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

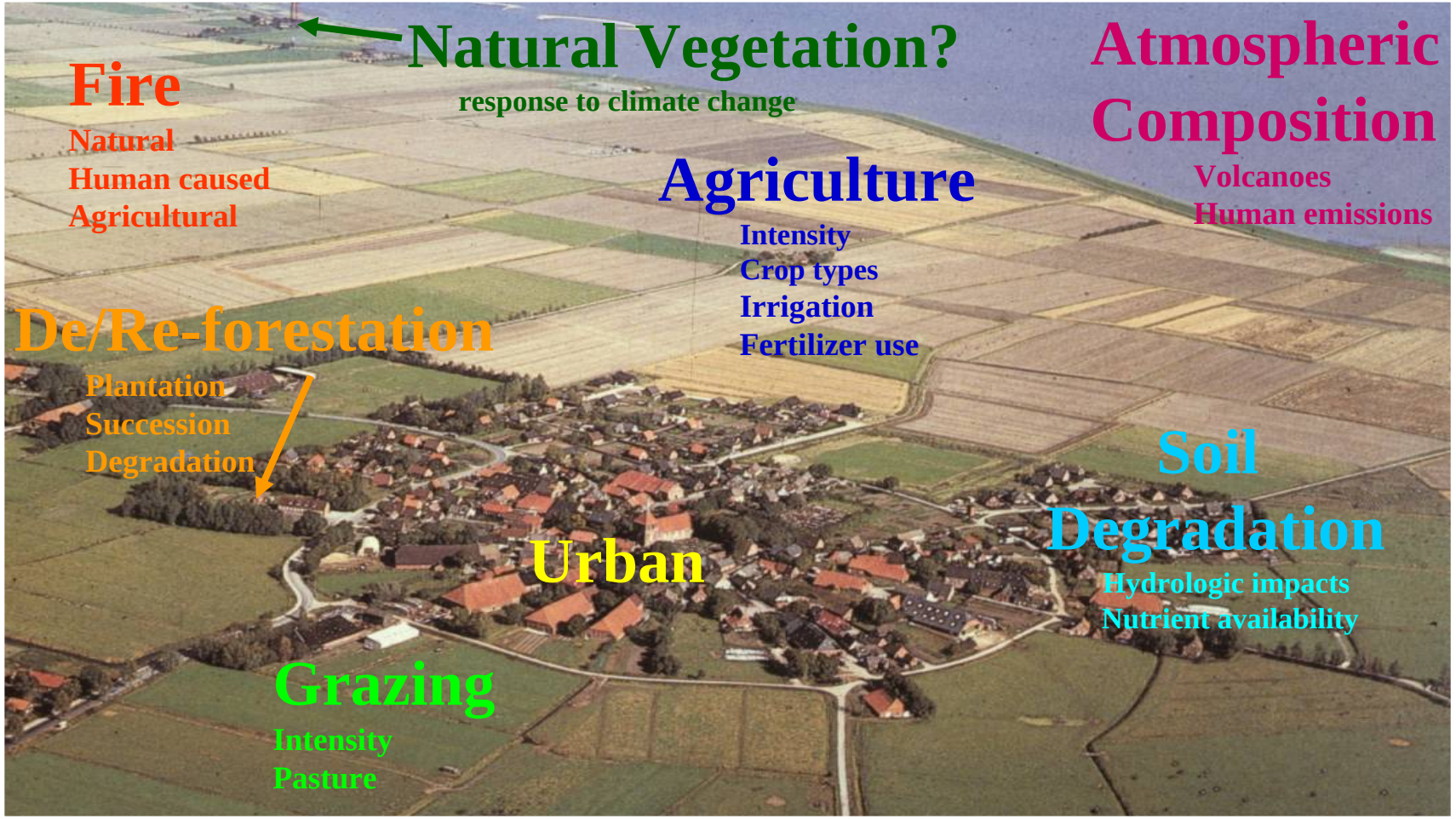
Incorporating human activities into ESMs

Considerations for developing human activities in models:

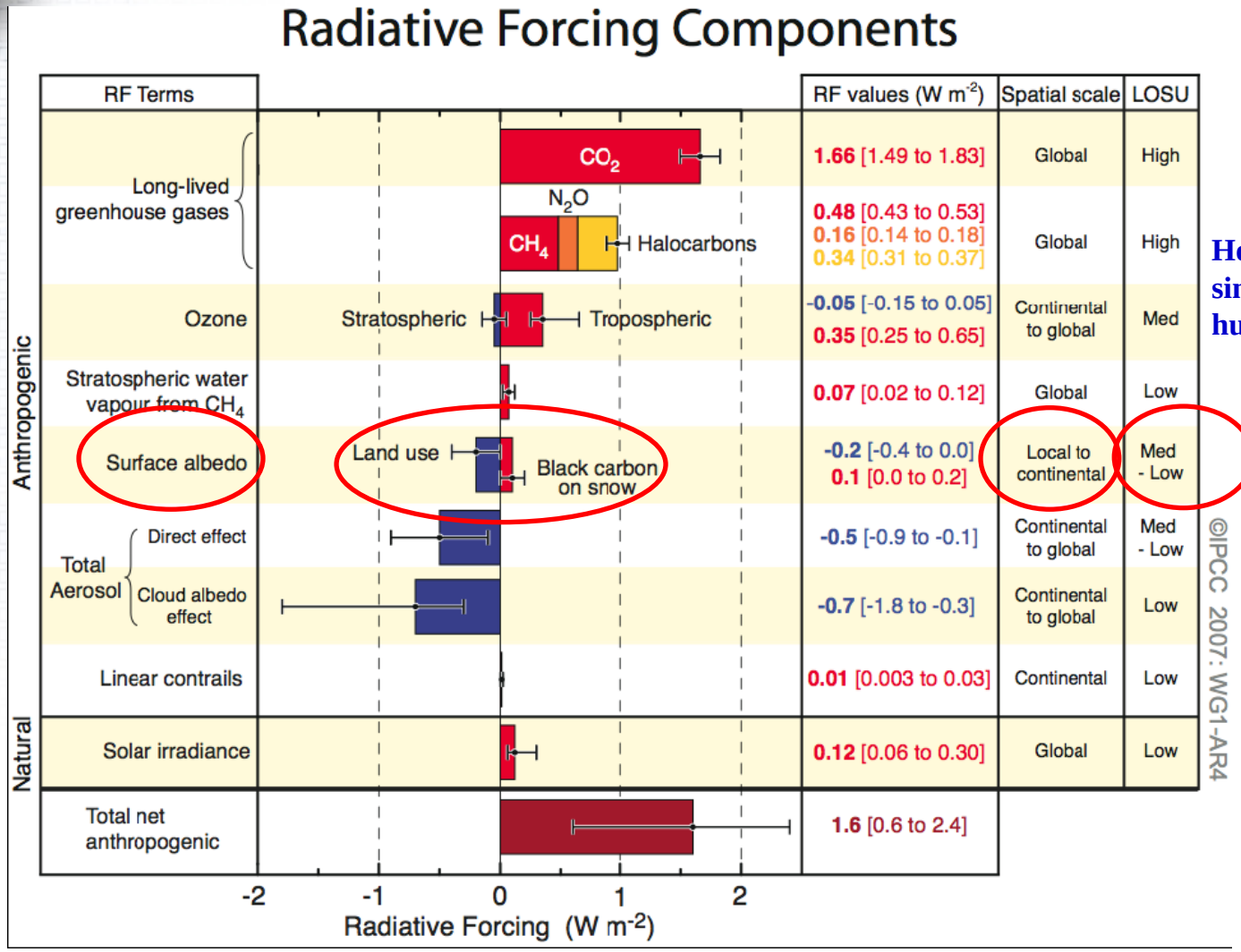
- What processes are actually important to simulate?
- Which ones can we simulate?
- How should these processes be simulated?
- How should human decision making be included?
- How can these models improve impact assessment?
- How do we gather the historical, present and future information needed to drive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



How well do we simulate the human impacts?

Simulating Human Activities in an ESM

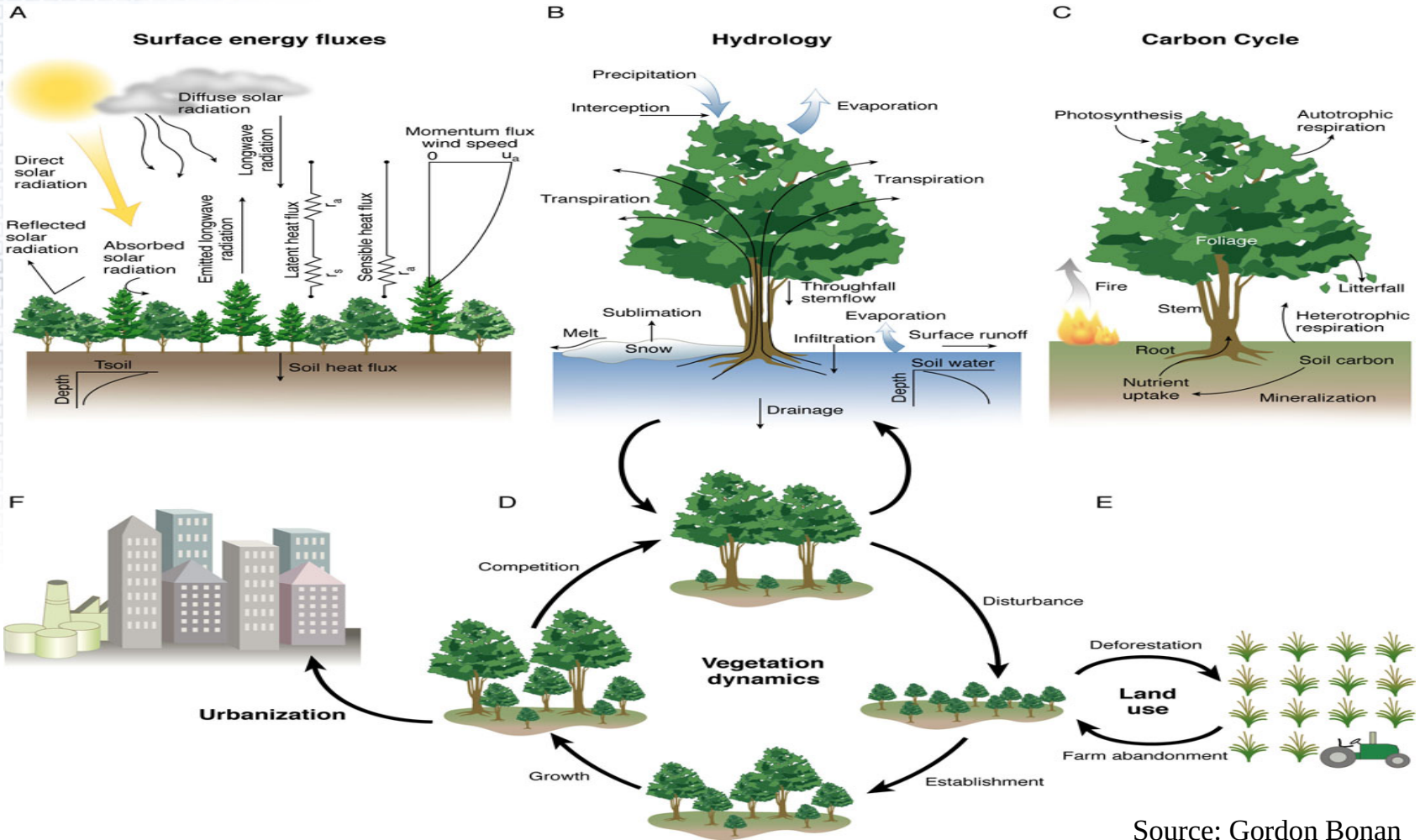
Each of these human activity sub-models should have the following properties:

- They should 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

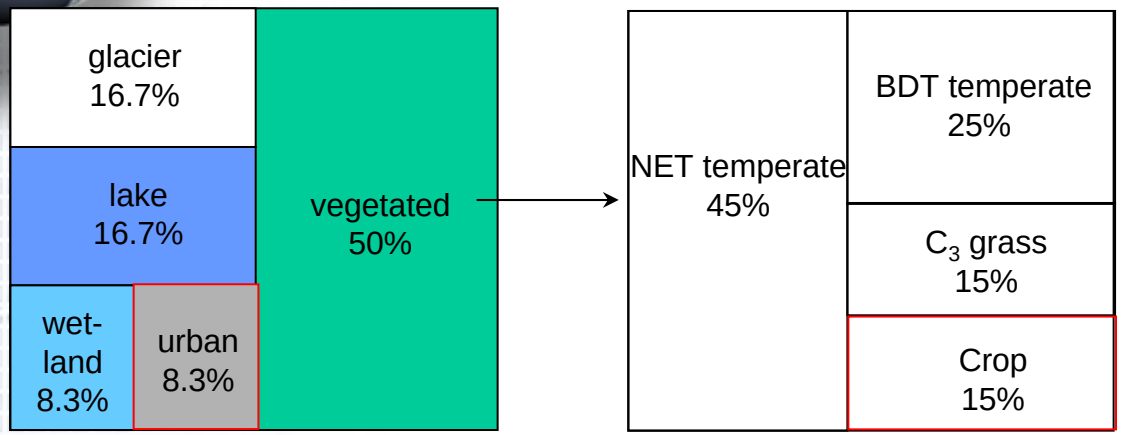
- Reliability of our information about present day land cover
- How to construct historical and future scenarios
- Flexible of data input/output information systems
- Land models should run at their own resolution
- Improve processes such as ecological succession (natural and human controlled)
- Have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

How modelers see the world



Source: Gordon Bonan

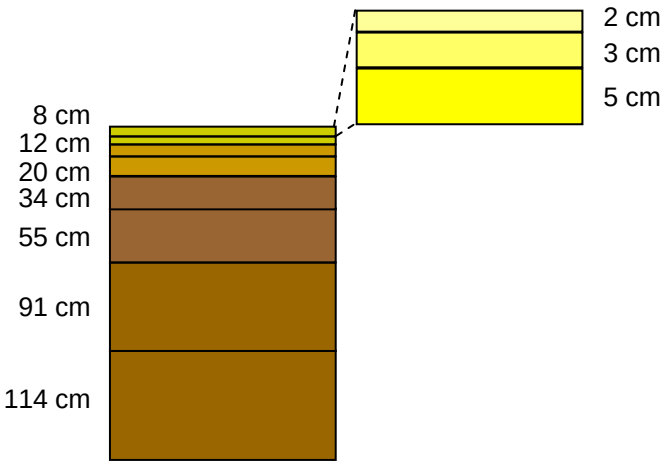
How the model sees the world



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
- C_3, arctic
- C_3
- C_4

Crop

Wheat

Winter wheat

Maize

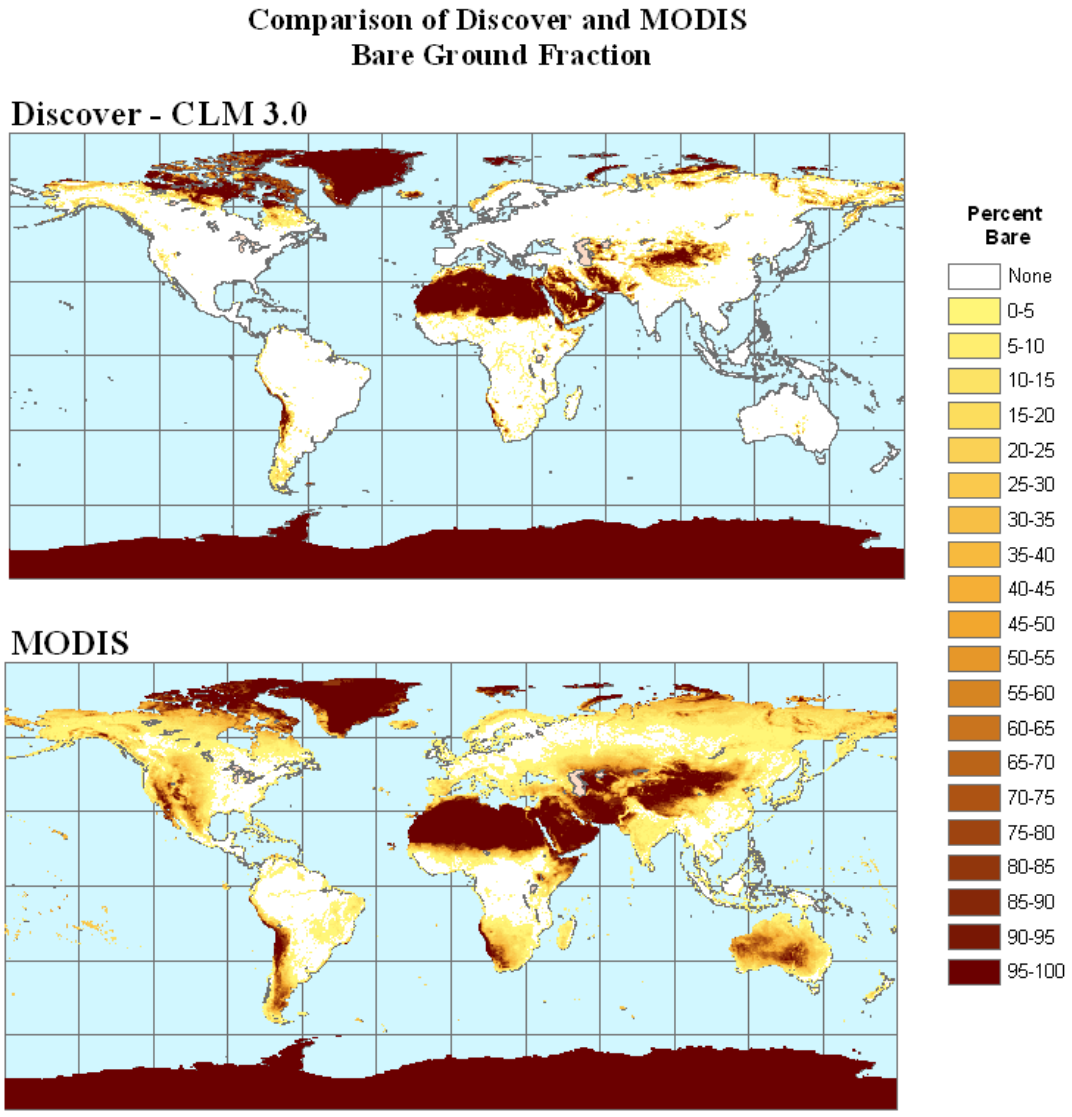
Soy

+ 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?



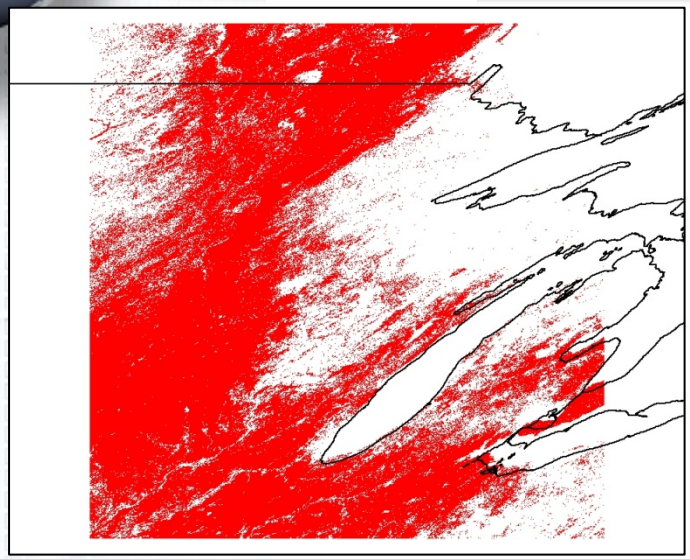
Challenge:

Improve access to, and reliability of Earth Observations

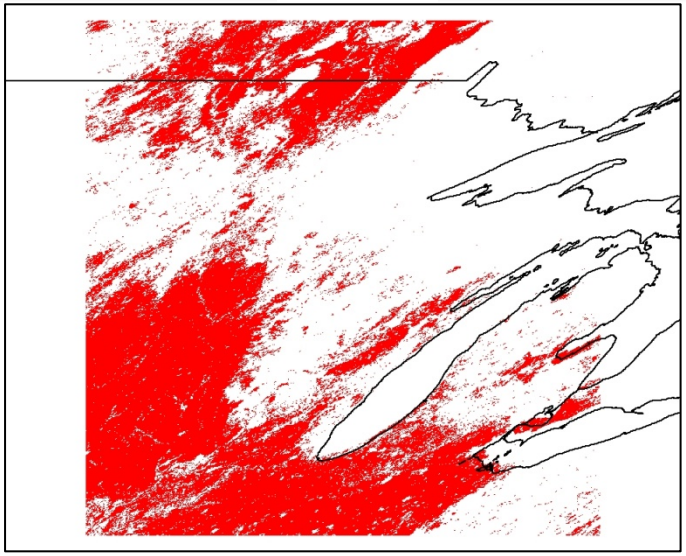
Source: Peter Lawrence, CIRES, University of Colorado

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

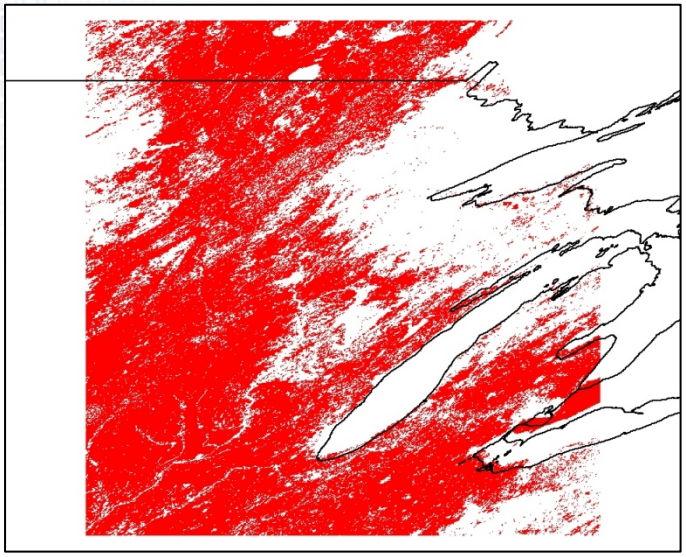
MODIS



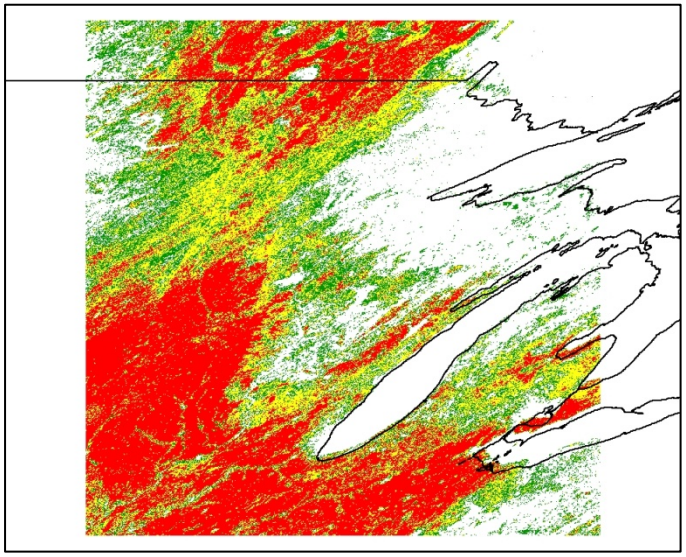
IGBP



GLC2000



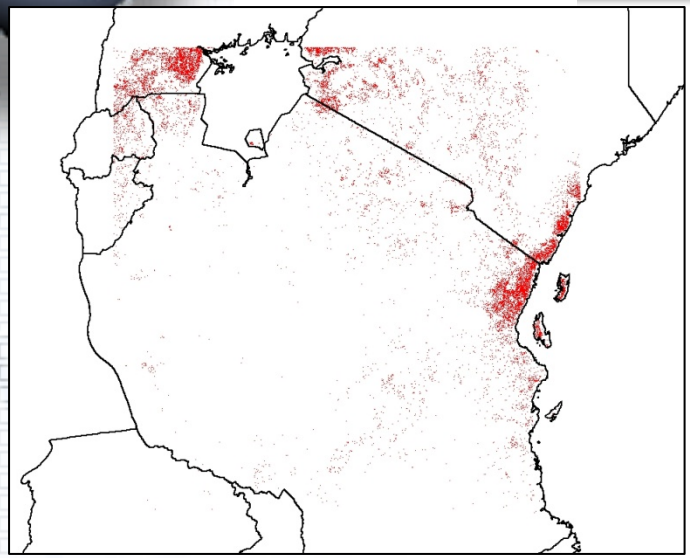
Agreement



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



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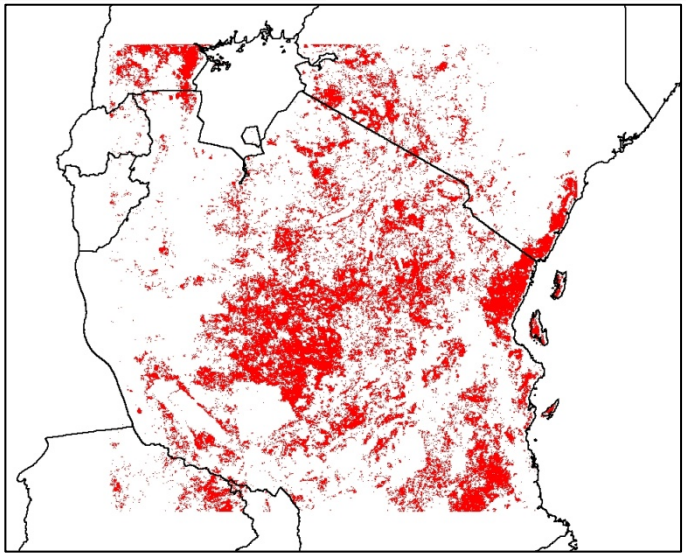

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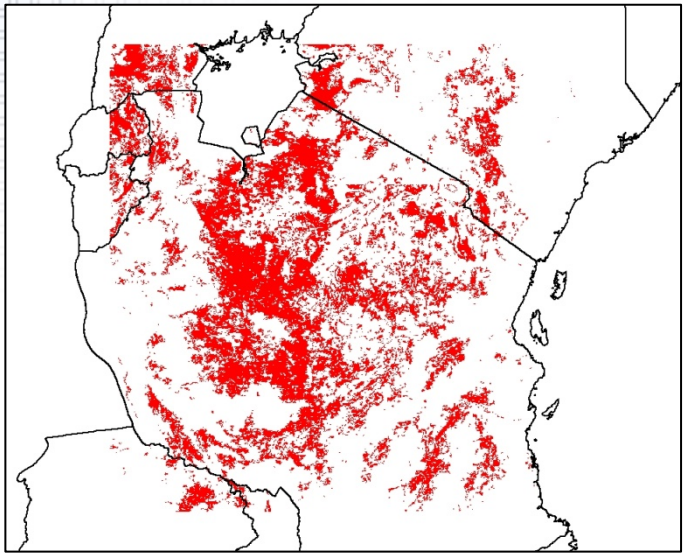

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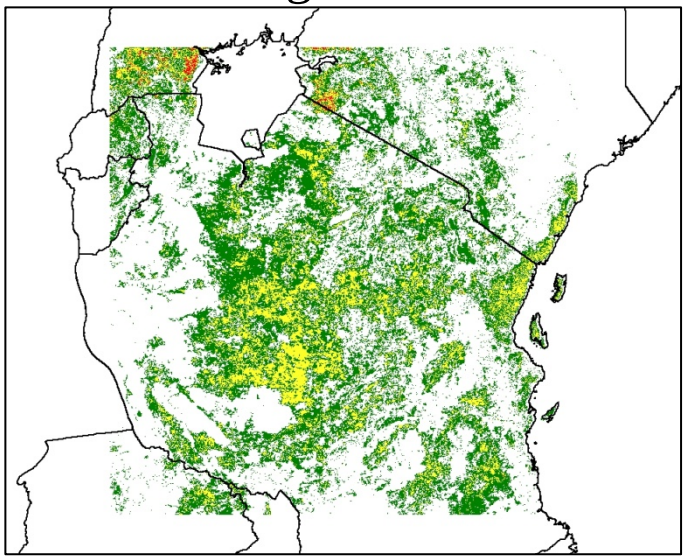


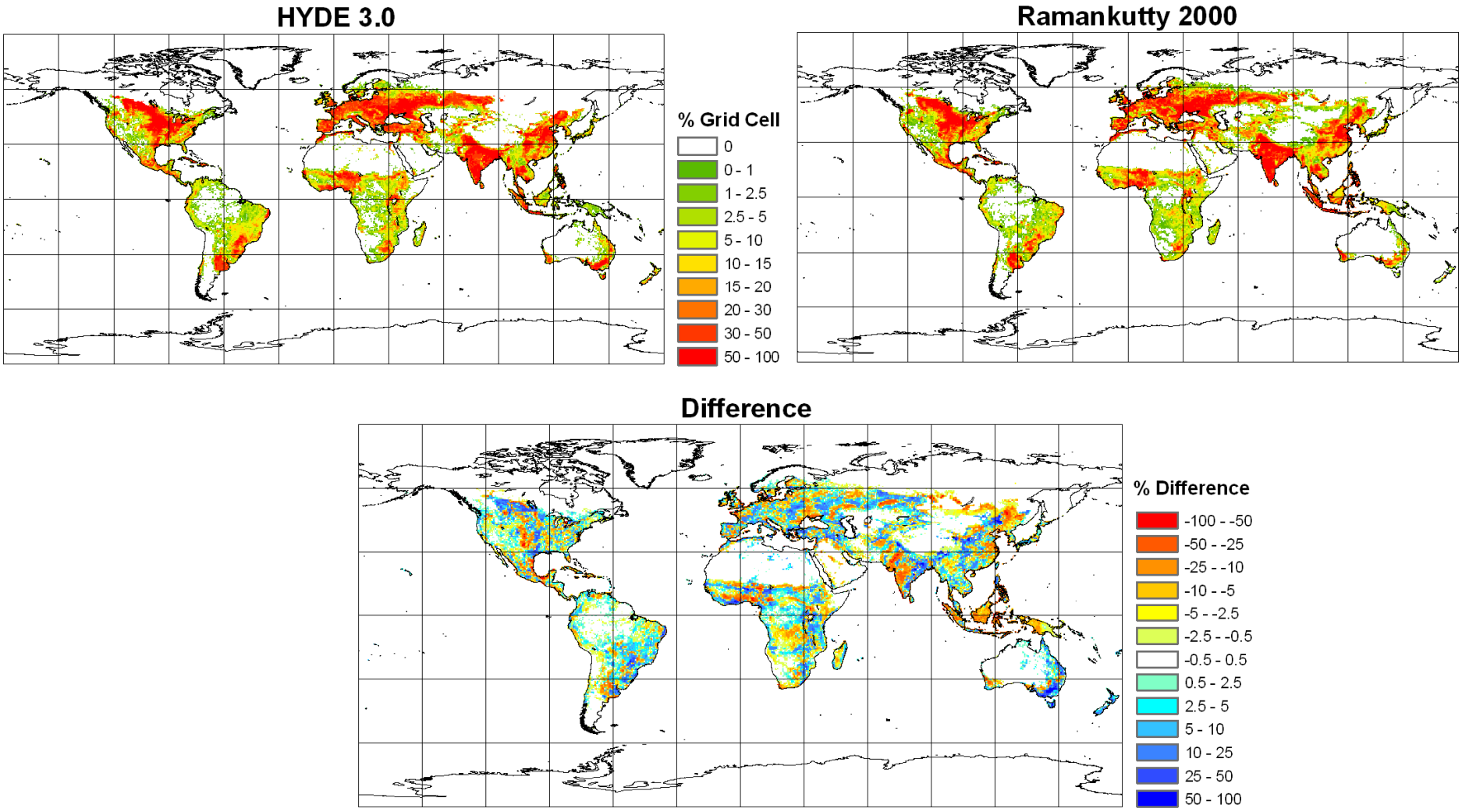
Challenge:

Improve access and reliability of Earth Observations

Agriculture?
Shrub?
What is this anyway?

What do we mean by croplands or agriculture

Present Day Options: Agriculture



Issues of definitions

e.g. What is Pasture/Grazing?

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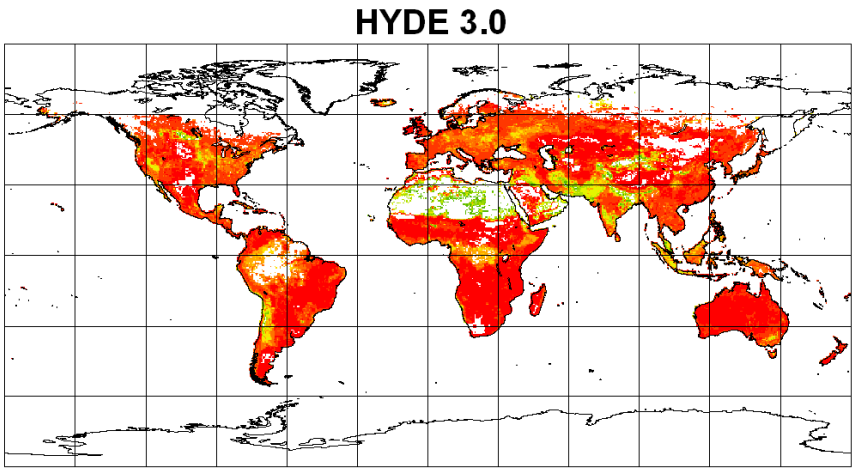
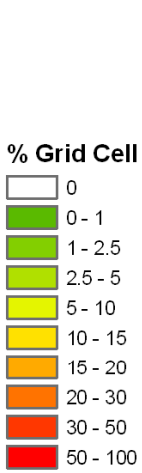
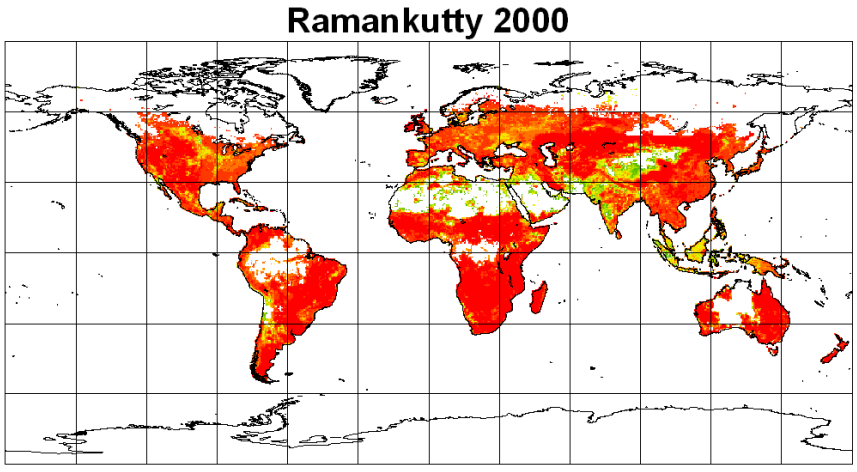
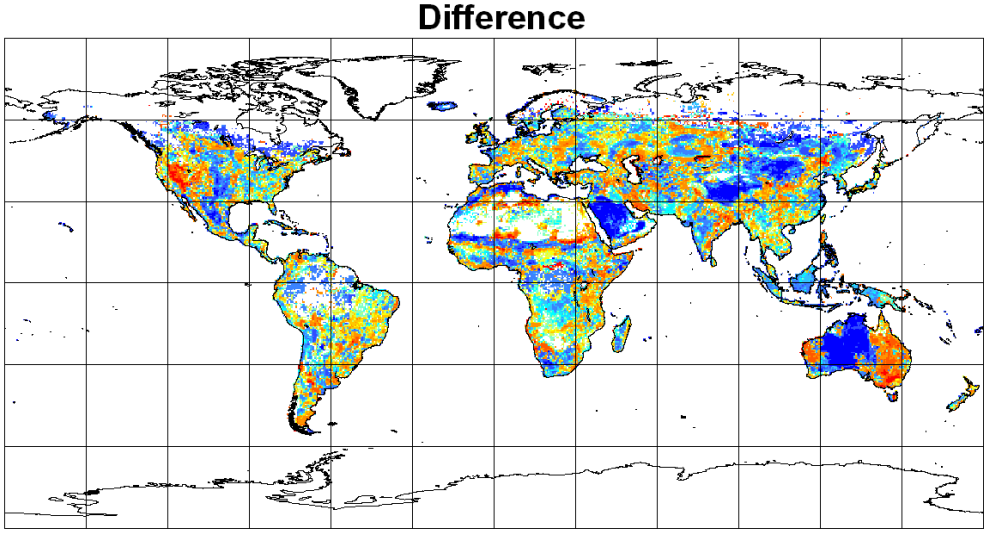
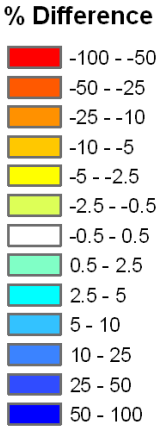
Present Day Options: Pasture



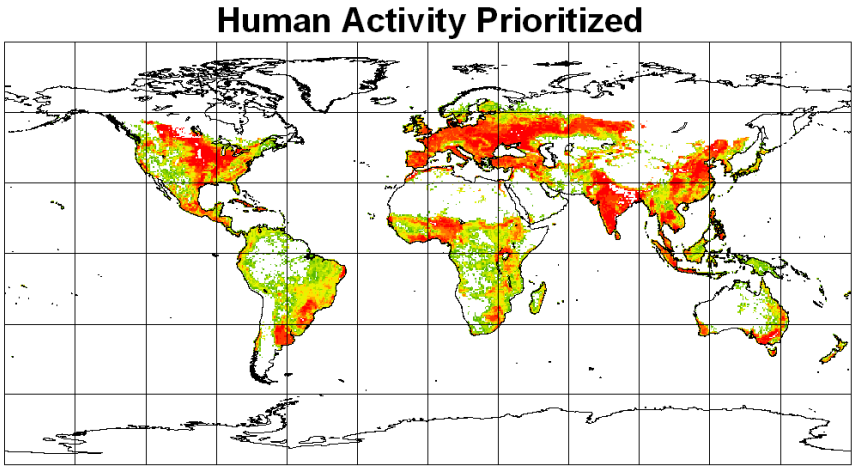


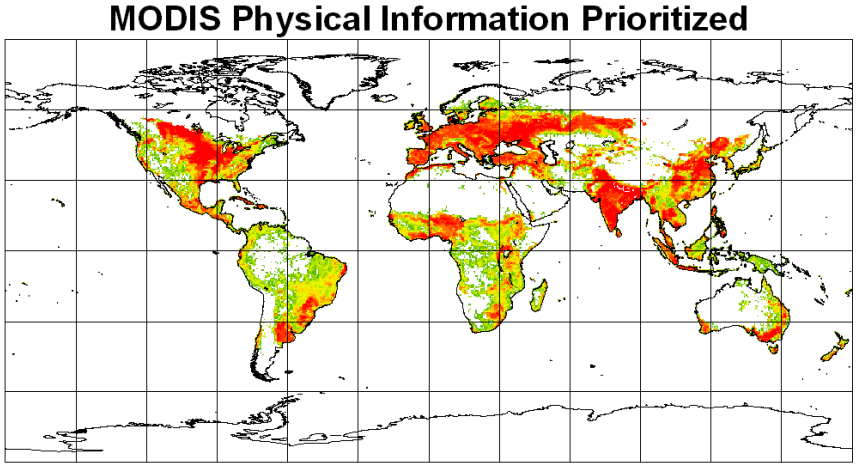




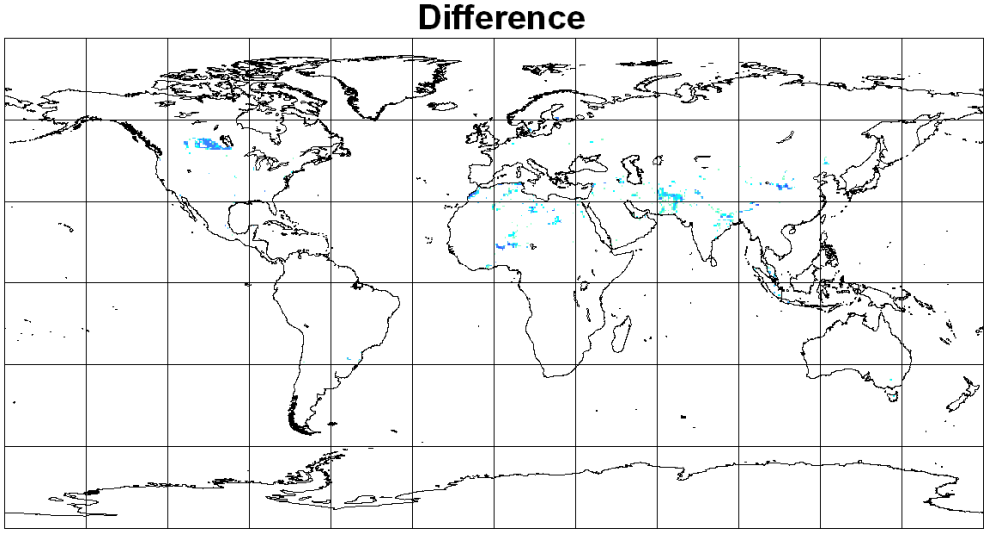


Creating datasets order of entry: Agriculture





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



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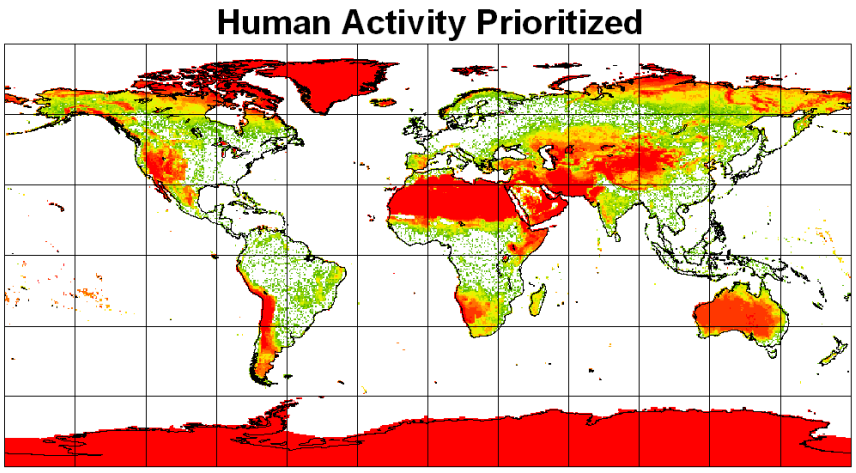
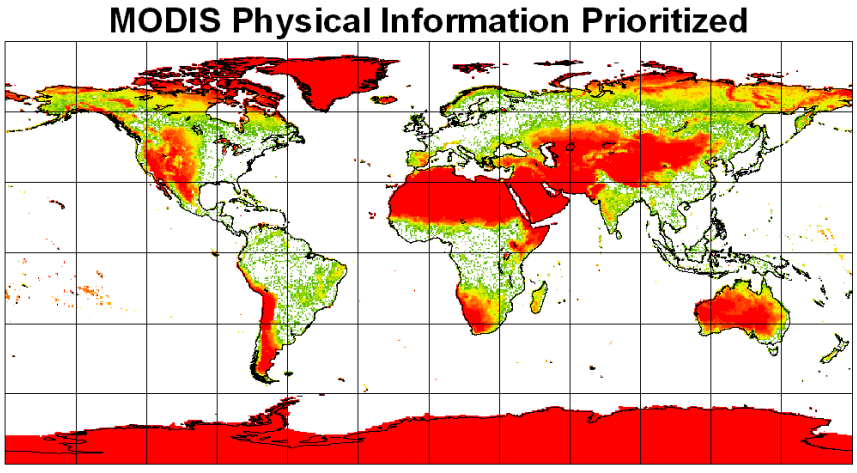
Creating datasets order of entry: Bare





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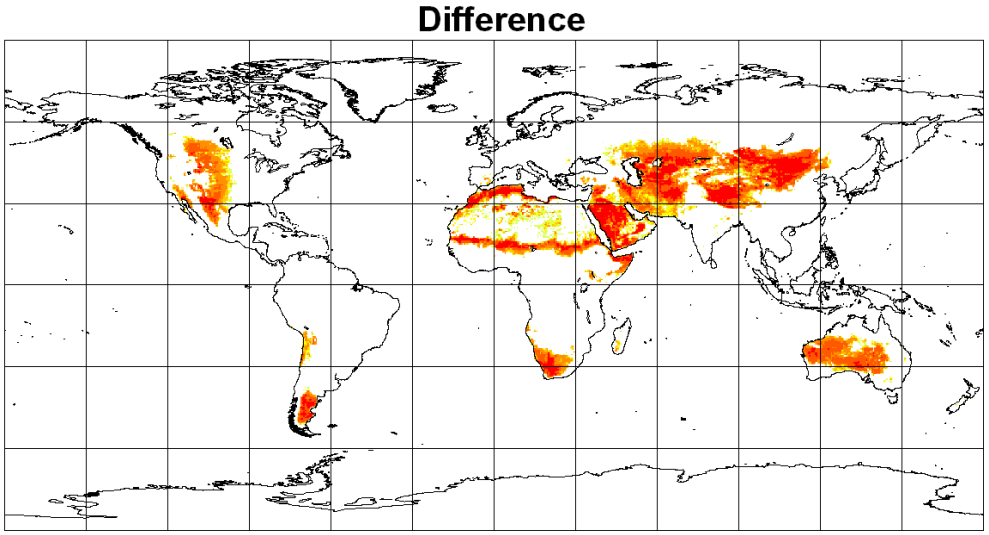

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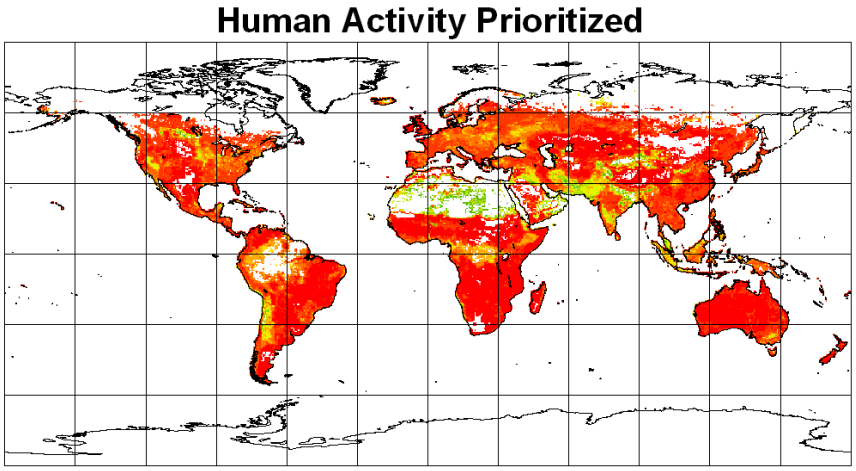
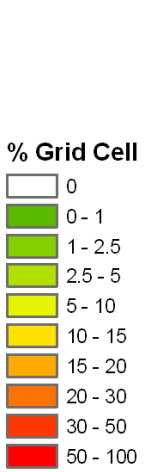
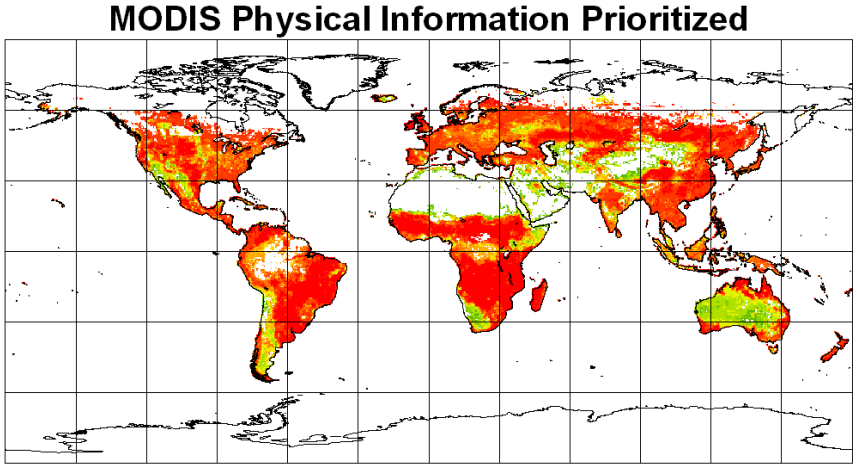
Creating datasets order of entry: Grasses







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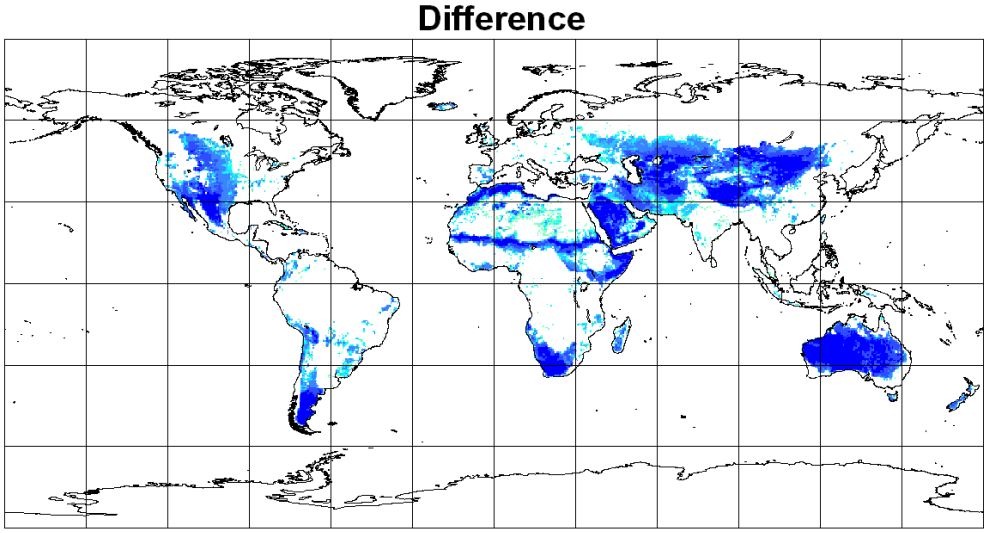

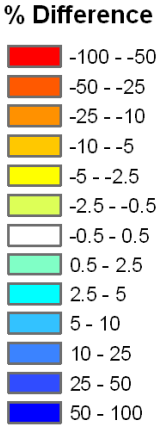

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Bare ground
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Grass

Question

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

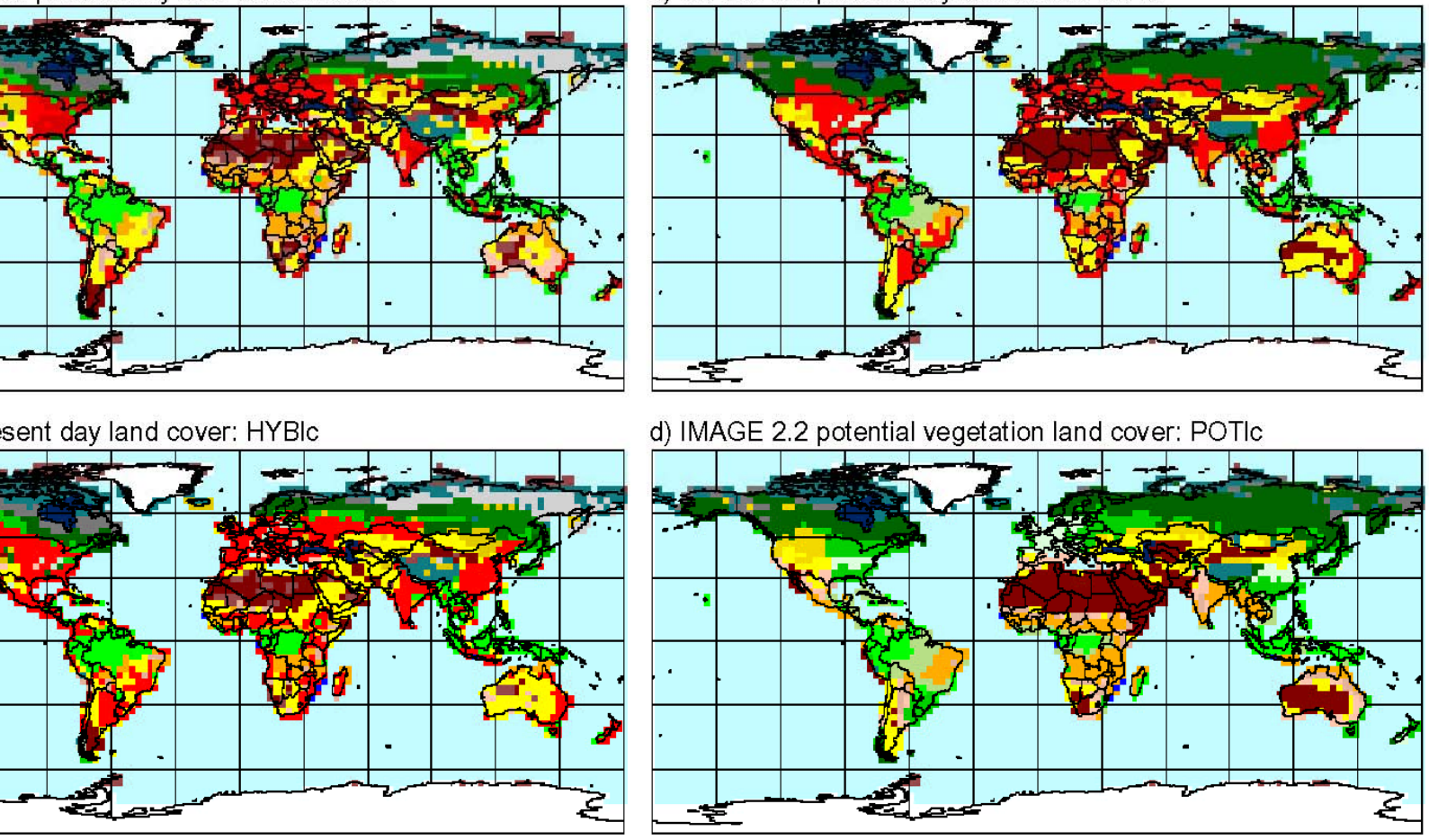
How important is the choice of present day land cover?

a) LSM original present day land cover: LSMlc

b) IMAGE 2.2 present day land cover: IMAlc

c) Hybrid present day land cover: HYBlc

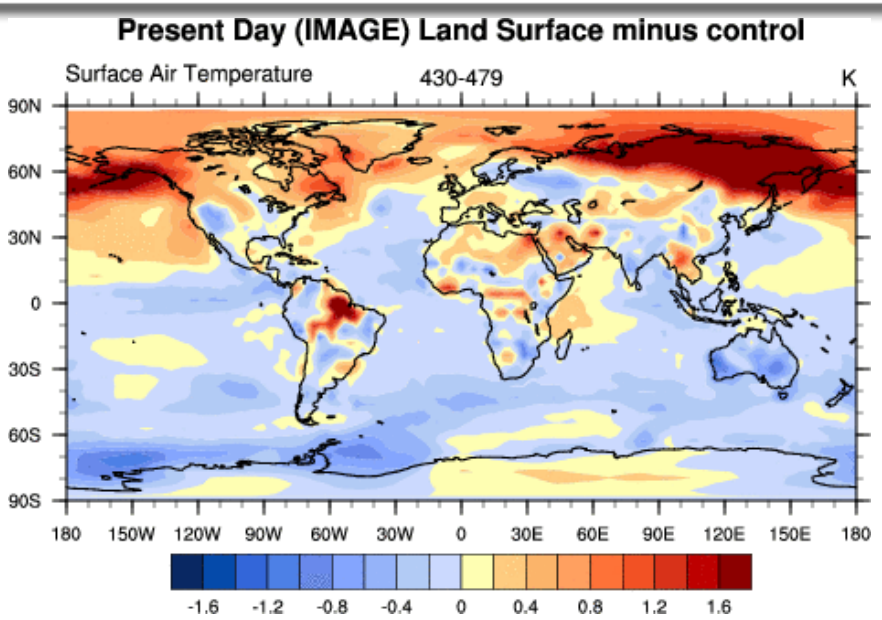
d) IMAGE 2.2 potential vegetation land cover: POTlc



PCM Uncertainty v.s. Historical Land Cover

PRESENT DAY UNCERTAINTY

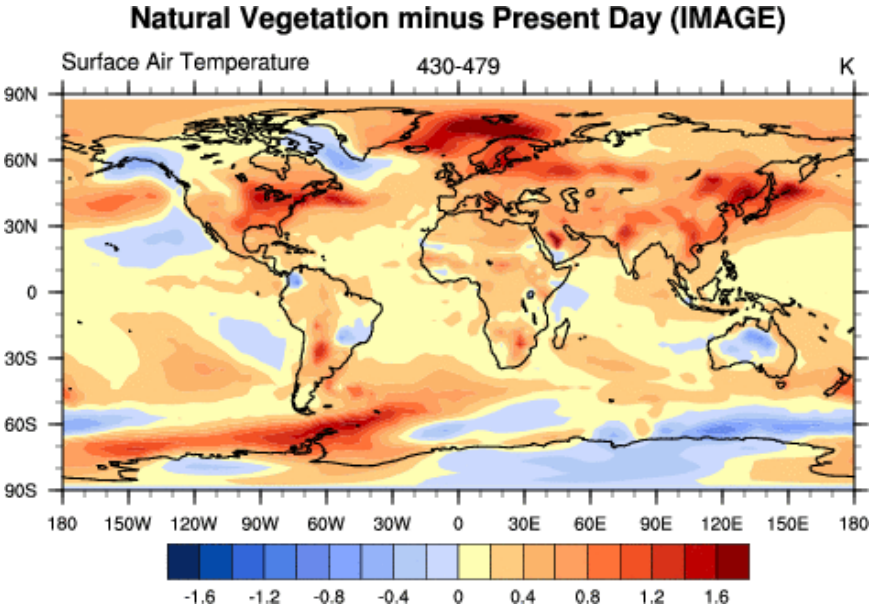
- Arctic – albedo
- Amazon – latent heat flux
- Australia – albedo



HISTORICAL CHANGE

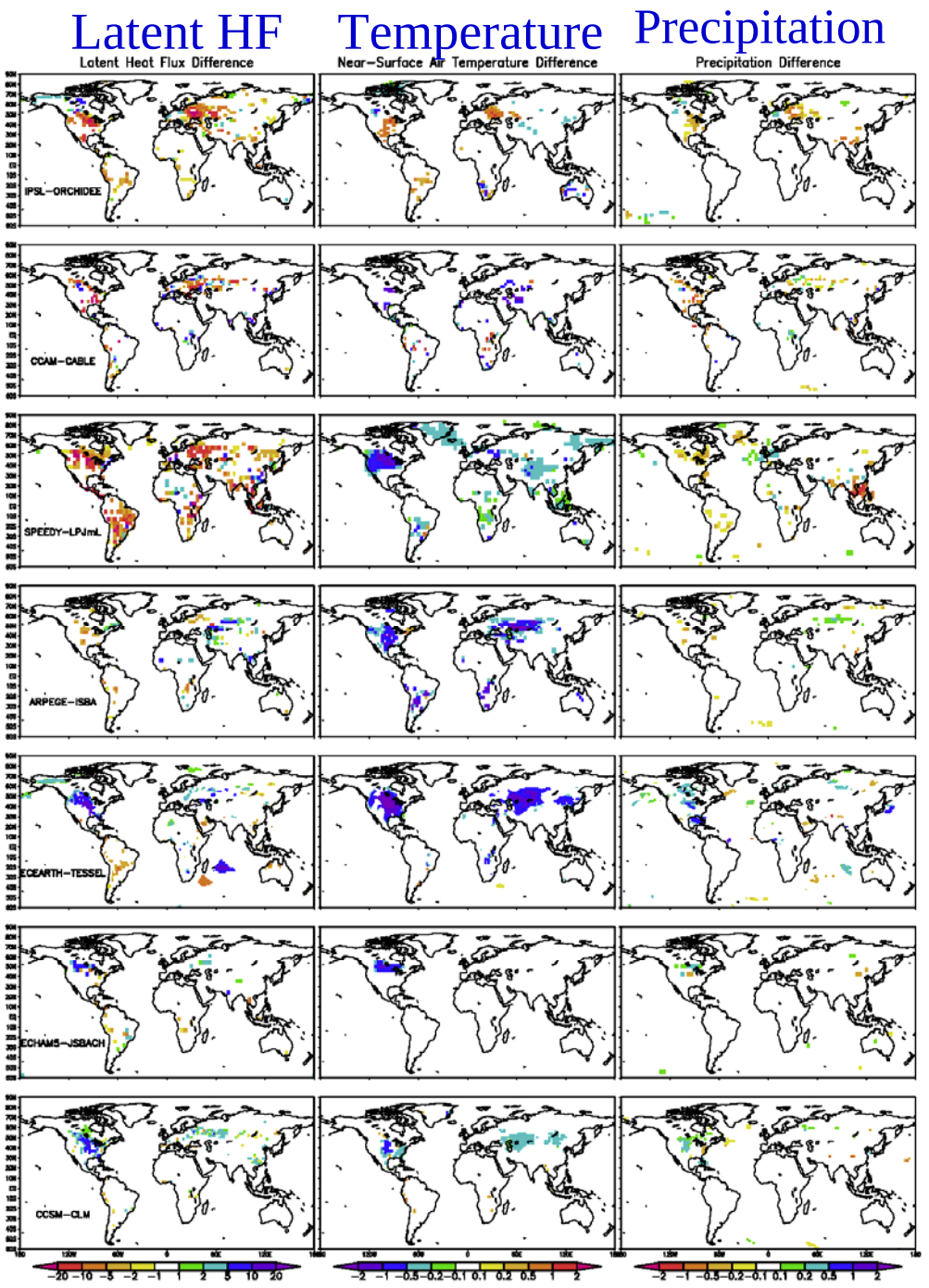
Climate difference from land cover classification is as large as the climate difference from land cover change

- Primarily shift due to agriculture



LUCID
1850-Present comparison

What is going on here?



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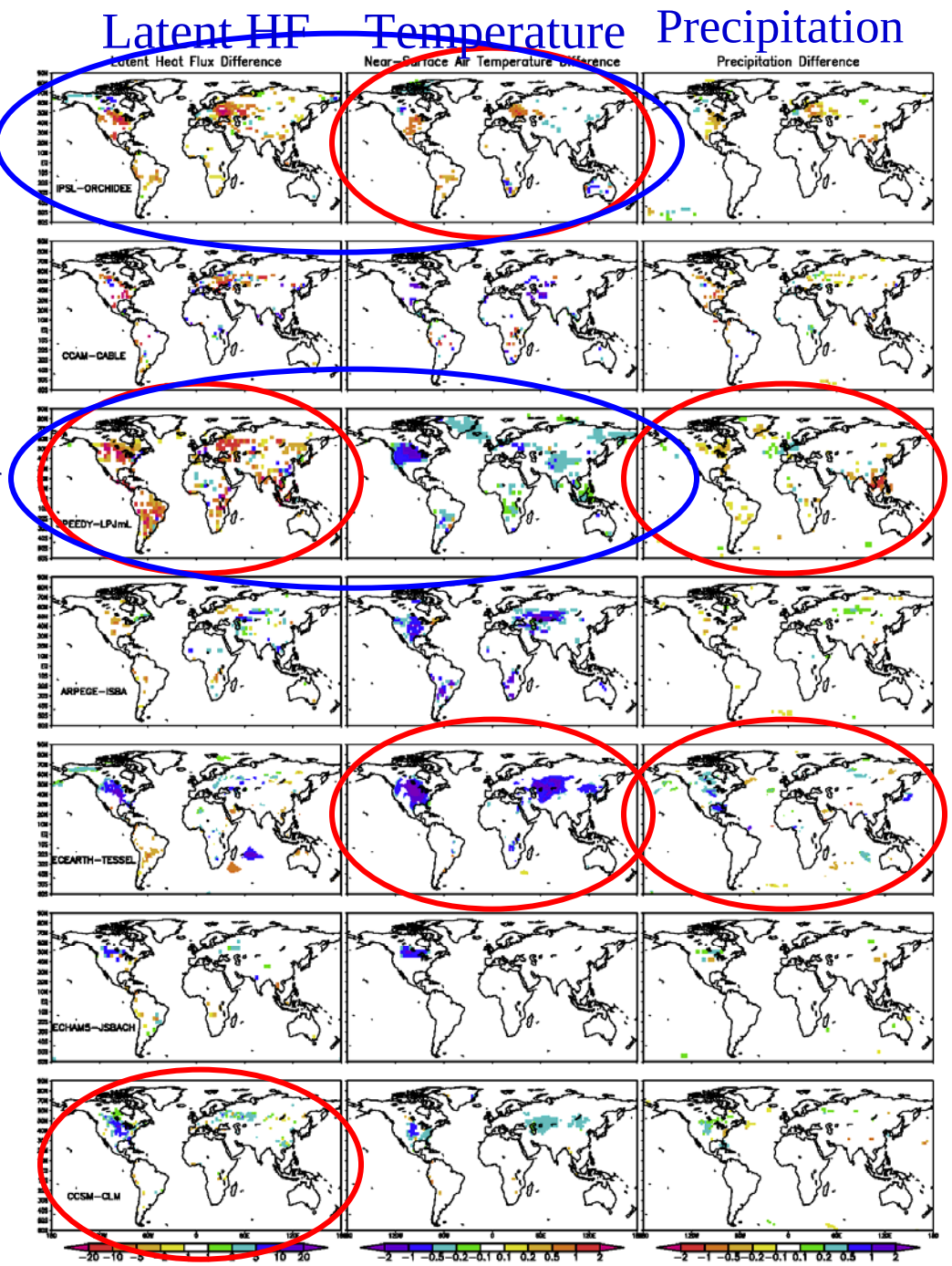
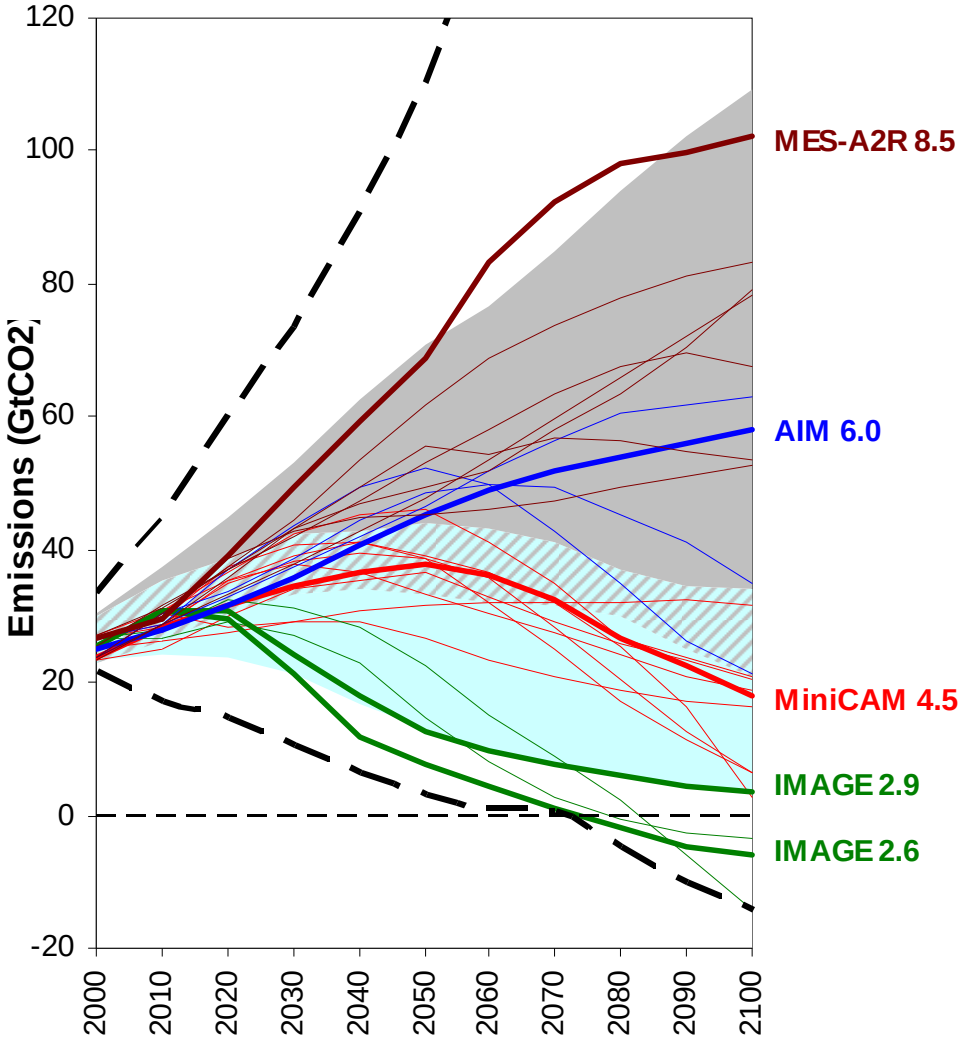
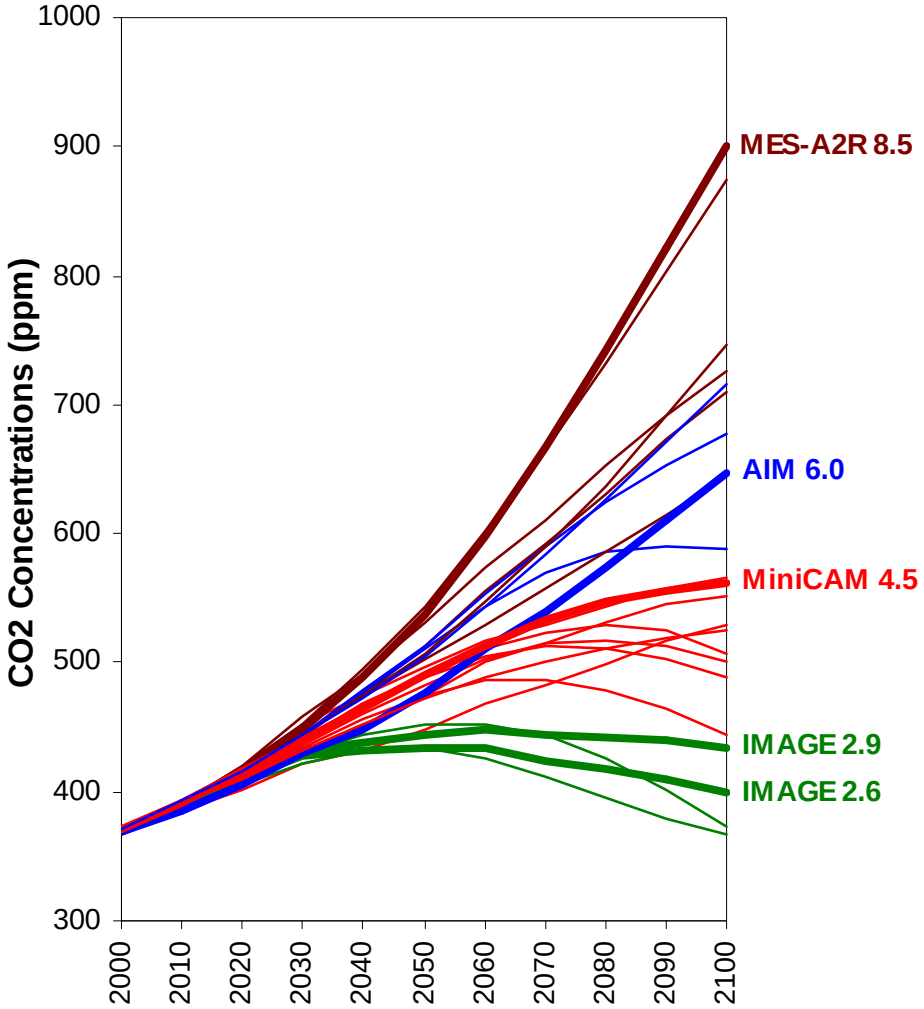


Landcover Change IPCC AR5

Selected RCP CO_2 Properties



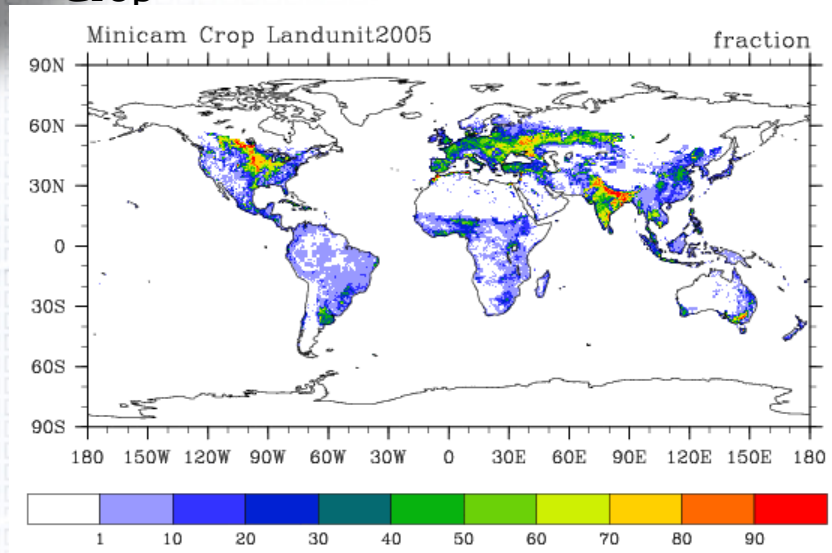


IPCC AR5 – RCP Standardization

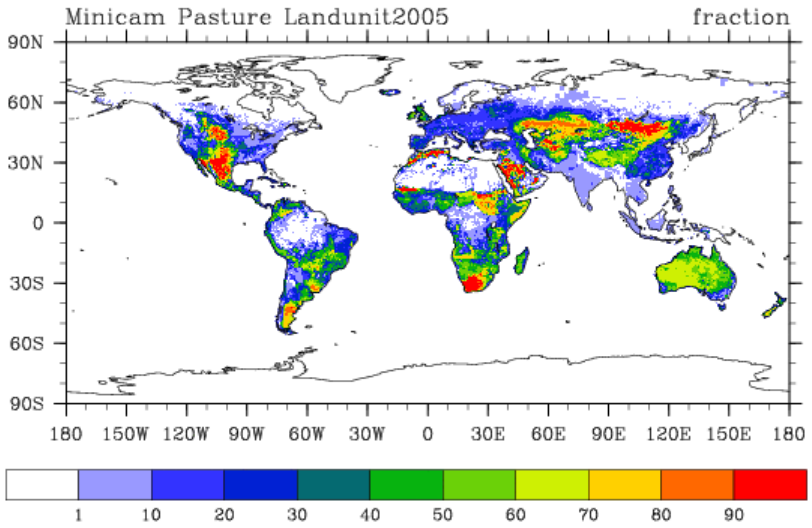
1. All scenarios will use an identical 2005 land cover as a starting point
2. All pathways share the same historical trajectory to 2005. After 2005 they diverge following their own representative pathway.
3. For each RCP, minimal information related to land cover change will provide changes in four basic 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

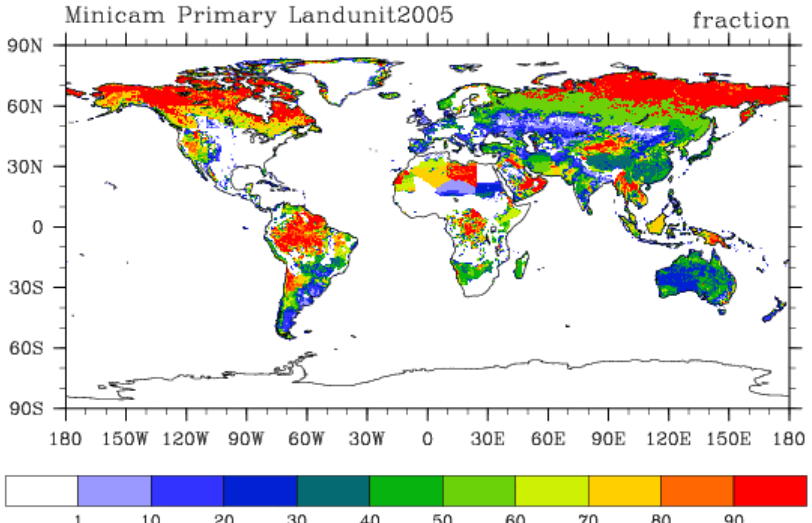
Crop



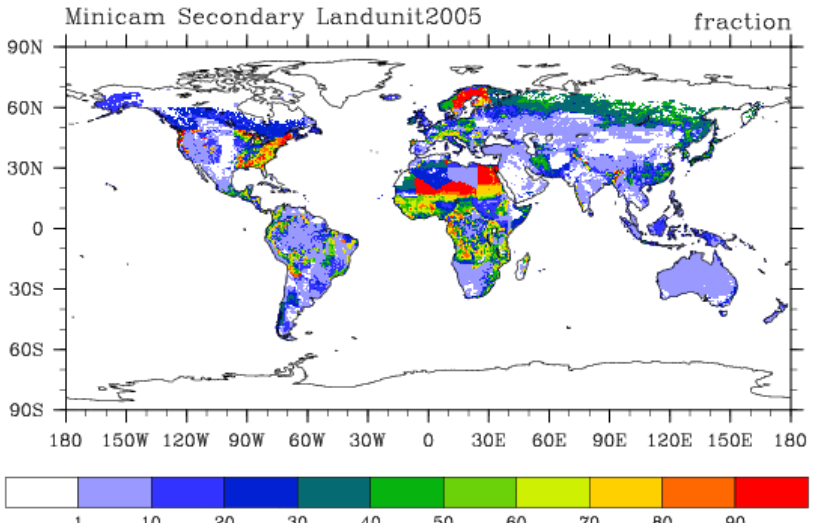
Pasture



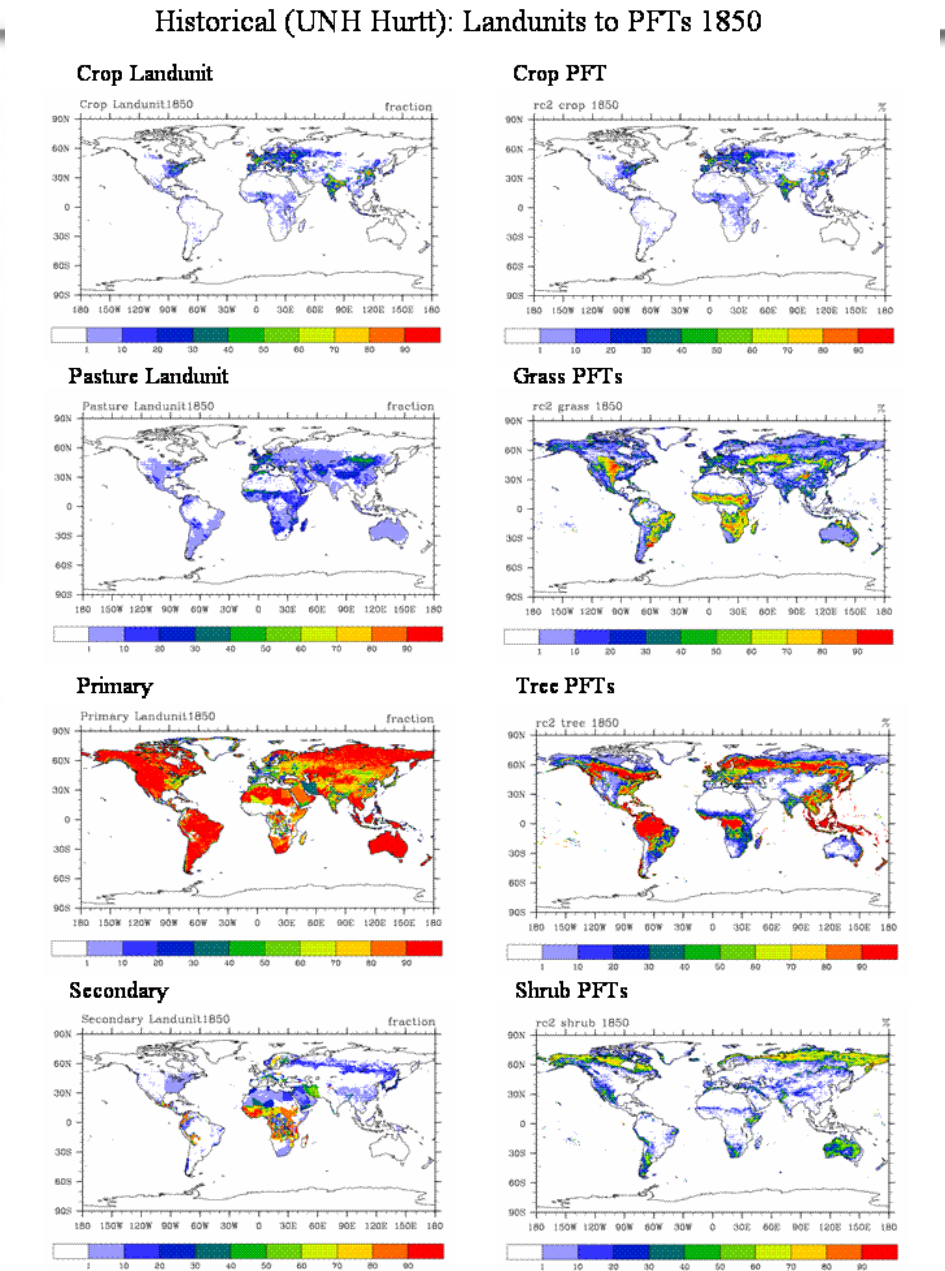
Primary



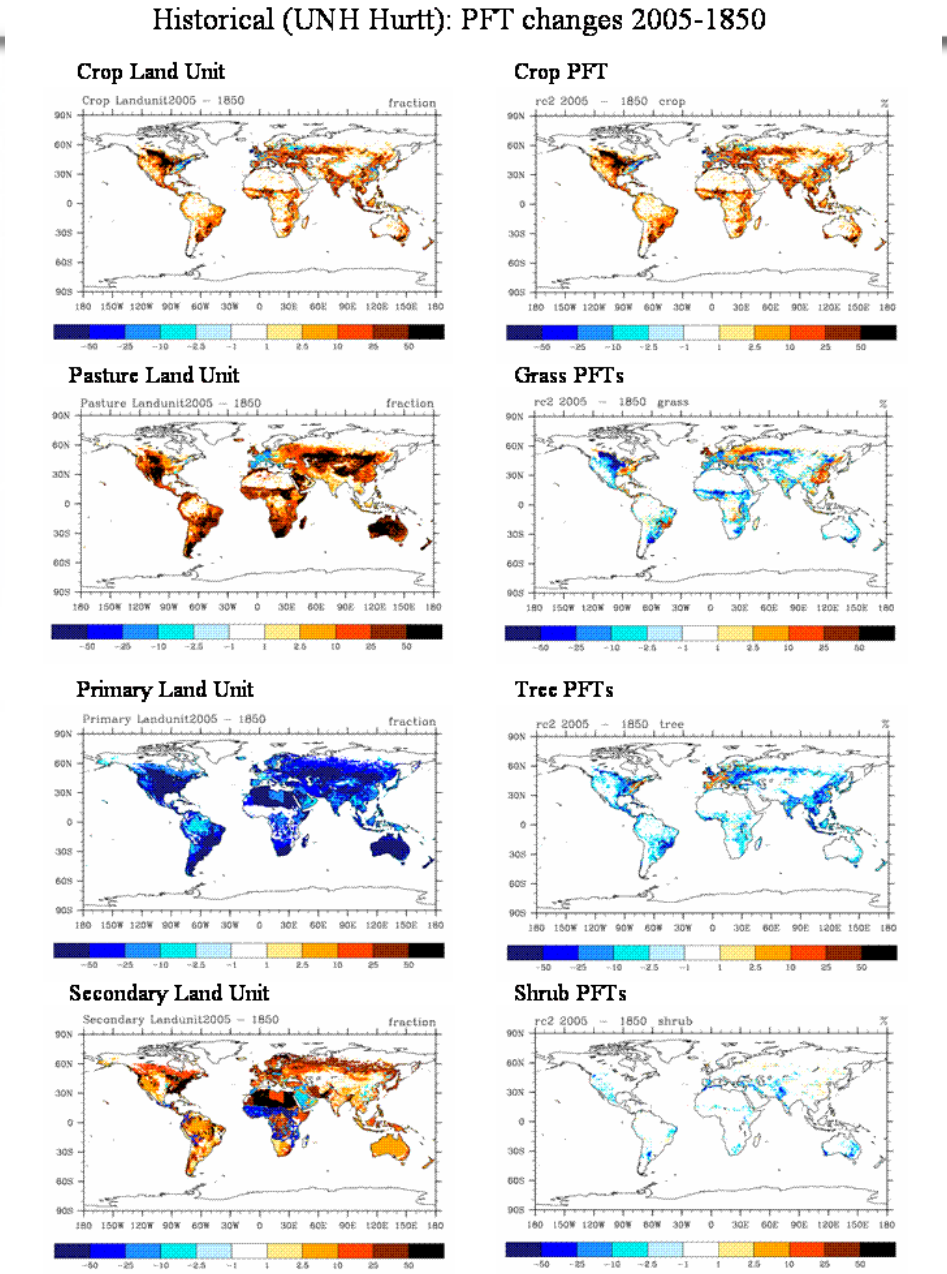
Secondary



Mapping UNH land units to PFTs 1850

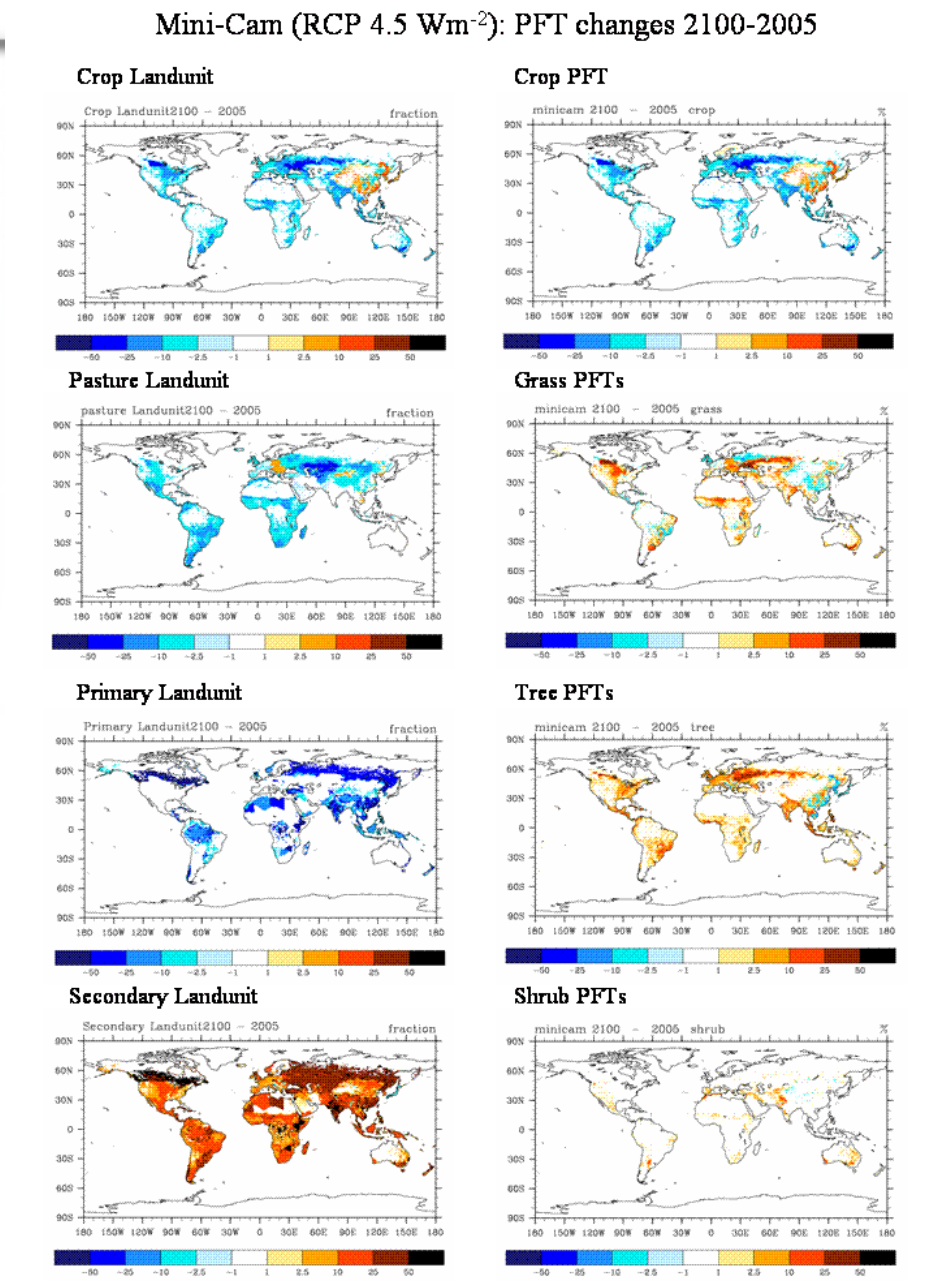


Mapping change in UNH land units to PFTs (1850-2005)

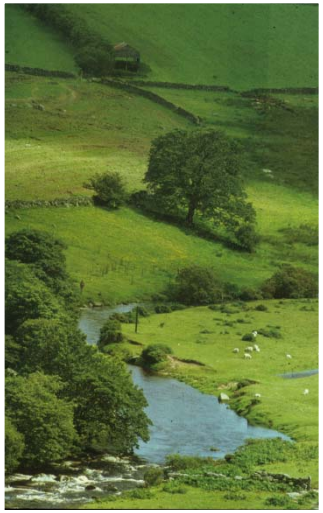


Mapping change in UNH land units to PFTs (2005-2100)

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

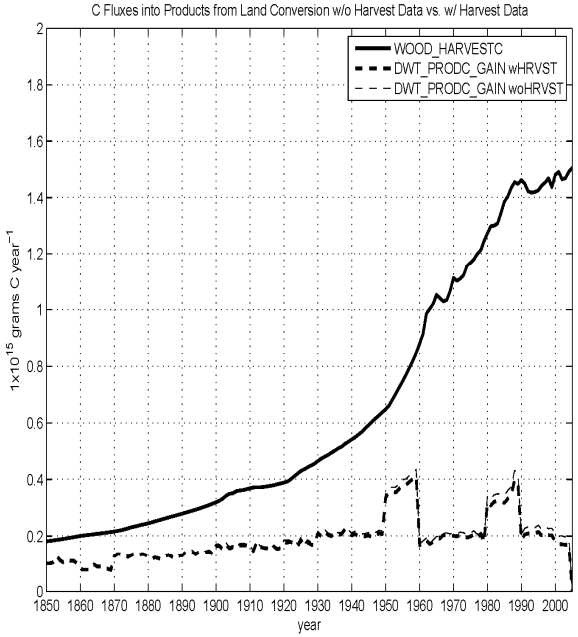
	Average global carbon density in harvested grid cells kgm^{-2} (**percent of vh1 value**)				
	Vh1	**Vh2**	**Sh1**	**Sh2**	**Sh3**
1851	9.24	0.28 (**0.030**)	4.44 (**0.481**)	7.29 (**0.789**)	1.06 (**0.115**)
2001	8.84	0.30 (**0.034**)	4.67 (**0.528**)	5.83 (**0.660**)	0.42 (**0.048**)
2031 IMAGE	8.69	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**)
Average	*8.61*	*0.412 (**0.048**)*	*5.05 (**0.587**)*	*5.57 (**0.647**)*	*0.52 (**0.061**)*

Outcome:

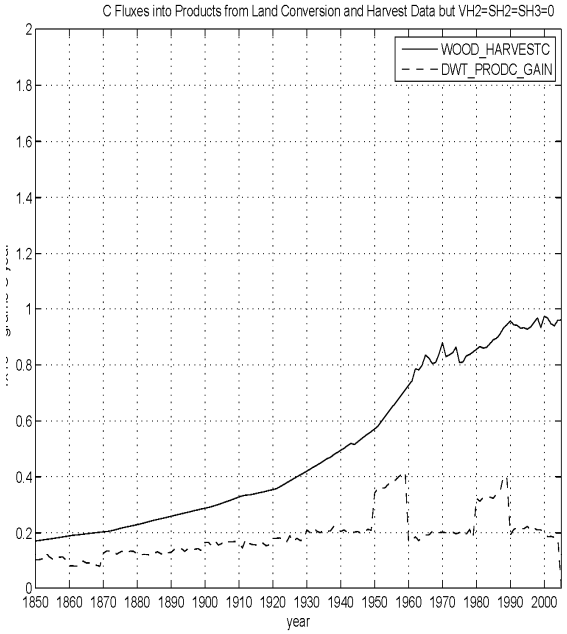
Wood Harvest area = vh1 + 0.05*vh2 + 0.6*sh1+ 0.6*sh2 + 0.05*sh3

Wood Harvest impact on land carbon cycle

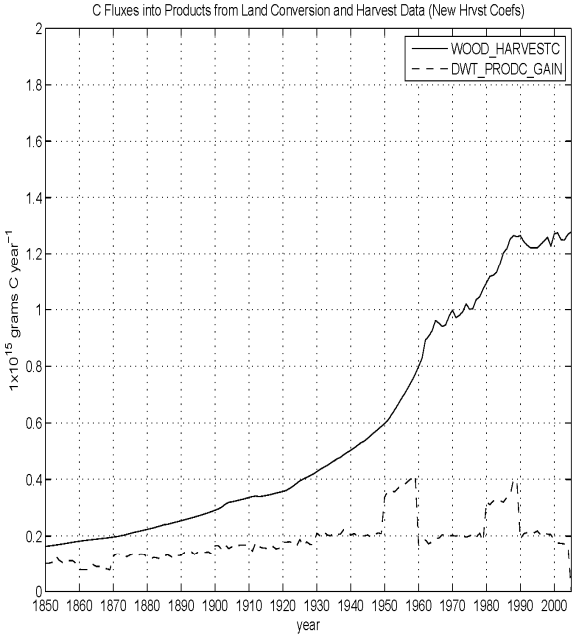
All areas



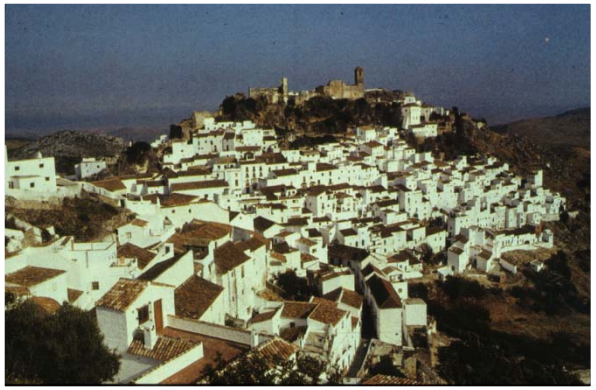
vh1 + sh1



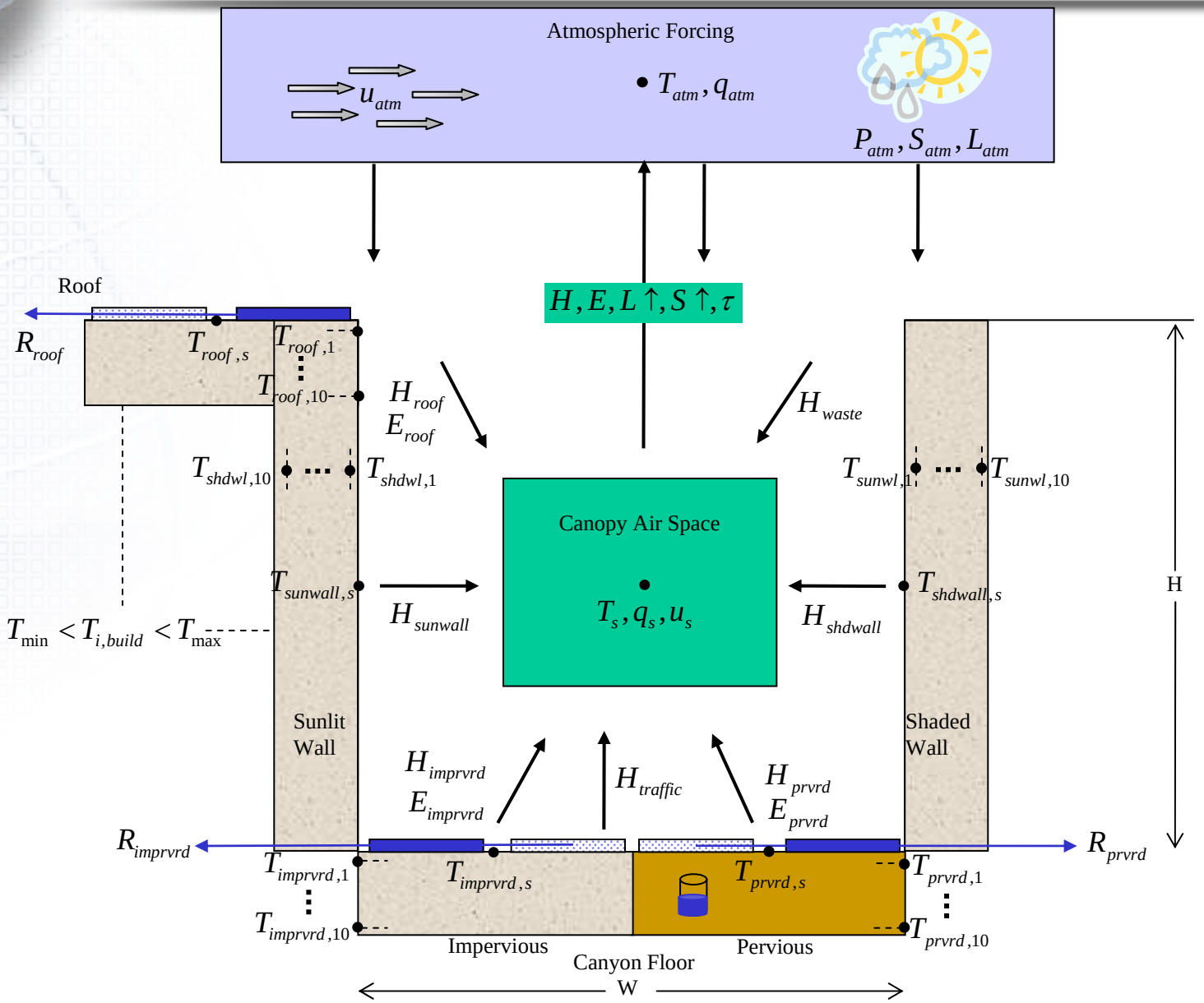
Coefficients



Urbanization



Example: Urban canyon type model

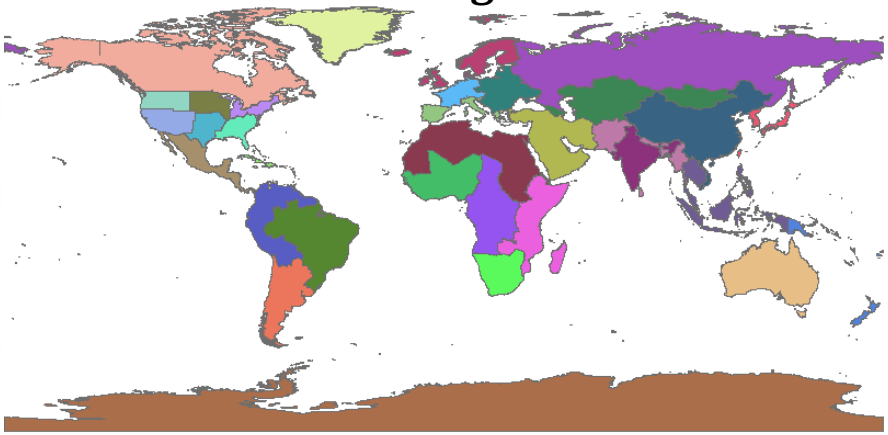


Defining Urban Classes (CBD/HD)

Defining Urban Classes (LD/HD ??)

Example: Urban Input data

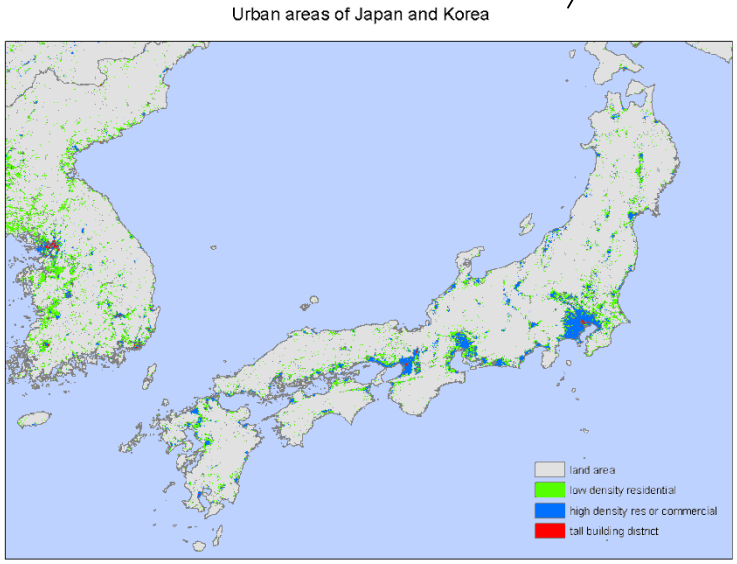
Global Regions



→ **To Model**

Urban Extent

- *4 classes*



Urban Properties

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

Wall properties

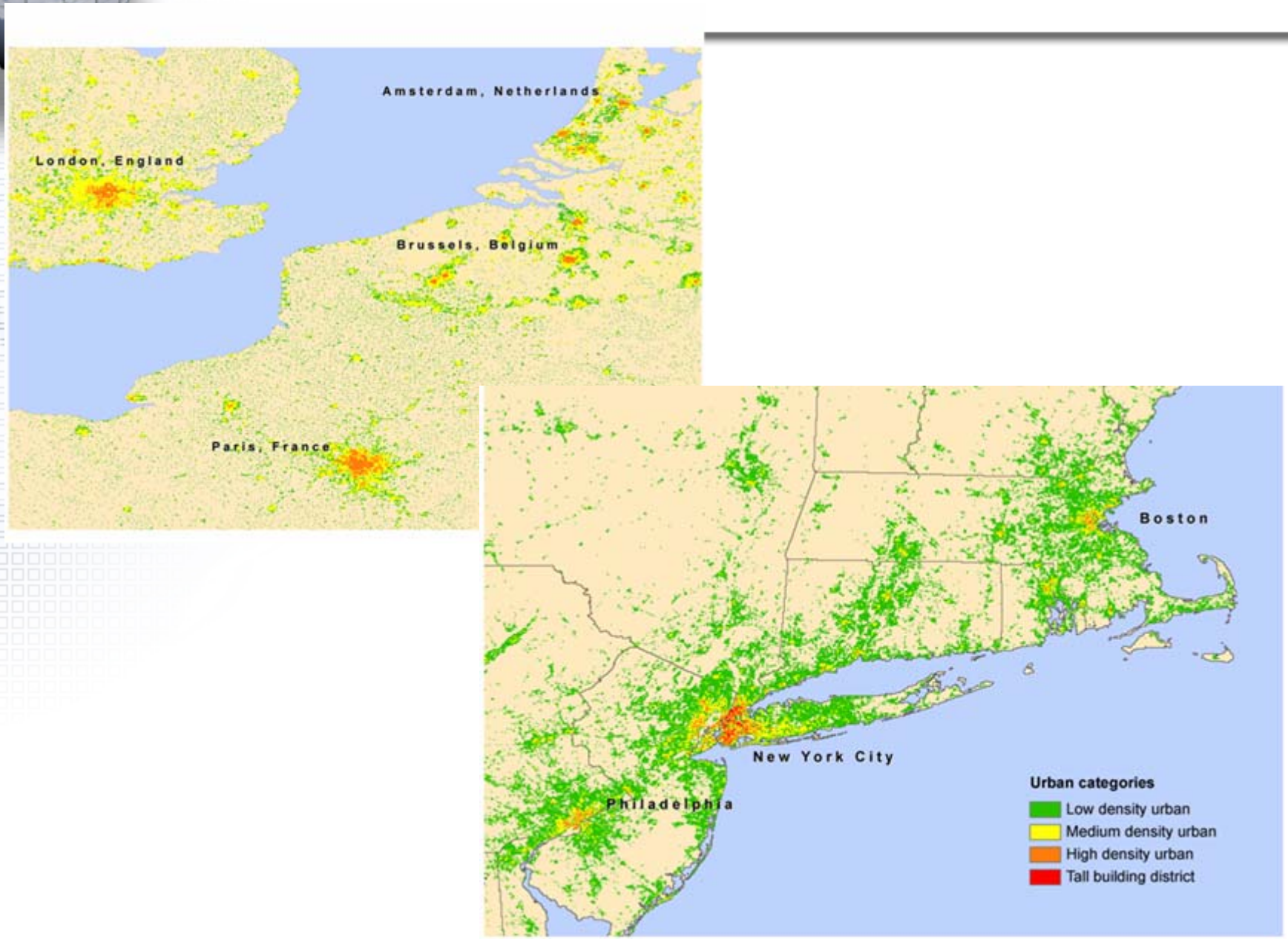
- ***Albedo***
- ***Thermal properties***
- ***Radiative properties***

Roof properties

Road properties

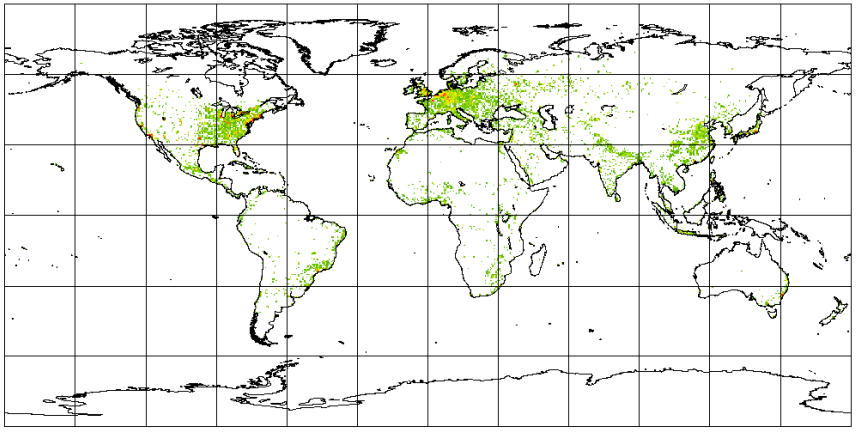
Interior temperature settings

Final Classified 1-km resolution product



Urban land cover

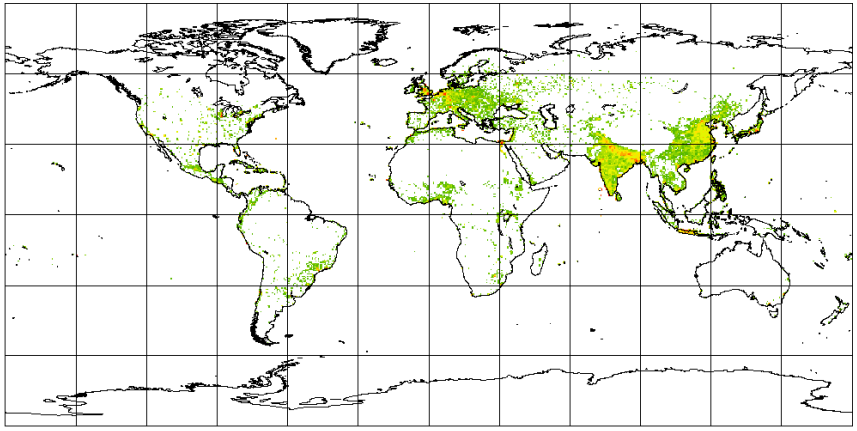
HYDE 3.0



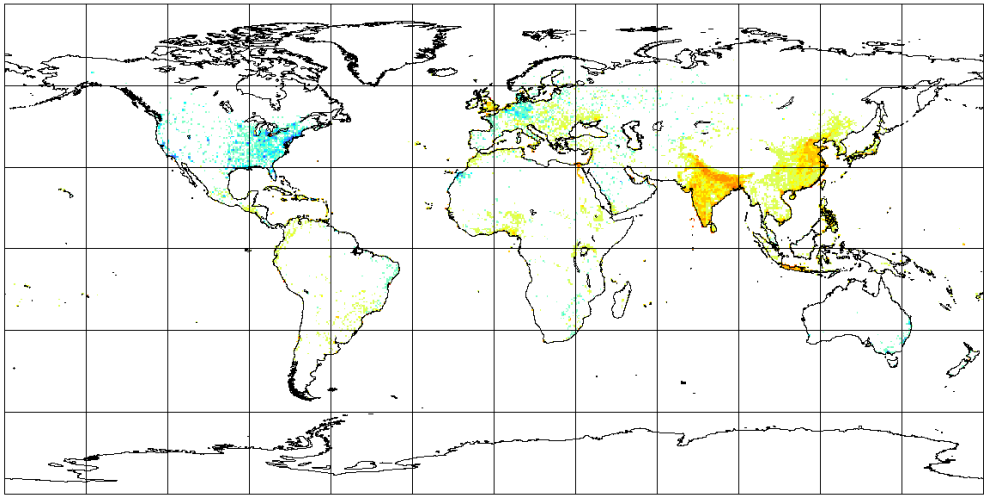
% Grid Cell

- 0
- 0 - 1
- 1 - 2.5
- 2.5 - 5
- 5 - 10
- 10 - 15
- 15 - 20
- 20 - 30
- 30 - 50
- 50 - 100

Jackson and Feddema 2004



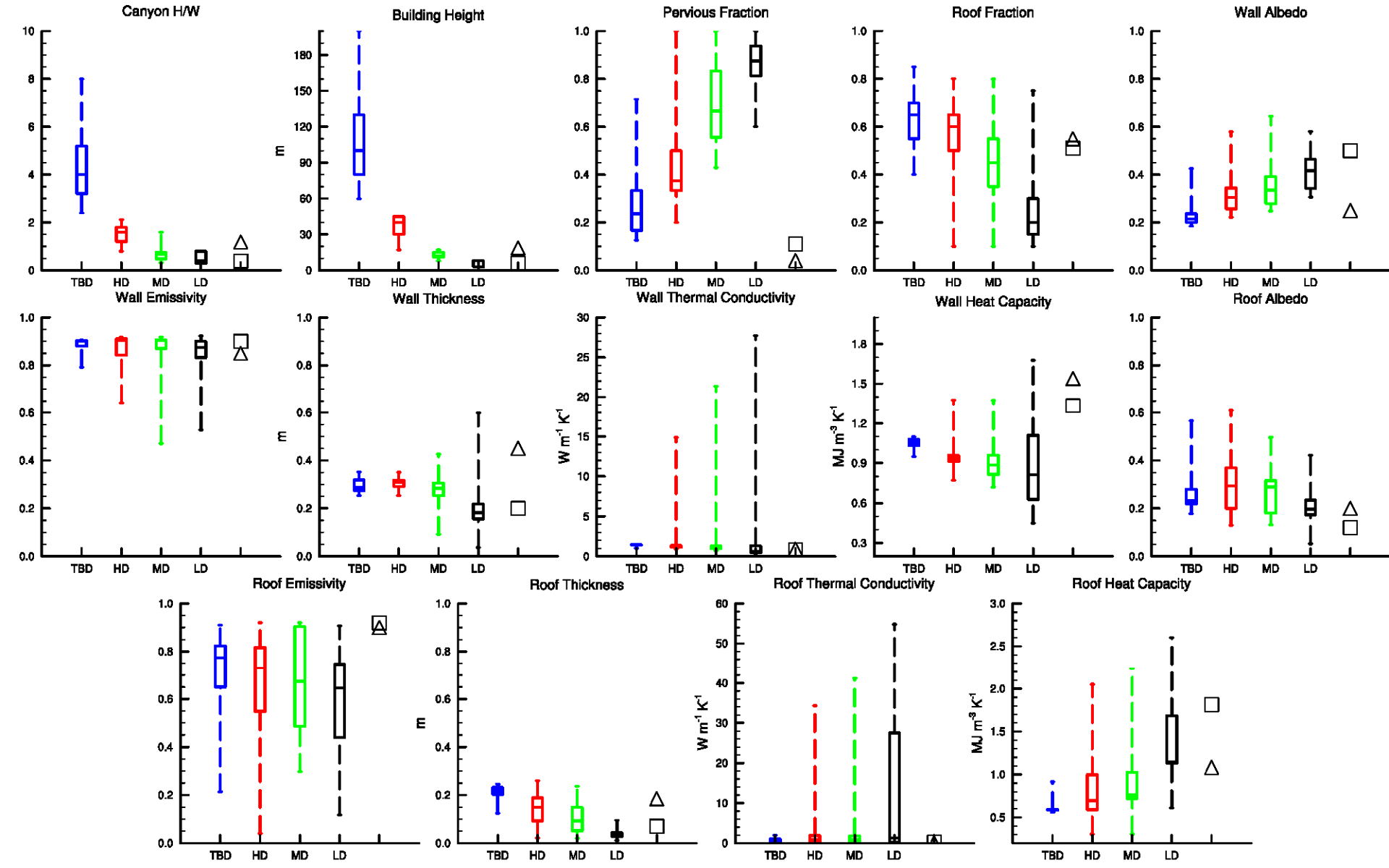
Difference



% Difference

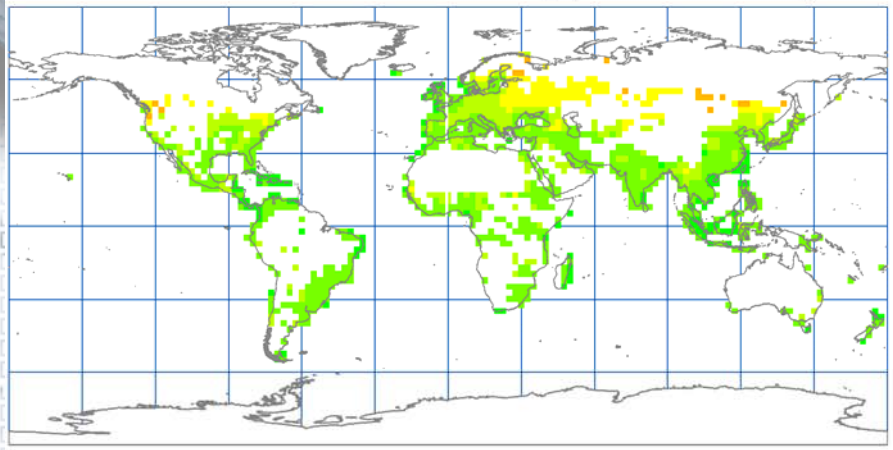
- -100 - -50
- -50 - -25
- -25 - -10
- -10 - -5
- -5 - -2.5
- -2.5 - -0.5
- -0.5 - 0.5
- 0.5 - 2.5
- 2.5 - 5
- 5 - 10
- 10 - 25
- 25 - 50
- 50 - 100

Global Urban Properties

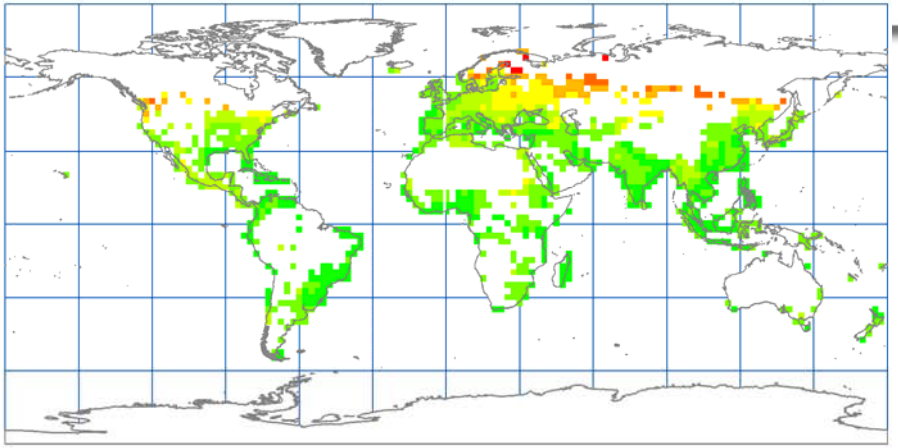


Urban Heat Island Comparison: Parameterization Sensitivity

Vancouver Parameters Applied Globally



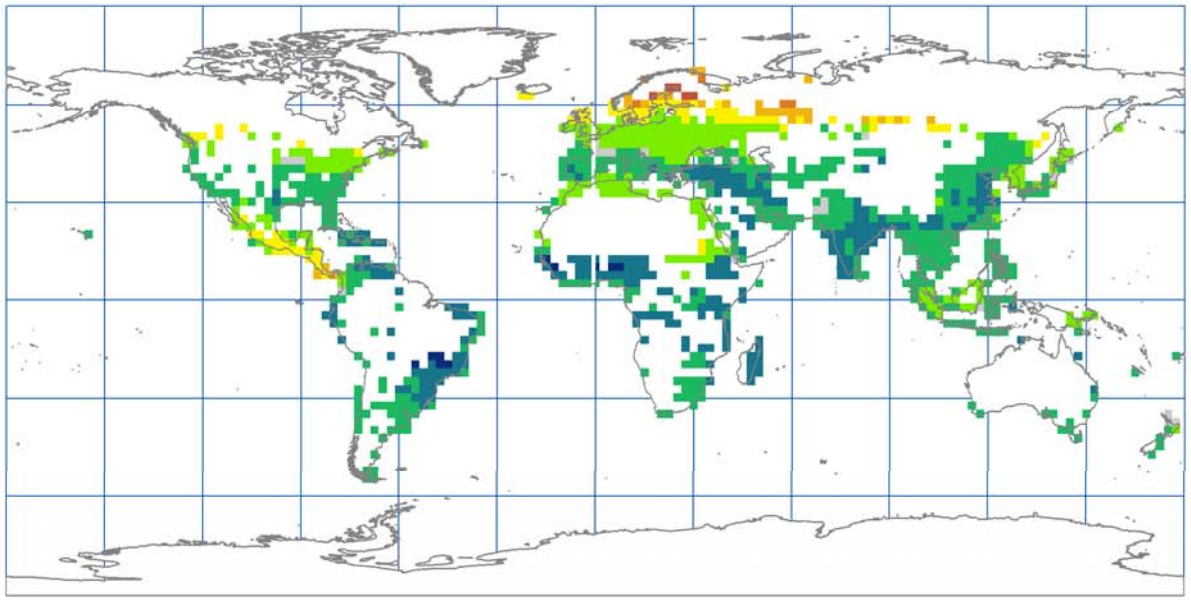
Global Parameter Set



Urban - Rural Temperature Difference (K)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5

Difference: Global - Vancouver



Global - Vancouver UHI Temperature Difference (K)

- -0.75 - -0.50
- -0.50 - -0.25
- -0.25 - -0.01
- -0.01 - 0.01
- 0.01 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.25

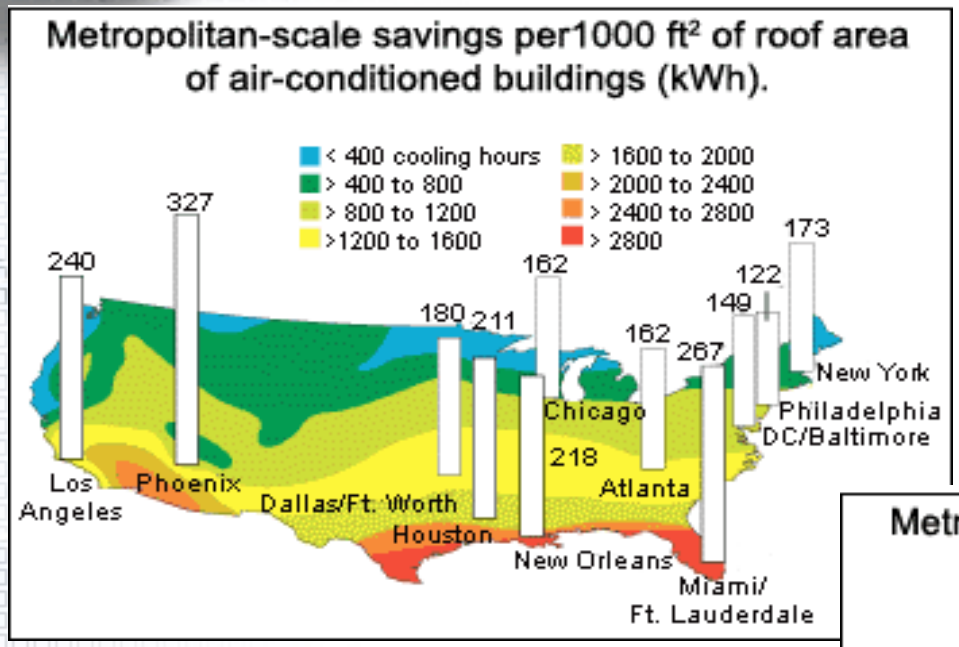
Climate Impact Assessment

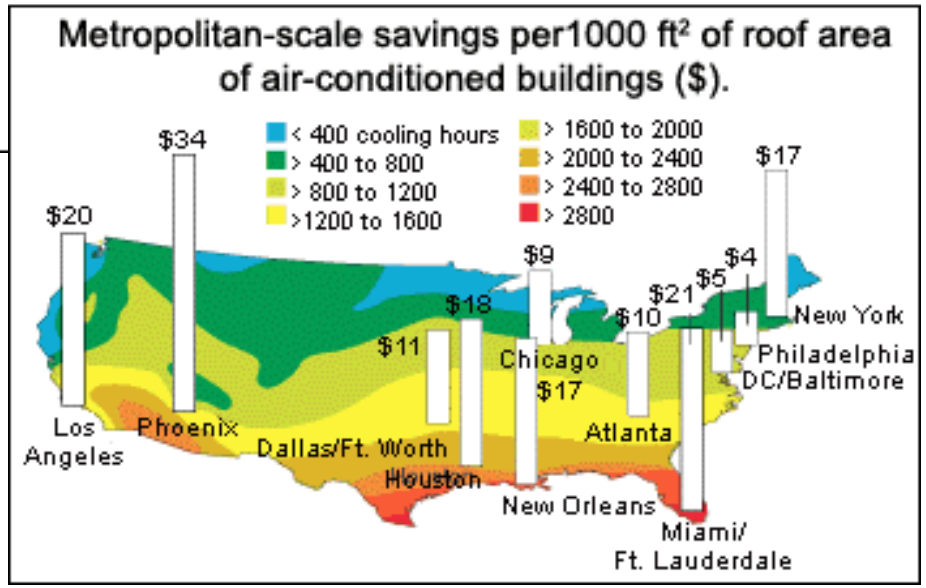
How can Human Activity Models improve climate impact assessment?

"*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 uniformally, 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

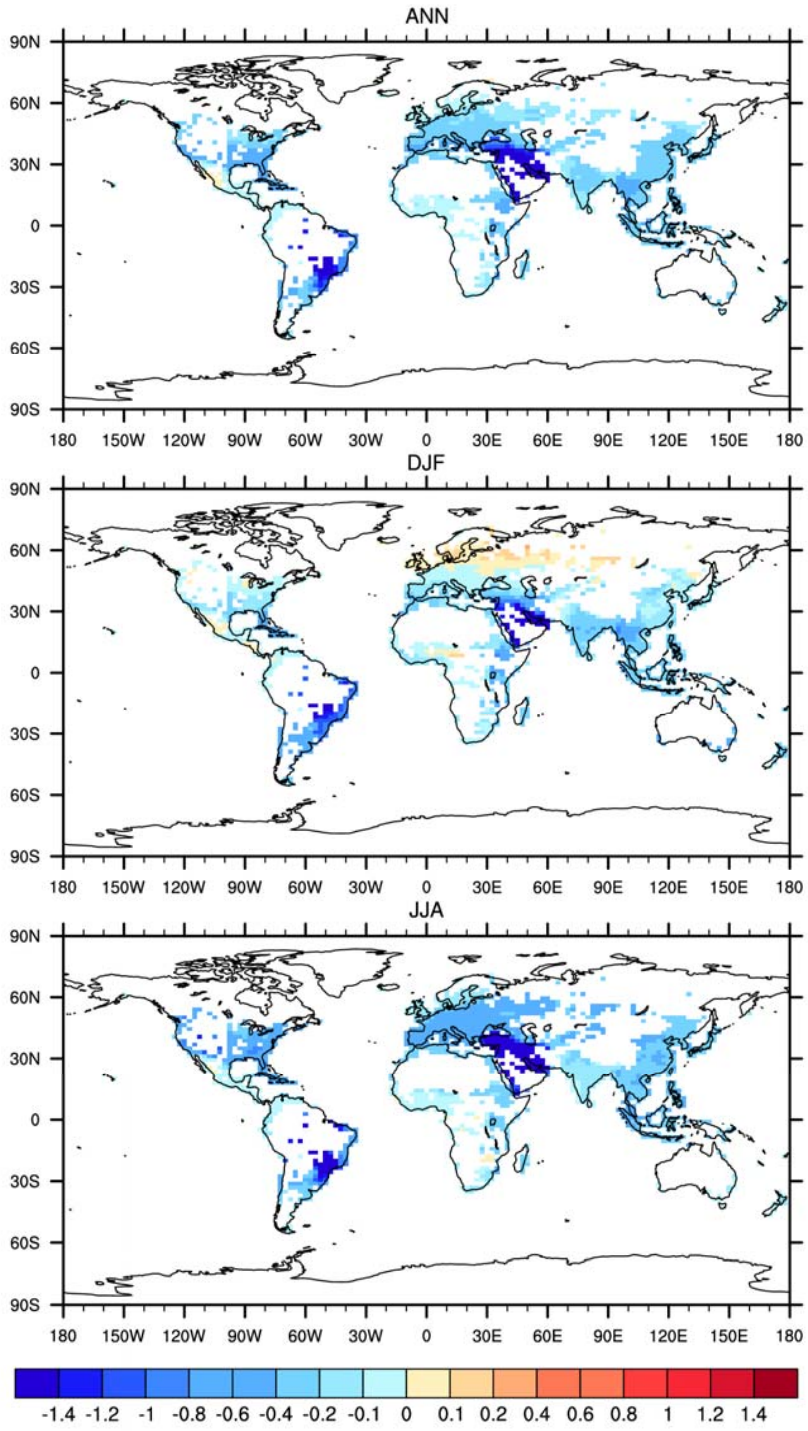




Source: U.S. Environmental Protection Agency

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 (˚ C). Land areas displayed in white are grid cells that have zero urban fraction in the model.



White Roof: Change in global energy demand

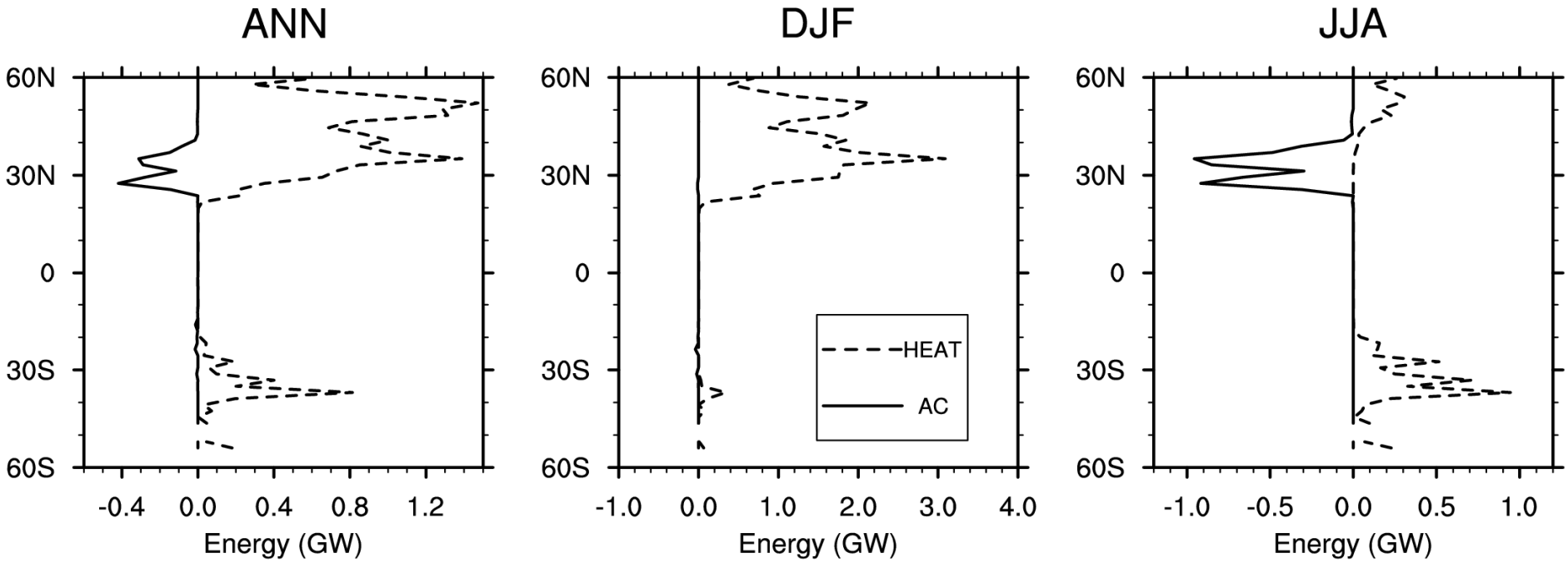


Figure 4. Zonal means of ALB minus CON simulations of urban space heating (HEAT) and air conditioning (AC) energy for 1980-1999 annual, DJF, and JJA climatology (gigawatts).

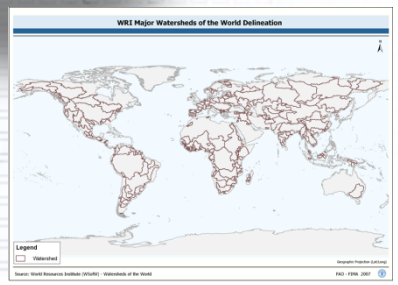
Conclusion:

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.

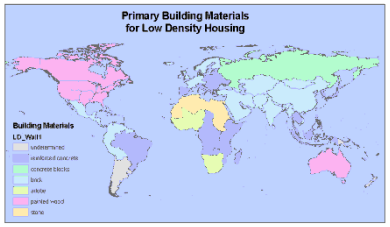
What Next?

Flexible data management schemes

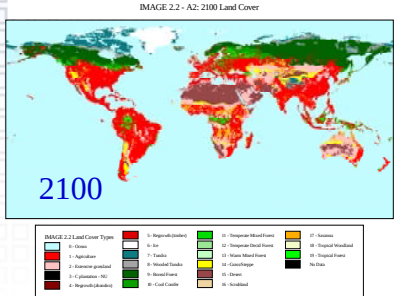
Raw data



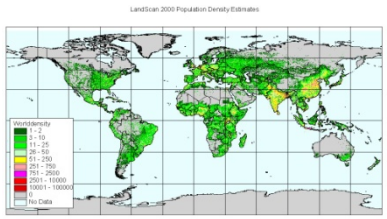
Watershed Management Decisions



National/Regional Policy Information



Land Cover 0.5 degree resolution



Population/urban 1 km resolution

Vector/ Polygon Datasets

Gridded/ Raster Datasets

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