The handshake between IAMs and ESMs: IPCC AR5 as a catalyst

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Steven Rose (US EPRI)
Jean-Francois Lamarque (NCAR/NOAA)
Detlef van Vuuren (PBL)
George Hurtt/Steve Frolking/Louise Chini (UNH)
And MANY MANY others
Outline:

• Some History: What led to current collaborations?

• Evolution of Earth system (Climate) and Integrated Assessment Models

• The Handshake between climate and integrated assessment models

• Implementing the handshake: a case study (!)
“HEY, I THOUGHT WE WERE WORKING WITH THE SAME DATA…”
AIMES and WGCM

AIMES/WGCM led series of workshops towards the use of Earth system models in climate change assessments (the Aspen Protocol). In 2006, a joint meeting with representatives from IA and IAV communities.
Three major outcomes:

1. Multi-temporal phase for climate model runs:
   - Near-Term (2005-2030) – e.g., extreme events, air quality
   - Longer term (to 2100 and beyond) – climate inertia.

2. Carbon Cycle Diagnostic Experimental Design

3. Coordinated IAM/CM New Scenarios: Representative Concentration Pathways (RCPs) as first steps
From AGCMs To ESMs

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From AGCMs To ESMs: another perspective

Climate Models circa early 1990s

Global coupled climate models in 2007

Regional models

Global models in <5 yrs

10 km
Present Day

Energy-climate multigas+landuse models

In the Decade Ahead

Fully integrated (emissions, climate, impacts and adaptation), science-based, decision support tools

- Fully closed systems
- Coastal zones
- Sea level and Ice
- Energy Demand
- Energy Infrastructure
- Health
- Biodiversity
- Timber
- Manufacturing
- Transport
- Energy impacts
- Urban air quality
- Ocean acidification
- Fisheries
- Hydrology
- Unmanaged Ecosystems
- Water Management
- Energy Demand
- Energy Infrastructure
- Health
- Biodiversity
- Timber
- Manufacturing
- Transport
- Energy impacts
- Urban air quality
- Ocean acidification
- Fisheries
- Hydrology
- Unmanaged Ecosystems
- Water Management
Integrated Assessment Framework
IPCC 2001

- Climate Change
- Impacts Vulnerabilities
- Emissions
- Mitigation

“A 10+ year process”

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RCPs:
A scientific community initiative, the work of many

- **Genesis:** Aspen, CO 2006 (Meehl et al. 2007; Hibbard et al., 2007)

- **Joint IAM-CMC-IAV development and vetting and presentation to IPCC at an Expert Meeting** (Moss et al, 2008; [www.ipcc.ch](http://www.ipcc.ch), [www.aimes.ucar.edu](http://www.aimes.ucar.edu))


- **RCP data preparation** (van Vuuren et al., being finalized, draft available from [http://www.aimes.ucar.edu](http://www.aimes.ucar.edu))

- **Many meetings and teleconferences along the way**
New scenarios development process: parallel vs. sequential approach

(a) Sequential approach
1 Emissions & socio-economic scenarios (IAMs)
2 Radiative forcing
3 Climate projections (CMs)
4 Impacts, adaptation & vulnerability (IAV)

(b) Parallel approach
1 Representative concentration pathways (RCPs) and levels of radiative forcing
2a Climate, atmospheric & C-cycle projections (CMs)
2b Emissions & socio-economic scenarios (IAMs)
3 Impacts, adaptation, vulnerability (IAV) & mitigation analysis
4

Figure from Moss et al., 2008, 2009
Scenarios selected to span climate space.
(and new scenario development process with scientific communities as responsible party, e.g., NOT IPCC)
Representative Concentration Pathways

Figure from Moss et al., 2008, 2009
New scenarios development process:
Critical path of scenario development

Figure from Moss et al., 2008, 2009
Integrated Assessment Framework: WCRP, and IGBP and IAMC

- Climate Change
- Impacts Vulnerabilities
- Revised Fluxes
- Adaptation
- Emissions
- Revised Development Paths
- Mitigation

INTEGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC)

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RCPs are just a beginning to facilitate research across communities…

the critical work comes next to explore and characterize uncertainties
RCP selection process

**Defined requirements**
- Desirable characteristics for RCPs
- Desirable types of RCPs

**Identified candidates**

**Selected RCPs**
Identified desirable characteristics for RCPs

- **Range:**
  - Set “should be compatible with the full range of stabilization, mitigation, and baseline emissions scenarios available in the current scientific literature.”

- **Number:**
  - Four RCPs – even number avoids the natural inclination to select the intermediate case as the “best estimate”

- **Separation and Shape:**
  - To be statistically distinguishable, radiative forcing pathways should be well separated by the end of the 21st century and/or have distinctive shapes

- **Robustness:**
  - Given the substantial resource requirements associated with running CMs, the RCPs and the scenarios on which they are based should be robust. A key criterion is whether several models can produce similar radiative forcing outcomes with plausible and technically sound scenarios.

- **Comprehensiveness:**
  - For internally consistent data, models need to model all radiative forcing factors (full suite of GHGs, aerosols, chemically active gases, and land use/land cover)

- **Near-term resolution:**
  - Produce data at higher resolution for the first 30 years (to 2035) for experimental climate change and atmospheric chemistry projections
### Candidates and RCPs

<table>
<thead>
<tr>
<th>IAM (affiliation)</th>
<th>RCP8.5</th>
<th>RCP6</th>
<th>RCP4.5</th>
<th>RCP3-PD</th>
<th>Reference(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIM (NIES)</td>
<td></td>
<td>²</td>
<td></td>
<td>²</td>
<td>Fujino et al. (2006), Hijiioka et al. (2008)</td>
</tr>
<tr>
<td>GRAPE (IAE)</td>
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<td></td>
<td></td>
<td></td>
<td>Kurosawa (2006)</td>
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<td>IGSM (MIT)</td>
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<td>Reilly et al. (2006), Clarke et al. (2007)</td>
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<tr>
<td>IMAGE (MNP)</td>
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<td></td>
<td></td>
<td>²</td>
<td>van Vuuren et al. (2006, 2007)</td>
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<tr>
<td>IPAC (ERI)</td>
<td>²</td>
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<td></td>
<td></td>
<td>Jiang et al. (2006)</td>
</tr>
<tr>
<td>MiniCAM (PNNL)</td>
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<td>²</td>
<td></td>
<td></td>
<td>Smith and Wigley (2006), Clarke et al. (2007)</td>
</tr>
</tbody>
</table>

- Peer-reviewed and published
- Meet definition of RCP type (from defined desirable characteristics)
- Data requirements – radiative forcing components, amenable to developing full resolution
- Modeling requirement – radiative forcing results must have been generated with an IAM that contained carbon cycle and atmospheric chemistry representations
- Meet timeline
The Four RCPs

All RCPs:
- Selected from existing literature (with updates)
- Span a wide range of different possible futures and trajectory shapes
- Provide full range of emissions
- Provided in gridded format

From Moss et al., 2008, 2009

Table 1.1: Overview of Representative Concentration Pathways (RCPs)

<table>
<thead>
<tr>
<th>RCP</th>
<th>Description</th>
<th>Publication – IA Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCP8.5</td>
<td>Rising radiative forcing pathway leading to 8.5 W/m² in 2100</td>
<td>Riahi et al. (2007) – MESSAGE</td>
</tr>
<tr>
<td>RCP6</td>
<td>Stabilization without overshoot pathway to 6 W/m² at stabilization after 2100</td>
<td>Fujino et al. (2006) and Hijioka et al. (2008) – AIM</td>
</tr>
<tr>
<td>RCP4.5</td>
<td>Stabilization without overshoot pathway to 4.5 W/m² at stabilization after 2100</td>
<td>Clarke et al. (2007) – MiniCAM</td>
</tr>
<tr>
<td>RCP3-PD</td>
<td>Peak in radiative forcing at ~ 3 W/m² before 2100 and decline</td>
<td>van Vuuren et al. (2006, 2007) – IMAGE</td>
</tr>
</tbody>
</table>
User guidance: Intended uses and limits of RCPs

• **Intended uses**
  – Input to climate models to jump-start scenario development across research communities
  – To facilitate pattern scaling of climate model outcomes
  – To explore ranges of socioeconomic conditions consistent with different forcing pathways
  – To explore climate implications of spatial forcing patterns
  – To provide a consistent analytical thread through the literature

• **Limits**
  – Not forecasts or absolute bounds
  – Not policy prescriptive
  – Socioeconomics underlying each RCP are not unique; and, across RCPs, are not a set or representative of the range of assumptions
  – Uncertainties in the translation of emissions profiles to concentrations and radiative forcing
RCP data requirements:
Full set of radiative forcing components

<table>
<thead>
<tr>
<th>Variable</th>
<th>Units</th>
<th>Spatial scale</th>
<th>Concentrations</th>
<th>Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Greenhouse gases</strong></td>
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<td></td>
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<tr>
<td>CO₂ (fossil fuel, industrial, land use change)</td>
<td>ppm and Pg/yr</td>
<td>Global average</td>
<td>Sum</td>
<td></td>
</tr>
<tr>
<td>CH₄</td>
<td>ppb and Tg/yr</td>
<td>Global average</td>
<td>Grid¹</td>
<td></td>
</tr>
<tr>
<td>N₂O</td>
<td>ppb and Tg/yr</td>
<td>Global average</td>
<td>Sum</td>
<td></td>
</tr>
<tr>
<td>HFCs²</td>
<td>ppb and Tg/yr</td>
<td>Global average</td>
<td>Sum</td>
<td></td>
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<tr>
<td>PFCs²</td>
<td>ppb and Tg/yr</td>
<td>Global average</td>
<td>Sum</td>
<td></td>
</tr>
<tr>
<td>CFCs²</td>
<td>ppb and Tg/yr</td>
<td>Global average</td>
<td>Sum</td>
<td></td>
</tr>
<tr>
<td>SF₆</td>
<td>ppb and Tg/yr</td>
<td>Global average</td>
<td>Sum</td>
<td></td>
</tr>
<tr>
<td><strong>Aerosols²</strong></td>
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<td></td>
</tr>
<tr>
<td>Sulfur (SO₂)</td>
<td>Tg/yr</td>
<td>Generated by CM community³</td>
<td>Grid</td>
<td></td>
</tr>
<tr>
<td>Black Carbon (BC)</td>
<td>Tg/yr</td>
<td>Generated by CM community³</td>
<td>Grid</td>
<td></td>
</tr>
<tr>
<td>Organic Carbon (OC)</td>
<td>Tg/yr</td>
<td>Generated by CM community³</td>
<td>Grid</td>
<td></td>
</tr>
<tr>
<td><strong>Chemically active gases</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO</td>
<td>Tg/yr</td>
<td>Generated by CM community³</td>
<td>Grid</td>
<td></td>
</tr>
<tr>
<td>NOₓ</td>
<td>Tg/yr</td>
<td>Generated by CM community³</td>
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<td></td>
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<td>VOCs²</td>
<td>Tg/yr</td>
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<td>Grid</td>
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<td>NH₃</td>
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<td><strong>Land use &amp; land cover</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂ flux (land use change)</td>
<td>Tg/yr</td>
<td>n/a</td>
<td>≤ 1° x 1°</td>
<td></td>
</tr>
<tr>
<td>Land use &amp; land cover</td>
<td>Fraction of types⁴</td>
<td>Regional results (grid)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
RCP data hand-shake:
An IAM-ESM-inventory-chemistry collaboration

• IAM teams need to round-out their published scenarios to satisfy the full data request for climate and atmospheric chemistry modeling
  – Harmonize definitions and historic data
  – Provide additional detail for emissions
  – Provide additional detail for land use & land cover change
  – Extend scenarios to 2300 – currently only 2100

• Consistency and coordination between the communities required and essential to increase comparability and provide a smooth transition from historic to future periods

• Coordination events:
  – Joint Meeting, February 2008, Washington, DC
  – Emissions meeting, May 2008, Paris
  – Joint Meeting, Summer 2008, Snowmass, CO
  – IAMC meeting, September 2008, Vienna
  – CM/IAM Land Use/Land Cover and Wetland May 2009, Hamburg, DE
Central IAM Data Repository
IAM working environment & data dissemination

- Database open for scientific review:
  [http://www.iiasa.ac.at/web-apps/tnt/RcpDb/](http://www.iiasa.ac.at/web-apps/tnt/RcpDb/)

### Query Results

<table>
<thead>
<tr>
<th>Region</th>
<th>Scenario</th>
<th>Variable</th>
<th>Unit</th>
<th>2000</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
<th>2060</th>
<th>2070</th>
<th>2080</th>
<th>2090</th>
<th>2100</th>
</tr>
</thead>
</table>

**Notes:**
- RCP Database (Version 0.7.17) generated: 2008-09-20 10:16:38
- "Energy Modeling Forum Snowmass, CO USA 30-31 July 2009"
RCP status

- Significant coordination within and outside RCP teams over two years
- Completed IMAGE 2.6 review for lowest RCP (Weyant et al., 2009)
- Developed RCP database: web-based central repository with standardized set of reporting variables
- Developed emissions and land-use standardization data: spatially explicit base year and historic data for standardizing the RCP base years and projections
- Completed detailed internal review (data to 2100)
- Outside technical review underway (for 3 of the RCPs to 2100) – IAM, climate, and atmospheric chemistry communities, as well as others
- Completing internal review of 4th RCP
- Atmospheric chemistry runs beginning
- Forthcoming: Land-use transition standardization, recent request for historic concentrations, RCP 2300 extensions
Land-use/land-use change data on a gridded (0.5° lat x 0.5° lon) format:

- Cropland
- Harvested forest area (secondary forests)
- Deforested area (primary forests)
- Pasture and grazing land
- Urban land

Supplementary data that has also been requested includes:

- Irrigated area
- Timber and wood harvest amounts (and disposition)
- Standard of living indicator
- Fertilizer use

ftp://tarot.sr.unh.edu

RCP Land Use from the IAMs:
Land Use Harmonization Attributes

- gridded, with sub-grid information
- land-use transitions
- continuous (realistic ~ annually)
- consistent with historical reconstruction
- consistent with IAM futures
- smooth history → future
- wood harvest & shifting cultivation
1. For IPCC AR5 land use and land cover change are to be described consistently with Representative Concentration Pathways (RCP) scenarios.

2. All pathways share the same historical trajectory to 2005. After 2005 they diverge following own representative pathway.

3. For each RCP, land use that results in land cover change is described through annual changes in four basic land units:
   - Primary Vegetation (V)
   - Secondary Vegetation (S)
   - Cropping (C)
   - Pasture (P)

4. Harvesting of biomass is also prescribed for both primary and secondary vegetation land units.
LULC Harmonization Strategy (UNH)

HYDE 3: Cropland & rangeland in 2000 (Klein Goldewijk et al. 2007)

 cropland
 rangeland

Area (km²) per 5 min. grid:
- 0
- < 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- > 60

Other area = total area - cropland area - rangeland area - urban area

Global Land Area 1700 - 2100 Showing Range of Future IAM Scenarios

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The RCP emissions data will be provided in greater sectoral detail than for previous scenario exercises:

- Ground Transportation
- International Shipping
- Aviation
- Power Plants, Energy Conversion, Extraction, and Distribution
- Solvents
- Waste (landfills, wastewater, non-energy incineration)
- Industry (combustion & processing)
- Residential and Commercial

- Ag waste burning on Fields
- Agriculture (e.g. Animals, Rice, & Soil)
- Savannah Burning
- Land-Use Change (Deforestation)

Aim to have data at regional, national and grid scale
Emissions Harmonization:

<table>
<thead>
<tr>
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<td>ppm and Pg/yr</td>
<td>Global average</td>
<td>Sum</td>
<td></td>
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<tr>
<td>CH\textsubscript{4}</td>
<td>ppb and Tg/yr</td>
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<td>Sum</td>
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<td>PFCs\textsuperscript{2}</td>
<td>ppb and Tg/yr</td>
<td>Global average</td>
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<td>CFCs\textsuperscript{2}</td>
<td>ppb and Tg/yr</td>
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<tr>
<td>SF\textsubscript{6}</td>
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<td><strong>Aerosols</strong>\textsuperscript{2}</td>
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<td>Sulfur (SO\textsubscript{2})</td>
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<td><strong>Land use &amp; land cover</strong></td>
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<td>Tg/yr</td>
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<td>$\leq 1^\circ \times 1^\circ$</td>
<td></td>
</tr>
</tbody>
</table>
Non-CO$_2$ emissions

International effort to provide improved emissions 1850-2300, consistent across 2000 for anthropogenic (including ships and aircraft) and biomass burning emissions of ozone precursors and aerosols.
NCAR simulation results

[Graph showing annual concentration (ug/m^3) and relative difference of annual SO4 concentration with RSMAS]

R = 0.972119
NCAR simulation results

Sulfur deposition at D4, Greenland

BC deposition at D4, Greenland

Hydrophilic BC deposition

To be used in CMIP-5 by AOGCMs

Surface ozone

Total ozone column

Model evaluation: Stratosphere: CCMval- Troposphere: ACC-MIP
Emissions Data Status


- Processing (addition of seasonal cycle and vertical distribution where appropriate) of RCP8.5 done and emissions are being evaluated by a small group of collaborators

- RCP2.6 and RCP4.5 next

- Still some issues with RCP6.0

- With regard to fossil fuel data: Patricia Cadule from IPSL contacted Bob Andres, who provided fossil fuel data files. A continuous file from 1751 to 2006, monthly data, netcdf format is now available (as of Tuesday morning!).
The CM Perspective: Proposed AR5 Simulations

1. Four Representative Concentration Pathways (RCP) have been selected for IPCC future climate simulations that include emissions and land cover change scenarios.

2. Each future simulation is based on a different Integrated Assessment Model (IAM) simulation that makes specific assumptions about the human activities creating the RCP outcome.

3. Each Earth System Model (ESM) group will run a number of specified simulations and ensembles as resources permit:
   - Simulations for RCPs through 2100/2300 (priority 8.5, 2.6 then 4.5 and/or 6.0).
   - High resolution (0.5 degree) “climate forecast” simulation from 1980 to 2030 (tentatively 4.5).
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.
RCP Comparisons

RCP 8.5: Message

RCP 6.0: AIM

RCP 4.5: Mini-Cam

RCP 2.6: IMAGE
Translating from harmonized to Earth system model: the CLM 4.0 Land Cover Representation

19 Plant Functional Types
- Needleleaf evergreen tree
- Needleleaf deciduous tree
- Broadleaf evergreen tree
- Broadleaf deciduous tree
- Shrub
- Grass
- Crop
- Ocean
- Permanent Snow & Ice
- Permanent Lake
- Permanent Wetland
- Permanent Urban
- Transient PFTs
- Intransient Land Units
- Grid Cell

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Issues of definitions

e.g. What is Pasture/Grazing
Creating datasets order of entry: bare ground

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: grasslands

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

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

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

Human Activity Prioritized

MODIS Physical Information Prioritized
Historical (UNH Hurtt): Land cover change 2005-1850

Crop

Primary

Pasture

Secondary
Mini-Cam (RCP 4.5 Wm$^{-2}$): Land cover change 2100-2005

Crop

Pasture

Primary

Secondary
Global Urban Parameters for CLM

University of Kansas
Trisha Jackson
Johannes Feddema
John Bauer

NCAR
Keith Oleson
Gordon Bonan
Eric Kluzek

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CLM 4.0 Urban Subgrid Structure: a ‘permanent’ land cover type: e.g., no transient or development.
NCAR Urban Canyon Model

Model Parameter/data needs
- Global delineation of urban areas
- Geometric and radiative properties of the canyon
- Surface and conductive properties of walls, roofs (road properties assumed constant)
- Information on human activity and energy consumption levels
Required parameters in CLM

- Height to Width ratio
- Roof Area Fraction
- Radiative properties: Emissivity, Albedo
- Impervious Surfaces
- Pervious Surfaces
- Soil Layers
- Vegetation Area Fraction
- Interior Temperature
- Include thermal properties: Volumetric Heat Capacity, Thermal Conductivity
Urban parameterizations

Wall types: concrete, brick, stone, plaster, etc.
Roof types: PVC, BUR/concrete deck, ceramic tiles, etc.
Exterior wall materials and properties
Interior wall materials and properties
Wall type construction from 10 types of materials
Roof type construction from 10 layers of materials
Road types and properties (asphalt, concrete, unpaved, etc.)
Bridging factors applied across various wall types
What is urban?
Defining Urban Classes (US)

Low Density

Medium Density

High Density

CBD
Defining urban classes (CBD/HD)
Urban characteristics: Nairobi
Urban characteristics: Nairobi (Kibara slum)
Defining urban classes (LD/HD???)
Population dataset - LandScan

Dobsen et al., 2000
LandScan and MODIS

MODIS Mask of Mexico City

Mexico City (Landscan)

MODIS Mask of Paris

Paris (Landscan)
33 Urban Regions:
Similar climate and housing characteristics
Final Classified 1-km resolution product
Example: Urban input data

Urban Fraction at 0.5°

Final product aggregates TBD, HD and MD areas
No LD included
Urban land cover

HYDE 3.0

Jackson and Feddema 2004

Difference
Defining urban properties
Example results

Roof Albedo

Wall Thermal Conductivity

Energy Modeling Forum Snowmass, CO USA 30-31 July 2009
Global urban properties
Urban heat island comparison:
Parameterization sensitivity
Some Common Ground: carbon cycle and climate

From Janetos et al., BER workshop on IA assessment, 2009
Growing Overlap in Domains

From Janetos et al., BER workshop on IA assessment, 2009
Beyond the Handshake: next steps and priorities

New Scenarios development charged with an integrative and collaborative approach. At least two approaches possible:

1. Use existing RCPs to develop new storylines
2. Use new, multiple concentration pathways to develop new storylines.

The handshake activity is extremely new – there will certainly be pitfalls and difficulties with implementation and assumptions by both IA and CM groups, the least of which are development of alternative historic reconstructions for both land cover/land use and emissions.

As the models evolve, both with regard to increased spatial and process information, it will be important to recognize what is important for global vs. regional, vs local analyses.

Introduction of observations (e.g., satellite and regional studies) as well as evolving observatories (e.g., NEON, Europe and Asian counterparts) for model evaluation and forecasting, data assimilation skill as building towards future.
Beyond the Handshake: 
new models, **new collaborations**

Despite the ongoing model development with regards to embedding existing structures, new models and ideas; still missing hooks to even basic and simple models of human behaviour, links to states, institutions and governance structures.

There are fundamental differences between the social and biophysical sciences; not just in modeling paradigms, but in culture (e.g., reward systems, perceptions of ‘success’).

There are opportunities to develop a networked suite or system of models through collaborations, integrative research that can provide insight into the coupled human-environmental system that is meaningful for resource managers, decision makers and policy communities, BUT, the hooks to the socio-ecological, economic and policy as well as climate modeling communities must be present.