Using Economic Models to Simulate Land-Use Change for Biofuels

Issues for Discussion

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Workshop on LUC and GTAP

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U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY

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Summary – Issues for discussion

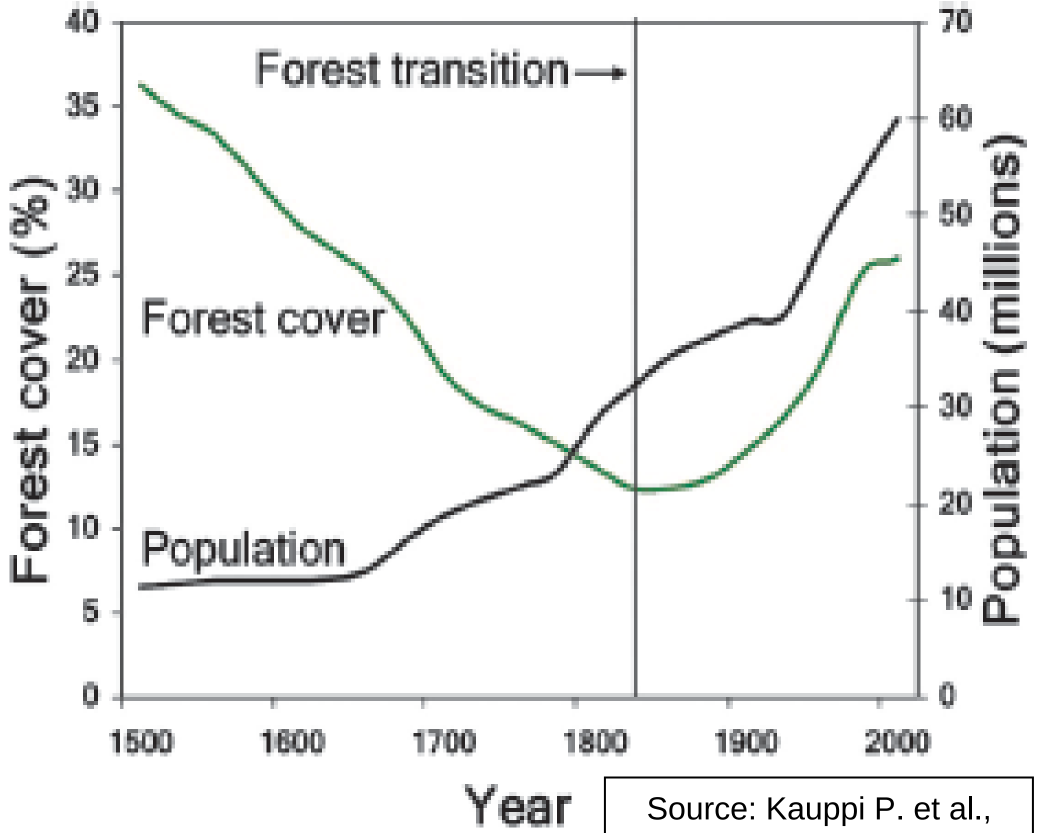
- **Land-Use Change (LUC) – many different types and issues**
- **Are underlying assumptions for LUC applicable to agricultural frontiers (areas of greatest environmental concern)?**
- **Baseline data for land cover and LUC**
  - **Significant uncertainty, inconsistency**
  - **Does it matter? How could it affect results?**
- **Calibration and validation for LUC in economic modeling**
- **Yields, rents, representation of land-use decisions**
- **Sensitivity analysis versus many larger uncertainties**
- **Representation of results**

Different types of LUC

- **LUC model looks at three categories: Cropland - Grassland/Pasture - Forests**
  - **Can it differentiate land cover and land use?**
  - **Simulations estimate changes between classes and within cropland class**
    - **At what point do transitions occur? When does abandoned cropland become grassland/pasture or forest?**
  - **Many data limitations**
- **Priority: "high conservation value" areas, especially first time conversion of natural ecosystems**
  - **Can we improve understanding of the drivers for "first time" conversion LUC?**
  - **What is biofuel impact in these areas?**
  - **Is there any causal relationship?**

First-time LUC follows predictable patterns

- **Classic 'Mather' curve (forest cover). Important to consider: What determines the "bottom"?**
- **Analysis of land-cover change always scale dependent (temporal and spatial)**
  - **Lack of evidence that biofuels are significant cause of indirect LUC in first time conversion - 'agriculture frontiers'**
  - **Much evidence for alternate hypotheses for LUC in first time conversion and 'agriculture frontiers'**



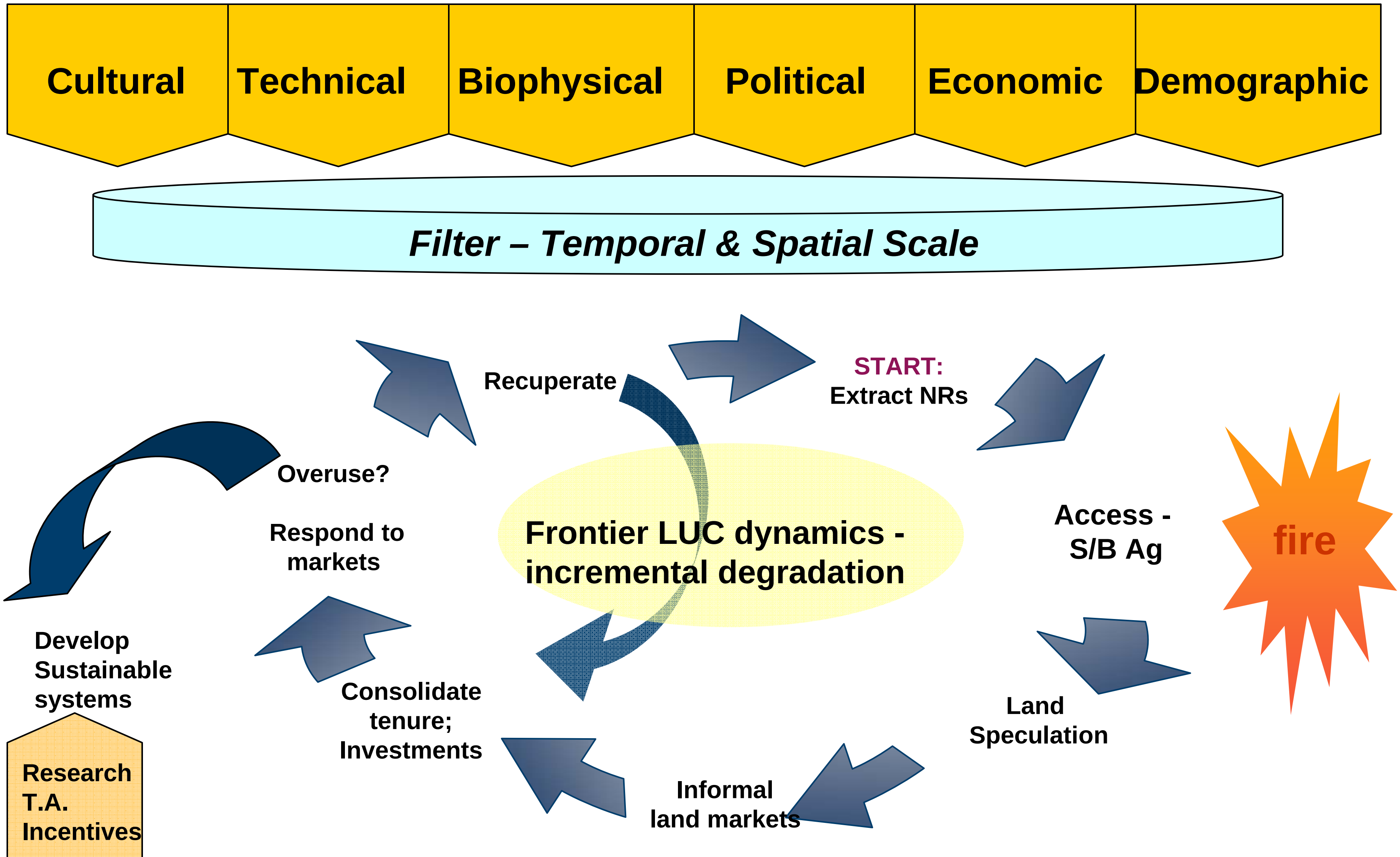
Source: Kauppi P. et al., PNAS 2006

- Mather curve applies in developed and less developed countries;
- Different nations, different points on curve => Equity issues?

Land-use change and associated carbon emissions are complex

- **Driven by interactions among cultural, technological, biophysical, political, economic, and demographic forces**
- **Not singular events**
  - **Shifting land-use mosaics**
  - **Recurring anthropogenic fires in agricultural frontiers; increasing extent and intensity**
- **Essential to understand the forces behind degradation, land clearing and fires to reduce emissions**
  - **Measurement challenges and data complexity: land cover in constant flux; multiple uses overlap and change with time**

Drivers of frontier land-use change



Important drivers of 1st change: extractive industries/access; making claims, poverty. Where & how do biofuel policies interact with these processes?

Analysis of threats to tropical forests: poverty, corruption, lack of governance, insecurity

Solutions involve support for:

- Sustainable rural livelihoods – improve prices for products (and sustainable land practices that reduce fire)
- Improved land tenure
- Inventory & protect key conservation areas
- Improved governance, local capacity, enforcement
- Land-use plans and management

Source: USAID – FAA Sec. 118/119 Reports 2000-2008

Alternate hypothesis: Could biofuels help reduce first time land-use change?

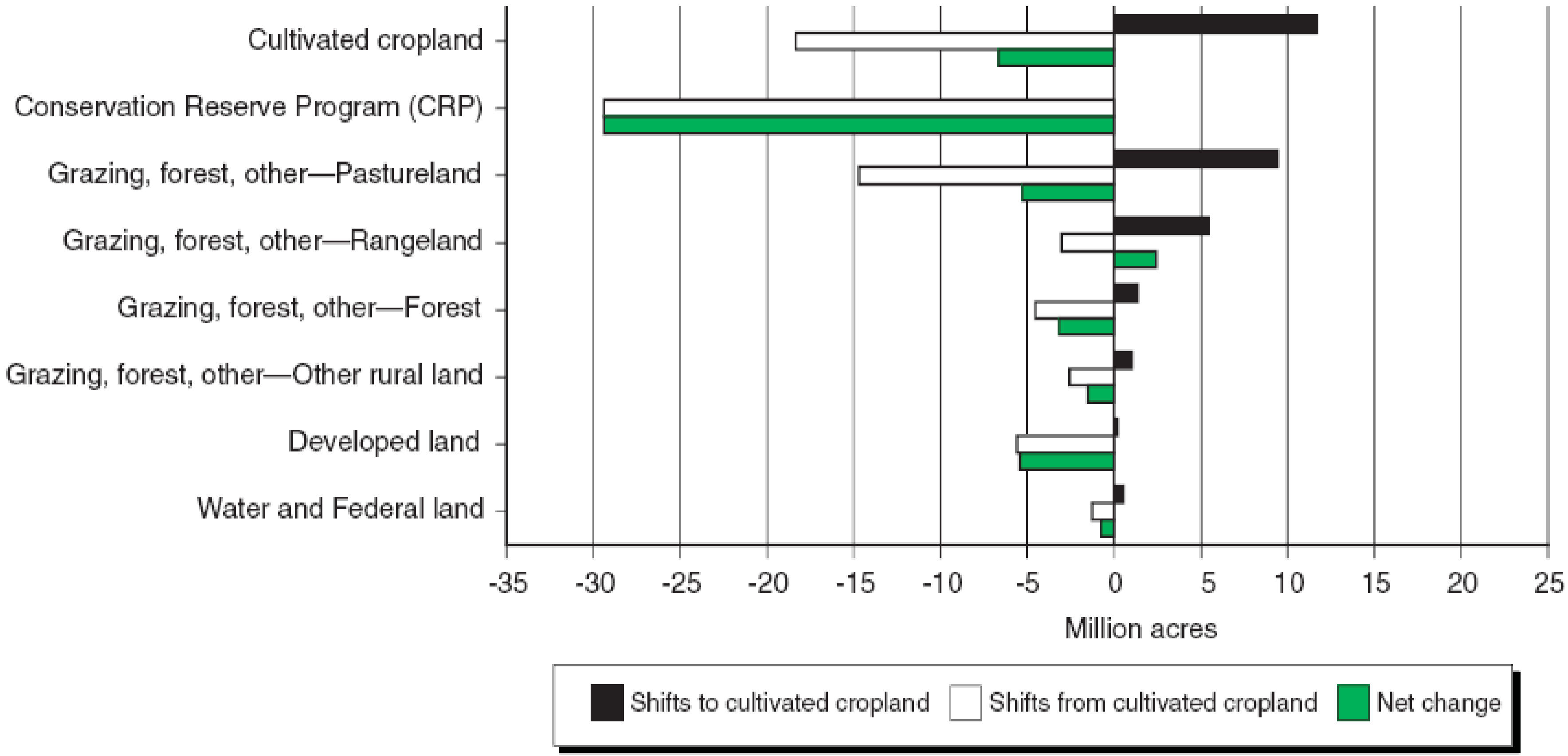
- **Can increased crop prices create incentives to…**
  - **Invest in previously cleared land?**
  - **Increase yields, efficiency and rural employment?**
  - **Reduce pressure to clear 'new' land?**
  - **Reduce recurring use of fire and GHG emissions?**
  - **Improve soil carbon (depending on situation, crops)?**
- **Would biofuels address threats (prior slide) if they:**
  - **Promote "best practices"?**
  - **Bring sustainability issues to forefront?**
  - **Draw attention to long-standing needs for change?**
- **Effects of biofuel policies could be positive or negative.**
  - **Difficult to measure or generalize at global scale**
  - **Estimates of net impacts, including land use, depend on many assumptions**

Comparing underlying assumptions

GTAP Model Assumptions for LUC	Empirical Evidence and Alternate Assumptions	Comment / Significance
Model simplifies world to 3 competing uses (crop, pasture, forest) and estimates % change from a single point. Assumes crop area displaces others to meet increased demand and ILUC must be >0. Historic LU trends, past cropland areas and rotations are not accounted for.	Global land in constant flux; cropland rotating in and out; multiple overlapping "uses." US census data analysis: gross shifts in cropland over 15 years as high as 40% of total final cropland (136 million acres moved in or out of cultivation 1982-97); Net change was 42 million acre cropland reduction (about 29 net out to CRP). Historic data show consistent net losses in harvested area lock-step with increased output.	ILUC estimates derive from simplified data with high uncertainty. Baseline and LUC validation lacking. Magnitude of cropland dynamics (trends shifting in/out of use) not captured. Cropland changes in US (15 yrs) dwarf simulated US land needs for biofuel (15 yrs) with gross shifts ≈ 40 times larger than biofuel area requirements. Could idle lands + induced yields supplant assumed ILUC?
Initial land allocation is considered optimal with respect to prices. 'New' cropland assumed to be less productive than existing cropland.	Real world allocation suboptimal. Ongoing, significant shifts in production move crops toward higher yielding places over time. 'New' cropland is just as productive as average cropland.	Shocks to system can accelerate shift toward more efficient production and higher yields – consistent with historic data but ***opposite of model assumptions***.

Gross change (per 5-yr census data): >136M acres moved in or out of US cropland, with net loss of 42M acres

Shifts to and from cultivated cropland, 1982–97

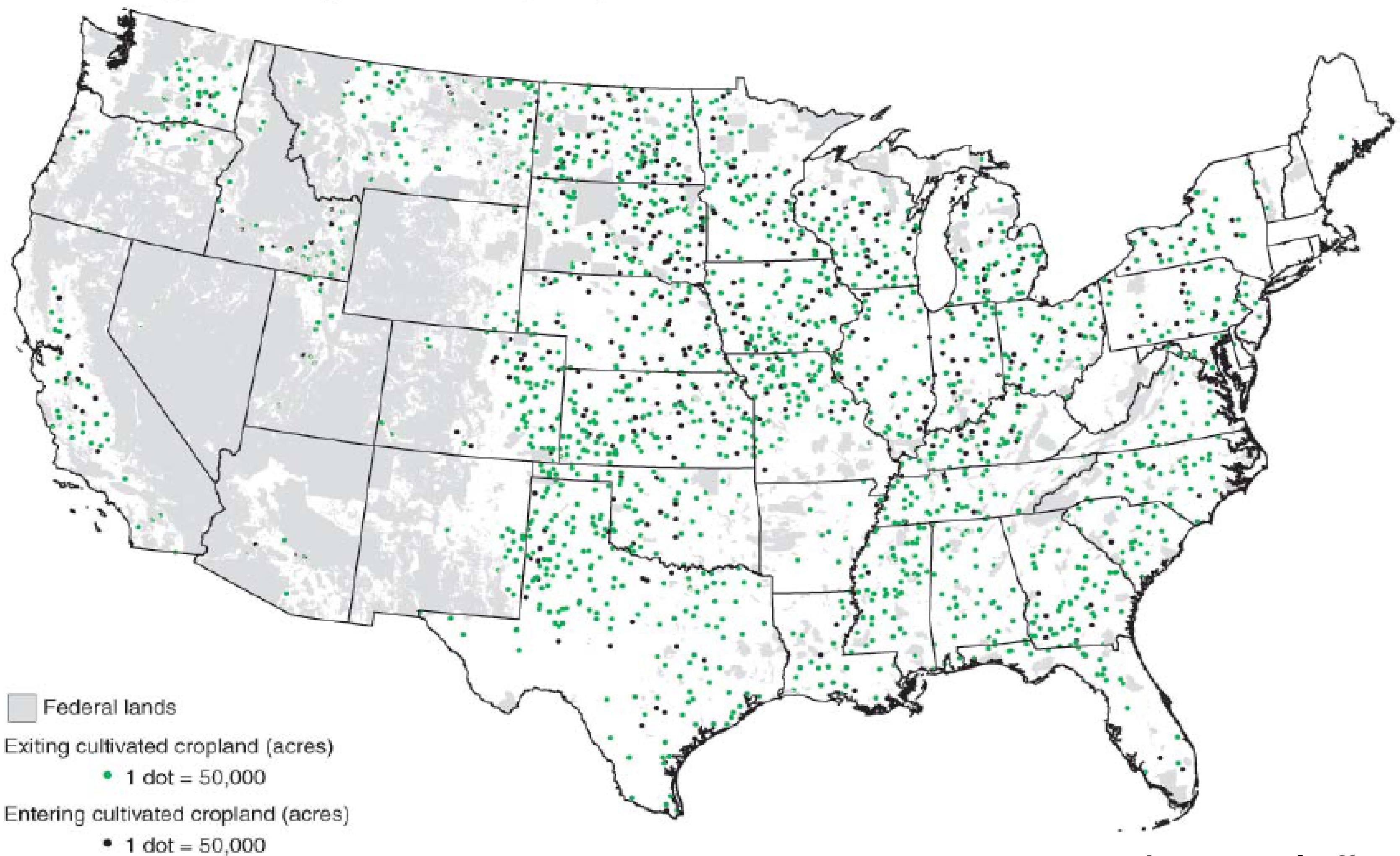


Source: 1997 National Resources Inventory.

Source: USDA ERS ERR-25 "Environmental Effects of Agricultural Land Use Changes." Chart shows only 1982-97 change (2 points). 136M acres = sum cropland shifts between each five year census.

U.S. LUC widespread – Impacts? If models suggest 3M acres for biofuels has large impact, what was ILUC from 42M acre net cropland removal from 1982-97?

Land entering and exiting cultivated cropland, 1982-97



Note: Size of dots is not proportional to actual land area.

Source: 1997 National Resources Inventory.

Source: USDA ERS ERR-25 "Environmental Effects of Agricultural Land Use Changes"

More underlying assumptions

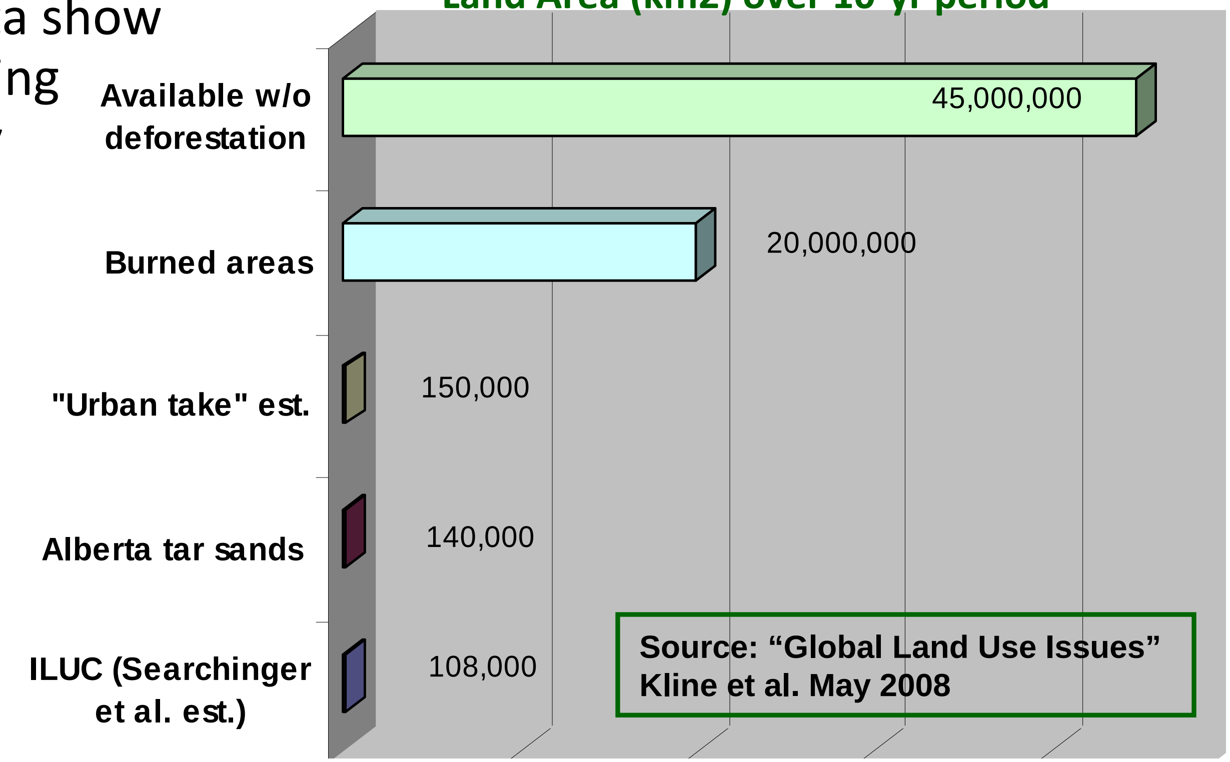
GTAP Model Assumptions for LUC	Empirical Evidence or Alternate Assumptions	Comment / Significance
All available land is owned and allocated to a defined use (pasture, accessible forest or cropland). Land use governed by economic principles and decisions.	Majority of global land that has been cleared for crop production is underutilized or fallow. Agriculture frontiers are characterized by lack of tenure/ ownership; lack of rules/law; and isolation from commodity markets.	Global land suited and available for cultivation without deforestation ≈ 6 billion hectares compared to total annual harvested area (per model) of 1.3 billion. Models appear to misclassify or omit major land resources available for agricultural production.
Biofuels increase prices, causing crop expansion in pasture & forest and reduced exports. ILUC must compensate for 'displacement.' Role of stocks in moderating supply/demand shocks not captured.	U.S. biofuel output went up 3.1 billion gallons (2001-06) while cropland area fell 7.4 million acres and exports unchanged. Prices stimulate more efficient land use; high apparent yield response to price.	Losses, waste and stocks vary by year; can represent significant variables that help balance supply/demand w/o forcing LUC. Could reasonable changes in assumptions generate significant differences in ILUC estimates?

Data on available land: FAO-IIASA 2007 and others

- Available land "suitable" for rain-fed agriculture after excluding all urban, closed forests & reserves, bare lands, etc. = 58.8 (+2.8 irrigated) or ≈ 60+ million km2. More if all land suited for pasture included. Plus "equivalent cropland" from area suited to multi-cropping
- Ramankutty: actual cropland in 2000 ≈ 15 million km2. Subtract from above ≈ 45m km2 underutilized and available for expansion (note: GTAP based on FAO 2000 harvested area ≈ less than 13 M km2 globally)
- MEA and RS tracking data show widespread fires impacting 2-4 million km2 annually
- Searchinger et al. postulated 0.1 M km2 ILUC from biofuels globally; assumed causal relationship not supported…
- Even assuming this, what is significance?

Putting numbers in perspective

Land Area (km2) over 10-yr period

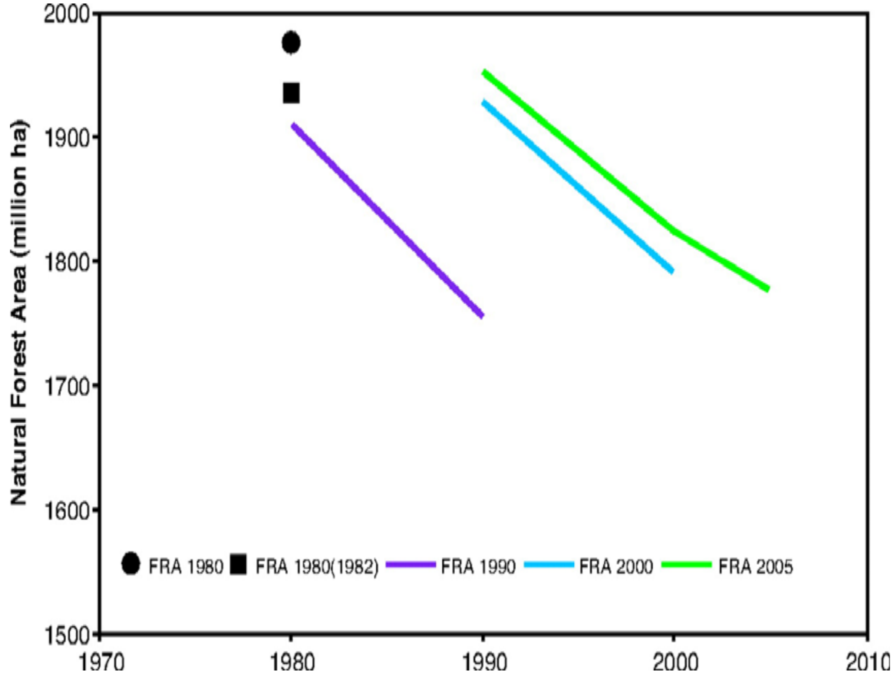


Challenges for baseline data

- Land cover and use are constantly changing
  - Lines between classes blur
  - Data at different temporal & spatial scales differ
  - Land 'cover'such as grassland is difficult to measure; Land use (pasture) nearly impossible from remote sensing and current data sets
  - Results highly dependent on questions asked, sources, methods, definitions, input order… many details
  - At global scale, data become homogenized, simplified
  - Cropland is always shifting → becomes idle land → grassland and eventually → secondary forest
  - ***Data suggest net change trend shift to increasing forest cover world-wide even as agricultural output grows…***

Uncertainty: land use versus land cover – even most basic cover relies on iffy data

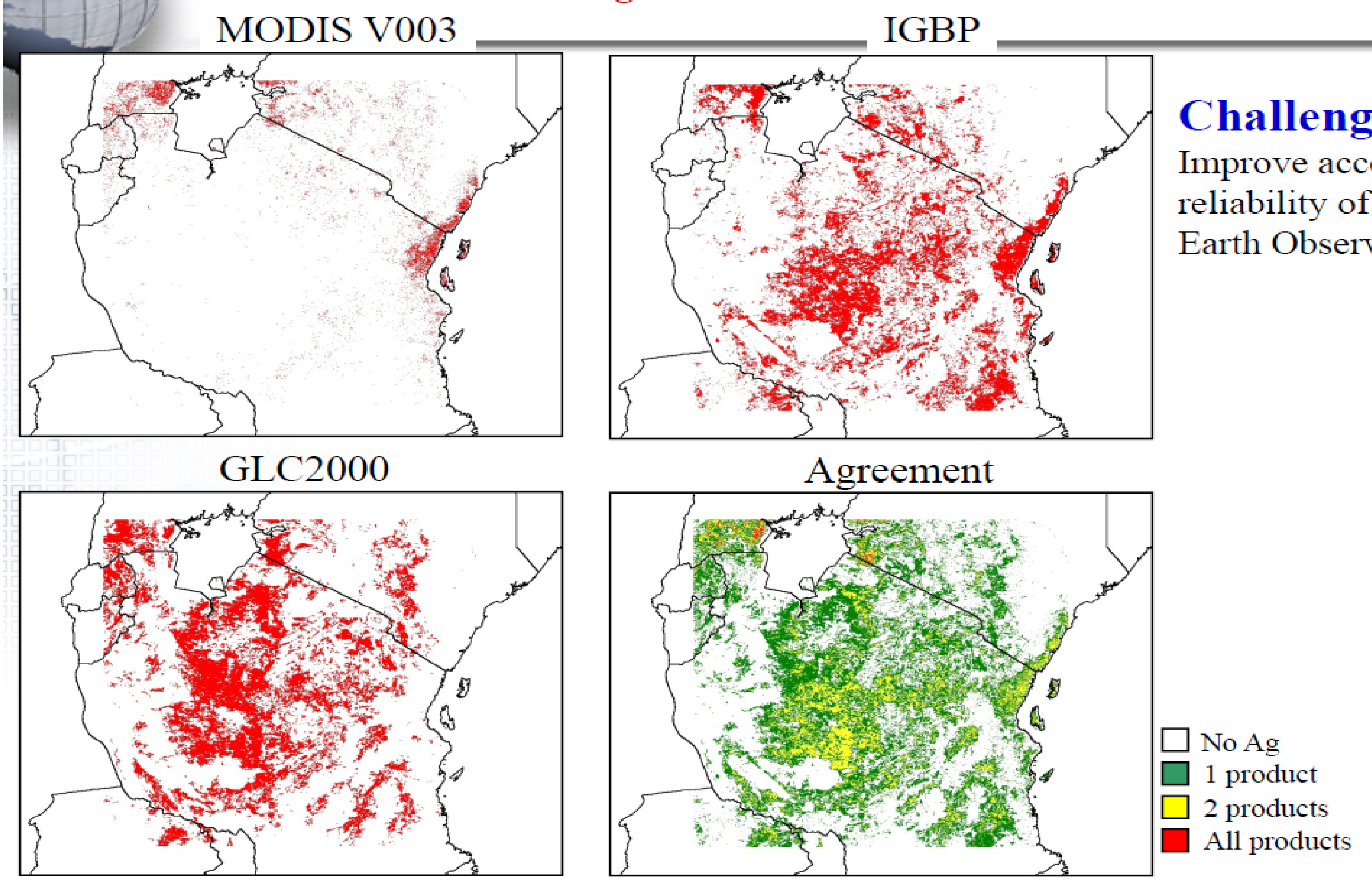
- **Remote sensing *interpretations* ~ apparent land *cover* often lacks adequate ground truth**
  - **Costly and difficult**
  - **Errors common, significant**
- **Remote sensing can estimate cover change within limits (resolution place, time) but does not tell *why*.**
- **Land-use much more difficult to verify**
- **Large scale remote sensing often misrepresents land-use, especially "pasture" (Morton 2006 example)**



Grainger (PNAS 2008): Large contradictions in forest area. Reliable trend analysis very difficult. No apparent decline in "moist forests" - partly influence of errors. Also "forest return effect" estimated at 850 million has replacement (FAO 2005).

Uncertainty for baseline data sets

Comparison of Agriculture land classes from 3 satellite products
10 degree tile over East Africa

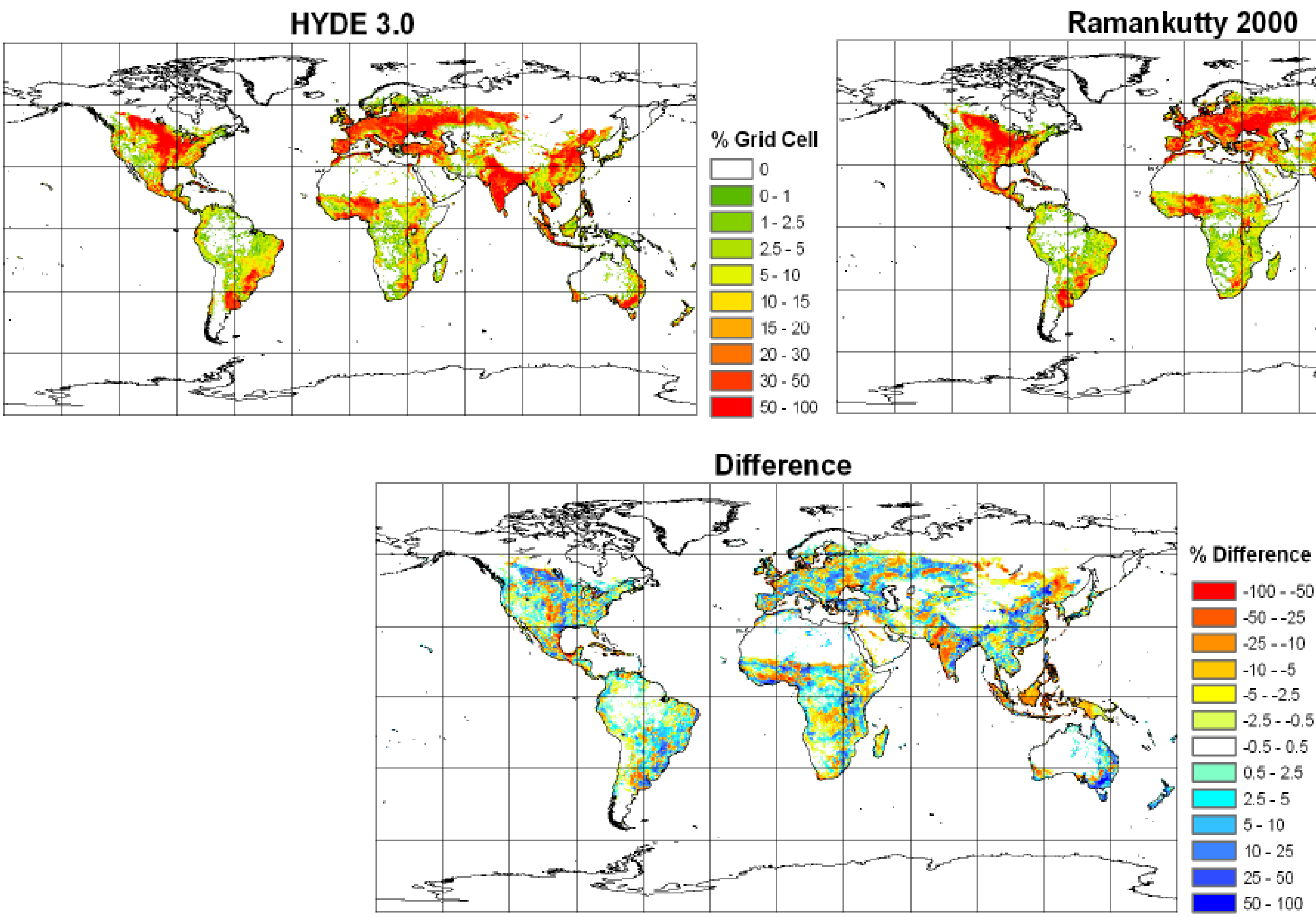


Challenge:

Improve access and reliability of Earth Observations

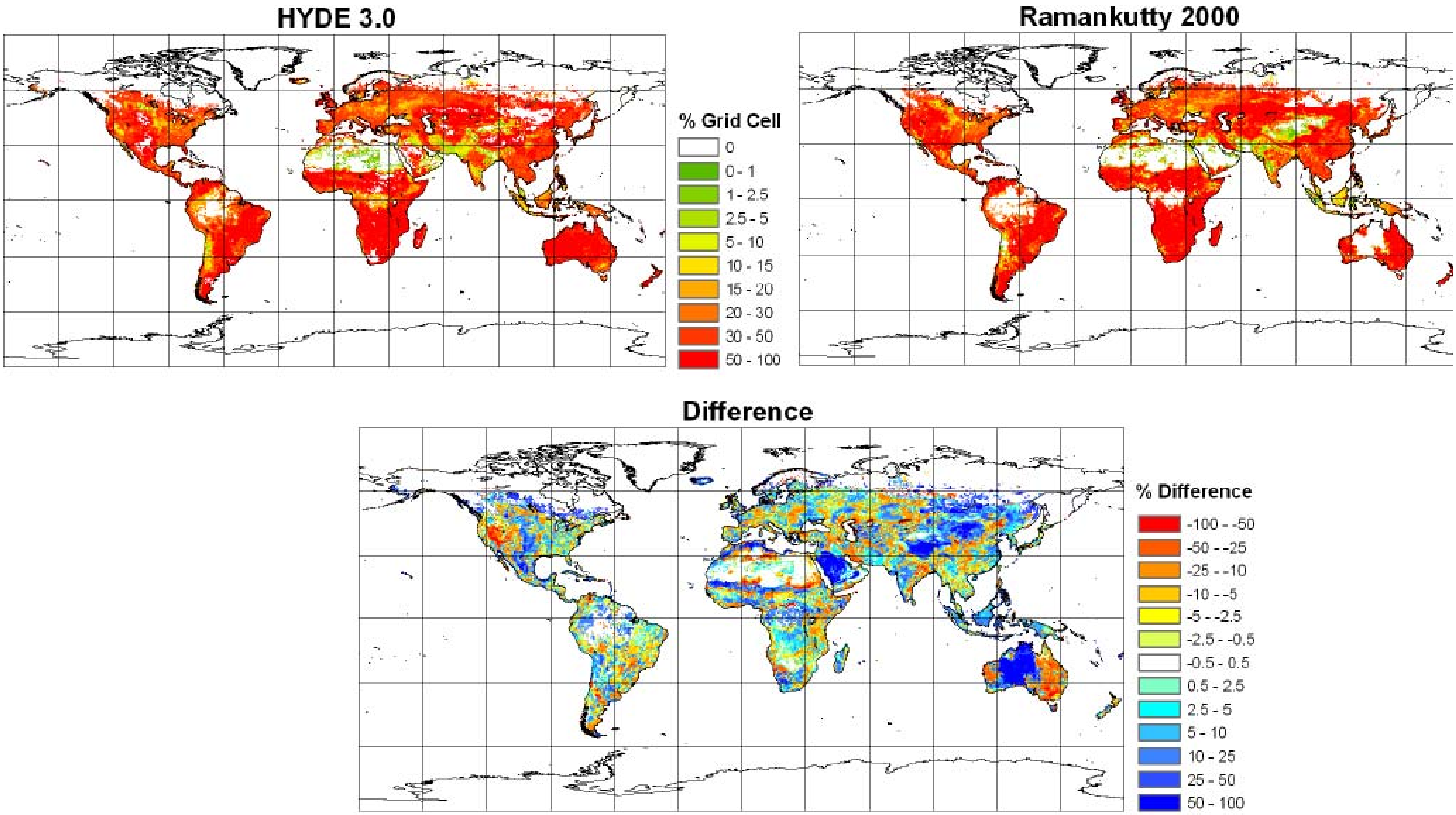
Source: Preliminary results, Johannes Feddema, Geography Department, University of Kansas

Agriculture cropland baseline: major differences are widespread



Source: Preliminary results, Johannes Feddema, Geography Department, University of Kansas

Grassland baseline: greater differences (often 100%) more prevalent



Source: Preliminary data, Johannes Feddema, Geography Department, University of Kansas

Baseline data uncertainty

- Global *cropland* data sets required for baseline have tremendous uncertainties
- *Forest* definitions and areas, even greater uncertainty
- *Grasslands and pasture*, still more uncertain
- ESM-IAM community: "climate difference from land cover classification is as large as the climate difference from land cover change"*
- Uncertainty in baseline data is many magnitudes larger than estimated biofuel LUC impacts
- Critical to improve definitions, quality and consistency of data for current land cover and, building on that, "land-use"

*** Preliminary results, Johannes Feddema, Geography Department, University of Kansas**

Model Validation

- Models are meant to improve understanding (not predict)
  - Often more valuable for learning if models "fail"
- For models to approximate real world systems:
  - Need to validate underlying assumptions
  - Need good data
  - Need resources for ground truth and local research
- Need to reconstruct land-use history at source to identify causation, drivers and model relationships
  - Learn from past: many current "agricultural mosaics" are legacy of extractive industries (oil, gas, timber…)
- To properly model "with and without" we must define a reasonable "without" baseline scenario.
  - **In absence of RFS2, what would global LUC trend be? With RFS2 is it more, less, same? Scale matters.**

GTAP Working paper #53

- "Validates model for 2001-2006" - calibrates model to fit feedstock shares and ethanol to historic data
- Estimates energy-biofuel-feedstocks relationships reasonably well (changes in prices/outputs)
- Compares GTAP coarse grain estimation to historic corn (planted area) and that looks reasonable

Table 5. Validation of the Model from Historical Evidence in the US, Brazil, and EU-27.

US.	Ethanol-1 Production Million gallons	Model Prediction[1]: Ethanol Production ($ million)	Corn Area Million hectares	Corn Production Million tonnes	Model Prediction[1]: Coarse Grain Production ($ million)	Share of Corn for Ethanol	Model Prediction[1]: Corn Share for Ethanol (% share)	Share of Corn for Exports	Model Prediction[1]: Corn Share for Exports (% share)
2001	1770	2489.30	30.28	241.38	20936.5	6.5%	6.8%	19.4%	27.6%
2002	2130		31.56	227.77		7.5%		17.5%	
2003	2800		31.44	256.28		11.0%		18.8%	
2004	3400		32.37	299.92		11.7%		15.3%	
2005	3900		32.71	282.31		14.5%		19.5%	
2006	4855	6886.80	31.33	267.60	22335.0	20.2%	17.0%	20.5%	25.1%
2007*	7123		37.15	316.50		23.0%			
%Ch 2001-06	**174.29**	**176.66**	**3.47**	**10.86**	**6.68**	**209.05**	**150.0**	**5.50**	**-9.06**

Source: Birur, Hertel & Tyner, Purdue University, GTAP Paper #53, 2008

GTAP #53

- Focused on "biofuel shock" – but no baseline LUC for comparison.
- Accepts and highlights results that fit historic data and assumes that if estimates do not fit data, exogenous factors are responsible
  - Example: Model predicted 9% drop in corn share for exports, but actual exports remained steady (critical issue for indirect LUC assumptions)
- Estimated significant direct and indirect land-use changes…

Table 8. Change in Land Cover and Crop Area due to Biofuel Drivers: 2001-2006

Region	*Land Cover (% ch)*			*Crop Harvested Area Change (%)*			
	Crops	Forest	Pasture	Coarse Grains	Oilseeds	Sugar-cane	Other Grains
US	1.3	-0.3	-0.4	5.0	-0.6	-2.0	-3.3
Canada	0.8	-0.1	-0.1	1.4	-0.1	-0.4	0.8
EU-27	1.9	-1.1	-1.2	-0.4	15.0	-1.4	-2.1
Brazil	2.8	-0.5	-0.4	-0.3	0.7	15.5	-1.0

Source: Birur, Hertel & Tyner, Purdue University, GTAP Paper #53, 2008

GTAP #53

- Illustrates that the model offered reasonable est. of biofuel feedstock shares comparing historic data (2001-2006)
- Model results were not reasonable for estimating direct LUC by category… and certainly not for indirect LUC

TABLE A: Comparing USDA NASS data to GTAP LUC Estimates 2001-2006

Changes in US Cropland from 2001-2006 Comparing Recent GTAP Papers to historic USDA data 2001-2006				**GTAP #53 versus USDA data: approx. difference - million acres**
Category: harvested area* for	**GTAP #52 Estimate**	**GTAP #53 Estimate**	**USDA Actual Change**	
All crops (100%)	**+2.5%**	**+2.1%**	**-2%**	11.4
Coarse Grains (30%)	**+8.3%**	**+5.0%**	**-4%**	7.7
Oilseeds (26%)	**-5.8%**	**-0.6%**	**+0.5%**	0.9
Other grains (17%)	**-6.5%**	**-3.3%**	**-4%**	0.4
Other agriculture (27%)	**-1.8%**	**-1.2%**	**-3%**	1.4
Forest (N.A.)	**-1.5%**	**-0.5%**	**+0.6%**	9.9

* Percent of 2001 harvested cropland is noted in blue for each category of harvested area only to illustrate the relative importance of each category compared to total harvested cropland area

Source: Kline and Oladosu - informal discussion paper shared with GTAP, 2008

Representation of land-use decisions

- 1st - Several options allow increased production without costly expansion to new areas (efficiency, inputs, etc.)
- 2nd - If harvested area is to expand, most likely to occur first where easiest and perceived benefit/cost ratio is highest:
  - *Shifts "within category" – e.g. corn replaces sorghum and similar coarse grains (as occurred from 2001-06)*
  - *Shift to other available idle (non-CRP) fallow lands*
  - *Multi-crop using current equipment & land base*
  - Displace other crops; then displace pasture cropland and pasture/grassland (previously cleared lands)
  - Forests likely to be last due to costs (unless at end of clear-cut cycle, when it is actually "other cleared land" anyway*)

*** Model will over-estimate LUC and ILUC if excluding these options and appropriate choice hierarchy among them ***

Potential significance for LUC results:

- Corn expansion within GTAP "coarse grains"
  - Non-corn coarse grains 2001 base year = 22 m acres (9 m hectares, or Ha)
  - Model assumes no expansion within "coarse grains" class so all LUC must impact other land classes, leading to ILUC
- **Consider sensitivity of results to this assumption:**
  - Max. potential expansion within coarse grains (before any necessary impact on other crop types and land-use class) = 9 m Ha * 380 bu/Ha (actual 2008 yield) * 2.7 gal/bu = = 9.4 billion gallons
  - With projected increases in yield and efficiency by 2015, output reaches 11.4 billion gal
  - Represents > 85% of requirement to reach 15 b gal

This reflects *maximum* potential from non-corn land within 2001 'coarse grain' baseline, an extreme case. It provides a "bracket" for the alternate extreme case that *all* expansion occurs elsewhere (as assumed in model).

Potential significance for LUC results:

- US "idle cropland" fluctuates widely by year. Non-CRP idle land (USDA) ≈ 7 to 23 million acres (1992-2002 USDA census). If CRP added, range for same period ≈ 39 to 56 million acres.
- Can models incorporate non-CRP idle land available for expansion?

Consider sensitivity of this assumption:

  - Potential expansion on idle non-CRP land ≈ 7 to 23 million acres before any necessary impact on other crop types and land-use classes = 2.7 to 9.6 million hectares.
  - Lower value = 2.7 m Ha * 380 bu/Ha (actual 2008 yield) * 2.7 gal/bu = 2.8 billion gallons.
  - Upper value is 9.4 b gal with 9.6 m Ha
- Globally: idle lands range from 1 – 2 billion acres
  - Available idle and underutilized (shifting use) land areas far exceeds model demand for biofuels

Notes on yields – significance?

- Corn expanded to 18 million new cropland acres in Midwest (1945-2002) while average yields tripled (are ‘new’ lands less productive?)
- 2001-2006, 75% of actual increase in corn output was attributable to yield
- In 2008, yields continue to represent half of total increase in corn output relative to 2001
- U.S. farm output increases 2% per year while cropland area falls by 0.7% per year (USDA average over past 50 years)

Representation of modeling results

- Amplify description of "sensitivity analysis" and its significance relative to "uncertainties"
  - Consider multiple-factor analysis for reasonable composite scenarios to define upper/lower bounds.
- Take precautions to avoid or minimize potential misrepresentation of data and results, particularly in tables and graphs
  - Absolute statements of change are easily misinterpreted
  - Forest ≠ "commercial forest" ≠ "accessible forest"
- Acknowledge potential significance of excluded factors and assumptions

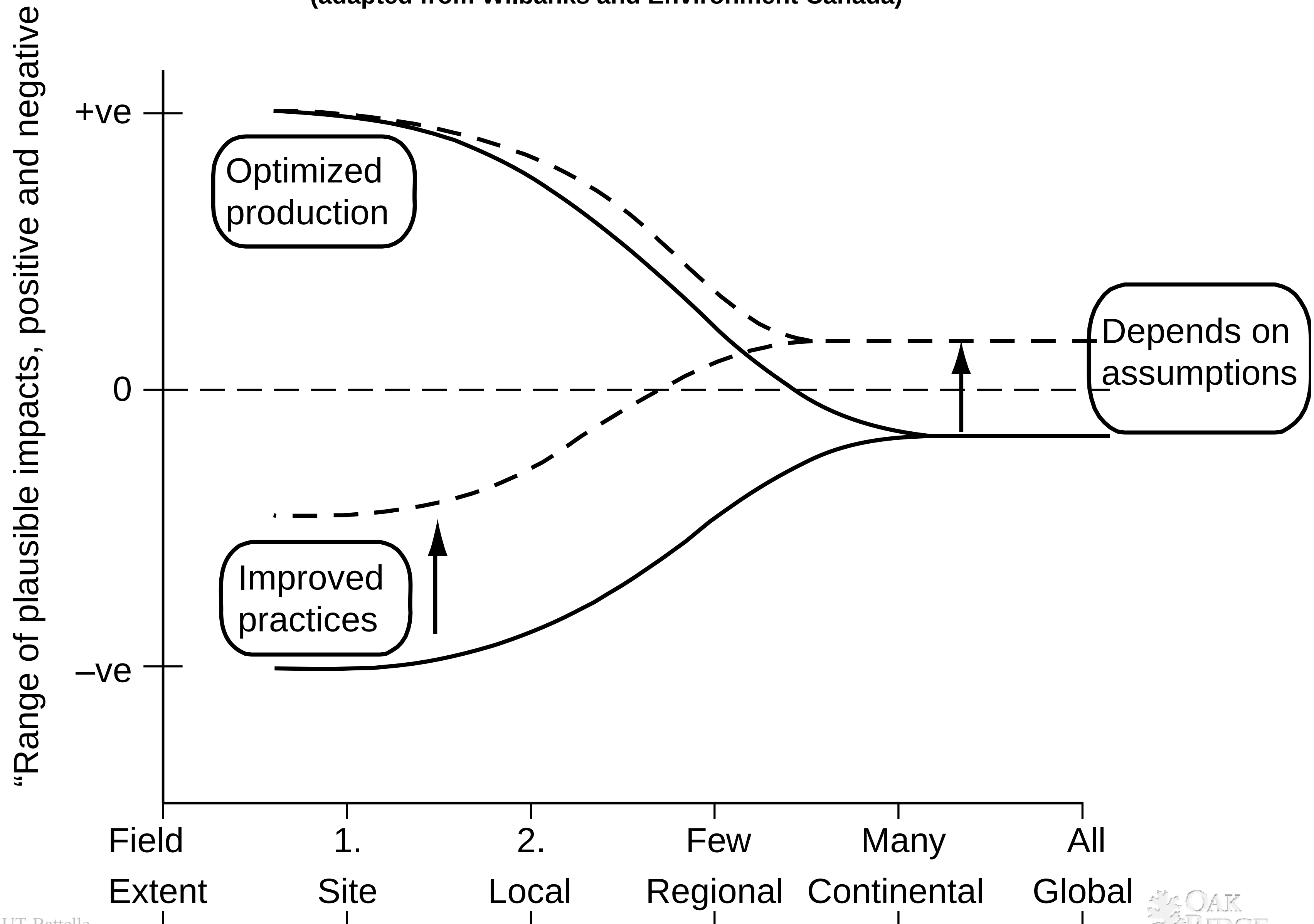
Thank you!

Note: Photo Credits to Virginia Dale, ORNL
from Brazil LUC fieldwork

Extra slides

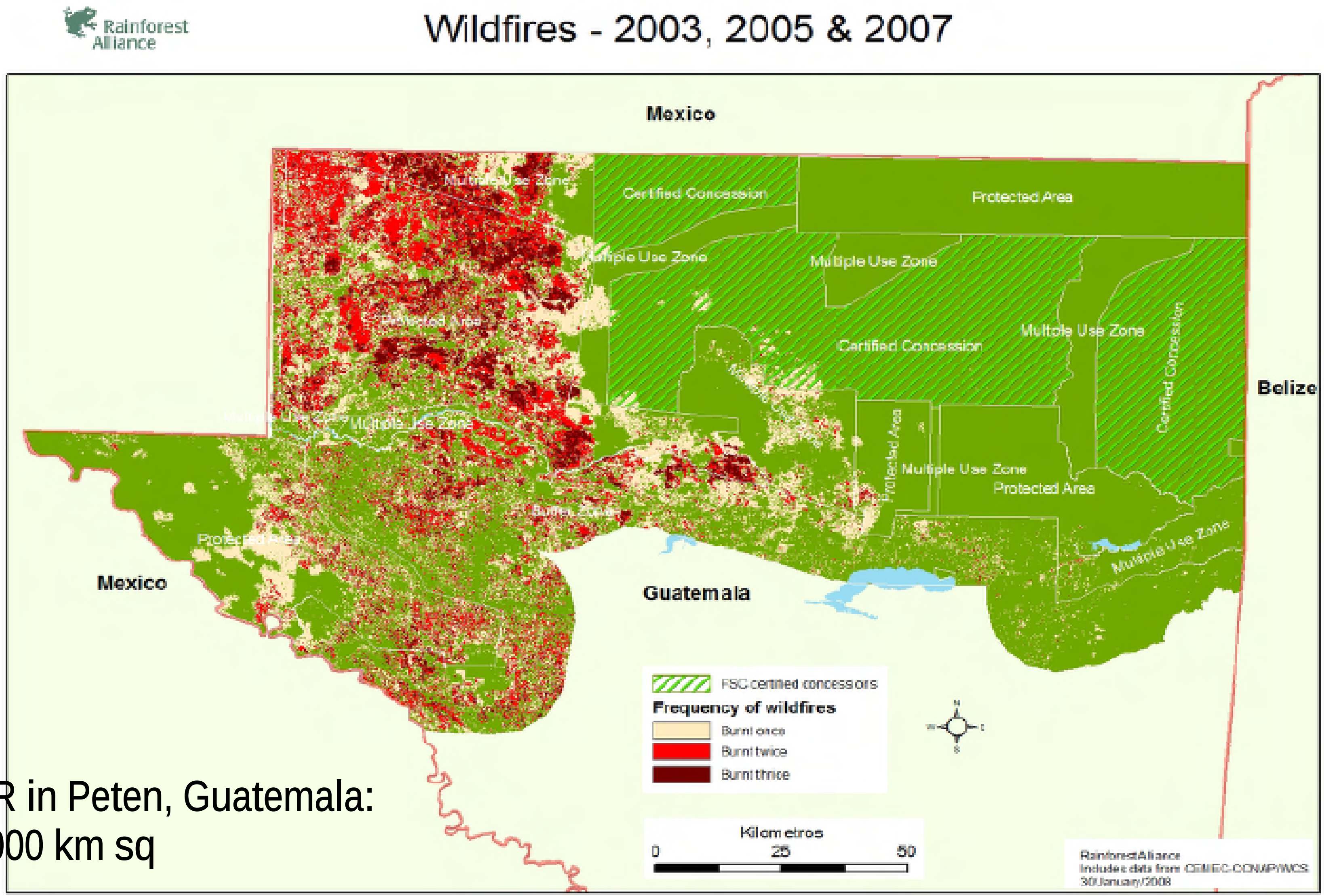
Scale-dependent distribution of biofuel environmental effects

(adapted from Wilbanks and Environment Canada)



Example: Maya Biosphere Reserve – deforestation legacy of oil industry

Map 4. Frequency of wildfires for 2003, 2005 and 2007 fire seasons in the MBR.



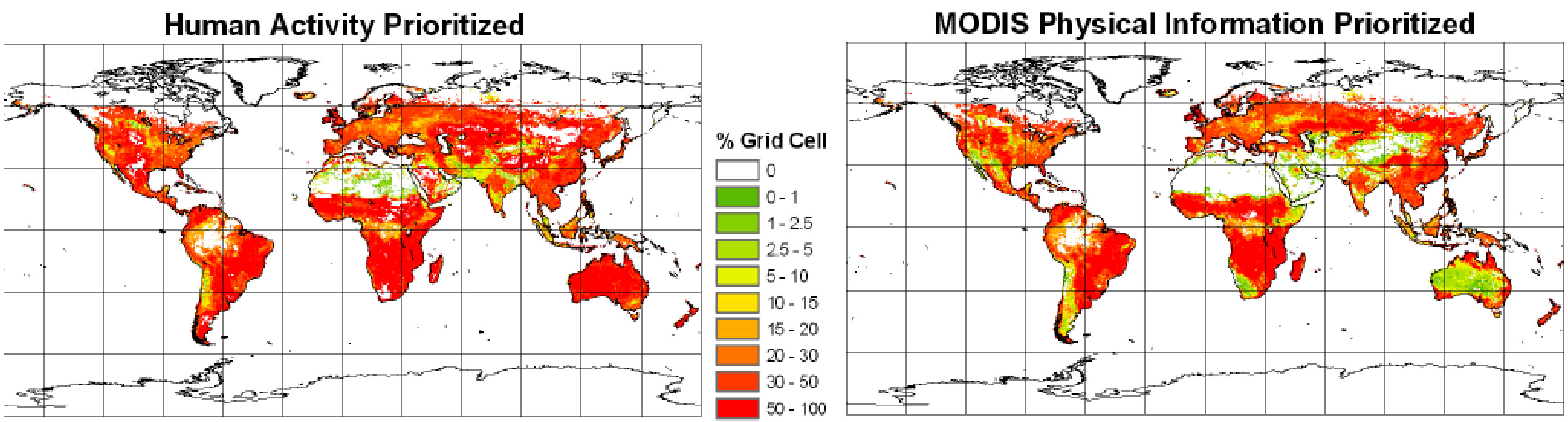
MBR in Peten, Guatemala: 20,000 km sq

Reduction of slash and burn agriculture can reduce carbon emissions

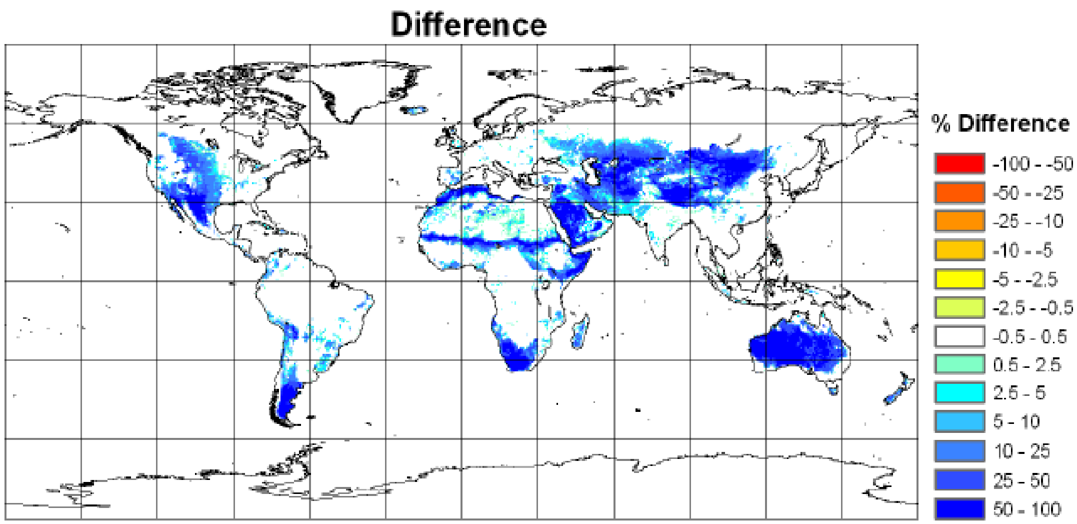
- Repeated fire is used to make and maintain land claims at low perceived cost.
- Fires cover large areas:
  - 250-400 million ha burned each year between 2000 and 2005.
  - Compare to Searchinger's 10.8 million postulated for future biofuels
- Biofuels offer enhanced employment and incomes:
  - Can help establish economic stability
  - And thus reduce
    - Recurring use of fire on previously cleared land
    - Pressures to clear more land

Small variations in approach…

Creating datasets order of entry: Grasses



Order of entry
Urban
Agriculture
Pasture/Grazing
Bare ground
Forest
Shrub
Grass



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Source: Preliminary results, Johannes Feddema, Geography Department, University of Kansas