South Asian Forests and Carbon Sequestration

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Acknowledgements
Xiaoming Xu, Past and Present Group Members, and Collaborators, and Funding Agencies
Overall Objective

• Evaluate and understand the forest carbon sources and sinks in South Asia
  – achieve by systematically developing and using data sets and models
    • Socioeconomic and Biophysical data and models
  – Evaluate models
    • Data-model comparison
    • Model-model comparison
    • Data & model-model comparison
Countries in South Asia

SOUTH ASIA
- Bangladesh
- Bhutan
- India
- Nepal
- Pakistan
- Sri Lanka
Carbon Fluxes

- Net Ecosystem Productivity
  \[ \text{NEP} = \text{NPP} - \text{RH} \]

- Net Biome Productivity
  \[ \text{NBP} = \text{NEP} - E_{\text{LUC}} - E_{\text{FIRE}} \]

- NPP: Net primary productivity
- RH: Heterotrophic respiration
- \( E_{\text{LUC}} \): Emissions due to land use change (here forest change)
- \( E_{\text{FIRE}} \): Emissions due to fires.

*Positive values are the land sink of carbon*
Global Carbon Budget 2019

Estimations of NEP, NBP and $E_{LUC}$ Emissions

- Used five different dynamic vegetation model results, which are calculated based on one set of LCLUC data for SA (5 DGVM and 1 LCLUC Date Set)

<table>
<thead>
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<th>Model</th>
<th>Resolution (lat x lon)</th>
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<tr>
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<td>1.0° x 1.0°</td>
</tr>
<tr>
<td>CLASS-CTEM</td>
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</tr>
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Estimations of NEP and $E_{LUC}$ Emissions

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Land-use Harmonization 2 (LUH2) 
Land-Cover Change (1980-2018)

*2010s: 2011-2018

Friedlingstine et al. (ESD, 2019)
Forest NEP (1980-2018)

Yearly variations are driven by the temperature variations.

Error bars represent standard deviation between model results.
Results: Forest $E_{LUC}$

Error bars represent standard deviation between model results.
Mean Carbon Fluxes SA Average for 2000-2018

*Positive values are the land sink of carbon*
Country Specific Mean Carbon Fluxes Average for 2000-2018

- Bhutan
- India
- Nepal
- Pakistan
- Sri Lanka
- Bangladesh

TgC yr⁻¹

NEP, Eluc, Efire, NBP
Components of the Forest Carbon Budget for SA (1997-2016)

*Positive values are the land sink of carbon*
Why Large Uncertainties?
Estimating the Impact of LUC on Carbon Stocks and Fluxes

- Uncertainty in Carbon Stocks and Fluxes could be due to
  - Uncertainty in LUC Data
  - Uncertainty in process level understanding of parameterization of different biogeochemical (BGC) and biophysical (BGP) processes
  - Uncertainty in feedbacks: Interactions with environmental and management variables
Moving forward?
Estimating the Impact of LUC on Carbon Stocks and Fluxes

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  - Uncertainty in feedbacks: Interactions with environmental and management variables
Maximum grid-level differences using Various Realizations of LUC data (Average for the period 2001-2013)

Various Realizations:
- HYDE
- SAGE (RF)
- Houghton (HH)
- Satellite data sets
Satellite derived forest cover products
LUC Drivers and Data at Global Scale - Mix of top-down and bottom-up approaches

- **Top-down**
  - Global scale

- **Bottom-up**
  - Country scale
  - Regional scale

**Examples**
- Example of South and Southeast Asia (SSEA)
- Examples of India & Bangladesh

- Needs solid national to regional scale analyses of drivers and data
- Upscale the drivers and data from national and regional scales to global scale using a model
LUC Drivers and Data at Global Scale - Mix of top-down and bottom-up approaches

- **Top-down**
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- **Bottom-up**
  - Example of South and Southeast Asia (SSEA)
  - Example of India & Bangladesh

- **Global scale**
- **Regional scale**
- **Country scale**
Prevailing uncertainties in LUC over India

Dynamics and determinants of land change in India: integrating satellite data with village socioeconomics

Prasanth Meiyappan¹ · Parth S. Roy² · Yeshu Sharma³ · Reshma M. Ramachandran² · Pawan K. Joshi⁴ · Ruth S. DeFries⁵ · Atul K. Jain¹
LUC Dynamics at National Scale (India)

Meiyappan et al. (2017)
Forest Dynamics in Meghalaya - Satellite Derived Vegetation Type Maps

Roy and Tomar (2001); Roy et al. (2015)
Dynamics and determinants of land change in India: integrating satellite data with village socioeconomics

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Major findings

Notation
- Forest gain
- Forest loss
- UTL -> Crop
- Crop -> UTL
- 10 - 100 km²
- 100 - 300 km²
- 300 - 500 km²
- > 500 km²
- Built-up and Urban

Land Cover
- Forest
- Others
- Cropland
- Shrubland
- Grassland
- Wasteland
- Fallow land
- Plantations
- Barren land
- Water Bodies

- Firewood/Construction Materials
- Lack of Electricity
- Wooden Furnitures
- Sheep Overbrowsing

- Wooden Furnitures/Timber
- Lack of irrigation
- Low incomes

- Low Infrastructure for Agriculture
- Wooden Furnitures/Timber
- Cattle overgrazing

- Mining/Quarrying Activities
- Industrial Development
- Low Agricultural Productivity

- Mining/Quarrying Activities
- Coconut Plantations (Encroached)
- Protected areas (-ve)
Forest cover change assessment (2000-2010) - An example from South India

Hansen et al. (2013)
Sexton et al. (2013)
Meiyappan et al. (2017)
Evaluation: Meta-synthesis of more than 100 case studies

Notation
- Agro-Ecological Zones
- State level
- Group of districts or villages
- District level
- Village level

Color coding
- Cropland -> Under-utilized land
- Under-utilized land -> Cropland
- Forest area loss
- Increase in forest area
Validation: How good are the reconstructed maps?

Pattern validation: an example

Topographic Map (1950) → Data Clean-up + Digitization → Digitized Topographic Map (1950) → Comparison → Reconstruction Data (1950)

Ground truthing at over 12000 locations for year 1950
High resolution military toposheets (circa 1950)

Pattern validation: an example
Illustrating the new data product with population density as example (notice the high granularity captured in the new data)

Data currently available >100x improvement in resolution My new data product

Decadal Land Use and Land Cover Classifications across India, 1985, 1995, 2005

Overview

<table>
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<tr>
<th>DOI</th>
<th><a href="https://doi.org/10.3334/ORNLDAAC/1336">https://doi.org/10.3334/ORNLDAAC/1336</a></th>
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<tr>
<td>Published</td>
<td>2016-09-06</td>
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<td>Updated</td>
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<tr>
<td>Citations</td>
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http://dx.doi.org/10.3334/ORNLDAAC/1336.
Bangladesh
LCLUC Change Area (km²) between 2000 and 2010

Xu et al (2019)
Quantifying the biophysical and socioeconomic drivers of changes in forest and agricultural land in South and Southeast Asia

Xiaoming Xu¹ | Atul K. Jain¹ | Katherine V. Calvin²
Spatial modeling of agricultural land use change at global scale

Prasanth Meiyappan a,*, Michael Dalton b, Brian C. O’Neill c, Atul K. Jain a,**
Process-Based Modeling
Evaluation of the DGVM using the International Land Model Benchmarking system
The Effect of Indian Summer Monsoon on the Seasonal Variation of Carbon Sequestration at a Tropical Forest Ecosystem over North-East India

In 2016 this ecosystem acts as a net source of atmospheric CO₂ with net ecosystem exchange of \(207.51 \pm 611.64 \text{ gC m}^{-2} \text{ y}^{-1}\), and gross photosynthesis and ecosystem respiration of \(2604.88 \pm 1287.67\) and \(2812.38 \pm 1104.48 \text{ gC m}^{-2} \text{ y}^{-1}\), respectively. The monsoon clouds are seen to introduce a bimodal pattern in the

Burman et al. (2019)
Thank you..
Integrated Science Assessment Model (ISAM)

Carbon Nitrogen
Single Soil Layer
CH₄ CO NOx NMHC N₂O O₂
Multiple Soil Layer
Conceptual diagrams of belowground structure and processes for original (a) and extended version (b) of ISAM.

(a) 

(1) Litter input  
(2) SOC degradation  
(3) SOC decomposition  
(4) Moss thermal insulation  
(5) Organic layer formation  
(6) Cryoturbation/Bioturbation

(b) 

Permafrost table

(c) 

- Leaf litter
- Woody litter
- Fine root litter
- Coarse root litter

- Metabolic Litter
- Structural Litter
- Foliar Microbial Soil
- Young Humus Soil

- Decomposable Litter
- Resistant Litter
- Woody Microbial Soil
- Stabilized Humus Soil
Carbon, Nitrogen and LUC Interaction

CO₂ emissions from land-use change affected more by nitrogen cycle, than by the choice of land-cover data

ATUL K. JAIN*, PRASANTH MEIYAPPAN*, YANG SONG* and JOANNA I. HOUSE†

Global Biogeochemical Cycles

Increased influence of nitrogen limitation on CO₂ emissions from future land use and land use change

Prasanth Meiyappan¹, Atul K. Jain¹, and Joanna I. House²

¹Department of Atmospheric Sciences, University of Illinois at Urbana-Champaign, Urbana, Illinois, USA, ²Department of Geography, Cabot Institute, University of Bristol, Bristol, UK
Estimates of Land Use Emissions for $CO_2$
Calculated based on Various Dynamic Vegetation Models

Pongratz (2013, Nature)
Country Specific Dynamics of Forest and Agricultural Land in SSEA (1992-2015)
Modeling the effects of two different land cover change data sets on the carbon stocks of plants and soils in concert with CO₂ and climate change

Atul K. Jain and Xiaojuan Yang

Department of Atmospheric Science, University of Illinois, Urbana, Illinois, USA

Received 2 August 2004; revised 5 January 2005; accepted 9 March 2005; published 5 May 2005.
Land-use emissions play a critical role in land-based mitigation for Paris climate targets


DOI: 10.1038/s41467-018-05340-z
Country-specific relative importance of each driver category

Forest → Agriculture

Biophysical drivers: 28%
Socioeconomic drivers: 72%

Xu et al. (2018a)
Synthesis of case studies & hotspot regions
Example: Forest areas gain and loss

Xu et al (2018a)
Results: $E_{\text{FIRE}}$

- Fire emissions were obtained from the Global Fire Emissions Database (GFED)
  - Calculated based on satellite data and model.