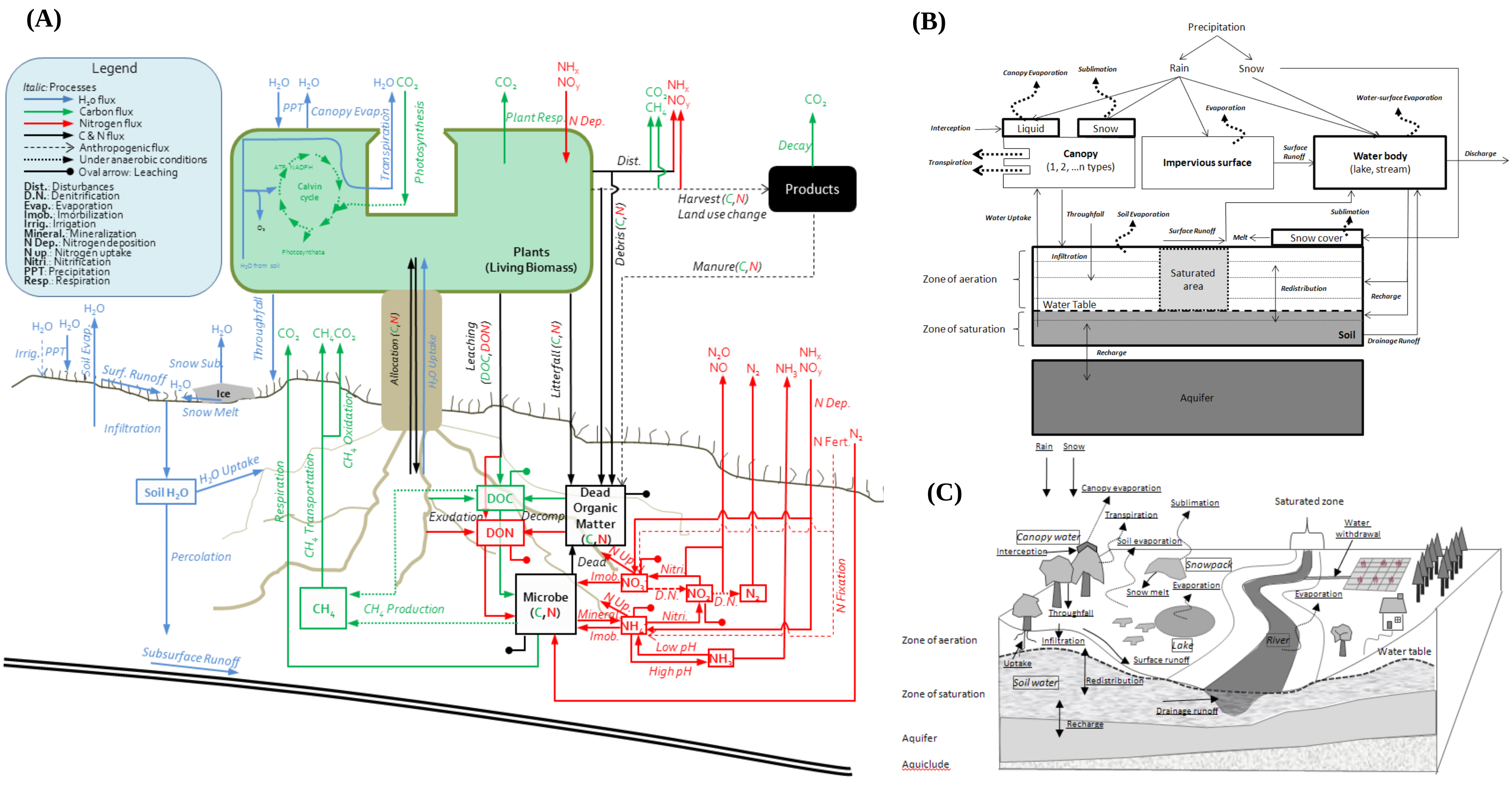
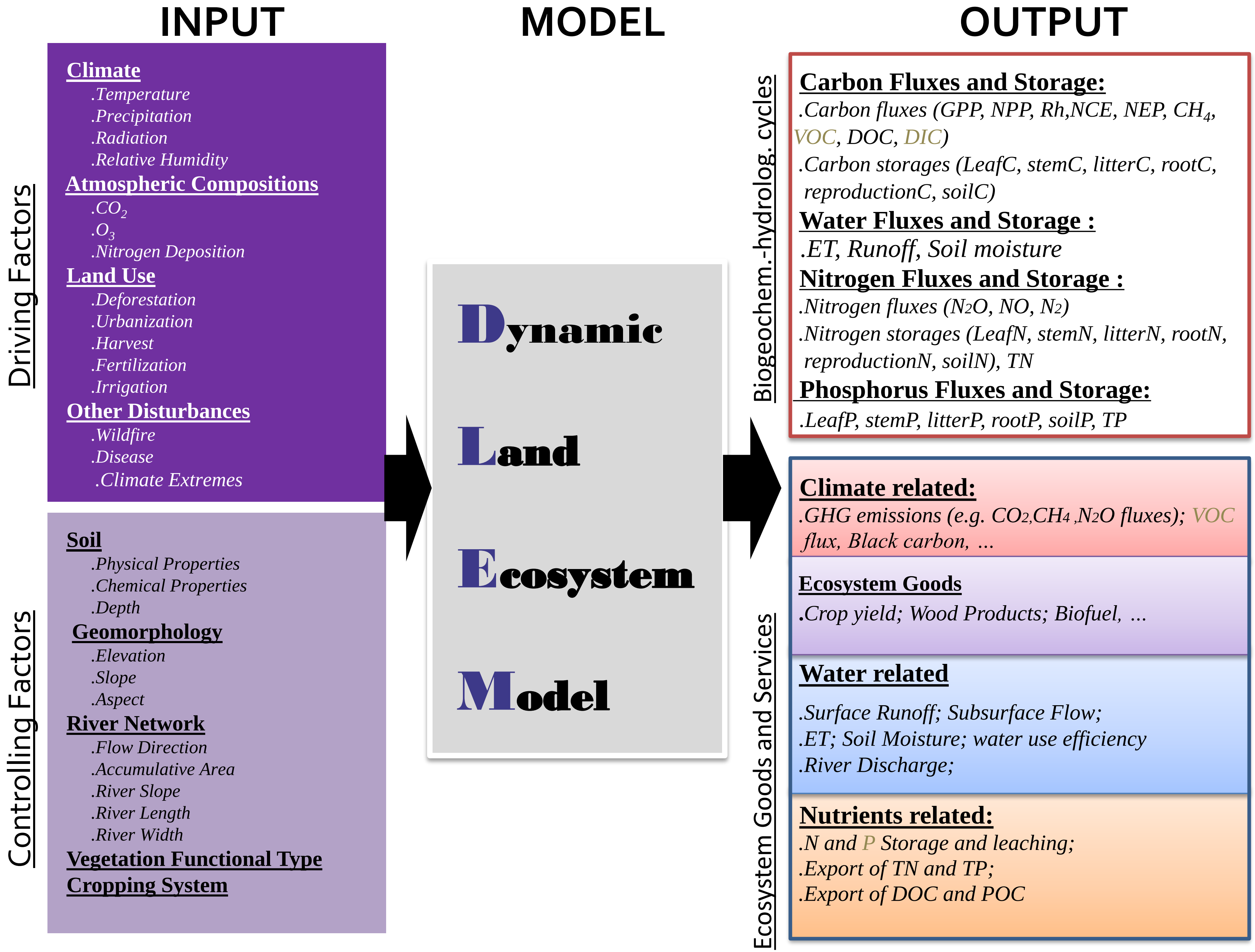
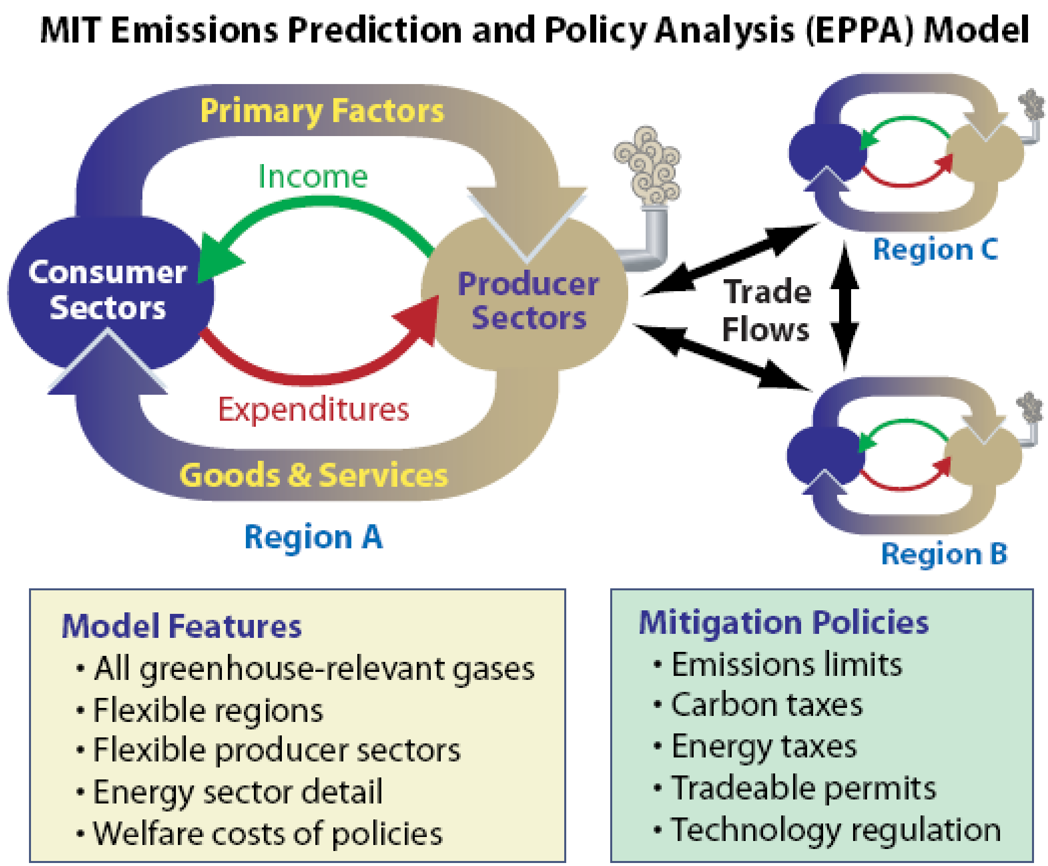


Figure (A) Coupling of biogeochemical and hydrological cycles (C, N, P, H_2O) in ecosystem module of IRESM - DLEM ;
(B) Representations of multi-soil layer and interactions between vegetation root zone and ground water in DLEM;
(C) Cohort structure and major hydrological processes represented in DLEM.

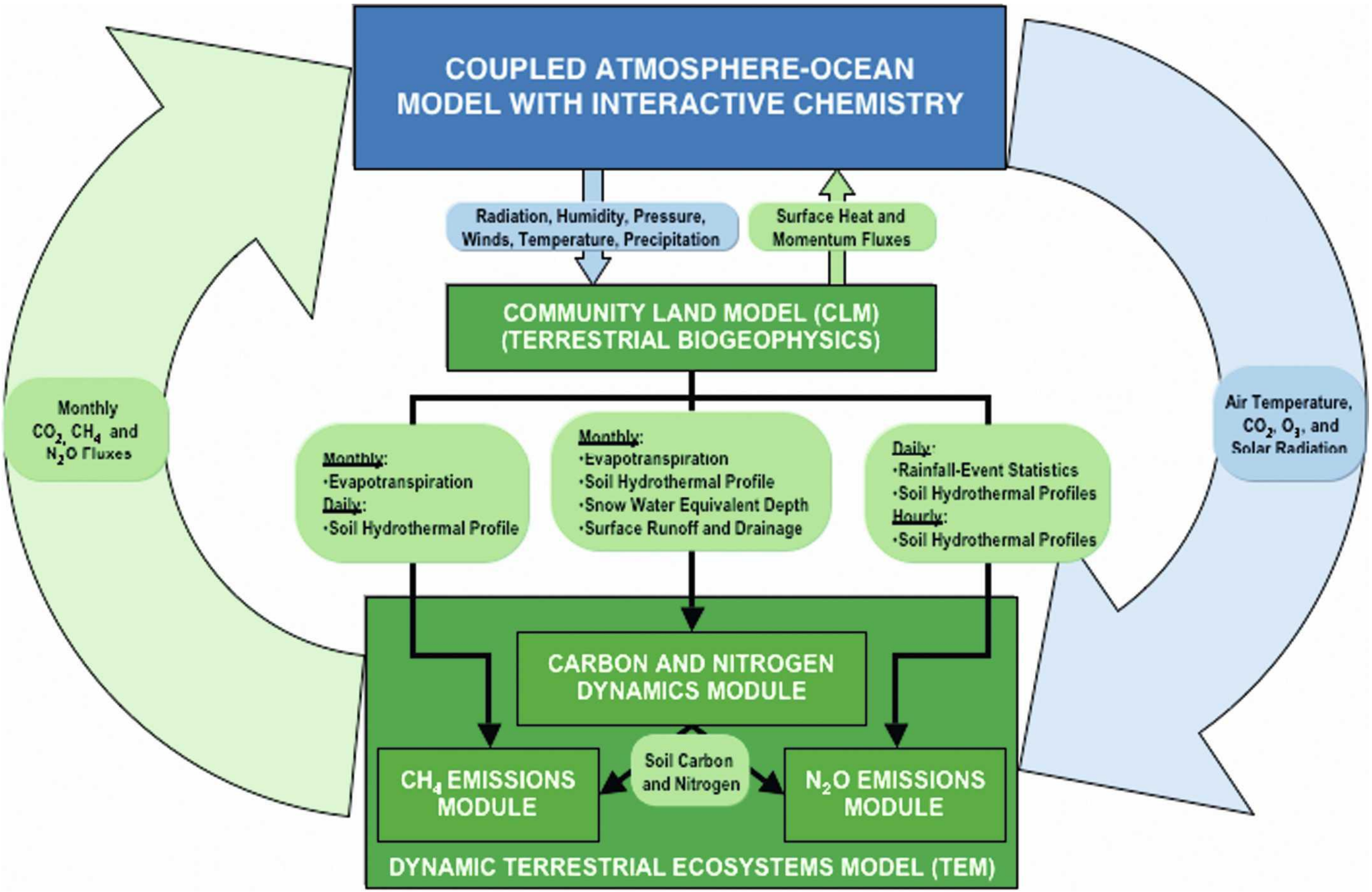

INPUT
MODEL
OUTPUT
Driving Factors
Climate
.Temperature
.Precipitation
.Radiation
.Relative Humidity
Atmospheric Compositions
.CO_2
.O_3
.Nitrogen Deposition
Land Use
.Deforestation
.Urbanization
.Harvest
.Fertilization
.Irrigation
Other Disturbances
.Wildfire
.Disease
.Climate Extremes
Controlling Factors
Soil
.Physical Properties
.Chemical Properties
.Depth
Geomorphology
.Elevation
.Slope
.Aspect
River Network
.Flow Direction
.Accumulative Area
.River Slope
.River Length
.River Width
Vegetation Functional Type
Cropping System
Dynamic
Land
Ecosystem
Model
Biogeochem.-hydrolog. cycles
Carbon Fluxes and Storage:
.Carbon fluxes (GPP, NPP, Rh,NCE, NEP, CH_4, VOC, DOC, DIC)
.Carbon storages (LeafC, stemC, litterC, rootC, reproductionC, soilC)
Water Fluxes and Storage :
.ET, Runoff, Soil moisture
Nitrogen Fluxes and Storage :
.Nitrogen fluxes (N_2O, NO, N_2)
.Nitrogen storages (LeafN, stemN, litterN, rootN, reproductionN, soilN), TN
Phosphorus Fluxes and Storage:
.LeafP, stemP, litterP, rootP, soilP, TP
Ecosystem Goods and Services
Climate related:
.GHG emissions (e.g. CO_2,CH_4 ,N_2O fluxes); VOC flux, Black carbon, …
Ecosystem Goods
.Crop yield; Wood Products; Biofuel, …
Water related
.Surface Runoff; Subsurface Flow;
.ET; Soil Moisture; water use efficiency
.River Discharge;
Nutrients related:
.N and P Storage and leaching;
.Export of TN and TP;
.Export of DOC and POC

MIT Emissions Prediction and Policy Analysis (EPPA) Model

- Computable General Equilibrium (CGE) model of world economy with regional/sectoral detail.
- Fully treats demand/supply, capital/investment, macroeconomy/trade implications of growth, policies, alternative technologies

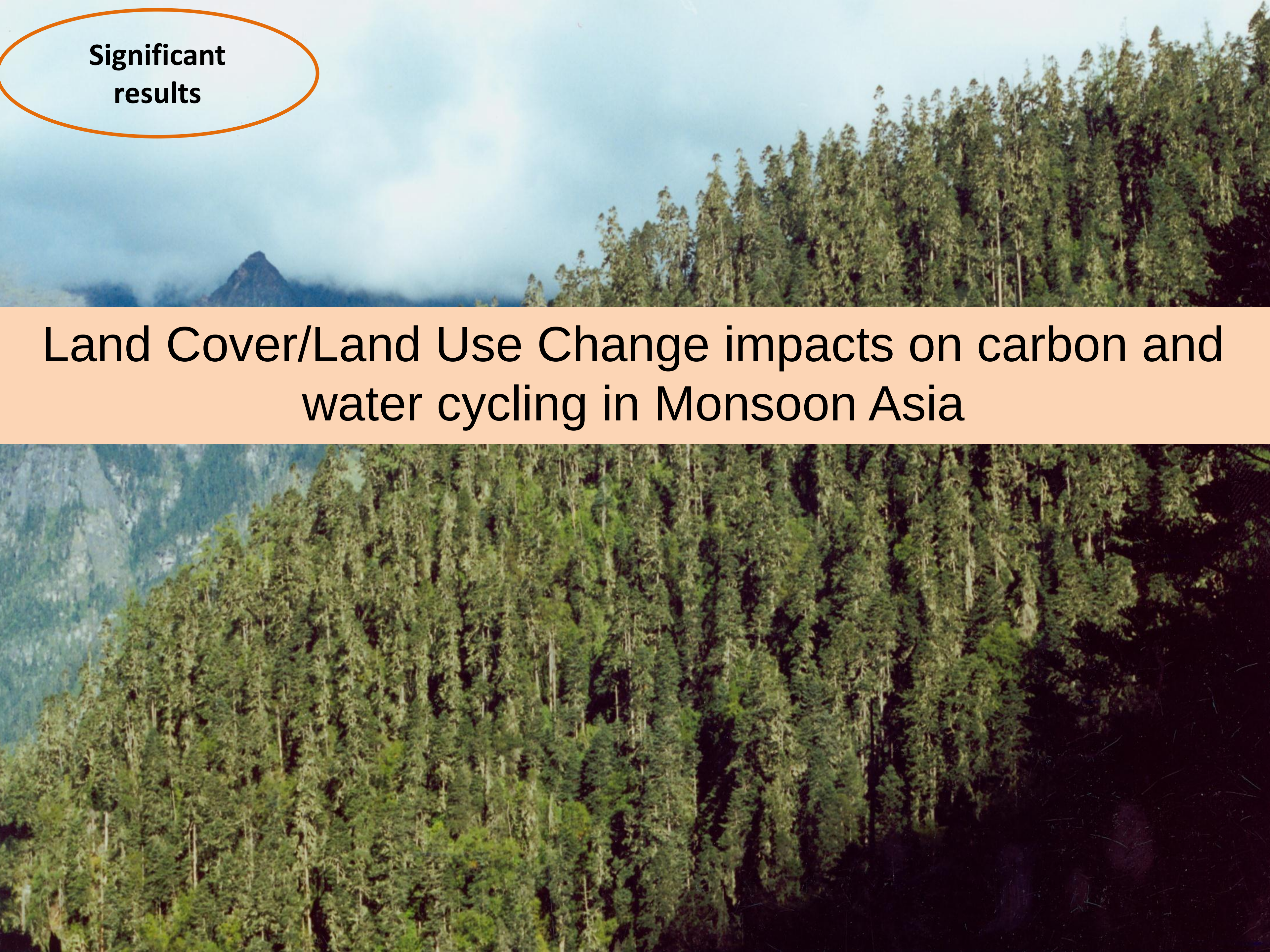


Global Land System Interactions

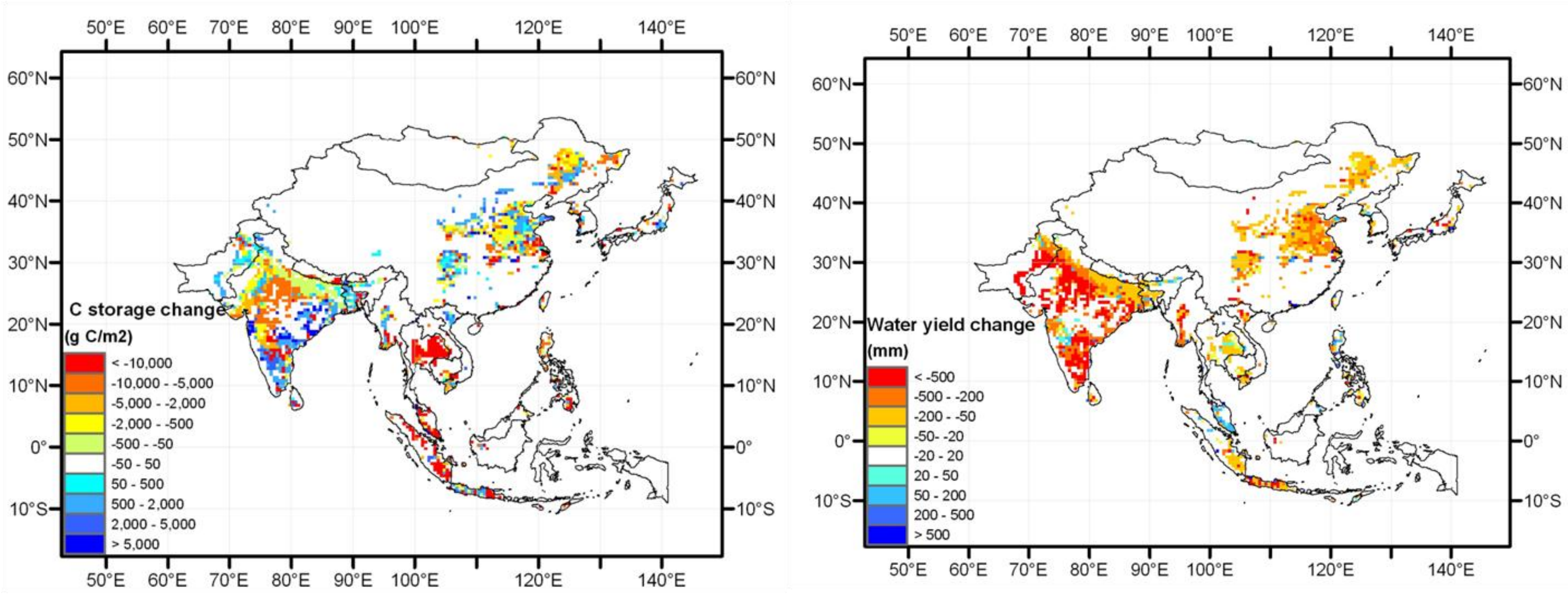


Significant results

Land Cover/Land Use Change impacts on carbon and water cycling in Monsoon Asia

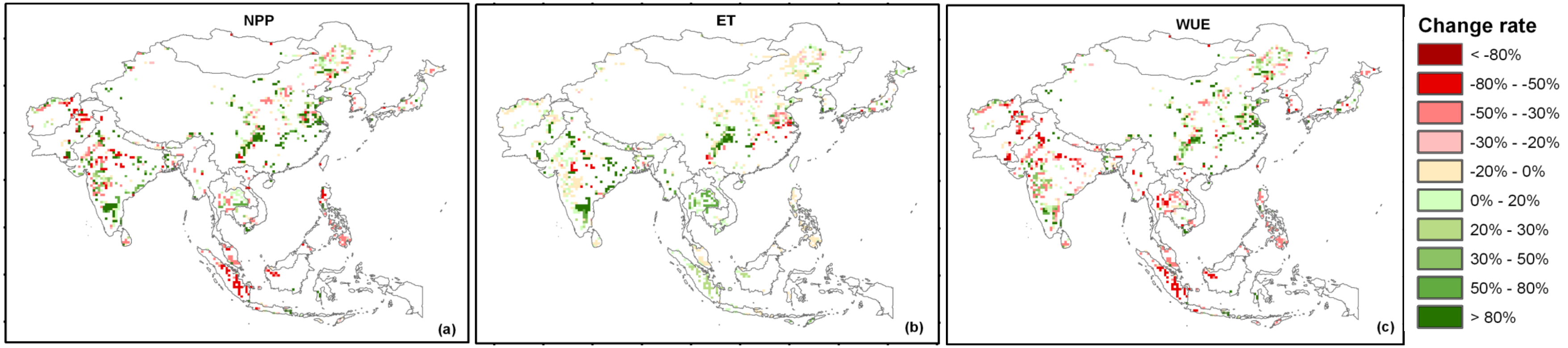


Historical LCLUC-induced changes in C storage and water yield over MA region

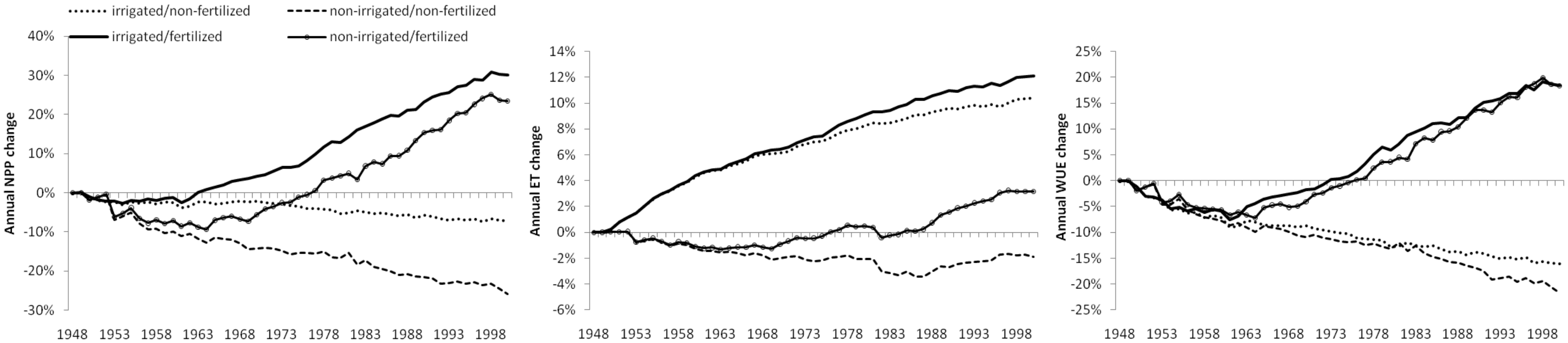


Changes in carbon storage (left) and water yield (right) in terrestrial ecosystems of monsoon Asia induced by land use and land cover change during 1700-2005 as simulated by the Dynamic Land Ecosystem Model (DLEM).

Historical LCLUC-induced changes in carbon and water fluxes over MA region

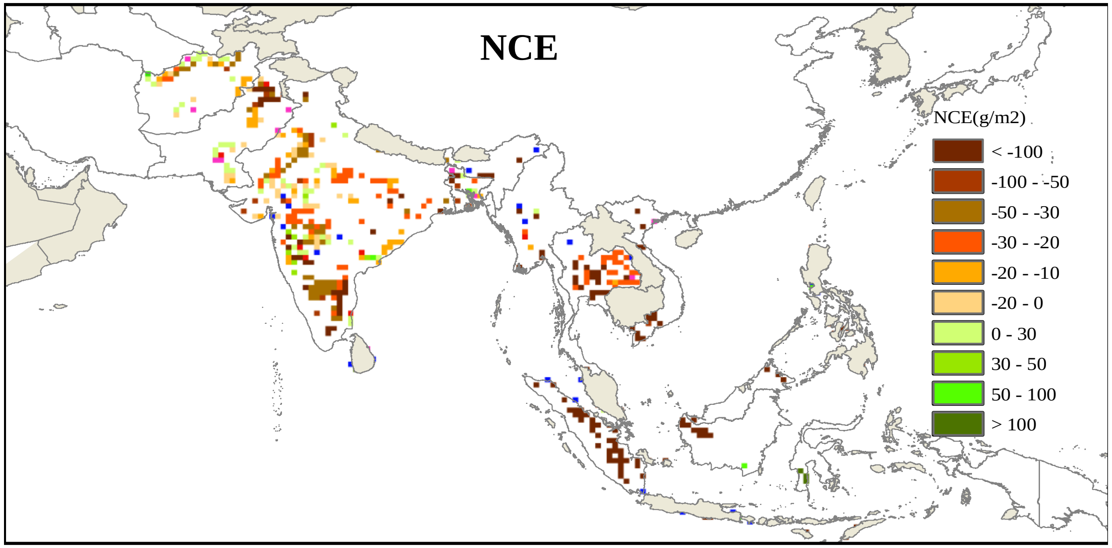


Spatial distributions of annual changes in NPP (a), ET (b), and WUE (c) due to LCLUC in monsoon Asia during 1948-2000 (Tian et al. 2011).



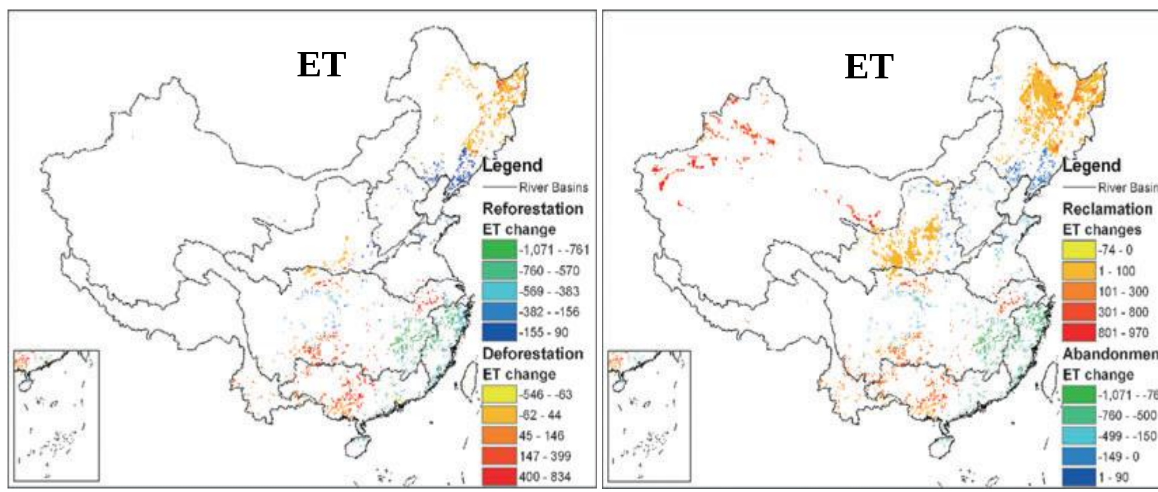
Changes of NPP, ET and WUE induced by LCLUC in irrigated and non-irrigated croplands in monsoon Asia during 1948-2000 (Tian et al. 2011).

Historical LCLUC induced changes in regional carbon and water fluxes

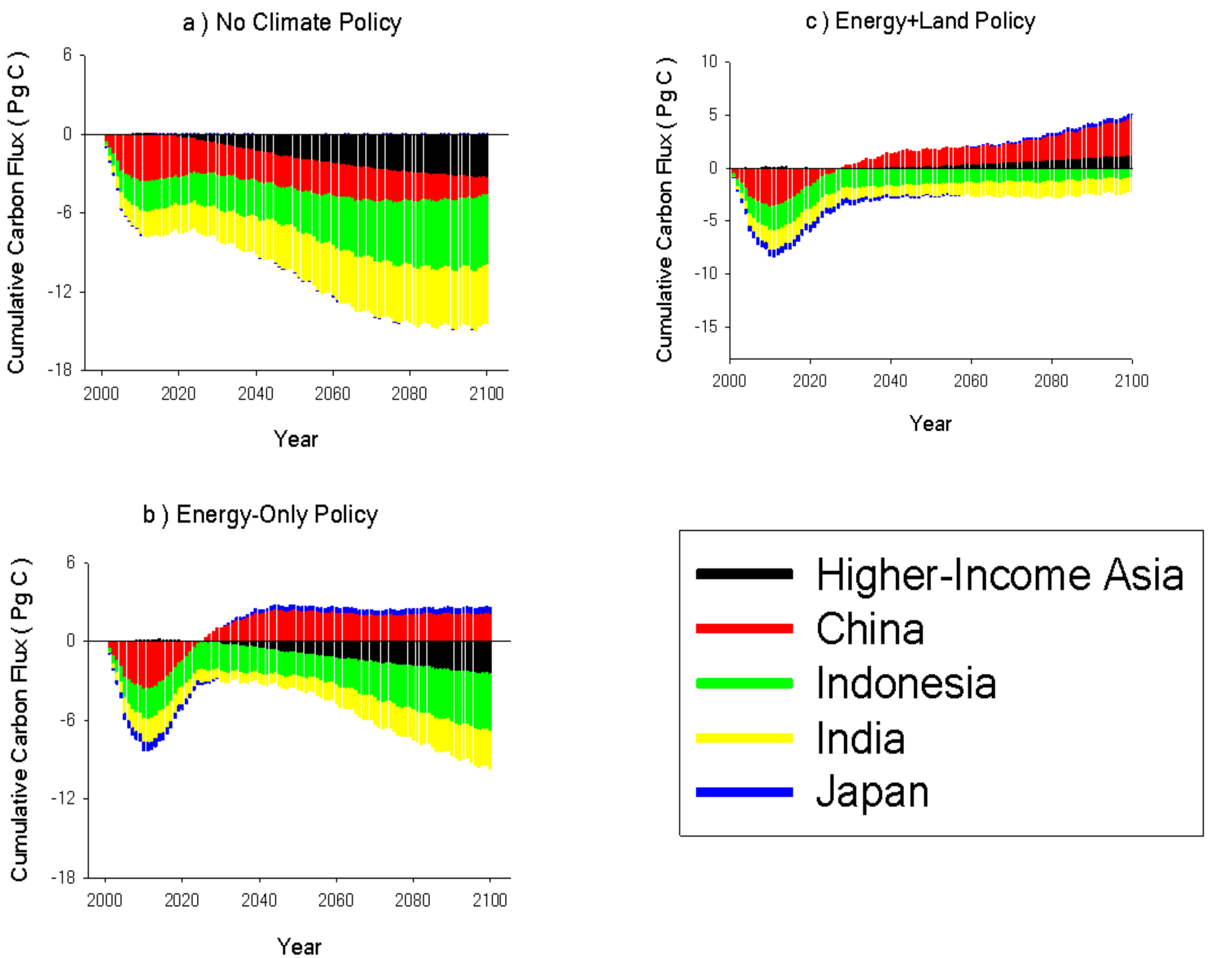


Crop expansion induced carbon storage change during 1951-2000 in South and Southeast Asia
Tao et al., 2011, In Review.

Impacts of (A)Deforestation /Reforestation and (B) Crop expansion on evapotranspiration over China during 1900-2000.
Liu et al., 2009, JAWRA



Future LCLUC induced changes in accumulative land C flux in MA region



Changes in the cumulative land carbon flux for selected countries in the monsoon Asia region over the 21st century.

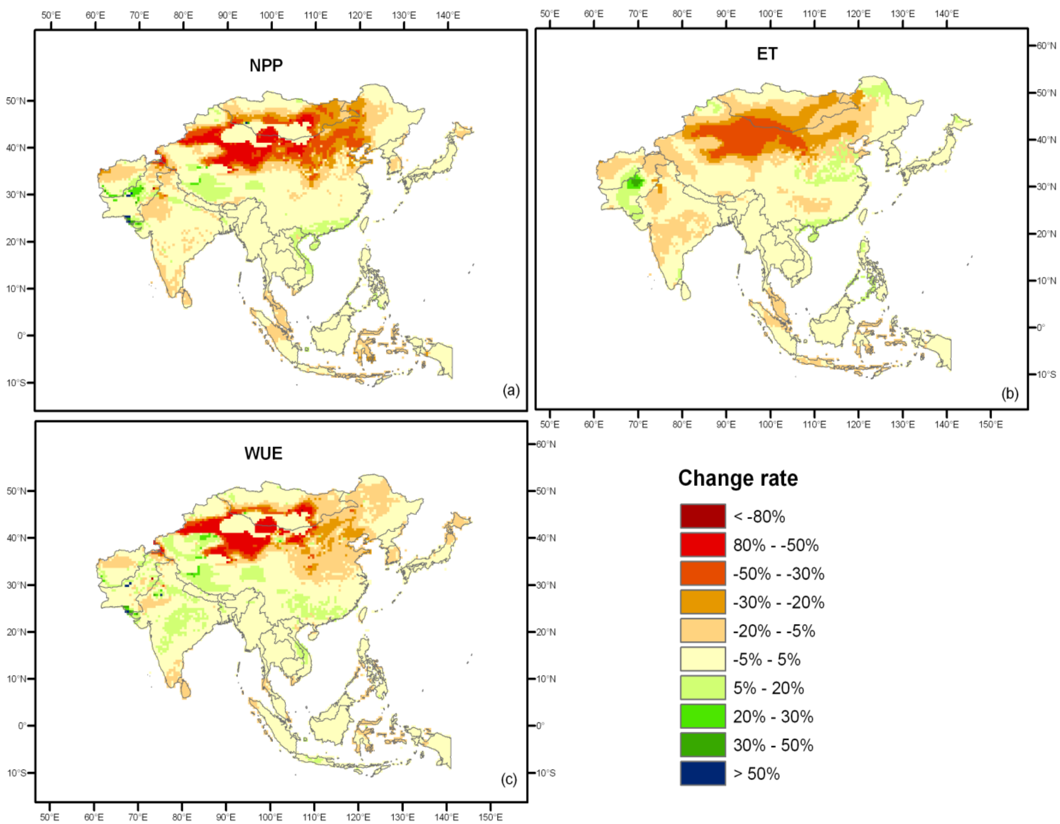
III

What are relative roles of LCLUC and non-LCLUC factors (e.g., climate variability/change, nitrogen deposition, troposhereic ozone concentration) on carbon/water and cycling?

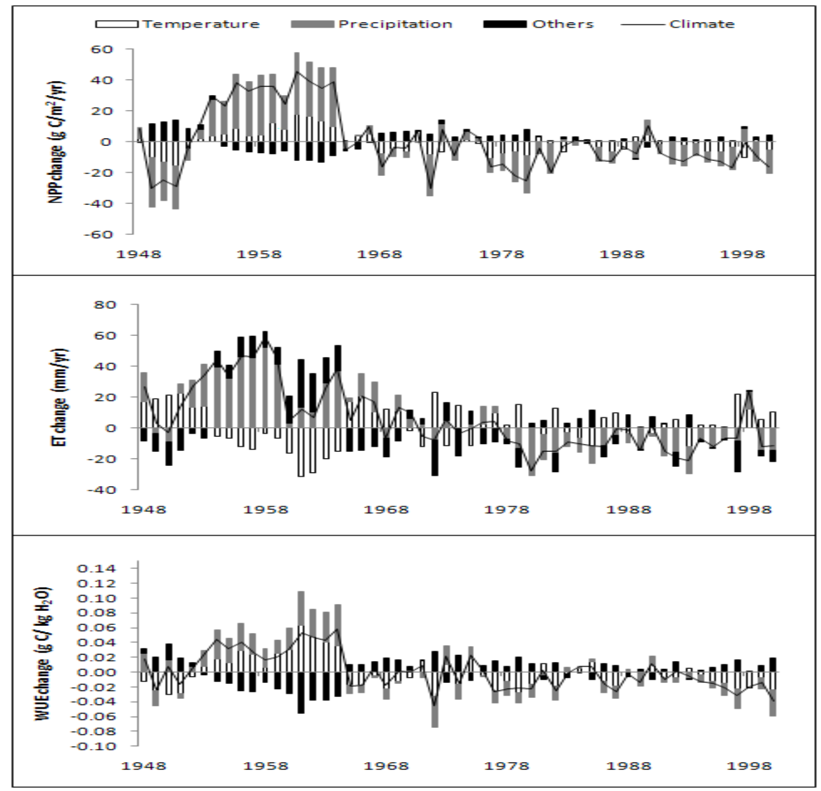
Significant results

Impacts of major environmental factors and their combination with LCLUC on carbon/water cycling and GHG emissions in Monsoon Asia

Historical climate impacts on carbon and water fluxes



Spatial patterns of annual average change rates of NPP (a), ET (b) and WUE (c) due to climate change in monsoon Asia during 1948-2000.(Tian et al. 2011)



Impacts of climate change (temperature, precipitation and others) on net primary productivity (a), ET (b) and water use efficiency (c) in Monsoon Asia over the period 1948-2000. (Tian et al. 2011)

Future climate impacts on C and water fluxes over MA region

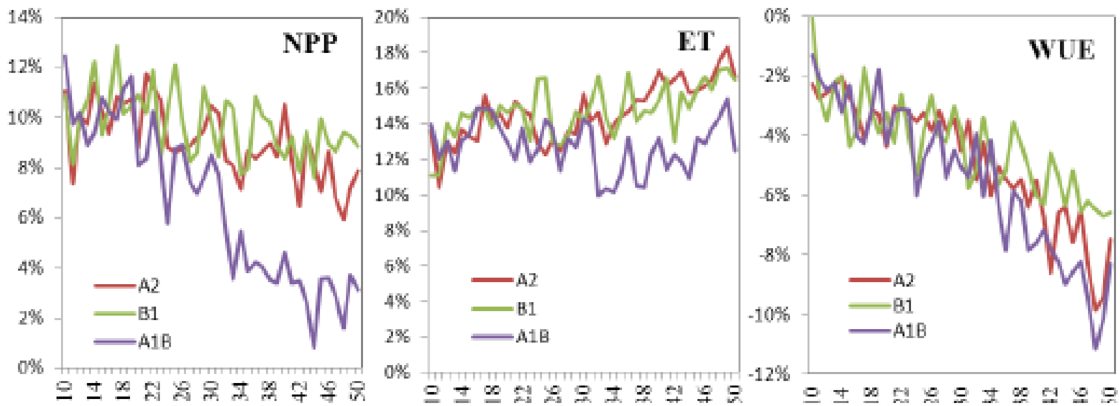


Figure Annual change rates of NPP, ET and WUE across MA region during 2010-2050.

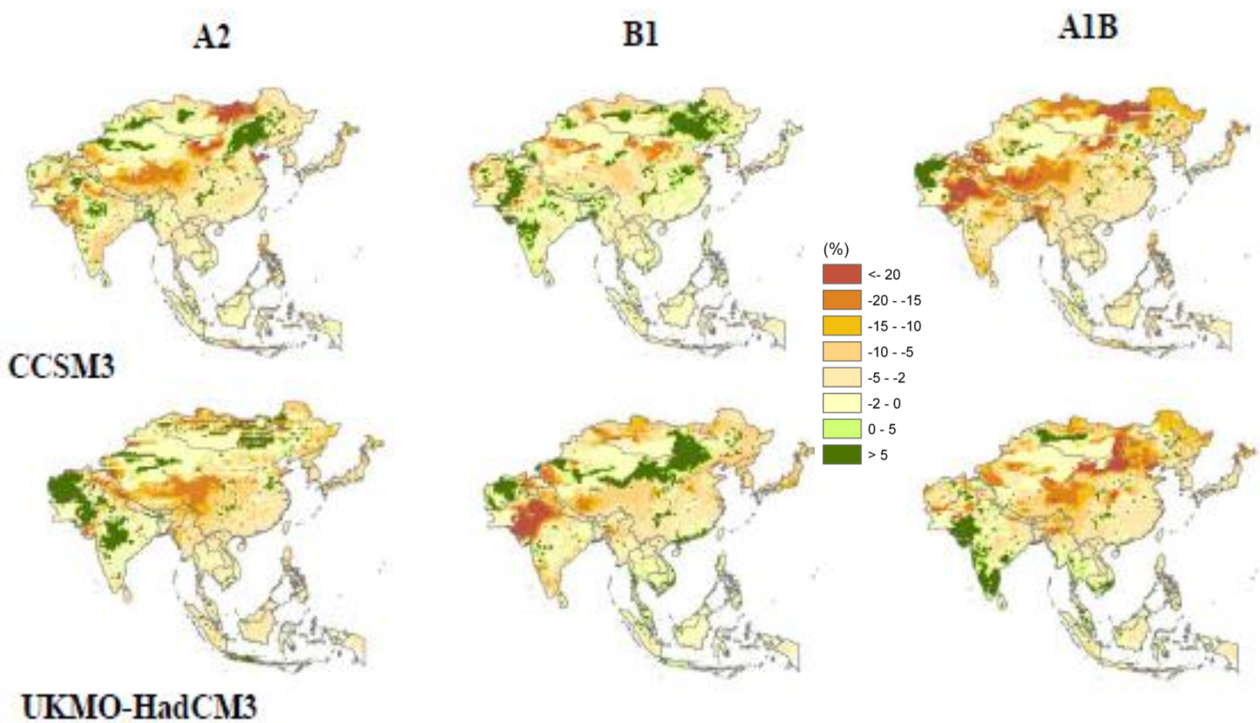
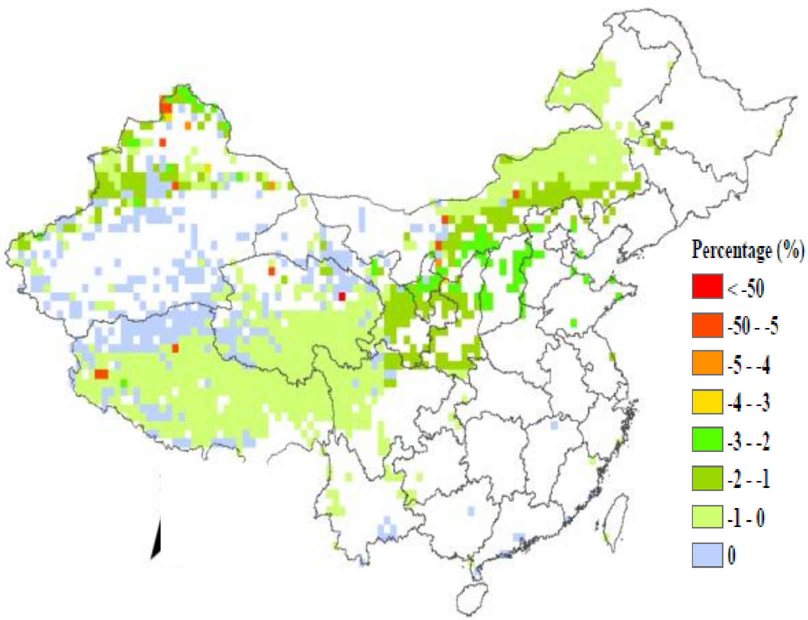


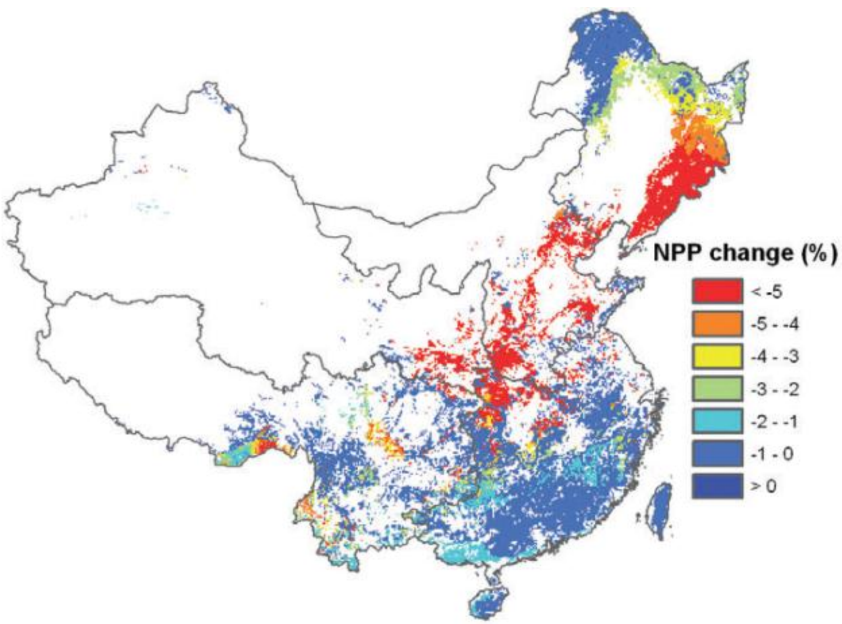
Figure change rates of water use efficiency (WUE: the ratio of net primary productivity-NPP and evapotranspiration-ET) across MA in the 2040s relative to 2000s under three climate scenarios using two climate models, estimated by DLEM model.

Impacts of tropospheric ozone pollution on carbon flux (Net Primary Productivity-NPP)

Grassland

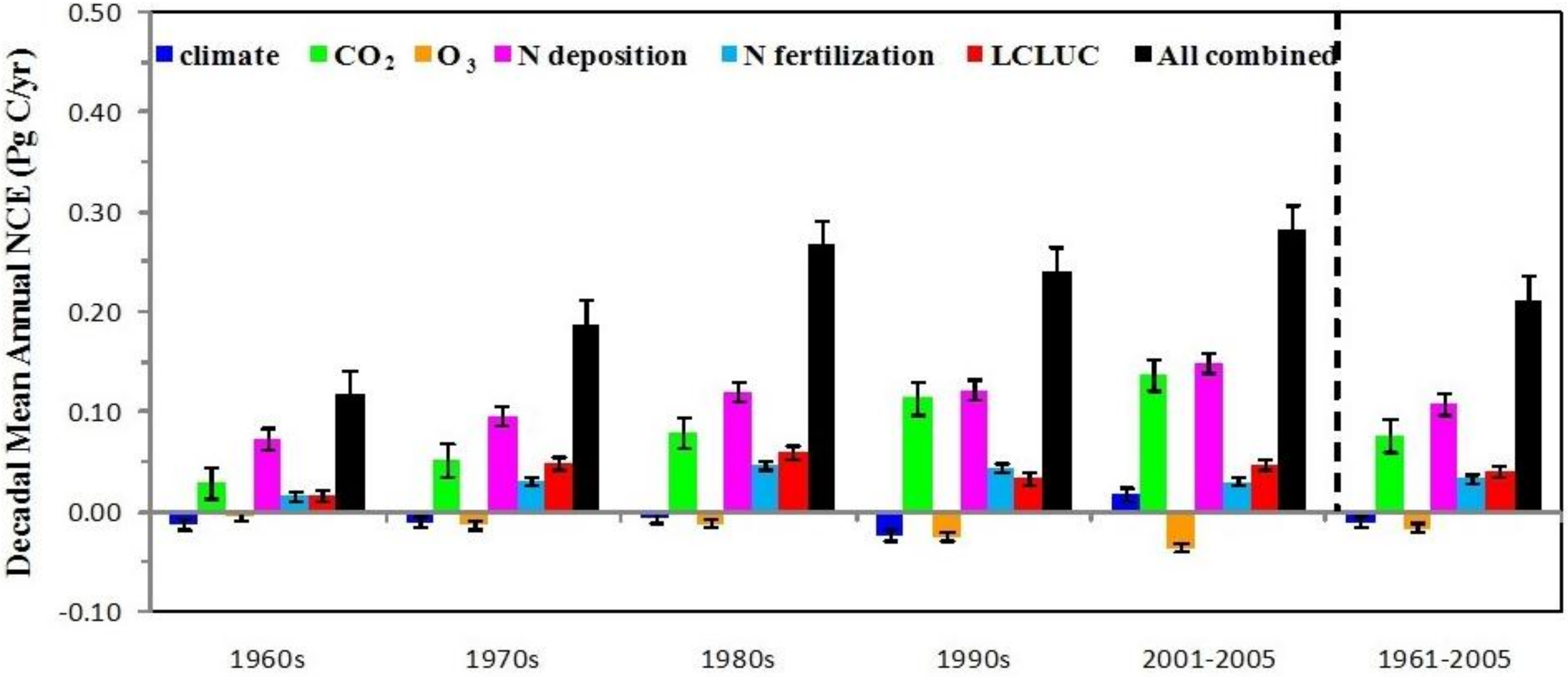


Forest



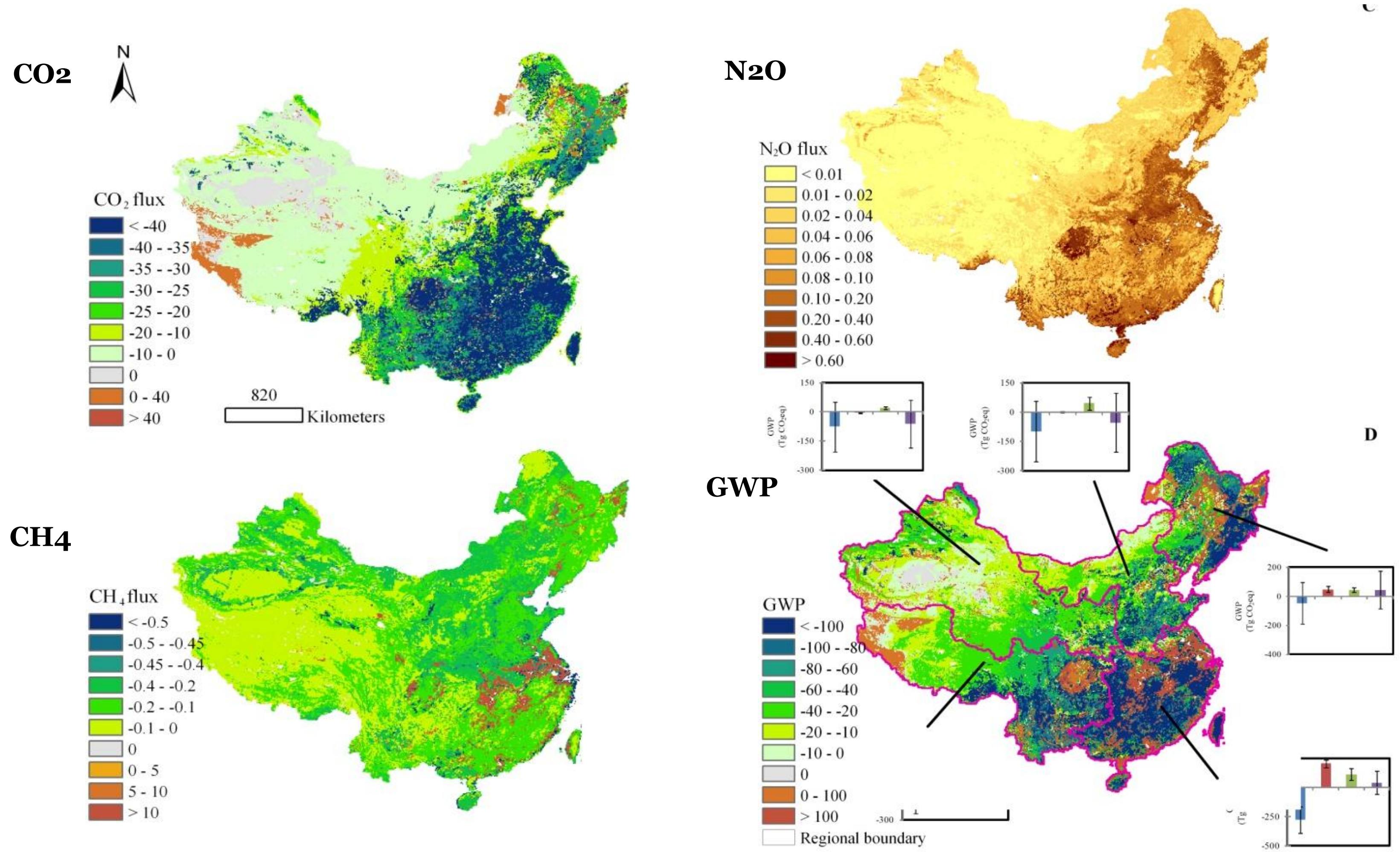
Change rates of net primary productivity induced by tropospheric ozone pollution between the 190s and the 1990s over China’s grassland (a) and forest area (b). (Ren et al. 2007, JGR; Ren et al. 2010, GEB)

Impacts of LCLUC and other environmental factors on C flux in China



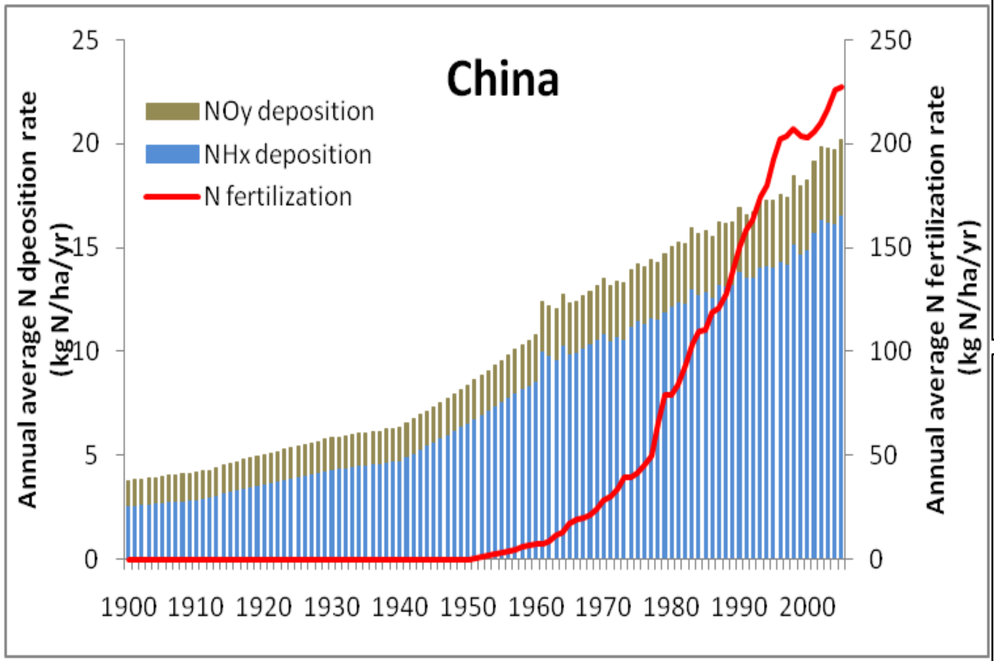
Tian, HQ, et al. 2011. China's terrestrial carbon balance: Contribution from multiple global change factors, *Global Biogeochemical Cycle* (Tian et al. 2011).

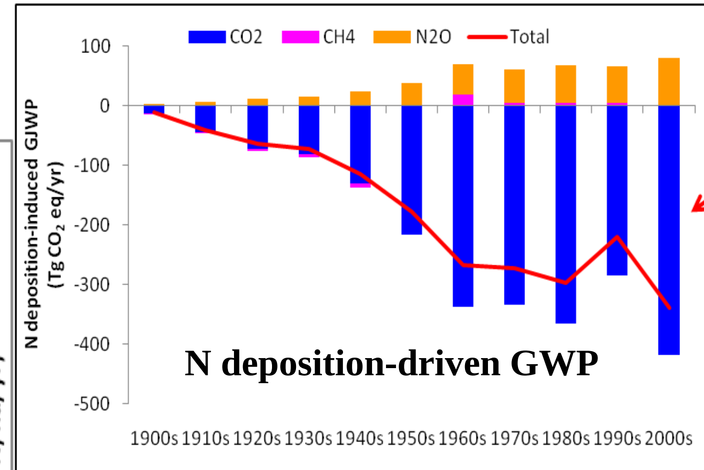
GHGs emissions in China



85% of cooling effect due to CO_2 sink was offset by CH_4 and N_2O emissions, *Tian et al., 2011, JGR (Tian et al. 2011)*

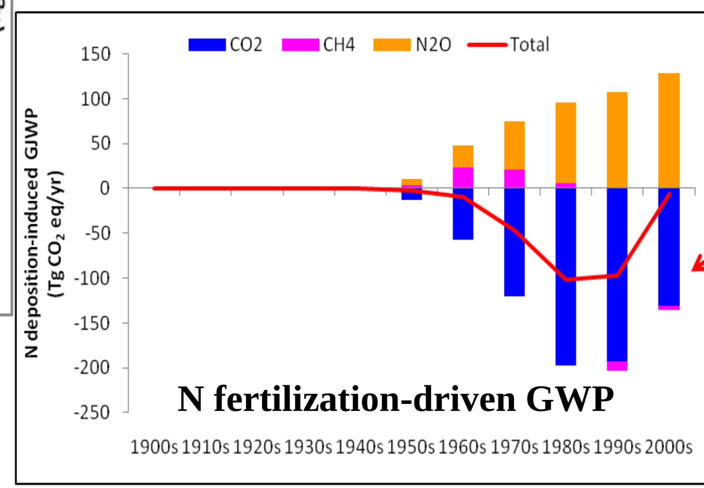
N inputs (N deposition and Fertilizer application) and their impacts on Global Warming Potential (GWP) in China





-19%

Offset percentage



-95%

GHG in MA

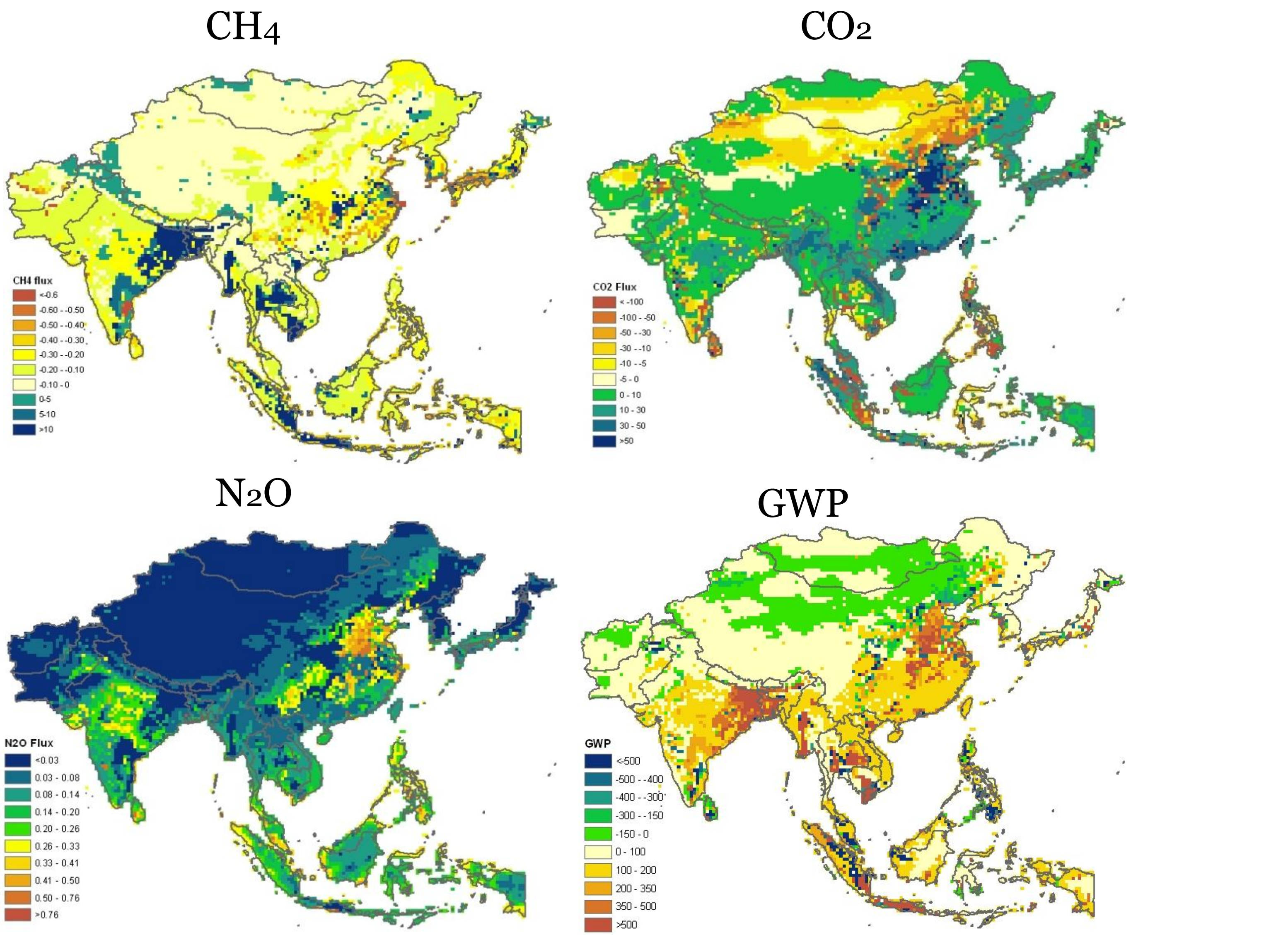


Figure The 50-year average of ecosystem-atmosphere exchange of CO2 (g $Cm^{-2}a^{-1}$), CH4(g $Cm^{-2}a^{-1}$), and N2O (N $m^{-2}a^{-1}$), the resulted global warming potential GWP(CO2 eq $m^{-2}a^{-1}$) during 1951-2000 estimated by DLEM model.

Future LCLUC induced changes in GHG balance

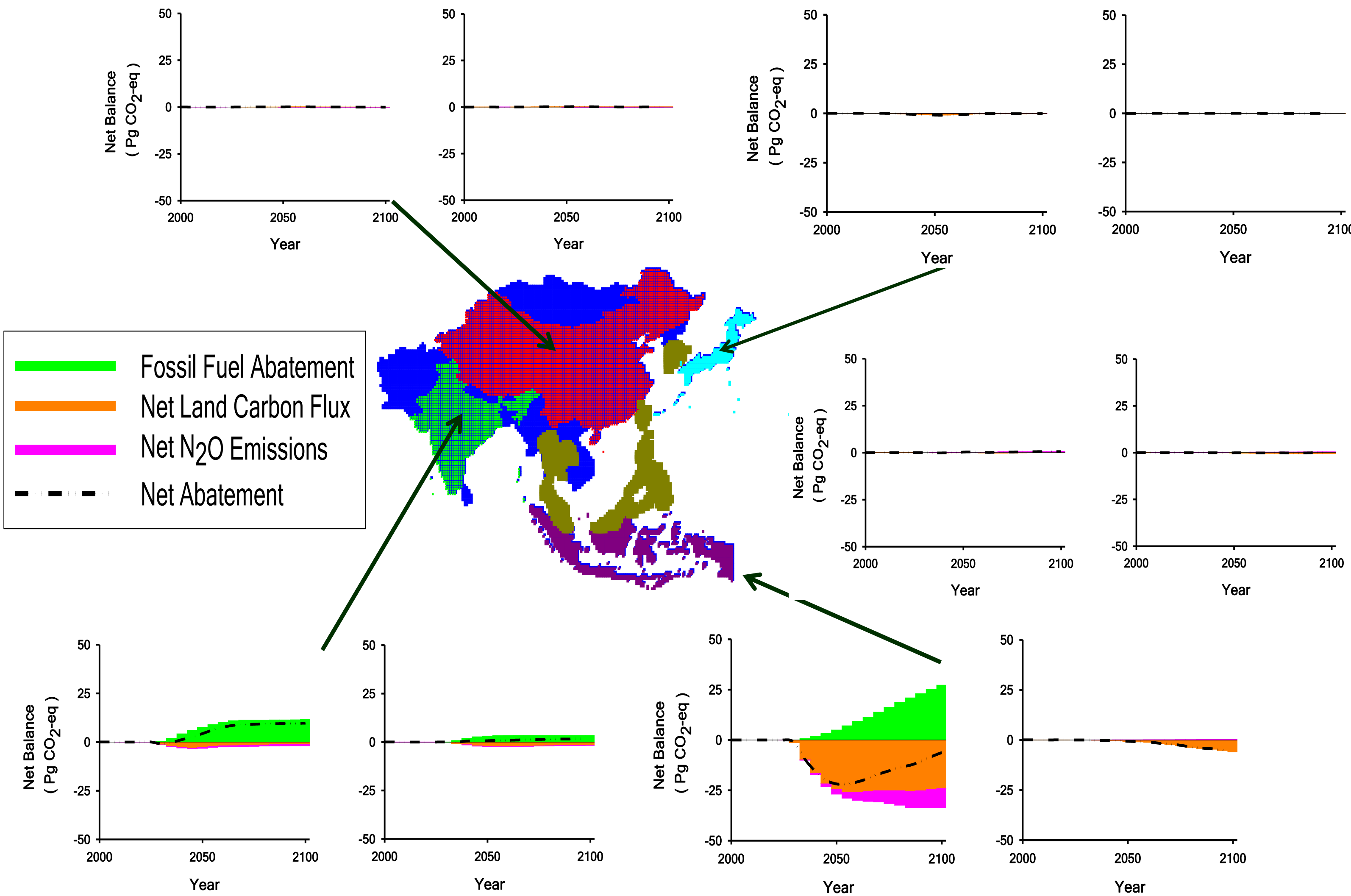


Figure Partitioning of greenhouse gas balance since 2000 as influenced by cellulosic biofuel production for two land-use cases. Positive values are abatement benefits, and negative values are emissions. (Melillo et al 2009)

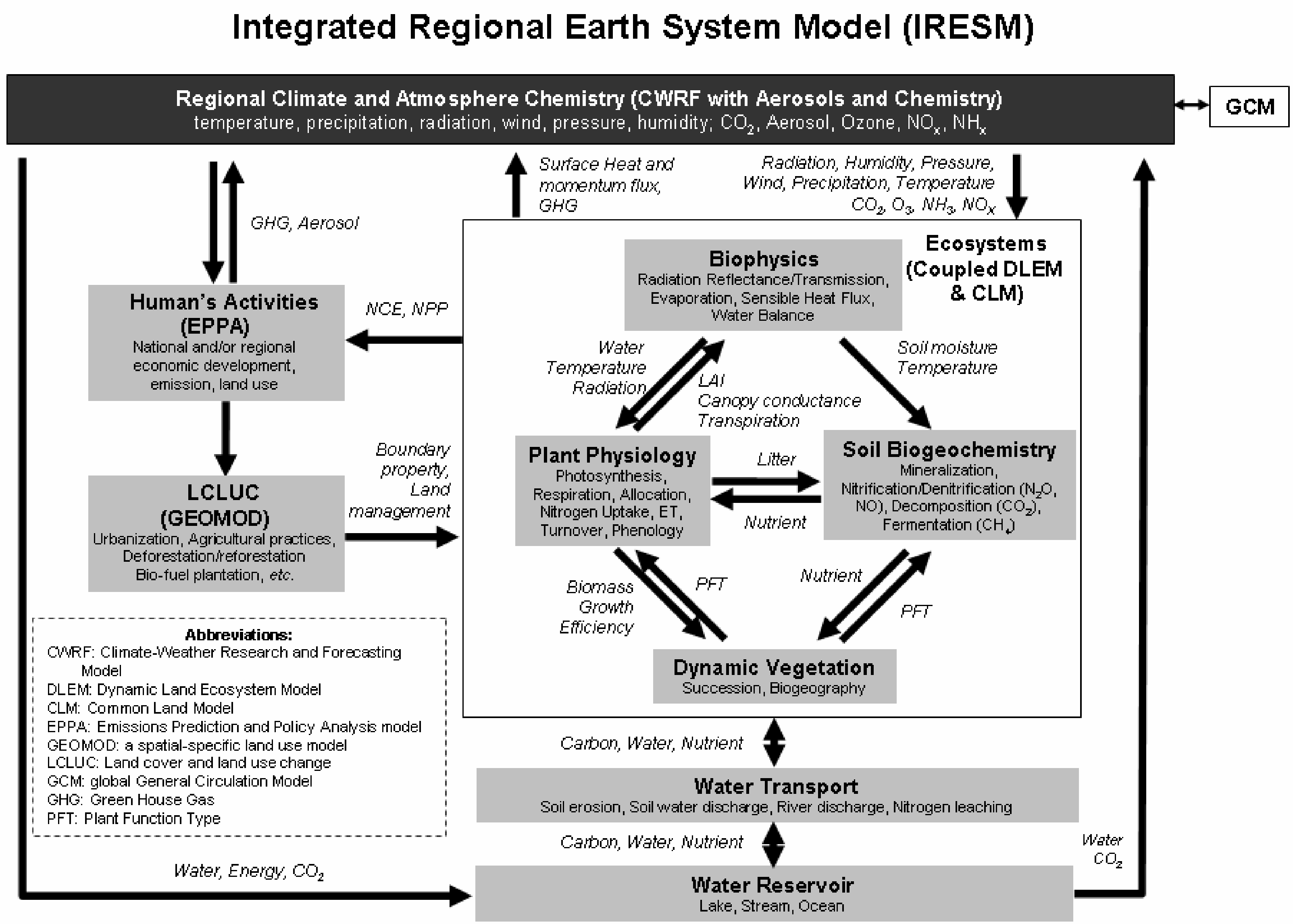
IV

How do the LCLUC modulate the Asian monsoon climate?

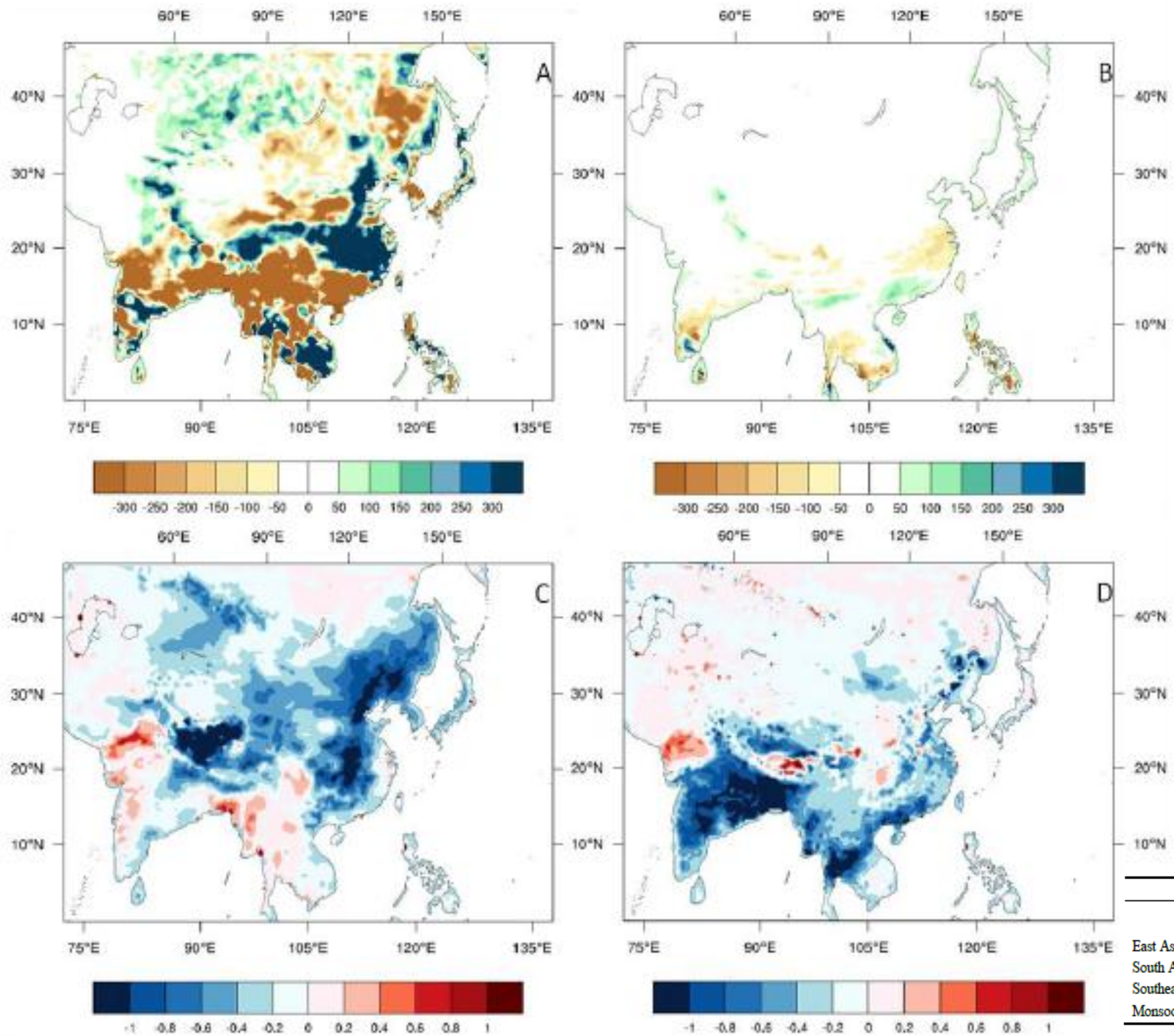
Significant results

Land Cover/Land Use Change impacts on climate system in Monsoon Asia

Integrated Regional Earth System Model (IRESM)



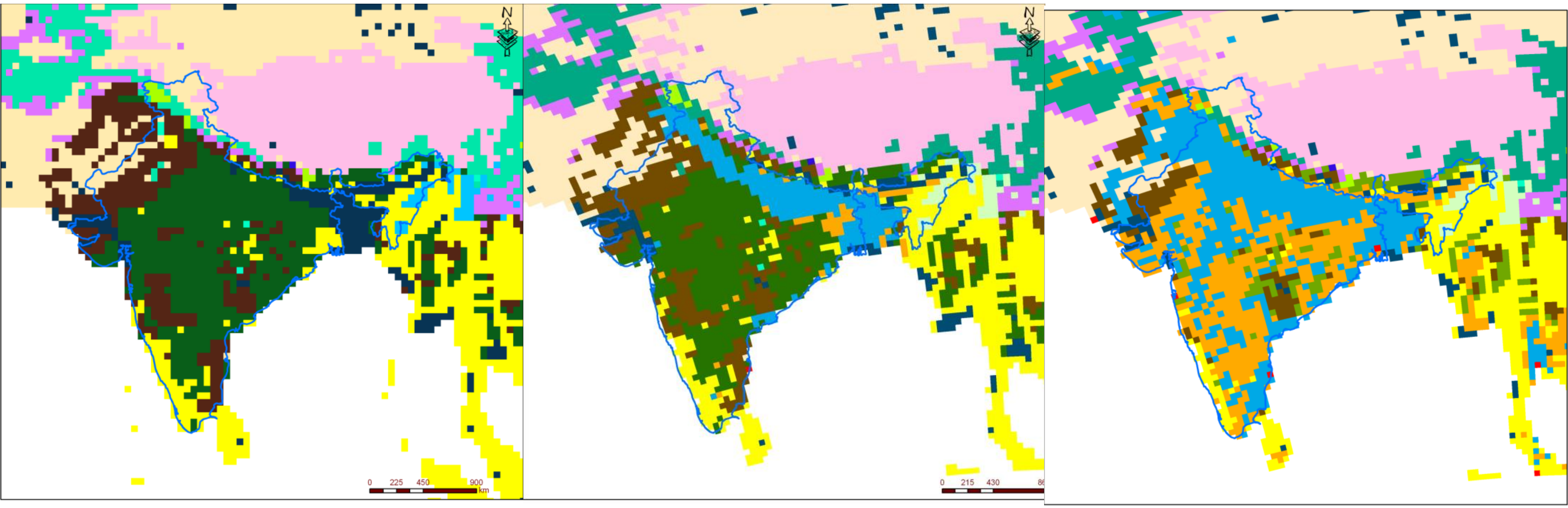
Seasonal changes in Temperature and Precipitation induced by LCLUC across MA region



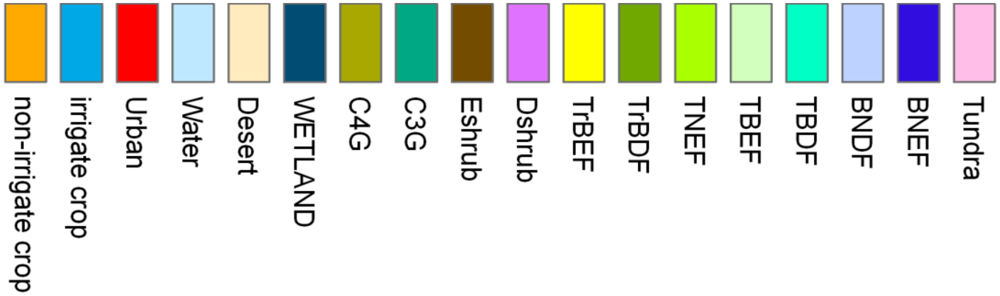
LCLUC Impacts on precipitation and temperature comparing 1700 and 2000 as simulated by IRESM with WRF: Precipitation variations in (A) summer (mm/year) and (B) winter (mm/year); Temperature variations in (C) summer (0C) and (D) winter (0C) between LULC2000 and LULC1700.

	summer		*winter*	
	precipitation change (mm/year)	temperature change (°C)	precipitation change (mm/year)	temperature change (°C)
East Asia	-13.1	-0.49	-5.6	-0.20
South Asia	-109.6	-0.05	-5.0	-0.47
Southeast Asia	-130.3	0.04	-31.9	-0.40
Monsoon Asia	-54.6	-0.30	-8.9	-0.30

Historical Land Cover/Land Use change in Indian continent

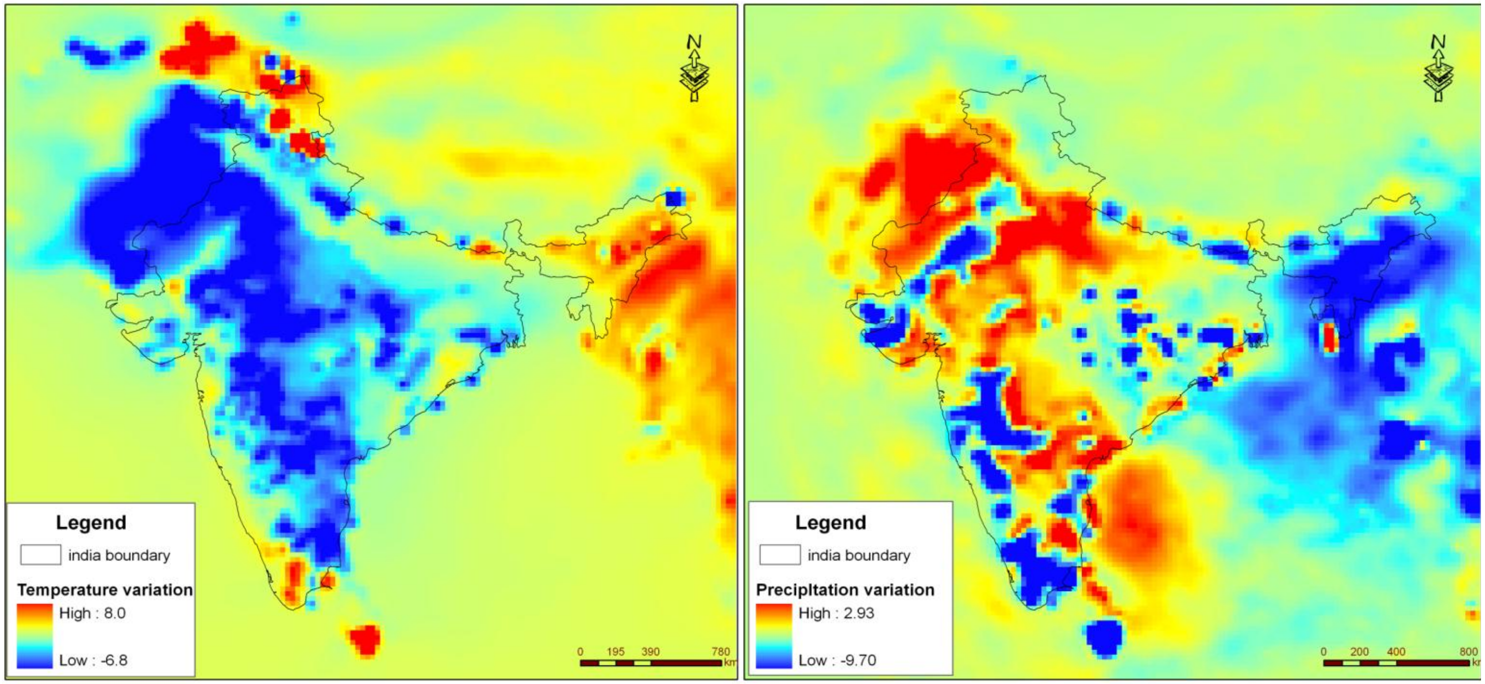


Potential vegetation LUCC in 1700 LUCC in 2000



From 1700 to 2000, the area of crop increases **55.2%**, including:
irrigate crop: +21.9%
Non-irrigate crop : 33.3%

A B



Items of LCLUC	Temperature ($^0C/yr$)	Precipitation (mm/day)
Total LULC effect	-0.52	0.0
Conversion from potential vegetation to irrigated crop	-1.13	0.40
Conversion from potential vegetation to non-irrigated crop	-0.56	-0.37

Changes in (A) temperature and (B) precipitation induced by land-cover and land-use change between 1700 and 2000 as simulated by the Regional Climate model.

Mao et al., 2010a, 2010b

Model evaluation

1. Regional NPP (RS-derived and Model-estimated)
2. Site NEP (Observed- and Model-estimated)
3. Site CH_4
4. Site N_2O
5. Site ET

Regional level

Spatial comparison of MODIS-derived NPP and simulated NPP

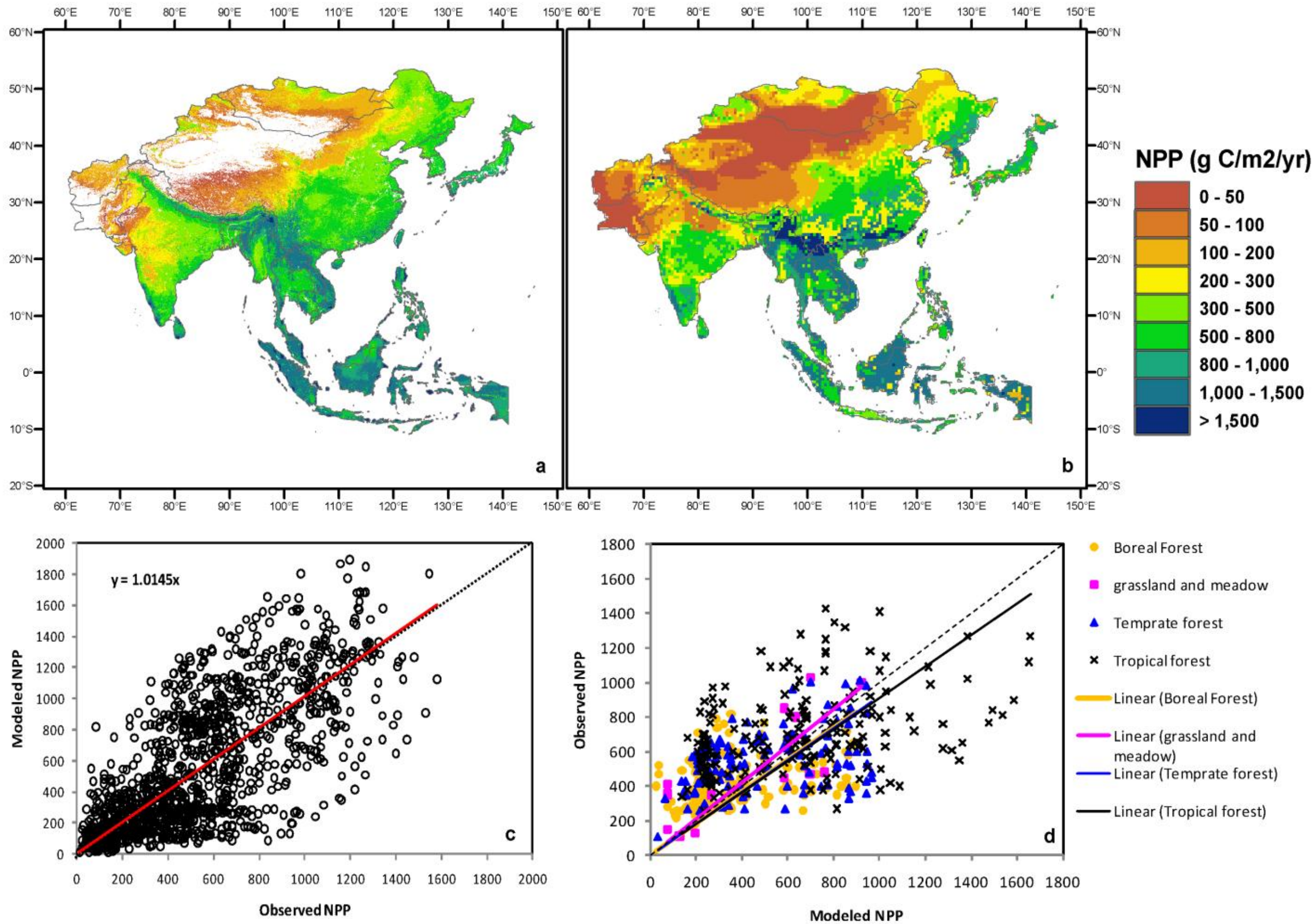
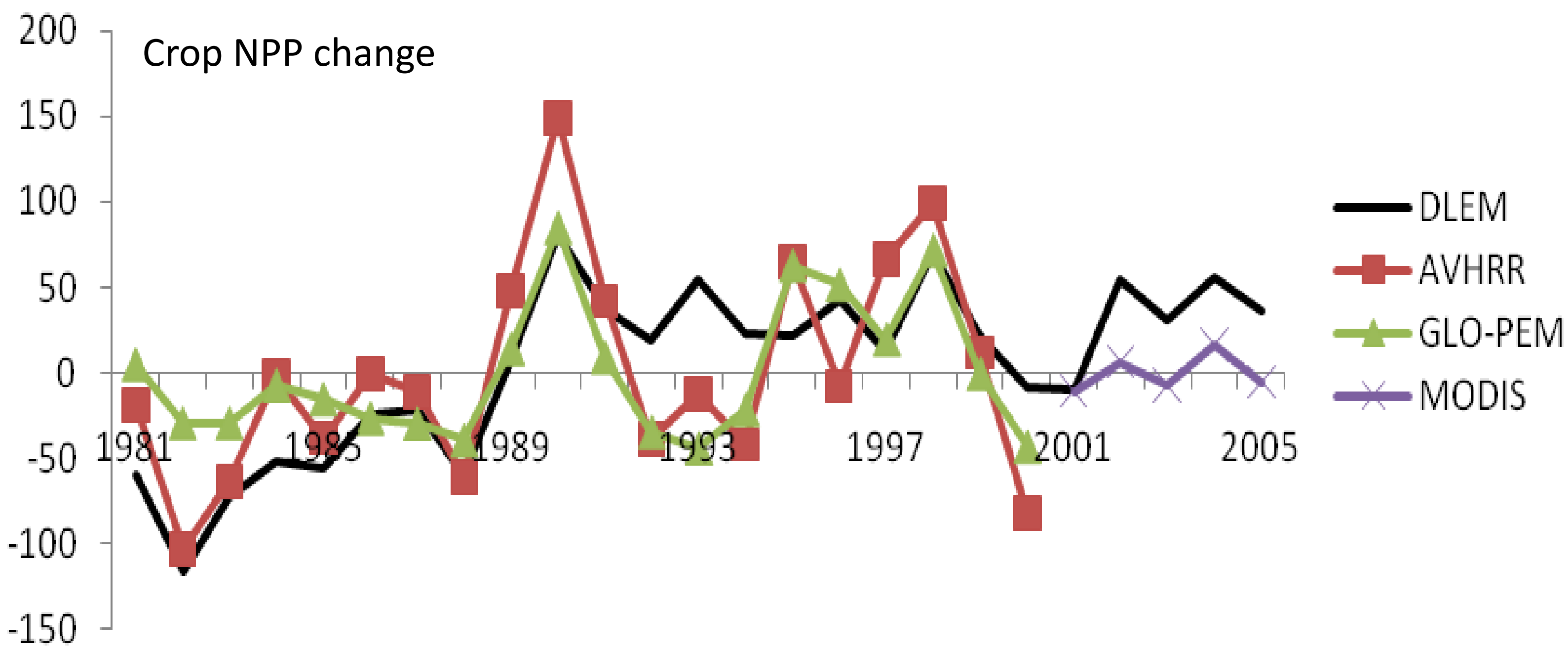


Figure Spatial patterns of MODIS-derived NPP (a) and simulated NPP (b) in Monsoon Asia during 2000-2006 and comparisons of the simulated NPP with MODIS-NPP (c) and field observational data (d) during 1980-2000 (Unit is g $C/m^2/yr$). The solid line is linear trend with regression equation and the dash line is 1:1 line. The data points in figure c are randomly sampled from MODIS-derived NPP and modeled estimates in the same period. Model performance is statistically accepted (y=1.0145x, U=0.22). In comparison with observed NPP data, the indices used for measuring model validity in each biome type in figure d are: boreal forests (y=0.823x, U=0.30, N=153), grassland and meadow (y=1.053x, U=0.20, N=14), temperate forests (y=0.922x, U=0.20, N=119), tropical forests (y=0.913x, U=0.23, N=195).

Regional level

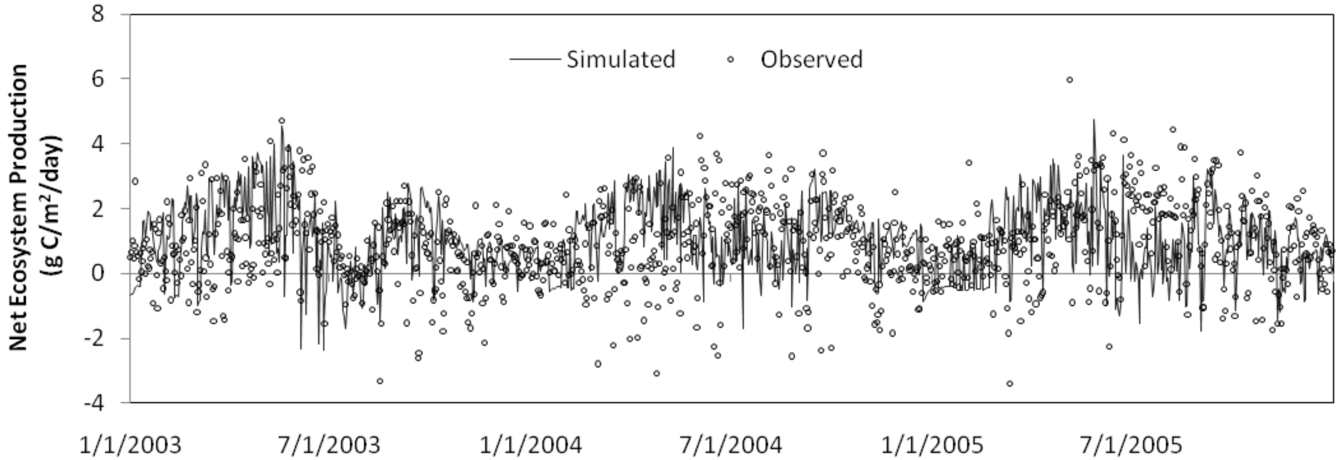
Temporal comparison of RS-derived NPP and simulated crop NPP



Changes in annual net primary production (NPP: Tg C/yr) of China's croplands estimated by DLEM-Ag model, GLO-PEM model, AVHRR, and MODIS database during 1981-2005. *(Prince and Goward 1995; Goetz et al. 2000; Cao et al. 2004; Running et al. 2004; Heinsch et al. 2003)*

Site level

Comparison of simulated NEP and observed NEP



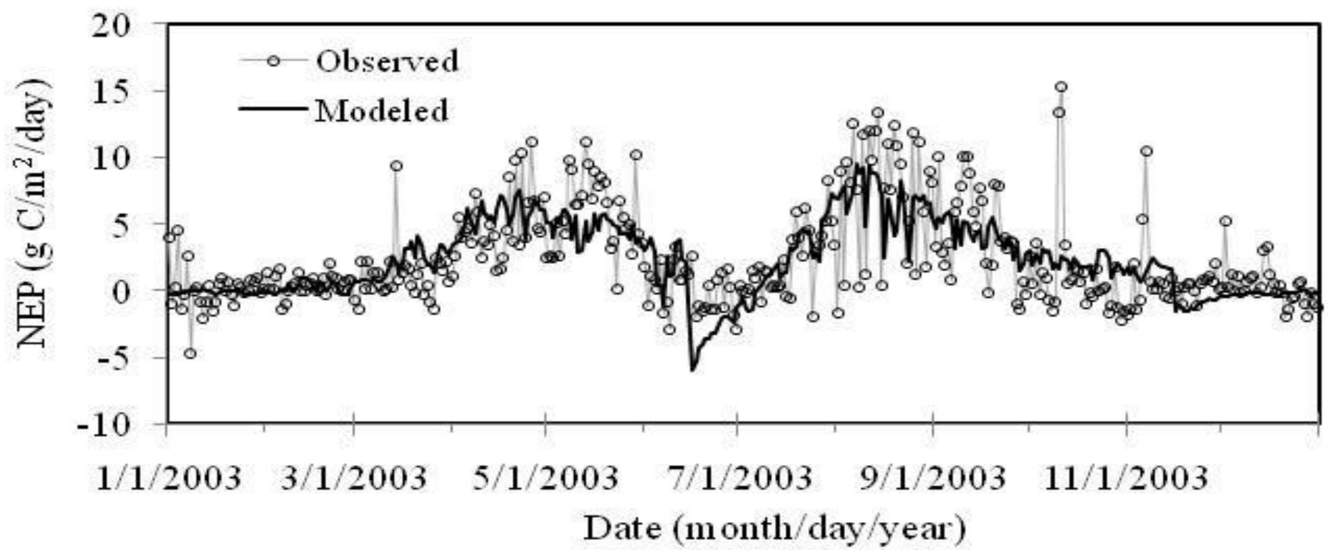
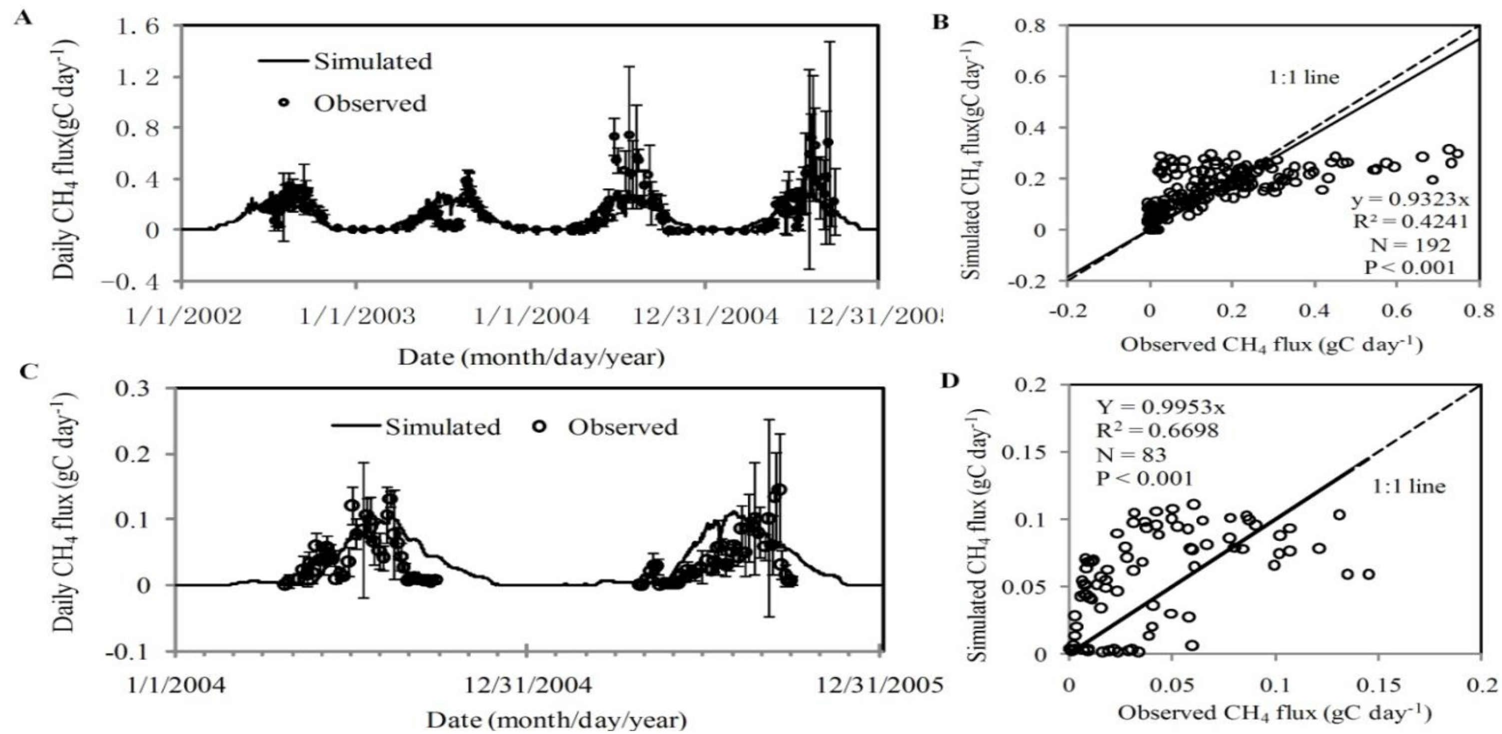
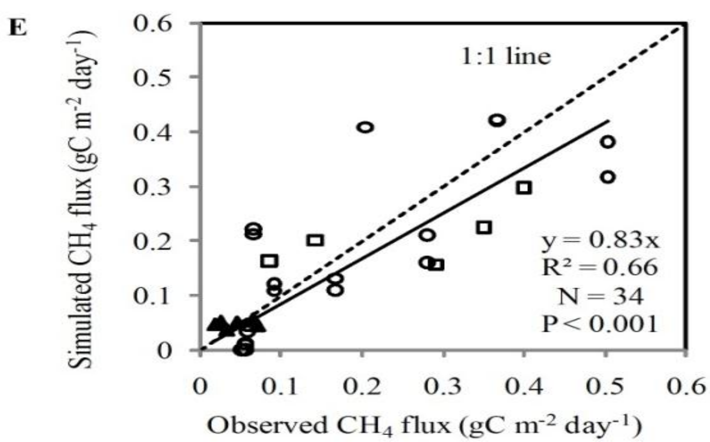


Figure Comparison of daily net ecosystem production simulated by DLEM (a, upper) in temperate evergreen needleleaf forest in Qianyanzhou, Southeastern China ; Comparison of DLEM-simulated daily Net Ecosystem Production (NEP) against observed data in dry farmland of Yucheng, northern China(b, lower) . *Tian et al.,2011*.

Site level

Comparison of simulated CH_4 and observed CH_4

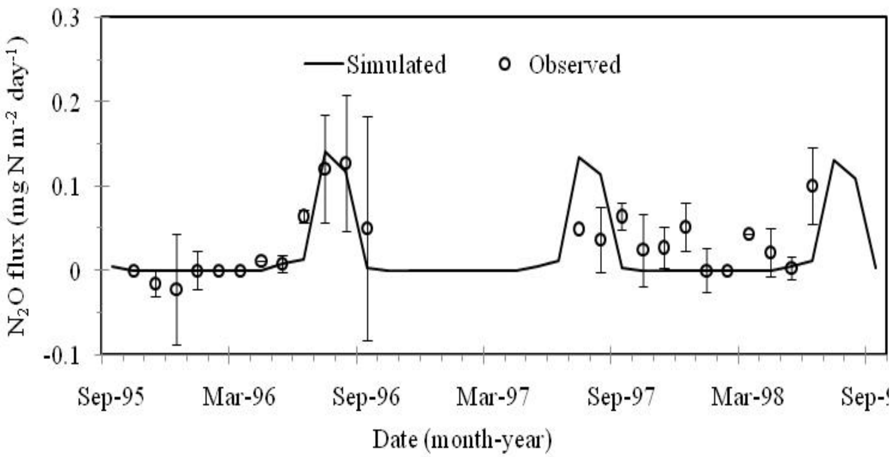


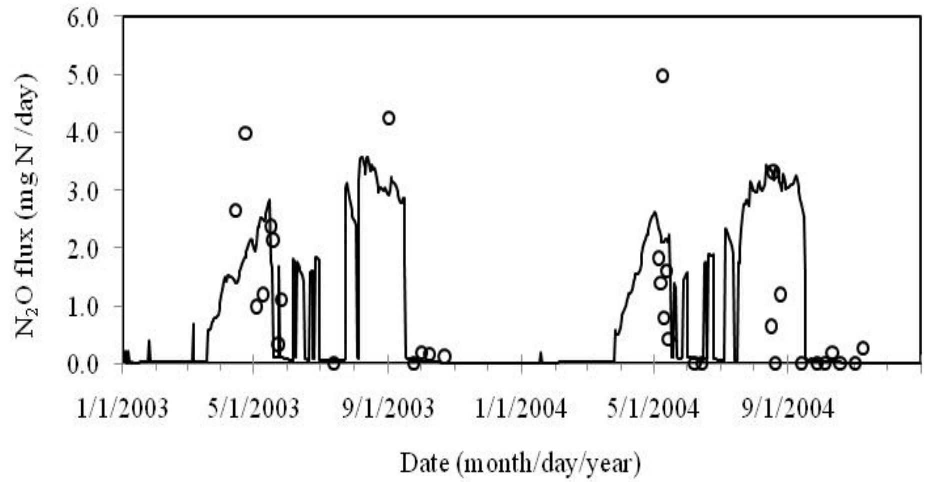


Verification of model performance on simulating CH4 flux over marshland in China (A: Time-series comparison of observed and simulated CH4 flux in the Sanjiang marshland; B: scatter plot of simulated and observed CH4 flux for the Sanjiang marshland; C: Time-series comparison of observed and simulated CH4 flux in the Ruoergai marshland; D: scatter plot of simulated and observed CH4 flux for the Ruoergai marshland; E: scatter plot showing comparison between simulated and observed CH4 flux over China (Circles represent observations from Wang et al.,[*2009*]; Squares represent observations from Cui et al., [*1998*]; Triangles represent observations from Hirota et al [*2004*])) (Cited from Xu 2010)

Site level

Comparison of simulated N_2O and observed N_2O





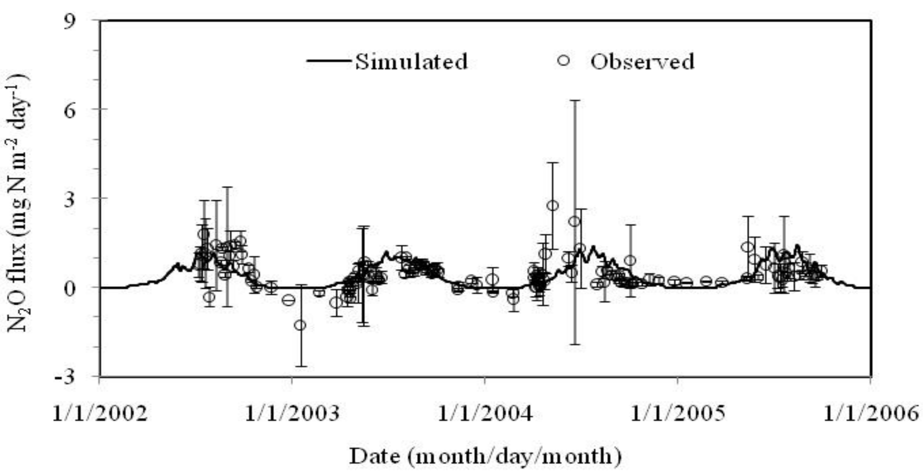


Figure The comparison of simulated N2O flux against observational data for a grassland ecosystem at Inner Mongolia (44.05°N, 113.85°E) (R2 = 0.3763) (A); The comparison of simulated N2O flux against observational data at Qingyuan rice paddy field (23° N, 112° E) (R2 = 0.2379) (B); The comparison of simulated N2O flux against observational data in natural wetland ecosystem at the Sanjiang Plain station (47.58°N, 133.52°E) (R2 = 0.2959)(C).
Tian et al., JGR, 2011

Site level

Comparison of simulated ET and observed ET

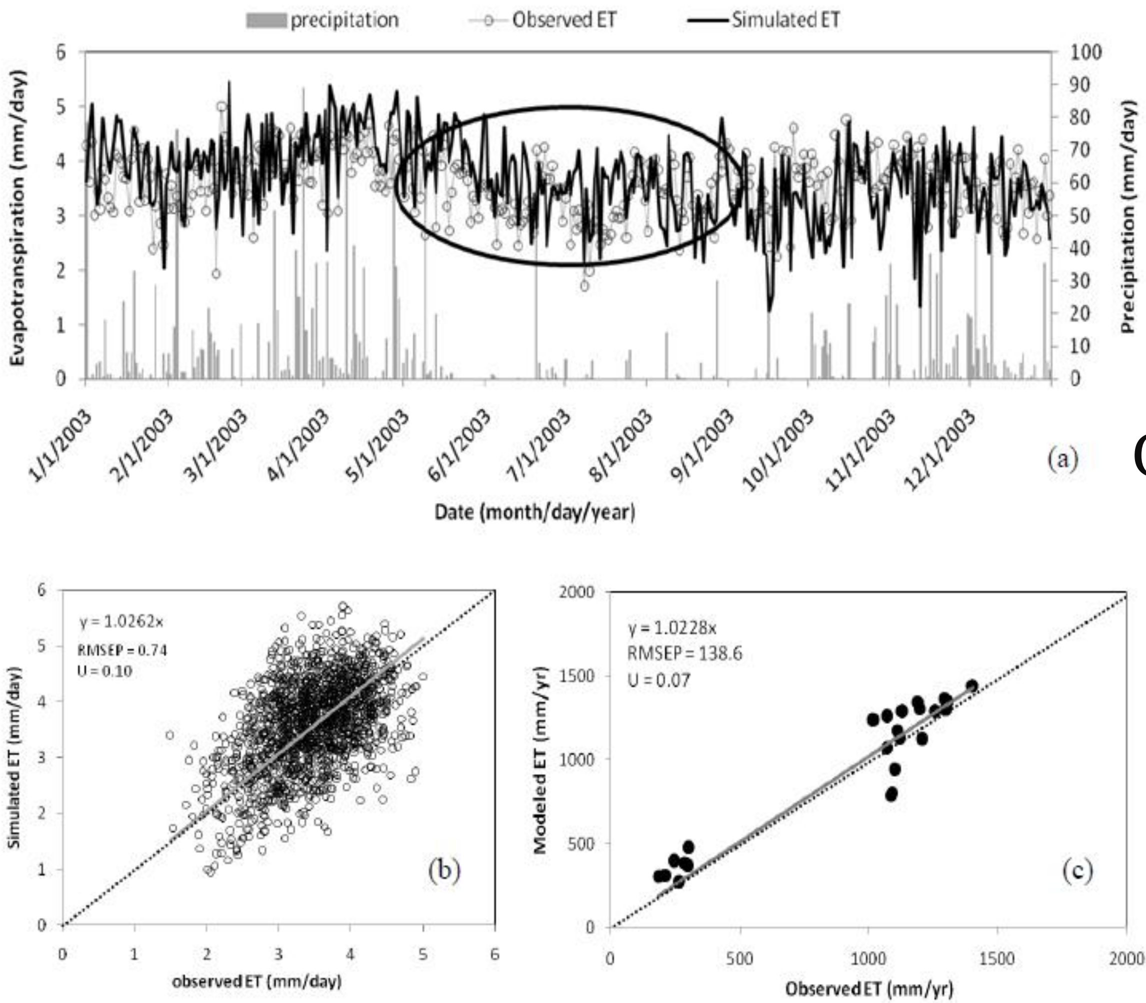


Figure comparison of DLEM-simulated and field observed ET at flux tower of Palangkaraya drained forest (PDF) in Indonesia: (a), daily pattern of precipitation, simulated and observed ET (unit: mm/day) during Jan. 1-Dec. 31, 2004; (b), scatter plot of simulated and observed ET during Jan.1, 2002-Dec. 31, 2005. (c) is the simulated ET compared with observations in monsoon Asia, including mixed forest in Changbai Mountain, China (Zhang et al., 2009), conifer-hardwood mixed forest in Teshio CC-LaG experiment site, Janpan (AsiaFlux, *http://asiaflux.yonsei.ac.kr/network/009TSE_1.html*), rainforest in Lambir Hills National Park, Malaysia (Lim et al., 2009), tropical peat swamp forest in Palangkaraya drained forest (PDF),
Indonesia (AsiaFlux, *http://asiaflux.yonsei.ac.kr/network/008PDF_1.html*), cropland in Tongyu, China (CEOP, *http://www.eol.ucar.edu/projects/ceop/dm/insitu/sites/ceop_ap/Tongyu/Cropland*) and 12 meteorological stations in China (Song et al., 2010). The gray solid lines in b and c are linear trend with regression equation and the dash line is 1:1 line.

Selected Publications (from 30+)

Tian, HQ, J. Melillo, C. Lu, D. Kicklighter, M Liu, J. Liu,W. Ren, X. Xu, G. Chen, C. Zhang, S. Pan and S. Running. Contribution of multiple global change factors to terrestrial carbon balance in China. *Glob. Biogeochem. Cyc.* (in press).

•**Tian, HQ**, X. Xu, M. Liu, C. Lu, W. Ren, G. Chen, J. Melillo and J. Liu. Net exchanges of CO_2, CH_4, and N_2O between China's terrestrial ecosystems and the atmosphere and their contributions to global climate warming. *Journal of Geophysical Research* (in press)

•**Tian, HQ**, GS Chen, C. Zhang, JM Melillo and C Hall. Pattern and variation of C:N:P ratios in China's soils: A synthesis of observational data. *Biogeochemistry* 98:139-151.

•**Tian, H., Q**., S. Wang, J. Liu, S. Pan, H. Chen, C. Zhang, and X. Shi. 2006. Patterns of Soil Nitrogen Storage in China. *Global Biogeochemical Cycles* 20, GB1001, doi:10.1029/2005GB002464..

•**Tian, H**., J. Liu, J. M. Melillo, M. Liu, D. Kicklighter, X. Yan and S. Pan. 2008. The Terrestrial Carbon Budget in East Asia: Human and Natural Impacts. In: C. Fu, J. Freney and J. Steward (eds). Changes in the Human-Monsoon System of East Asia in the Context of Global Change. World Scientific Publishing Co. Pte.Ltd., Singapore, Hackensack, London. Pp. 163-176

•**Tian, H**., C. Lu, G. Chen, X. Xu, M. Liu, W. Ren, B. Tao, G. Sun, S. Pan and J. Liu. Controls of climate and land use over terrestrial primary productivity, evapotranspiration and water use efficiency in Monsoon Asia during the 20th Century. *Ecohydrology* (Accepted).

•Liu, M. and **HQ Tian**. 2010. China's land-cover and land-use change from 1700 to 2005: estimations from high-resolution satellite data and historical archives, *Global Biogeochemical Cycles* doi:10.1029/2009GB003687

•Ren, W., **HQ Tian**, X. Xu, M. Liu, C. Lu, G. Chen, J. Melillo, J. Reilly and J. Liu. Spatial and temporal patterns of CO_2 and CH_4 fluxes in China's croplands in response to multifactor environmental changes, *Tellus B* DOI: 10.1111/j.1600-0889.2010.00522.x

•Lu, C and **H.Q. Tian**. Spatial and temporal patterns of nitrogen deposition in China: Synthesis of observational data. *Journal of Geophysical Research – Atmosphere*, **112(D22S05)**, doi:10.1029/2006JD007990.

•Liu, M. **HQ Tian**, GS Chen, W. Ren, C. Zhang and J. Liu. Effects of land use and land cover change on evapotranspiration and water yield in China during the 20th century. *Journal of the American Water Resources Association (JAWRA)* 44(5):1193-1207. DOI: 10.1111/j.1752-1688.2008.00243.x.

Summary

- **In most area of Monsoon Asia, total carbon storage decreased from the year 1700 to 2005. However, net carbon exchange for the recent 10 years has been increased particularly in East Asia primarily due to increased forest plantation and elevated nitrogen input.**

- **Climate extremes, especially drought, have significantly reduced carbon storage and productivity in cropland, grassland and forest. The negative impacts of climate change or extreme events, however, could be adapted/mitigated through optimizing land management practices including irrigation and fertilizer applications.**

- **From both scientific and policy perspectives, it is of critical importance to take multiple greenhouse gases into consideration. For example, 85% of the cooling effects caused by atmospheric CO_2 sequestration could be offset by CH_4 and N_2O emissions from China's terrestrial ecosystems.**

- **Land conversion from forests to croplands led to a decrease in water use efficiency (WUE). In contrast, WUE increased largely while cropland was converted to grassland and forest. Simulated results also showed that intensive land management practices could alleviate the decrease in WUE induced by climate change and land conversion.**

- **Model simulation indicates that annual mean water yield shows a significant gradient from North to South, Southeast Asia. In the recent decade, water yield considerably decreased in northern and southern parts of Monsoon Asia, which means a drought occurred in North China, most area of India.**

- **Large-scale land cover/land use change could alter regional climate. Conversion from natural vegetation to cropland leads to decreases in both temperature and precipitation, but could increase precipitation if converting from natural vegetation to irrigated cropland.**

- **Uncertainties could emerge from three different sources: input dataset, key model parameters, different model components and their integration.**

Needs for Synthesis Studies

- Developing consistent data sets for driving models.
- Model-Data intercomparison
- Model-model intercomparison
- Uncertainty analysis associated with:
  - model parameters, coupling, scaling, Legacy effect (Disturbance and land use history);

Land Use – Ecosystem – Climate Interactions in Monsoon Asia:

Evaluating the impacts of current and projected LCLUC on climate, water and carbon cycling in the first half of 21st Century