# Land use- Ecosystems- Climate Interactions in Monsoon Asia: Evaluating the impacts of historical and future LCLUC on terrestrial ecosystems and the climate system

Hanqin Tian,[1] Jerry M. Melillo,[2] John Reilly,[3] Hassan Virji,[4] Robert Dickinson,[5] Jiyuan Liu,[6] and Other Participants (DW Kicklighter, ML Liu, CQ Lu, H Mao, SF Pan, W Ren, B Tao, XF Xu)

1. Ecosystem Dynamics and Global Ecology Laboratory (EDGE), School of Forestry & Wildlife Sciences, Auburn University, Auburn, AL 36849, USA, email: tianhan@auburn.edu; 2. Marine Biological Laboratory (MBL), Woods Hole, Massachusetts 02543, USA, 3. Massachusetts Institute of Technology (MIT), Cambridge, MA 02139, USA, 4. International START Secretariat (START), Washington, DC 20009, USA; 5. University of Texas at Austin, TX 78712, USA; 6. Institute of Geographical Sciences and Natural Resources, Chinese Academy of Sciences, Beijing 100101,China

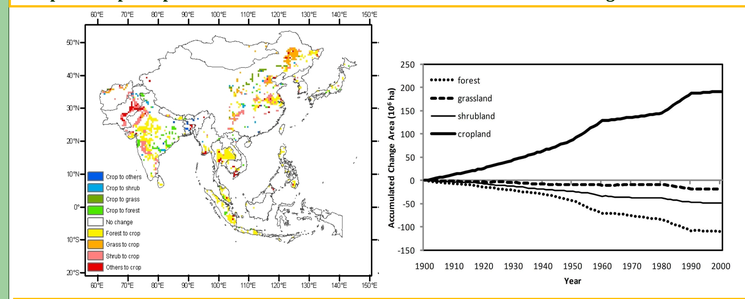
## BACKGROUND, OBJECTIVES AND APPROACHES:

The Monsoon Asia, home to more than 60% of world populations, has experienced an unprecedentedly fast land-cover/land use change (LCLUC) in the past decades, and is likely to undergo further rapid development in the 21st century. There is an increasing concern that LCLUC caused by urbanization, deforestation/afforestation, desertification and biofuel production may affect local, regional and global climate and further influence the provision of goods and services by terrestrial ecosystems in the region of monsoon Asia. Therefore, it is of critical importance to better understand the complex interactions and feedbacks among LCLUC, climate changes, C budget and water cycling over Monsoon Asia. An integrated research is urgently needed to understand how LCLUC and climate interact to affect the structure and functioning of terrestrial ecosystems, and to predict to what extent future land use scenarios would modify climate, water and carbon cycling throughout Monsoon Asia, and even the whole globe.

Currently, our approach is to combine a set of global biogeochemical models (TEM and DLEM) and Emission Predictions and Policy Analysis (EPPA) model, along with remote-sensing observation data (MODIS, AVHRR and Landsat-TM/ETM) and field experiments and monitoring data, to quantify the impacts of historical and projected future LCLUC on terrestrial ecosystems ( carbon & water cycles, GHGs) and climate system (temperature and precipitation) throughout Monsoon Asia. The Coupled Regional Earth System Model (CRESM) has been developed to explore to what extent LCLUC has modulated and will modulate the Asia monsoon climate in the past and future, and how the changed monsoon climate will impact LCLUC in the region of Monsoon Asia in the first half of 21st century.

## DATABASE:

**A Spatiotemporal pattern of land-cover and land-use in Monsoon Asia during 1900-2000**




**B Future Land-cover and Land-use Change in Monsoon Asia during 2000-2100**

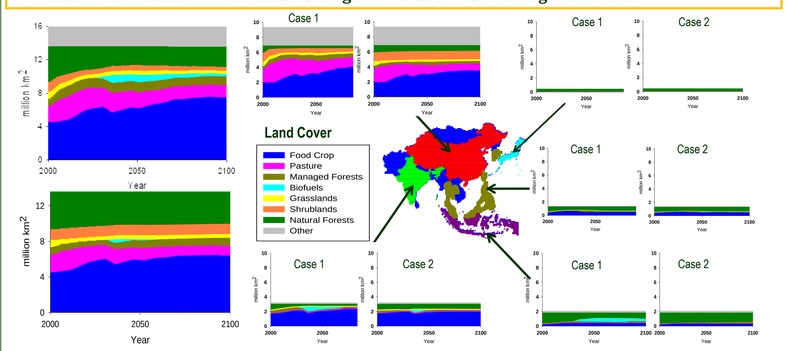



Figure 1 A) Historical land-cover and land-use change in Monsoon Asia during 1900-2000 developed by EDGE lab; B) Future land-cover and land-use change in Monsoon Asia during 2000-2100 under two different scenarios (case1 allows the conversion of natural areas to meet increased demand for land, case2 is driven by more intensive use of existing managed land) derived from EPPA model (Gurgel et al.,2007)

**C Changes in other major environmental factors**

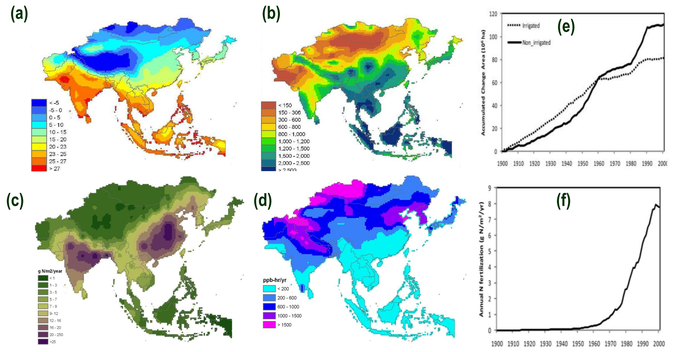



Figure 2 Spatial pattern of annual average for a) Temperature(°C/yr), b) Precipitation (mm/yr), c) Nitrogen deposition, and d) Ozone (AOT40) across Monsoon Asia over 1948-2000. Annual average of e) irrigation/non-irrigation land area, and f) fertilizer application rate from 1900 to 2000.

## PRIMARY RESULTS:

**GHGs fluxes, Carbon &Water cycles in monsoon Asia over the 20th century**

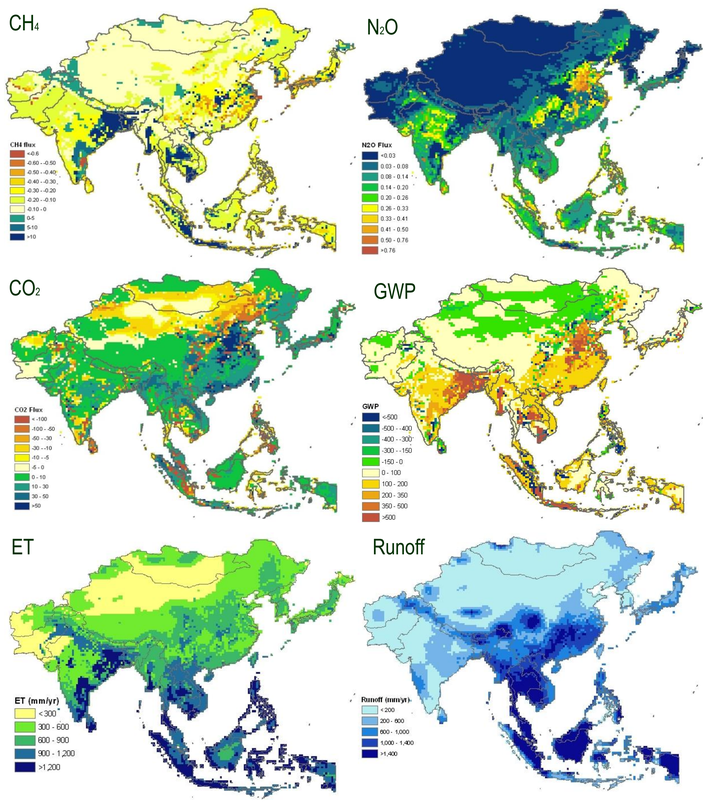



Figure 3 The annual average of ecosystem–atmosphere exchanges of $CH_4$, $N_2O$, and $CO_2$ (units: g C/m²/yr for $CO_2$ and $CH_4$ fluxes, and g N m²/yr for $N_2O$ flux) and the resulted global warming potential GWP (g $CO_2$ eq/m²/yr), evapotranspiration (ET: mm/yr), and runoff (mm/yr) over monsoon Asia during 1948-2000, estimated by the Dynamic Land Ecosystem Model(DLEM).

**Changes in Carbon Storage and Water Yield induced by historical LCLUC**

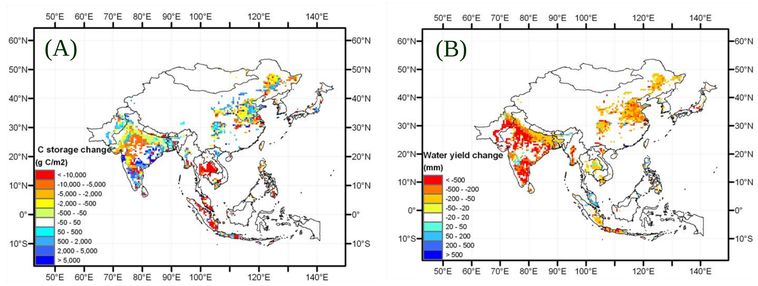
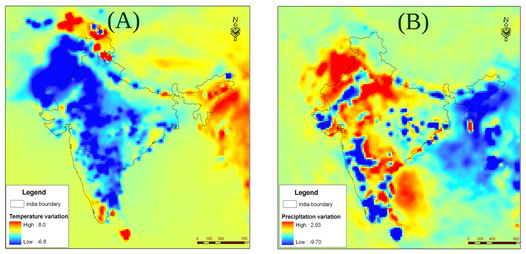



Figure 4 Changes in carbon storage (A) and water yield (B) in terrestrial ecosystems of monsoon Asia induced by land-cover and land-use change during 1700-2000 as simulated by the Dynamic Land Ecosystem Model (DLEM) (Tian et al. 2010).

**Changes in Temperature and Precipitation induced by historical LCLUC**




| Items of LCLUC | Temperature ($^0$C/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 |

Figure 5 Changes in (A) temperature and (B) precipitation induced by land-cover and land-use change between 1700 and 2000 as simulated by Regional Climate model.

**Cumulative Net Land Carbon Flux driven by biofuel production in two land use scenarios across Monsoon Asia over the 21st century**

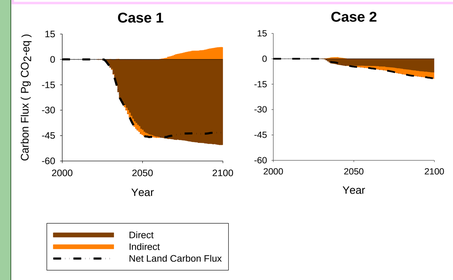



Figure 6 Partitioning of Direct and indirect effects of Cellulosic Biofuels on Projected Cumulative Land Carbon flux since 2000 across Monsoon Asia.
*(Direct C fluxes are those occurred on land devoted to biofuel crops and indirect fluxes are driven by increasing land demand due to biofuel crops. Positive values represent carbon sequestration, whereas negative values represent carbon emissions by land ecosystems.* Melillo et al., 2009, Science 326:1397-1399 )

**Regional partitioning of greenhouse gas balance in the 21st century driven by biofuel production in two land use scenarios**

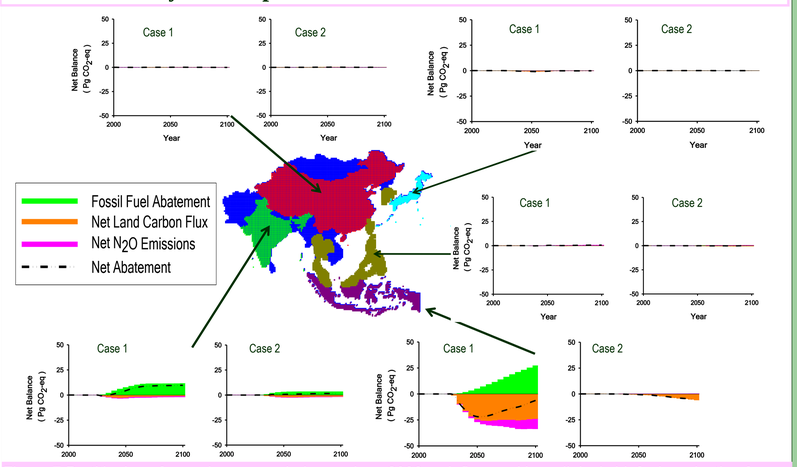
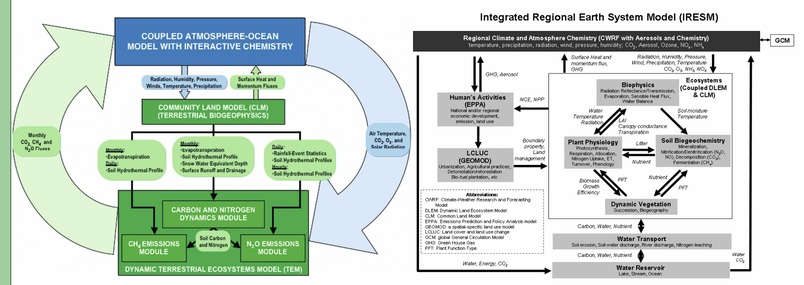
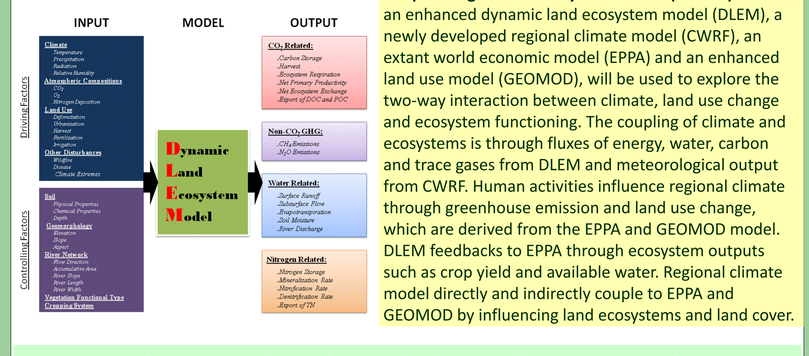



Figure 7 Partitioning of greenhouse gas balance since 2000 as influenced by cellulosic biofuel production for two land-use cases. Positive values are abatement benefits, and negative values are emissions. (Melillo et al 2009)

## Coupled Regional Earth System Model (CRESM)




**Coupled Regional Earth System Model (CRESM)** includes an enhanced dynamic land ecosystem model (DLEM), a newly developed regional climate model (CWRF), an extant world economic model (EPPA) and an enhanced land use model (GEOMOD), will be used to explore the two-way interaction between climate, land use change and ecosystem functioning. The coupling of climate and ecosystems is through fluxes of energy, water, carbon and trace gases from DLEM and meteorological output from CWRF. Human activities influence regional climate through greenhouse emission and land use change, which are derived from the EPPA and GEOMOD model. DLEM feedbacks to EPPA through ecosystem outputs such as crop yield and available water. Regional climate model directly and indirectly couple to EPPA and GEOMOD by influencing land ecosystems and land cover.

- **Monsoon Asia has experienced rapid changes in land cover and land use pattern in the past century and is likely to undergo further rapid changes in the 21st century due to urbanization, deforestation, desertification etc. Land area devoted to biofuels in case 1 is larger than that in case 2 and the biofuel production is mainly distributed in the region of India and Indonesia.**
- **Anthropogenic activities, such as land cover conversion, land management, have imposed significant impacts on carbon and water cycles (C storage and water yield), GHG emissions ($CH_4$, $CO_2$ and $N_2O$) and climate system (temperature and precipitation). Future LCLUC, e.g. expanded global cellulosic bioenergy program, could considerably alter net carbon fluxes and GHGs balance in Monsoon Asia. In both land use cases, indirect effects of biofuel production contribute to more carbon uptake or less carbon release than direct effects do. The resulted GHG balance in terms of warming potential vary significantly among regions.**
- **The Coupled Regional Earth System Model(CRESM) has shown the potential to explore the complex interactions among land use, ecosystems and monsoon climate in Monsoon Asia, a critical area affecting the world environment and economic development. Future work is needed to further validate the CRESM model and to explore the likely uncertainties.**

**Acknowledgement: This study has been supported by NASA Land Cover and Land Use Change Program (NNX08AL73G); NASA Interdisciplinary Science Program (NNG04GM39C)**