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Climate Science and Uncertainty: Improving Assessments and Decision Support and an Overview of the IPCC Special Report on Extremes

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For
Rutgers University Initiative on Climate and Society
Extreme Weather and Climate Change:
How Can We Address Uncertainty?

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Acknowledgements

- Numerous colleagues including Jae Edmonds, Leon Clarke, Allison Thomson, Jennie Rice, Stephen Unwin, Michael Scott, Anthony Janetos, Elizabeth Malone, John Weyant, Tom Wilbanks, Ken Kunkel, Adam Parris, Holly Hartman, Kathy Jacobs, Gary Yohe, Kris Ebi, Tom Kram, Detlef van Vuuren, Keywan Riahi, Elmar Kriegler, Tim Carter
- DOE Integrated Assessment Research Program, Bob Vallario
- NASA, Jack Kaye

How can we inform decisions that need to be made under deep uncertainty?

Assessments

Selected past and ongoing assessments:

- A series of international **Stratospheric Ozone Assessments** (started in 1980s)
- **Intergovernmental Panel on Climate Change (IPCC)** periodic comprehensive assessments (1990, 1995, 2001, 2007) plus numerous special reports
- **National Assessment of Climate Change Impacts** on the United States (2000, 2009, 2013)
- **U.S. Climate Change Science Program (CCSP) Synthesis and Assessment Products** (21 reports, 2006-2009)
- **Global Biodiversity Assessment (GBA)** (1995)
- **Millennium Ecosystem Assessment (MEA)** (2004)
- **Arctic Climate Impact Assessment** (2005)
- **Intergovernmental Platform on Biodiversity & Ecosystem Services** (IPBES) proposed IPCC-like assessment (2011-12)

Source: NRC (2007), Analysis of Global Change Assessments: Lessons Learned

Uncertainty language for assessments

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- Purpose: inform users of confidence levels and uncertainties
- IPCC (Moss and Schneider, 2001) 3rd assessment, with revisions for 4th and 5th assessments
- US National Climate Assessment
  - Confidence assessment process and language
- Progress, but consistent failure to perform serious evaluations

Brief statement of conclusion, referenced to report or chapter:

1. Framing and stakeholder information needs

One or more types of stakeholder decisions (or uses of the information) have been considered in formulating the conclusion.

[Yes] [No]

2. Initial evaluation of evidence

An evidence rating has been assigned, considering the type, amount, quality, and consistency of evidence. In light of the use of the information, the evidence is:

[Strong] [Moderate] [Suggestive] [Inconclusive]

3. Preparation of conclusion

The conclusion reflects the diversity of evidence. For quantitative estimates of relevant parameters or metrics, a range is provided (in which there is a 90% chance the true value falls), and a “best estimate” is given, if warranted. High consequence outliers have been considered,

[Fully] [Partially]

4. Identification of key uncertainties

Sources of uncertainty and steps for improving the information base have been identified.

[Fully] [Partially] [Limited extent]

5. Assessment of confidence based on evidence and agreement

In light of the potential uses of the information, a confidence level has been assigned.

[High] [Moderate] [Fair] [Low]

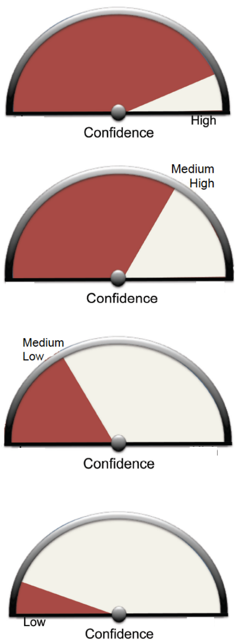
6. Indication of how likely it is that an outcome or event will occur

If you indicate how likely an event is to occur, the standardized numerical ranges and likelihood words have been used.

>9 in 10 Very Likely	>2 in 3 Likely	~1 in 2 Likely as Not	<1 in 3 Unlikely	<1 in 10 Very Unlikely

7. Traceable account:

National climate assessment confidence terms



Confidence Level	Example combinations of factors that could contribute to this confidence evaluation
High	Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus
Medium High	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus
Medium Low	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought
Low	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Issues and questions

- The rate at which new knowledge becomes available?
- The burden on the scientific community?
- Participation from industry?
- Role of an authorizing environment or mandate from governments?
- Adequacy of budgets?
- Communications strategy?
- Link to decision making?
- Analysis and communication of uncertainty?

Source: NRC (2007), Analysis of Global Change Assessments: Lessons Learned

Theme and topics

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- Theme: Communication requires more engagement with users – there is some progress to report

1. Scenarios
   - New international scenario process
   - US National Climate Change Assessment scenarios
2. Integrated regional modeling for adaptation and mitigation
   - Stakeholder driven uncertainty characterization

- IPCC Special Report on Extremes

What are scenarios and why use them?

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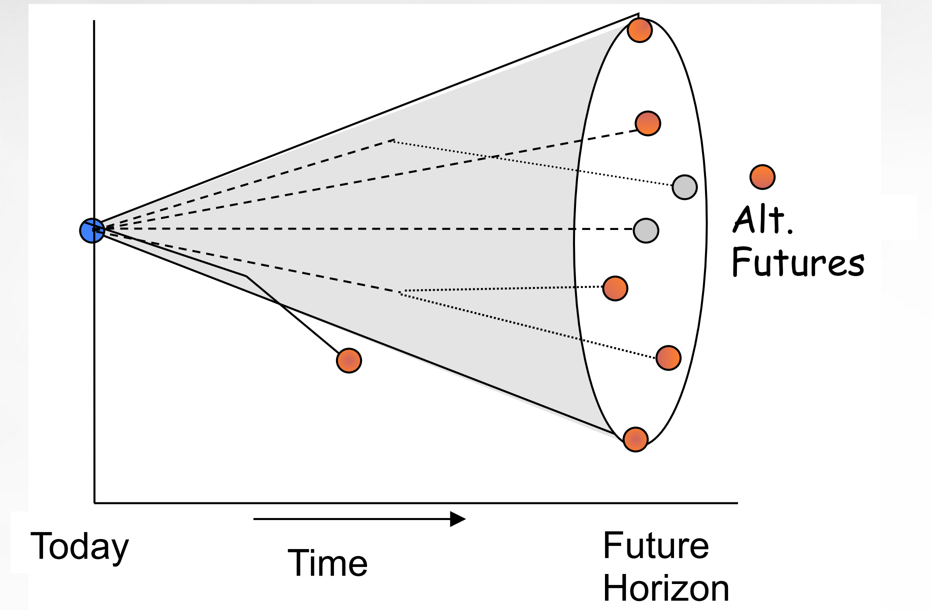
- Scenarios are plausible descriptions of how the future might unfold
  - Used to gain insight into the future, not to "predict" it
  - Encourage creative thinking
  - Inform decisions
- Scenarios in climate research:
  - Establish consistent inputs to modeling
  - Frame uncertainty (including risks)
  - Communicate



Why we can't predict climate change (and why scenarios are important)

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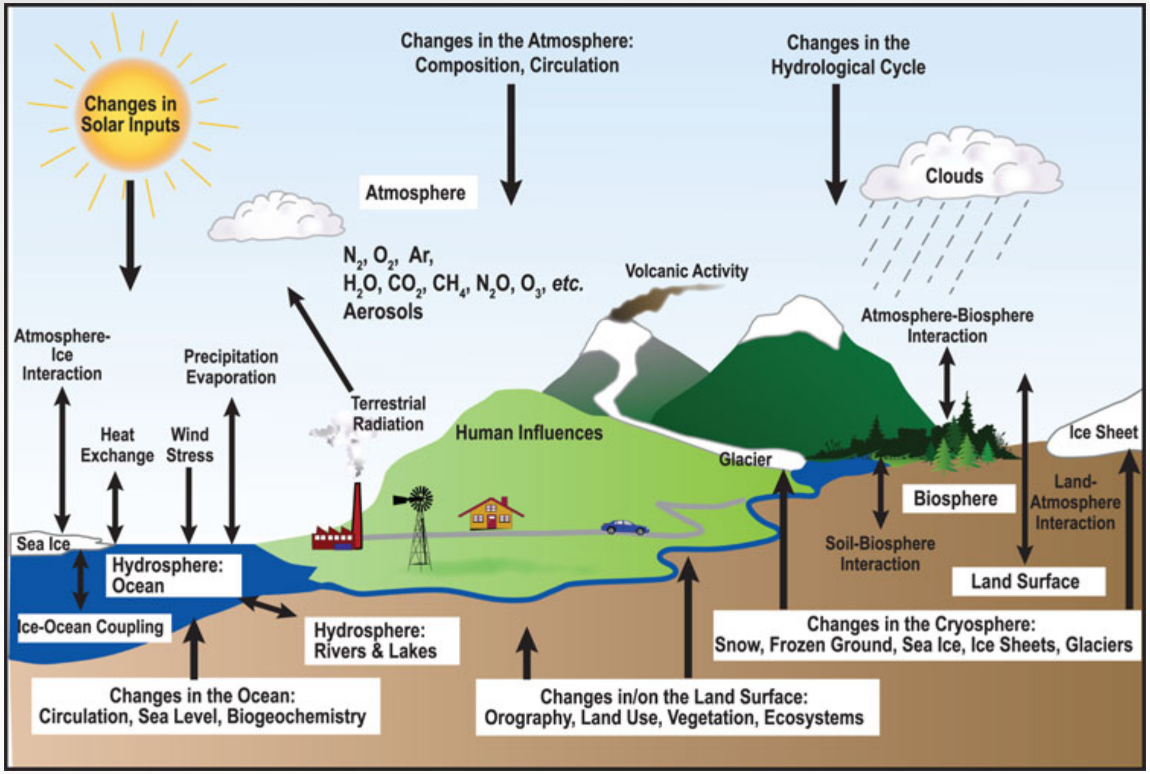
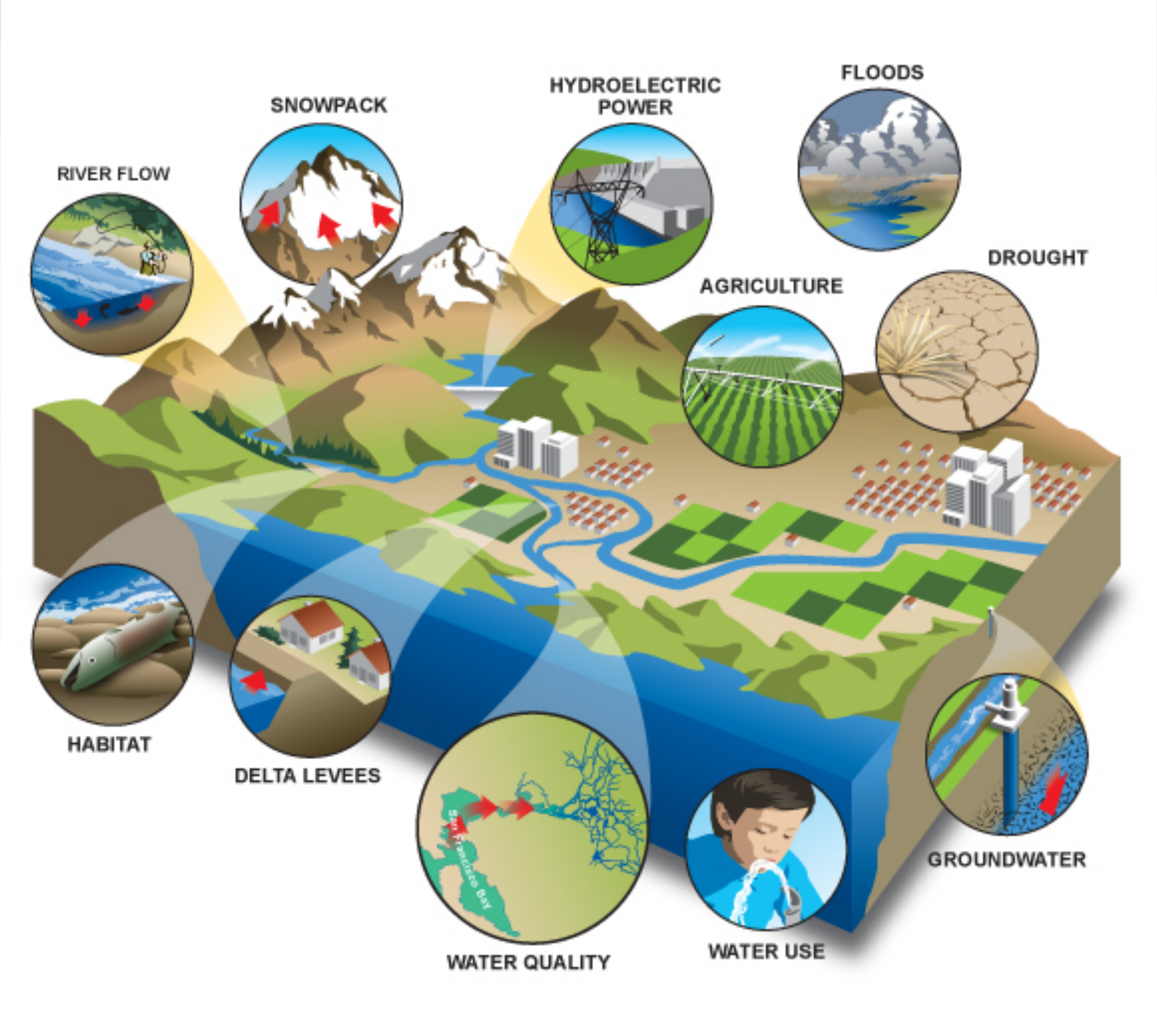
- Human choices are driving change and aren't predictable
- Scenarios provide "if-then" insights and a basis for *projecting* change given assumptions
- Projecting climate change is difficult due to
  - Natural variability
  - Numerous processes
  - Many parameterizations
- Climate process research and modeling are the foundation for climate projections
- Social science research provides foundation for emissions scenarios



Credit: USGCRP

Climate change research depends as much on social science as natural science

- Drivers
- Resource use and scarcity
- Exposure
- Sensitivity
- Adaptive capacity
- Capacity for mitigation
- Decision making under uncertainty and risk management



Historical perspective on emissions scenarios for climate research

- Early period: instantaneous 2x (or 4x) increases in CO_2 concentrations
- Early 1990s: transient increase (1%/yr) in CO_2
- 1990s: increasing complexity of gases and particles
  - SA90 (included policy cases)
  - IS92 (multiple realizations of "business as usual")
- 2000: Special Report on Emissions Scenarios (SRES)
  - Narratives of socioeconomic futures drive emissions
- 2009: "Parallel" scenario process
  - Shorter development time
  - Socioeconomic futures explore vulnerability as well as emissions

Scenario types and sequencing in climate change research

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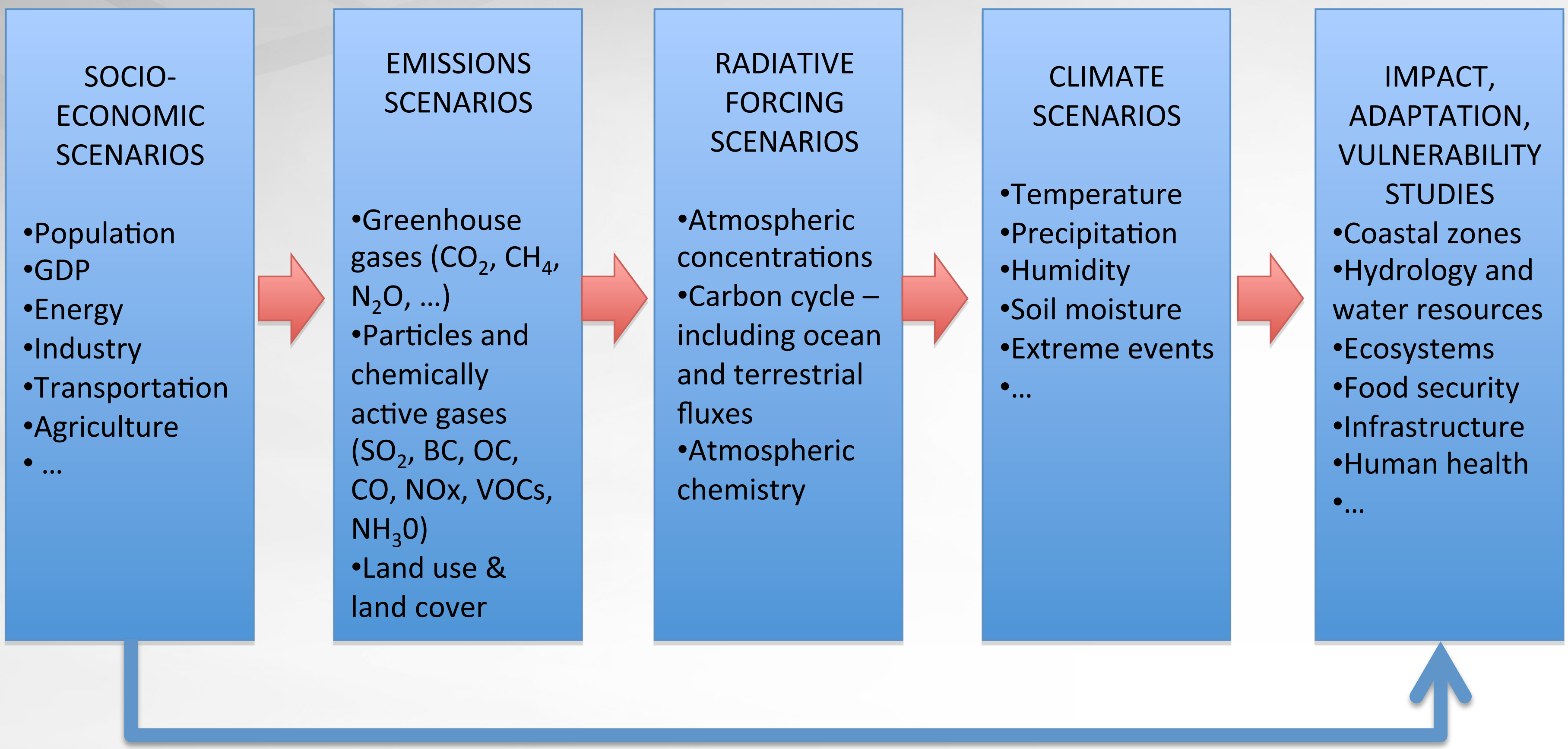
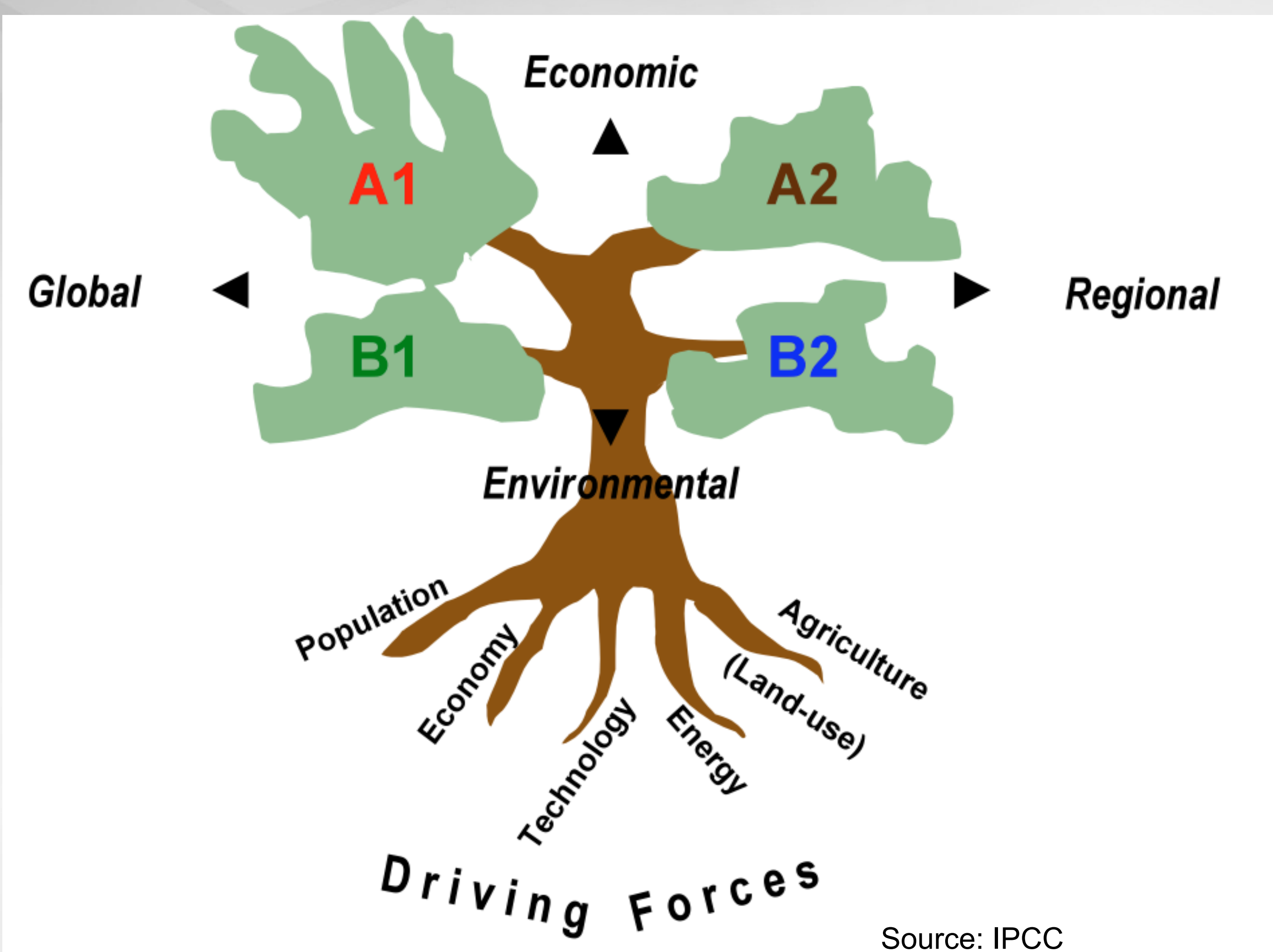


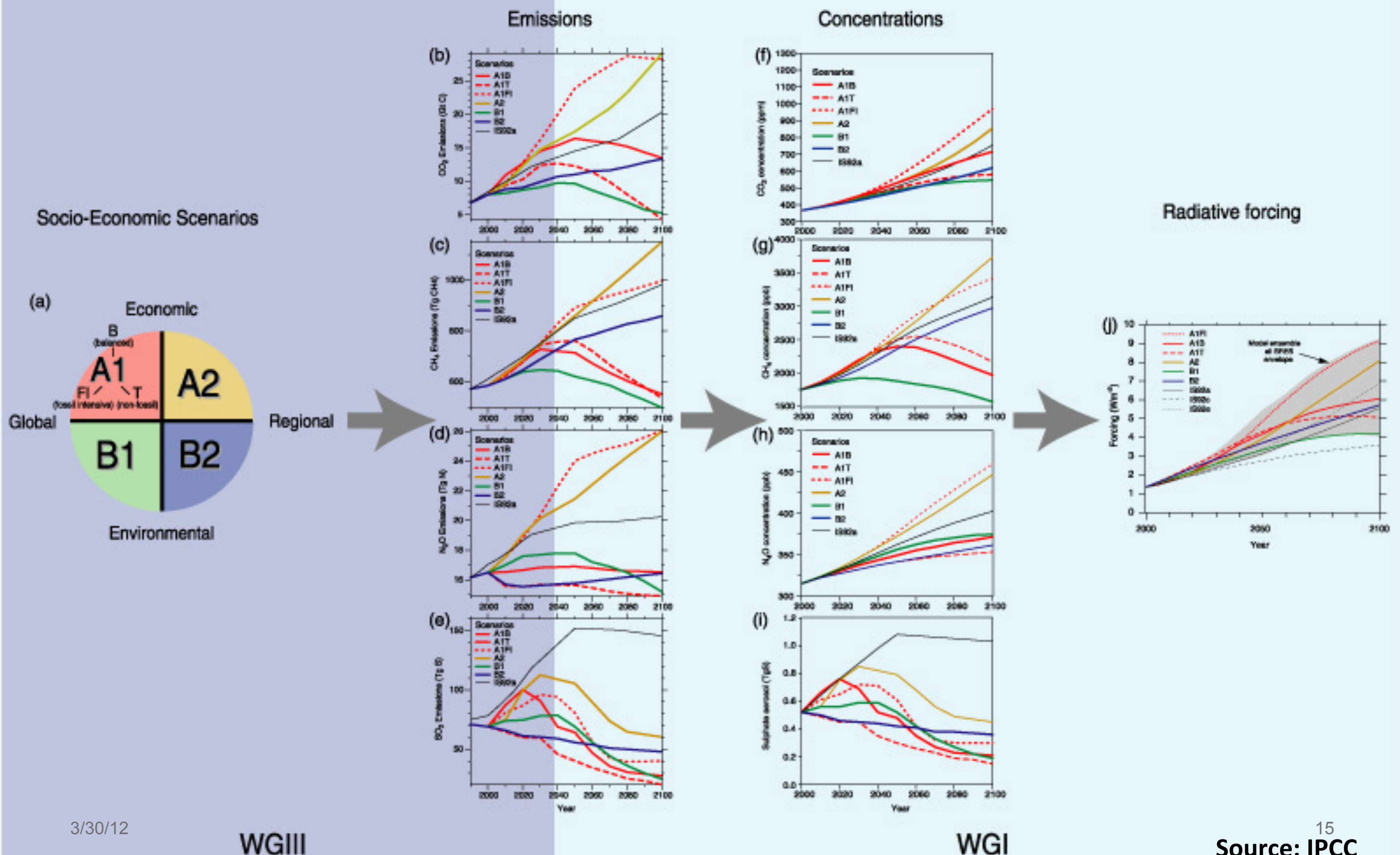
Source: Moss et al. 2010

Schematic illustration of SRES logic



Source: IPCC

Socioeconomic narratives to radiative forcing



Source: IPCC

Radiative forcing to impacts and responses

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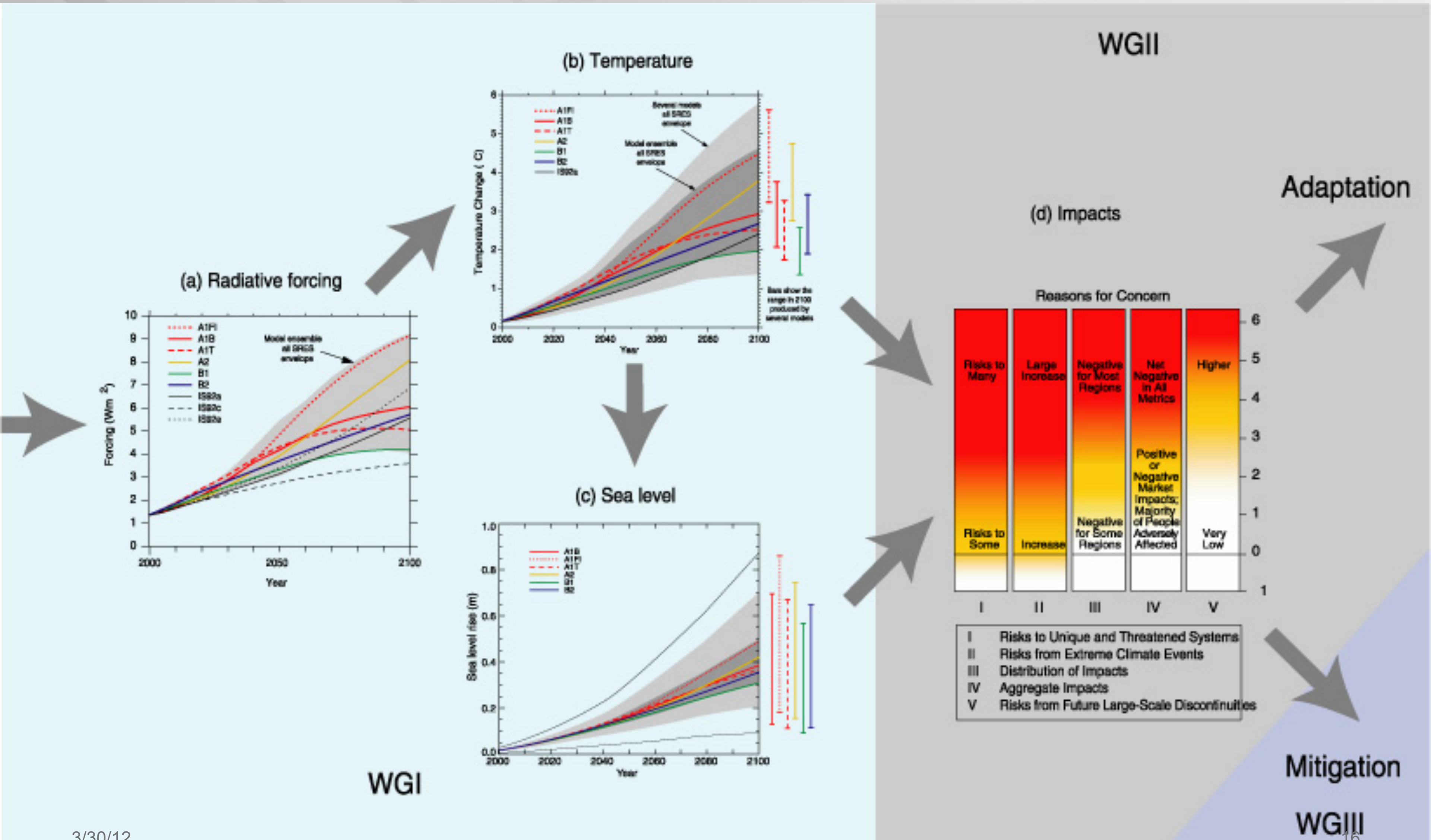


Source: IPCC

Motivations for a new process

- Address critiques
  - Overconfidence in scenario details
  - Long lead times
  - Misperceived one-to-one correspondence between socioeconomic scenarios and climate futures
- Evolving information needs
  - Increasing focus on adaptation
- Scientific requirements
  - Improve coordination to manage model overlaps
- IPCC's new role

Vol 000|00 Month 2010|**doi:10.1038/nature08823** nature

PERSPECTIVES

The next generation of scenarios for climate change research and assessment

Richard H. Moss[1], Jae A. Edmonds[1], Kathy A. Hibbard[2], Martin R. Manning[3], Steven K. Rose[4], Detlef P. van Vuuren[5], Timothy R. Carter[6], Seita Emori[7], Mikiko Kainuma[7], Tom Kram[5], Gerald A. Meehl[2], John F. B. Mitchell[8], Nebojsa Nakicenovic[9,10], Keywan Riahi[9], Steven J. Smith[1], Ronald J. Stouffer[11], Allison M. Thomson[1], John P. Weyant[12] & Thomas J. Wilbanks[13]

Advances in the science and observation of climate change are providing a clearer understanding of the inherent variability of Earth's climate system and its likely response to human and natural influences. The implications of climate change for the environment and society will depend not only on the response of the Earth system to changes in radiative forcings, but also on how humankind responds through changes in technology, economies, lifestyle and policy. Extensive uncertainties exist in future forcings of and responses to climate change, necessitating the use of scenarios of the future to explore the potential consequences of different response options. To date, such scenarios have not adequately examined crucial possibilities, such as climate change mitigation and adaptation, and have relied on research processes that slowed the exchange of information among physical, biological and social scientists. Here we describe a new process for creating plausible scenarios to investigate some of the most challenging and important questions about climate change confronting the global community.

New scenarios: "Parallel Process"

Current task

Socioeconomic pathways

Vulnerability: exposure, sensitivity, adaptive capacity

Emissions drivers, mitigative capacity

Integrated Analyses

Mitigation, adaptation, impacts

Radiative Forcing: Representative Concentration Pathways

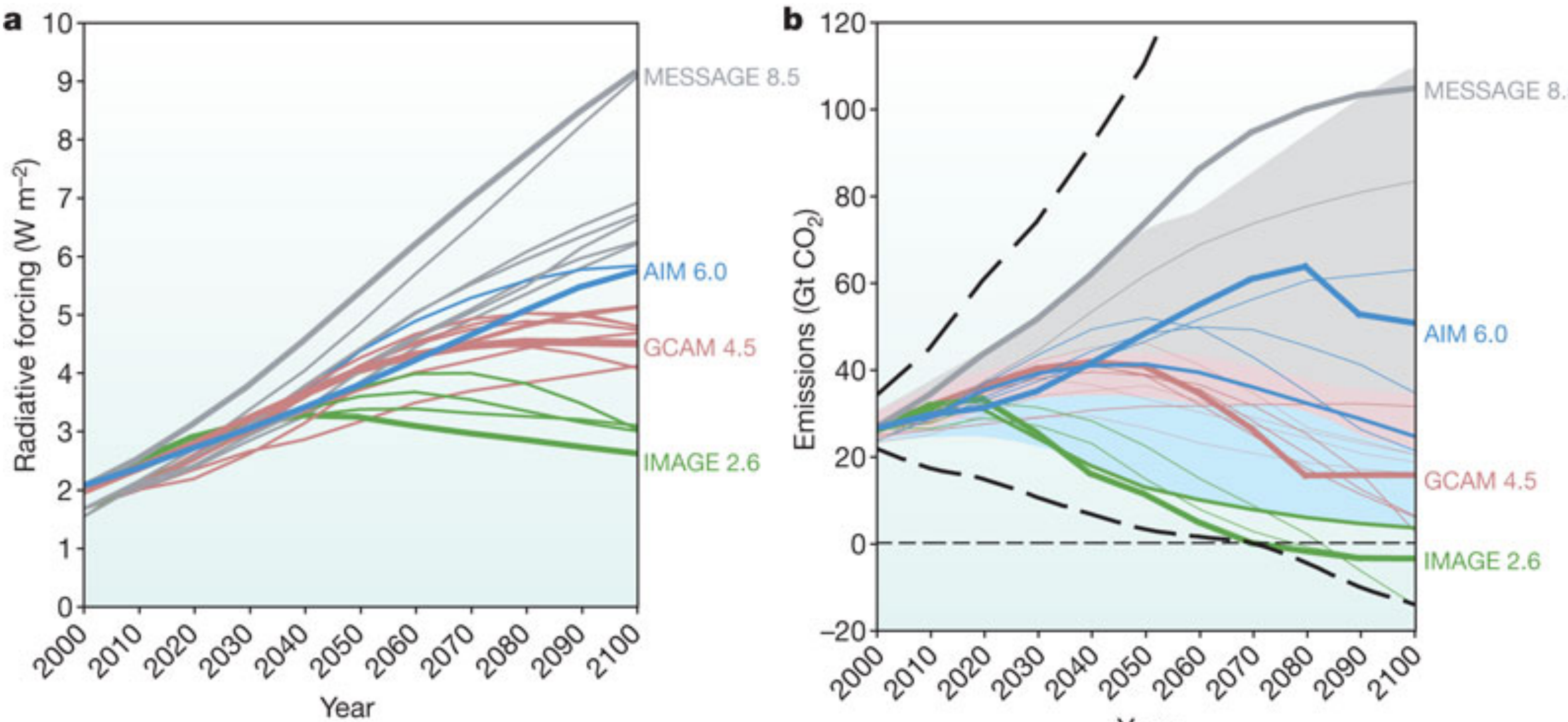
GHGs, other gases, and particle concentrations over time; land cover W/m^2 in 2100

Ongoing (CMIP5)

Earth System Model Simulations

Climate change, climate variability

FOUR RCPs



Source: Moss et al., 2010

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, PFCs, 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)**

Framing: challenge to adaptation and mitigation in "Shared Socioeconomic Pathways" (SSPs)

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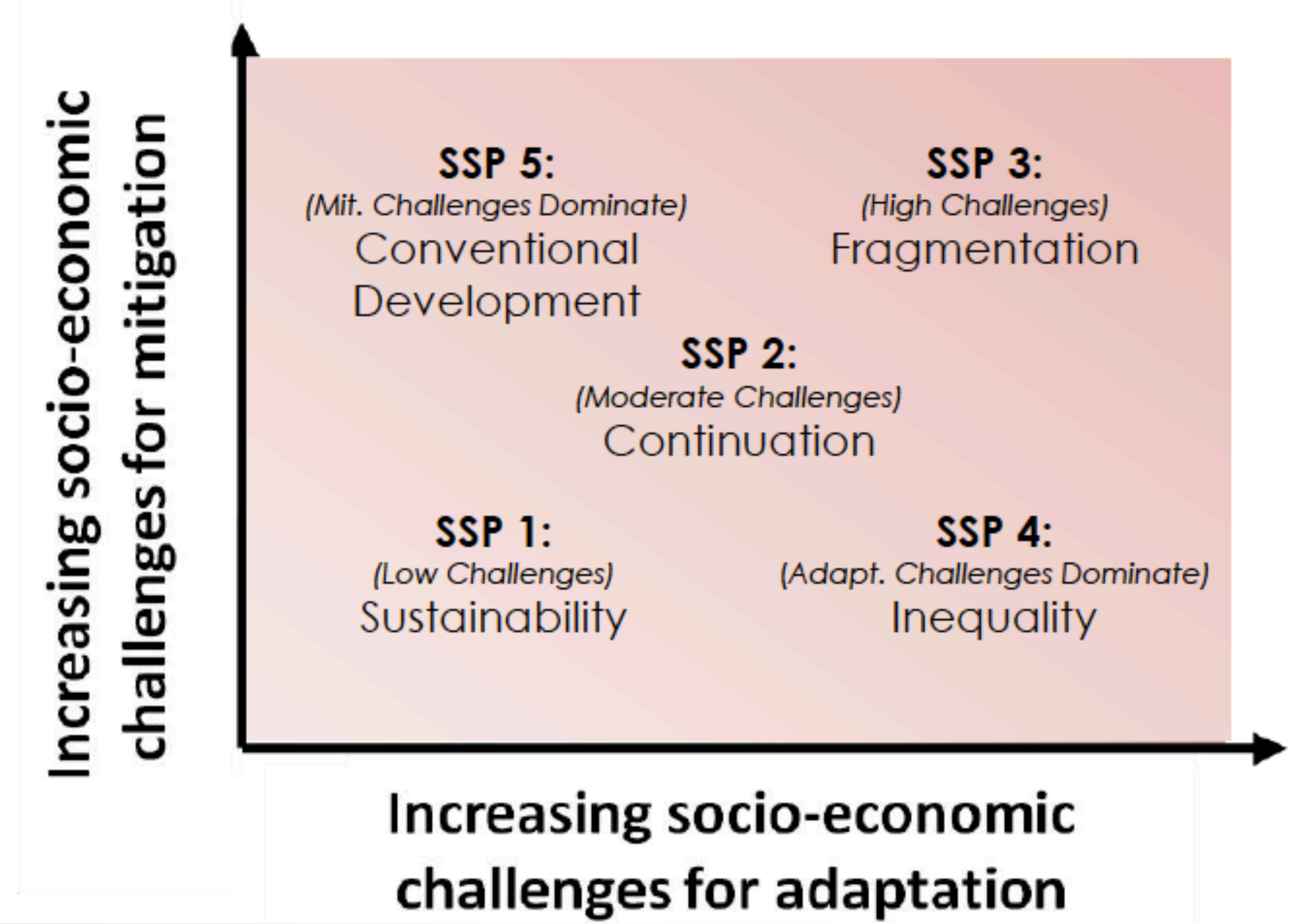

Adaptation challenges

Exposure
Sensitivity
Adaptive capacity

Average wealth
Extreme poverty
Governance
Water availability
Innovation capacity
Coastal population
Educational attainment
Urbanization
…
Quality of healthcare
Availability of insurance

Mitigation challenges

Baseline(no-policy) emissions
Mitigation capacity

Population
Carbon intensity
Agricultural productivity
Energy intensity
Energy-related tech. change
CCS availability
…
Effectiveness of policy institutions
Energy tech. transfer
Diet

Schweizer & O'Neill, in prep.

Alternative futures: population, social progress, and technology uncertainties

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Scenario Characteristics					
Pop6		Pop9		Pop14	
MDG+ "Sustainability"	MDG- Derailed Development	MDG+ Conventional Market-oriented Growth	MDG- Muddling Through	MDG+ Hustle	MDG- Chaos
-Rapid transition to sustainability -Social progress -Low fertility -High int'l trade and cooperation	-A shock derails initial positive trends -Economic, population, and environmental collapse -Highly inequality both within and across countries	-Sustained social progress -Rapid market-oriented economic growth -Moderate pop growth -Conventional (fossil) fuels dominate	-Stagnation -Sporadic economic growth -Apathy about the less fortunate and the environment - Mixed technological progress	-Traditional cultural values and life styles -High pop growth -Good economic growth -Engineered ecosystems -Social cohesion	-Mired in problems -High population growth, low migration - Slow economic growth -Conventional technologies -Resource competition -Slow diffusion of technology

Application in user-driven impacts research: nested scenarios – working across scales

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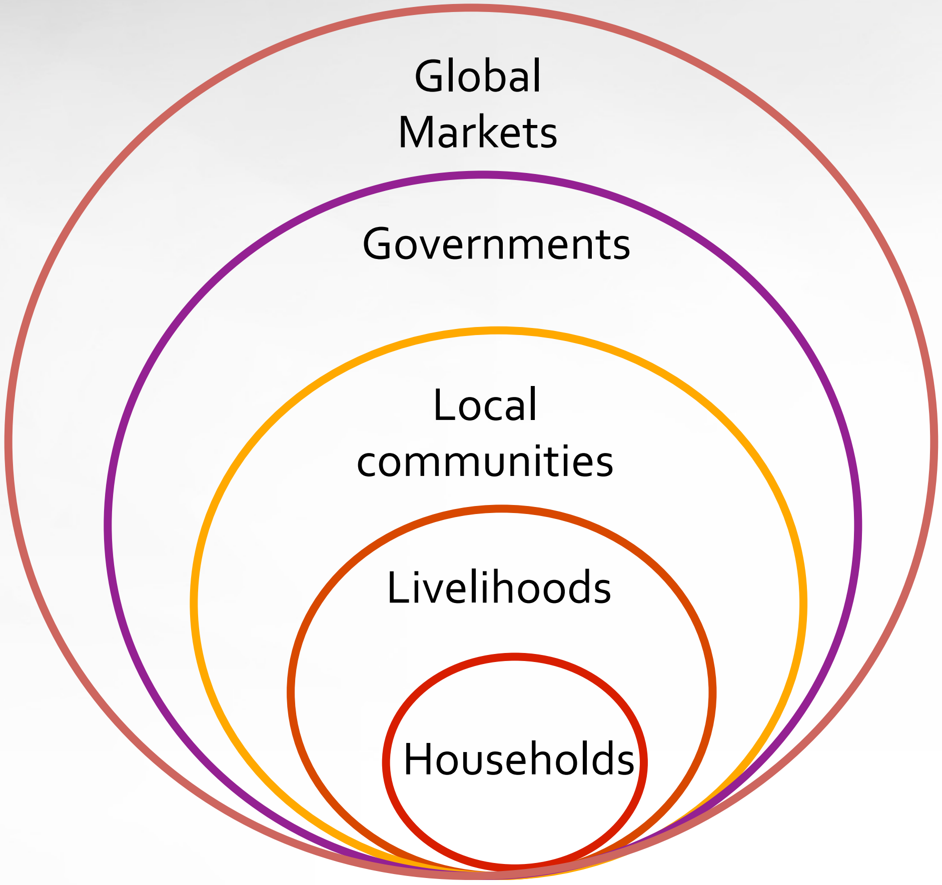
Finer scale information needed for impacts, adaptation, and vulnerability (IAV) research

- "Downscaling", or
- "Place-based" scenario process
  - Greater credibility, legitimacy, and salience
  - Incorporate local knowledge
  - Degree of coupling can vary from global to local – can be constructed consistently with global scenarios



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Scenarios in US National Climate Assessment

US National Climate Assessment and its use of scenarios

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- Mandate, process, and near-term deliverable
- Long-term goal: establish an ongoing, distributed process
- Uses of scenarios:
  - Provide context of range of potential future conditions
  - Establish common assumptions for modeling
- Types of scenarios:
  - Four sets using existing resources based on SRES A2 and B1 scenarios:
    - Climate outlooks, data, and downscaling
    - Sea level – core and extended "risk management" ranges
    - Land use – demographic allocation using SRES logic
    - Socioeconomic – existing Census and modeled data
  - Participatory scenario planning: inventory and pilot studies

National Climate Assessment
U.S. Global Change Research Program

Now for something completely different: Participatory scenario planning

- Group visioning and planning process
  - Systematic and creative evaluation of objectives and implications of uncertain forces
  - Community/user driven
- Many approaches/methods, but common steps include...
  1. Discuss values and objectives, prioritize issues, and select focus
  2. Identify "drivers" (including uncontrollable external forces)
  3. Analyze potential impacts and risks; test plausibility of ends and means
  4. Assess implications for decision making
- E.g.s; National Park Service, Western Lands and Communities, Wildlife Conservation Society, Army Corps of Engineers, Tucson Water, ...

NCA participatory scenario pilot studies: integrating different types of scenarios

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Bring climate change scenarios into a participatory scenario planning process

- Participants conduct planning/visioning and then consider ability to achieve objectives under two futures
  - “*The Best Chance You’ll Get*” – "B1 world": environmental values, rapid socioeconomic progress, "smart growth", low climate change
  - “*Big Problems, Low Capacity*” – "A2 world": consumerism, slow socioeconomic progress, sprawling urban development, high climate change
- In second stage, participants explore adaptation *strategies* (not just technologies) for A2 conditions

National Climate Assessment
U.S. Global Change Research Program

Conceptual relationship among different types of scenarios and their uses

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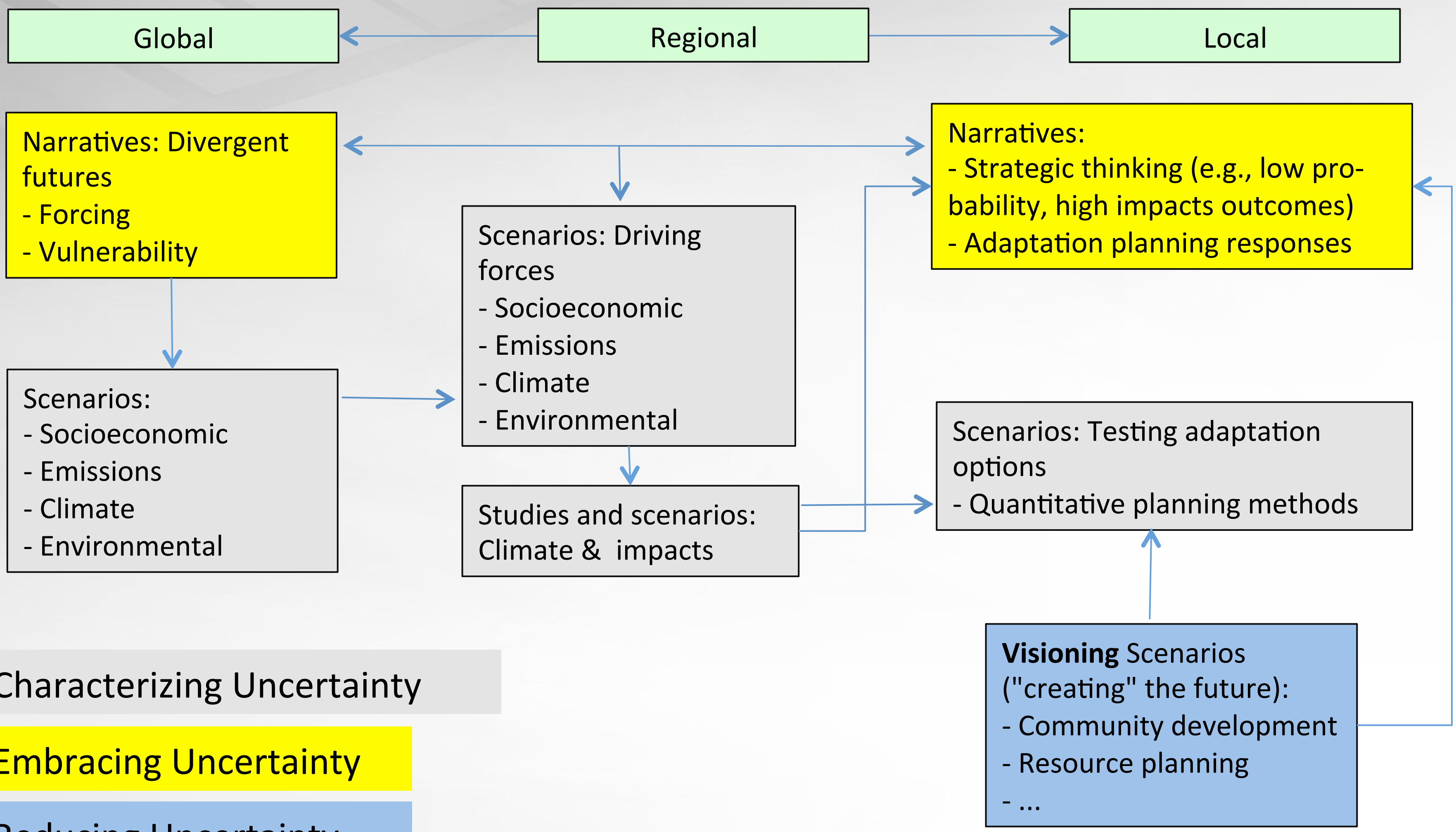


Characterizing Uncertainty

Embracing Uncertainty

Reducing Uncertainty

Hartman and Moss, in prep.

Stakeholder driven uncertainty characterization in regional modeling

nature
www.nature.com/nature
Vol 463 | Issue no. 7283 | 18 February 2010

Validation required

Transparency and quality control are essential in the highly uncertain business of assessing the impact of climate change on a regional scale.

Climate scientists are engaged in a lively debate about how — or whether — the Intergovernmental Panel on Climate Change (IPCC) should reform itself (see *Nature* 463, 730–732; 2010). At a minimum, the panel needs to hold itself to the highest possible standards of quality control in future assessments.

But so do climate scientists themselves — especially those who study the links between global climate change and its potential regional effects on factors such as weather patterns, ecosystems and agriculture. Governments faced with the need to make difficult, disruptive and politically fraught decisions about when and how to respond to climate change are understandably eager for certainty. But certainty is what current-generation regional studies cannot yet provide. Researchers need to resist the pressures to overstate the robustness of their conclusions, and to be as open as possible about where the uncertainties lie.

As an example of the scientific challenges involved, imagine a regional authority wanting to plan for water resources in a river basin over the next four decades. An applicable study might be probabilistic in approach. It could take into account a range of global greenhouse-gas-emission trajectories, and involve multiple runs of global climate models using different values for a number of parameters. However, such models cannot reproduce some important atmospheric phenomena such as circulation trapping, and cannot be validated against real climate behaviour over decadal timescales. The multiple runs will produce a probability distribution of precipitation which itself will contain intrinsic uncertainties. These outcomes then need to be fed into a catchment model with its own range of parameters and limitations of knowledge, and which in turn needs to be coupled to models of water demand as local housing and populations change over the period (M. New *et al. Phil. Trans. R. Soc. A* 365, 2117–2131; 2007, and other papers in that issue).

Climate projections at the national level are crucial for such efforts. One such study was published last year, when the UK Met Office produced its climate projections of the next eight decades, including analysis down to a resolution of 25-kilometre squares (http://ukclimateprojections.defra.gov.uk). The British government is now conducting a national climate-change risk assessment, due for completion in early 2012, that uses the projections. But such an application could well be problematic: it is likely that the projections reflect the limitations of the models and analyses as much as probabilities intrinsic to the real world. Yet regional planners and others might easily miss the detailed discussions of uncertainties, and misguidedly seize on these projections as a solid basis for investment decisions. And depressingly for decision-makers, the more the uncertainties are explored, the greater the ranges in the projected possible outcomes are likely to become.

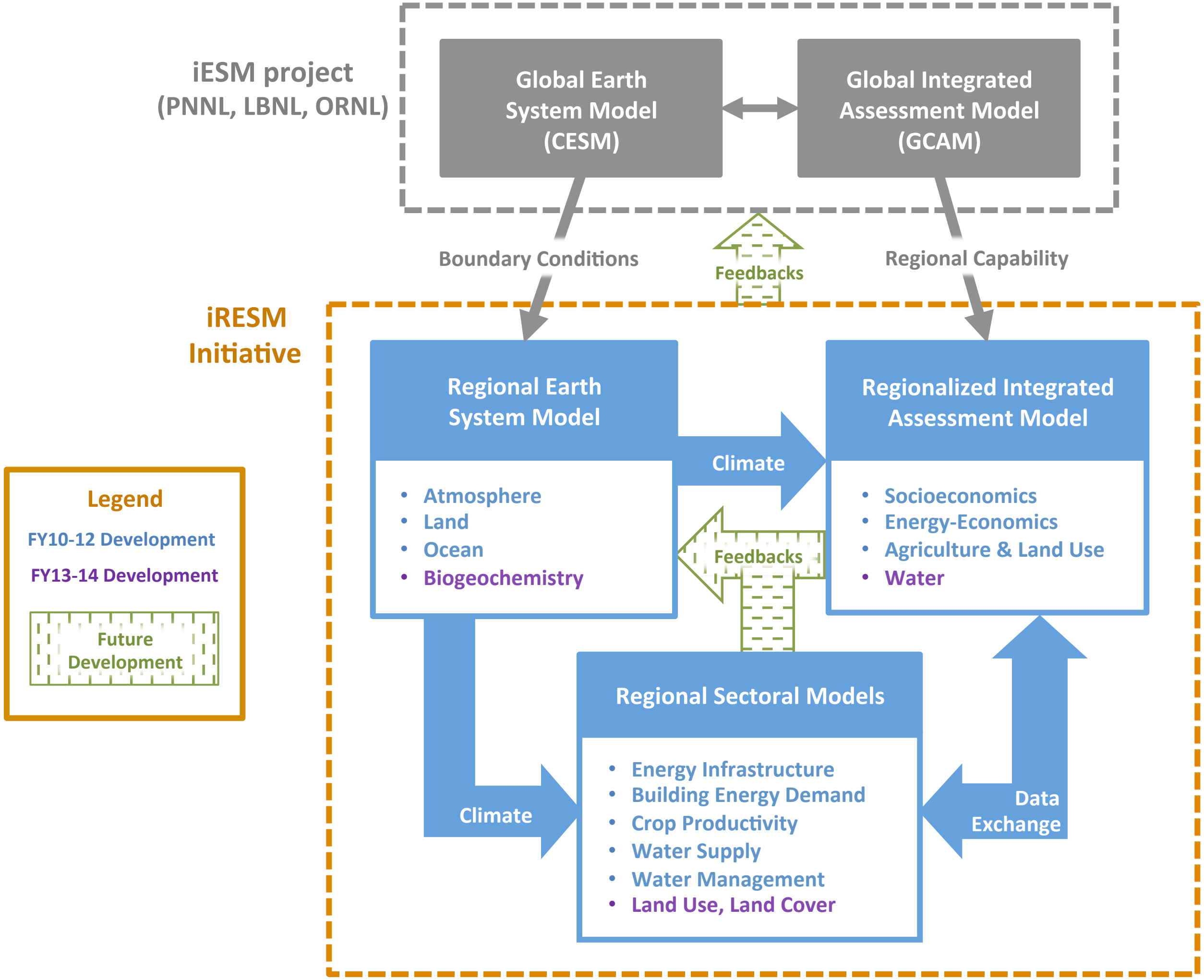
This combination of projections and risk analysis is one way in which an over-reliance by decision-makers on modelling may be setting up the scientific community for a loss of trust. What is more, like regional-impact studies, such analyses often appear not in peer-reviewed journals but in 'the grey literature' — in reports, or on websites. Yet they are no less important in representing the outputs of climate science, and need to be included in the IPCC assessment. For these reasons, such grey studies should be transparently peer reviewed as a part of their commission.

> "Grey-literature studies should be transparently peer reviewed as a part of their commission."

Uncertainties about future climate effects do not undermine the case for action to reduce greenhouse-gas emissions. But there is a long way to go in the science before regional-impact studies provide a suitable basis for detailed planning. Whatever the pressures, statements by scientists and government agencies about such studies need to be well qualified, and policies based on them need to be kept as flexible as possible. It is intrinsic to this research, after all, that scientists' best judgements will be subject to change. ■

The need for transparent evaluation of uncertainty in regional modeling

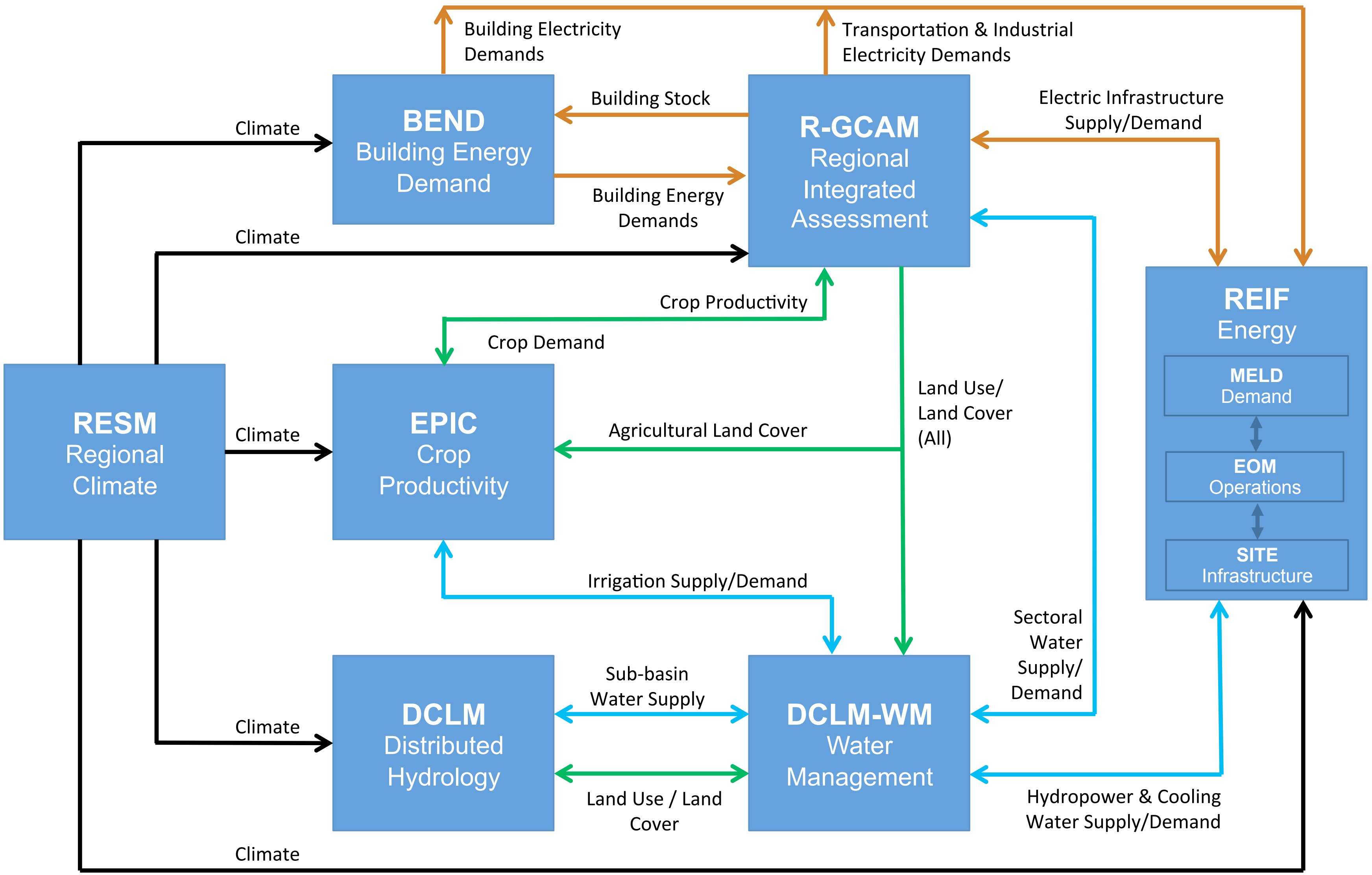
iRESM conceptual framework



Key Attributes:

- Open source
- Flexible and modular
- Capable of simulating interactions and resolving impacts at high resolution
- Uncertainty characterization for stakeholder questions and issues

Detailed iRESM framework



Numerical experiments – stakeholder perspectives

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Stakeholder organizations met with as of March 2012:

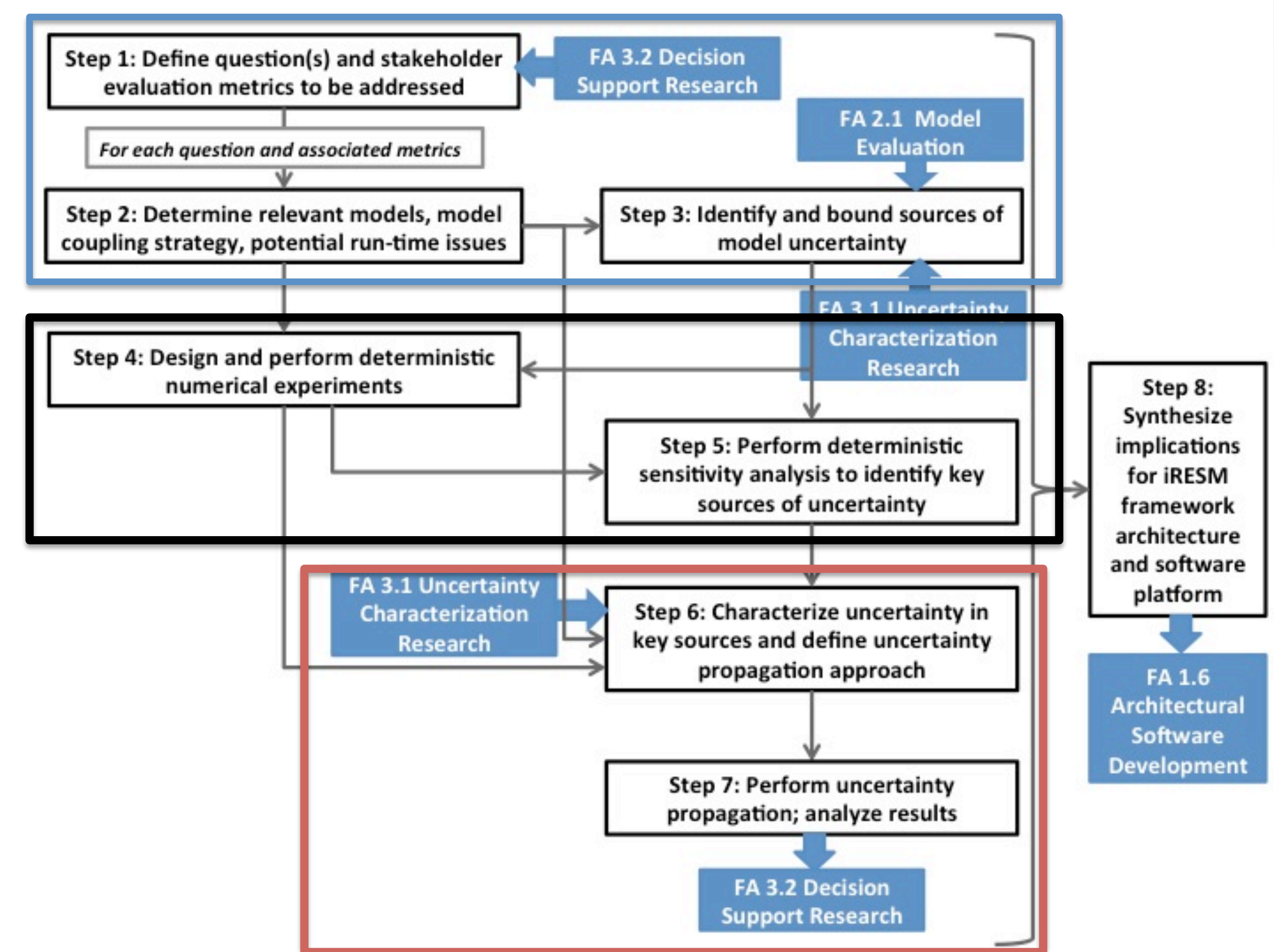
- Wisconsin Bioenergy Initiative
- Wisconsin Climate Change Initiative (represents a wide range of stakeholders)
- Nelson Institute for Environmental Studies, University of Wisconsin
- Center for Sustainability and the Global Environment, University of Wisconsin
- Center for Science, Technology and Public Policy, Humphrey School of Public Affairs, University of Minnesota
- Minnesota Forest Resources Council
- Minnesota Pollution Control Agency
- Iowa State University, Climate Science Program, Agricultural Meteorology
- University of Iowa, Center for Global and Regional Environmental Research
- Great Lakes Commission
- Midwest Independent System Operators (MISO)
- International Plant Nutrition Institute
- U.S. Department of Agriculture, ARS
- Illinois Department of Agriculture
- Chesapeake Energy
- Illinois Energy Office, Illinois Department of Commerce & Economic Opportunity
- Illinois EPA
- City of Chicago Department of Environment
- Great Lakes and St. Lawrence Cities Initiative
- Metropolitan Water Reclamation District of Greater Chicago
- Pennsylvania State University, several departments

Numerical experiments – stakeholder perspectives

Key iRESM model outputs from stakeholder perspective:

Climate	Crops/Land Use	Energy	Water
▪ Changes in seasonal average temperatures and precipitation ▪ Increased intensity and/or frequency of extreme events (rainfall, drought, heat waves)	▪ Crop yield ▪ Land use ▪ Water use ▪ Erosion ▪ Soil carbon and nitrogen ▪ Climate feedbacks ▪ Emissions ▪ Crop prices ▪ Management costs	▪ Energy demand by end use ▪ Electricity demand by utility zone (peak and total annual energy) ▪ Electricity reserve requirements ▪ Electricity generation mix ▪ Infrastructure expansion requirements ▪ Electricity prices ▪ Emissions ▪ Fuel prices ▪ Water use ▪ Land use	▪ Water availability and conflicts between municipal, agricultural, hydropower, and thermo-electric cooling needs

Stakeholder-driven uncertainty analysis



Example of decision support process

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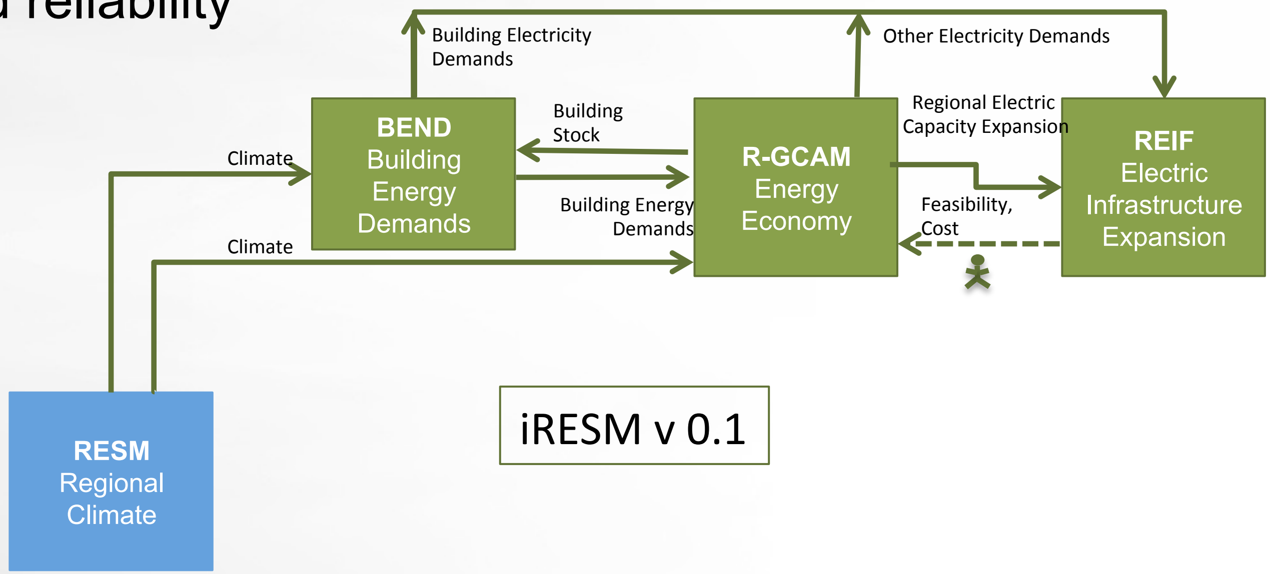
- Select a mitigation decision
  - Level/form of renewable portfolio standard?
- Select a single decision criterion
  - e=Electricity price (could be grid operational reliability, ag impacts, etc.)
- Select model components; assess runtimes; develop surrogates
- Address uncertainties in relevant models contributing to calculation of costs and grid reliability
  - R-GCAM
  - BEND
  - REIF
  - RESM



Need for development of UC methods for scientific insight and decision support

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- Estimated runtimes for integrated models can be long, with implications for UC
- A flexible architecture and surrogate models will need to be developed to make UC tractable
  - Facilitate coupling appropriate models for the research question at hand
  - Based on research question or decision needs, I-O requirements, and uncertainty source identification
  - Develop and use surrogate models as needed to address runtime issues
- This approach is reflected in the draft USGCRP strategic plan, but agency programs are still driven by a 'bigger and more detailed is better' philosophy

The IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation

ipcc
INTERGOVERNMENTAL PANEL ON climate change

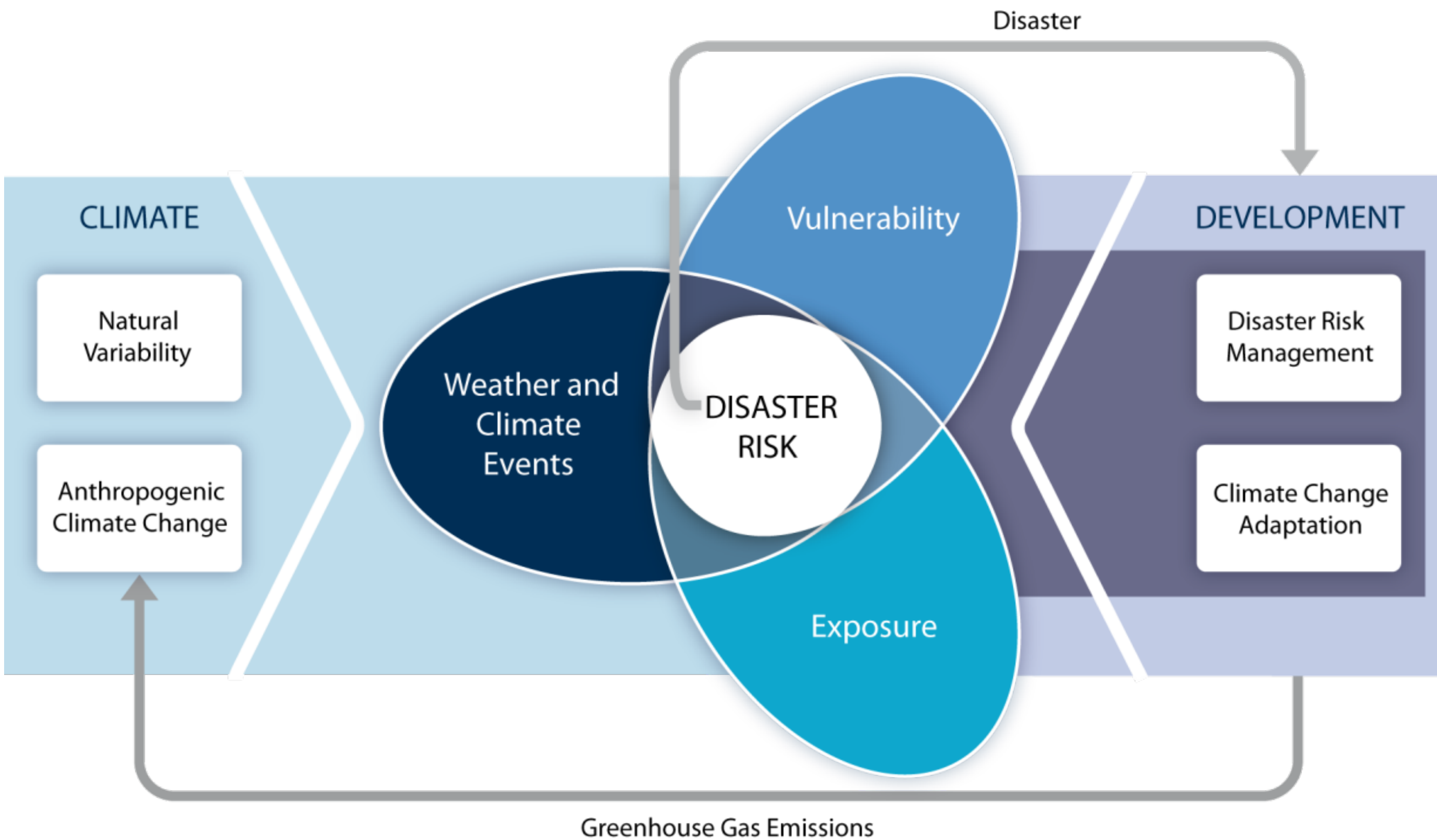
Impacts from weather and climate events depend on:

nature and severity of event

vulnerability

exposure

Increasing vulnerability, exposure, or severity and frequency of climate events increases disaster risk



*Disaster risk management and climate change adaptation can influence the degree to which **extreme events translate into impacts** and **disasters***

Effective risk management and adaptation are tailored to local and regional needs and circumstances

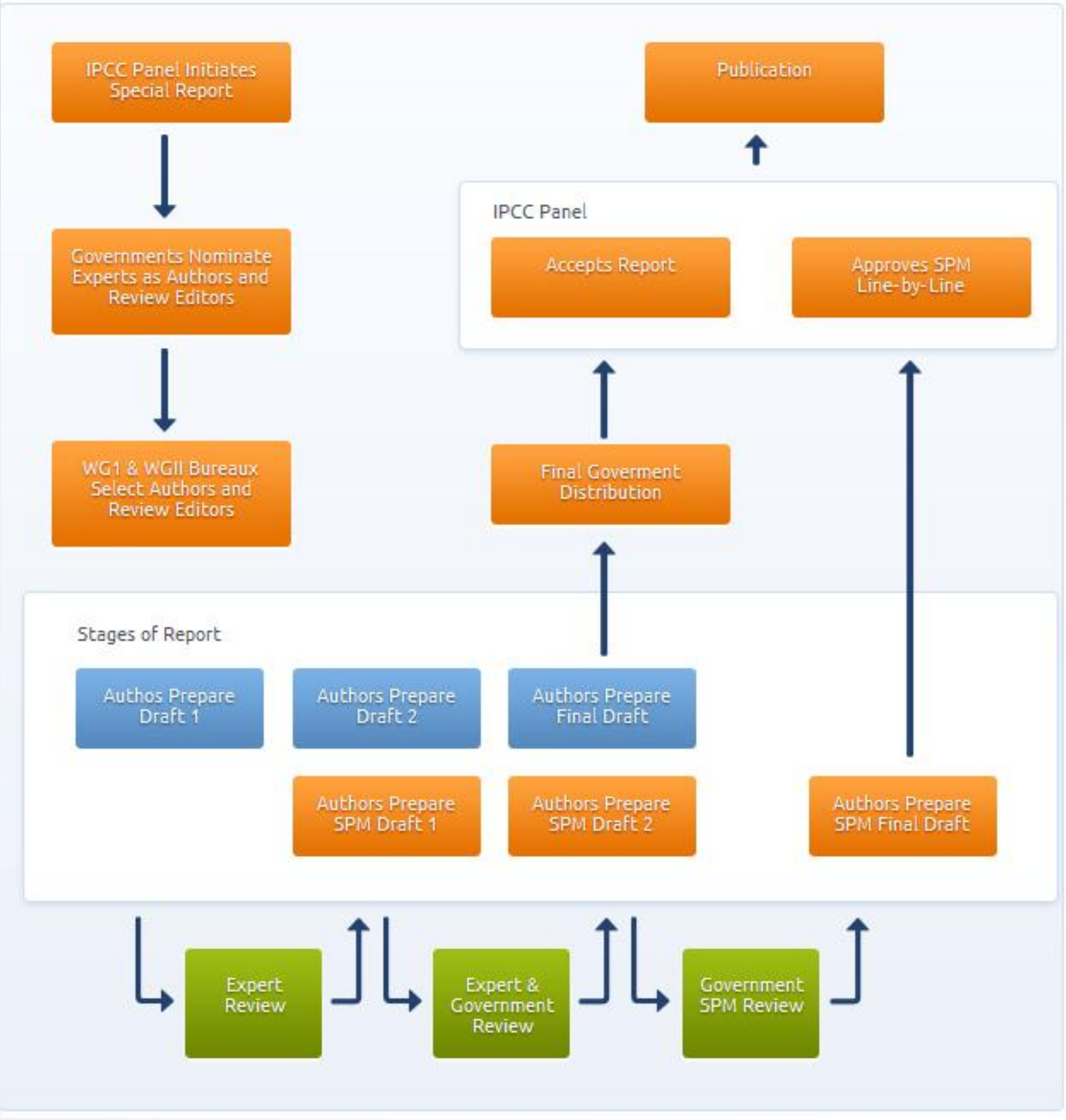
- Changes in climate extremes vary across regions
- Each region has unique vulnerabilities and exposure to hazards
- Effective risk management and adaptation address the factors contributing to exposure and vulnerability

INTERGOVERNMENTAL PANEL ON climate change

There are strategies that can help manage disaster risk now and also help improve people's livelihoods and well-being

The most effective strategies offer development benefits in the relatively near term and reduce vulnerability over the longer term

IPCC Assessment Reports: The Process



Thank you

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