The Future of Integrated Assessment Models of Human-Earth Systems Dynamics

JAE EDMONDS

Ohyama Memorial Hall, NIES
Tsukuba, JAPAN

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U.S. DEPARTMENT OF ENERGY | Office of Science

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Roadmap to the seminar

- Thanks to AIM and Toshi in particular for the opportunity to be here today.

- Integrated Assessment Models (IAMs)
- Who are we and what have we done?

- Where the field is going?
- The integrated Earth system model
- Regional integrated assessment modeling
- Building a community of practice (IAMC)

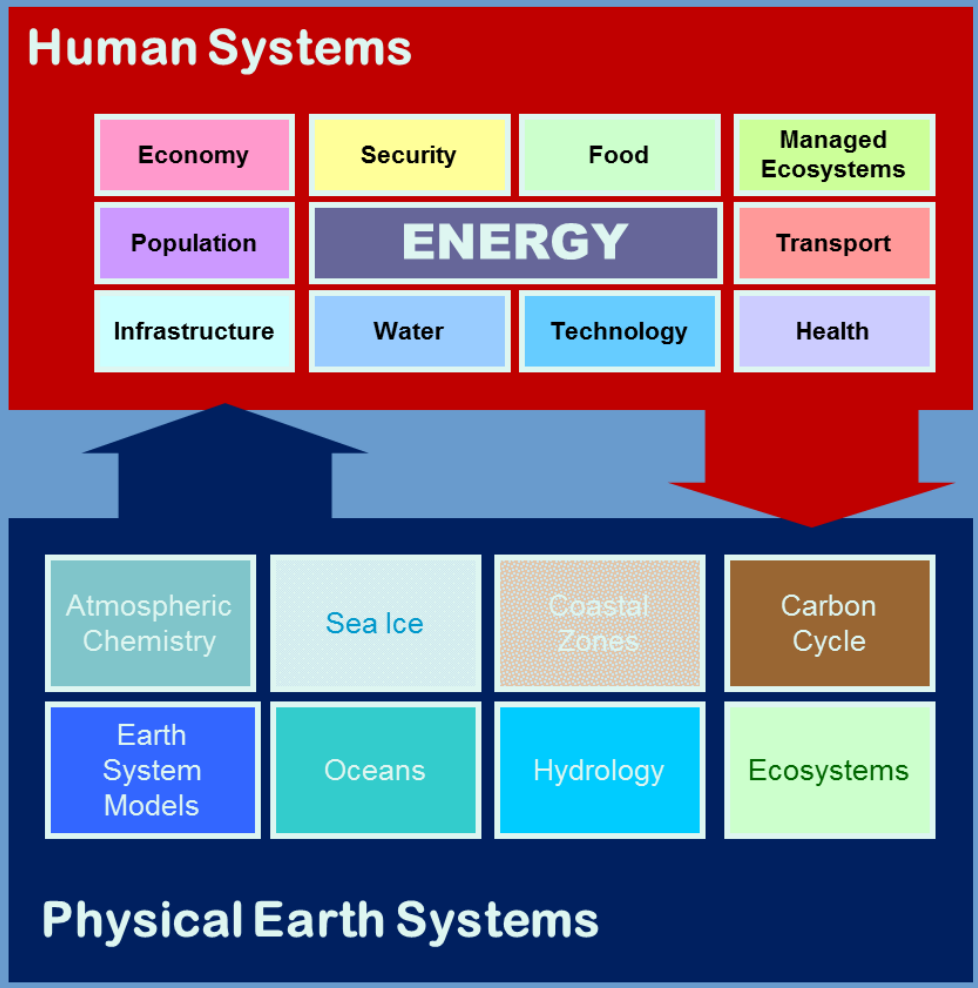
Integrated Assessment Models (IAMs)

IAMs integrate human and natural Earth system climate science.

- IAMs provide physical science researchers with information about human systems such as GHG emissions, land use and land cover.
- IAMs capture interactions between complex and highly nonlinear systems. IAMs provide insights that would be otherwise unavailable from disciplinary research.

IAMs provide important, science-based decision support tools.

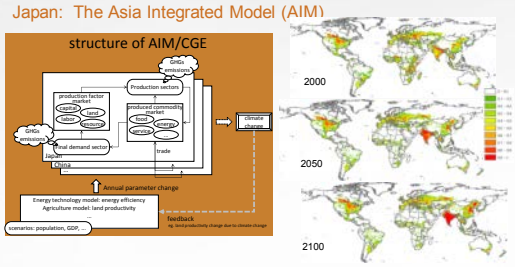
- IAMs support national, international, regional, and private-sector decisions.

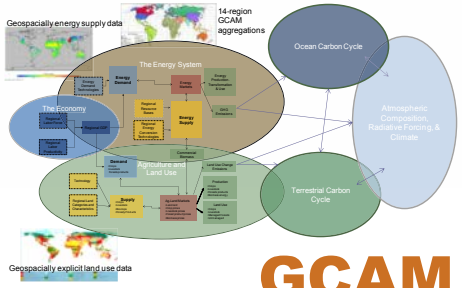


RCP-Class IAMs

- Models like NIES' AIM and PNNL's GCAM.
- Contains detailed representation of both human and physical Earth systems.
- Physical system models of intermediate complexity.
- Provide all of the information that state-of-the-art physical Earth system models need as drivers.
- Detailed process representation, e.g. water balance model, graded wind resources, population distribution, buildings, etc.
- Their central focus is representing human (e.g. economic) interactions with physical systems.
- Explicit representations of technologies.
- Beginning to incorporate climate impacts and adaptation for specific systems, e.g. agriculture, water, forestry, buildings energy.

AIM





GCAM

RCP-class IAMs Around the World

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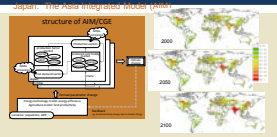
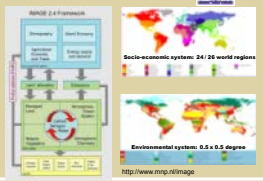
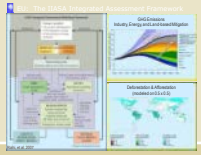
Model	Home Institution	
AIM Asia Integrated Model	National Institutes for Environmental Studies, Tsukuba Japan	
GCAM Global Change Assessment Model	Joint Global Change Research Institute, PNNL, College Park, MD	
IGSM Integrated Global System Model	Joint Program, MIT, Cambridge, MA	
IMAGE The Integrated Model to Assess the Global Environment	PBL Netherlands Environmental Assessment Agency, Bildhoven, The Netherlands	
MESSAGE Model for Energy Supply Strategy Alternatives and their General Environmental Impact	International Institute for Applied Systems Analysis; Laxenburg, Austria	
REMIND Regionalized Model of Investments and Technological Development	Potsdam Institute for Climate Impacts Research; Potsdam, Germany	

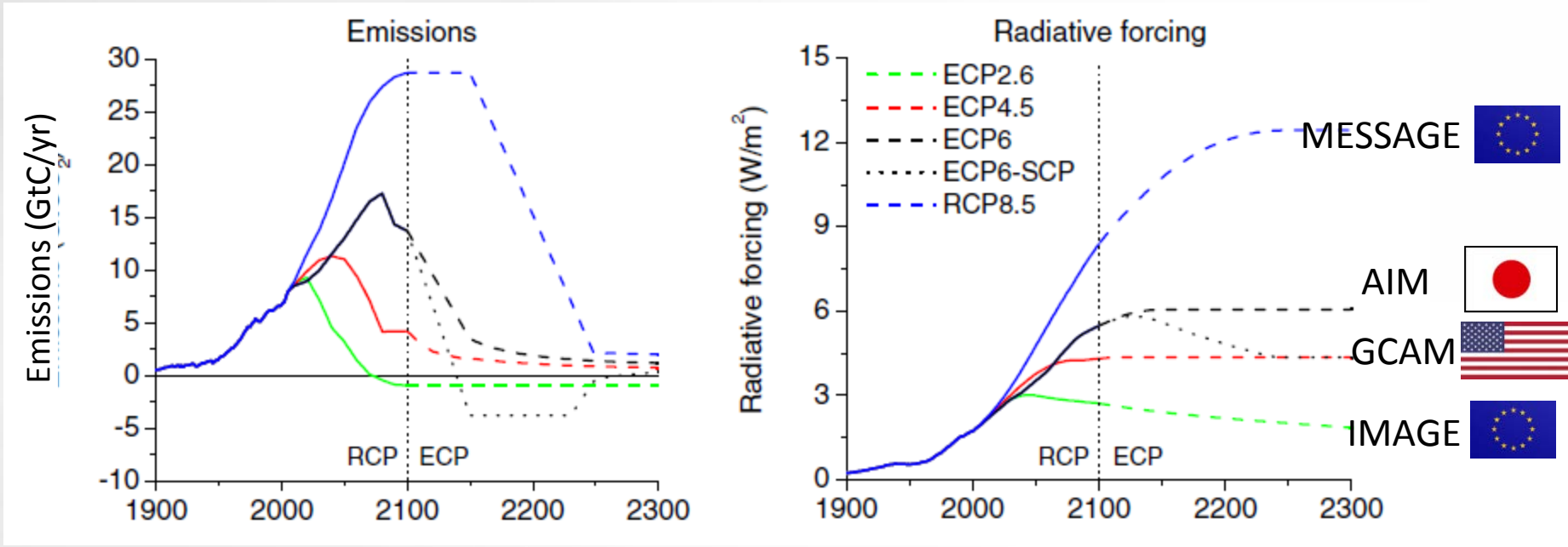
WHERE HAVE WE BEEN?

Where have we been?

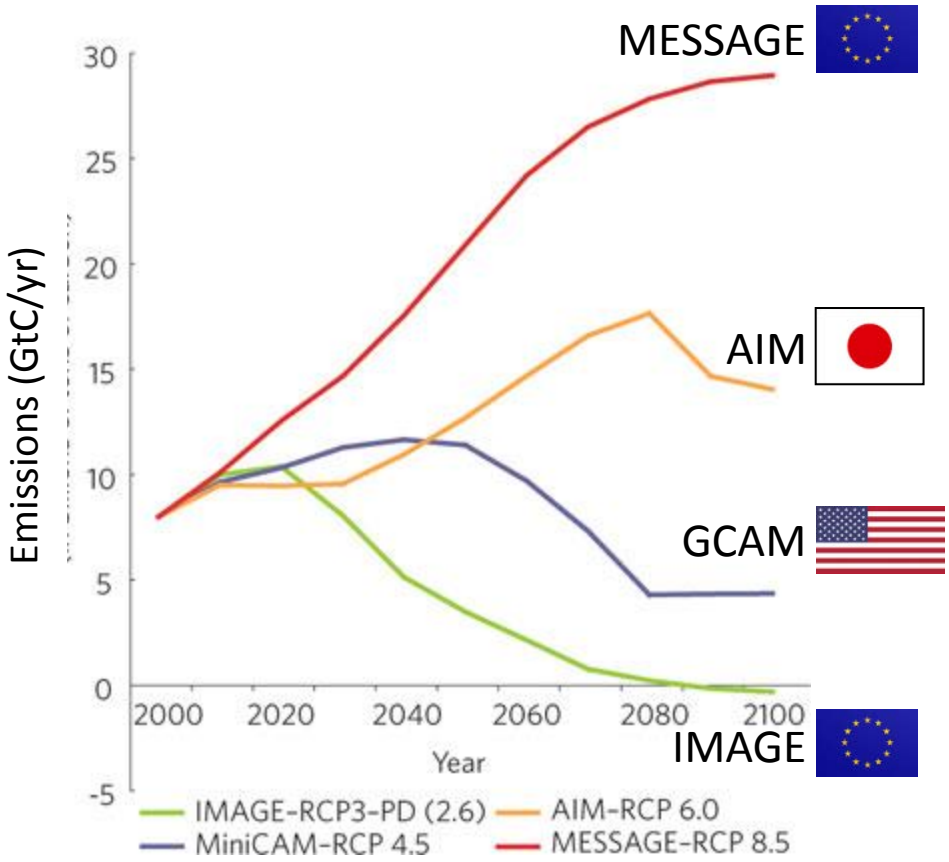
- Much of the focus of the RCP-class models has been on emissions mitigation including examination of
  - Future scenarios of greenhouse gas emissions from energy, industry, and land-use.
  - Cost-minimizing pathways to various long-term goals (decade to century time scales), e.g. 550 ppm CO_2, 2°C, 80% emissions reductions
  - The role of technology—nuclear, bioenergy, CCS, other renewables, end-use efficiency
  - The role of policy—carbon taxes (mostly), regulatory strategies (renewable energy requirements, technology performance standards, e.g. “front-runner” or U.S. EPA power plant emissions standards.

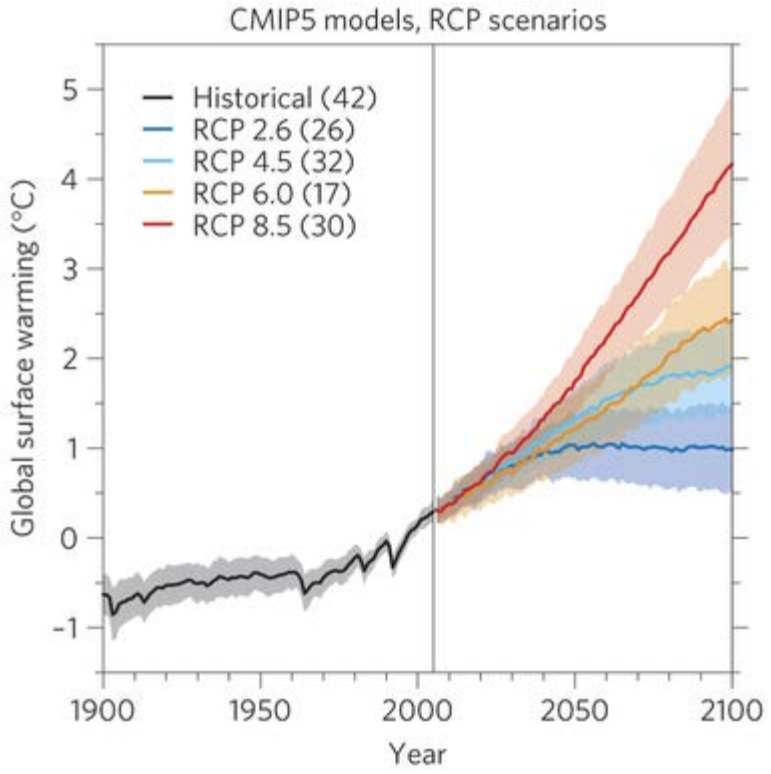
Scenarios: the Representative Concentration Pathways (RCPs)

- Four scenarios worked out with the 3 climate research communities.
- Used for the CMIP 5 and IPCC AR5
- Anthropogenic GHGs, gridded aerosols and short-lived species
- Gridded land use and land cover (½° x ½°)
- Extensions to 2300



RCPs have been used by climate modelers in CMIP5

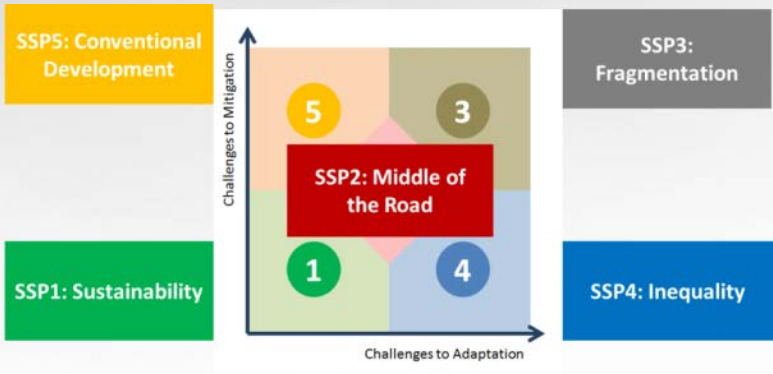


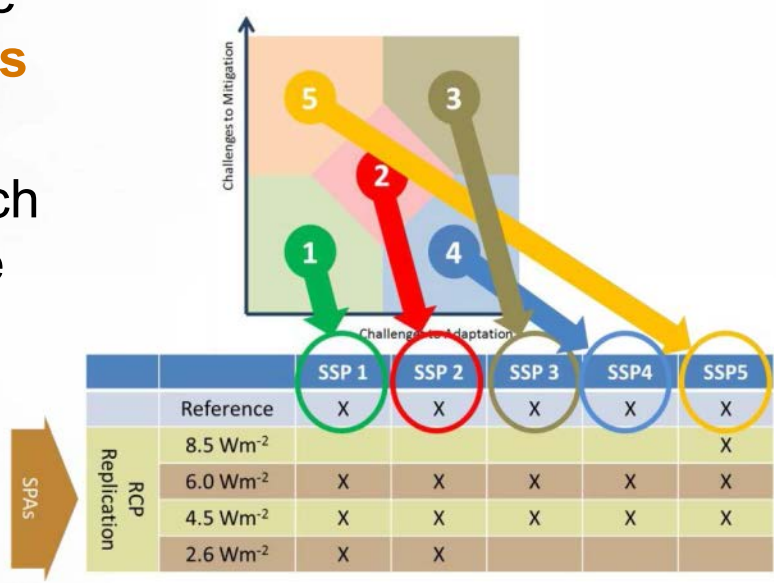


Source: Knutti, R. and J. Sedláček (2012), Robustness and uncertainties in the new CMIP5 climate model projections, *Nature Climate Change*, doi:10.1038/nclimate1716

The next generation of scenarios are the Shared Socioeconomic Pathways (SSPs)

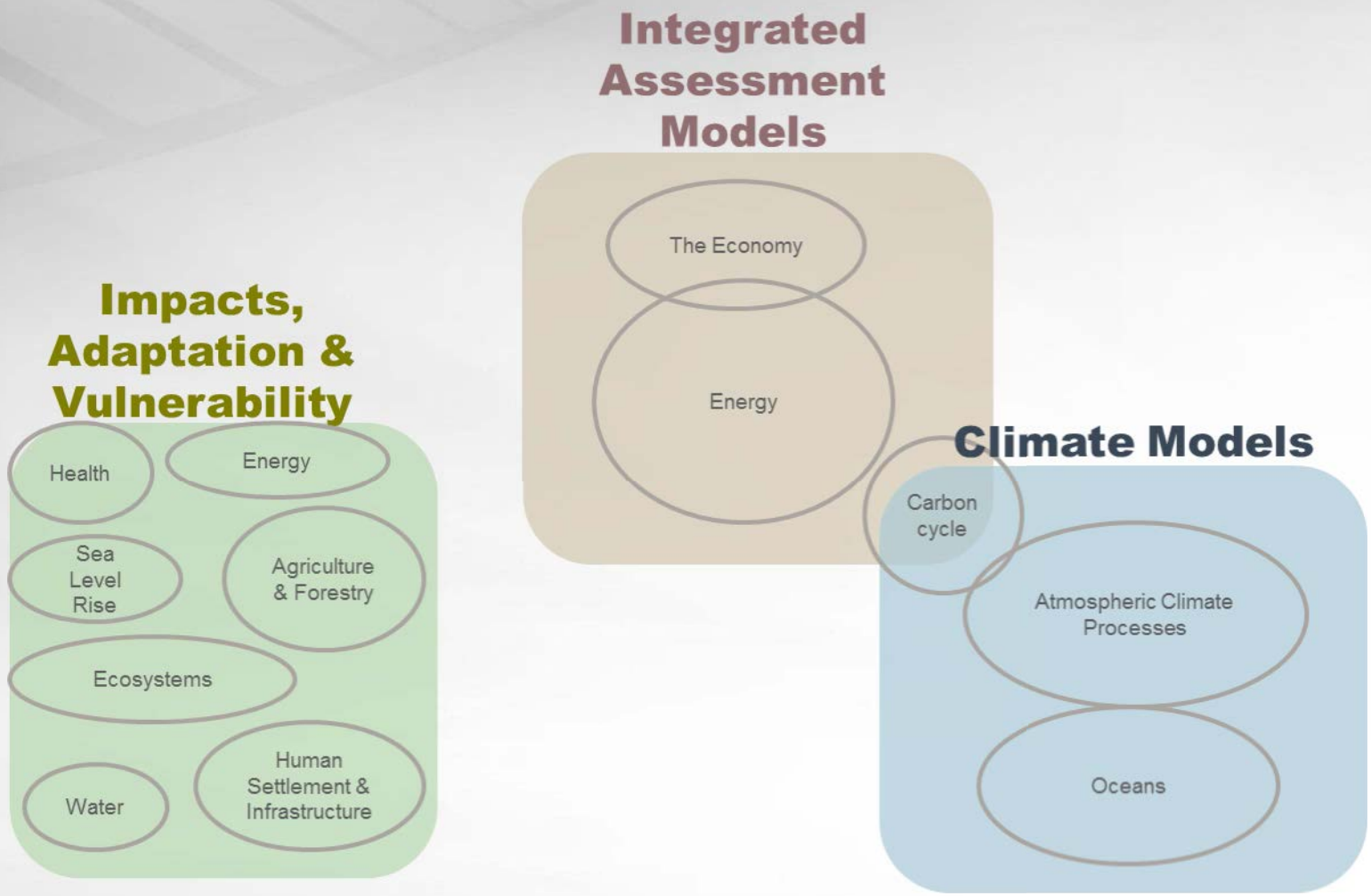
- Designed for faster climate assessment
  - Providing information for Impacts, Adaptation, and Vulnerability (IAV) researchers.
  - Link to the RCPs and CMIP5 (climate change data base)
  - Explore the full range of challenges to mitigation and adaptation to climate change
- 5 reference scenarios designed to explore **challenges to mitigation** and **challenges to adaptation**.
- Up to 4 policy intervention versions of each reference scenario—corresponding to the RCP levels
  - 6.0 Wm^{-2}, 4.5 Wm^{-2}, and 2.6 Wm^{-2}
  - Employing Shared climate Policy Assumptions (SPAs)



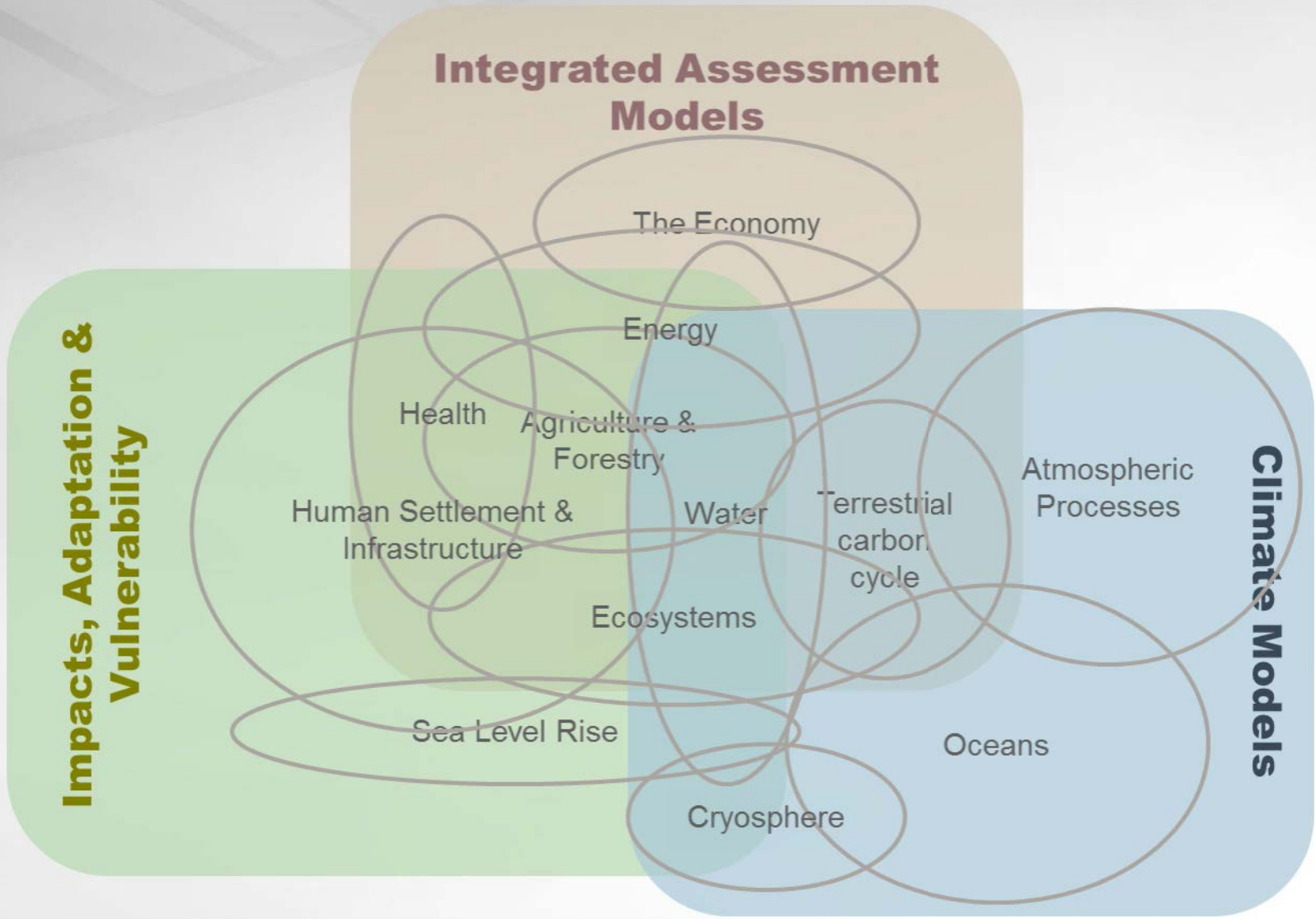


The Future of IAM Research

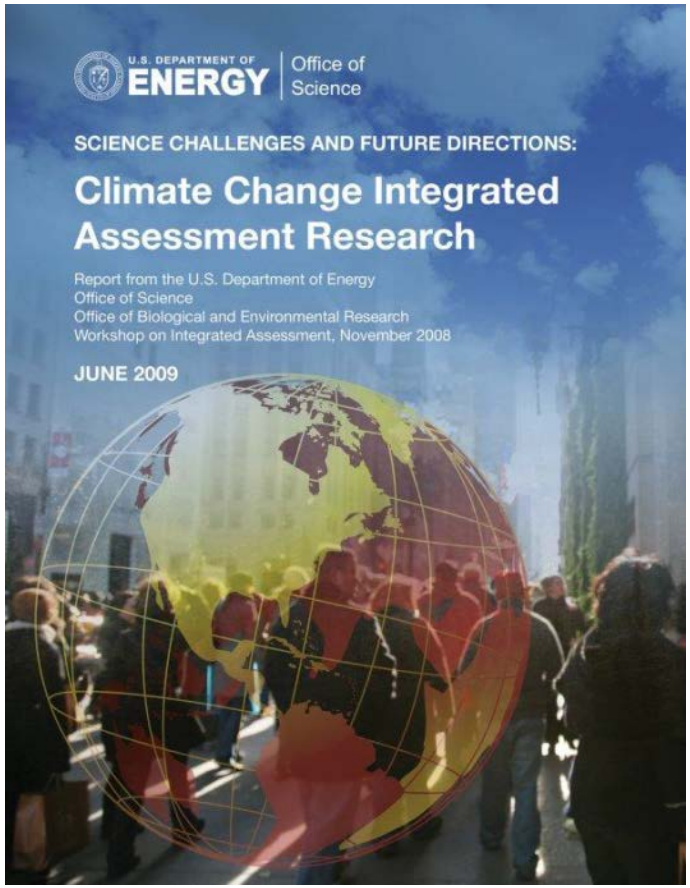
Growing overlap in climate research communities

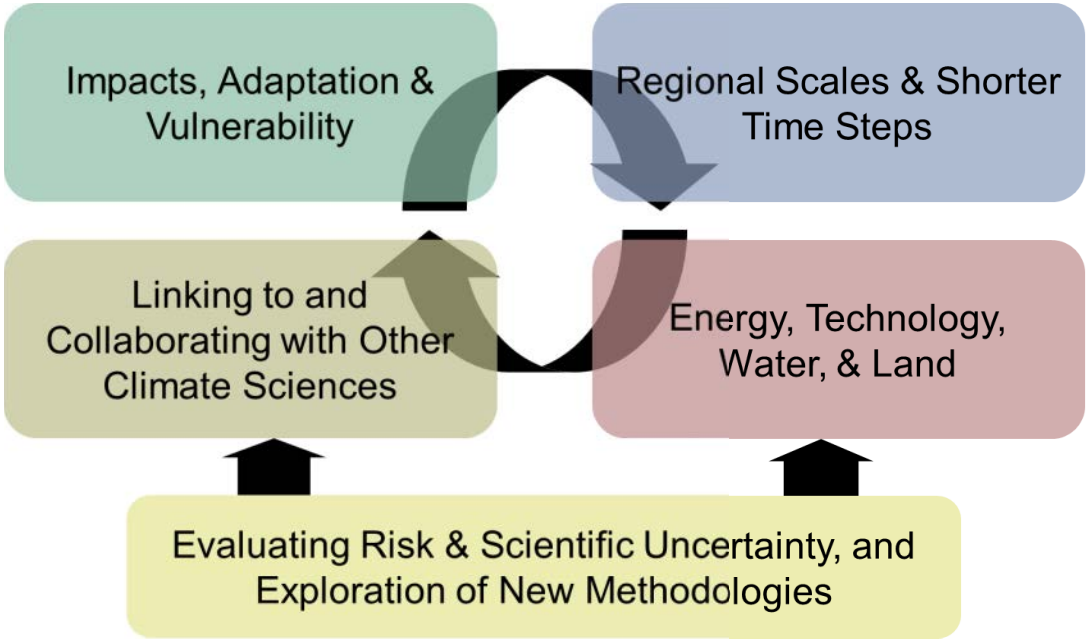


Growing overlap in climate research communities



Research Challenges Going Forward

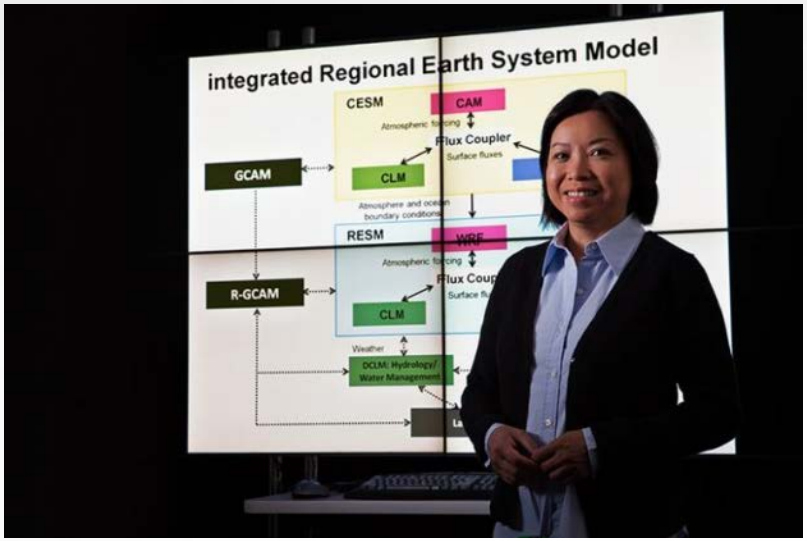




Many of the cutting edge developments for IAMs feature advances in more than one of these domains.

Two Emerging Frontiers for IAMs

- **Integrated Earth system models (iESM)**
  - Closely couple human systems from RCP-class model with a state-of-the-art physical Earth system model.
  - Creates the potential for fully-coupled experiments with feedbacks from human responses to climate change and feedbacks from climate change to human systems.
  - E.g. albedo feedbacks from bioenergy and changing land cover.



- **Regional integrated assessment models**
  - Their central problem is representing the near-term, sub-national, interactions between human and physical Earth systems, coupled to larger system models.

THE iESM PROJECT

The Grand Challenge: Closely couple human AND physical Earth systems in a single integrated Earth system model

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- **Scientific questions**
  - Is the present CMIP5 “parallel process” approach good enough?
  - Will human activities affect local and regional climate on scales that matter?
  - Will climate change itself affect human decision making (energy use, land-use, water use) in ways that feed back to local, regional and global climate forcing?

- **Scientific challenges**
  - Coupling—models designed for specific scientific applications, needed to be evolved for a more general, closely coupled, scientific application.
  - Data—reconciling multiple observational data sets
  - Verification—testing the validity of results, code and architecture
  - Building the scientific team—language, culture, paradigm

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The Integrated Earth System Model (iESM) Project

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- **The iESM project is a multi-laboratory, interdisciplinary collaboration between**:
  - PNNL,
  - LBNL,
  - ORNL and
  - the University of Maryland

- **Using four modeling systems**
  - GCAM (human system components
  - CLM (Community Land Model)
  - CESM (Community Earth System Model; containing CLM)
  - GLM (Global Land-use Model)

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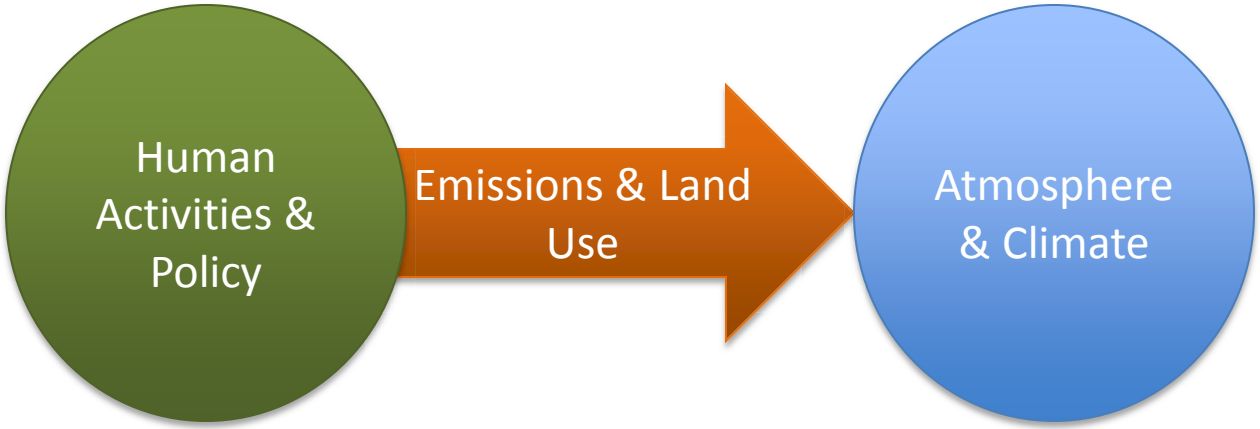
A first iESM experiment

- **Experiment**: One-way coupling
- **Scientific Question:** *How much difference does land-use emissions mitigation policy make for near-term and long-term climate change?*



- We run two scenarios: RCP 4.5 (UCT) and Rep 4.5 (FFICT)
- We hold total CO_2 and non-CO_2 GHG emissions fixed and run the two scenarios that limit year 2095 radiative forcing to 4.5 Wm^{-2}.
- In **RCP 4.5 (UCT)** we use the original RCP 4.5 land use.
- In **Rep 4.5** (FFICT) we use the alternative land use—the **ONLY** thing that is different between the two.
- *This alone created an interesting scientific challenge and resulted in a paper.*

Results of iESM one-way coupling experiment

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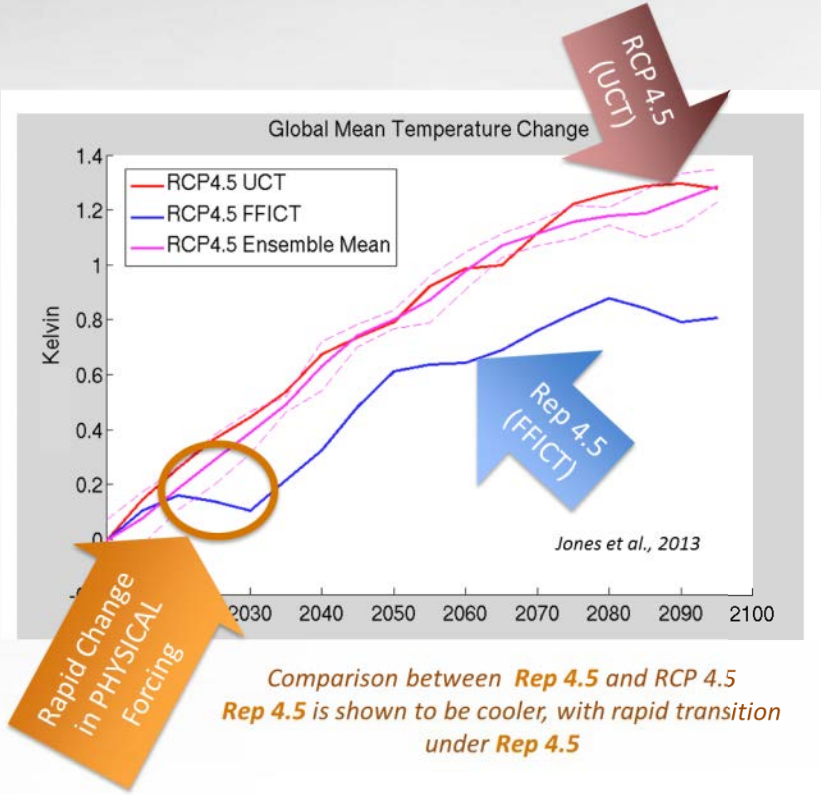
- **Finding**: Land-use policy exerts a major influence on the global climate system through direct physical effects.
- **Implications**: *The present assessment approach (the "parallel process") needs important revisions*
  - *The assumption that scenarios with a common radiative forcing from atmospheric constituents (i.e. ignoring direct physical effects from land-use) yields approximately the same climate change, is badly wrong.*
  - *Local and regional climate implications of human land-use change are large and may not be addressable outside of the context of a fully coupled iESM.*



*Comparison between **Rep 4.5** and RCP 4.5*
Rep 4.5** is shown to be cooler, with rapid transition under **Rep 4.5

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Two-way learning

- A project like the iESM creates the potential to parameterize IAM physical system emulators to reflect the behavior of the larger ESM.
- Creates the capability to rapidly assess scientific questions.
- Some questions can be answered using an IAM with an ESM emulator.
- Use of the IAM can quickly identify those for which full iESM calculations are needed.

Regional Integrated Modeling

Regional Integrated Assessment Models

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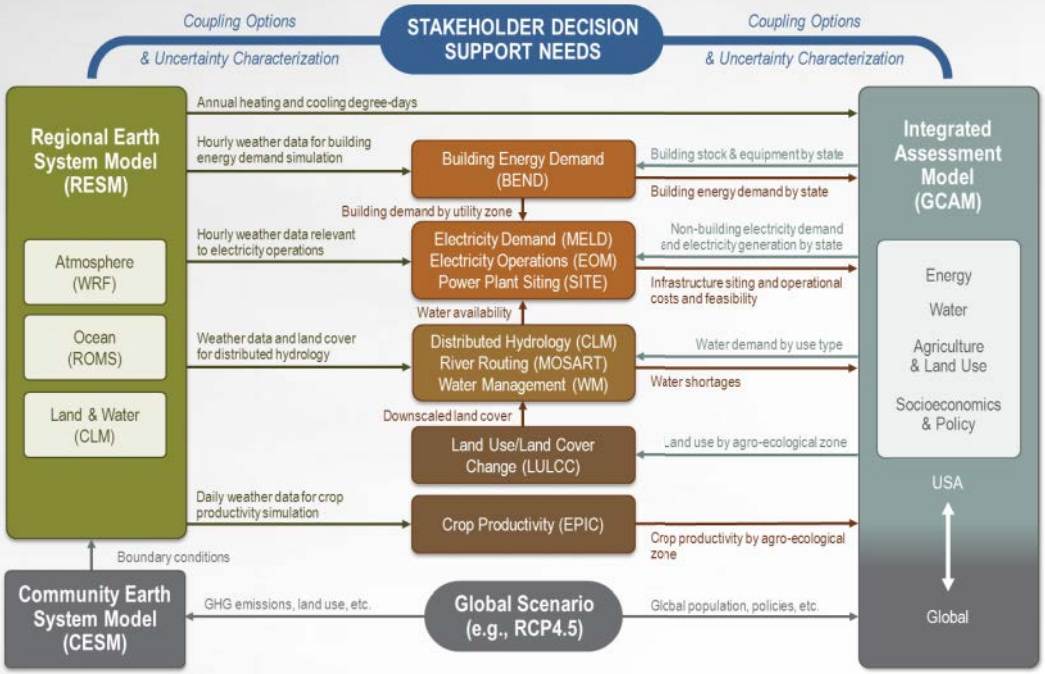
- With DOE leadership and support a new generation of models is emerging that are uniquely positioned to help inform **regional** decision making.
- **Couple global scale models**, e.g. CESM and GCAM, with
- **Regional scale models** of energy, land, water and infrastructure.
- For example, RIAM is a DOE/SC sponsored research project that is pushing models and science forward. It links:
  - regional climate,
  - hydrology,
  - socioeconomics,
  - energy infrastructure,
  - coastal processes, and
  - agriculture and land use models

  to investigate the multifaceted impacts of climate change, as well as potential adaptation and mitigation strategies being considered by regional stakeholders.

Linking global scale systems to regional and local systems—PRIMA as an example

- The Platform for Regional Integrated Modeling and Analysis (PRIMA) is a flexible, modular, tool that uses global scale models (currently working with GCAM and CESM) to provide a global context in which to set regional climate, energy, water, land and infrastructure models for the assessment of climate change and climate variability

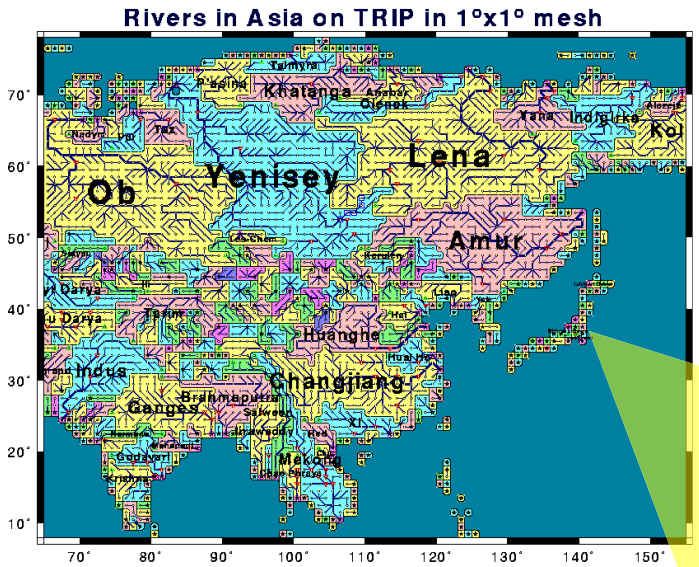


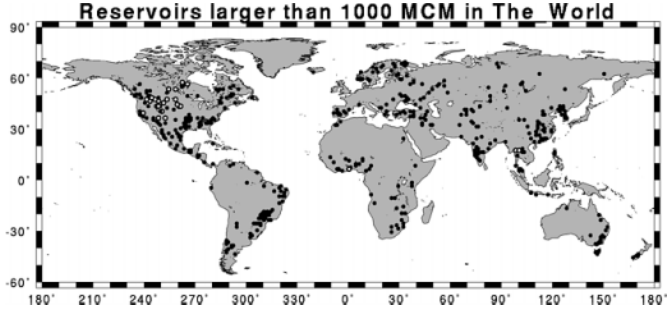
- DOE investments through RIAM are enhancing, extending, and applying modeling tools, e.g. PRIMA, to explore issues such as:
  - Impacts of hurricane-driven storm surge on Gulf Coast energy installations
  - Combined impacts of heat waves and drought on electricity reliability
  - Understanding the value of integrated, multi-scale modeling

AIM and Multi-scale Modeling

- AIM has the longest record of developing and coupling models at multiple scales.
- AIM's work includes work with energy, terrestrial systems, and hydrologic systems.

H08 model: Water resource model

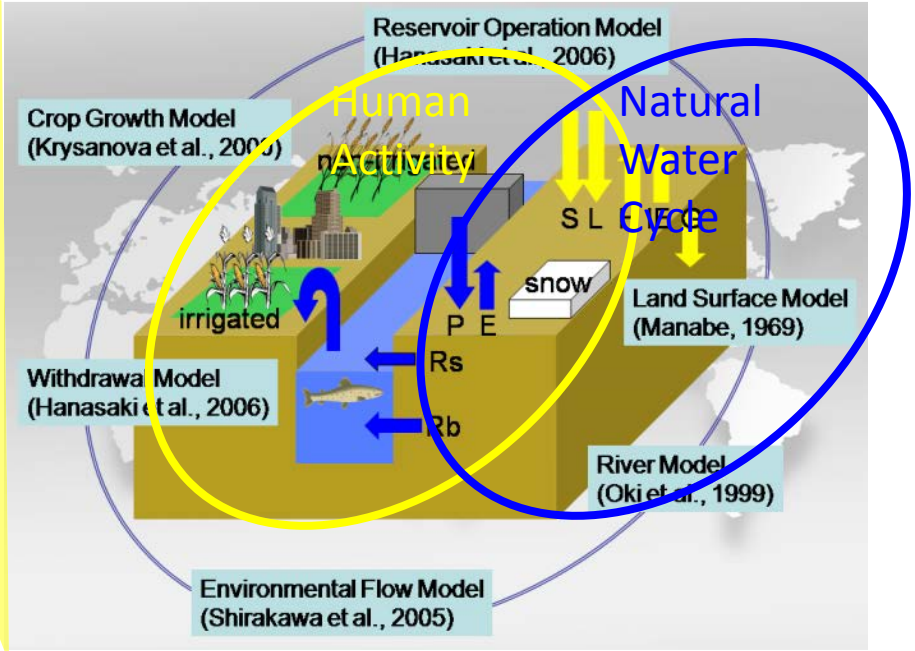




452 reservoirs, 4140 km^3

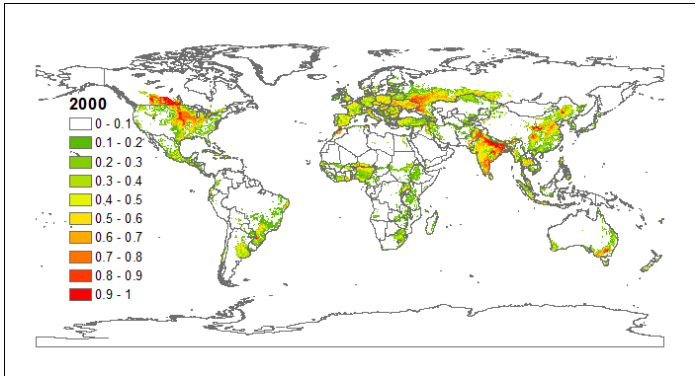
- Characteristics

1. High spatial resolution (0.5° ×0.5° , total 66,420 grid cells)
2. Simulate both water availability (streamflow) and water use at daily-basis
3. Deal with interaction between natural hydrological cycle and anthropogenic activities

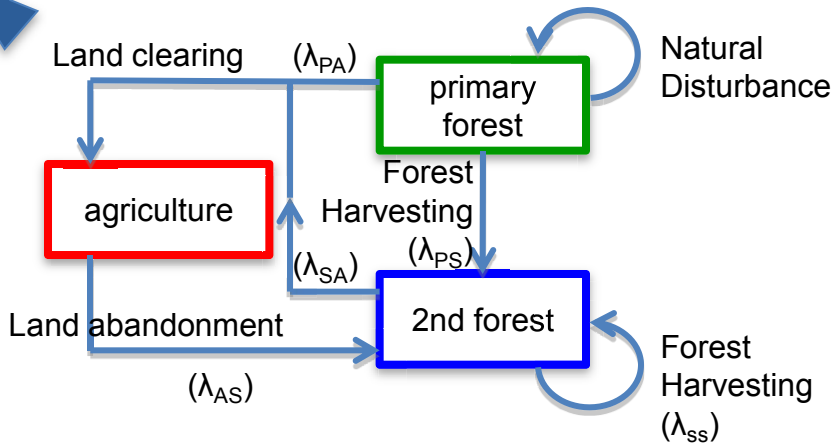


Hanasaki et al., 2006, J. of Hydrol.
Hanasaki et al. ,2008a,b, Hydrol. Earth Sys. Sci.
Hanasaki et al., 2010, J. of Hydrol

Ecosystem model linked with AIM for RCP

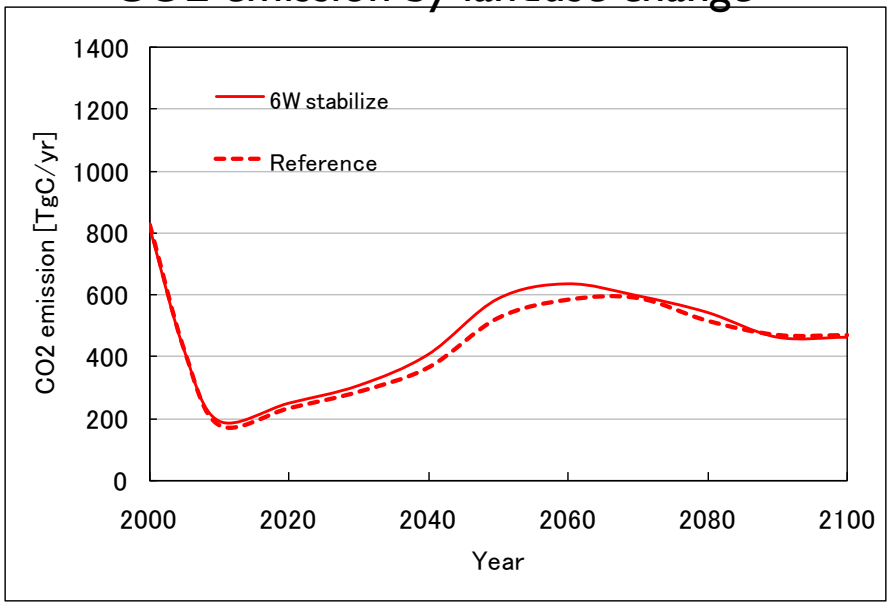


Transition Matrix (λ)

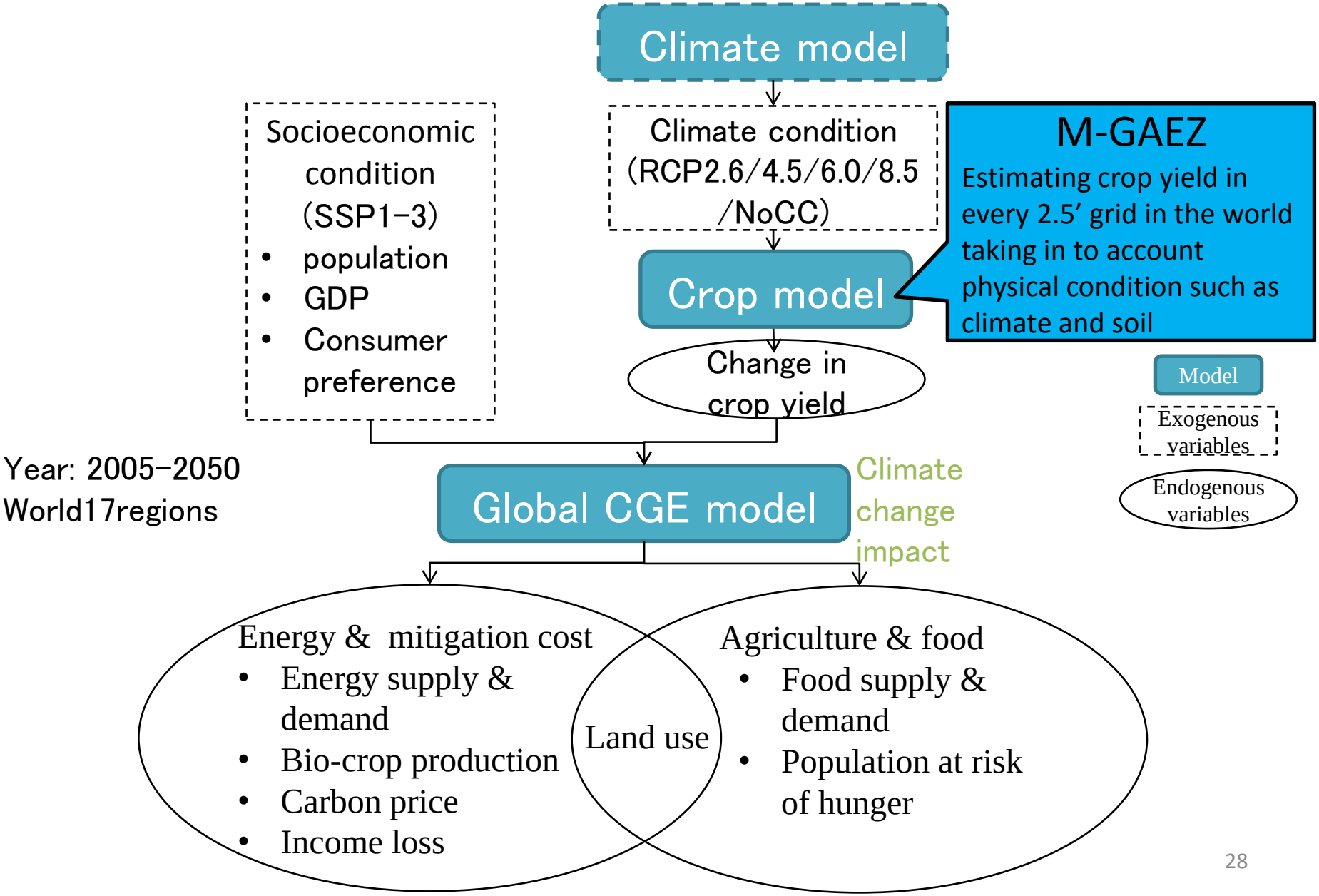


Assessing carbon cycle

CO2 emission by landuse change



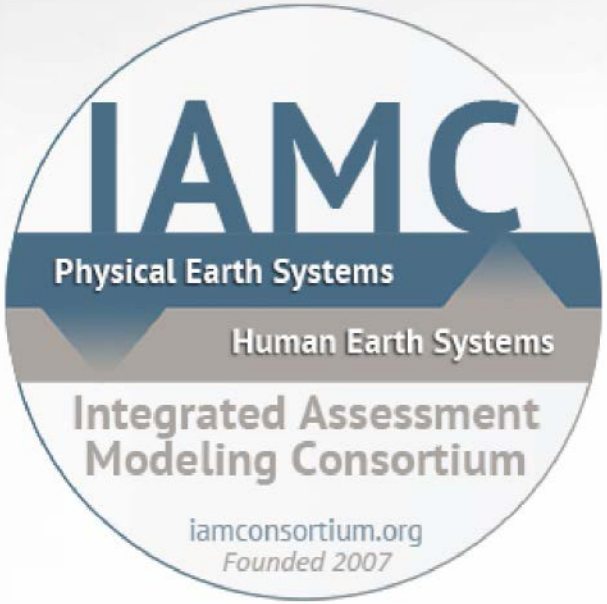
AIM linked with crop model



Building a community of practice and other developments

Building a community of practice

- *The Integrated Assessment Modeling Consortium (**IAMC**) is an organization of scientific research organizations that pursues scientific understanding of issues associated with integrated assessment modeling and analysis. The IAMC has three core missions.*
  - The IAMC facilitates and fosters the development of integrated assessment models (IAMs).
  - The IAMC promotes, facilitates and helps to coordinate interactions between IAMC members and members of other scientific research communities studying climate change such as the Climate Modeling (CM), the Impact, Adaptation, and Vulnerability (IAV), and the technology and engineering communities.
  - The IAMC provides a point of contact with other institutions and organizations that use the science results of the IAM community, such as the IPCC.
  - Meets annually to discuss future research priorities, standard, and interactions with the larger world.



The challenges

- Multiplicity of scales—temporal and spatial
- Complexity of systems
- Multiplicity of data sources—inconsistency between definitions of the same phenomenon
- Lack of data sources
- Computational capacity—particularly for iESM and Regional IAMs
- Model validation, quality assurance
- Uncertainty quantification

DISCUSSION