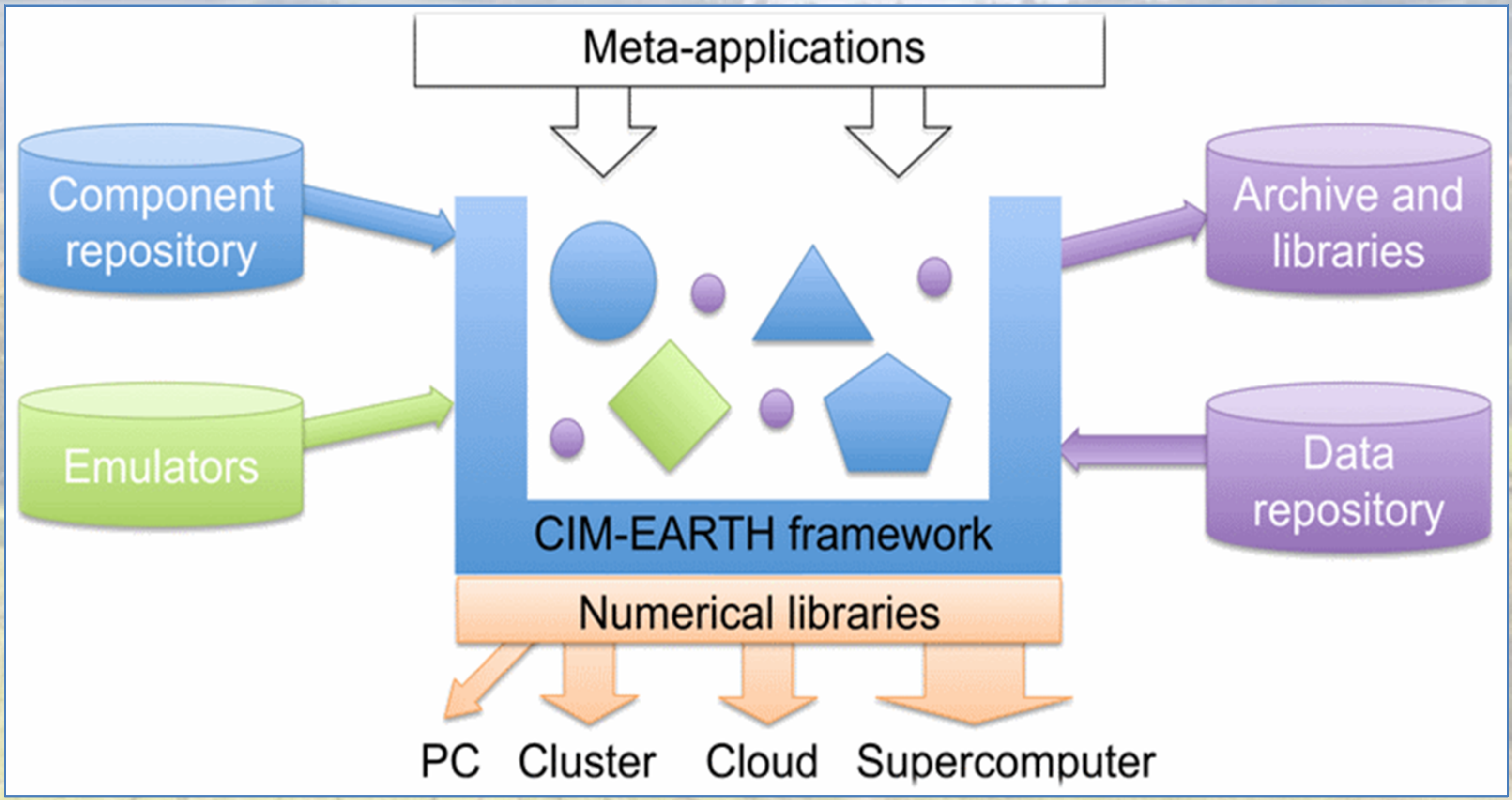
Integrating the Socio-economic and Physical Drivers of Land-use Change at Climate relevant Scales: an Example with Biofuels

Joshua W. Elliott

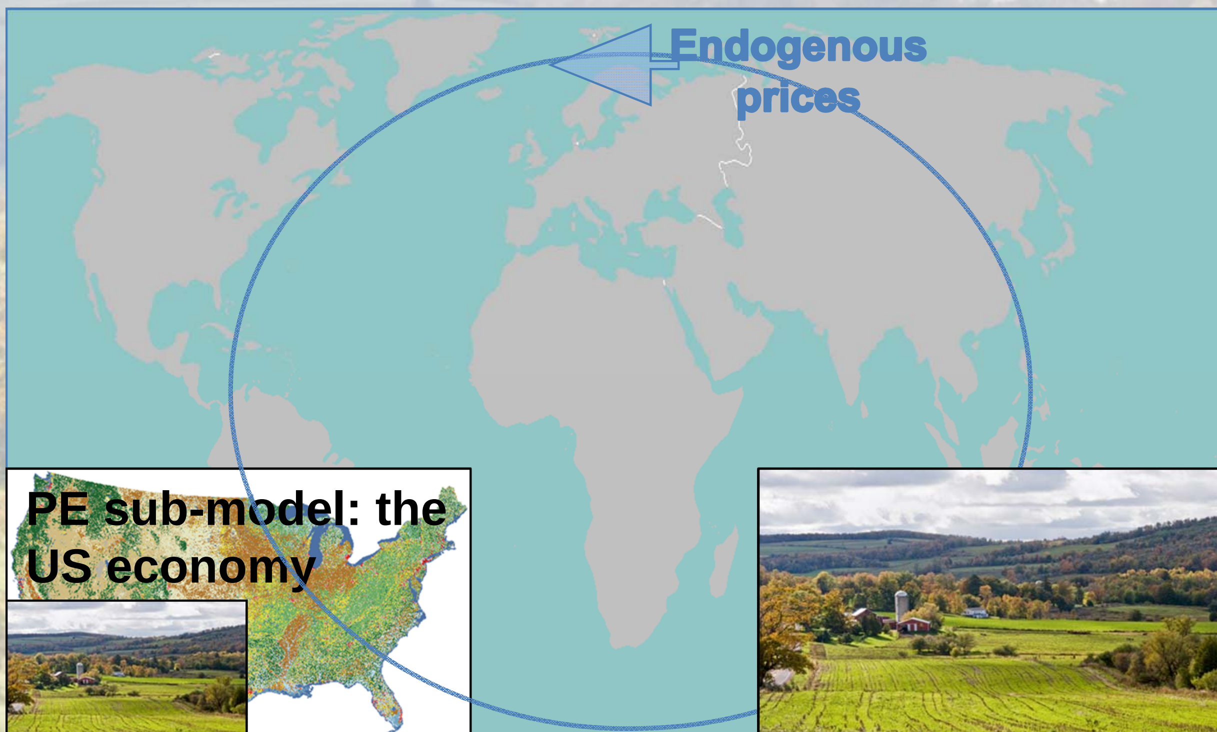
with

N. Best, I. Foster, and T. Munson.

Vision: the CIM-EARTH framework



Decomposing models and PE – GE hybrids



Global physical outputs:

— Volumes (production, consumption, trade, etc.)
— Expenditures
— Emissions
— etc.

The Partial Equilibrium Economic Land-use Model

- The foundation is a hybrid initialization product:
  - A consistent data set with crop type resolution.
- Improve/validate with local data (inventory, satellite, ground truth). Example: NLCD 30m, 2001 and 2005.
- Support a variety of allocation algorithms.
- Enable users to specify kernel fcns for algorithms to
  - Build new capicity into the model (forests, etc.)
  - Add regional expertise over limited extents.
  - Include new data at any scale or extent to improve allocation.
- Model climate impacts to crop yields at HR.
- Validate model output at many scales.

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The Partial Equilibrium Economic Land-use Model

- 2 optimizations per cell per year:
  - LC optimized given recent local prices and yields and land conversion costs.
  - Yield optimized on existing coverage given input costs, output prices, and yield potential.
- Few simplifications to facilitate ease of prototyping and development:
  - Farmers are ultra-local and myopic.
  - Linearized objective fcns.

Data sources for PEEL

- MODIS Annual Global Land Cover (MCD12Q1)
  - resolution: 15 seconds (~500m)
  - variables: primary cover (17 classes), confidence (%), secondary cover
  - time span: 2001-2008
- Harvested Area and Yields of 175 crops (Monfreda, Ramankutty, and Foley 2008)
  - resolution: 5 minutes (~9km)
  - variables: harvested area, yield, and scale of source
  - time span: 2000 (nominal)
- Global Irrigated Areas Map (GIAM) International Water Management Institute (IWMI)
  - resolution: 5 minutes (~9km)
  - variables: various crop system/practice classifications
  - time span: 1999 (nominal)

Data sources for PEEL

- NLCD 2001
  - resolution: 1 second (~30m)
  - variables: various classifications including 4 developed classes and separate pasture/crop cover classes.
  - time span: 2001
- World Database on Protected Areas (WDPA)
  - resolution: sampled from polygons; aggregated to 10km
  - variables: protected areas
  - time span: 2009
- FAO Gridded Livestock of the World (GLW)
  - resolution: 3 minutes (~5km)
  - variables: various livestock densities and production systems
  - time span: 2000 and 2005 (nominal)

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Previous and on-going related efforts.

- The PEEL model is informed by previous work on LC downscaling, and from a huge literature on local LULCC modeling:
    - **M. Heistermann, C. Muller, K. Ronneberger, Land in sight?: Achievements, deficits and potentials of continental to global scale land-use modeling, Agriculture, Ecosystems & Environment, Volume 114, Issues 2-4, June 2006.**
  - Downscaling models for land-cover change forecasts: KLUM@GTAP, LEITAP/LCM, LandShift, …
    - **K. Ronneberger, M. Berrittella, F.Bosello & R. S.J. Tol 2006. Working Papers FNU-105, Research unit Sustainability and Global Change, Hamburg University, revised May 2006.**
    - **B. Eickhout, H. van Meijl, A. Tabeau, & E. Stehfest 2008. GTAP Working Papers 2608, Center for Global Trade Analysis, Department of Agricultural Economics, Purdue University.**
  - Local LULCC modeling tools: CLUE, SLEUTH
    - Verburg, P.H. and Overmars, K.P., 2007. In: Modelling Land-Use Change. Progress and applications. The GeoJournal Library, Volume 90. Springer. Pp321-338.

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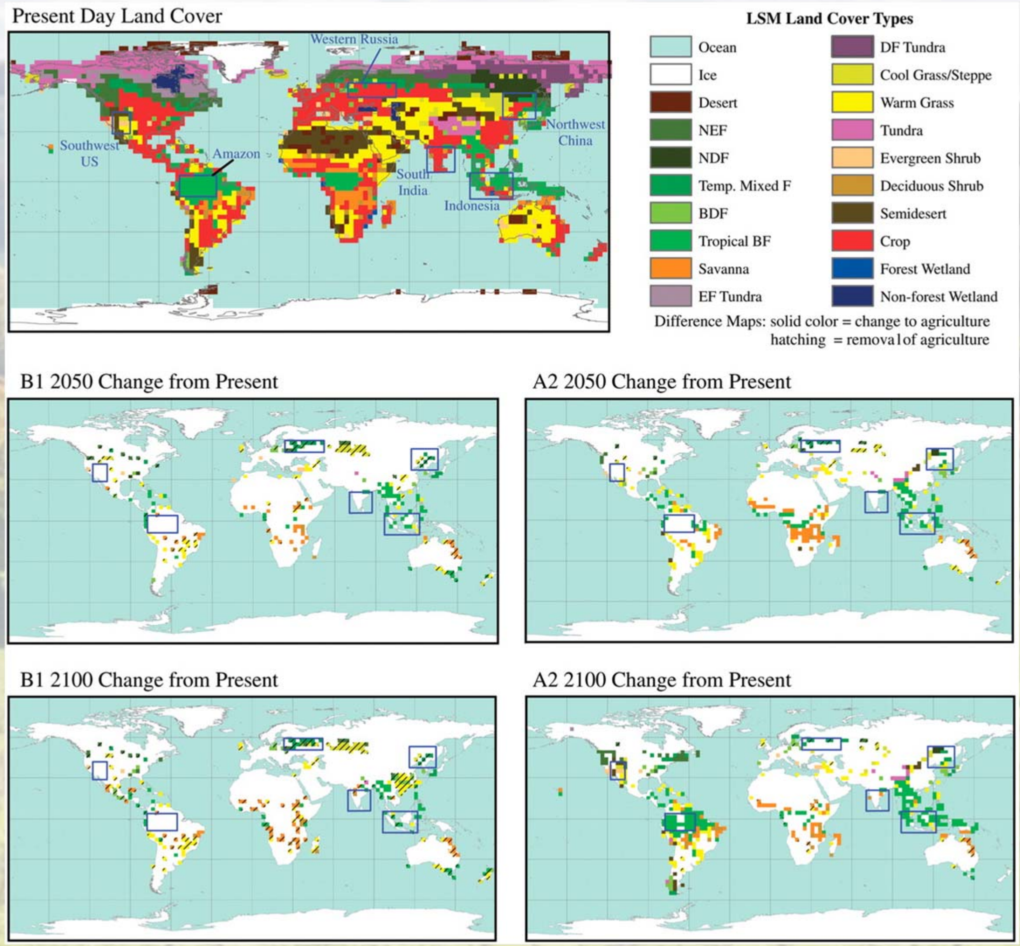
Can we better characterize the impact of LUC on climate?



Feddema et al. The Importance of Land-Cover Change in Simulating Future Climates , Science 9 December 2005

"From these results, we conclude that land cover change plays a significant role in anthropogenically forced climate change. Because these changes coincide with regions of the highest human population this climate impact could have a disproportionate impact on human systems."

– Feddema et al., A comparison of a GCM response to historical anthropogenic land cover change and model sensitivity to uncertainty in present-day land cover representations. Climate Dynamics (2005) 25: 581–609

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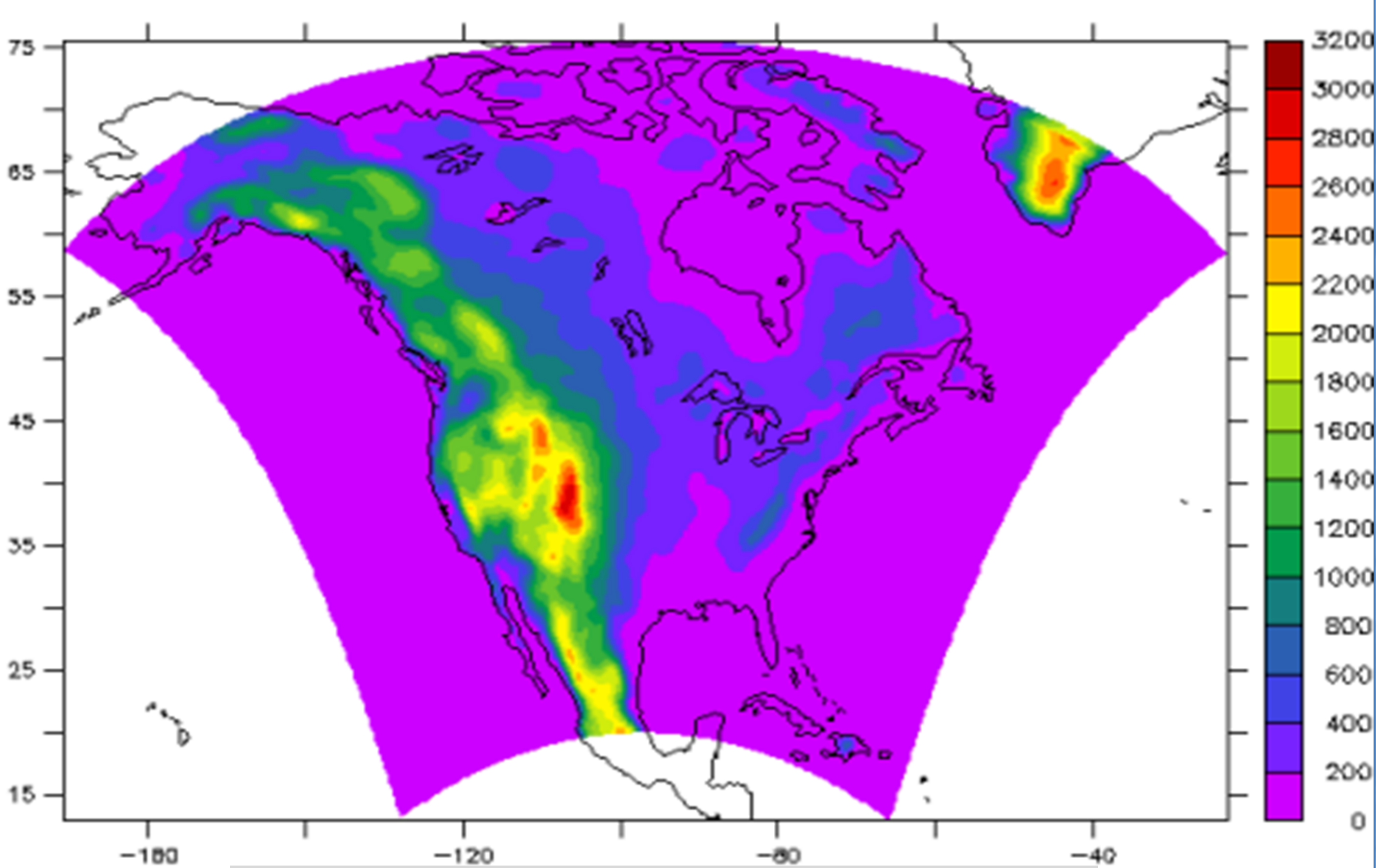

The NARCCAP experiment domain. http://www.narccap.ucar.edu/

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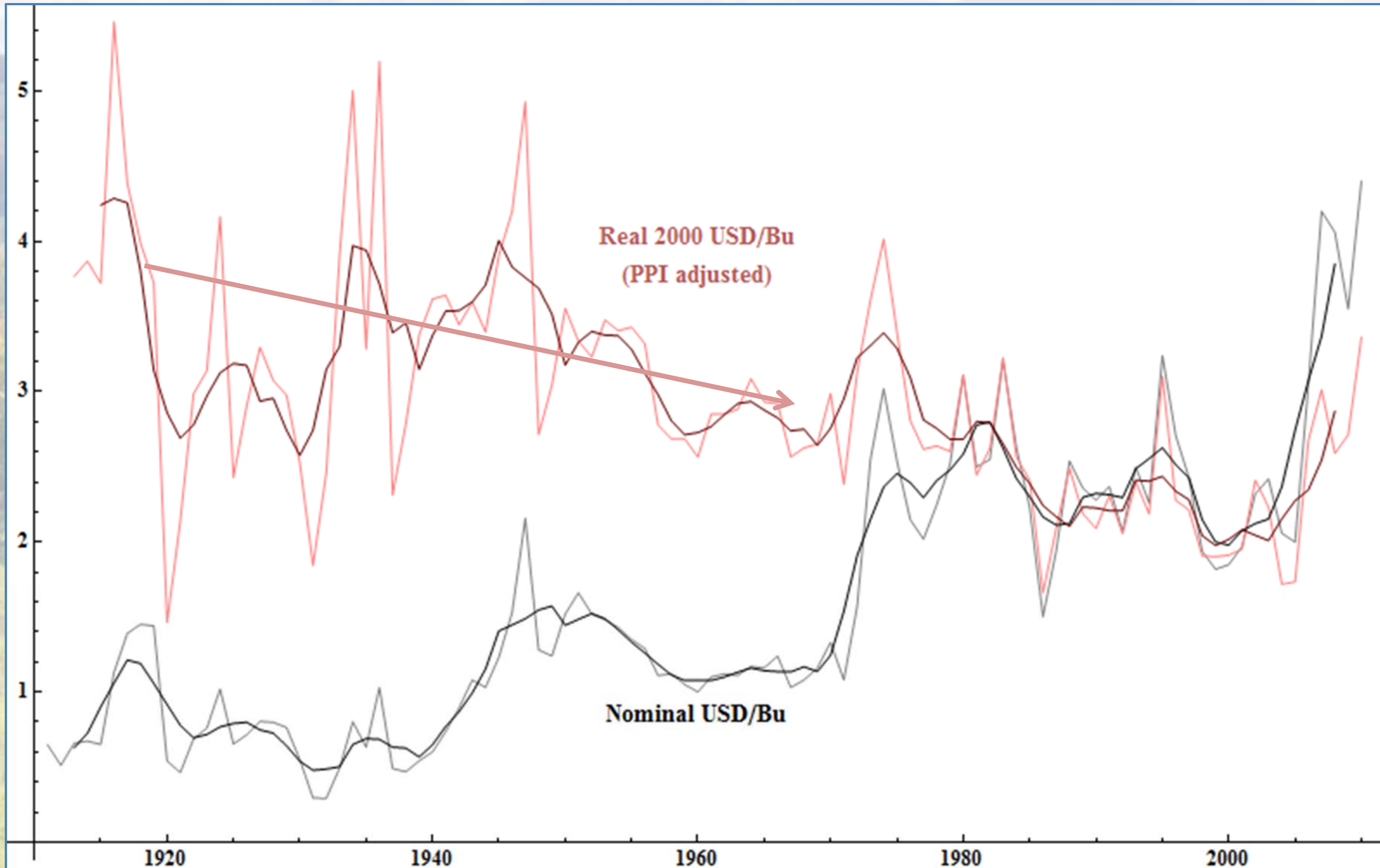
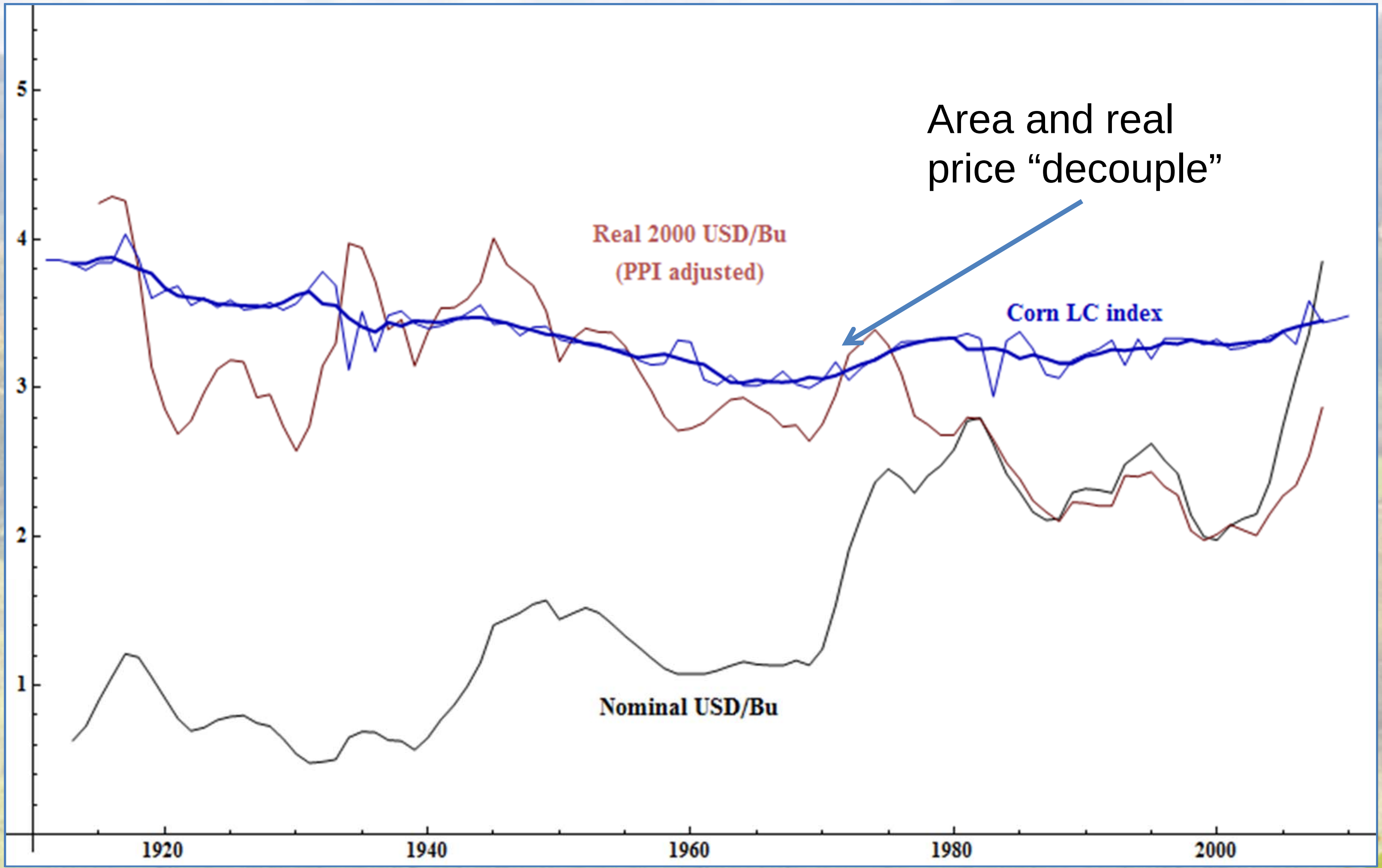
A look at historical land-use and land-cover change

- Does dynamic LULCC downscaling add value to a simulation beyond what could be achieved by interpolating global model predictions to a finer grid resolution?

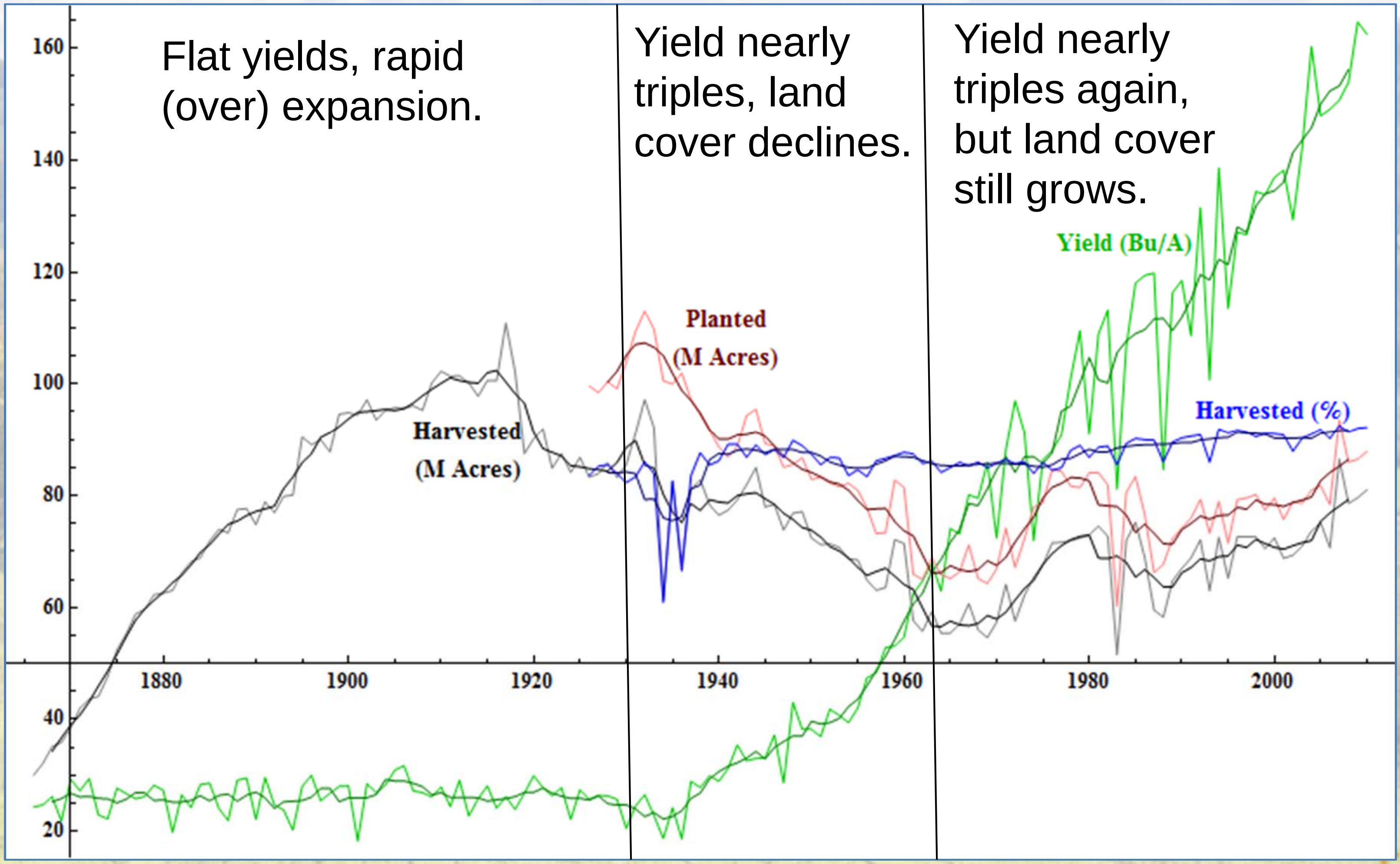
What drives land-cover?



Does corn price drive land conversion?



What does drive land conversion?



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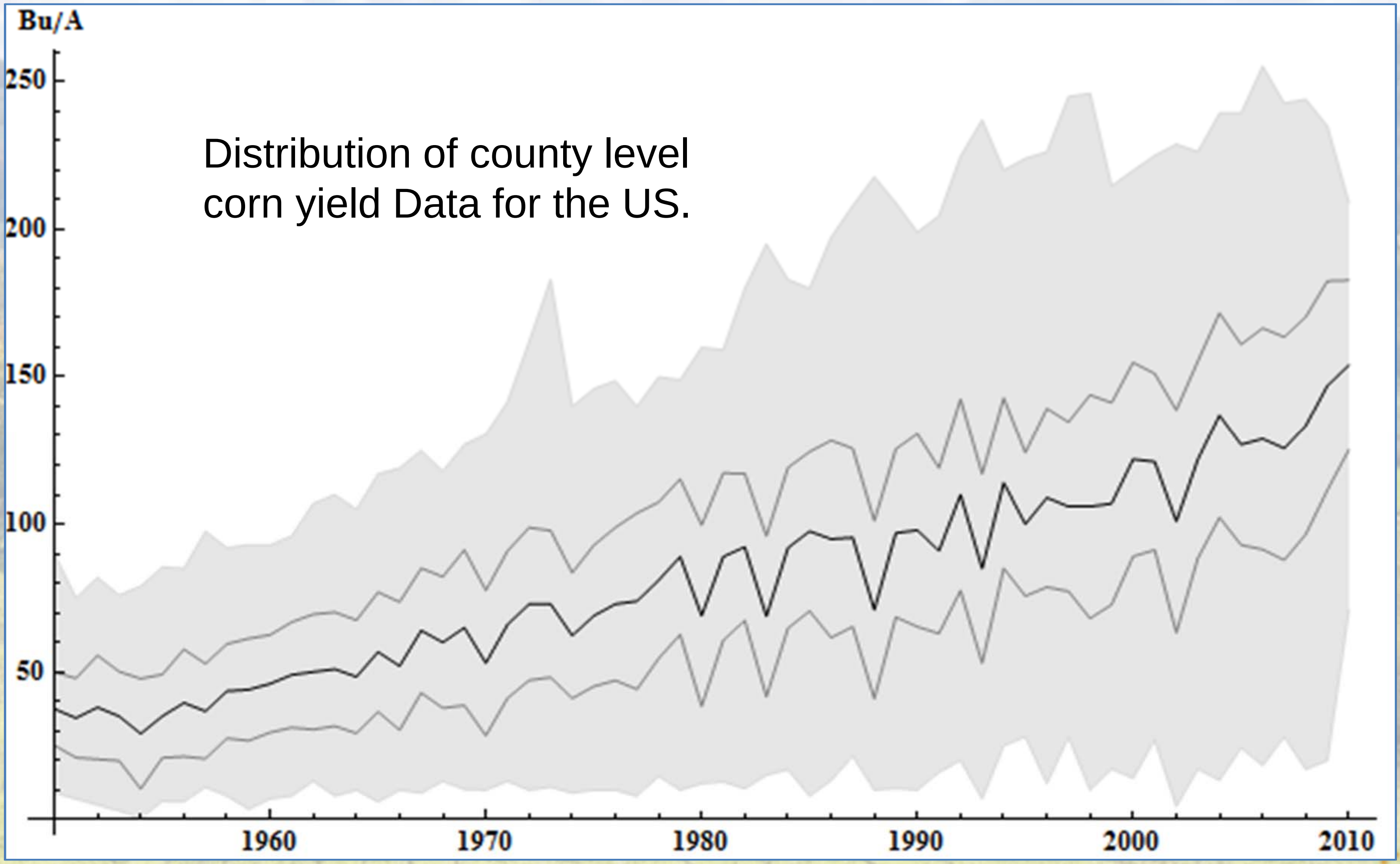
… but yield is a very complicated local affect of soil, weather, and management.



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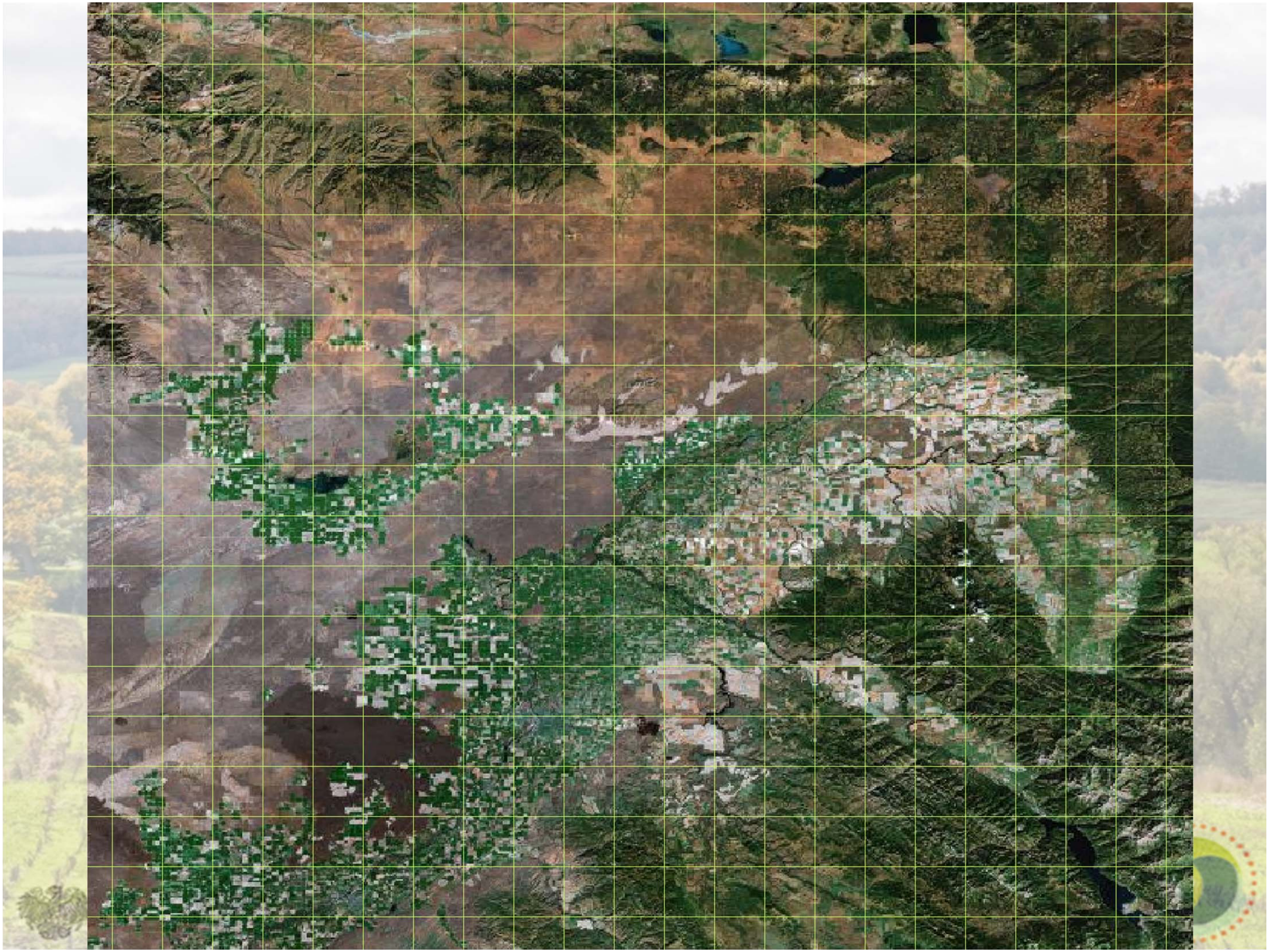
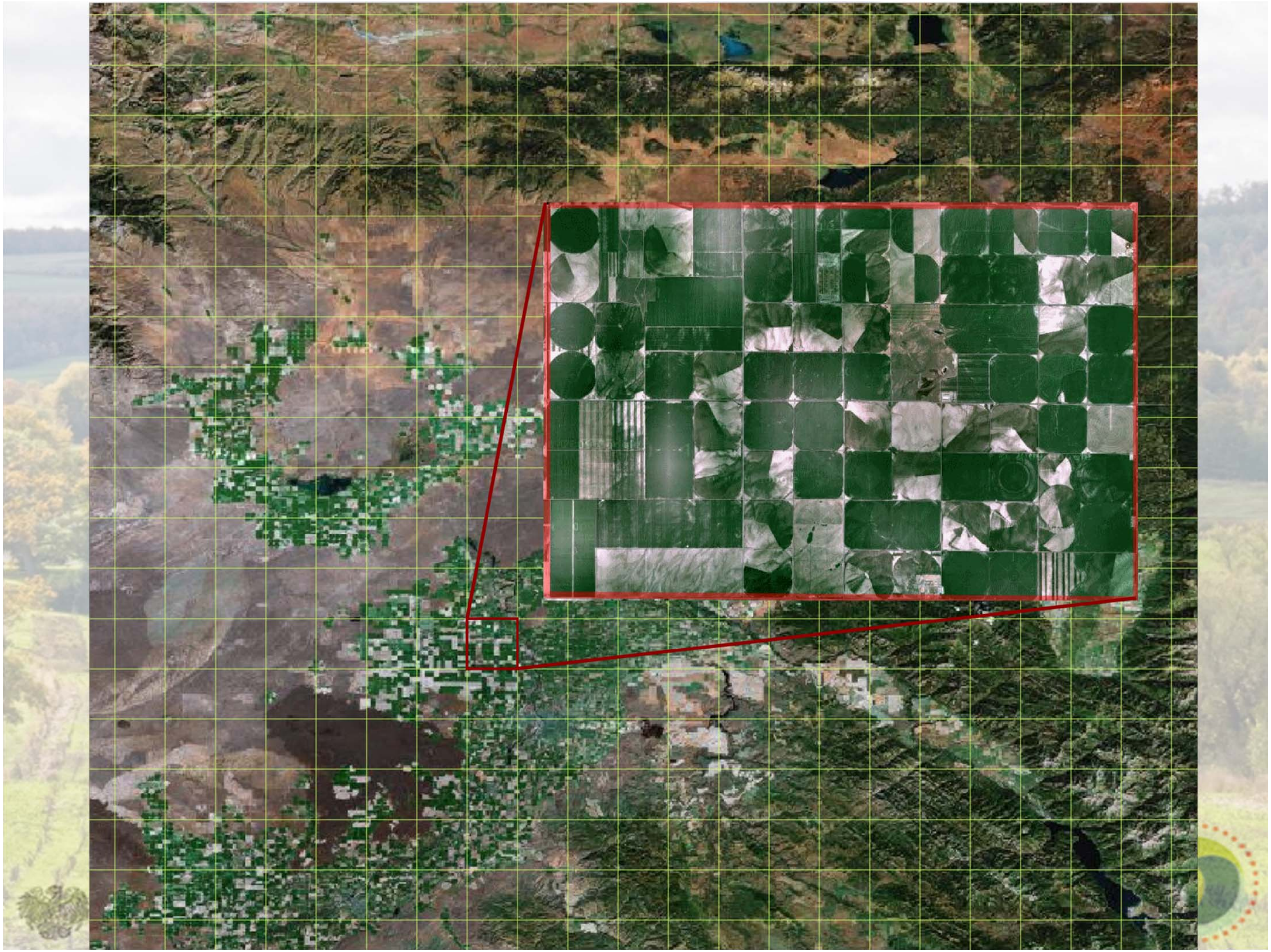
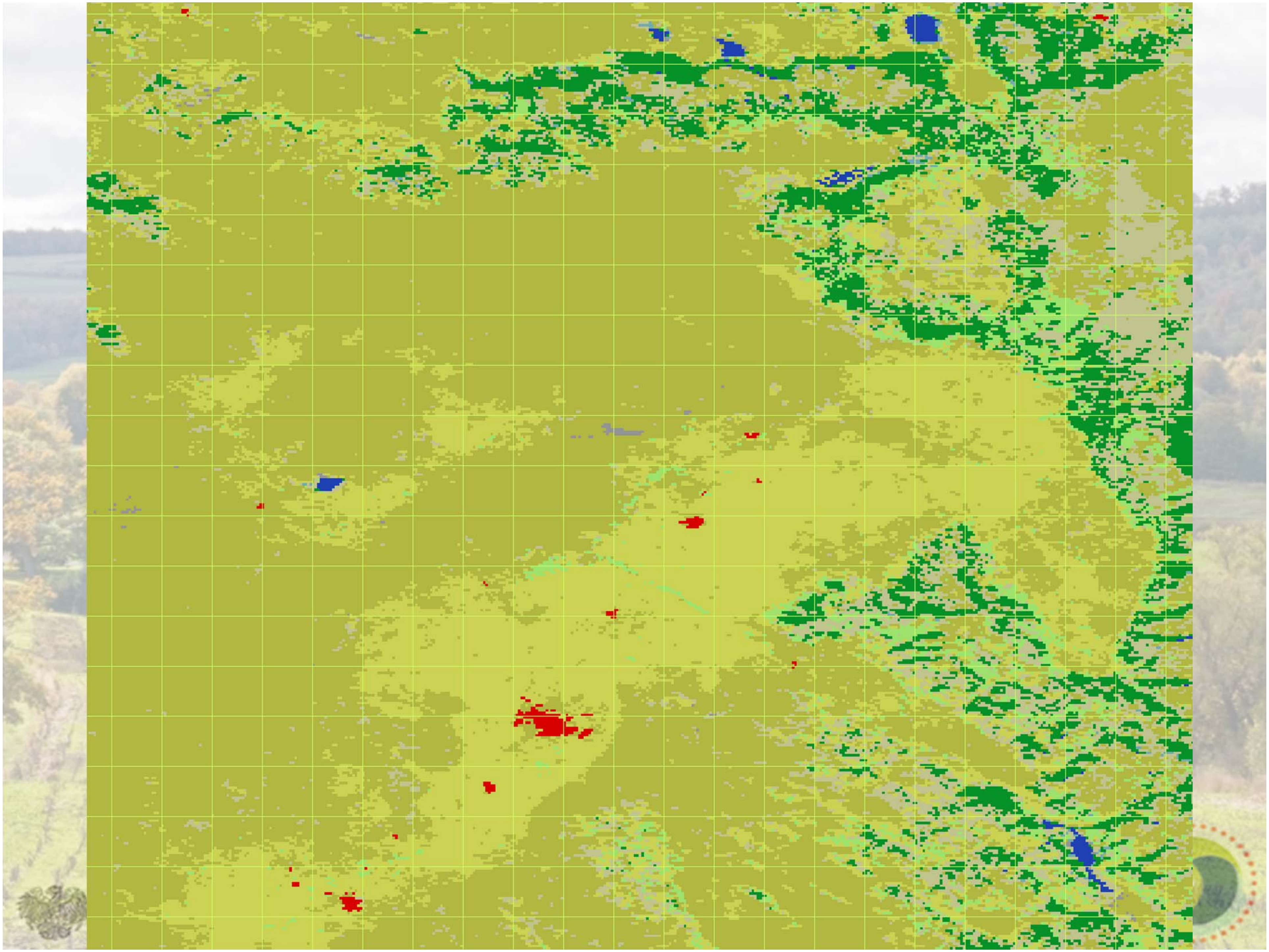
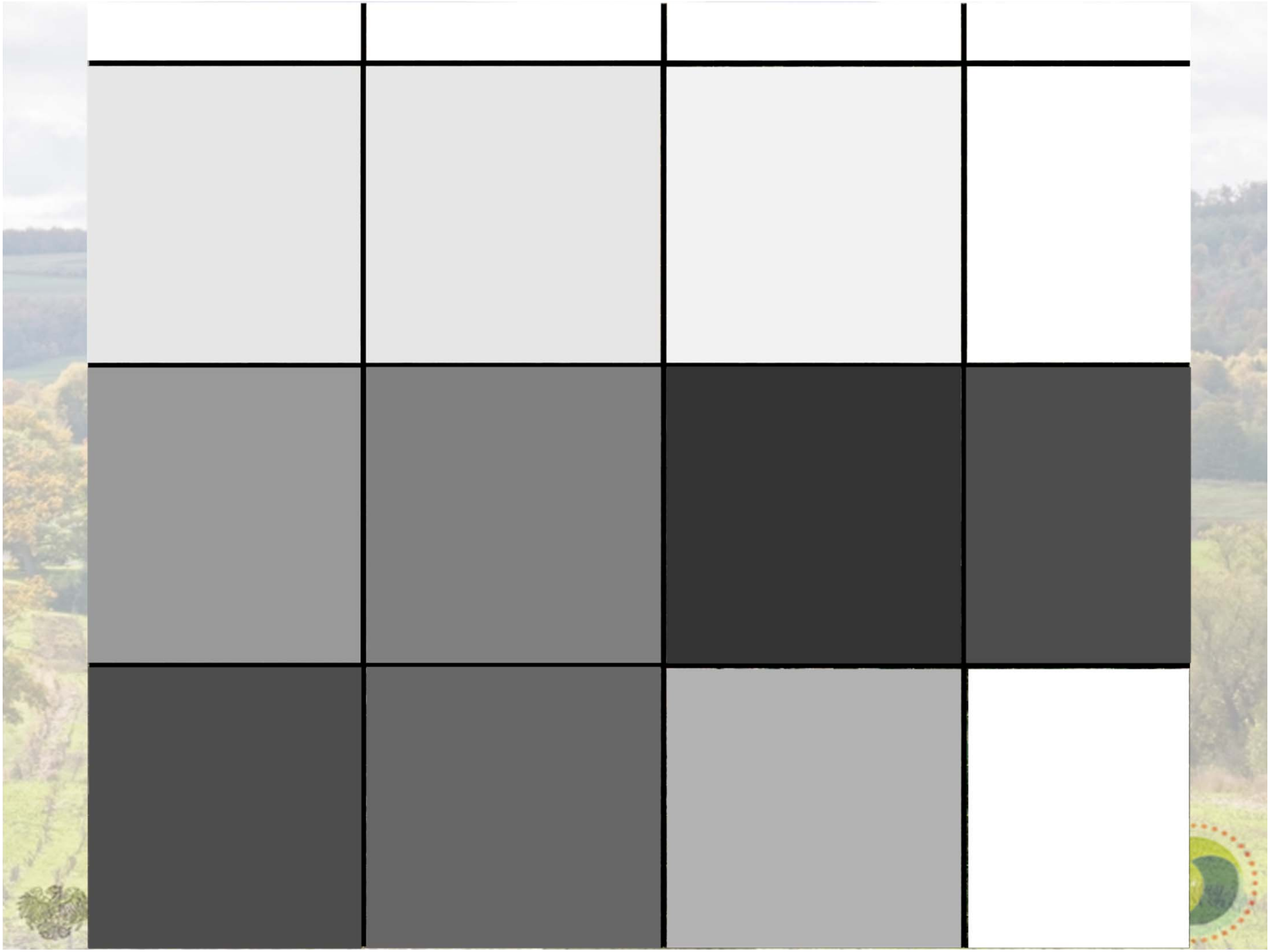


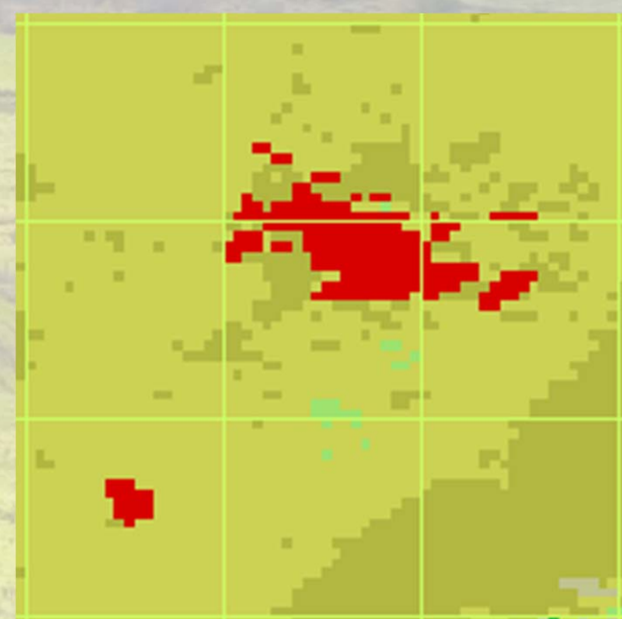






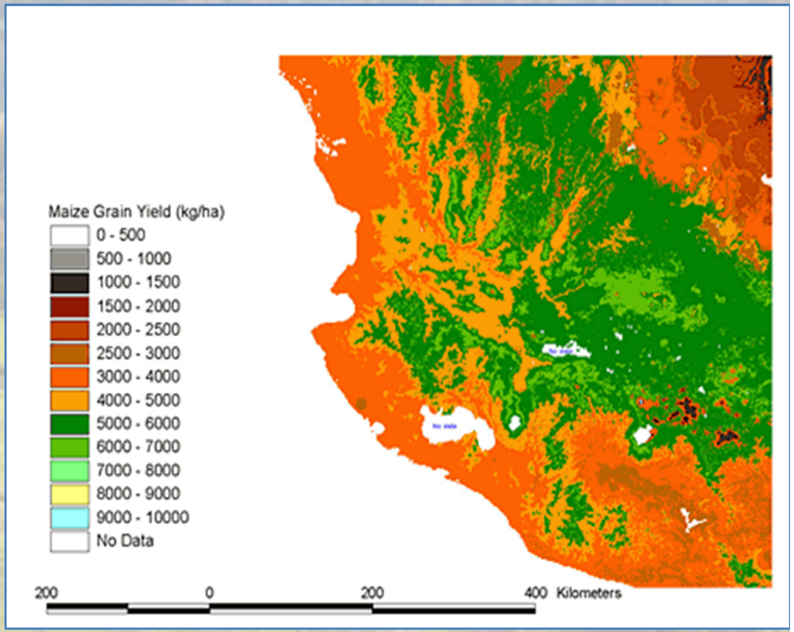
Which crops lose out first to development?

- In the 25 years between 1982 and 2007, ~23 M acres of US agricultural land were converted for development (about an acre/minute) – *2007 National Resources Inventory*.
- The most productive lands in the country are near developed areas (indeed, that's precisely why they were developed).
- Crops in near-urban areas:
  - 91% of US fruit, nuts and berries
  - 78% of vegetables and melons
- Further, this loss varies widely state-to-state, with the biggest percent losses in the East and NE (NJ, RI, MA, DE, and NH).



How about land-use change?

- AEZs use dozens of soil profiles and seasonal weather characteristics to characterize land suitability and potential within a region.
- PEEL will use 50,000 soil profiles and detailed weather from reanalysis products and simulations to characterize suitability and potential at grid and sub-grid scales.



CIM-EARTH Framework

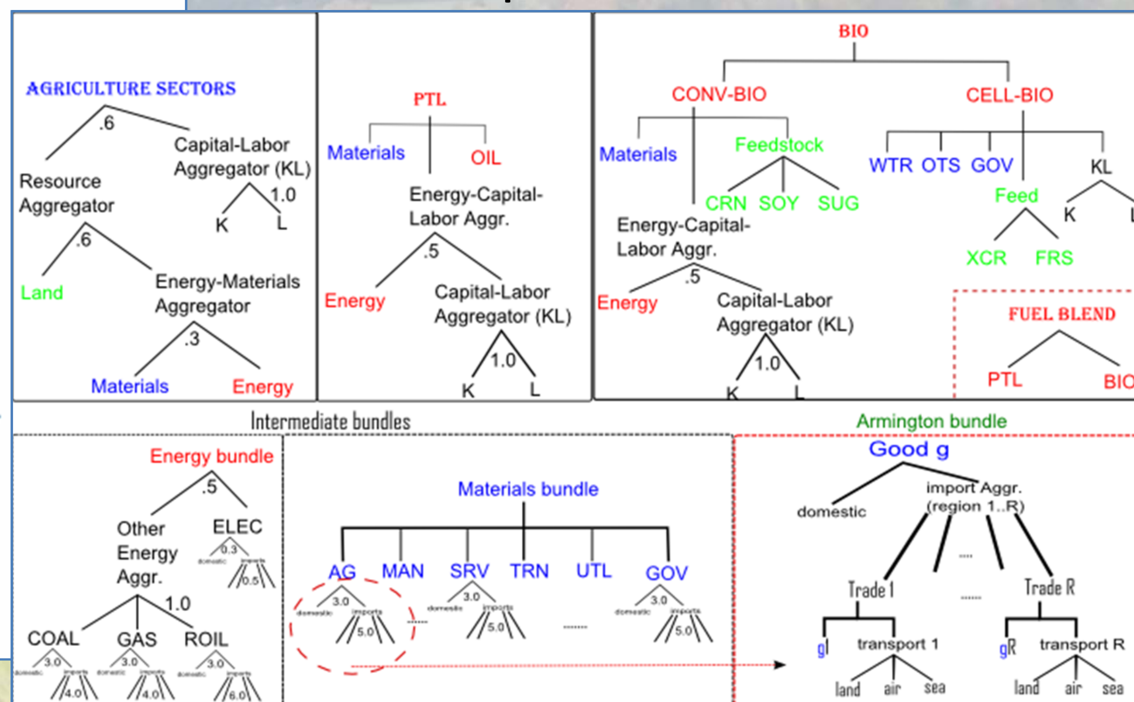
- Implementation
  - AMPL specification framework
  - Preprocessing, calibration, and generation of instances
  - Solution of instances using the PATH algorithm
- Current model
  - Myopic computable general equilibrium model
  - Nested constant elasticity of substitution
  - Support for homogenous commodities
  - Ad valorem and excise taxes, export and import duties and endogenous tax rates

Experimental design: details of the representation in CEbio

Regions	Sectors (per region)
Oceania	Corn, barley and rye
Southeast Asia	Soy, palm fruit and other oil crops
Japan and South Korea	Sugar cane and beet
China	Crops n.e.s.
South Asia	Live animals
Russia, Georgia & Asiastan	Forestry
Middle East & N. Africa	Processed foods
Sub-Saharan Africa	Biofuels
Western Europe	Coal
Rest of Europe	Oil
Brazil	Natural gas
Mexico	Manufacturing
Rest of Latin America	Refined petroleum
U.S.	Electricity
Canada	Distributed gas utility
	Water utility
	Land transport
	Air transport
	Sea transport
	Government services
	Other services

Prototype global model: 15 regions and 21 sectors

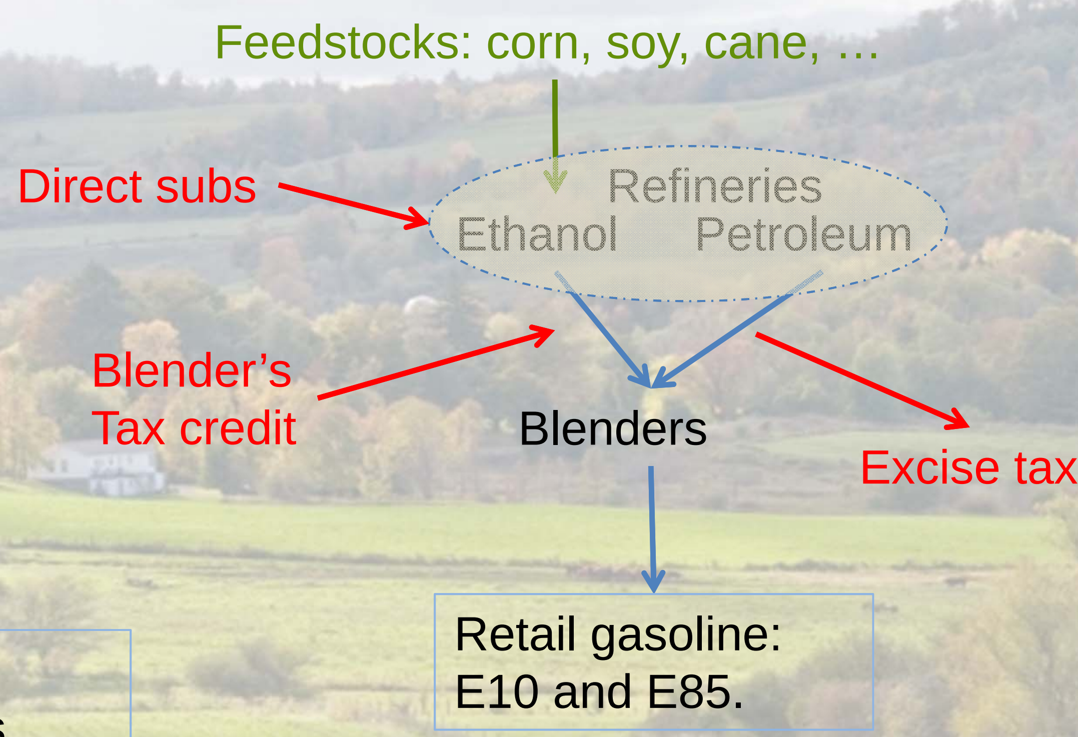
Nested production functions represent substitutions



Experimental design

- **CIM-EARTH-bio**

Biofuels policy scenario:
— blenders fuel credit
— direct subsidies
— production target



Technology scenarios:
— aggregate yield scenarios loosely representing different climate and technology futures.

An overview of the data used in the CIM-EARTH-bio model

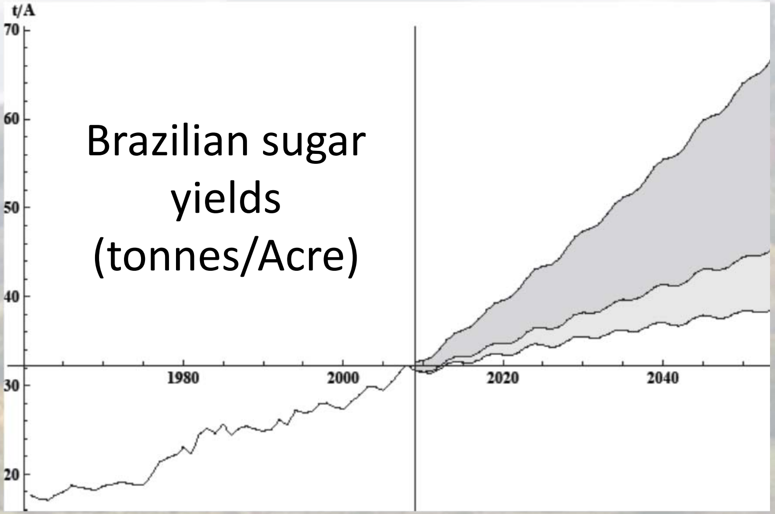
- GTAP v7 database
  - 2004 base year
  - Expenditure and revenue data
  - Energy volume data from GTAP-E
- Bio-fuel production costs and subsidies from literature
- Estimation of labor dynamics
  - 2008 UN population database
  - 2006 ILO economic activity rate database
  - 2008 US Bureau of Labor Statistics productivity database
- Estimation of land and natural resource dynamics
  - 2008 UN Food and Agriculture Organization database
  - 2007 World Energy Council survey of energy resources

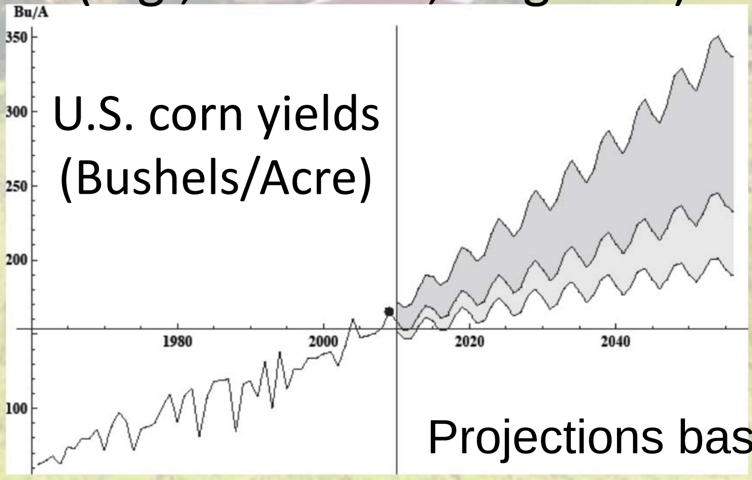
Many key elements of a biofuels economy depend strongly on detailed dynamics

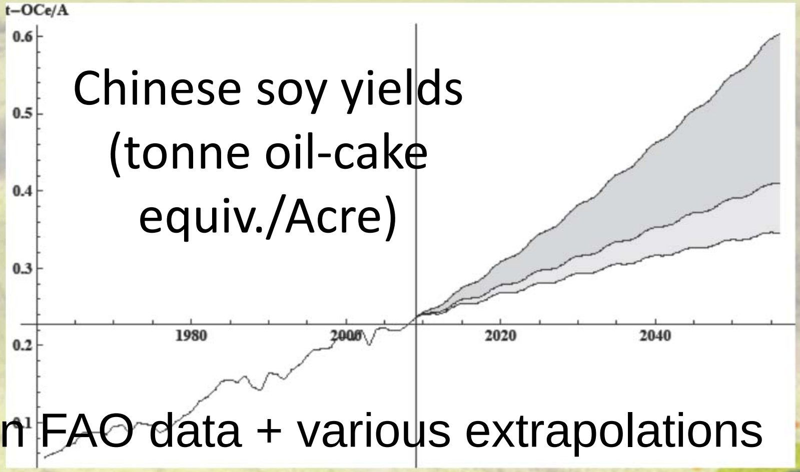
- Technology
  - Yield growth of conventional biofuels crops like corn and soy
  - Cellulose-to-ethanol conversion efficiencies
  - Development of new high-yield grasses or algae
- Land availability
- Fossil resource dynamics
  - Must get fossil resource prices, expectations and availability 'correct' to accurately forecast biofuels demand
  - Estimated Ultimately Recoverable (EUR) regional fossil resources are highly uncertain
- Global and regional policy changes
  - Governments are considering various options on biofuels and carbon policy for environmental, economic and security reasons.
  - What types of forecasts are robust to uncertain political landscapes?

Dynamic uncertainties: will linear yield increases continue or accelerate?

- Crop yields are key parameters
  - Hybrid/bio-tech crop-type development and distribution
  - Improved farming practices and adoption rates
  - Resource availability (e.g., fertilizers, irrigation)







Projections based on FAO data + various extrapolations

Dynamic uncertainties: how will biofuels and climate policies evolve?

- The U.S. uses several mechanisms to encourage biofuels
  - Ethanol mandates and production targets (portfolio standards)
  - Direct farm and bio-fuel subsidies
  - Gasoline excise tax exemption
- How will policies evolve in the future to meet targets?
  - Assume EISA 2007 is the final word in the U.S.?
  - 15 billion gallons of corn ethanol by 2022 (with ~0.5 $/g subsidy)
  - 21 B gallons of advanced ethanol by 2022(with ~1.0 $/g subsidy)
- How will biofuels be treated under carbon policies?
  - Biofuels are largely exempted from carbon policy in EU
  - Is it feasible to encourage sustainable land use practices through carbon policy?

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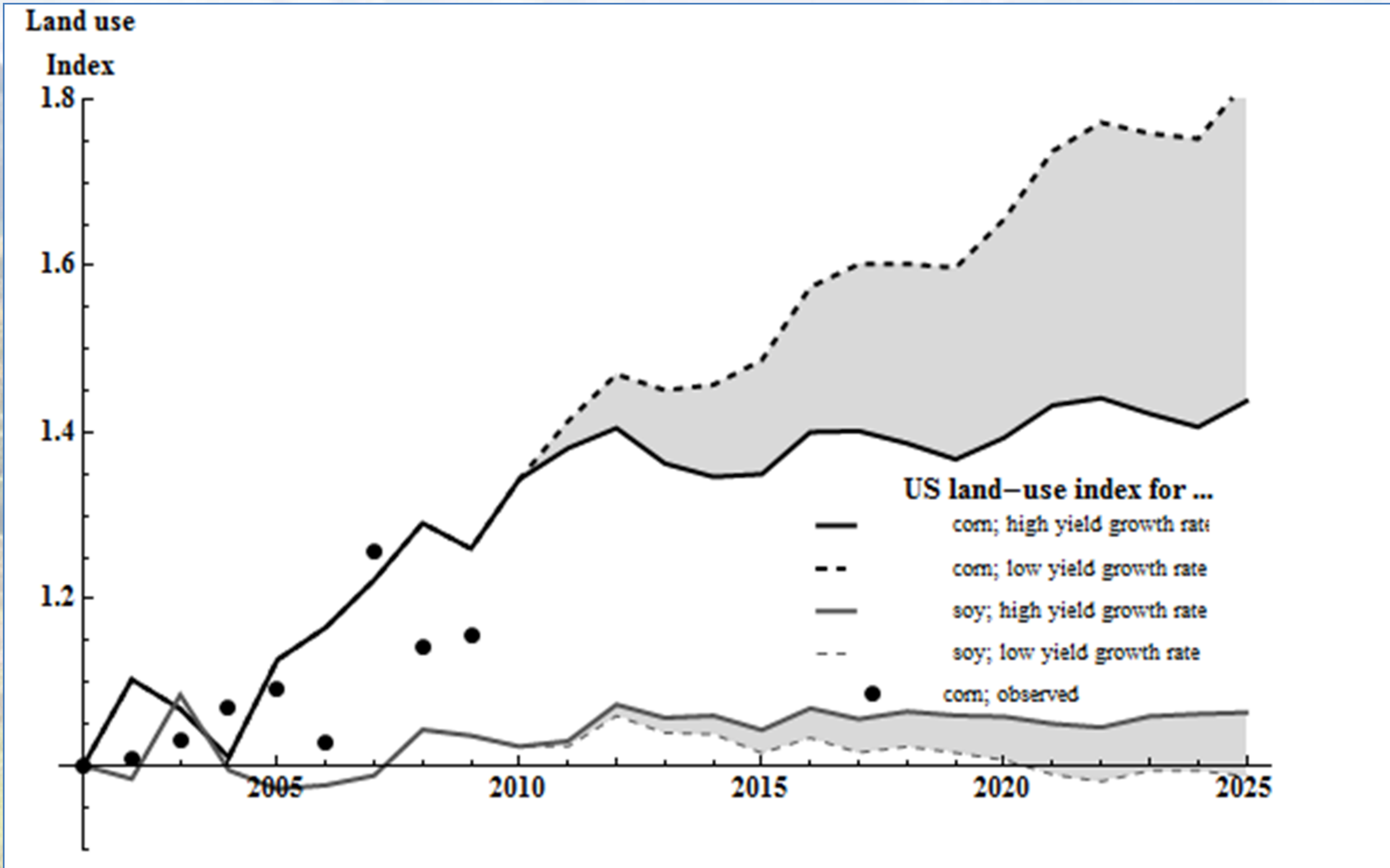
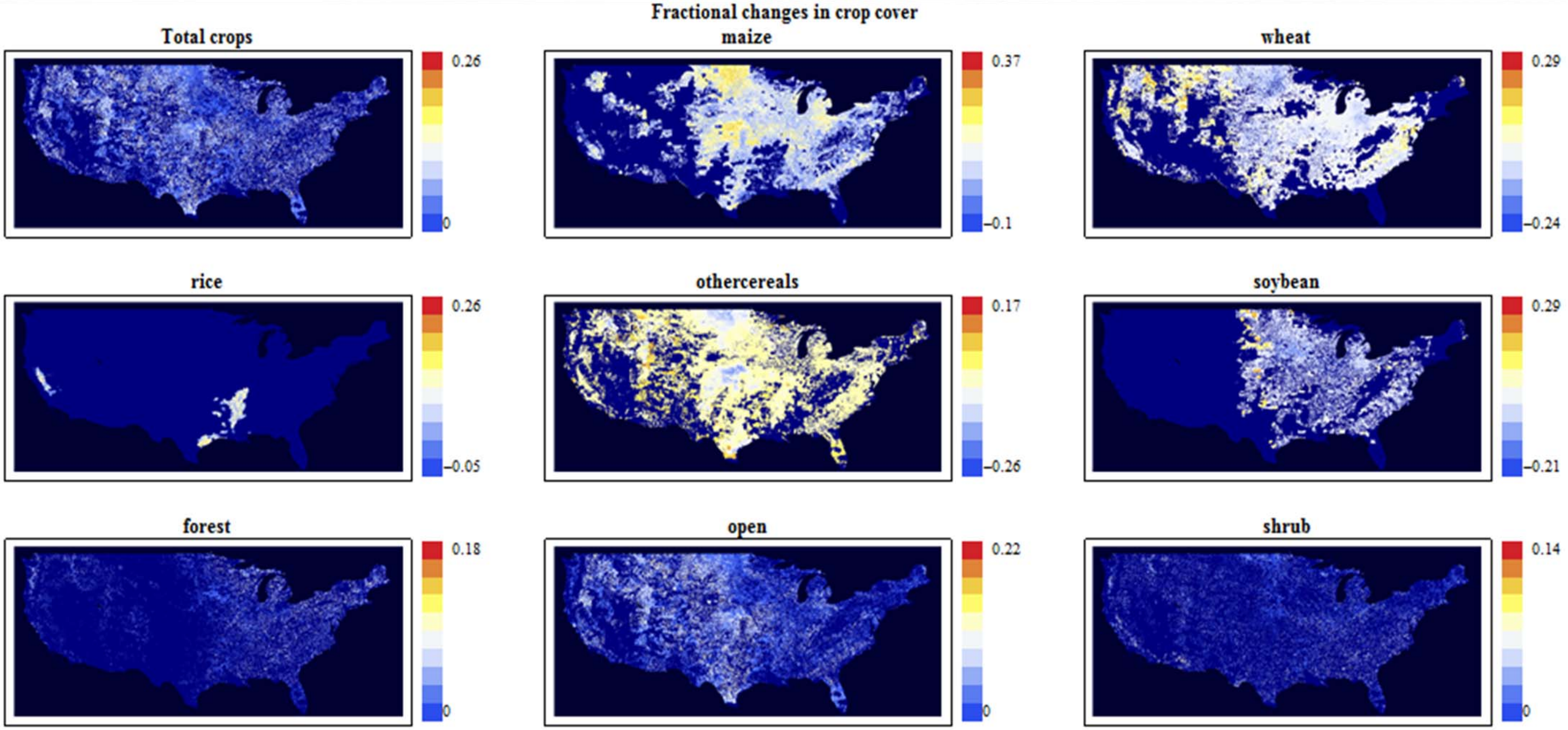
Output: CEbio



Preliminary land use change results from large scale biofuel demand

Difference between 2010 and 2000 cell coverage fractions.



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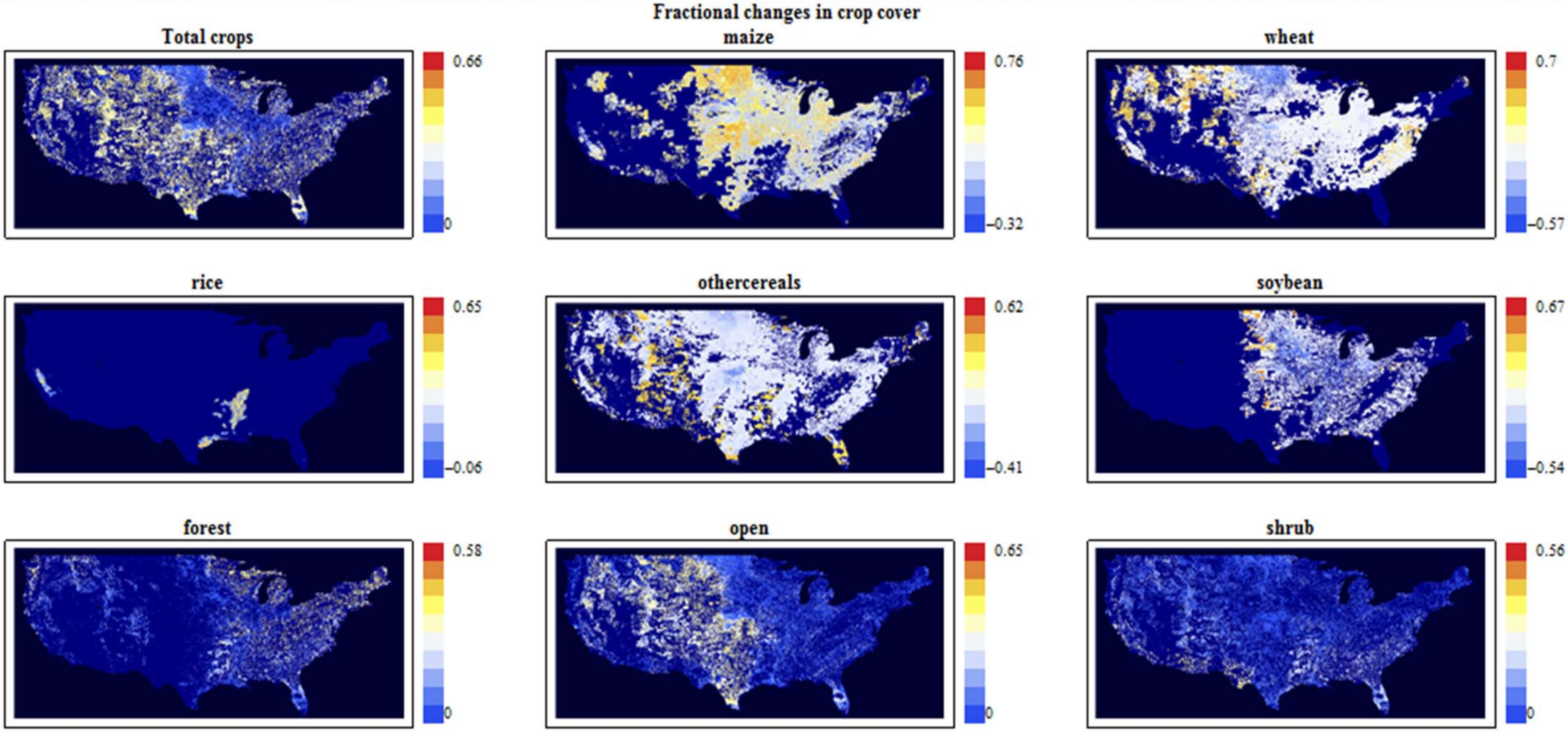

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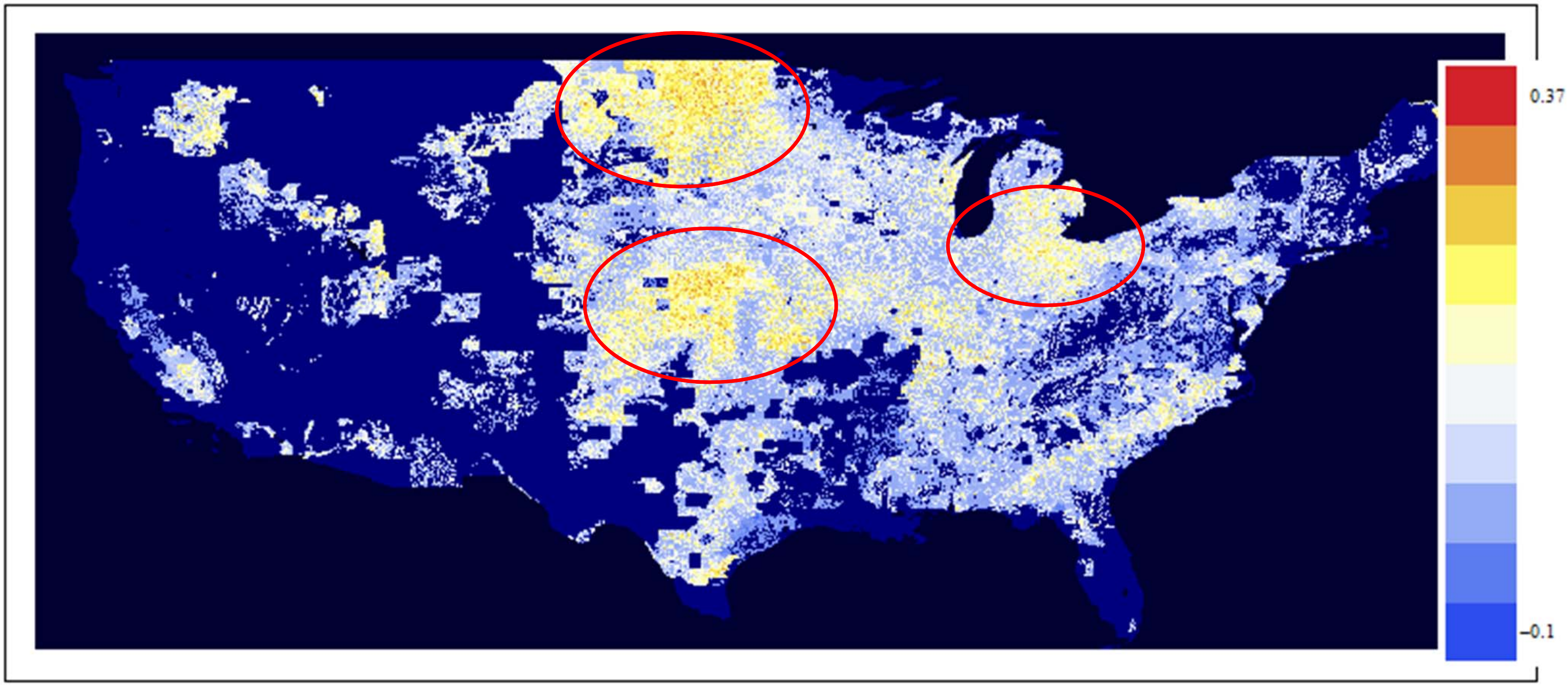

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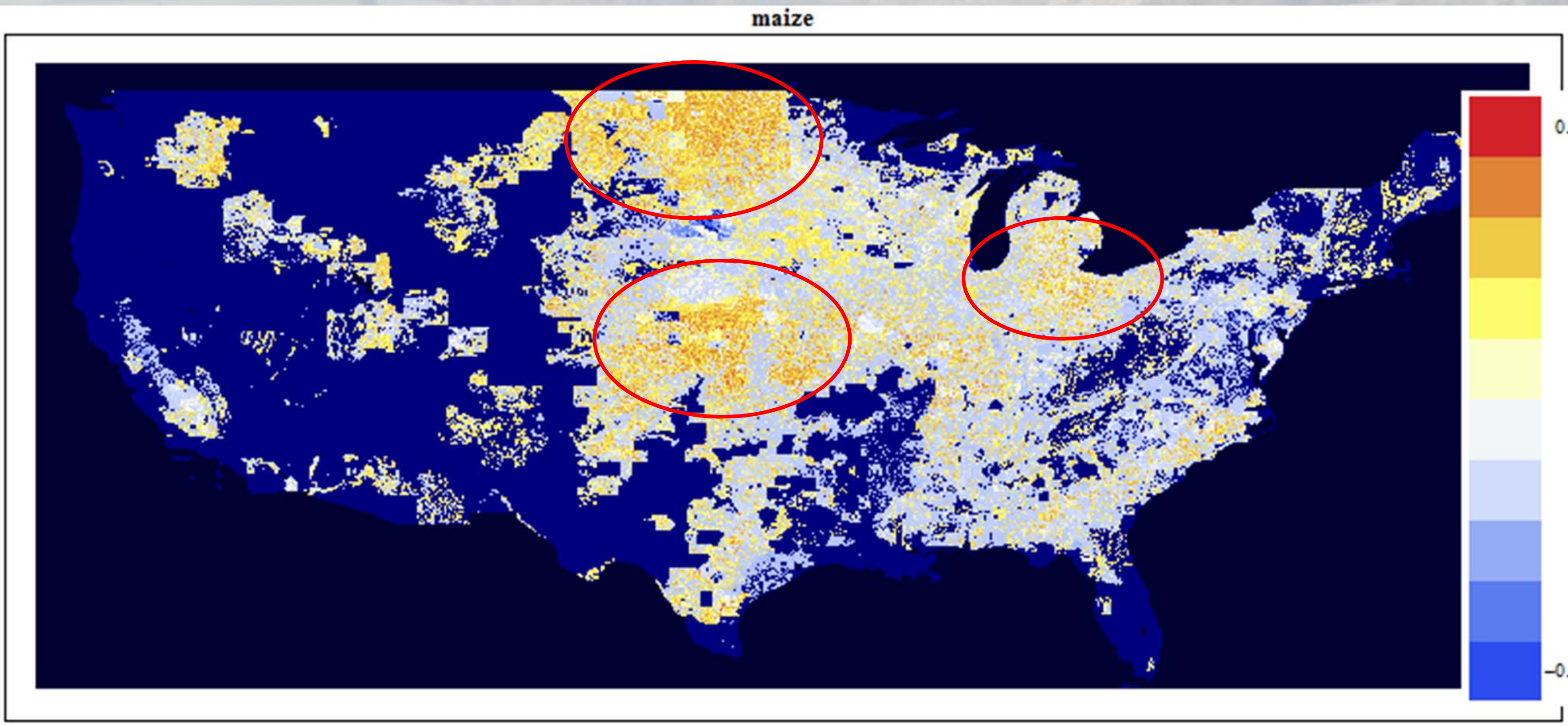

Conclusions

- Significant uncertainties in biofuel studies
- Need large scale and high-fidelity models with efficient numerics and powerful computation.
- Can get high-resolution land use change estimates without expensive computing using dynamic downscaling
- Openness is essential for transparency
  - Several instances are available at www.cim-earth.org
  - Generators and preprocessing code available soon
  - Documentation being written as code is developed
  - Framework is extensible and modifiable by others
  - Many studies planned or in progress
- Much more work to do!

Potential next steps to improve CIM-EARTH-bio capabilities

- Enhance core modeling capabilities, e.g.:
  - Forward looking dynamics
  - Endogenous technological change and technology transitions
  - Vintages
  - Mechanisms for detailed policy representations
- Biofuels details and applications
  - Integrate support for agricultural ecological zones (AEZs); use to refine land use change projections
  - Integrate additional technology detail for biofuels production
  - Extensive sensitivity studies: technological change, policies, climate change, population growth, etc.


The end.
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Anticipated future directions

Study improvements

- Improve region, sector details
- AEZ GE model of land endow
- Revenue recycling policies
- Endogenous computation of carbon amounts
- Account for land, labor, and capital carbon

Additional types of models

- Fully-dynamic CGE
- Dynamic-stochastic CGE

Framework improvements

- Research and development
- Capital and product vintages
- Overlapping consumer generations
- Many more….

PEEL model

- Nonlinear objectives
- Planning agents
- Forestry
- Yield emulator/climate impacts
- Urban sprawl model
- ……….

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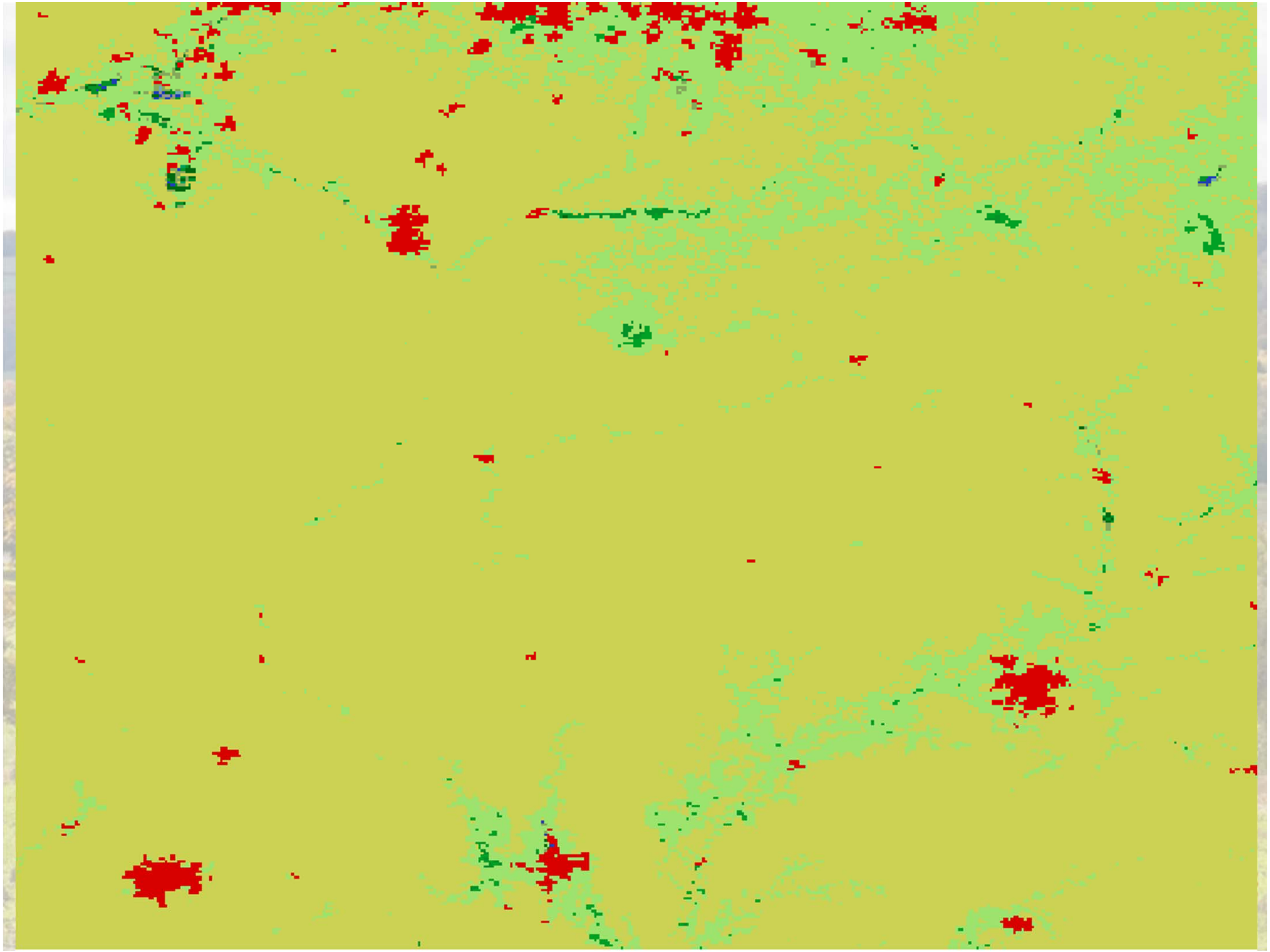
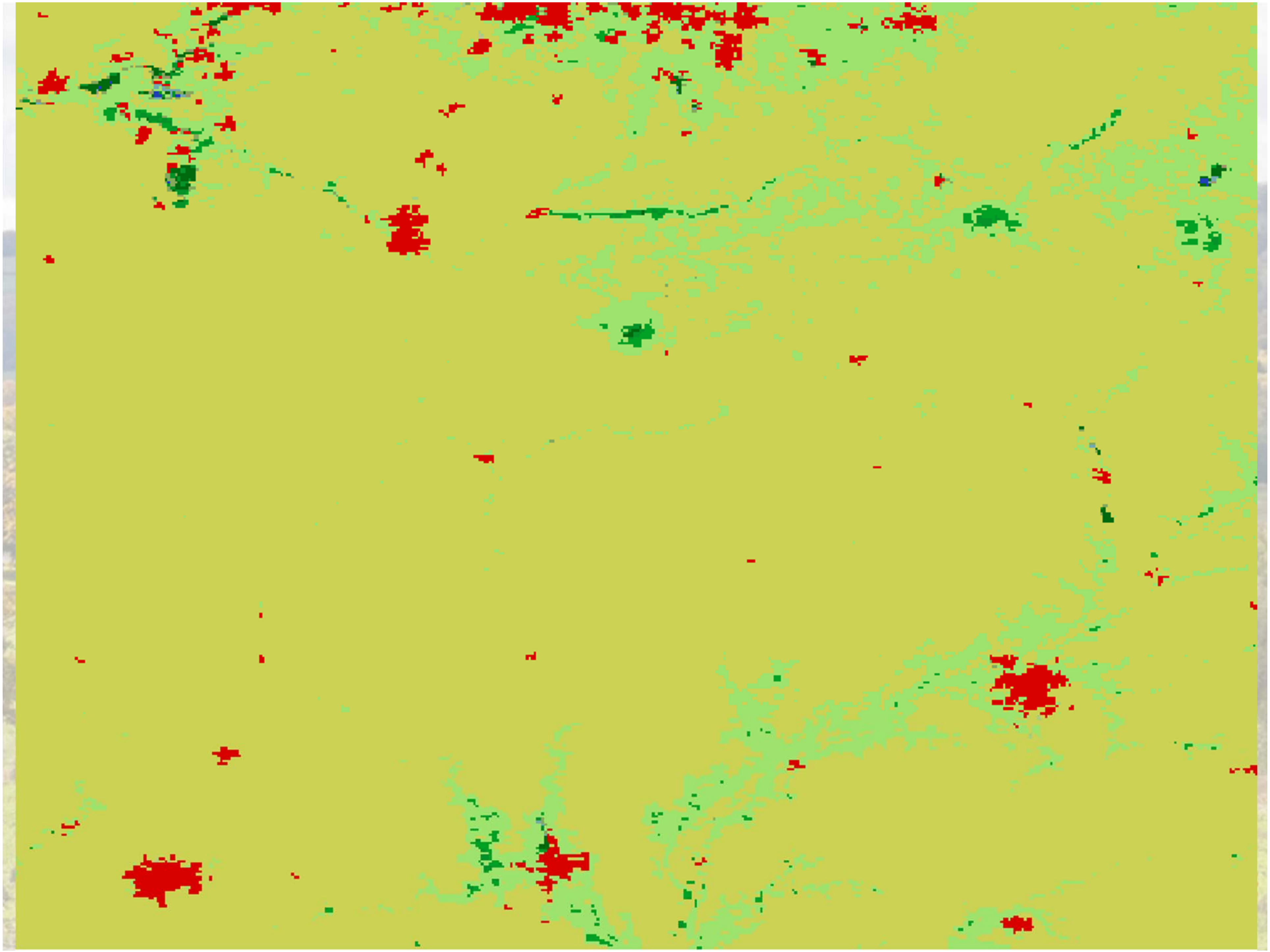
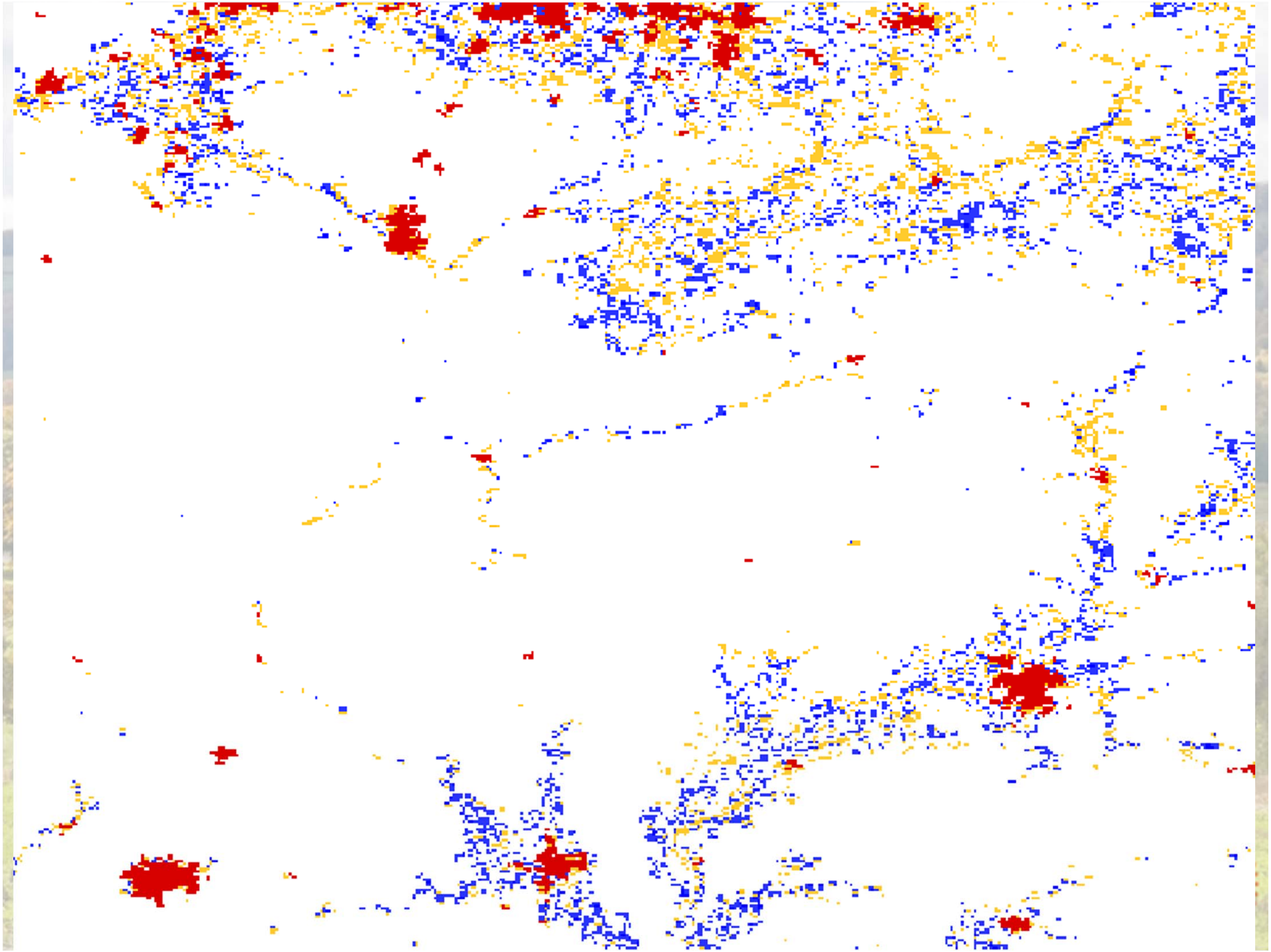
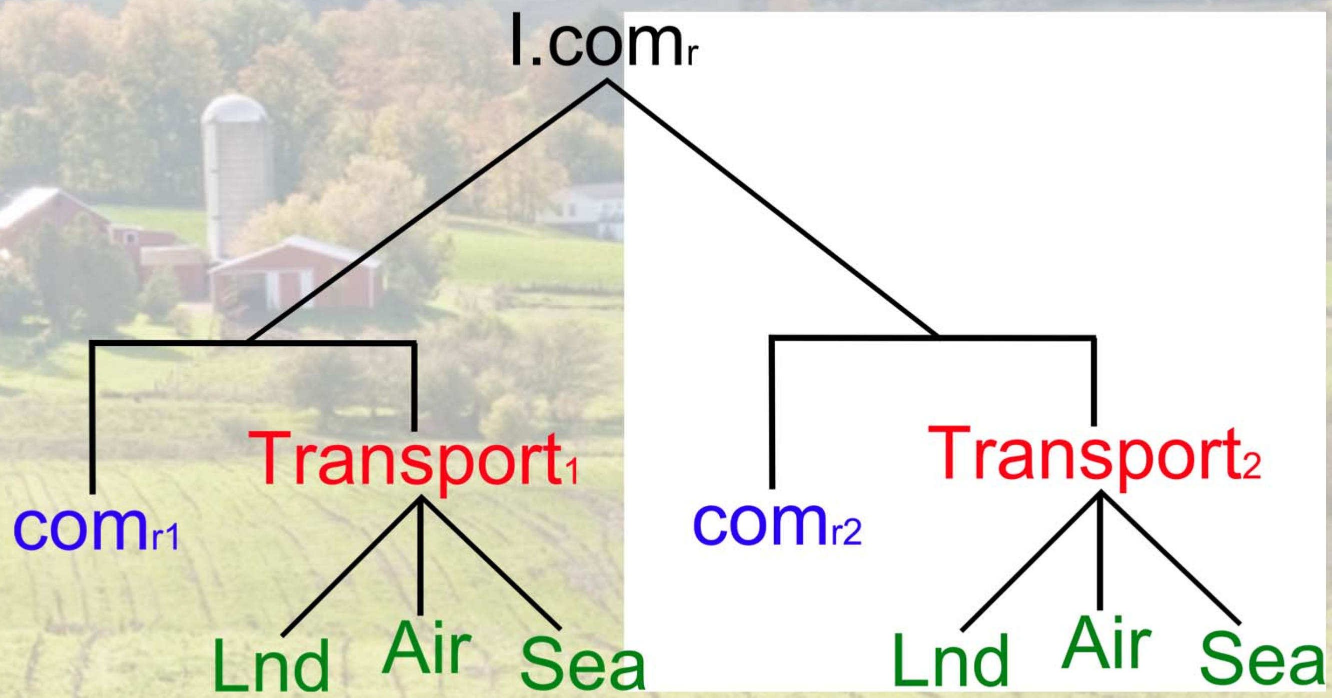




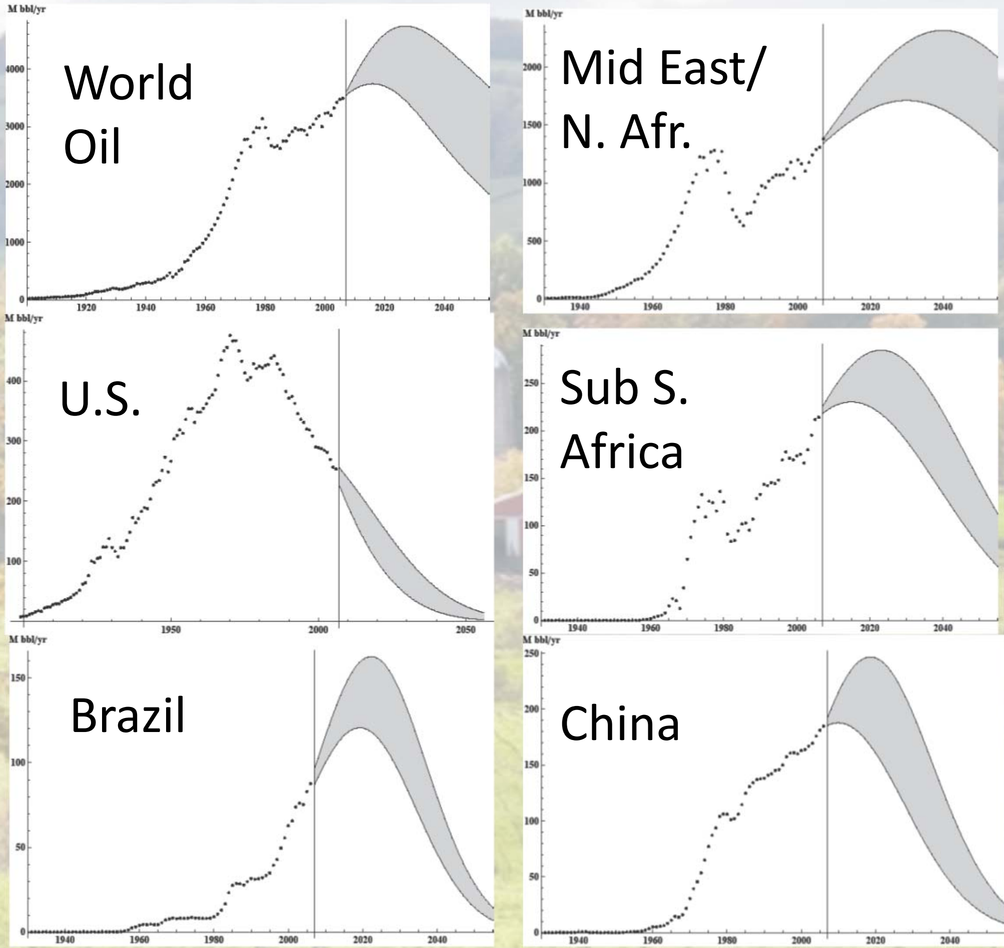


Importers and Transportation

- Three types of transport
- Each is a homogenous good
- Leontief nest for transport



Dynamic uncertainties: how much fossil energy is left in reserve?



- General consensus is that oil production peaks in the next 10-20 years
- Major uncertainty in the quantity of ultimately recoverable reserves
- We forecast regional depletion curves $E_r(t)$ with

$$\int_{2010}^{\infty} E_r(t)dt = R_r$$

- Vary reserve estimate to explore uncertainty

More future Directions

- Study improvements
  - Improve region and sector details
  - Incorporate revenue recycling policies
  - Endogenous tax rates that differ by region
  - Endogenous computation of carbon amounts
  - Account for land, labor, and capital carbon
  - Imperfect border tax adjustments
  - Distributional consumer impacts
- Framework improvements
  - Public and private learning
  - Research and development
  - Capital and product vintages
  - Overlapping consumer generations
  - Household production functions
  - Nonseparable utility functions
  - Heterogeneous beliefs

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