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# Modeling Complex Interactions of Climate, Ecosystems, and Human Activities:
## Progress and Future Challenges in Research Community Collaboration

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# Acknowledgements


- Many colleagues, including...

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- ... and many others.

# Topics I will cover



1. Inputs to CMIP5: IAM-ESM community interactions
   - Context: parallel process
   - RCPs: What was provided, early critiques, and factors to consider for CMIP6
2. One use of CMIP5 results: interactions with the IAV community
   - IAV modeling and assessment
   - MIPs
   - Of potential interest: Update on Shared Socioeconomic Pathways (SSPs)
3. Initial thoughts on improving future interactions

# 1. “Inputs” to CMIP5: IAM-ESM community interactions

# Context for CMIP 5: a new "parallel process" for structuring research community interactions



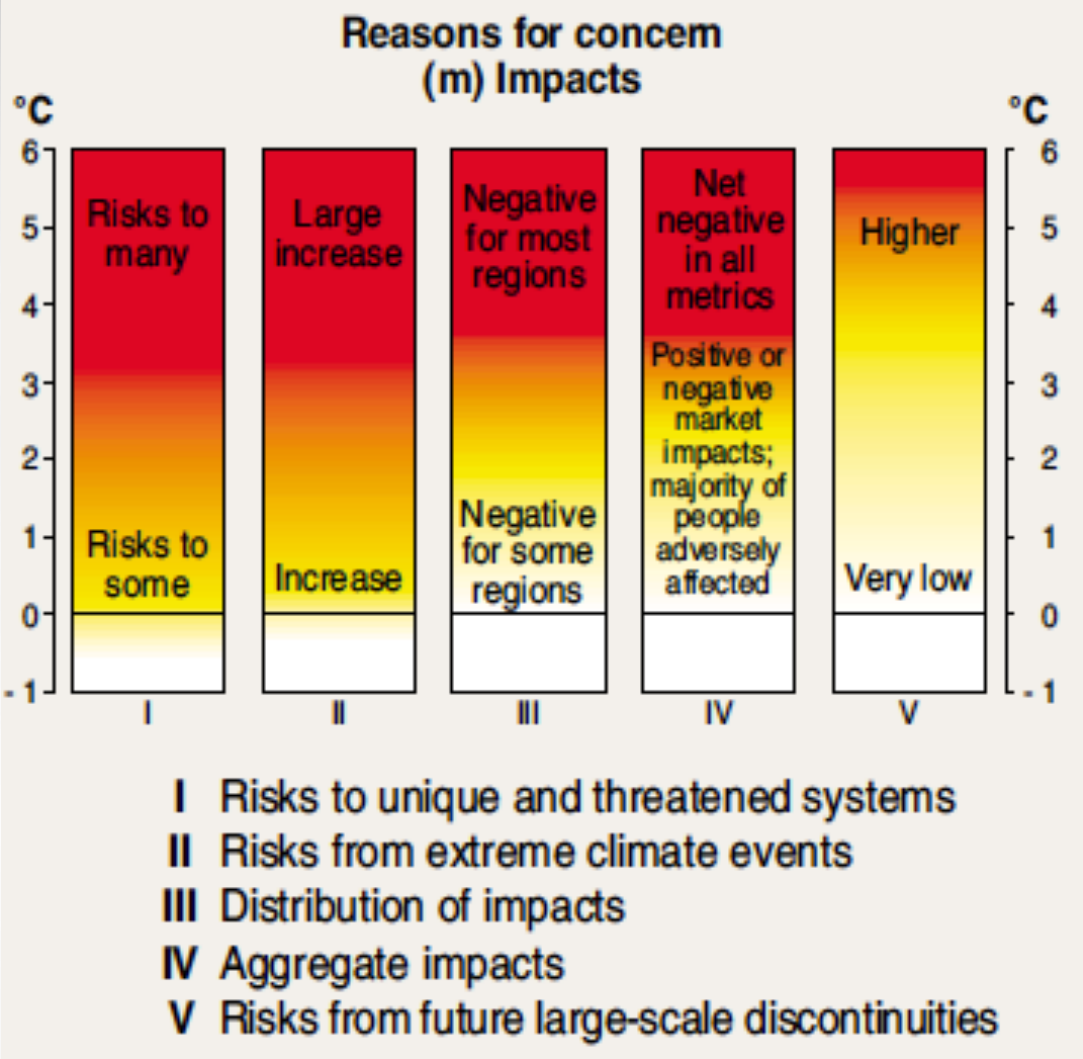
The parallel process was developed for a variety of reasons, including responding to new information needs

- Explore stabilization scenarios in addition to the traditional 'no climate policy' scenarios
- Increase attention to the impacts of climate change and the need for adaptation
- Address old and new research questions more systematically
  - Carbon cycle feedbacks
  - Importance of land cover and short-lived species in regional projections
  - Integrated analysis of climate shifts, extremes, stresses, tipping points, adaptation, mitigation options, etc.

# One obvious benefit: more rigorous synthesis

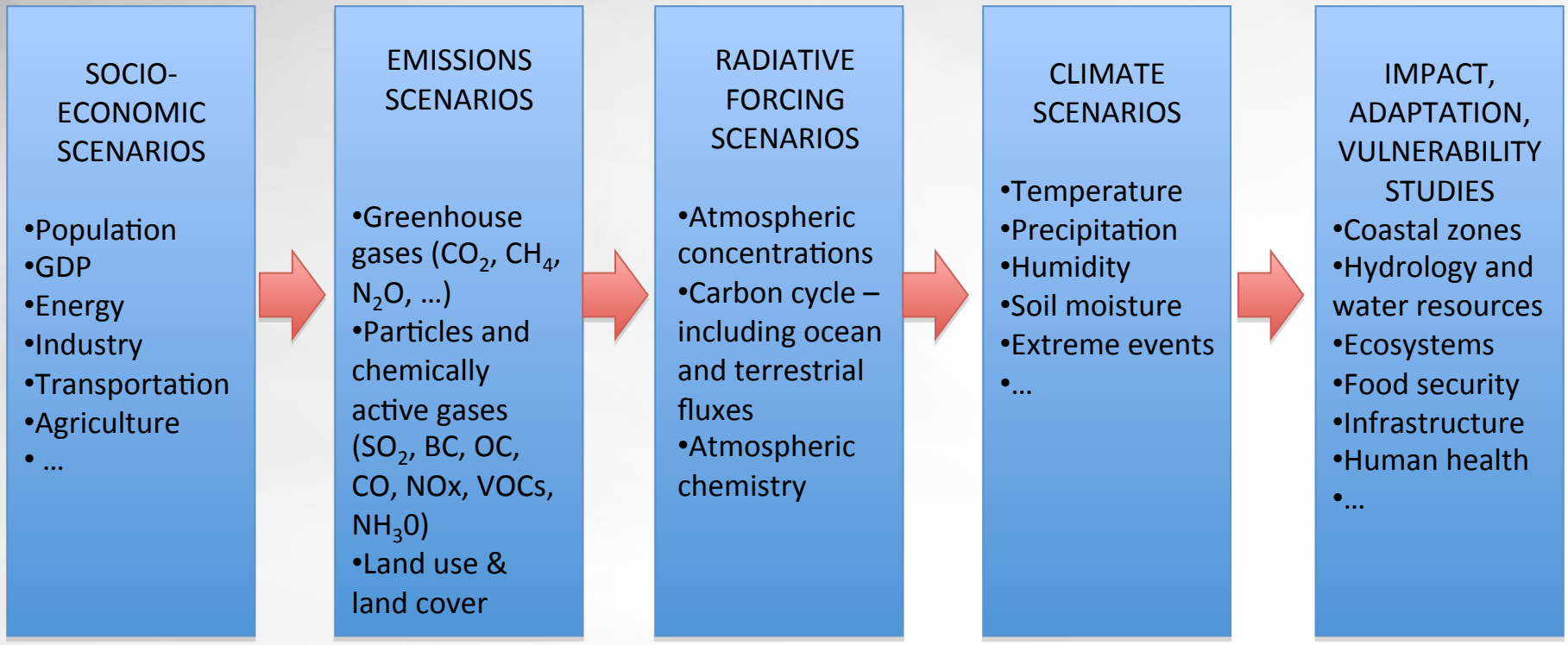


- Past IPCC synthesis based on studies using many different assumptions
- Poor characterization of climate, socioeconomic, and impact model uncertainties
- We can add value by improving coordination across research communities to support future assessments



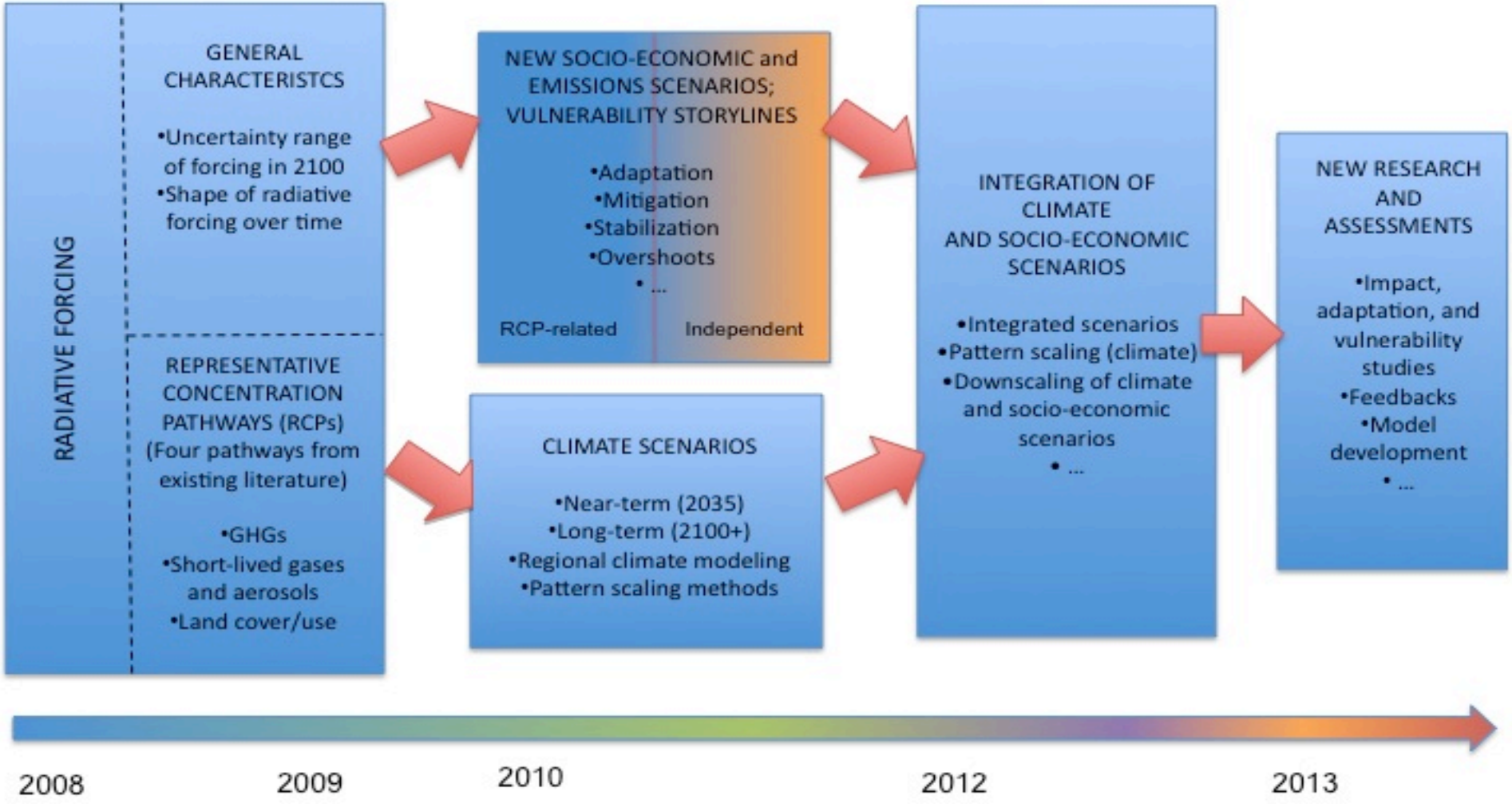

Source: IPCC TAR, Synthesis

# Sequential process




Source: Moss et al. 2010

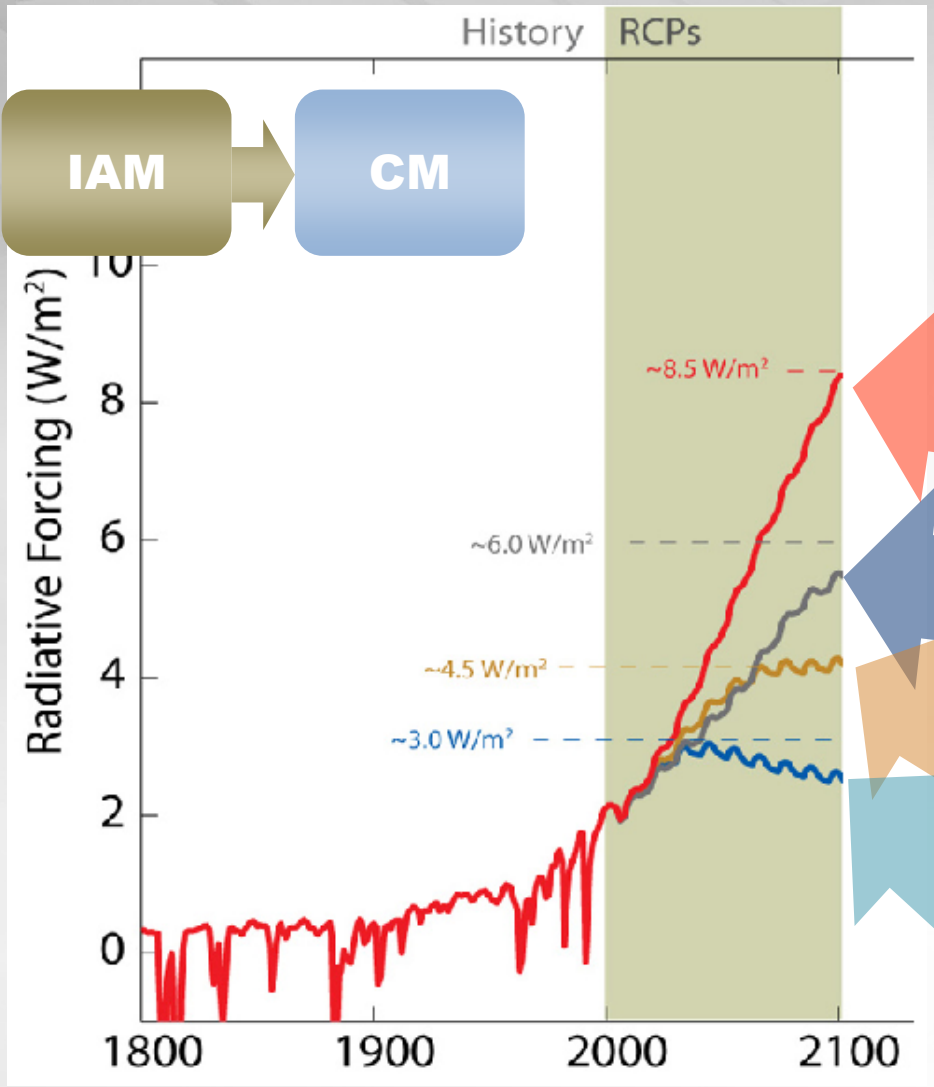
# Parallel process




Source: Moss et al. 2010

# Representative Concentration Pathways (RCPs)






- The climate modeling community wanted 4 levels of radiative forcing that would span the emissions literature.
  - 8.5 $Wm^{-2}$ (RCP 8.5, *1350ppm* $CO_2$-*e*)
  - 6.0 $Wm^{-2}$ (RCP 6.0, *850ppm* $CO_2$-*e*)
  - 4.5 $Wm^{-2}$ (RCP 4.5, *650ppm* $CO_2$-*e*)
  - 2.6 $Wm^{-2}$ (RCP 2.6, *450ppm* $CO_2$-*e*)

CLIMATIC CHANGE
Volume 109, Numbers 1-2 (2011), 5-31, DOI: 10.1007/s10584-011-0148-z

# Content of RCP database



- Data for climate modelers or atmospheric chemists
  http://www.iiasa.ac.at/web-apps/tnt/RcpDb/

## FORCING AGENTS

### GHG Emissions and Concentrations from IAMs

- Greenhouse gases: $CO_2$, $CH_4$, $N_2O$, CFCs, HFC's, PFC's, $SF_6$
- Emissions of chemically active gases: CO, $NO_x$, $NH_4$, VOCs
- Derived GHG's: tropospheric $O_3$
- Emissions of aerosols: $SO_2$, BC, OC
- **Land use and land cover [NEW]**

## EXTENSIONS

- **Extension of scenarios to 2300—ECPs.**

## WHAT YOU WON'T FIND

- **You will not find an integrated set of detailed socioeconomic storylines and scenarios (e.g., no common reference scenario)**

# Historical and future emissions

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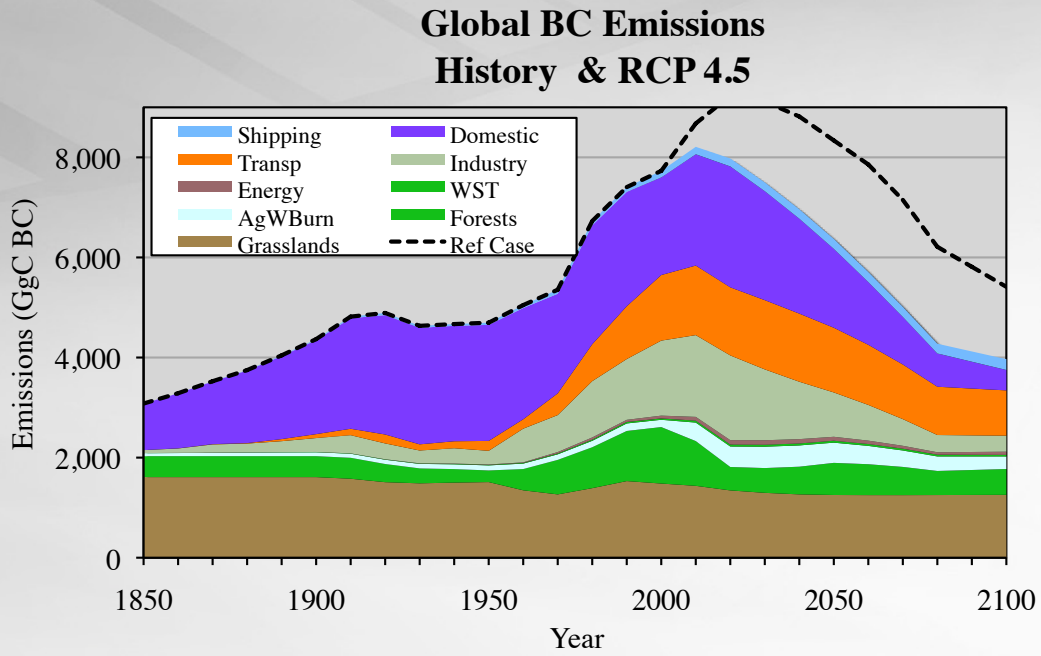
**The RCP process produced a consistent estimate of historical emissions (from 1850) plus four RCP projections that start from a common year 2000 data set.**




The RCPs provide: regional emissions of GHGs and pollutant substances, globally gridded emissions (at 0.5°) of short-lived compounds, and GHG concentration pathways.

- GHG Emissions: $CO_2$, $CH_4$, $N_2O$, Fluorinated Gases
- Pollutant Emissions: $NO_x$, CO, NMVOCs, $SO_2$, BC, OC, $NH_3$

Regional and gridded emissions are provided in 12 source sectors in order to allow for later spatial/temporal desegregation and NMVOC speciation.

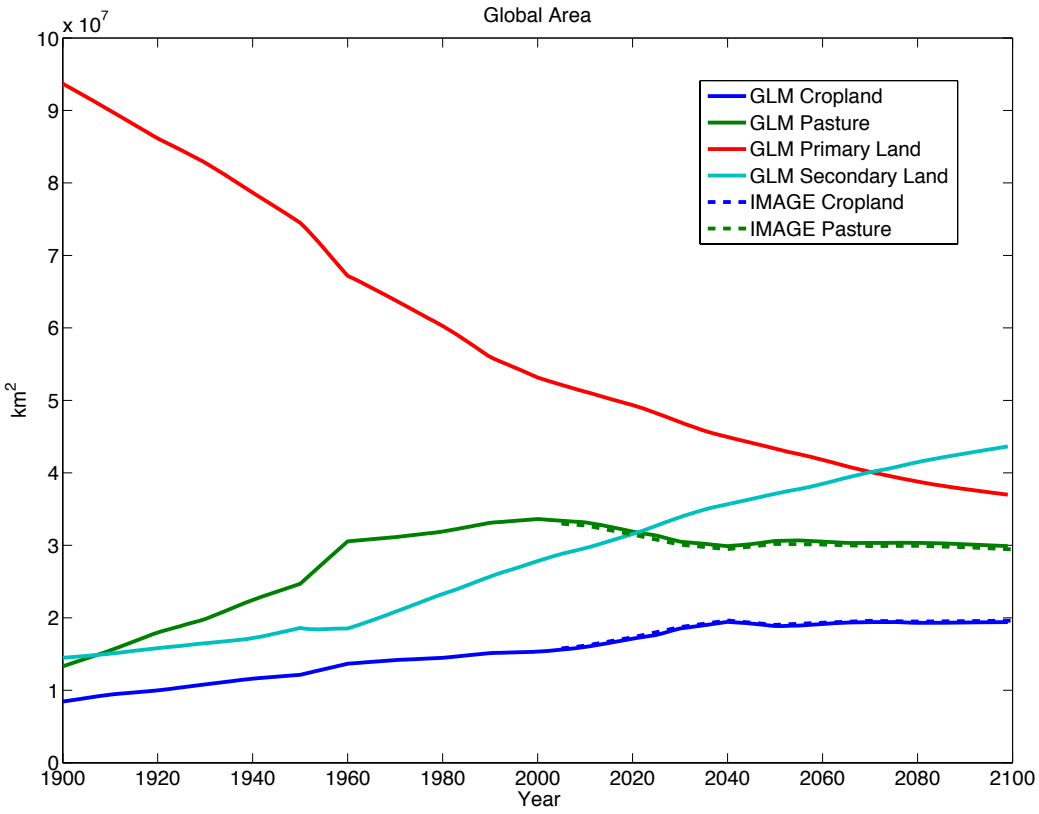
| | |
|---|---|
| *Air Transportation* | *Industry (combustion and process emissions)* |
| *International Shipping* | *Buildings (Residential and Commercial)* |
| *Ground transportation* | *Ag. waste burning on fields* |
| *Electric power plants, energy conversion, extraction and distribution* | *Agriculture (agricultural soils, other agriculture)* |
| *Solvents* | *Grassland burning* |
| *Waste (landfills, waste water, non-energy incineration)* | *Forest burning (Deforestation & Forest Fires)* |

+ Source: Lamarque et al., 2010

# Land use and land cover



- Harmonization of land use scenarios for 1500-2100
  - First of a kind collaboration among IAM, remote sensing, and historical research
  - 0.5° x 0.5° resolution
  - Estimates fractional land-use patterns and underlying land-use transitions
  - See G. C. Hurtt, et al., *Climatic Change*, Vol. 109, No. 1-2 (2011), 117-161, DOI: 10.1007/s10584-011-0153-2
  - Data at RCP website or http://luh.unh.edu



# IAM-IAV "Handshake" has been successful



- Provided requested input for CMIP5 process
- Detailed specifications for a wide range of variables/ factors
- Produced scientific advances
- Will likely need to be revisited for CMIP6

Work plan for data exchange between the Integrated Assessment and Climate Modeling community in support of Phase-0 of scenario analysis for climate change assessment (Representative Community Pathways).

*Authors: Detlef P. van Vuuren, Johannes Feddema, Jean-Francois Lamarque, Keywan Riahi, Steven Rose, Steve Smith, Kathy Hibbard*

**1. Background**

During its 26th meeting in Bangkok in May 2007, the IPCC requested the preparation of a new set of scenarios to facilitate future assessment of climate change. This new set (that is intended to replace and extend the scenarios used in earlier IPCC assessments) should be compatible with the full range of stabilization, mitigation and baseline emission scenarios available in the current scientific literature. The IPCC also decided that, in part because of the growing number of scenarios developed within the research community, and the research communities organizational structure, the research community itself would undertake development of scenarios for assessment in a possible AR5, while the IPCC's role would be that of catalyzing and assessing such work.

The research community has subsequently outlined three phases of scenario development: a preparatory phase and two main phases of scenario development—a parallel product development phase and an integration, dissemination, and application phase. In the preparatory phase, four integrated assessment (IA) concentration and emissions scenarios will be chosen from the existing literature and provided to climate modelers. These scenarios are referred to as "*representative concentration pathways*" (RCPs). These scenarios will be used to produce a new set of climate model simulations that will subsequently used for mitigation, impacts, adaptation, and vulnerability analysis. The primary goal of the RCPs is to provide, in a timely manner, the most up to date scenarios possible to be used to produce these new climate model simulations.

# 2. One use of CMIP5 results: interactions with the IAV community

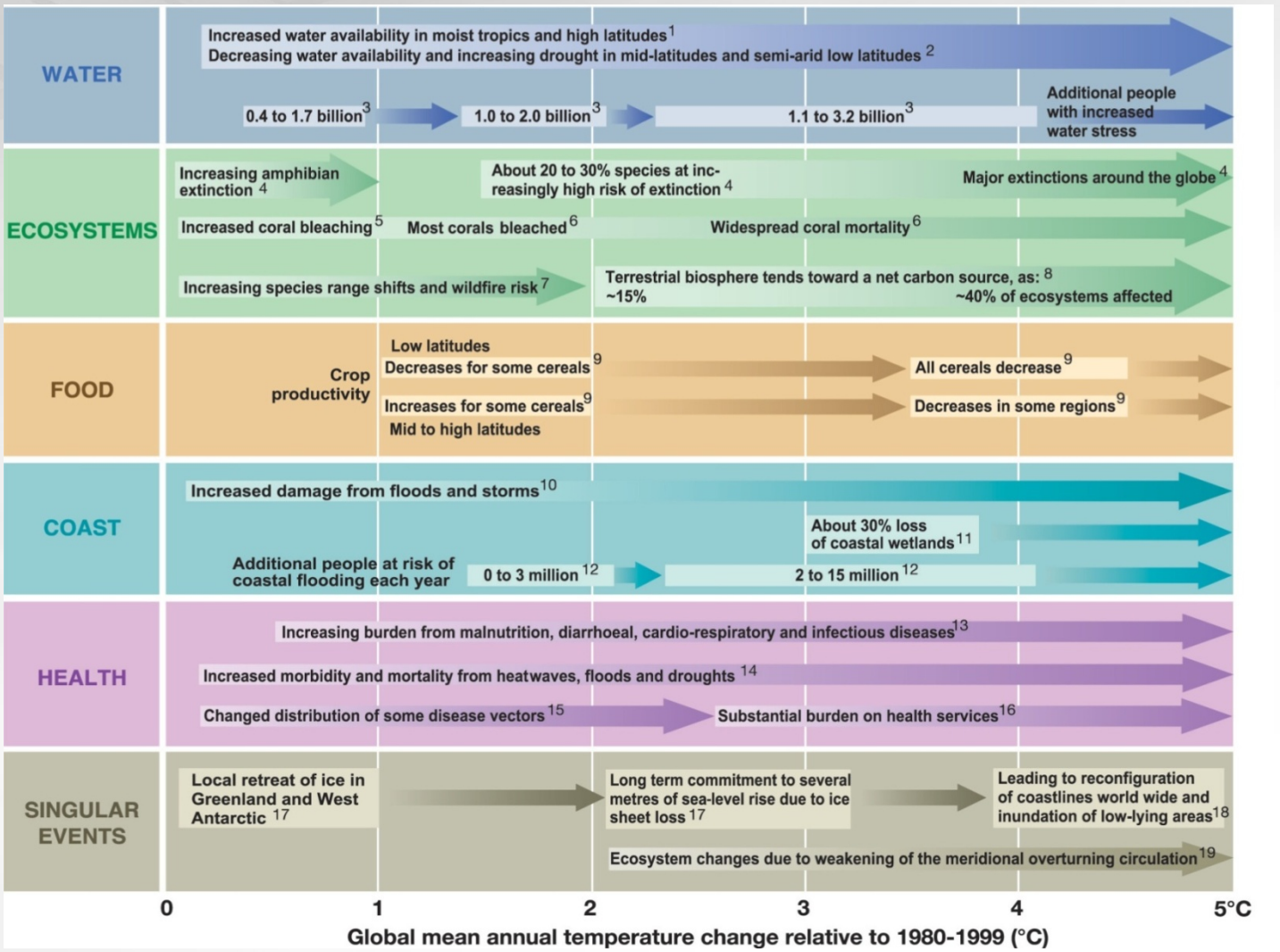
# Current state of the art in synthesis of impacts



Much literature, but...

Insights based on individual impact models

No consistent climate, socioeconomic, or other scenarios/ approach




IPCC AR4, WGII, Table 20.8

# Characteristics of different approaches to CCIAV assessment/research

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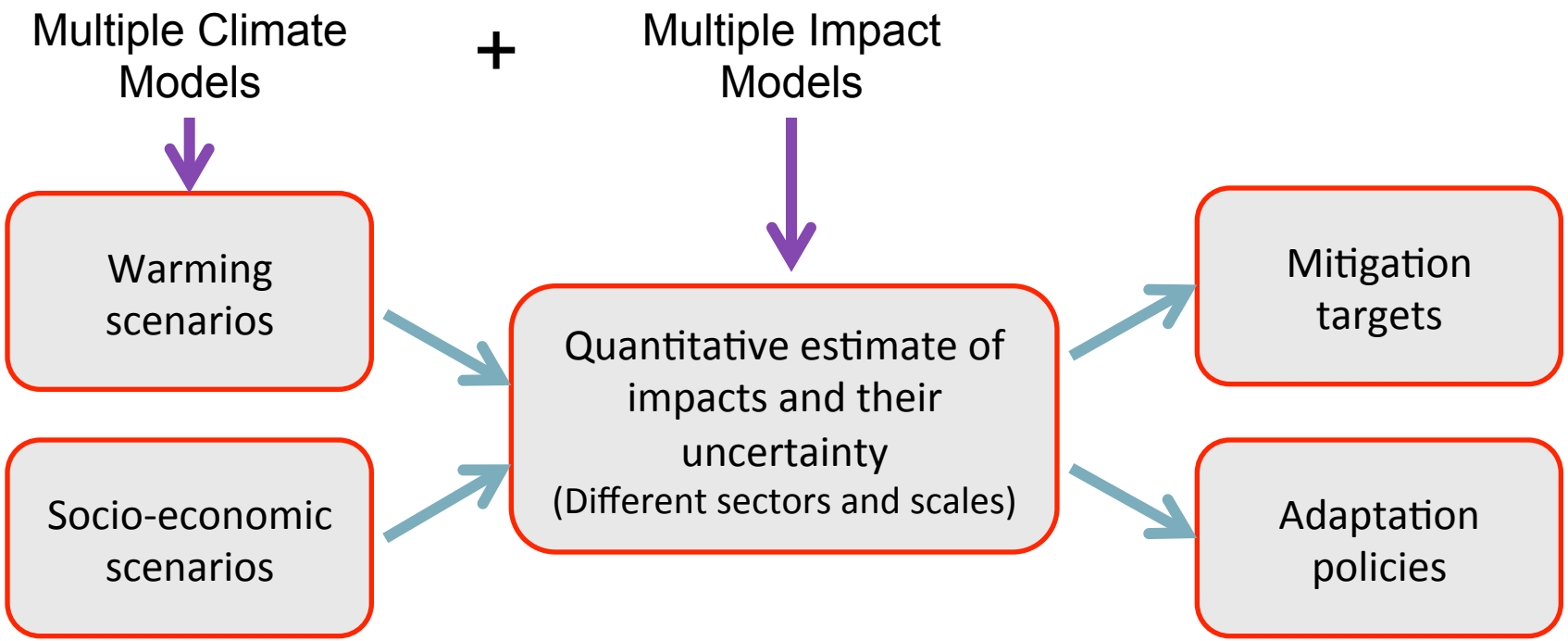
| | Impact | Vulnerability | Adaptation | Integrated |
|---|---|---|---|---|
| **Scientific objectives** | Impacts and risks under future climate | Processes affecting vulnerability to climate change | Processes affecting adaptation and adaptive capacity | Interactions and feedbacks between multiple drivers and impacts |
| **Practical aims** | Actions to reduce risks | Actions to reduce vulnerability | Actions to improve adaptation | Global policy options and costs |
| **Research methods** | Standard approach to CCIAV<br>Drivers-pressure-state-impact-response (DPSIR) methods<br>Hazard-driven risk assessment | Vulnerability indicators and profiles<br>Past and present climate risks<br>Livelihood analysis<br>Agent-based methods<br>Narrative methods<br>Risk perception including critical thresholds<br>Development/sustainability policy performance<br>Relationship of adaptive capacity to sustainable development | | Integrated assessment modelling<br>Cross-sectoral interactions<br>Integration of climate with other drivers<br>Stakeholder discussions Linking models across types and scales<br>Combining assessment approaches/methods |
| **Spatial domains** | Top-down<br>Global → Local | Bottom-up<br>Local → Regional<br>(macro-economic approaches are top-down) | | Linking scales<br>Commonly global/regional<br>Often grid-based |
| **Scenario types** | Exploratory scenarios of climate and other factors (e.g., SRES)<br>Normative scenarios (e.g., stabilisation) | Socio-economic conditions<br>Scenarios or inverse methods | Baseline adaptation<br>Adaptation analogues from history, other locations, other activities | Exploratory scenarios: exogenous and often endogenous (including feedbacks)<br>Normative pathways |
| **Motivation** | Research-driven | Research-/stakeholder-driven | Stakeholder-/research-driven | Research-/stakeholder-driven |

Source: IPCC AR4, WG2, CH2

# The Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP)



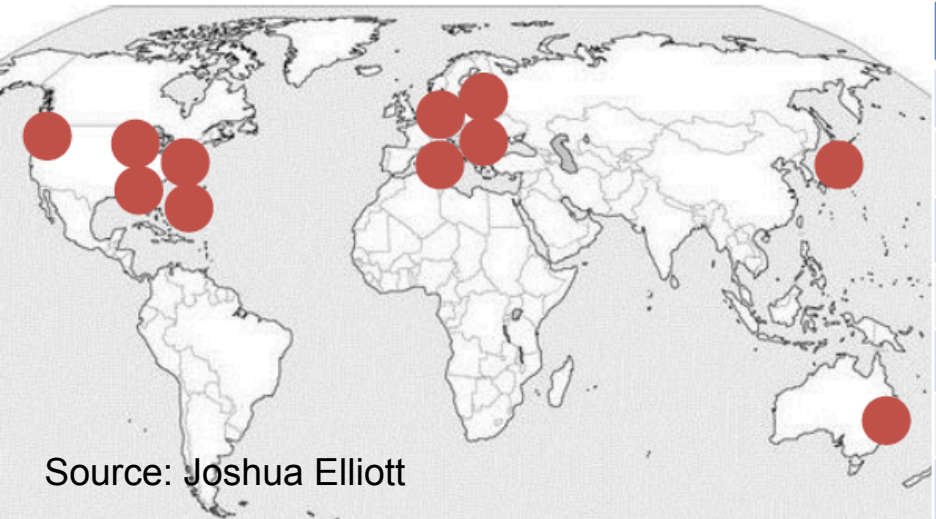

**Common** Background Scenarios | **Quantitative** Impact Models | **Policy-relevant**, **society-focused** metrics

PIK IIASA

Source: Katja Frieler

# Scenarios in the Agriculture Model Intercomparison Project (AgMIP)

- 2012 fast-track plan:
  - Basics: 11 models, SSPs 1-3, 4 RCPs
  - Output variables: Commodity prices, demands, land-use, etc.
  - Outputs: Synthesis and topic papers, follow-up meetings in Aug and Oct
- Comparisons based on common assumptions for a set of key drivers
  - Population and GDP growth (from core SSPs)
  - National level climate impact factors for each crop, under each RCP (LPJmL)
  - Oil prices and biomass demand (WEO forecasts)



Source: Joshua Elliott

| 7 General Equilibrium Models | 4 Partial Equilibrium Models |
|---|---|
| AIM (NIES, Japan) | GCAM (PNNL) |
| CIM-EARTH (U Chicago, USA) | GLOBIOM (IIASA, Austria) |
| ENVISAGE (FAO/World Bank) | IMPACT (IFPRI, USA) |
| EPPA (MIT, USA) | MagPie (PIK, Germany) |
| FARM (USDA, USA) | |
| GTEM (ABARE, Australia) | |
| LEITAP (LEI, The Netherlands) | |

# Shared Socioeconomic Pathways (SSPs)



- Are a set of reference, no climate policy pathways consisting of
  - 1. Storylines
  - 2. IAM inputs, and
  - 3. non-IAM quantitative variables
- A set of points of reference for linking detailed socioeconomic scenarios with CMIP5 results based on 4 original RCPs.
- Provide a framework for organizing new and existing scenarios in terms of their socioeconomic "challenges to adaptation and mitigation".

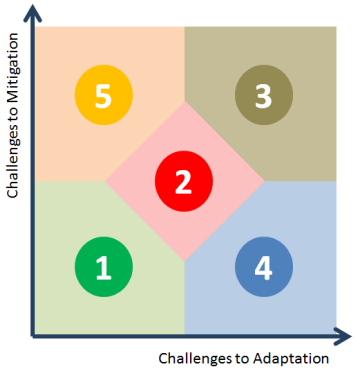
**Storyline**: The storyline is a verbal description of the scenario. All non-quantitative aspects of the scenario are included in the storyline.

**IAM Quantitative Variables** that define IAM reference "no-climate-policy" scenario. E.g. reference scenario population by region by year. Energy prices.

**Non-IAM Quantitative Variables** that define reference "no-climate-policy" scenario, but which are not IAM drivers. E.g. governance index or ecosystem productivity and sensitivity.

SPAs

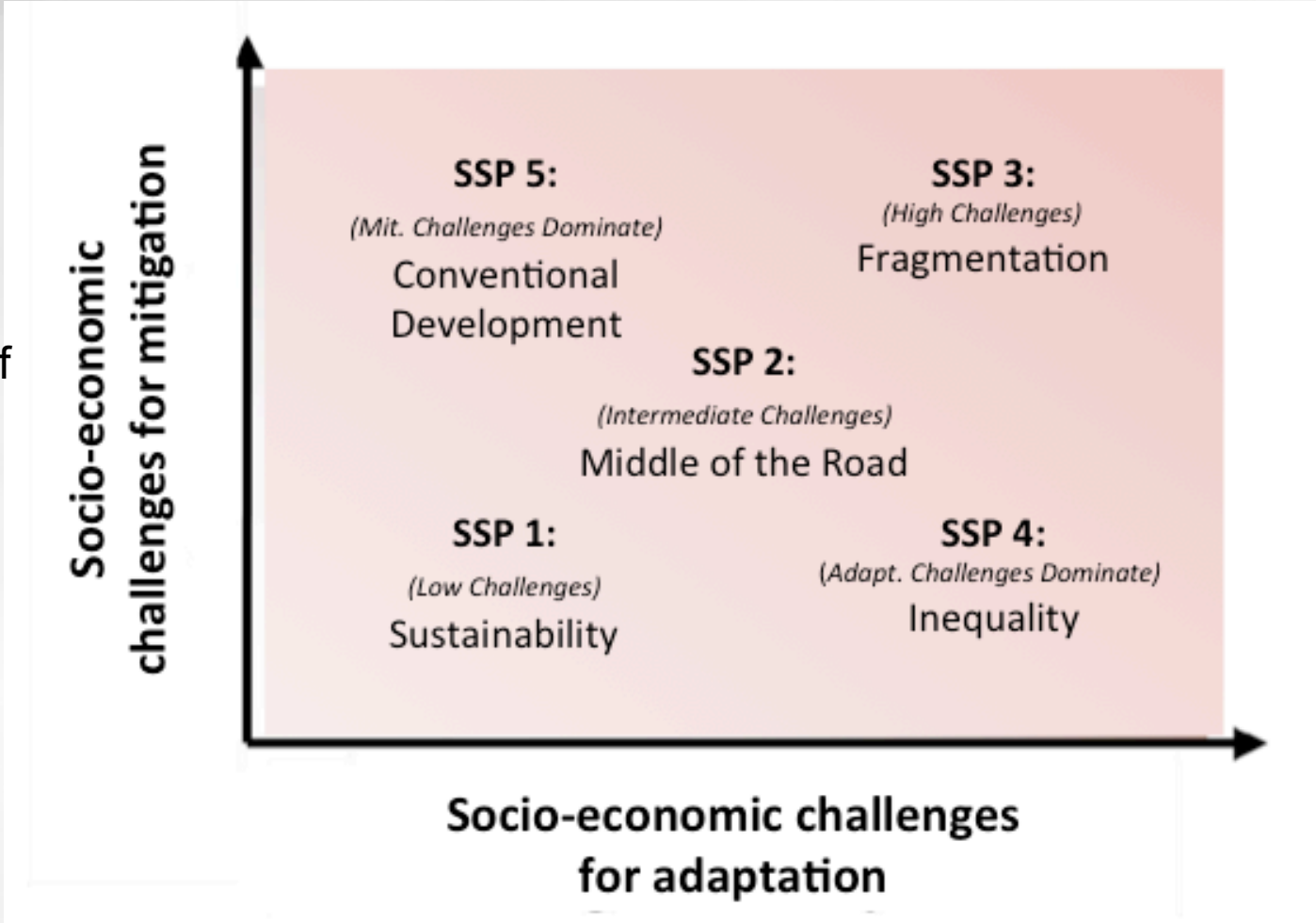
| RCP Replication | SSP 1 | SSP 2 | SSP 3 | SSP4 | SSP5 |
|---|---|---|---|---|---|
| Reference | X | X | X | X | X |
| 8.5 $Wm^{-2}$ | | | X | | |
| 6.0 $Wm^{-2}$ | | X | X | X | X |
| 4.5 $Wm^{-2}$ | X | X | X | X | X |
| 2.6 $Wm^{-2}$ | X | X | | X | |



# SSP Status



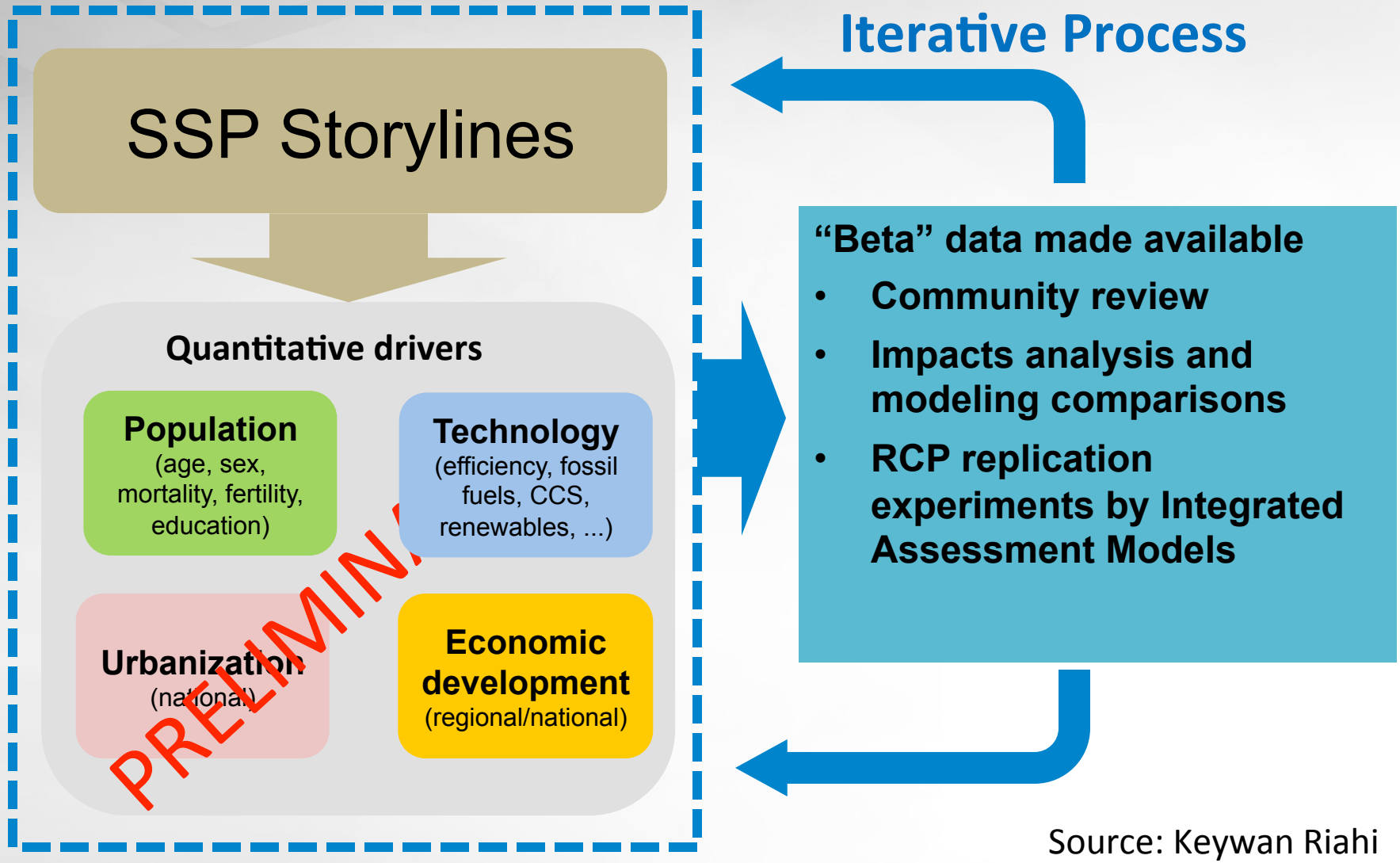
- In process
- Coordinated, bottom-up effort
- Two tracks:
  - Fast (for MIPs)
  - Longer-term (for wider set of users)
- Key questions:
  - Framework
  - Storylines
  - Measuring "challenges"




Source: Kriegler, et al., 2011

# Quantification of key drivers: development and review






Source: Keywan Riahi

# SSP framework and review process

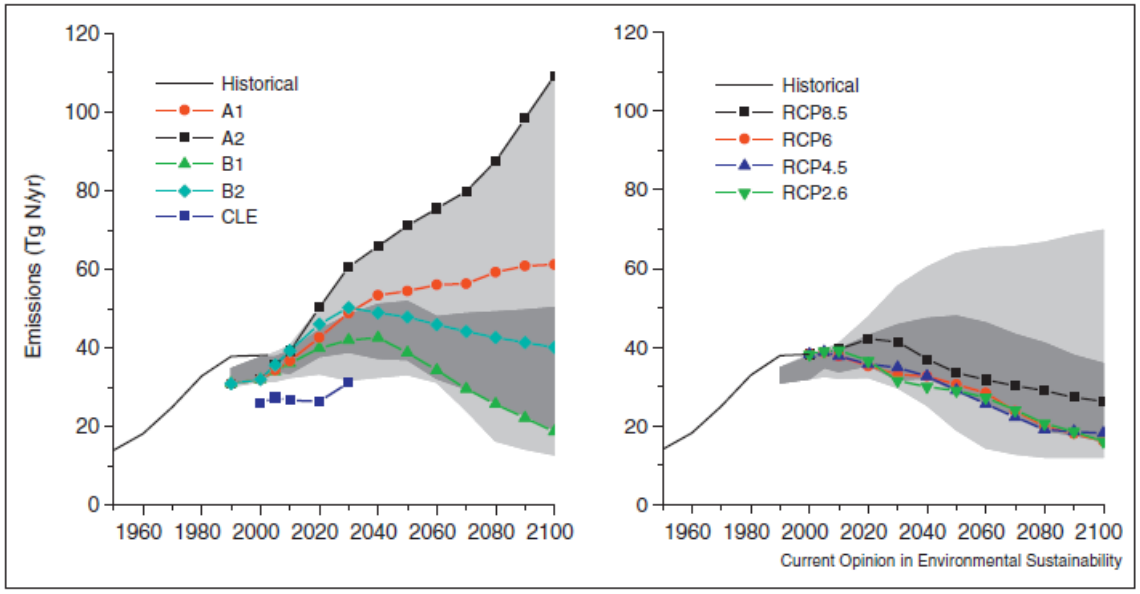
- "Framework paper"
  - http://www.isp.ucar.edu/sites/default/files/Scenario_FrameworkPaper_15aug11_0.pdf
- The population and GDP scenarios have been available for review since May and will remain open until October 15, 2012 and can be found at https://secure.iiasa.ac.at/web-apps/ene/SspDb/.
- The storylines are also open for review until October 15 and can be found at https://www.isp.ucar.edu/narratives-ssps-working-group.

# 3. Initial thoughts on improving future interactions

# “Mainstream” coordination in preparation of RCPs



- For CMIP6, need to start “handshake” process earlier and obtain funding to support it. Example issues:
  - How to take better account of the range/uncertainty of present-day estimates?
  - How to improve regional/sub-regional redistribution of emissions?




Current RCPs are not capturing the range of projected emissions

Figure: Detlef Vanvuuren
Thanks also to J.F. Lamarque

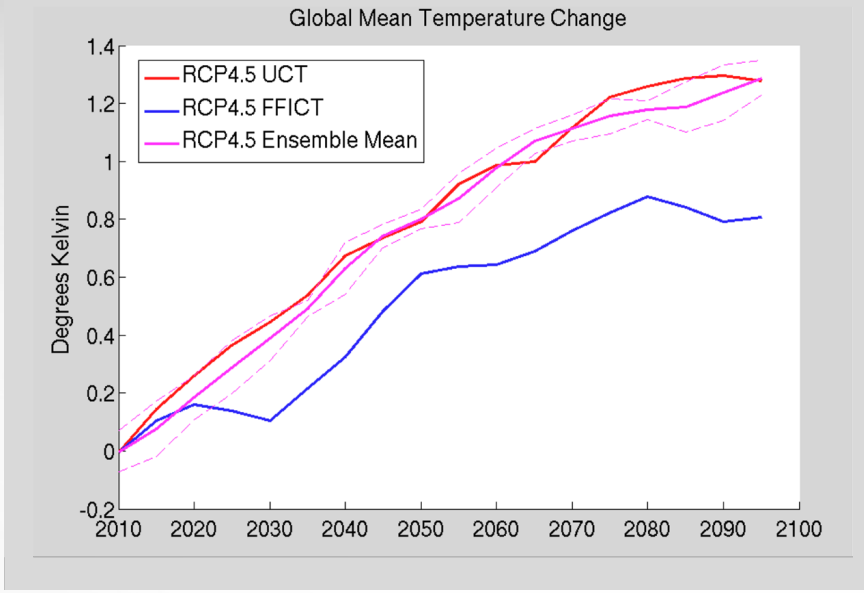
# Incorporate land use in radiative forcing



- Jones, et al. (2012) showed that RCP 4.5 and a replication, identical in every regard—EXCEPT for the land-use policy assumption—could yield radiative forcing that differed by approximately 1 $Wm^{-2}$!!!

- In CMIP 6 we need to revise climate model reporting of radiative forcing to include land use and land cover.

- The Integrated Assessment Modeling Community should revise its scenario reporting of radiative forcing to include land use and land cover.




# Improve integration and data sharing

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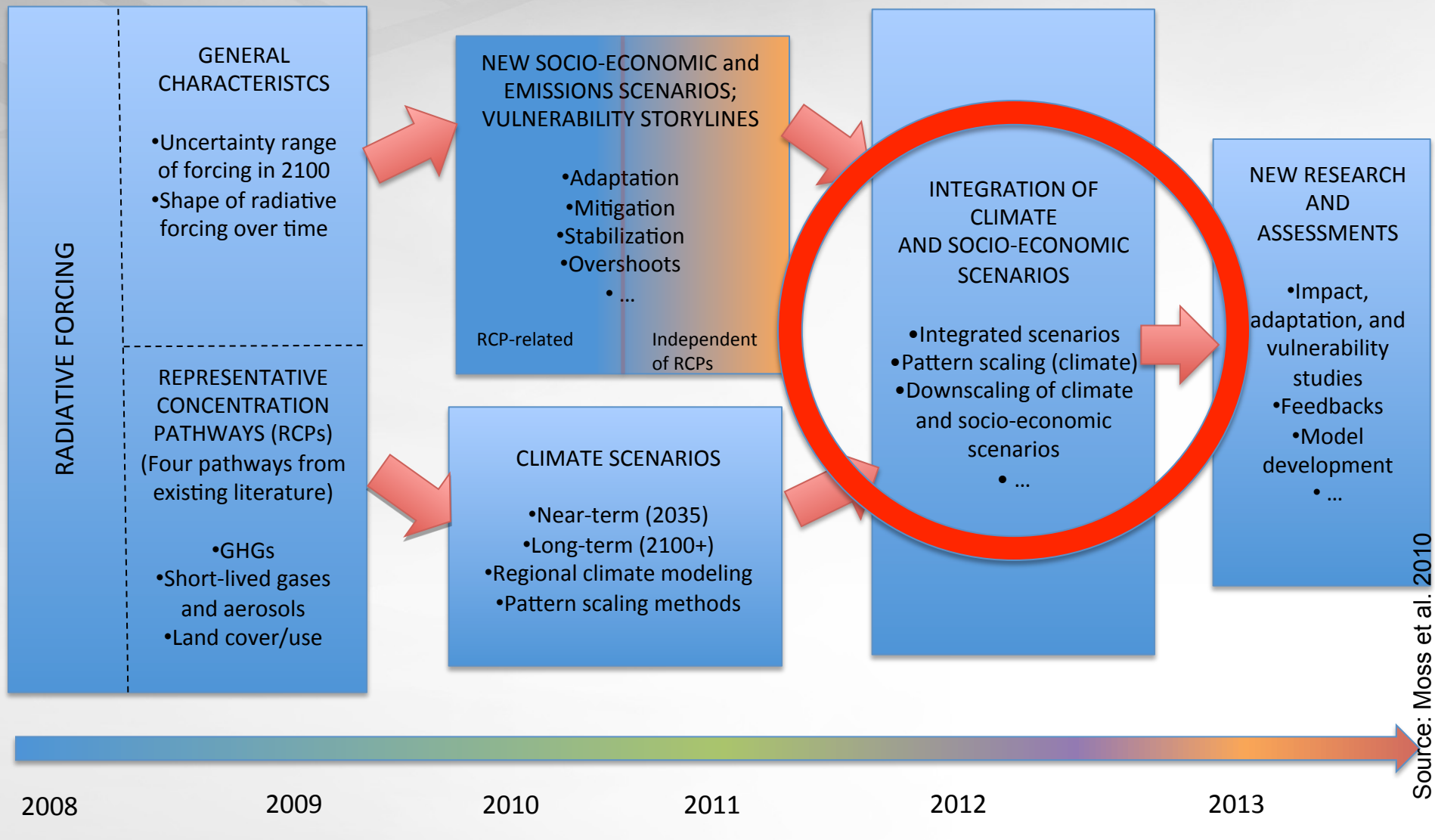


Source: Moss et al. 2010

# Improve framework for linking socio-economic and climate scenarios

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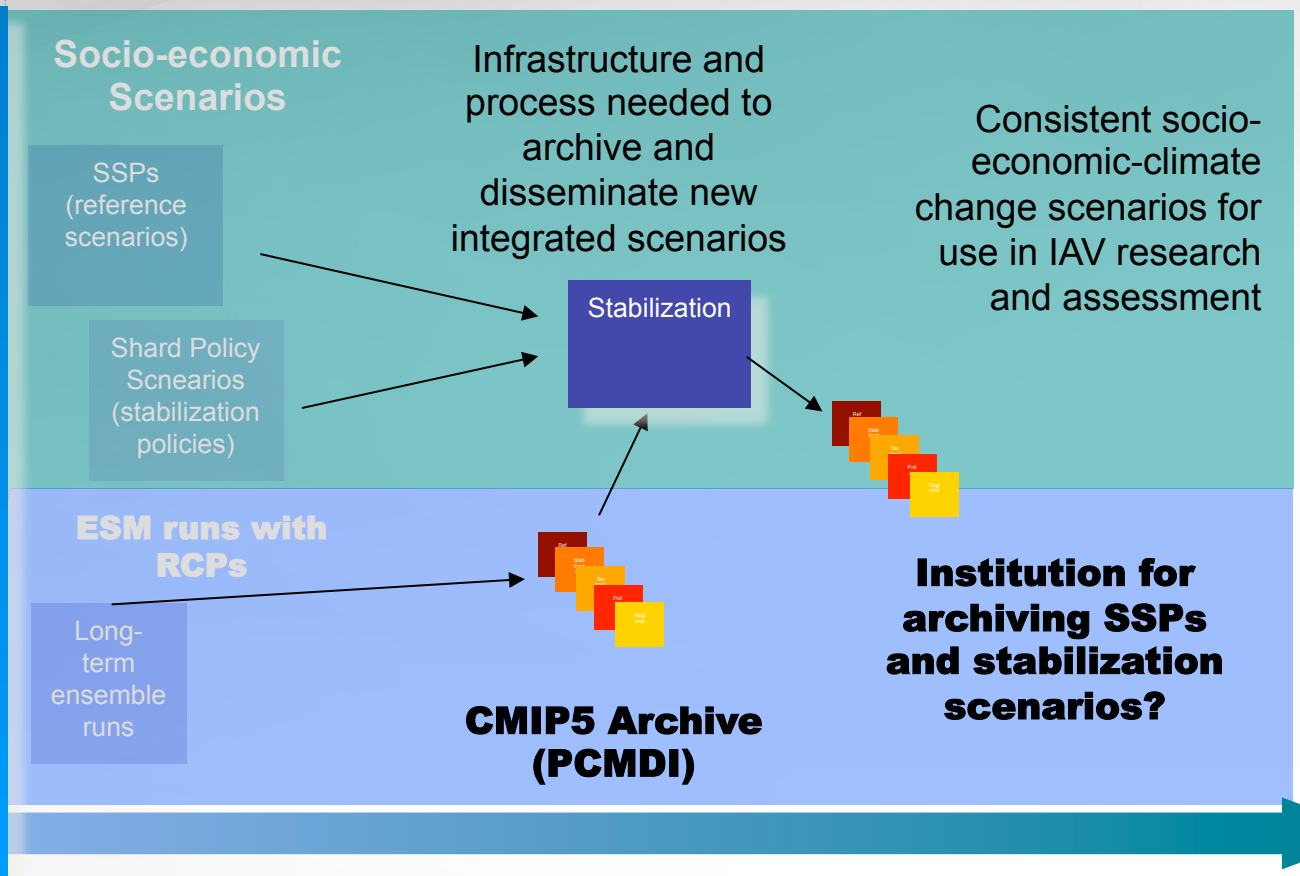
Needed for impact and regional mitigation assessments: integrated socioeconomic and climate scenarios in an accessible format from a distributed scenario archive




SPAs

| RCP Replication | SSP 1 | SSP 2 | SSP 3 | SSP4 | SSP5 |
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| Reference | X | X | X | X | X |
| 8.5 $Wm^{-2}$ | | | X | | |
| 6.0 $Wm^{-2}$ | | X | X | X | X |
| 4.5 $Wm^{-2}$ | X | X | X | X | X |
| 2.6 $Wm^{-2}$ | X | X | | X | |

# Use CMIP5 insights in an evolving user landscape

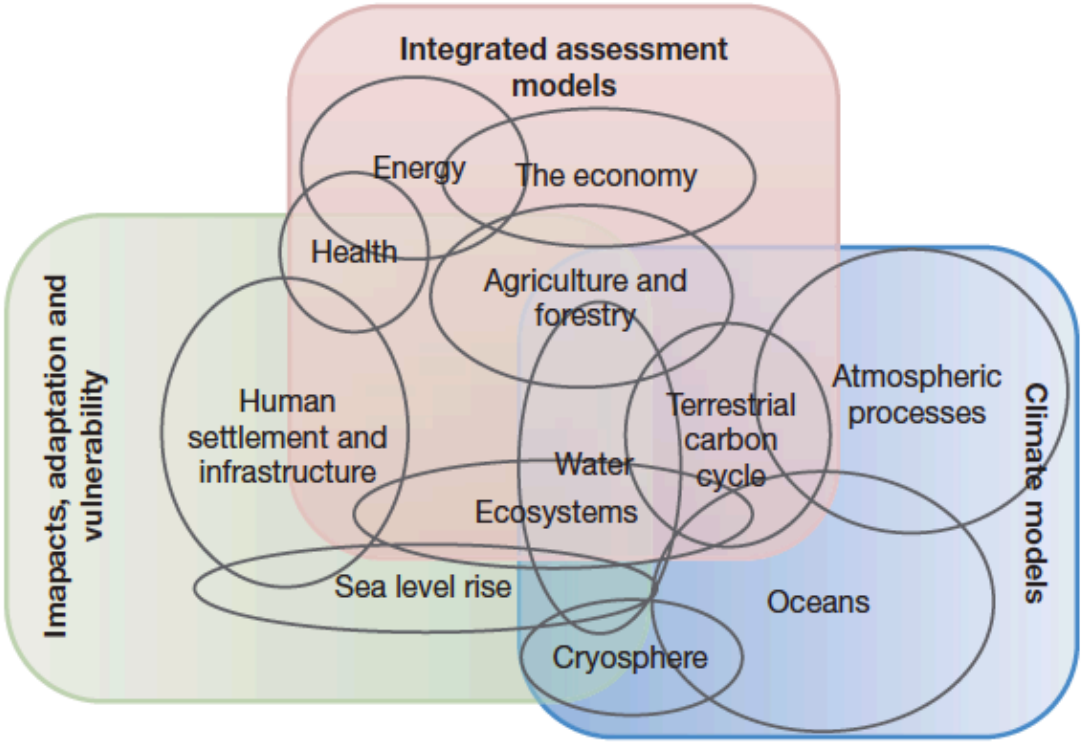


- User base has grown from small group of global-scale IAV modelers to a large and diverse set of actors
  - E.g., governments, business and industry, NGOs, and community groups, UNFCCC Nairobi Work Programme on adaptation, …
- Proliferation of portals and organizations providing climate information
- Increasing interest in
  - Mid-term time scales (10-20 years, 30-50 years)
  - High resolution information
  - A wider range of data products including simpler products appropriate for less-technical users
- How can we use insights and data developed through CMIP5 to better meet these challenges and needs?

# Improve exchange of knowledge across model communities



- Overlaps among model types is increasing
- This requires increasing coordination for intercomparison purposes
- There is an opportunity to increase exchange of information and learning (e.g., recent Sackler Symposium)
- What mechanism?

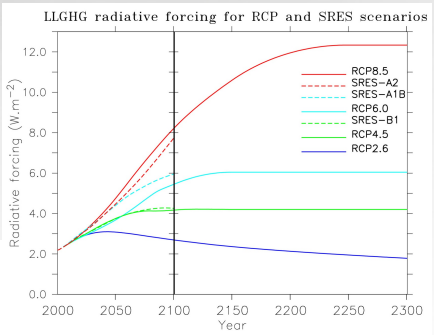


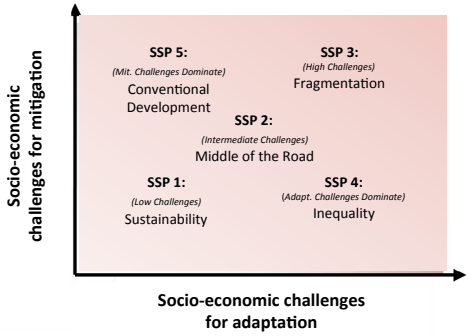

Source: Moss et al., 2010

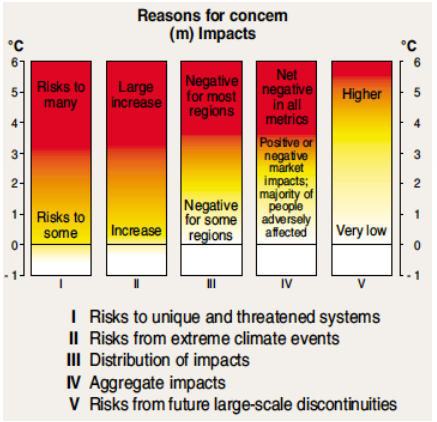
# Conclusions



- The parallel process is underway and supporting CMIP5
  - Slow start, bumps along the way, but much progress
- To prepare for CMIP6, we need to start the "handshake" process earlier and address several technical issues
- Major effort is needed to support integration and analysis of CMIP5, socioeconomic, and IAV data
- More generally, we need to identify an ongoing process for fostering interactions across the IAM, ESM, and IAV communities

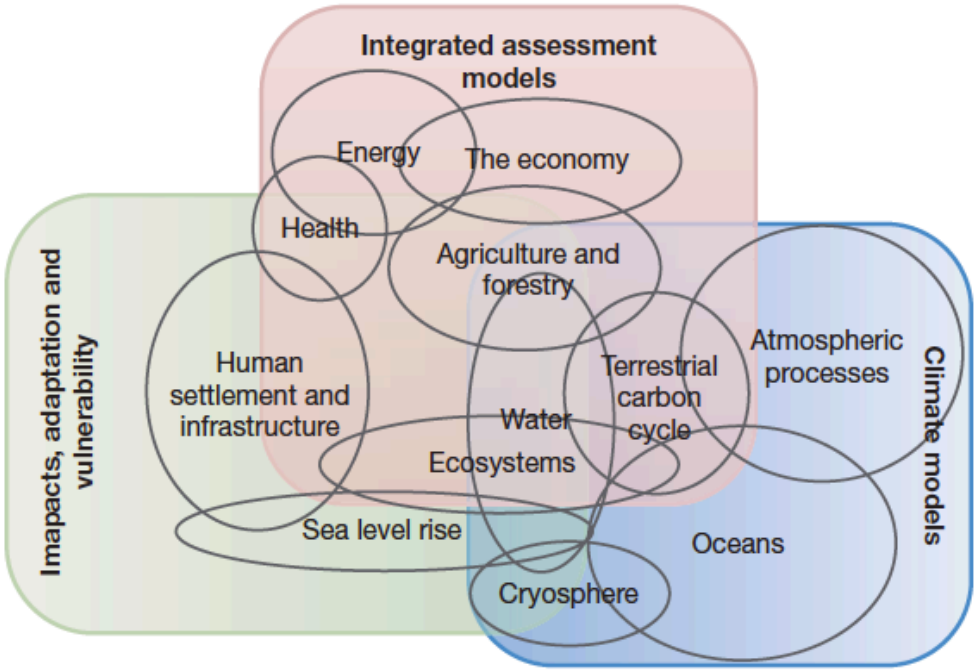



# Discussion




Integrated assessment models
Energy
The economy
Health
Agriculture and forestry
Human settlement and infrastructure
Water
Terrestrial carbon cycle
Atmospheric processes
Ecosystems
Sea level rise
Oceans
Cryosphere
Imapacts, adaptation and vulnerability
Climate models