Spatial land use in integrated assessment models: simulating decisions and their consequences for climate, carbon, and water

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Spatial Land Use Modeling
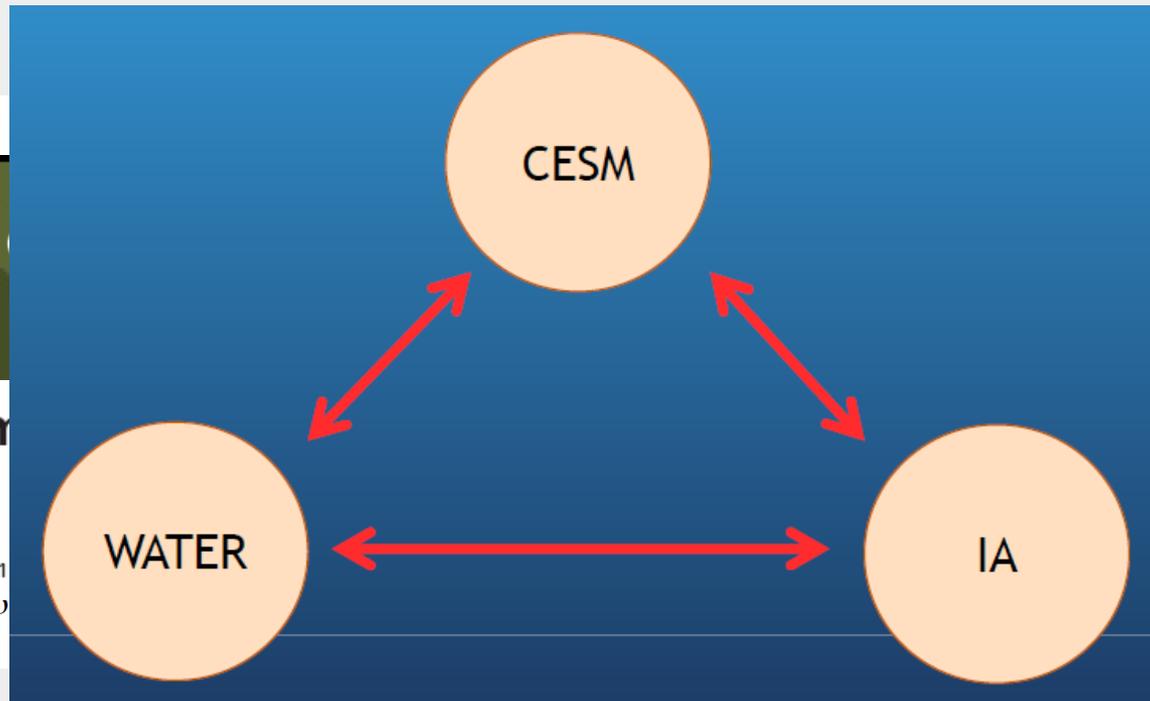
Previous meetings/activities

Why do we care?

Why do I care?

Session goals

Previous/ongoing meetings and activities

- **EMF-IAMC Snowmass 2008 -> Hibbard et al., 2010**
- **CSIRO-GLP Crackenback 2011 -> Rounsevell et al., 2012**
- **IGBP Synthesis on Land Use and Land Cover Change**
- **CESM Societal Dimensions Working Group**

Why do we care?

- Key driver of environmental outcomes (biodiversity, water stress, climate change, ...)
- Key determinant of mitigation, impacts and adaptation options
- Current modeling approaches can lead to widely divergent outcomes

**Change in European cropland areas for a range of scenario studies**
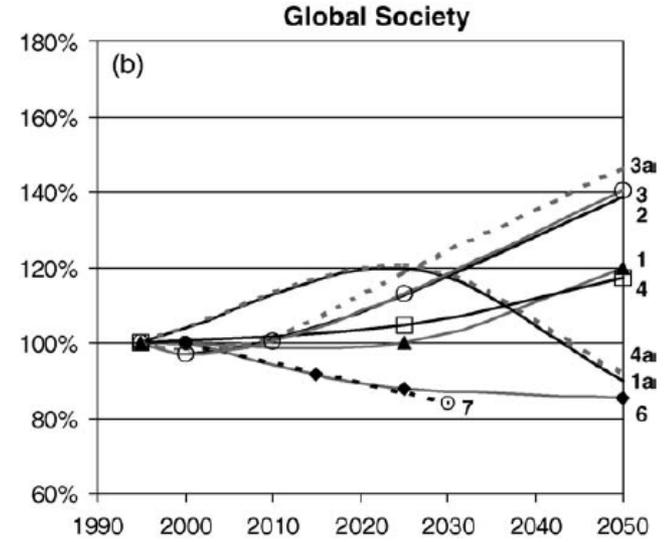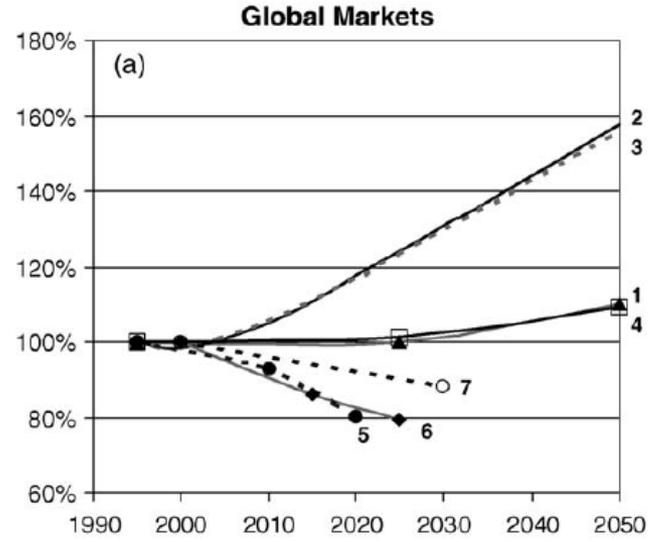
Global studies: 1, 2 (IMAGE), 3, 4, 5;

Regional studies: 6 (Ateam), 7 (EuRuralis)

Sources of uncertainty?
• Models
• Data
• Scenario assumptions

Source: Busch, G. (2006). Future European agricultural landscapes - What can we learn from existing quantitative land use scenario studies? *Agriculture, Ecosystems & Environment,* **114**
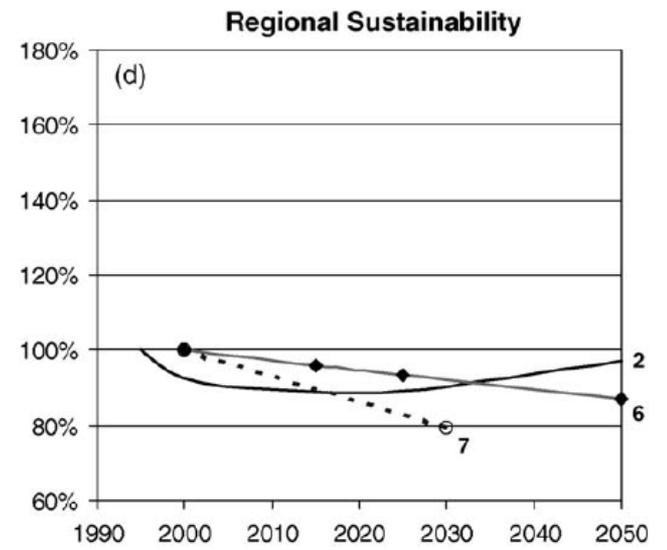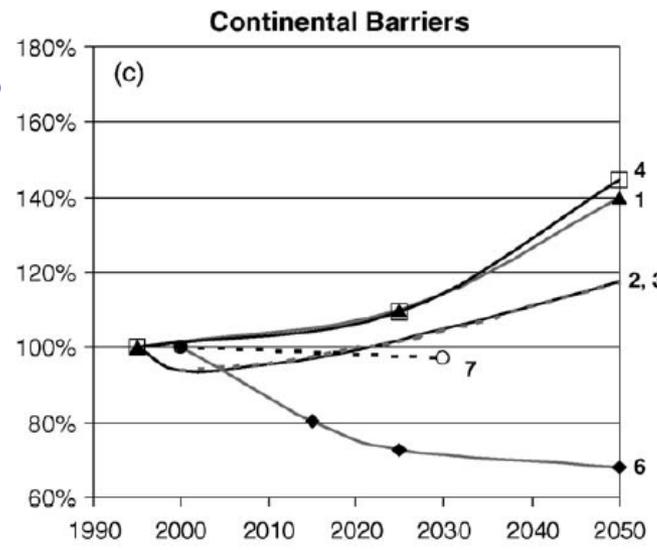
Why do we care?

- Key driver of environmental outcomes (biodiversity, water stress, climate change, …)
- Key determinant of impacts and adaptation options
- Current approaches can lead to widely divergent outcomes
- Consequences of outcomes not well understood (climate/water/BGC consequences of regional climate change)
- Two-way interactions between land use and climate/ water only beginning to be explored
- Land use key in IAMs as driver and in response options

Implications of large-scale bioenergy

Extensive case   Intensive case
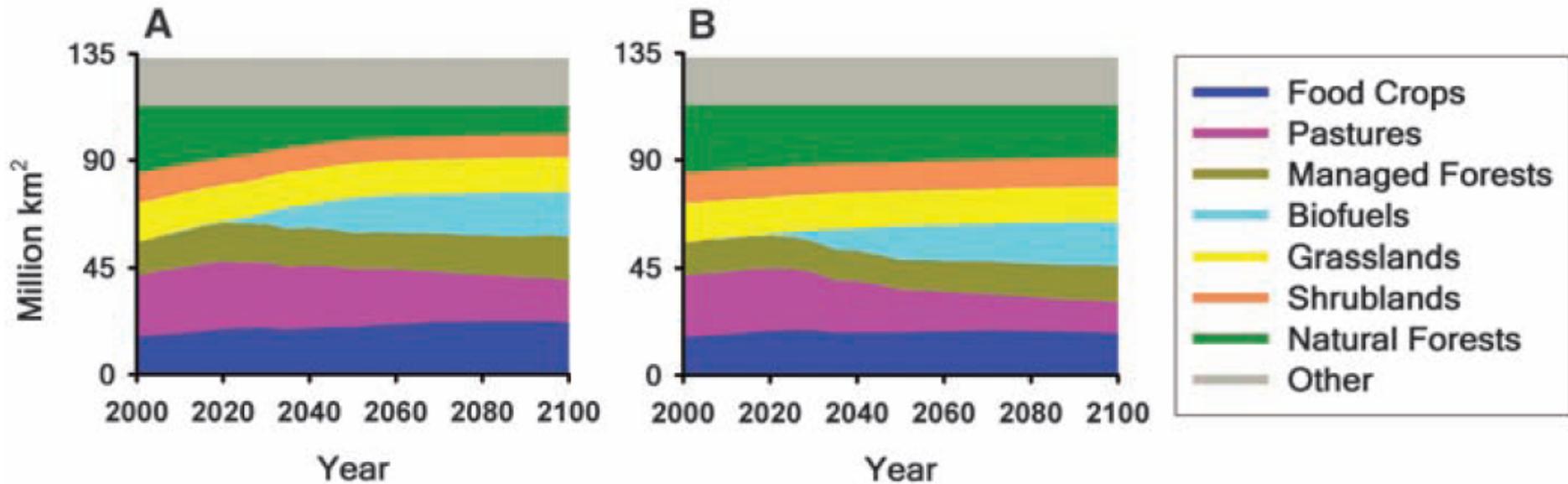
- Biomass provides most of liquid fuels by end of century
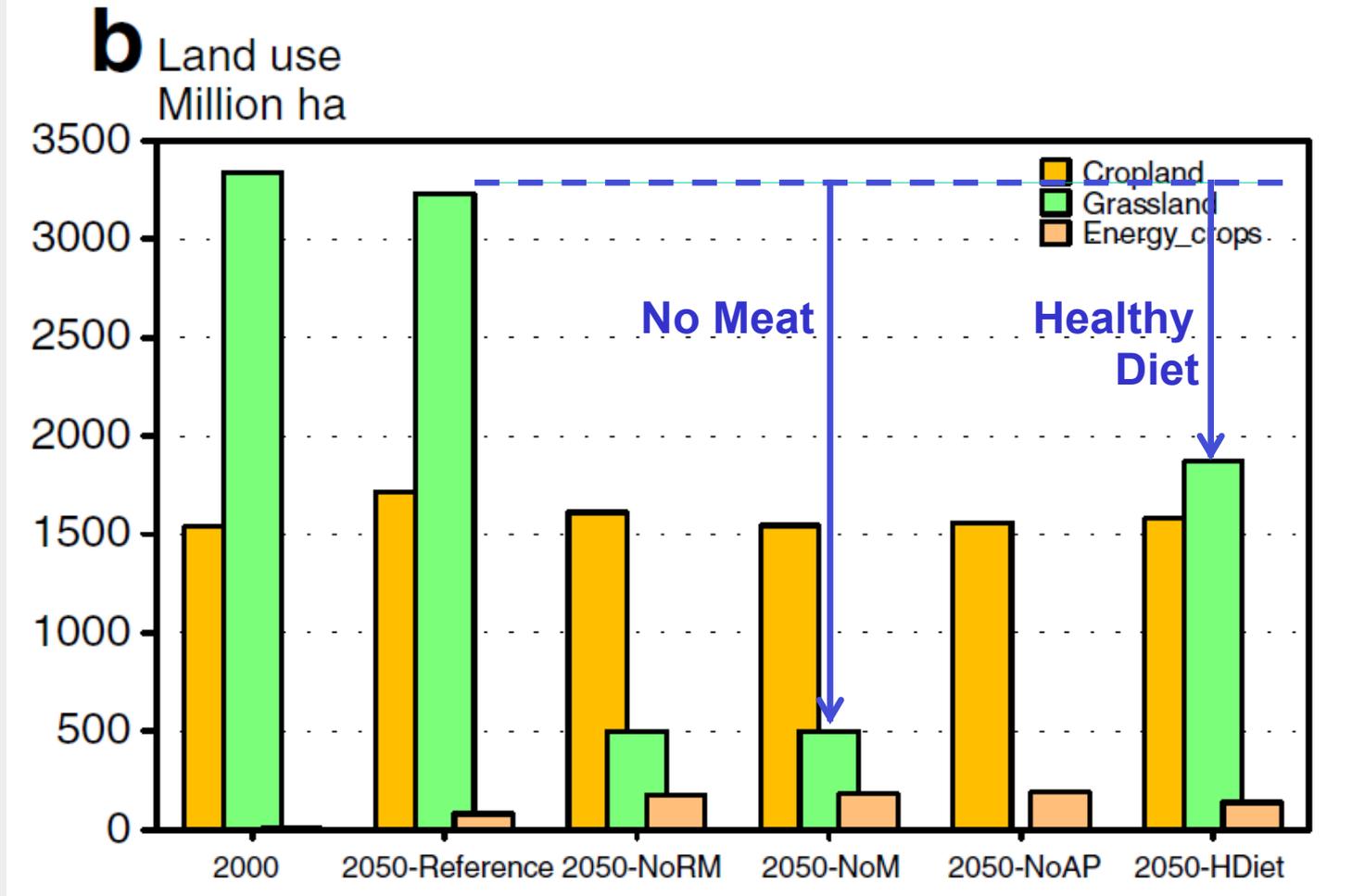- Indirect emissions 2x more important than direct emissions
- N2O emissions from fertilizer more important than CO2
- Effects largest in Latin America and Africa

Melillo et al., 2010. IGSM model.

Implications of diet changes

Stehfest et al., 2010. IMAGE model.

Why do I care?: Spatial Land Use in iPETS

- **Aggregate world region land use produced by CGE model; cropland, pasture, managed forest/wood harvest**

- **Downscaled to grid-cell level**

- **Theoretical approach based on hypothetical grid cell agent that is maximizing profits, subject to**
  - **local constraint (total grid cell land)**
  - **regional constraint (aggregate land use)**

- **Produces non-linear (quadratic) programming problem to solve for grid cell-specific land use**

$$Min \sum_{i=1}^{n} \sum_{j=1}^{m} (1 - s_{i,j})(x_{i,j} - (x_o)_{i,j})^2$$

grid cells

land use
types

suitability
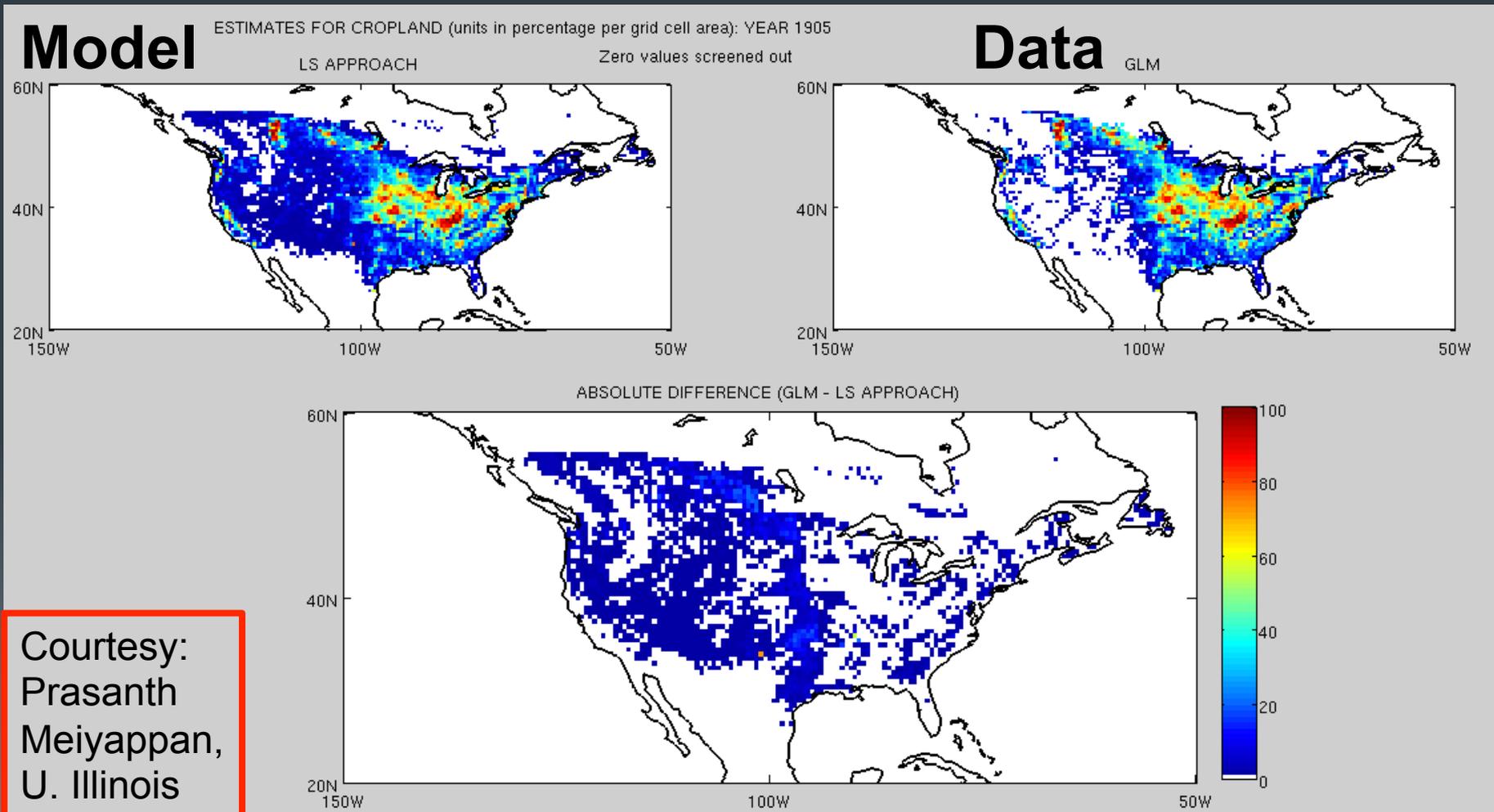
current land
use allocation

previous land
use allocation

Constraints: (1) can't use more land than each grid cell contains
(2) sum of land use across grid cells must equal regional land use

Suitability index example:

$$S_{crop} = S_{soil}(5) \times S_{terrain} \times S_{clim} \times S_{irri} \times S_{pop} \times S_{urb}$$

Testing the Model with HYDE Historical Reconstruction – for USA

After 55 years of Model Run (1905) – Cropland Distribution

Model

Data

ESTIMATES FOR CROPLAND (units in percentage per grid cell area): YEAR 1905
Zero values screened out

LS APPROACH

GLM

ABSOLUTE DIFFERENCE (GLM - LS APPROACH)

Courtesy: Prasanth Meiyappan, U. Illinois

Testing the Model with HYDE Historical Reconstruction – for USA

After 151 years of Model Run (2001) – Cropland Distribution

Model
LS APPROACH

Data
GLM

ABSOLUTE DIFFERENCE (GLM - LS APPROACH)

Underestimation a side effect →

Overestimation due to urban constraints not yet being implemented →

Courtesy: Prasanth Meiyappan, U. Illinois
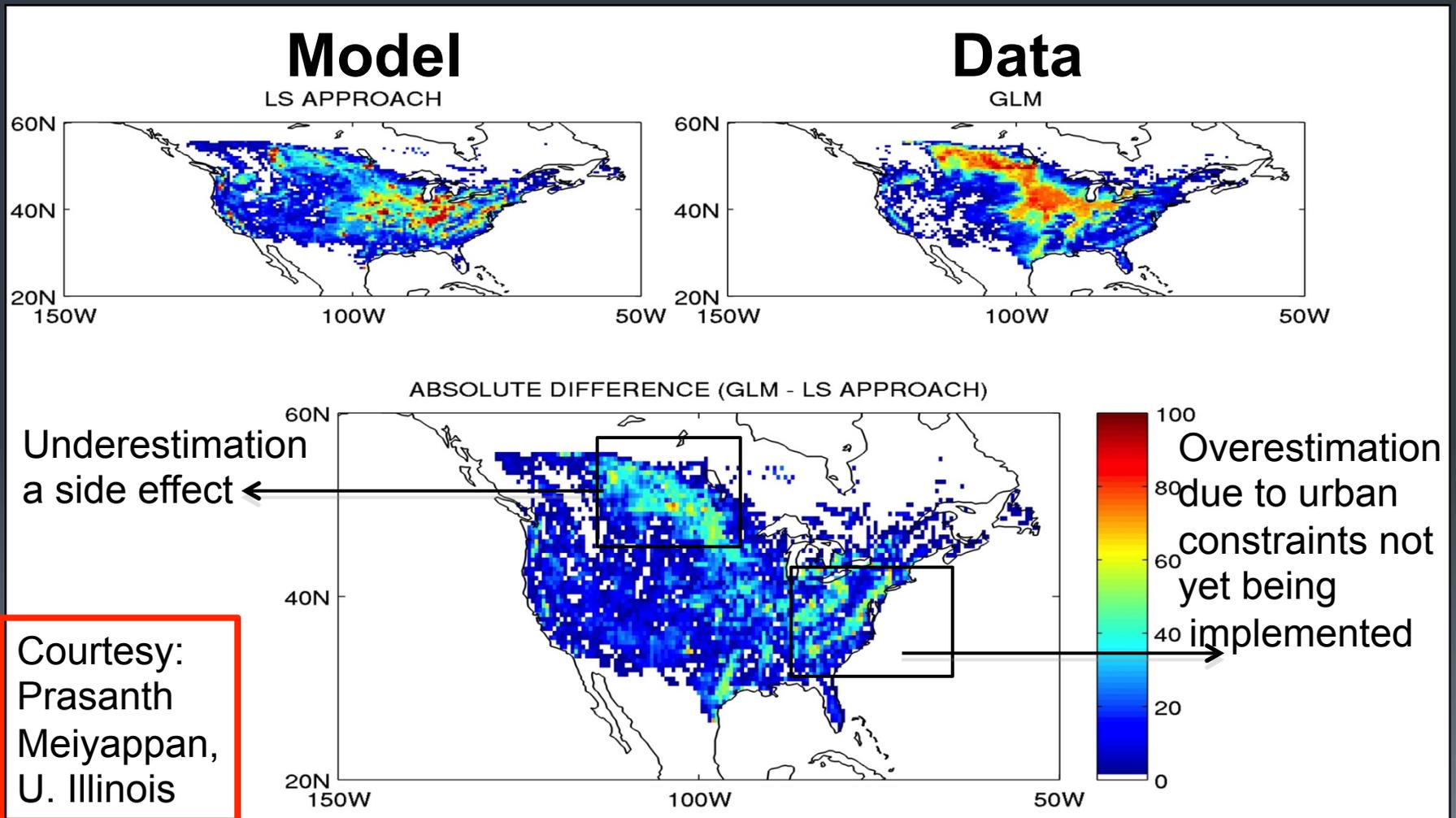
Challenges

- **Separate groups of scholars: IAM, Geography (Land Use Change Science), Demography**
- **Different approaches: agent-based, cellular (allocation), econometric, large scale optimizing, CGE**
- **Scale differences**
- **Few (any?) apples to apples comparisons**
- **Data limitations**

Questions

- **How sensitive are regional land use outcomes to the model of decision-making that is employed?**
  - **What approaches to modeling decisions are available? Strengths/weaknesses? Feasible to scale to global application?**
  - **What kind of activity(ies) could address this question?**
- **Are large-scale IAMs missing important processes?**
- **How can we best connect (more detailed?) regional land use modeling and data to global scenarios?**
- **How sensitive is climate and biogeochemistry to the pattern of land use at the regional scale?**
  - **What are key sensitivities/uncertainties of regional climate/bgc responses? Key feedbacks?**
- **Can validation of spatial land use modeling be improved? How?**

Agenda

Monday

- **IAM approaches to spatial land use**
- **Agent based models**
- **Spatial economic models**
- **Possibilities for scaling up**

Tuesday

- **Climate, water, BGC consequences, including approaches to interactions**
- **Data issues and opportunities**

Possible Outcomes

- **Written product?**
  - **Meeting report**
  - **Joint paper (to IGBP special issue of ESD?)**
- **Proposals**
  - **NSF RCN resubmission?**
  - **Other?**
- **CESM Societal Dimensions Working Group**
  - **New participants**
  - **Joint activitiy?**
- **Other ideas?**