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Incorporating Human Activities in Global Climate Models

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Introduction

The primary questions about future climate and environmental change are related to the question of how human activities affect the natural system.

To answer such questions we have to be able to properly simulate anthropogenic processes that affect climate and and evaluate the impacts of human activities in an Earth System Model (ESM).



Introduction

The challenge with respect to understanding human – climate interactions:

We need to identify those human activities that affect climate and provide a way to simulate these processes and their interactions with different components of the physical system

We need to identify those human activities that are most sensitive to climate change and have the greatest impact on society and provide a mechanism to simulate their response to climate change

We need to be able to project how human decision making will alter these activities in the future (i.e. assess feedbacks)



Human Activities v.s. Human Decisions

- For an ESM the focus should be on simulating human activities.
i.e. physical models that simulate human activities in a Earth System framework – many are already in progress
- There should be a parallel effort that focuses on human decision making processes.
i.e. These models would control the settings and actual activities that take place. Integrated Assessment Models (IAM) presently fulfill this role
- These should ultimately be coupled



Incorporating human activities into ESMs

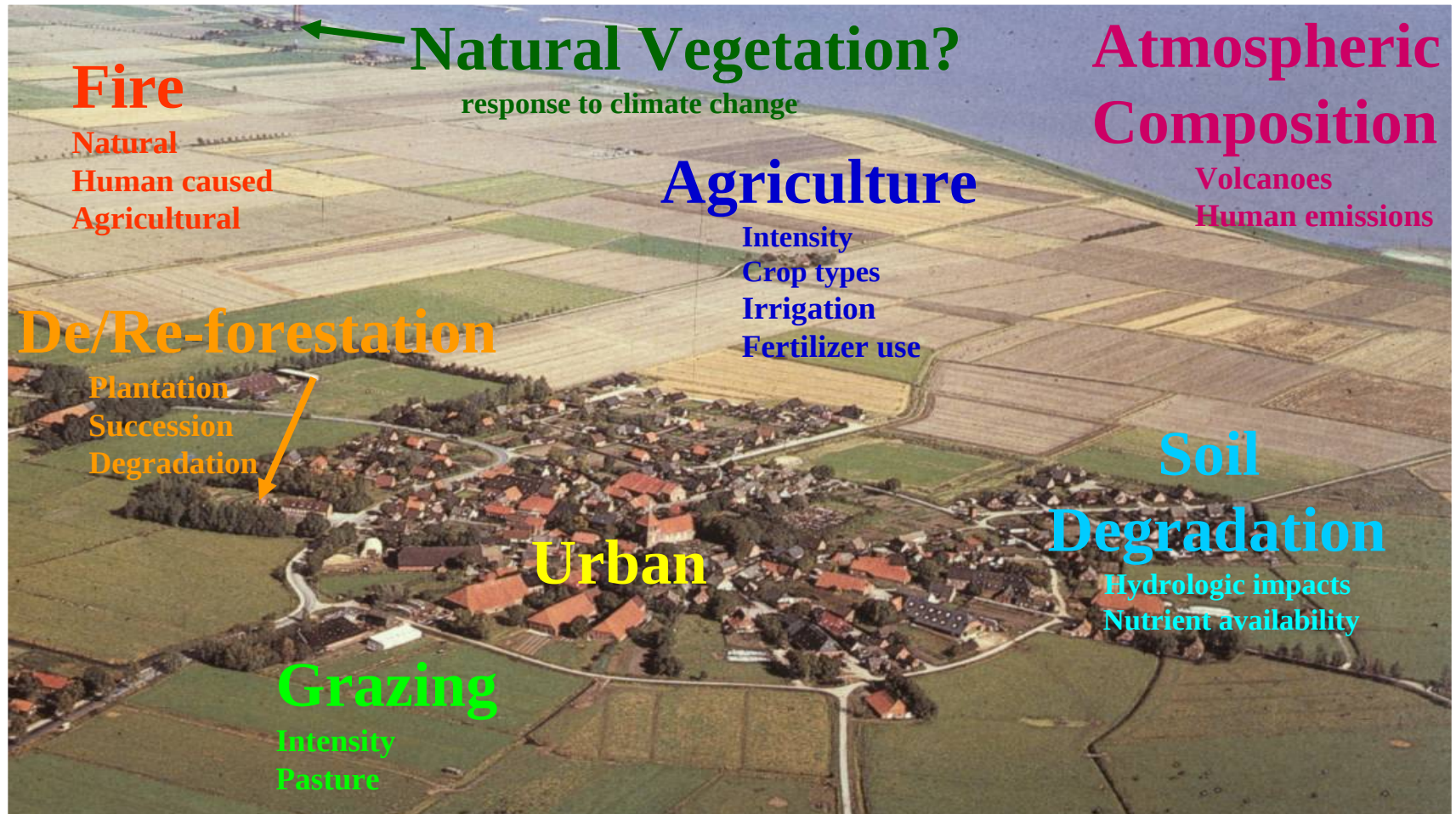
Considerations for developing human activities in models:

- What processes are actually important to simulate?
- Which ones can we simulate?
- How should these processes be simulated?
- How should human decision making be included?
- How can these models improve impact assessment?
- How do we gather the historical, present and future information needed to drive human systems?
- What spatial scale do we need to work at?



Background: Human Climate Interactions

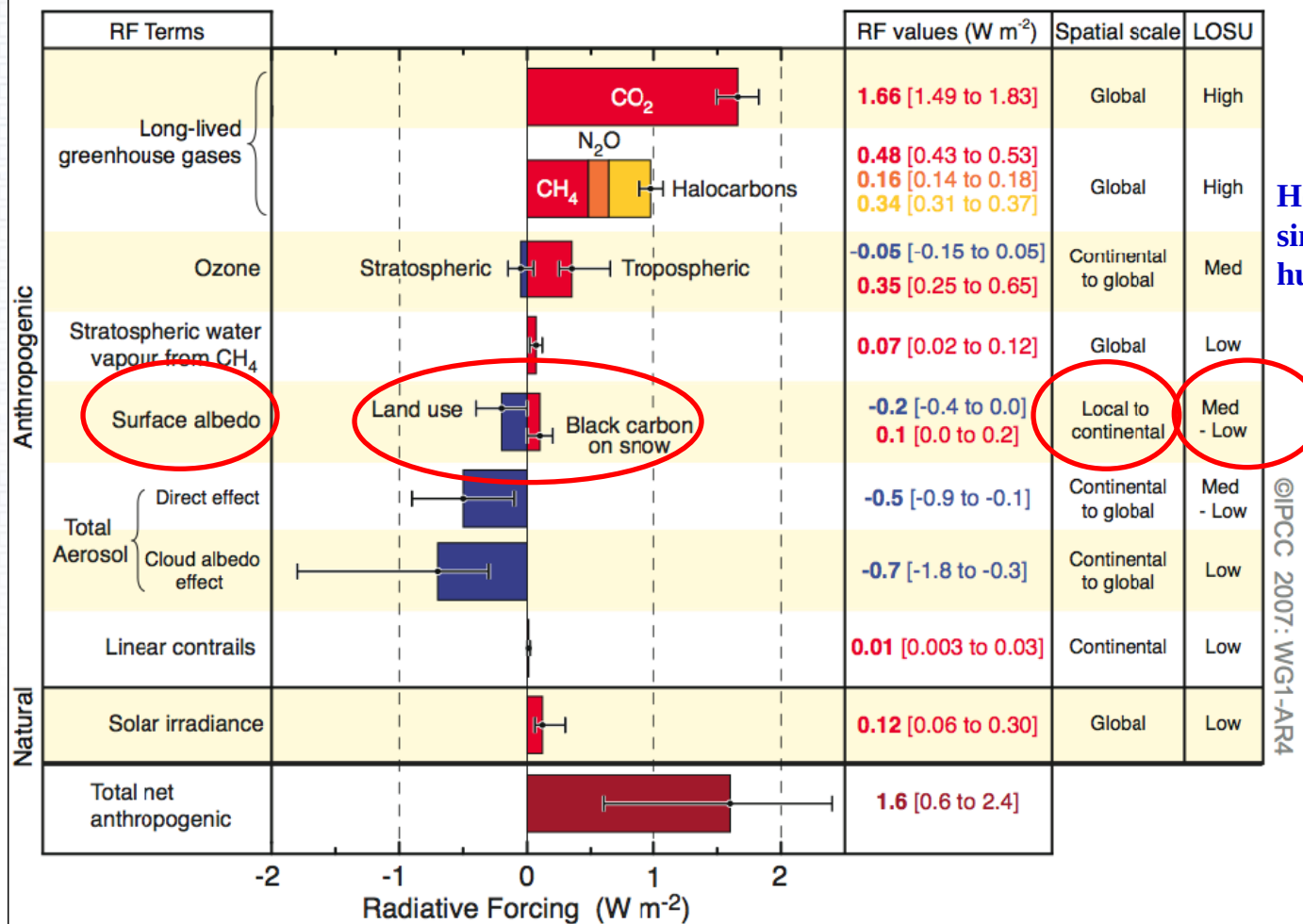
What exactly do we want to simulate?





Status of human land cover change simulation in GCMs

Radiative Forcing Components



How well do we simulate the human impacts?



Simulating Human Activities in an ESM

Each of these human activity sub-models should have the following properties:

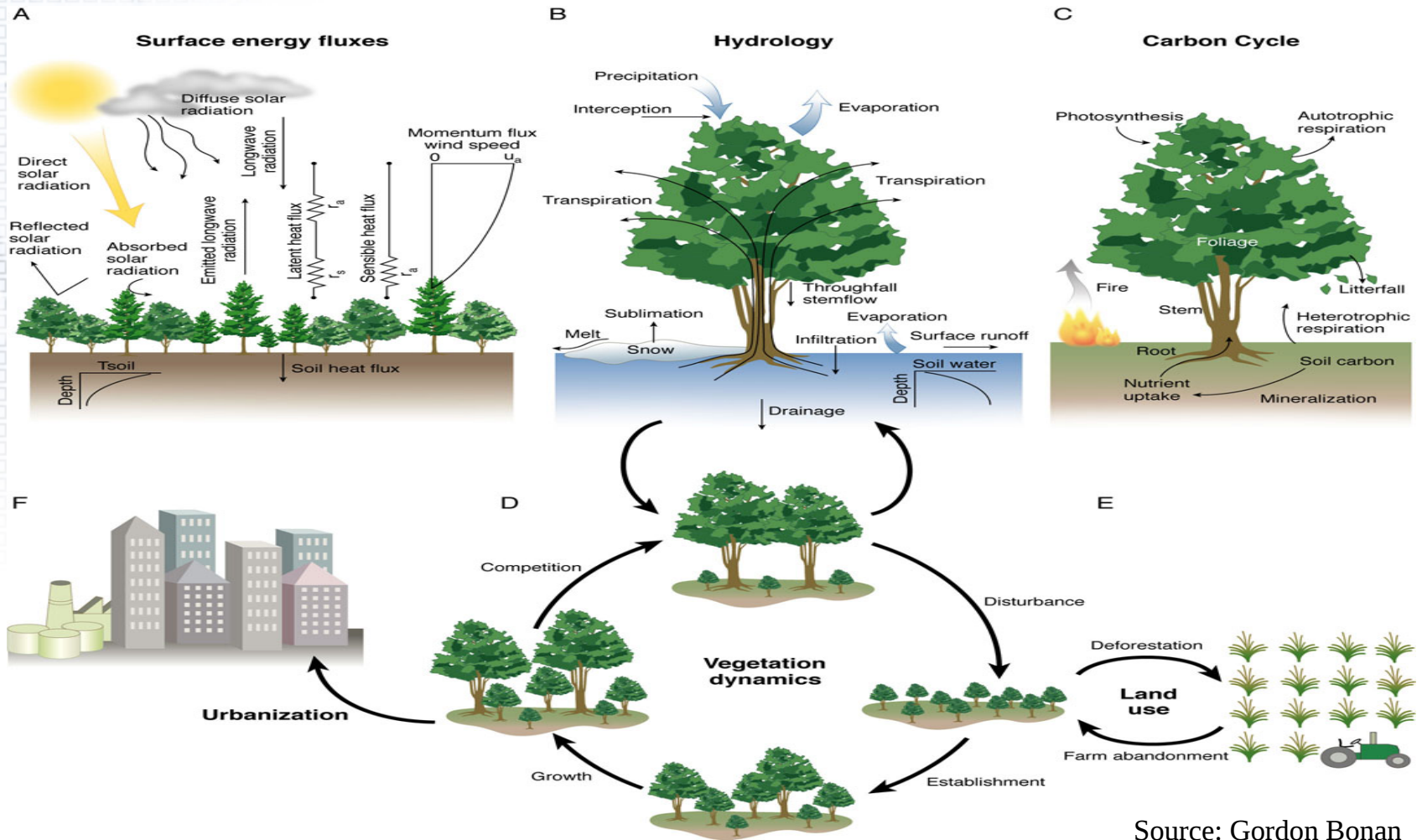
- They should be able to be turned on or off for major regions of the world
e.g. the regions used in Integrated Assessment Models should be able to act independently (e.g. are tropical responses the same as high latitude)
- They should be able to have a setting to indicate different intensities of each activity.
e.g. you could have intensive agriculture with max resource inputs (fertilizers) in one region, but it could be intensive with lower resources inputs in another region, and extensive agriculture with no resources in a third region
- They should have some possibility for recognizing threshold values that change human activities
e.g. River systems that automatically affect irrigation systems i.e. there is some implied management of the system
- They should be linked together so human impacts cascade through the system
e.g., a well integrated model would be able to simulate intensive cropping that leads to increased soil erosion and nutrient usage, from there the model should simulate the resultant increase in sediment and nutrient transport to a coastal ecosystems model



Issues that should be considered

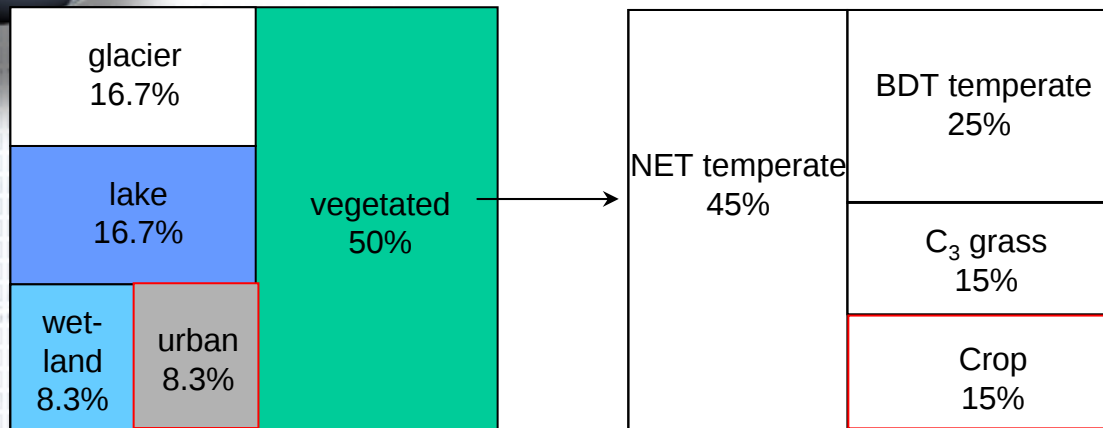
- **Reliability of our information about present day land cover**
- **How to construct historical and future scenarios**
- **Flexible of data input/output information systems**
- **Land models should run at their own resolution**
- **Improve processes such as ecological succession (natural and human controlled)**
- **Have canopy models that can simulate chemistry in the canopy layer**

How modelers see the world





How the model sees the world



Additional grid-cell data:

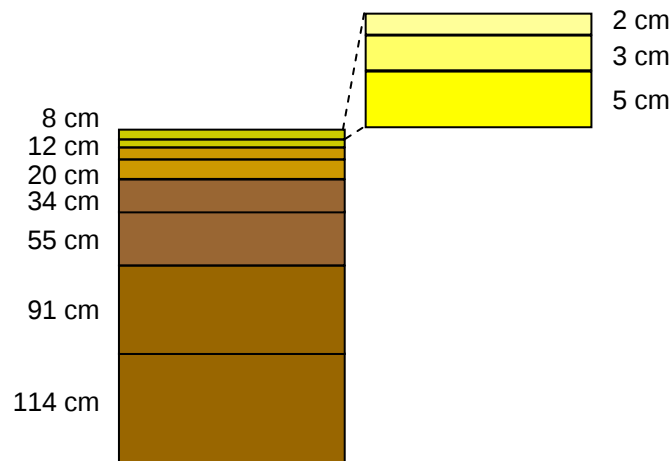
- land fraction
- soil color
- soil texture (% sand, % clay, mineral composition)

Additional data:

- ½° river network

Soil Profile

- total depth - 343 cm
- 10 layers
- texture varies with depth



Each patch has unique:

- PFT composition
- PFT abundance
- leaf area
- height
- biomass

19 Plant Functional Types

Needleleaf evergreen tree
temperate

boreal

Needleleaf deciduous tree

Broadleaf evergreen tree

tropical

temperate

Broadleaf deciduous tree

tropical

temperate

boreal

Shrub

broadleaf evergreen, temperate

broadleaf deciduous, temperate

broadleaf deciduous, boreal

Grass

C₃, arctic

C₃

C₄

Crop

Wheat

Winter wheat

Maize

Soy

+ Bare Ground



Information about the Natural System

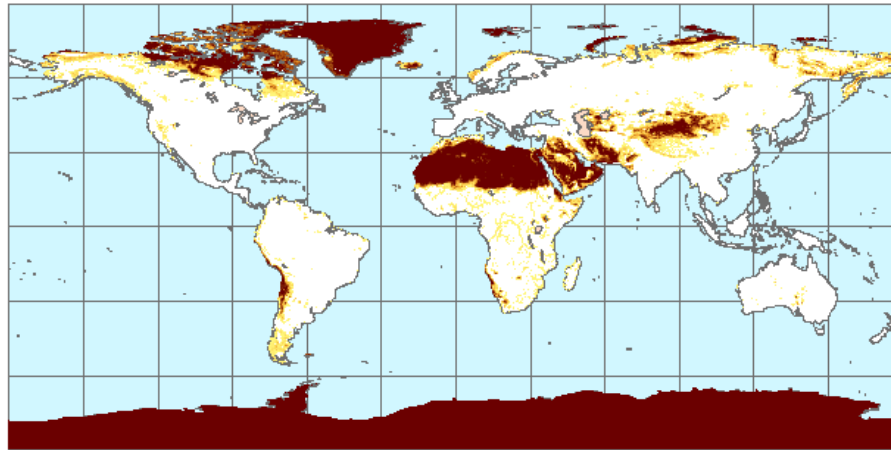
- Use satellite information to acquire information about present day land cover
- Use ground truth and socio-economic statistics to validate – in a few spots we have access to.
- Use socio-economic and population statistics to extrapolate back in time
- Use the IAM projections forward in time



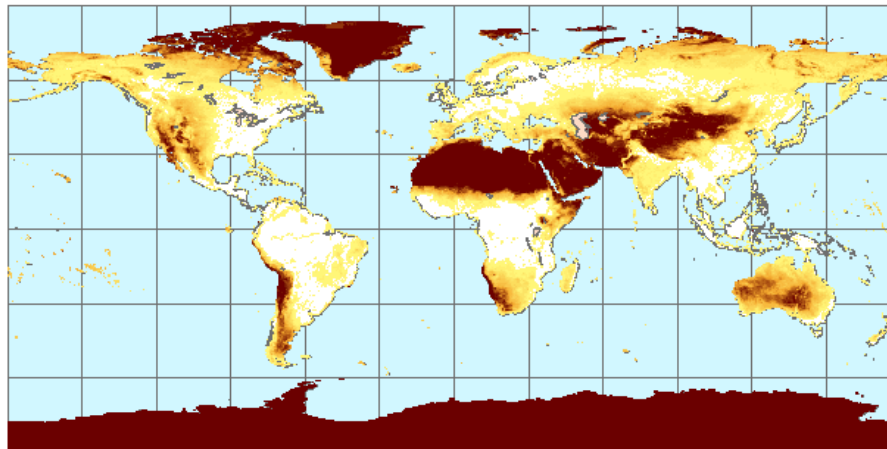
How good is our information about land cover?

Comparison of Discover and MODIS Bare Ground Fraction

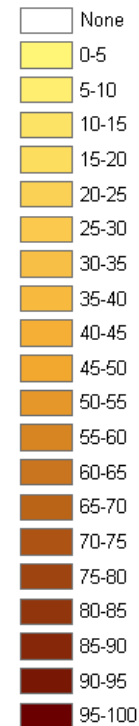
Discover - CLM 3.0



MODIS



Percent Bare



Challenge:

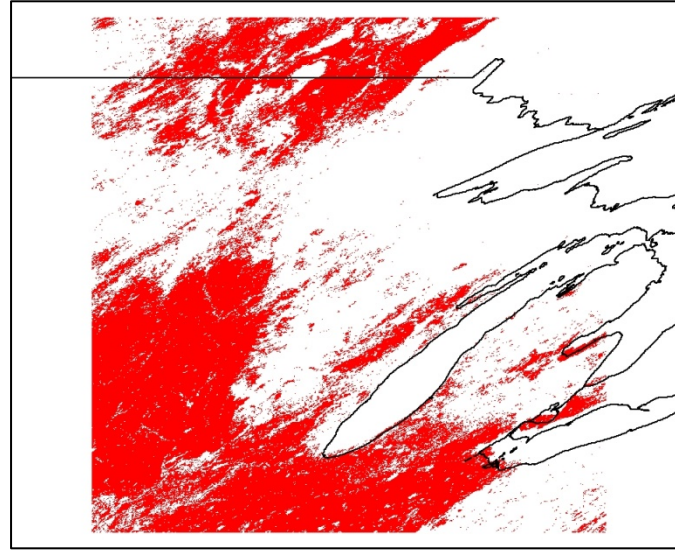
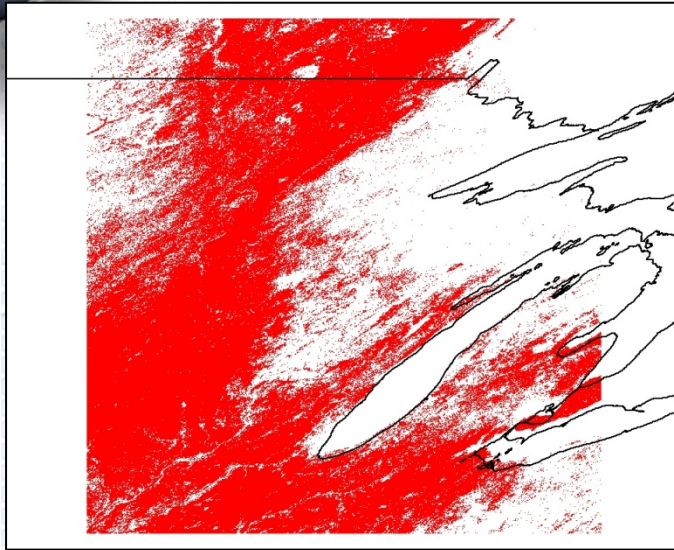
Improve access to,
and reliability of
Earth Observations

Source: Peter Lawrence, CIRES, University of Colorado

Comparison of Agriculture land classes from 3 satellite products 10 degree tile over northern Midwest US

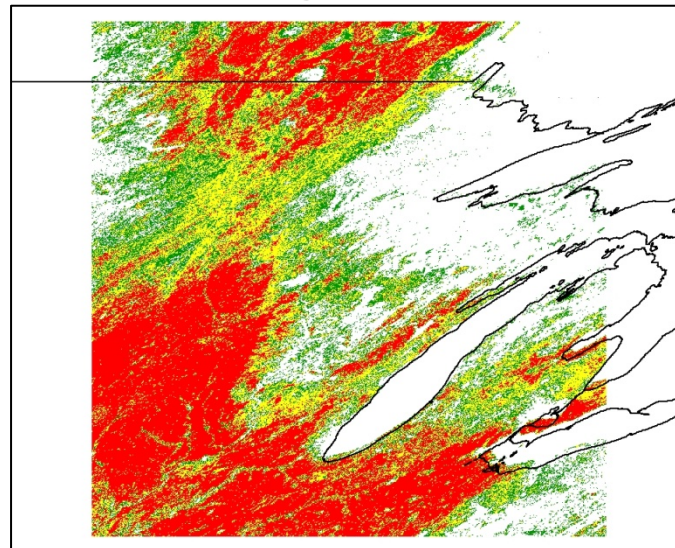
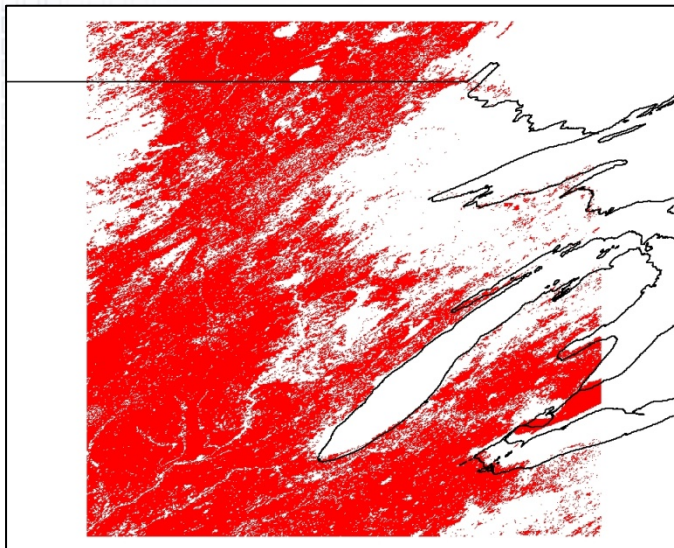
MODIS

IGBP



GLC2000

Agreement

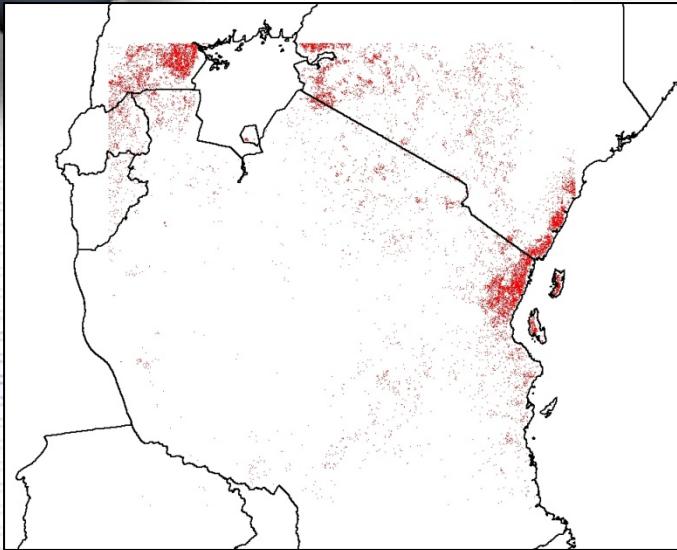


- ☐ No Ag
- ☐ 1 product
- ☐ 2 products
- ☐ All products

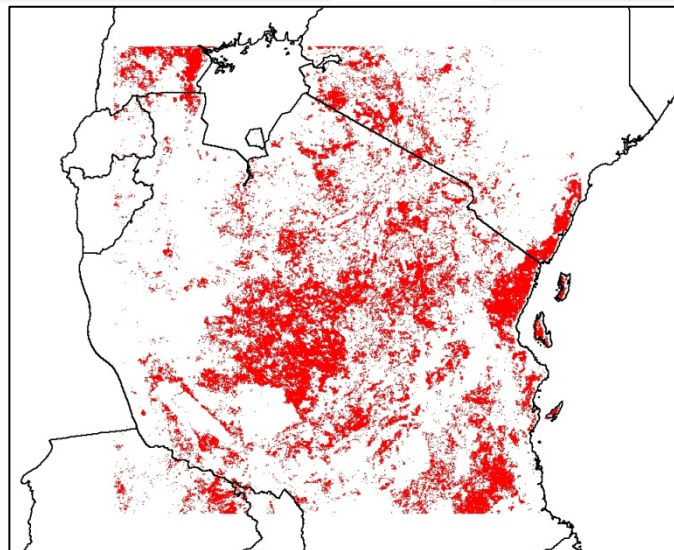


Comparison of Agriculture land classes from 3 satellite products 10 degree tile over East Africa

MODIS V003



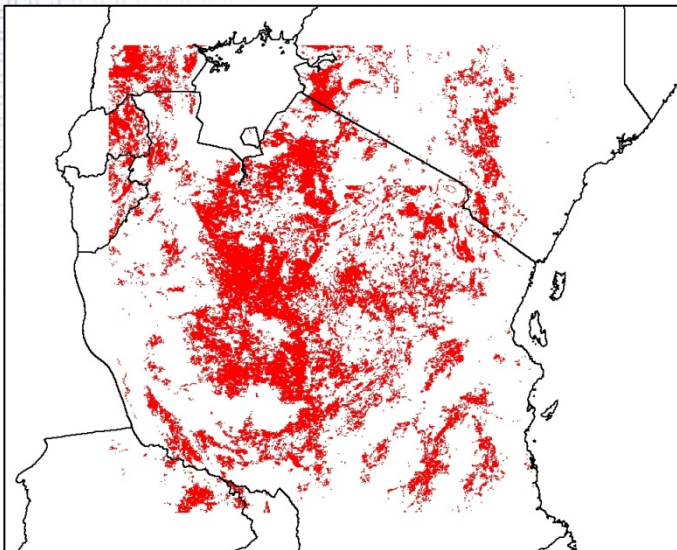
IGBP



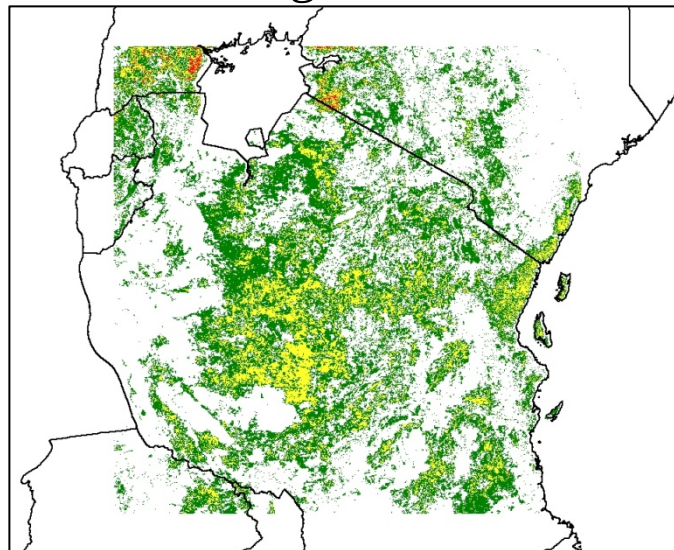
Challenge:

Improve access and reliability of Earth Observations

GLC2000



Agreement



- ☐ No Ag
- ☒ 1 product
- ☒ 2 products
- ☒ All products



Agriculture?
Shrub?
What is this
anyway?



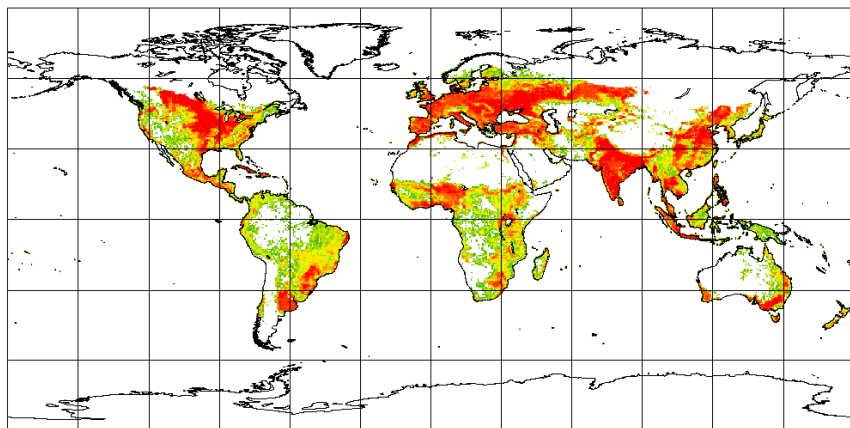


What do we mean by croplands or agriculture

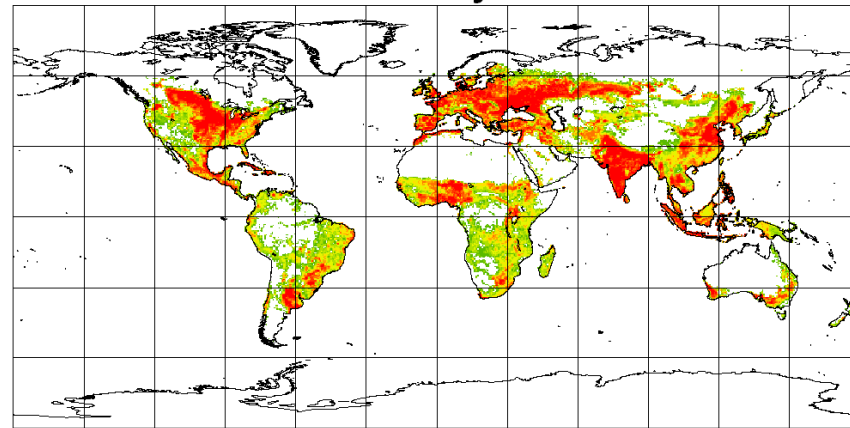


Present Day Options: Agriculture

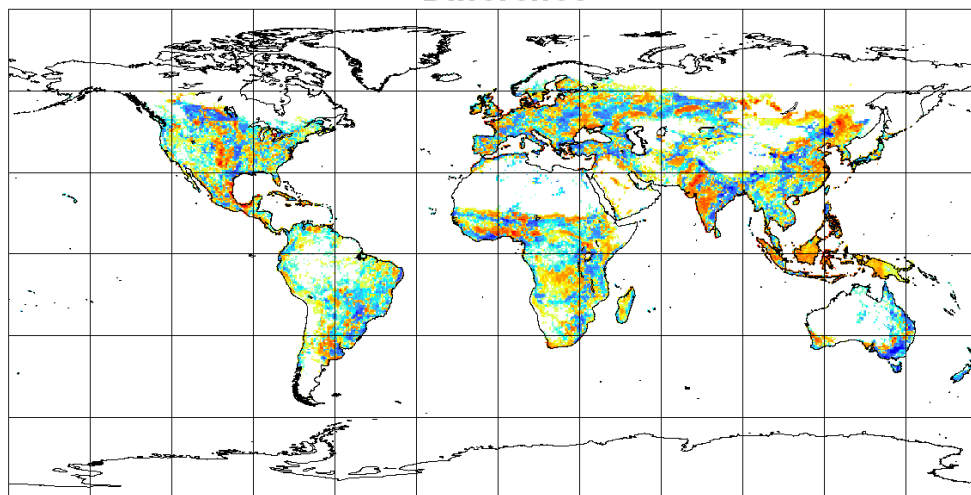
HYDE 3.0



Ramankutty 2000



Difference





Issues of definitions

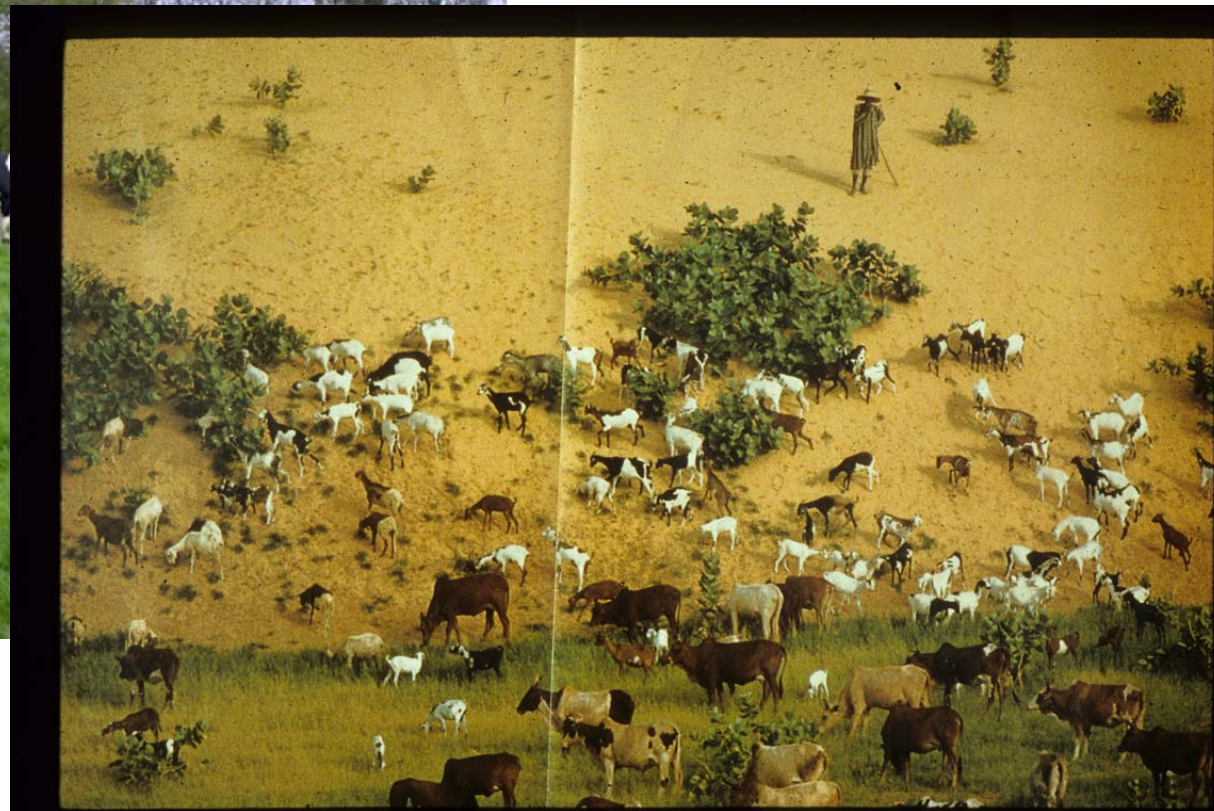
e.g. What is Pasture/Grazing?





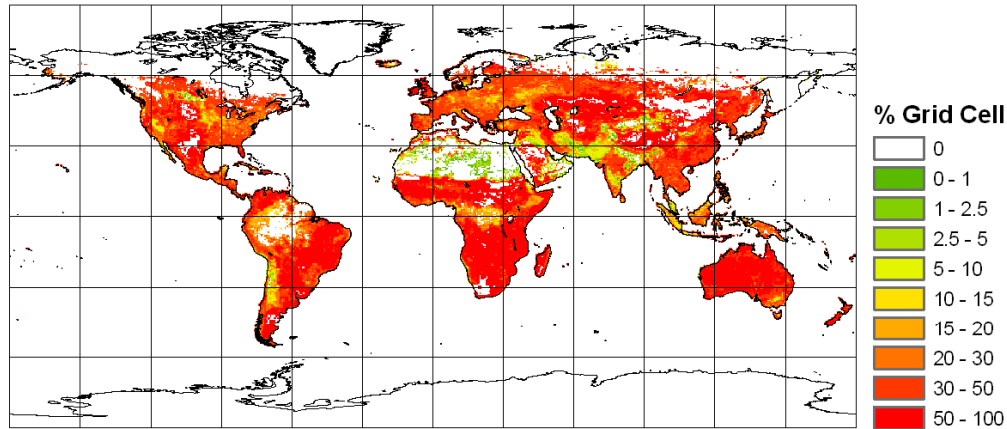
Issues of definitions

e.g. What is Pasture/Grazing?

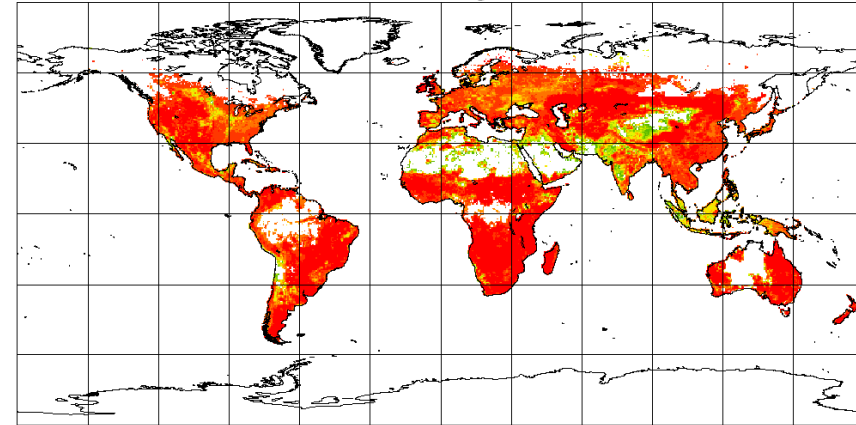


Present Day Options: Pasture

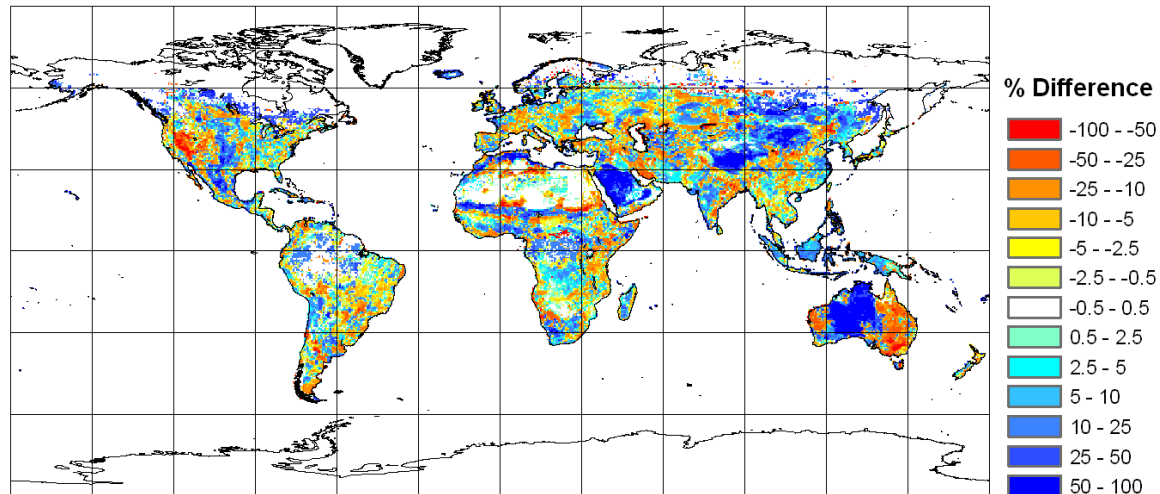
HYDE 3.0



Ramankutty 2000



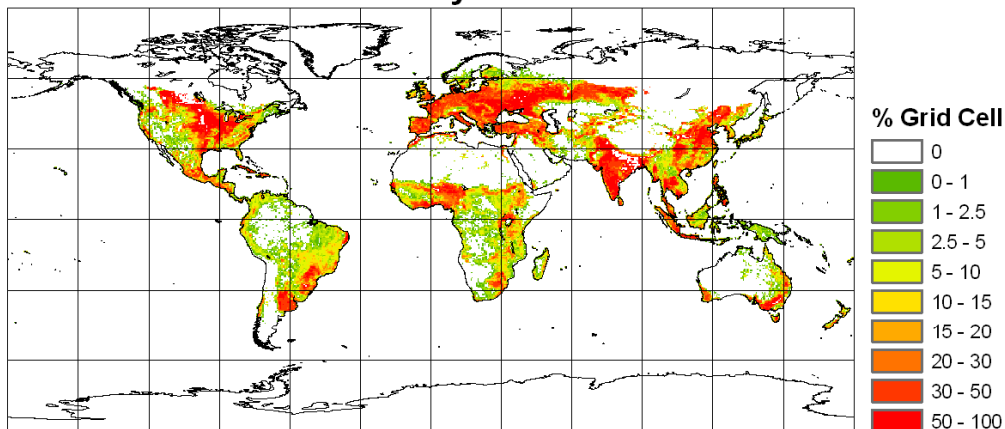
Difference



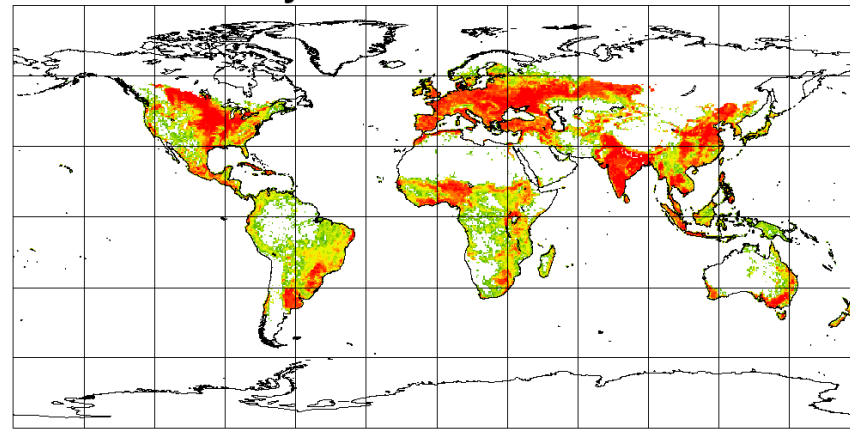


Creating datasets order of entry: Agriculture

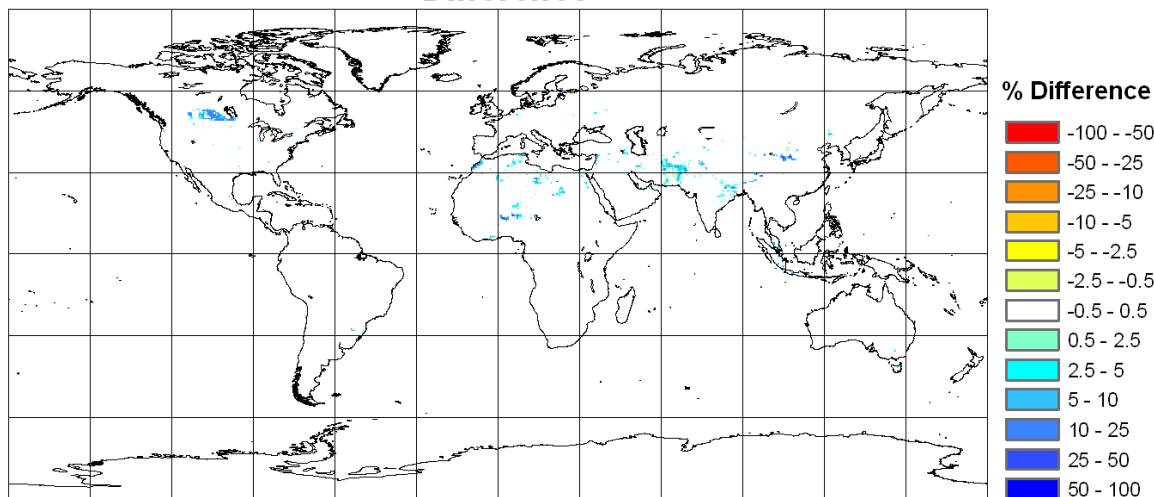
Human Activity Prioritized



MODIS Physical Information Prioritized



Difference



Order of entry

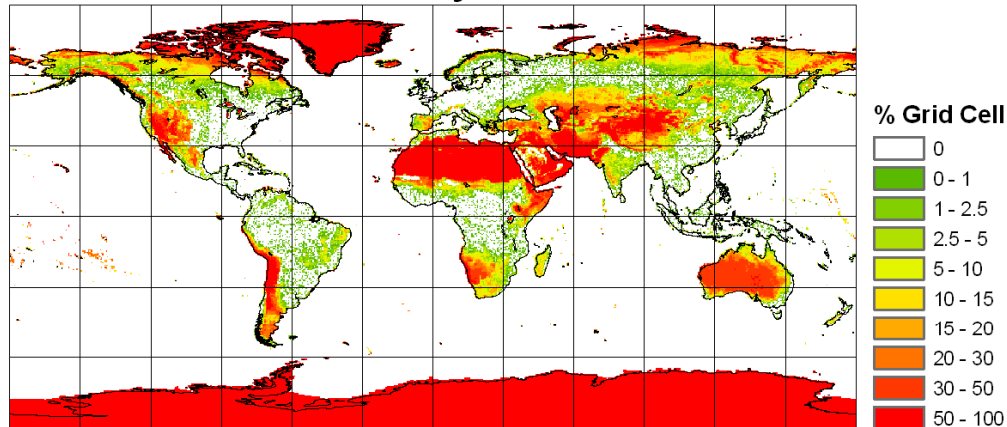
Urban
Agriculture
Pasture/Grazing
Bare ground
Forest
Shrub
Grass

Order of entry

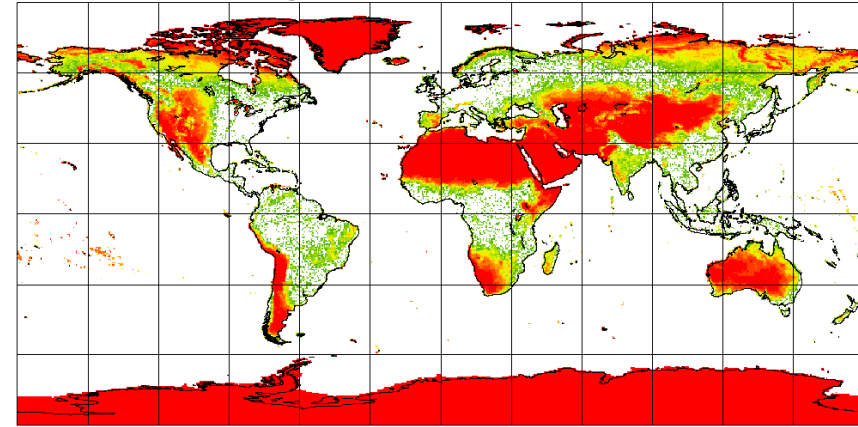
Urban
Bare ground
Forest
Agriculture
Pasture/Grazing
Shrub
Grass

Creating datasets order of entry: Bare

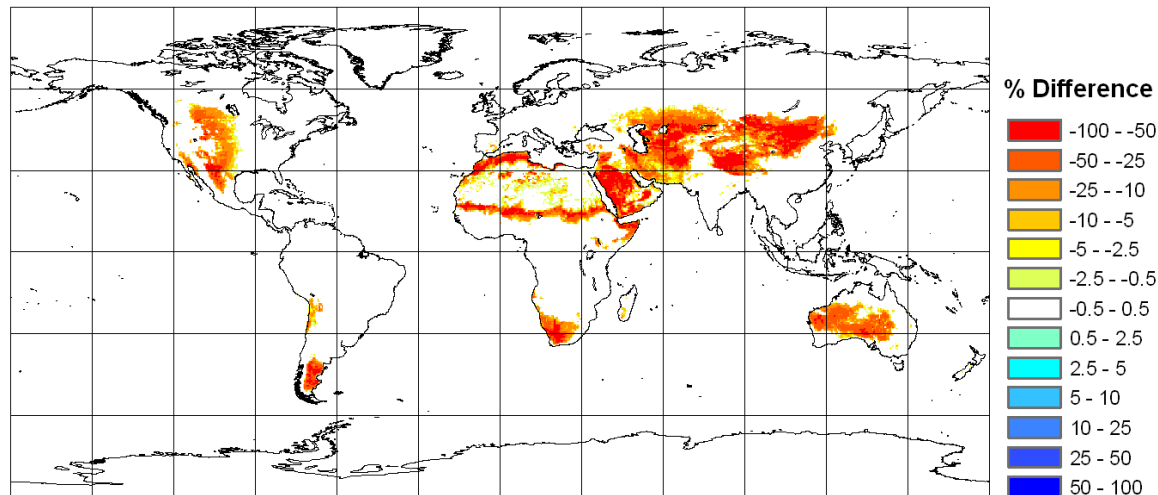
Human Activity Prioritized



MODIS Physical Information Prioritized



Difference



Order of entry

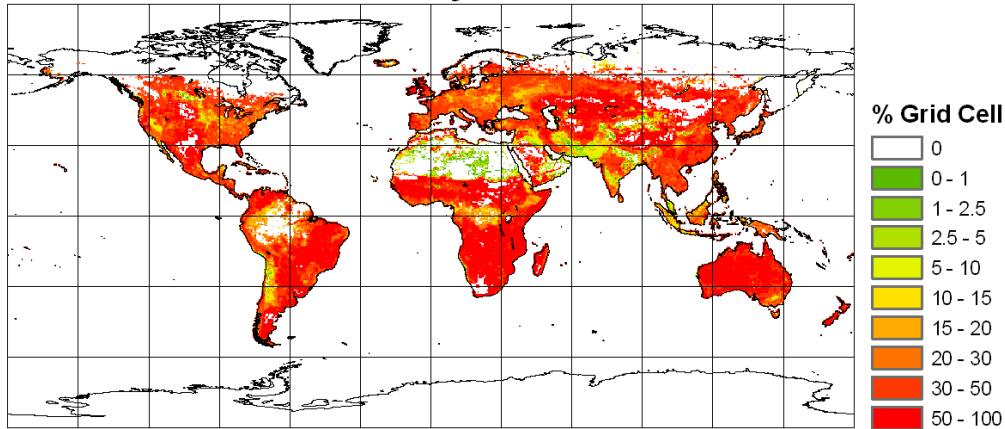
Urban
Agriculture
Pasture/Grazing
Bare ground
Forest
Shrub
Grass

Order of entry

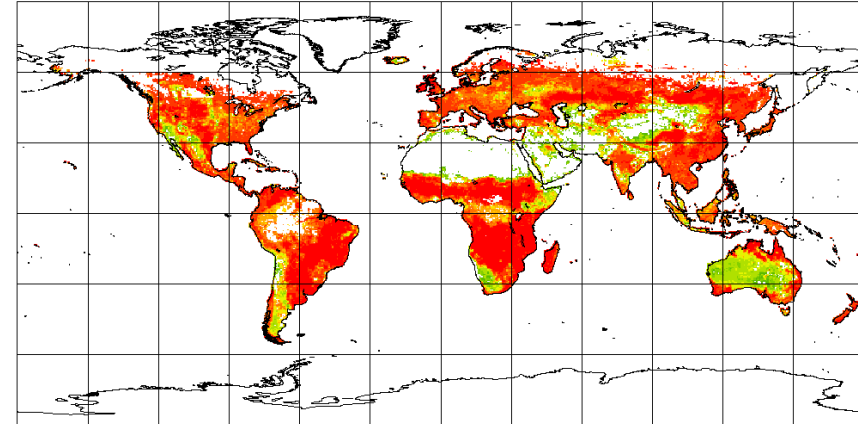
Urban
Bare ground
Forest
Agriculture
Pasture/Grazing
Shrub
Grass

Creating datasets order of entry: Grasses

Human Activity Prioritized



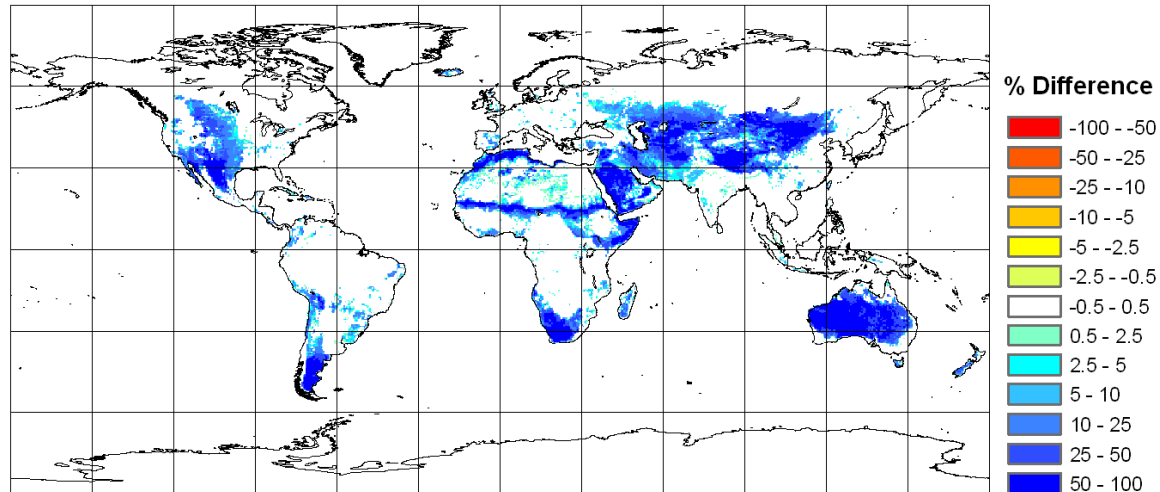
MODIS Physical Information Prioritized



Order of entry

Urban
Agriculture
Pasture/Grazing
Bare ground
Forest
Shrub
Grass

Difference



Order of entry

Urban
Bare ground
Forest
Agriculture
Pasture/Grazing
Shrub
Grass

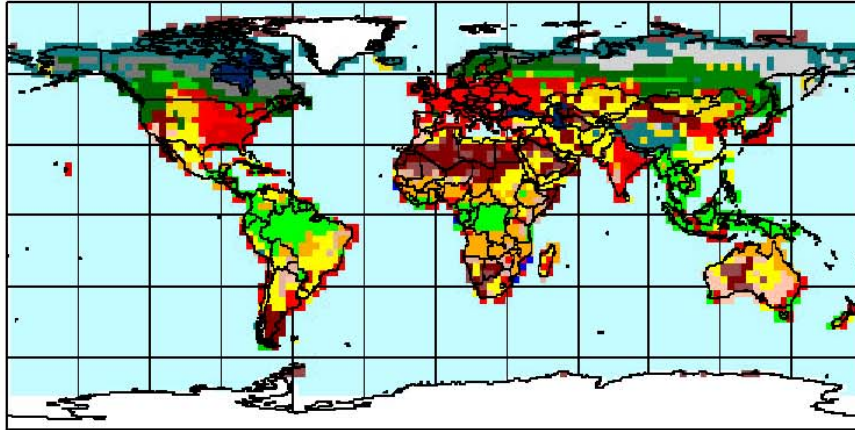


Question

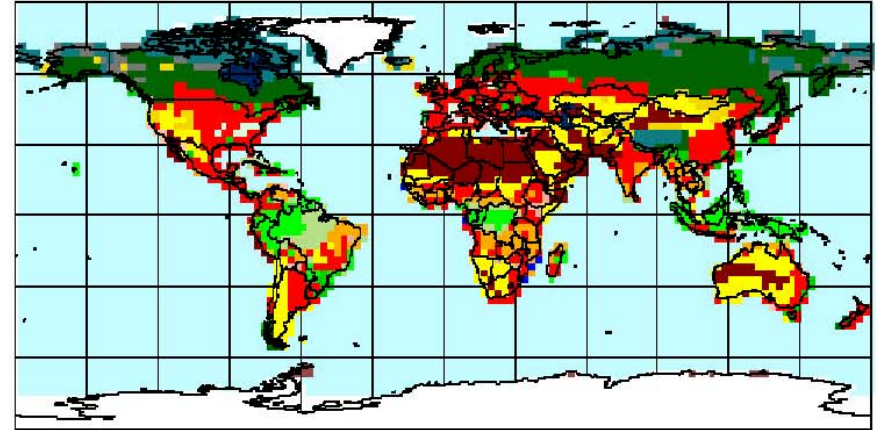
- How important is it to get this right and coordinated?

How important is the choice of present day land cover?

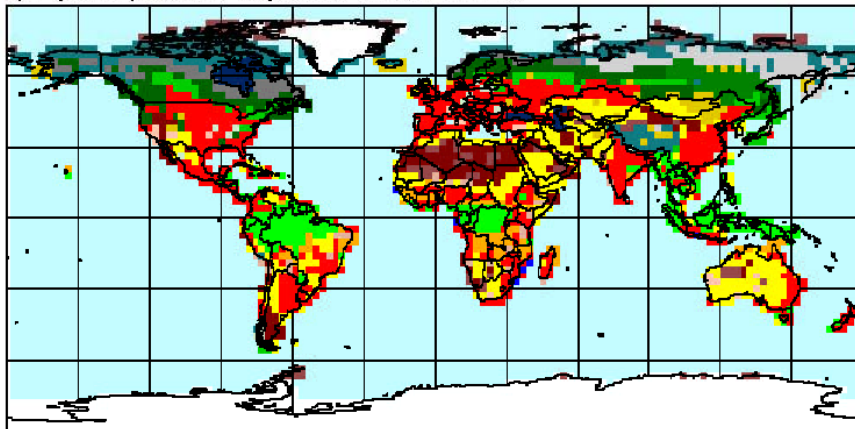
a) LSM original present day land cover: LSM1c



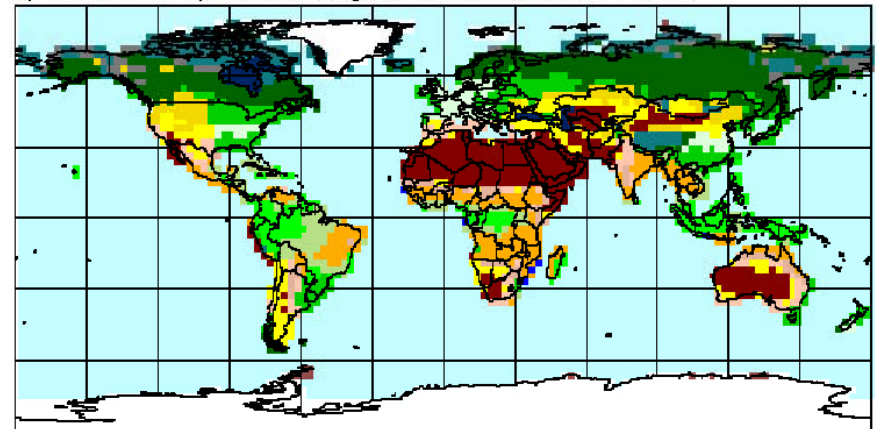
b) IMAGE 2.2 present day land cover: IMALc



c) Hybrid present day land cover: HYBLc



d) IMAGE 2.2 potential vegetation land cover: POT1c



LSM Land Cover Types

0 - Ocean	8 - Broadleaf decid	15 - Forest crop	22 - Semi-Desert
1 - Ice	10 - Tropical broadleaf	17 - Cool grassland/steppe	26 - Crop
2 - Desert	11 - Trop seasonal decid tree	18 - Warm grassland	27 - Forest wetland
3 - Needleleaf evergreen	12 - Savanna	19 - Tundra	28 - Non-forest wetland
4 - Needleleaf decid	13 - Evergreen forest tundra	20 - Evergreen shrub	
6 - Temp mixed forest	14 - Decid forest tundra	21 - Decid Shrub	



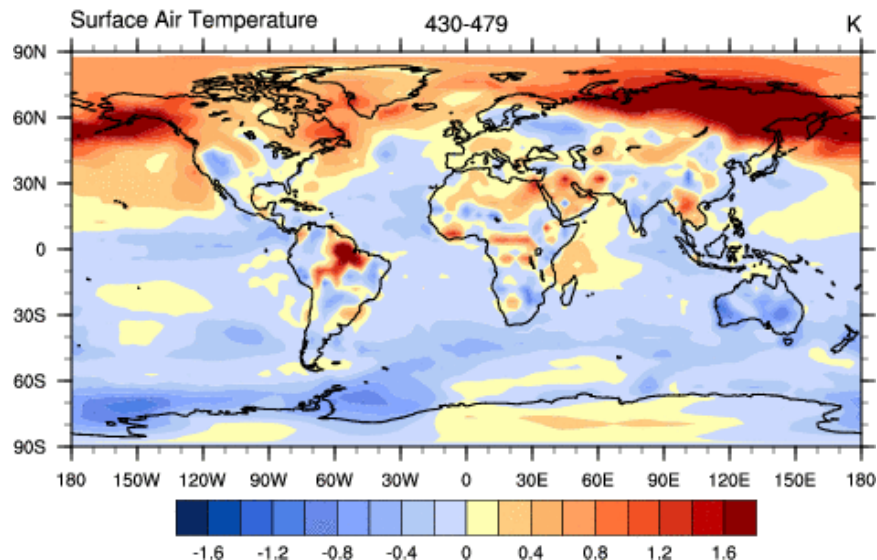
PCM Uncertainty v.s. Historical Land Cover

PRESENT DAY UNCERTAINTY

- Arctic – albedo
- Amazon – latent heat flux
- Australia – albedo



Present Day (IMAGE) Land Surface minus control



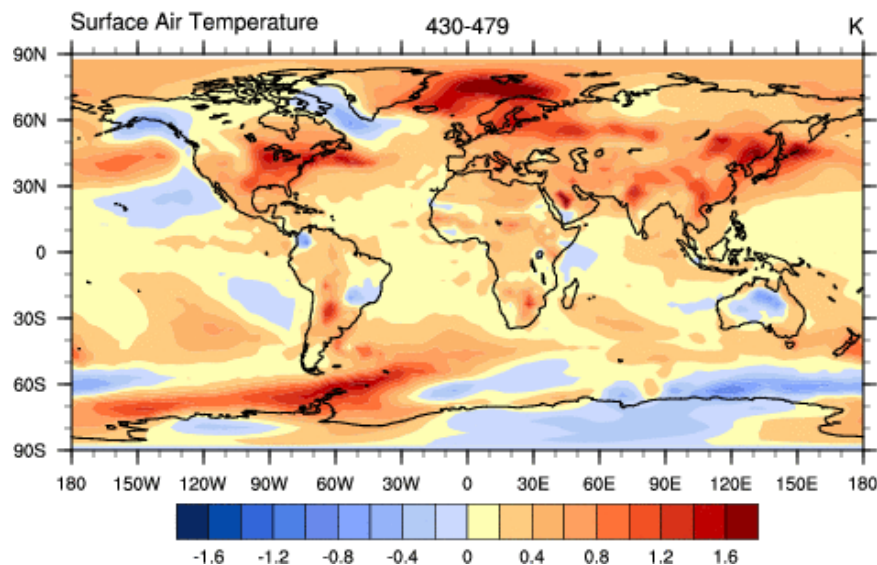
HISTORICAL CHANGE

Climate difference from land cover classification is as large as the climate difference from land cover change

- Primarily shift due to agriculture



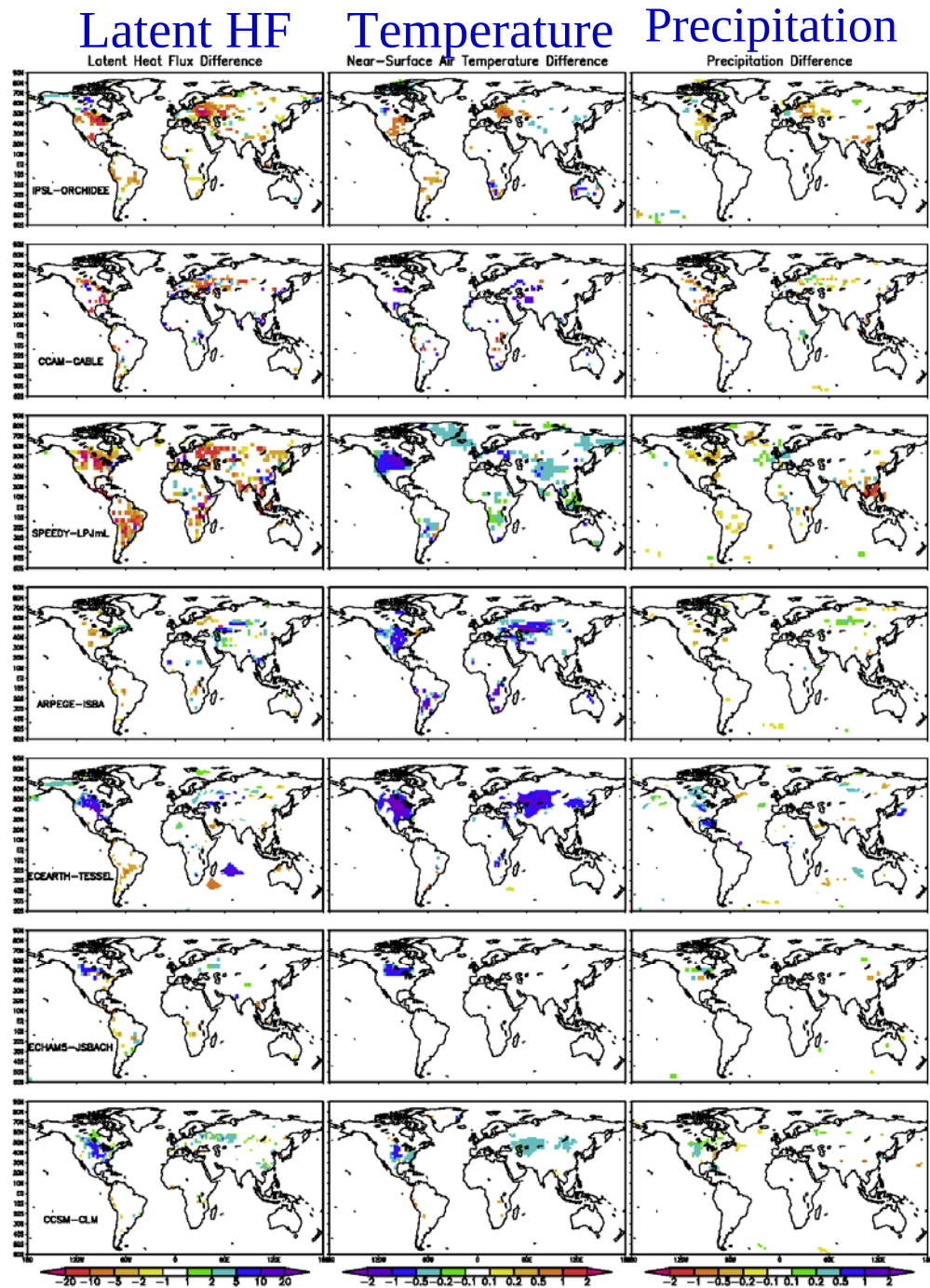
Natural Vegetation minus Present Day (IMAGE)





LUCID 1850-Present comparison

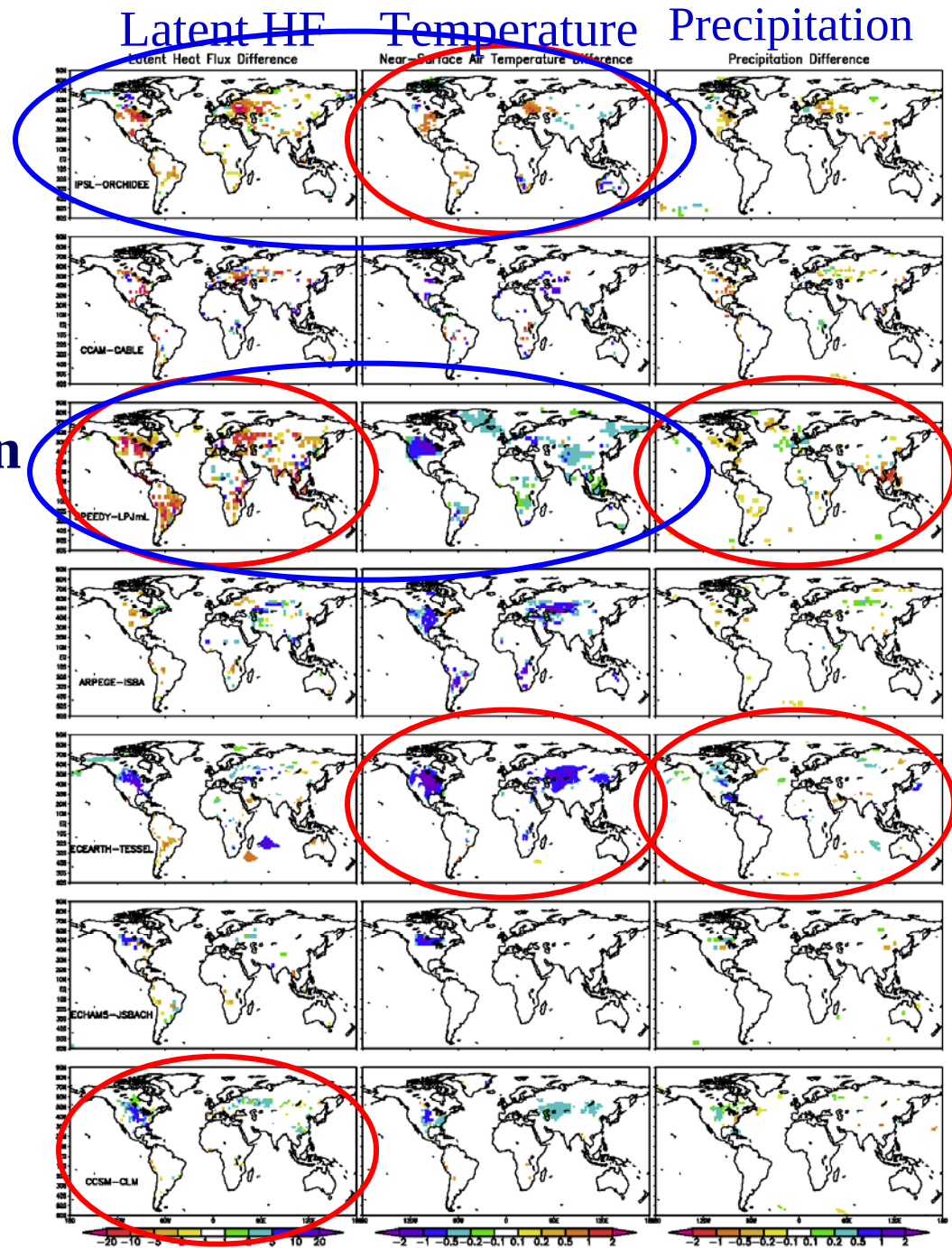
What is going on here?





LUCID 1850-Present comparison

What is going on here?

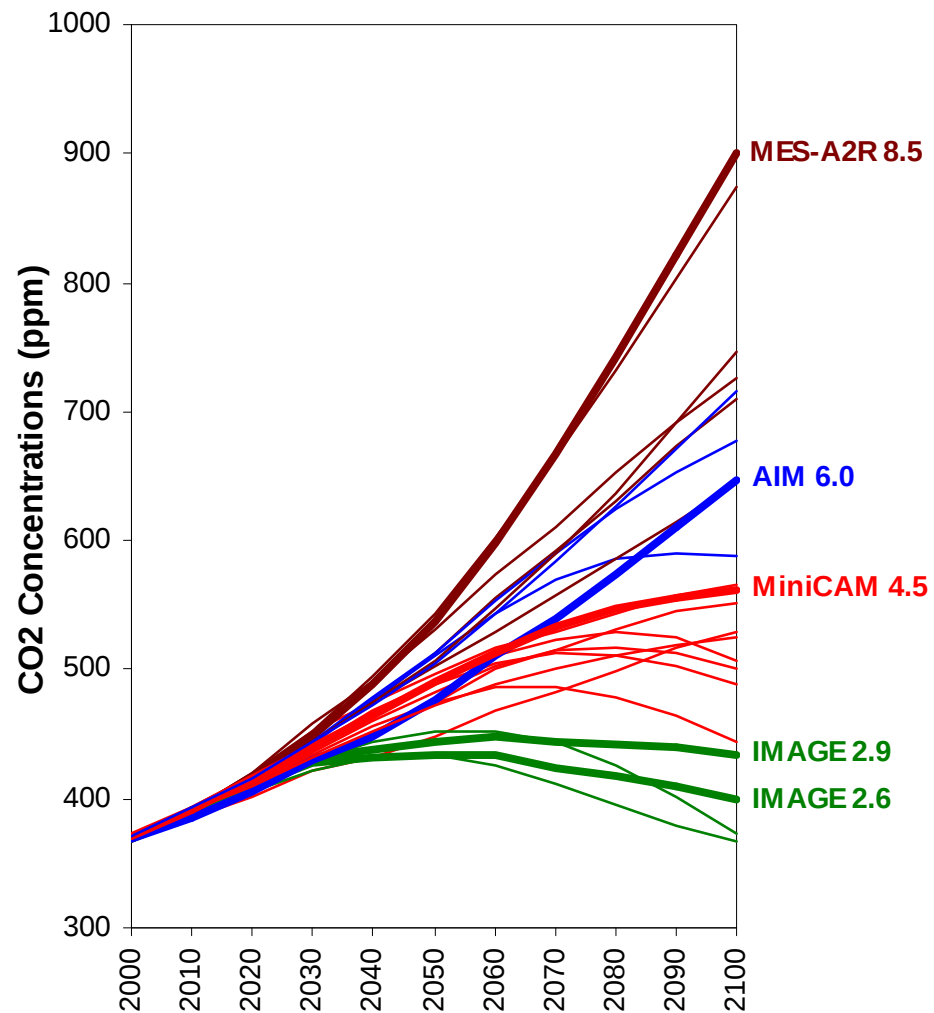
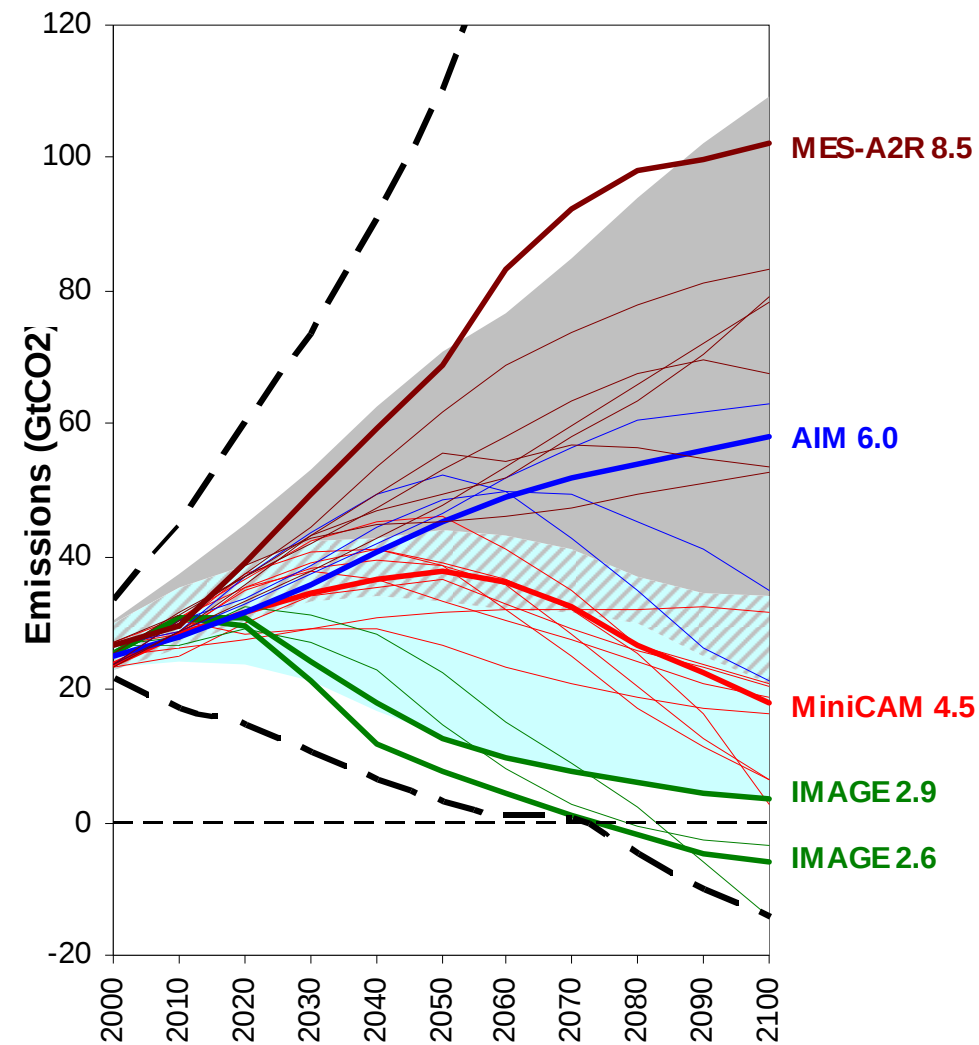




Landcover Change IPCC AR5



Selected RCP CO₂ Properties





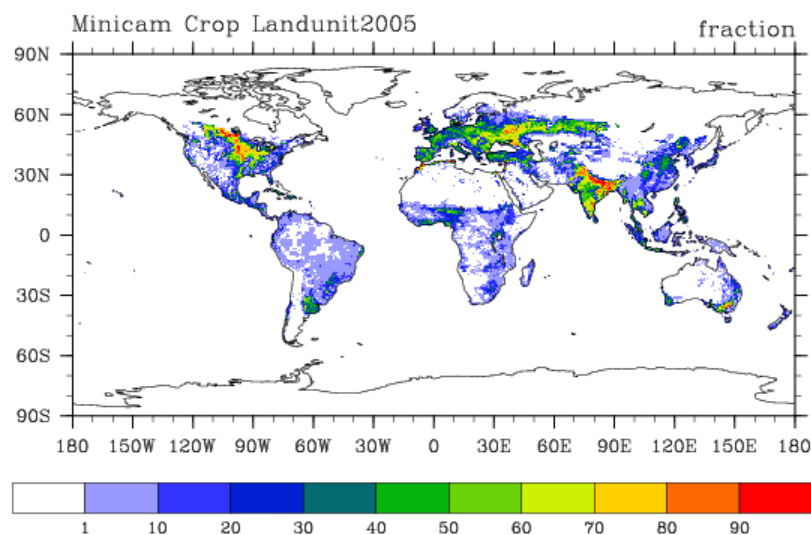
IPCC AR5 – RCP Standardization

1. All scenarios will use an identical 2005 land cover as a starting point
2. All pathways share the same historical trajectory to 2005. After 2005 they diverge following their own representative pathway.
3. For each RCP, minimal information related to land cover change will provide changes in four basic land units:
 - Primary Vegetation (V)
 - Secondary Vegetation (S)
 - Cropping (C)
 - Pasture (P)
4. Historical harvesting of biomass is also prescribed for both primary and secondary vegetation land units (Hurtt, 2006)
5. The University of New Hampshire (UNH) group is standardizing each scenario and the historical trajectory for harvest and land cover information
6. Each ESM group will have to construct land cover datasets by blending their own natural land cover with the prescribed human activities

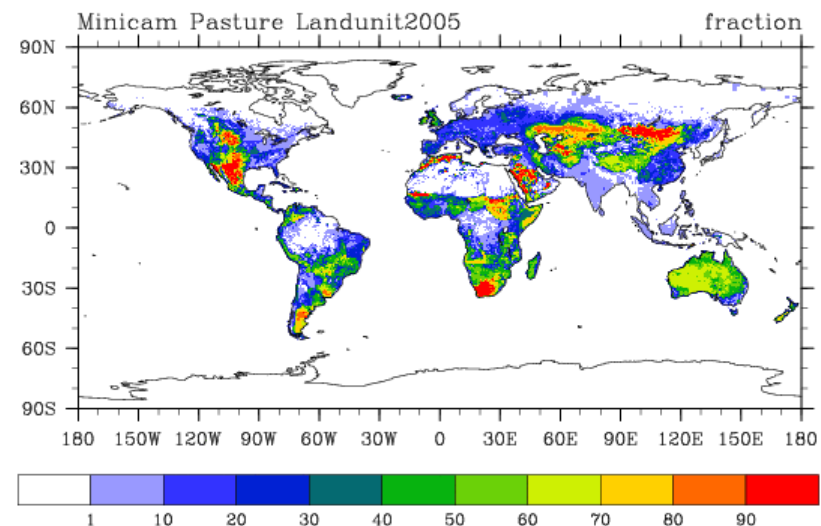


UNH land units 2005 Land Cover

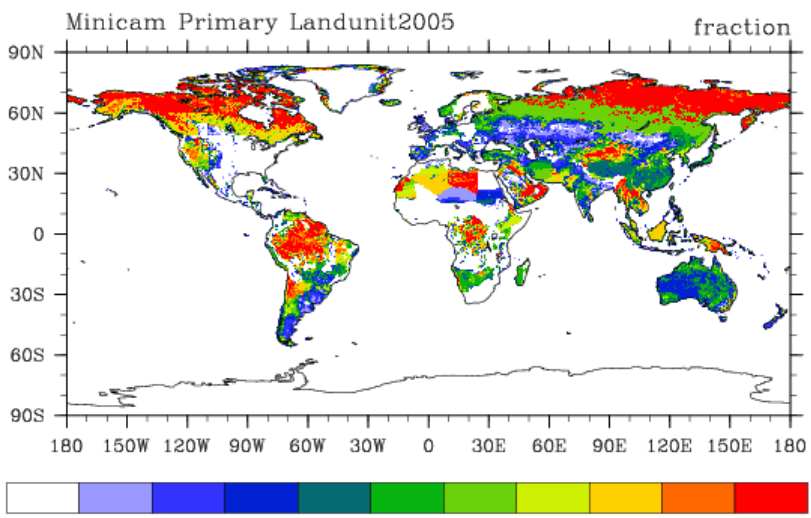
Crop



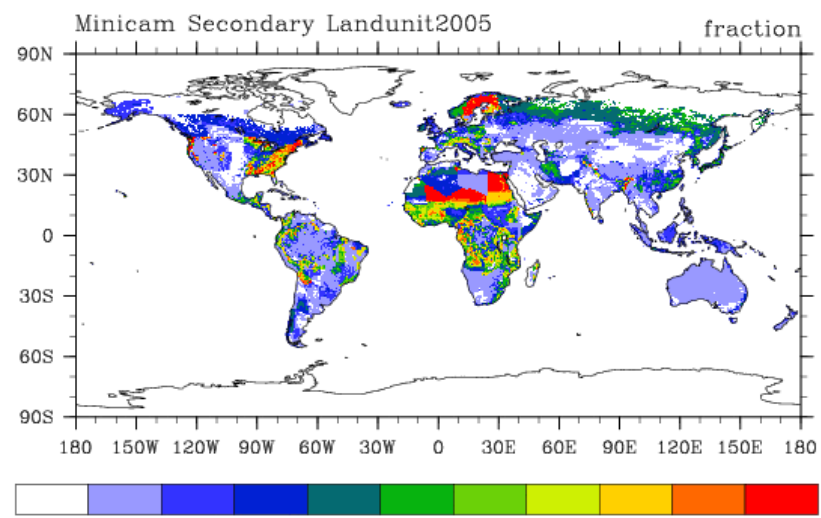
Pasture



Primary



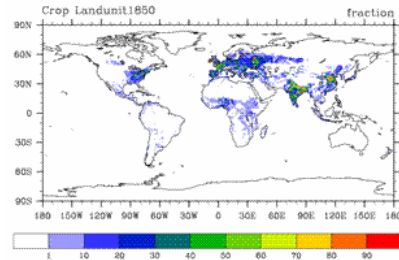
Secondary



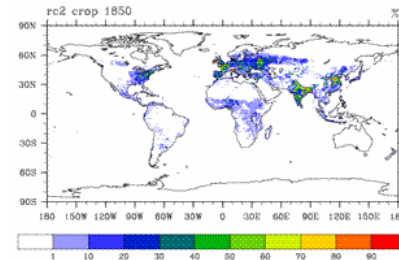
Mapping UNH land units to PFTs 1850

Historical (UNH Hurtt): Landunits to PFTs 1850

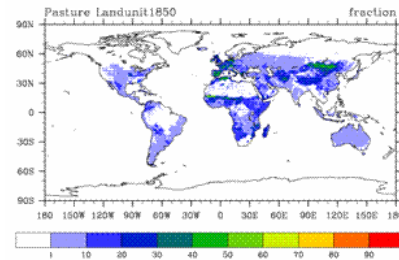
Crop Landunit



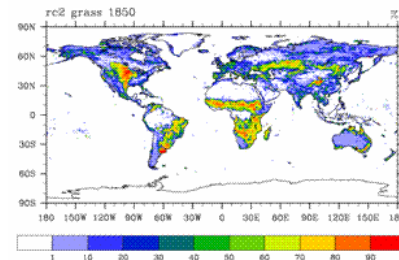
Crop PFT



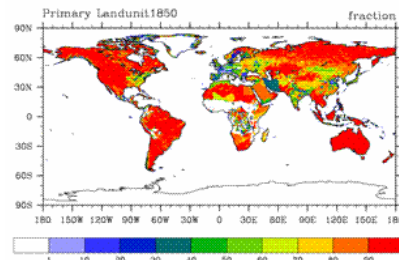
Pasture Landunit



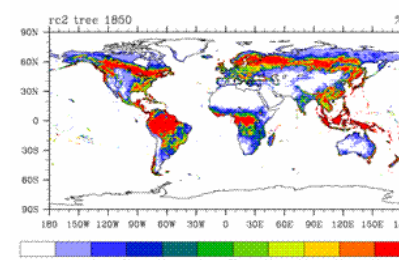
Grass PFTs



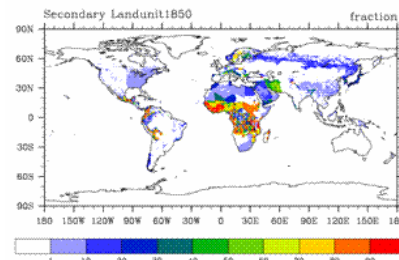
Primary



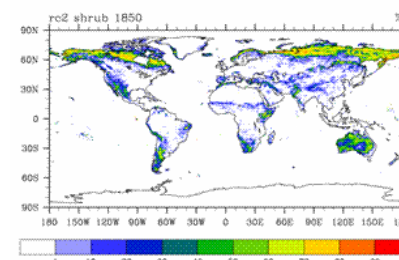
Tree PFTs



Secondary



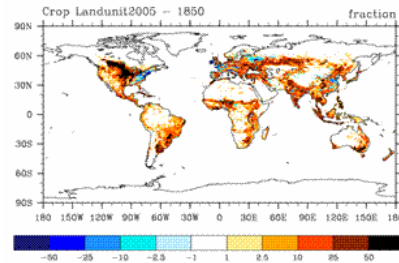
Shrub PFTs



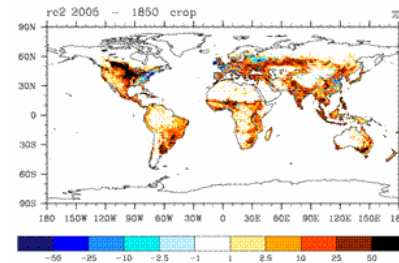
Mapping change in UNH land units to PFTs (1850-2005)

Historical (UNH Hurtt): PFT changes 2005-1850

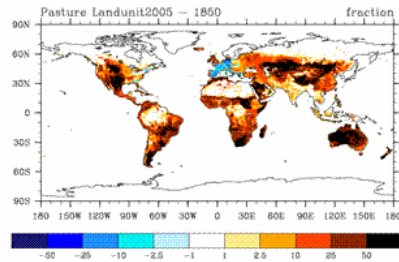
Crop Land Unit



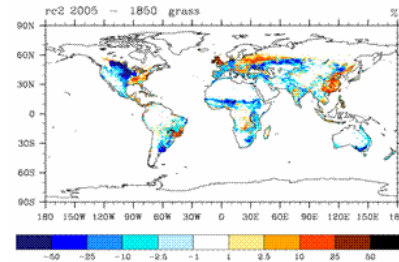
Crop PFT



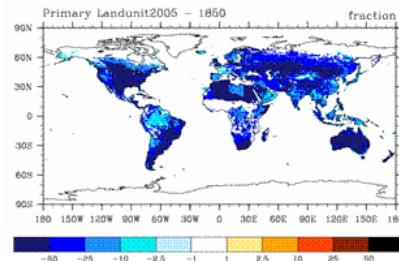
Pasture Land Unit



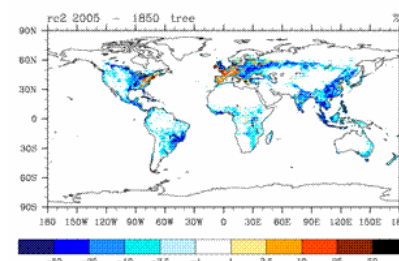
Grass PFTs



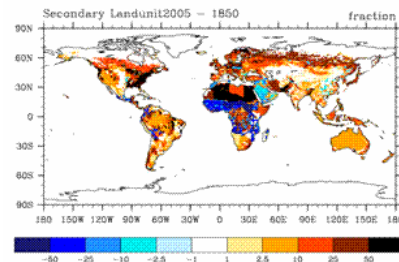
Primary Land Unit



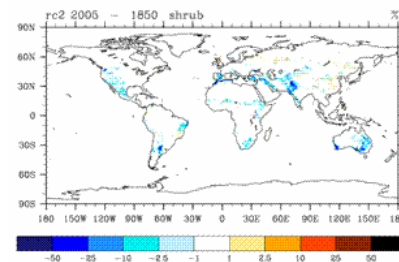
Tree PFTs



Secondary Land Unit



Shrub PFTs

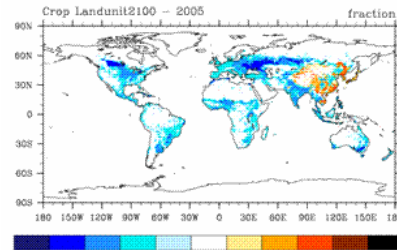




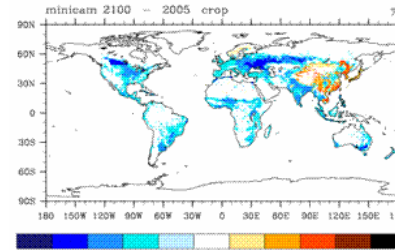
Mapping change in UNH land units to PFTs (2005-2100)

Mini-Cam (RCP 4.5 Wm⁻²): PFT changes 2100-2005

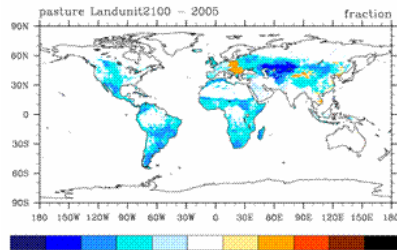
Crop Landunit



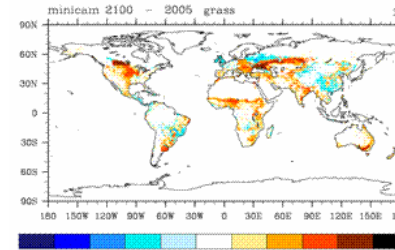
Crop PFT



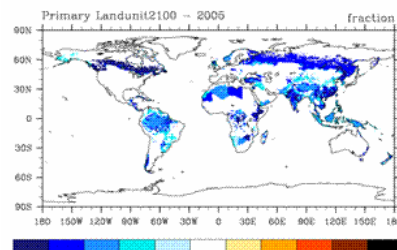
Pasture Landunit



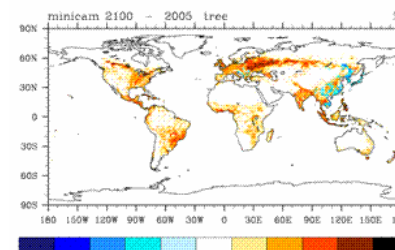
Grass PFTs



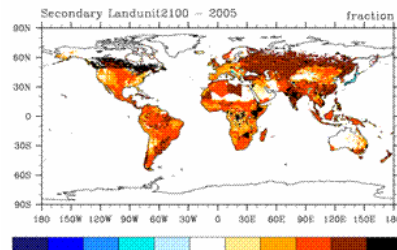
Primary Landunit



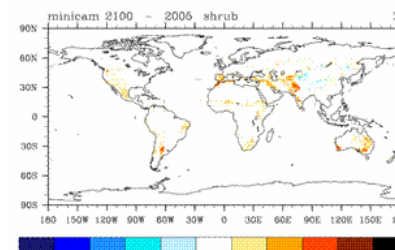
Tree PFTs



Secondary Landunit



Shrub PFTs



IPCC RCP:
Mini-Cam
4.5 Wm⁻² Scenario



Deforestation





Deforestation

To simulate deforestation we need:

- Deforestation activities to be prescribed
- Can be managed human land – treated like agriculture
- Can be incorporated through a DVGM
- Should include carbon sinks associated with deforestation
- Should incorporate succession changes
- Need information on tree species favored by humans
- Include type of logging/burning



Wood Harvest



Wood Harvest Classes (Hurtt et al. 2006)

vh1 : primary forest biomass harvested from each gridcell (in kgC)

vh2 : primary non-forest biomass harvested from each gridcell (in kgC)

sh1 : mature secondary forest biomass harvested from each gridcell (in kgC)

sh2 : young secondary forest biomass harvested from each gridcell (in kgC)

sh3 : secondary non-forest biomass harvested from each gridcell (in kgC)

Each also has an area associated with it.



Comparative Wood Densities for Harvest Classes

	Average global carbon density in harvested grid cells kgm ⁻² (percent of vh1 value)				
	Vh1	Vh2	Sh1	Sh2	Sh3
1851	9.24	0.28 (0.030)	4.44 (0.481)	7.29 (0.789)	1.06 (0.115)
2001	8.84	0.30 (0.034)	4.67 (0.528)	5.83 (0.660)	0.42 (0.048)
2031 IMAGE	8.69	0.54 (0.062)	4.95 (0.570)	5.42 (0.624)	0.36 (0.042)
2031 Mini-CAM	8.74	0.59 (0.068)	4.75 (0.543)	5.47 (0.626)	0.36 (0.041)
2100 IMAGE	7.56	0.43 (0.056)	5.54 (0.733)	4.55 (0.602)	0.43 (0.057)
2100 Mini-CAM	8.59	0.33 (0.038)	5.97 (0.695)	4.84 (0.563)	0.50 (0.058)
<i>Average</i>	8.61	0.412 (0.048)	5.05 (0.587)	5.57 (0.647)	0.52 (0.061)

Outcome:

Wood Harvest area = $vh1 + 0.05*vh2 + 0.6*sh1 + 0.6*sh2 + 0.05*sh3$

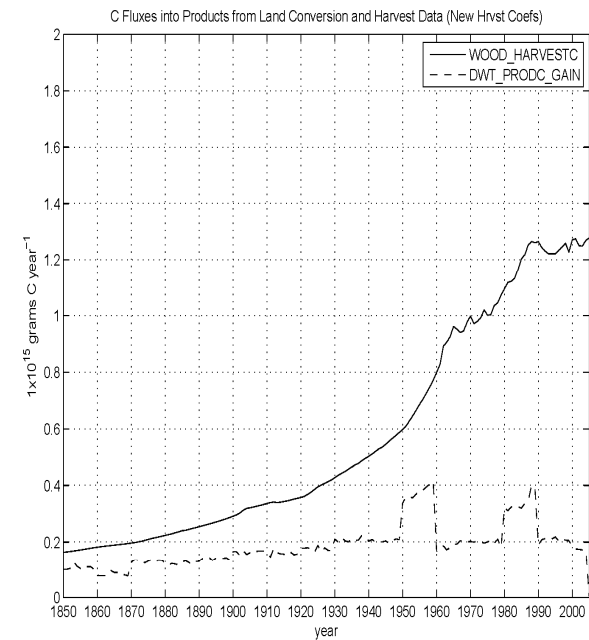
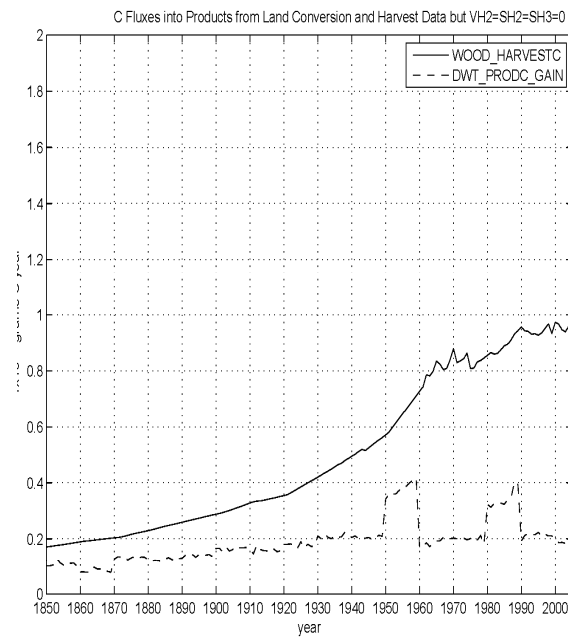
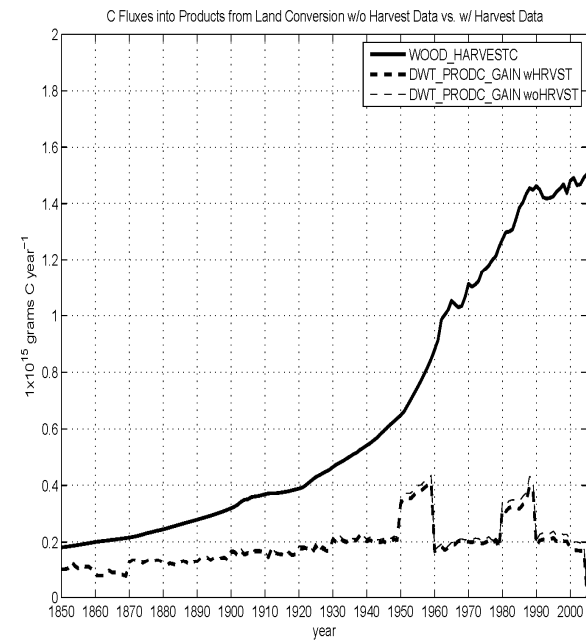


Wood Harvest impact on land carbon cycle

All areas

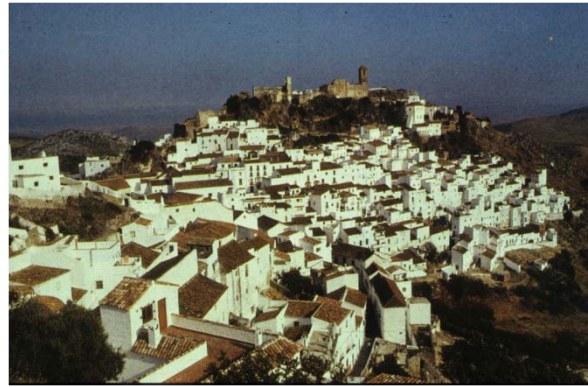
vh1 + sh1

Coefficients

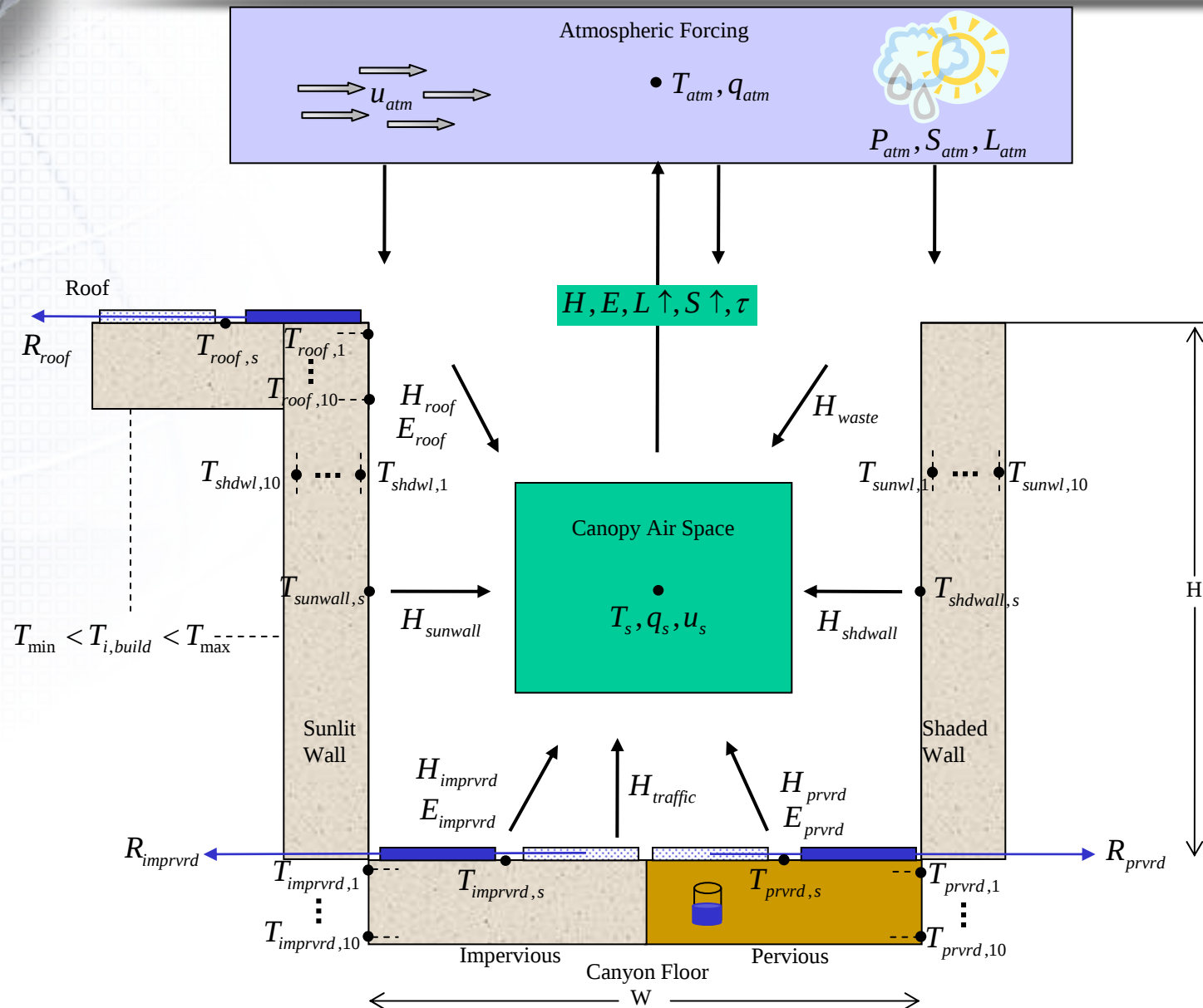




Urbanization



Example: Urban canyon type model



Defining Urban Classes (CBD/HD)





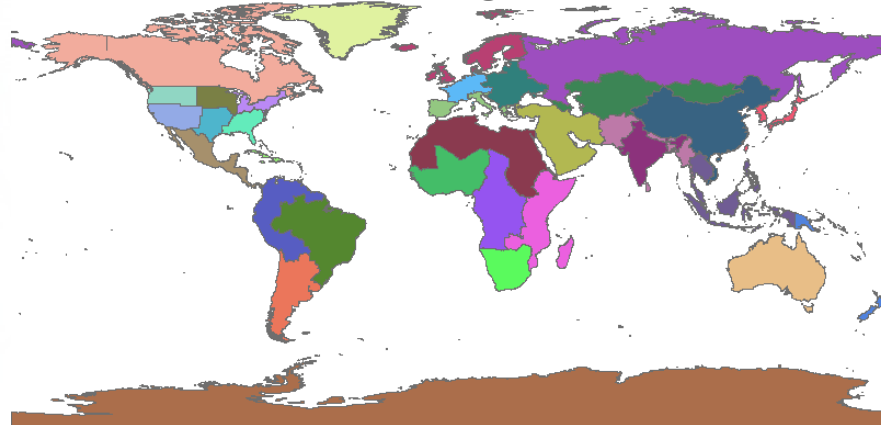
Defining Urban Classes (LD/HD ??)





Example: Urban Input data

Global Regions

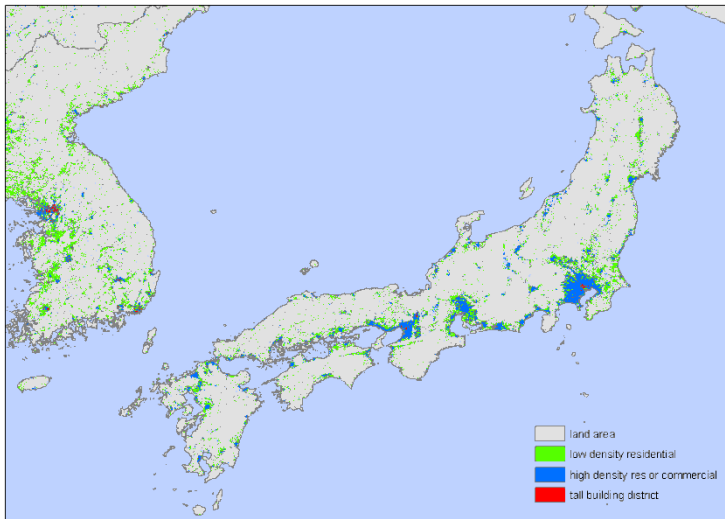


→ To Model

Urban Extent

- 4 classes

Urban areas of Japan and Korea



Urban Properties

- Height
- H/W ratio
- Vegetated fraction
- Roof fraction

Wall properties

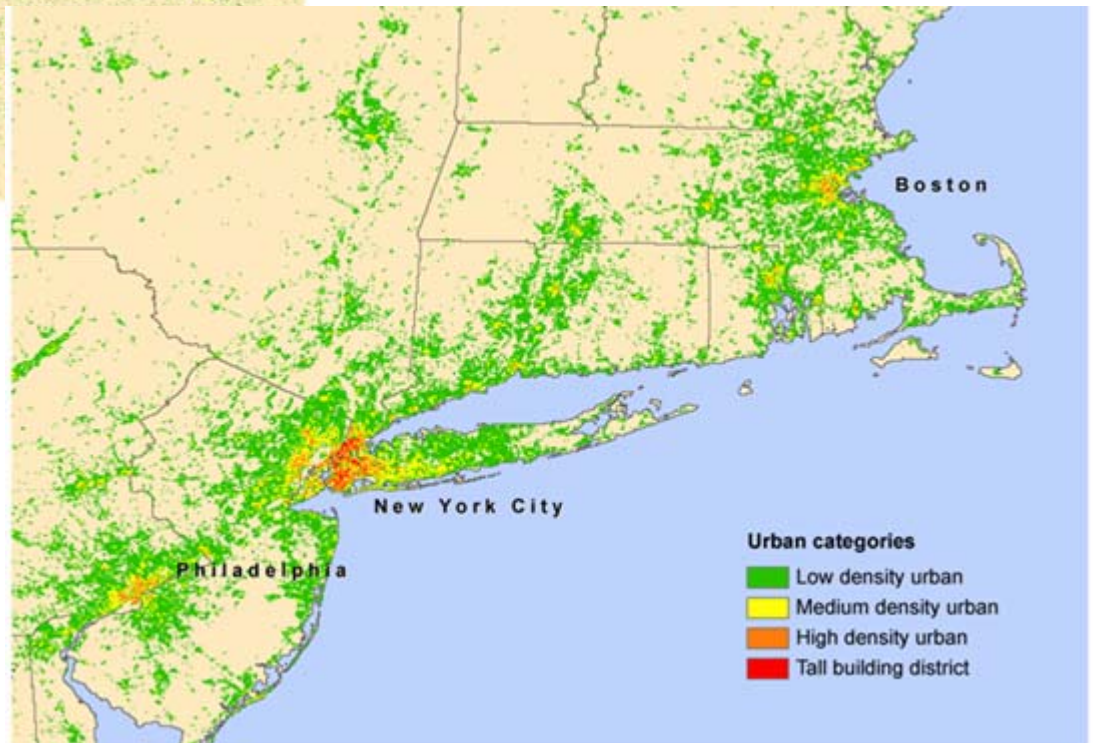
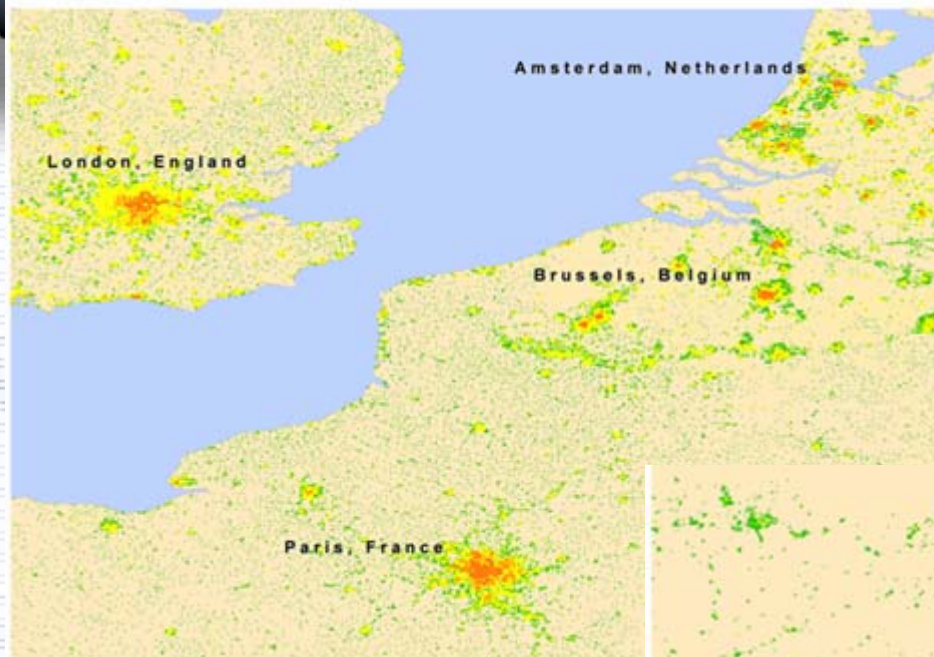
- Albedo
- Thermal properties
- Radiative properties

Roof properties

Road properties

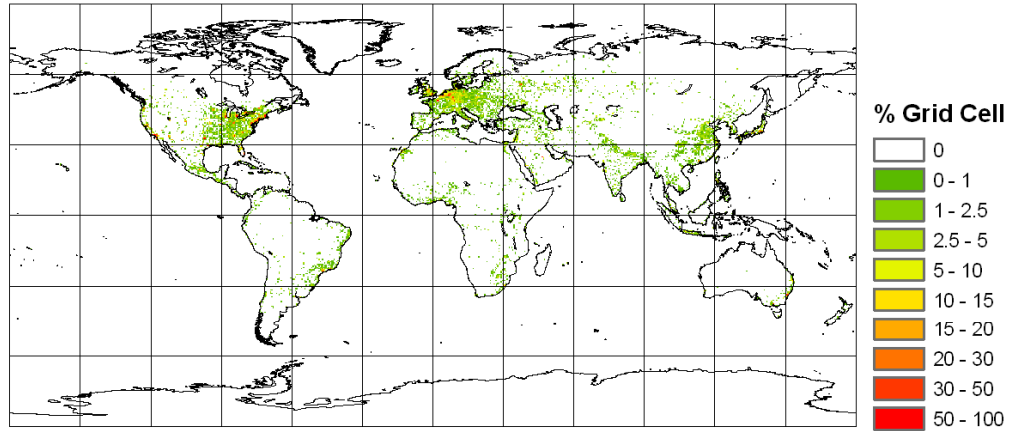
Interior temperature settings

Final Classified 1-km resolution product

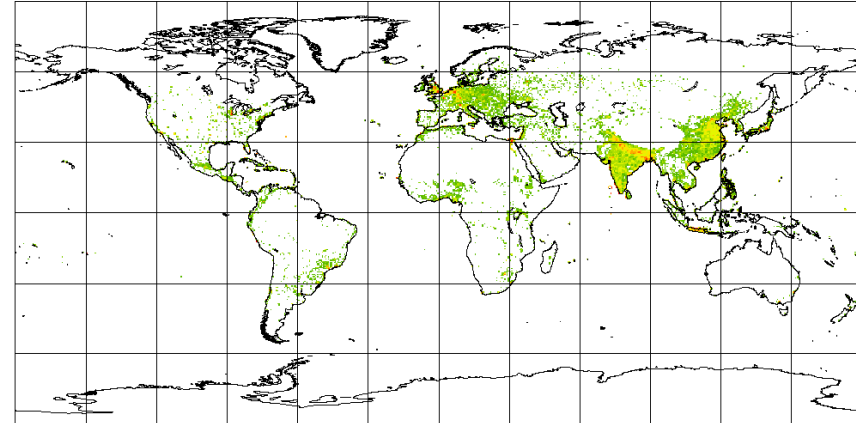


Urban land cover

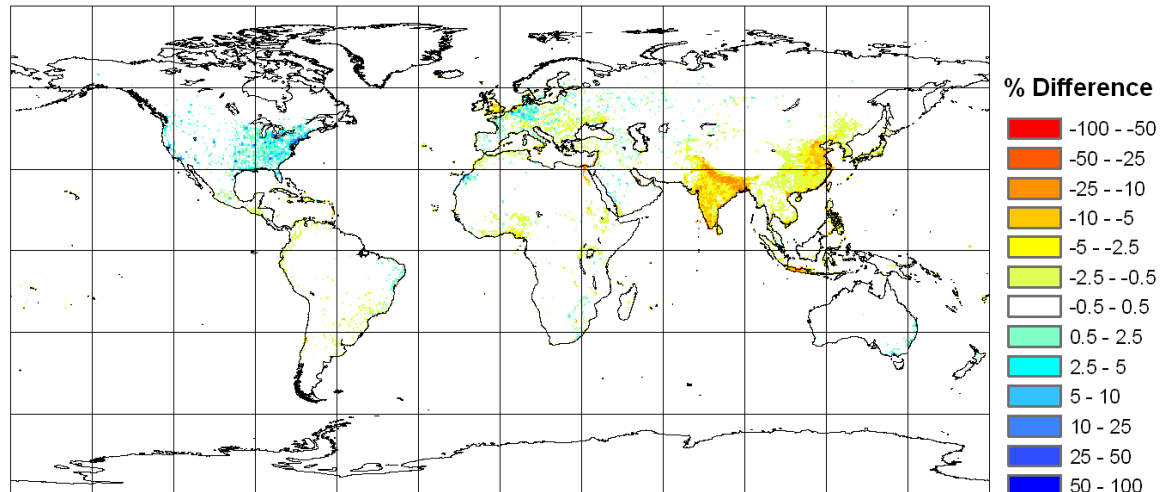
HYDE 3.0



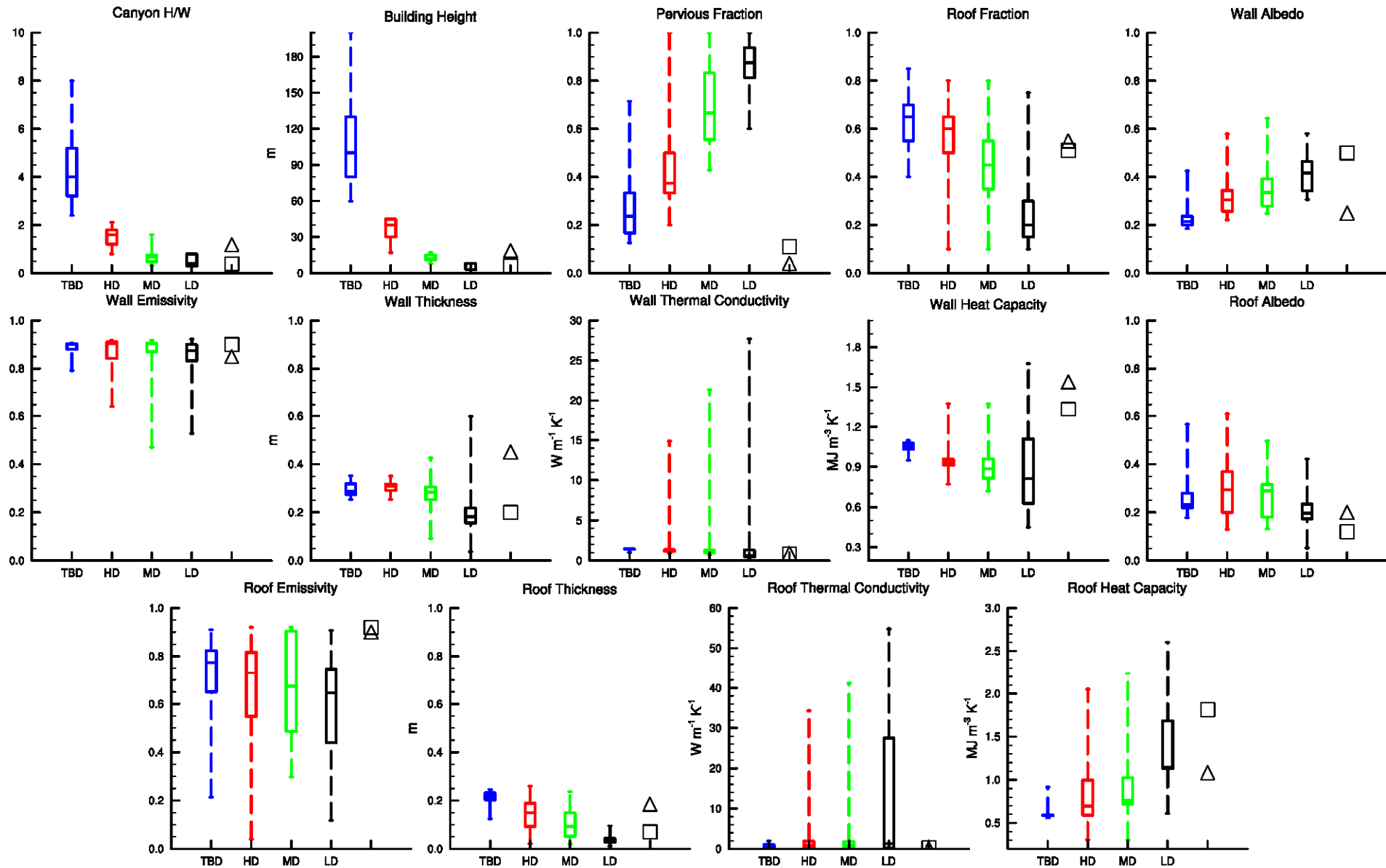
Jackson and Feddema 2004



Difference

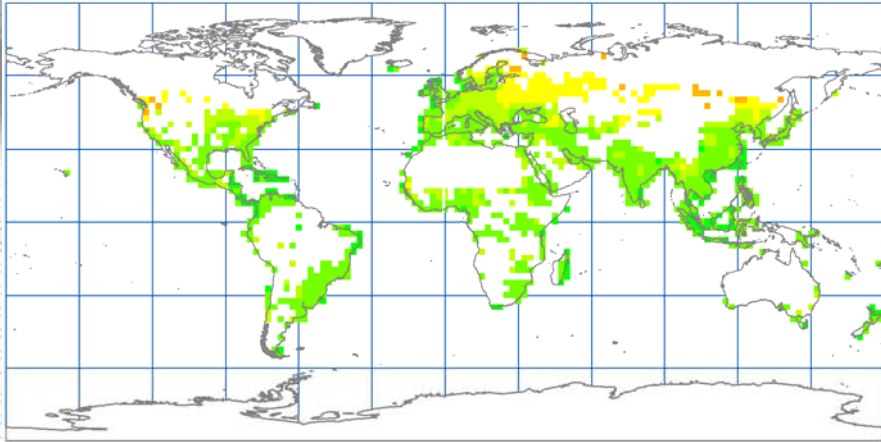


Global Urban Properties

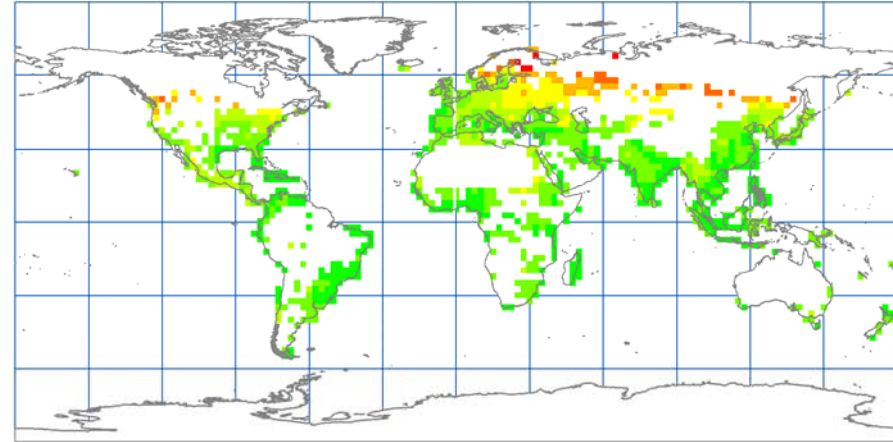


Urban Heat Island Comparison: Parameterization Sensitivity

Vancouver Parameters Applied Globally



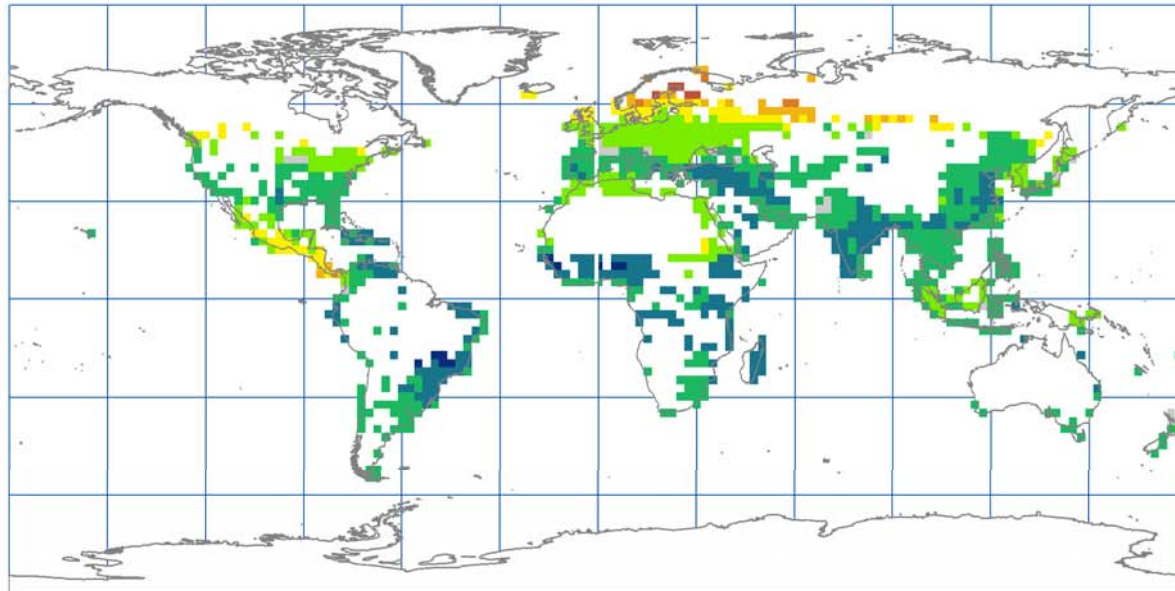
Global Parameter Set



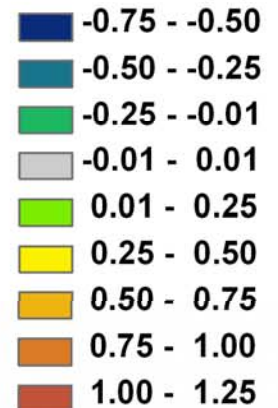
Urban - Rural
Temperature
Difference (K)



Difference: Global - Vancouver



Global - Vancouver
UHI Temperature
Difference (K)





Climate Impact Assessment

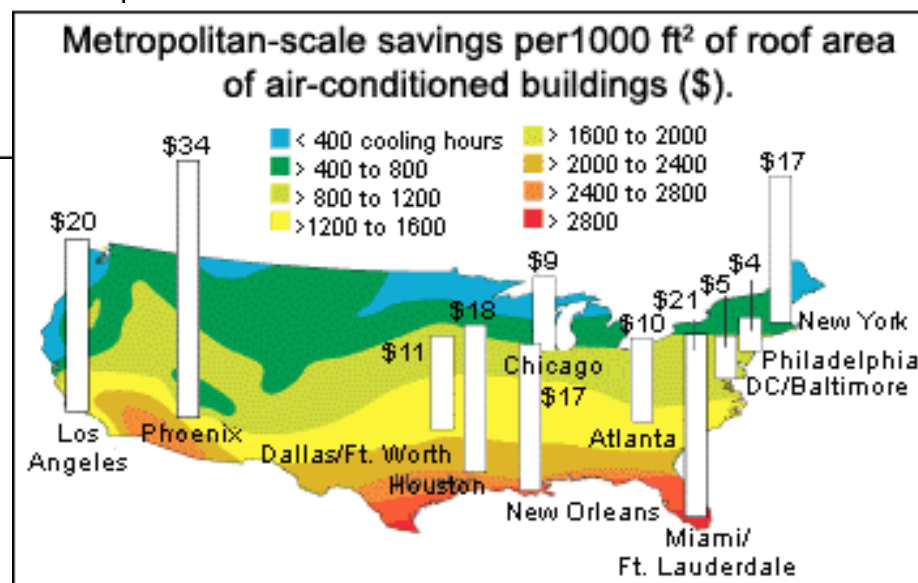
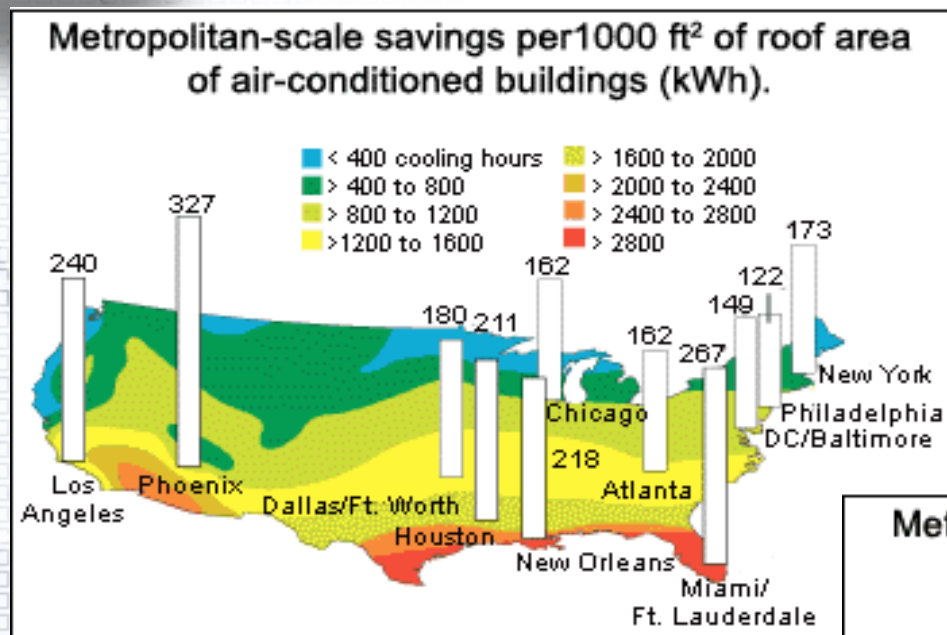
How can Human Activity Models improve climate impact assessment?

"If you look at all the buildings and if you make the roofs white and if you make the pavement more of a concrete type of colour rather than a black type of colour and if you do that uniformly, that would be the equivalent of... reducing the carbon emissions due to all the cars in the world by 11 years – just taking them off the road for 11 years,"

U.S. energy secretary, Professor Steven Chu, highlighting research by Akbari et al. [2009] who calculated that increasing the albedo of urban roofs and pavements globally could produce a negative radiative forcing equivalent to a 44 Gt CO₂ emission offset [TimesOnline, 2009].



Testing Policy Decisions: White Roof Experiment

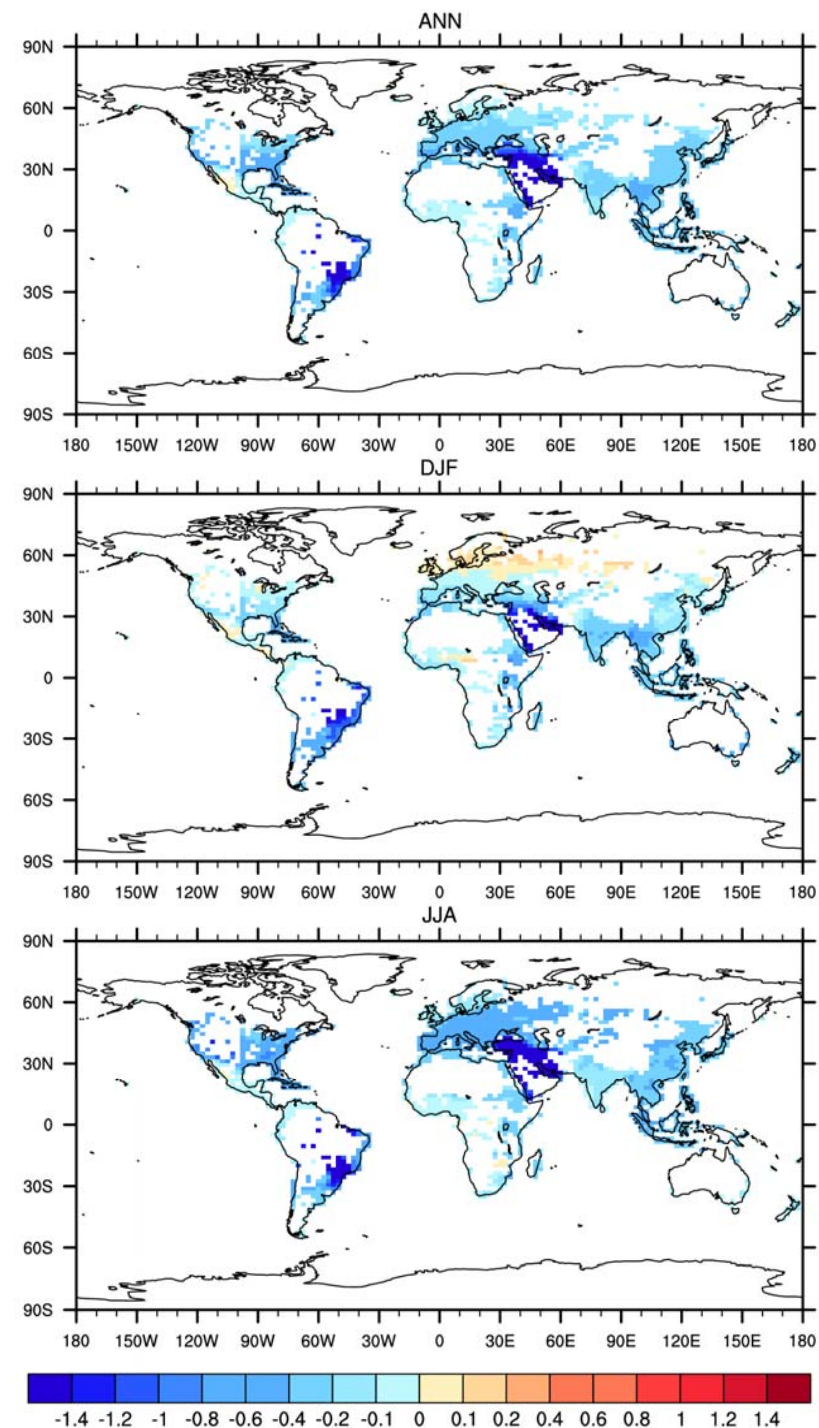


Source: U.S. Environmental Protection Agency



White Roof Experiment

White roof - Control simulations of the urban heat island (urban minus rural air temperature) for 1980-1999 annual (ANN), DJF, and JJA climatology ($^{\circ}$ C). Land areas displayed in white are grid cells that have zero urban fraction in the model.





White Roof: Change in global energy demand

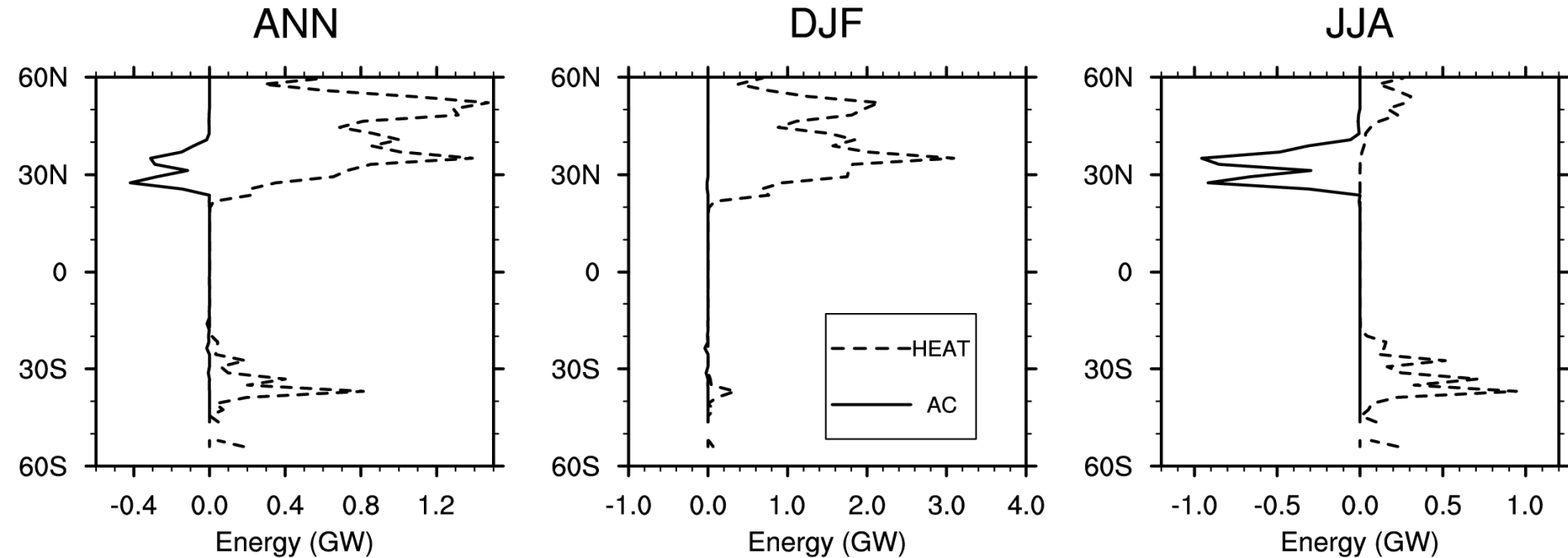


Figure 4. Zonal means of ALB minus CON simulations of urban space heating (HEAT) and air conditioning (AC) energy for 1980-1999 annual, DJF, and JJA climatology (gigawatts).

Conclusion:

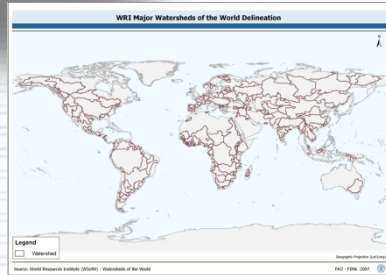
The globally averaged annual air conditioning demand decreases from 0.09 TW in the CON simulation to 0.02 TW in the ALB simulation, while space heating demand increases from 5.61 TW to 6.30 TW. Thus, the total **global energy demand increases by 0.62 TW** from 5.70 TW to 6.32 TW.



What Next?

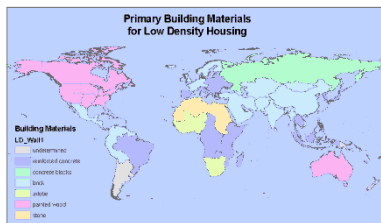
Flexible data management schemes

Raw data

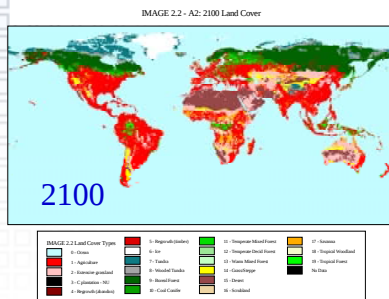


Watershed
Management
Decisions

Vector/
Polygon
Datasets

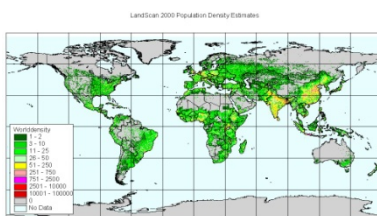


National/Regional
Policy Information



Land Cover
0.5 degree
resolution

Gridded/
Raster
Datasets



Population/urban
1 km resolution

Visual
GIS and data
Interpolation/
Translation
Interface

Model input dataset

Passed on to Assessment
community for impact analysis



Conclusions

The Challenge

To build human systems into ESMs

Considerations include:

- **Building a coordinated set of human activity models that integrate within an ESM**
- **Building human decision models that integrate well with human activity models within the ESM**
- **New and improved input data about human activities**
- **Better coordination between input data and data used for assessment**
- **Developing output that targets specific communities or human activities**



THE END