Communicating Climate Science and Uncertainty Through Scenarios and Integrated Regional Modeling

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For

National Weather Service Field Staff

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Acknowledgements

- Numerous colleagues including Jae Edmonds, Leon Clarke, Allison Thomson, Jennie Rice, Stephen Unwin, Michael Scott, Elizabeth Malone, John Weyant, Tom Wilbanks, Ken Kunkel, Adam Parris, Holly Hartman, Kathy Jacobs, Gary Yohe
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Climate science challenge: not "prediction" but gaining insight into an unpredictable future

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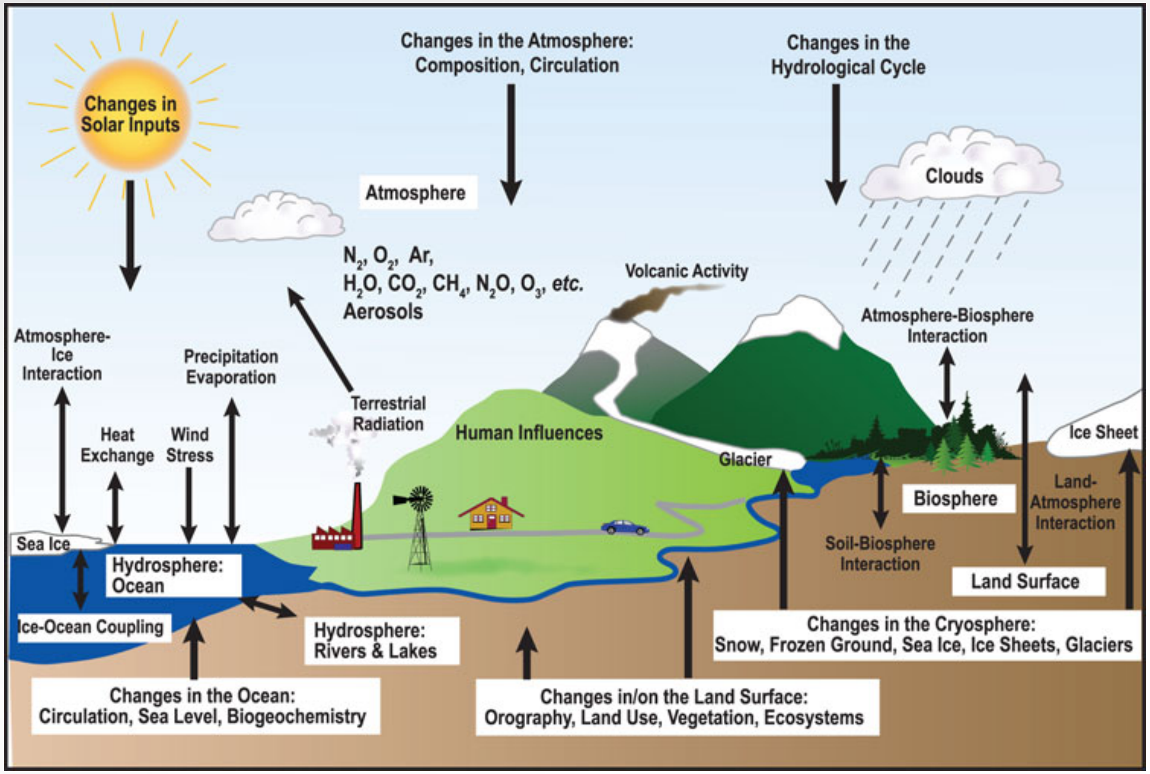
- Human choices are driving change, e.g., regarding
  - Population
  - Economics
  - Technology
  - Institutions
  - ...
- Scenarios provide "if-then" insights into the future for emissions, climate, impacts, and responses
- Climate *projections* are possible but challenging
  - Natural variability
  - Numerous processes
  - Many parameterizations
- Climate process research and modeling are foundation for projections



Credit: USGCRP

Climate science depends as much on social science as natural science

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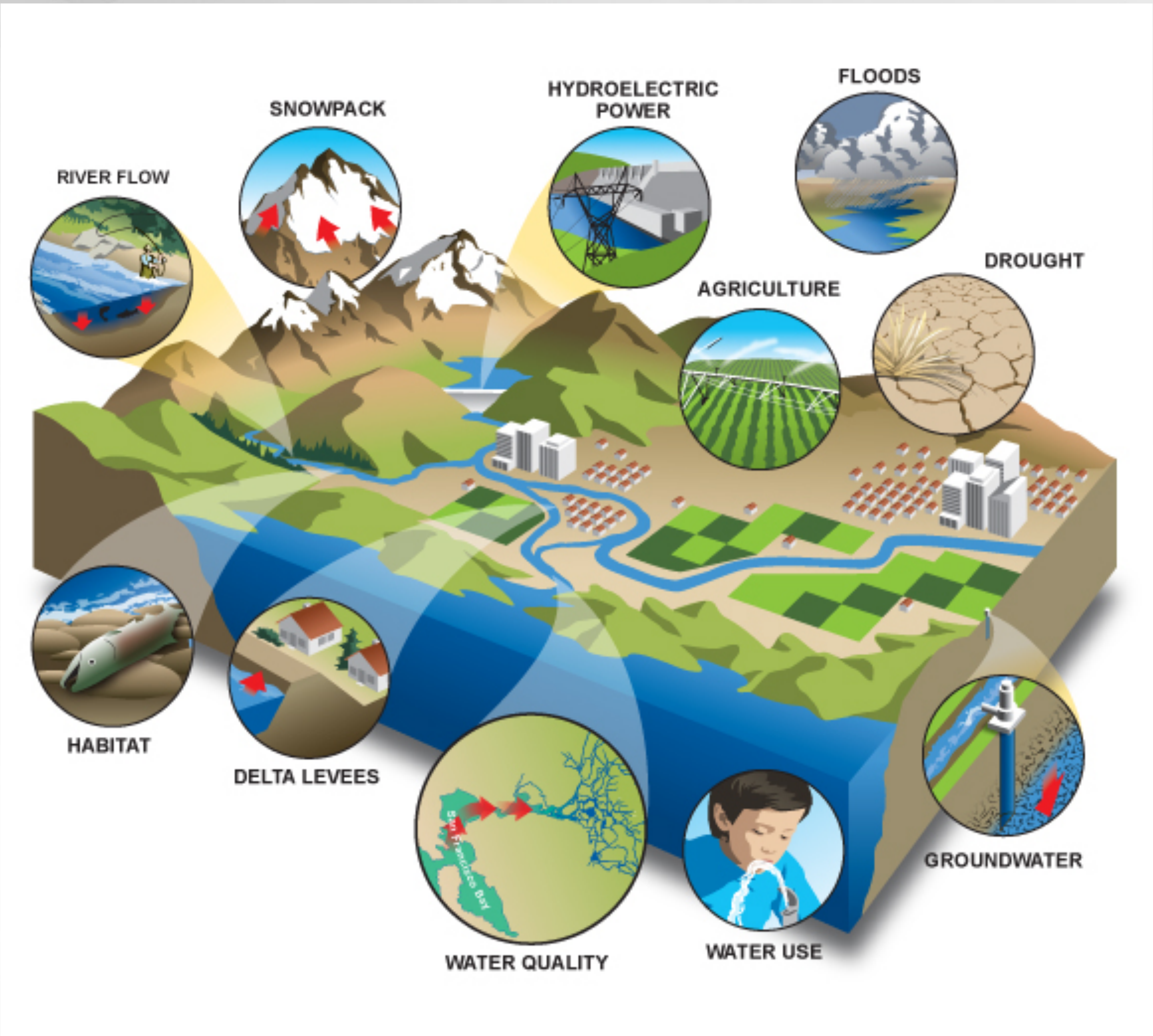
- Drivers
- Resource use and scarcity
- Exposure
- Sensitivity
- Adaptive capacity
- Capacity for mitigation
- Decision making under uncertainty and risk management



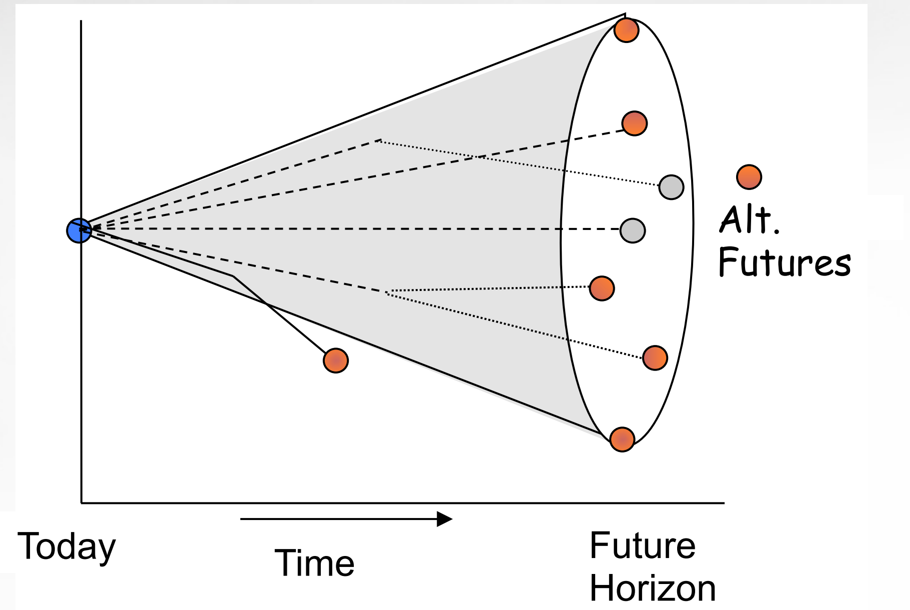
Theme and topics

- Theme: creative uses of scenarios and models will improve application of science in decision support

1. Traditional use of scenarios
2. New scenario process for research and IPCC
   - Socioeconomic futures
3. US National Climate Change Assessment scenarios
   - Participatory process – bridging communities of practice
4. Integrated regional modeling for adaptation and mitigation
   - Stakeholder driven uncertainty characterization

What are scenarios and why use them?

- 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.



Historical perspective on emissions scenarios for climate research

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- Early period: instantaneous 2x (or 4x) CO_2 concentrations.
- Initial period of 1990s: transient increase (1%/yr).
- 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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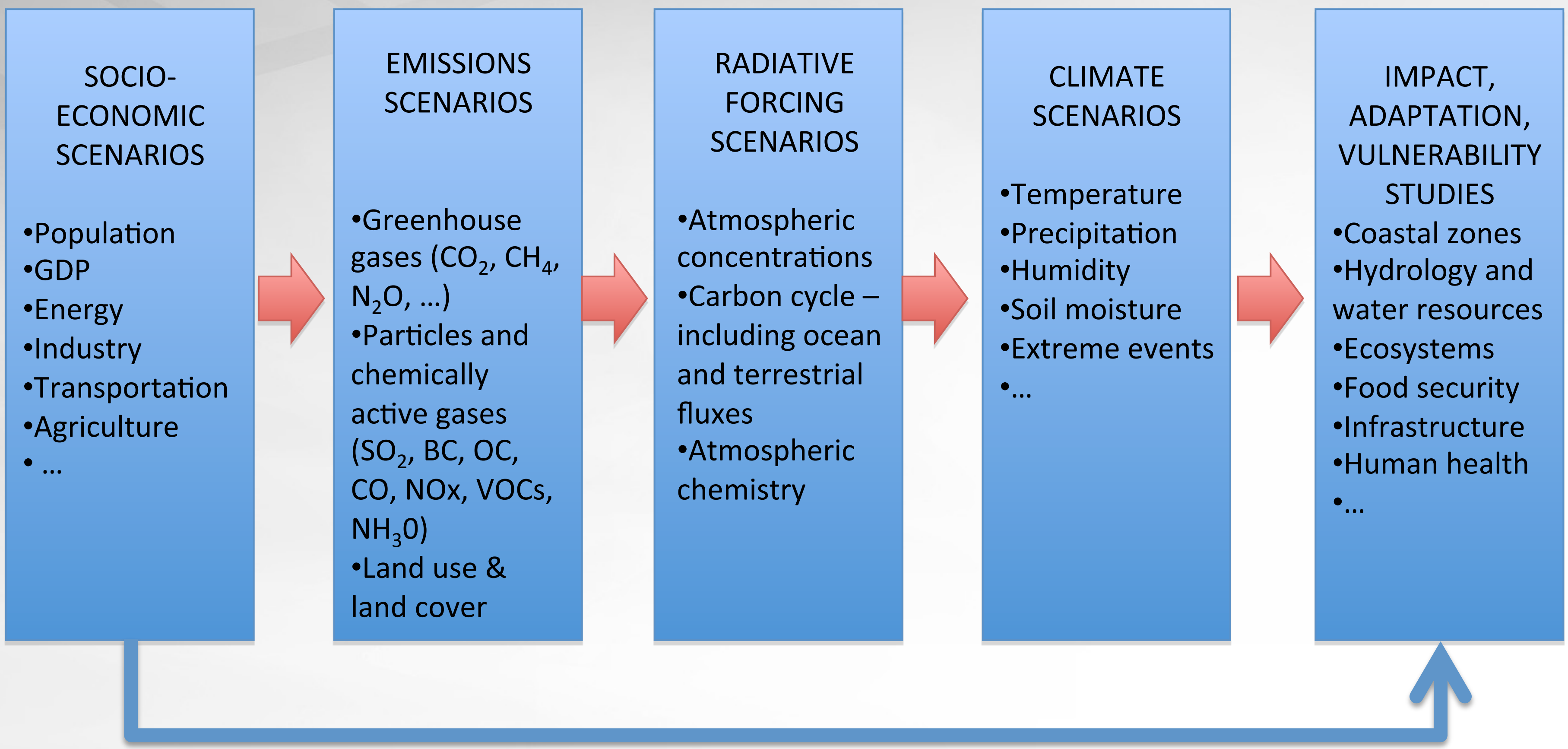
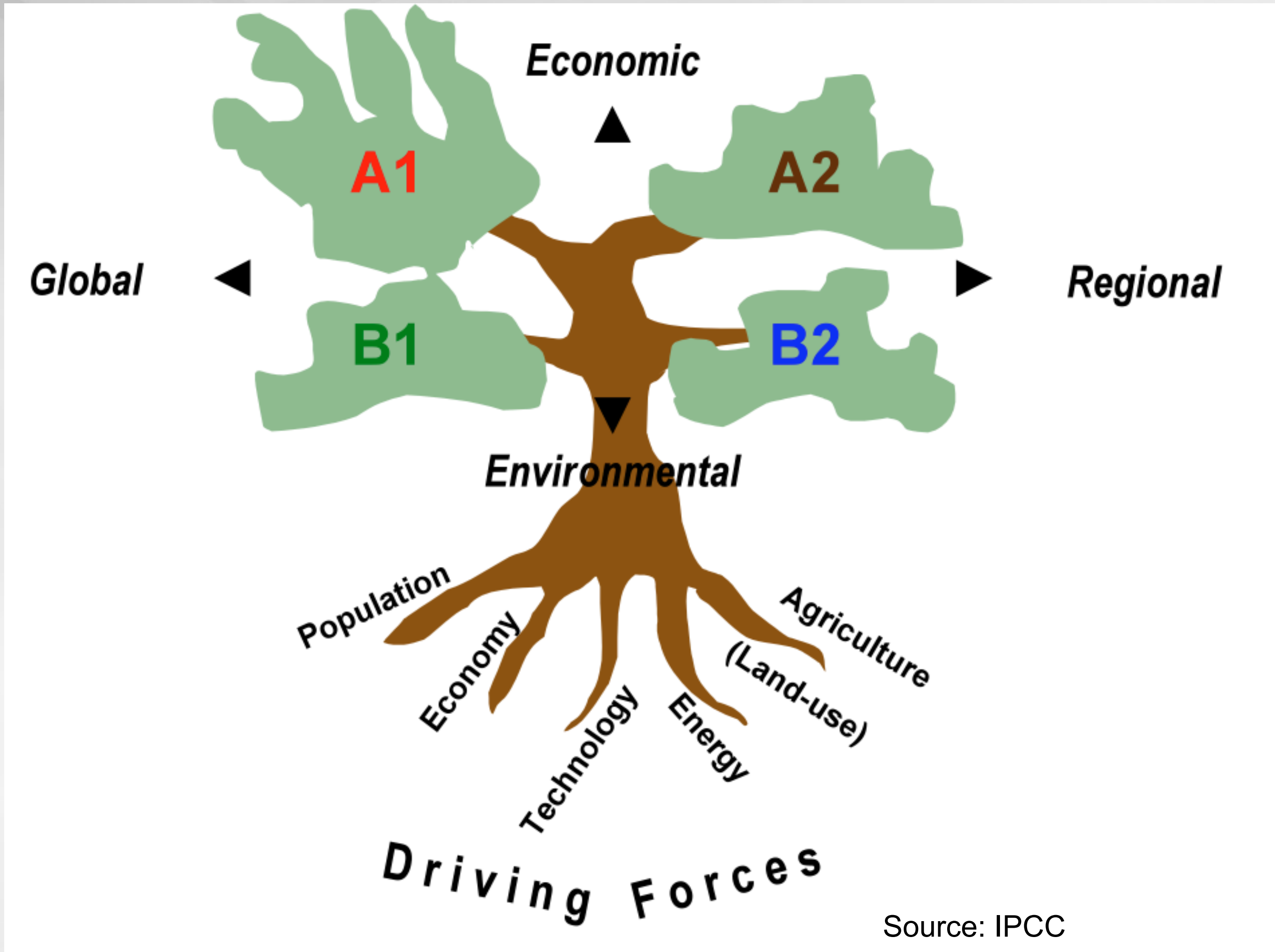


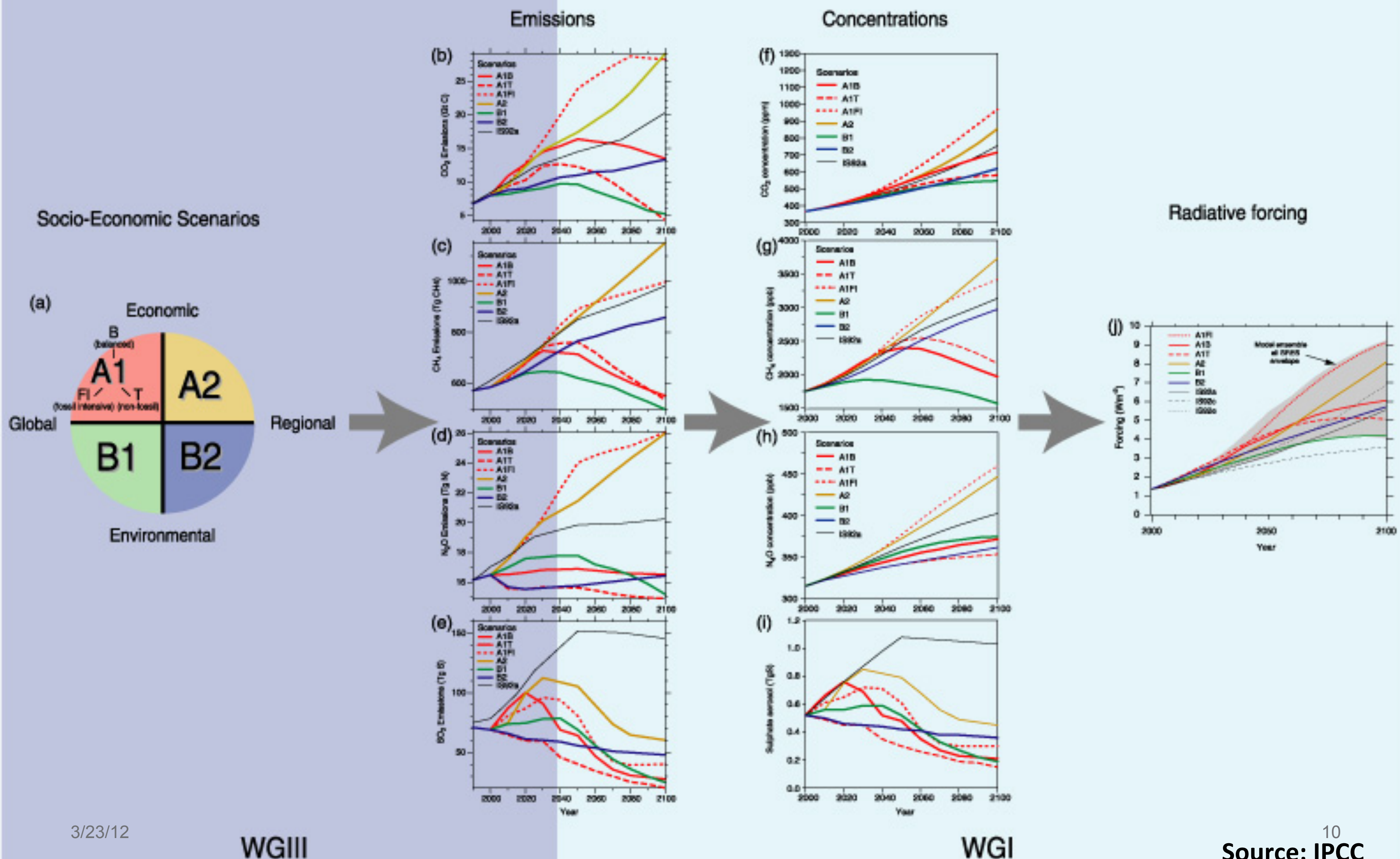
Source: Moss et al. 2010

Schematic illustration of SRES logic



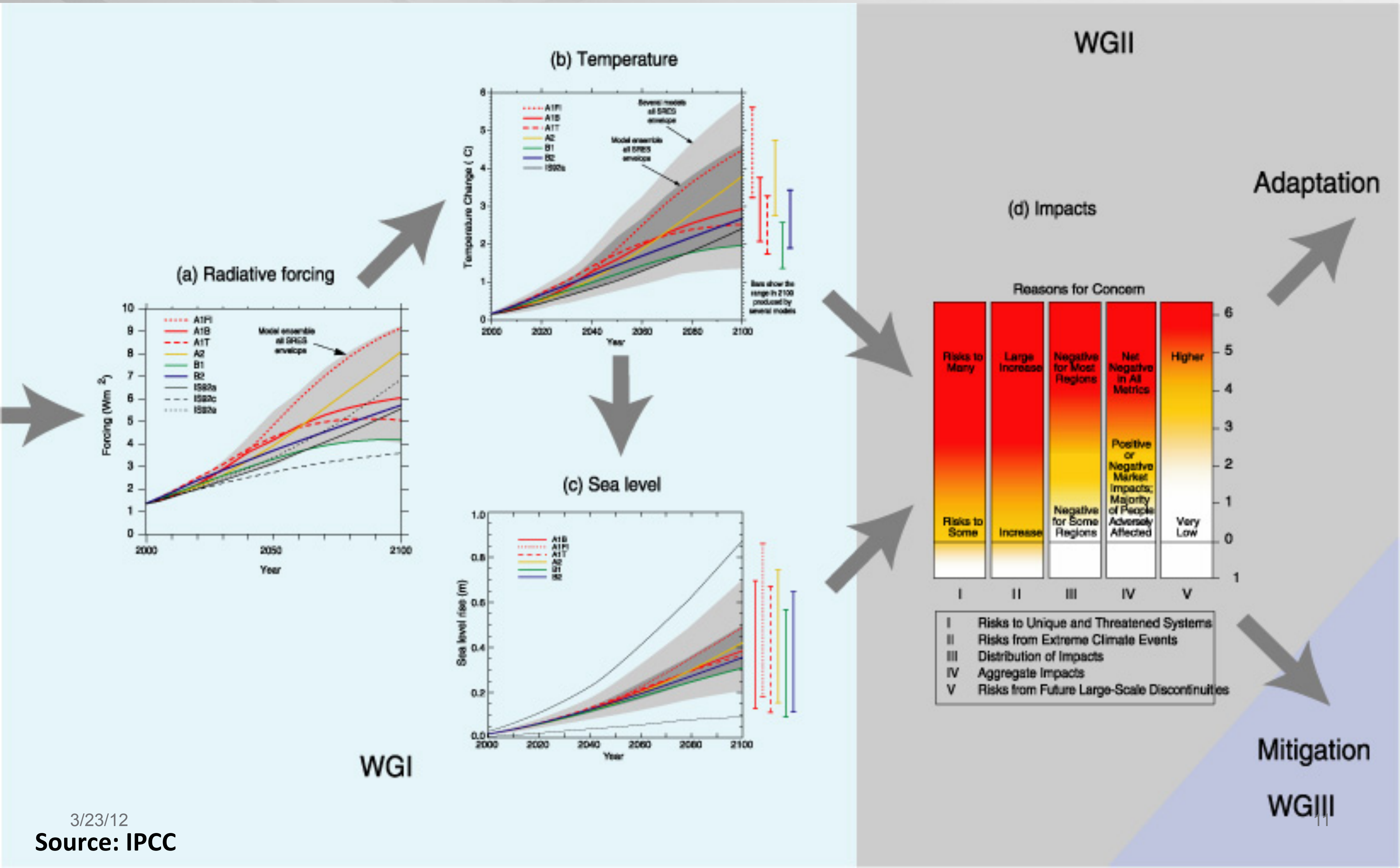
Source: IPCC

Narratives to radiative forcing



Source: IPCC

Radiative forcing to impacts and responses



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"

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Integrated Analyses

Mitigation, adaptation, impacts

Current task

Socioeconomic pathways

Vulnerability: exposure, sensitivity, adaptive capacity

Emissions drivers, mitigative capacity

Ongoing (CMIP5)

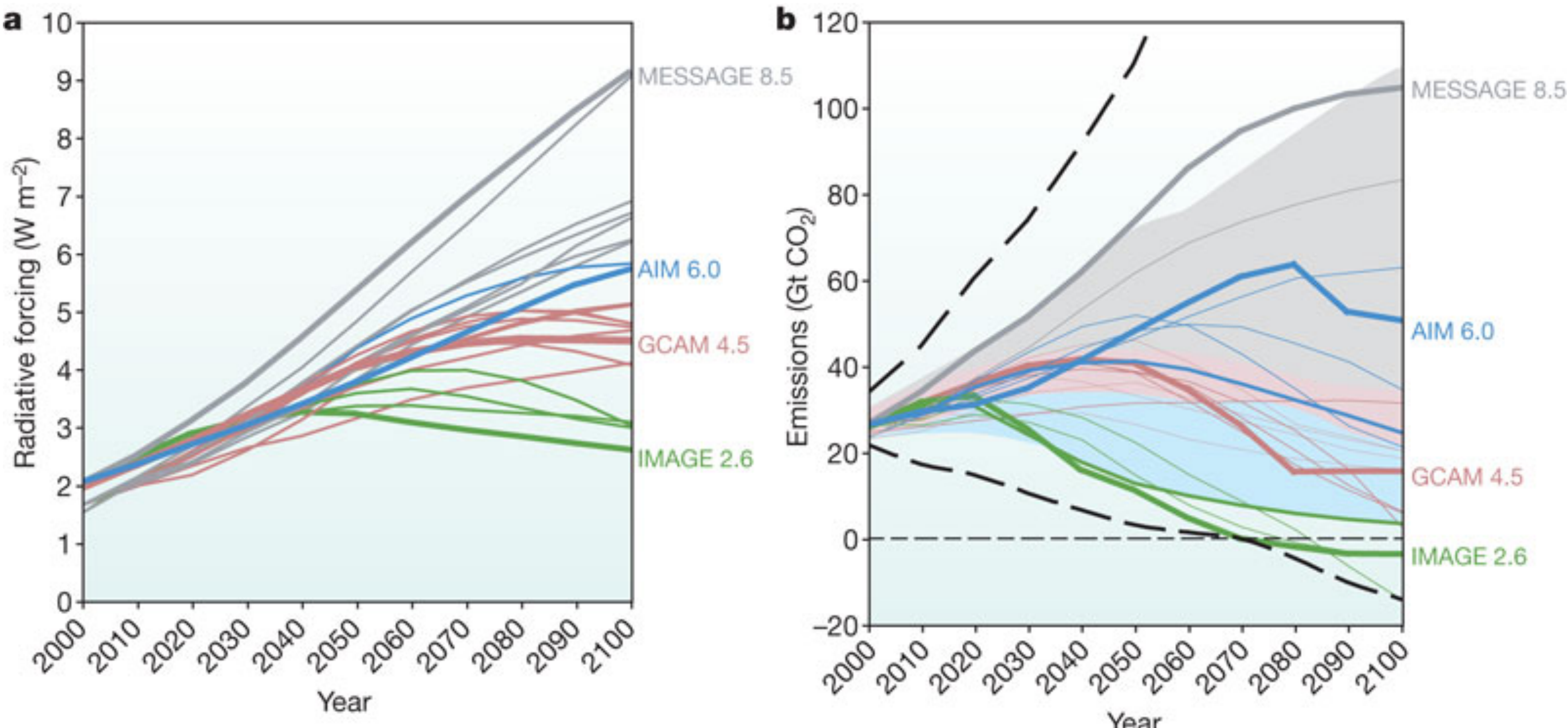
Earth System Model Simulations

Climate change, climate variability

Representative Concentration Pathways

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

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, 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)**

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

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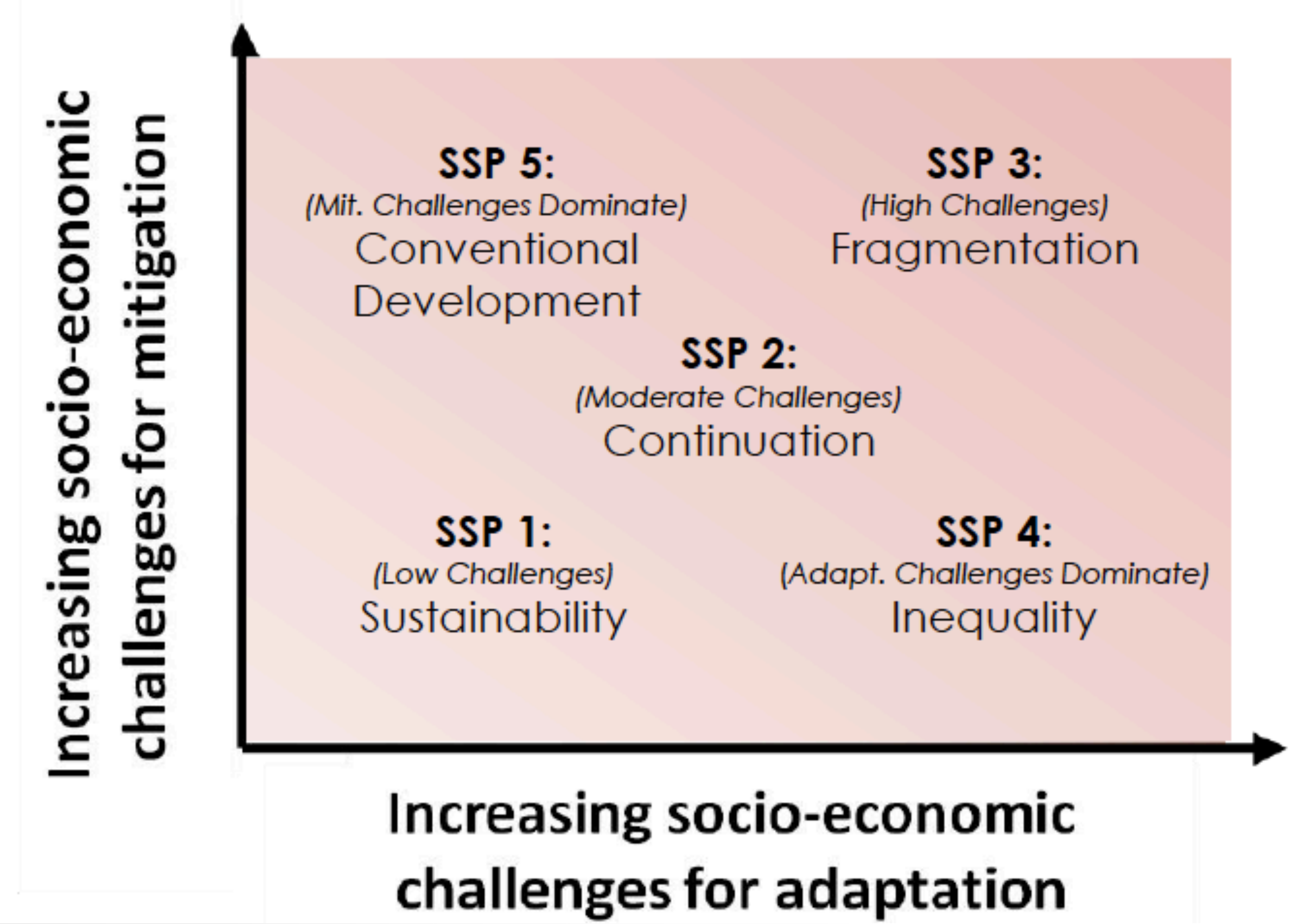

Adaptation challenges

↓

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.

An approach: framing scale, development pathway, 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 *"Low challenges to mitigation and adaptation."*	-A shock derails initial positive trends -Economic, population, and environmental collapse -Highly inequality both within and across countries *"High challenges to adaptation and low challenges to mitigation."*	-Sustained social progress -Rapid market-oriented economic growth -Moderate pop growth -Conventional (fossil) fuels dominate *"High challenges to mitigation and low challenges to adaptation."*	-Stagnation -Sporadic economic growth -Apathy about the less fortunate and the environment - Mixed technological progress *Mid-range challenges to adaptation and mitigation."*	-Traditional cultural values and life styles -High pop growth -Good economic growth -Engineered ecosystems -Social cohesion *"Mid-range challenges to adaptation and mitigation."*	-Mired in problems -High population growth, low migration - Slow economic growth -Conventional technologies -Resource competition -Slow diffusion of technology *"High challenges to mitigation and adaptation."*

Application in impacts research: nested scenarios – working across scales

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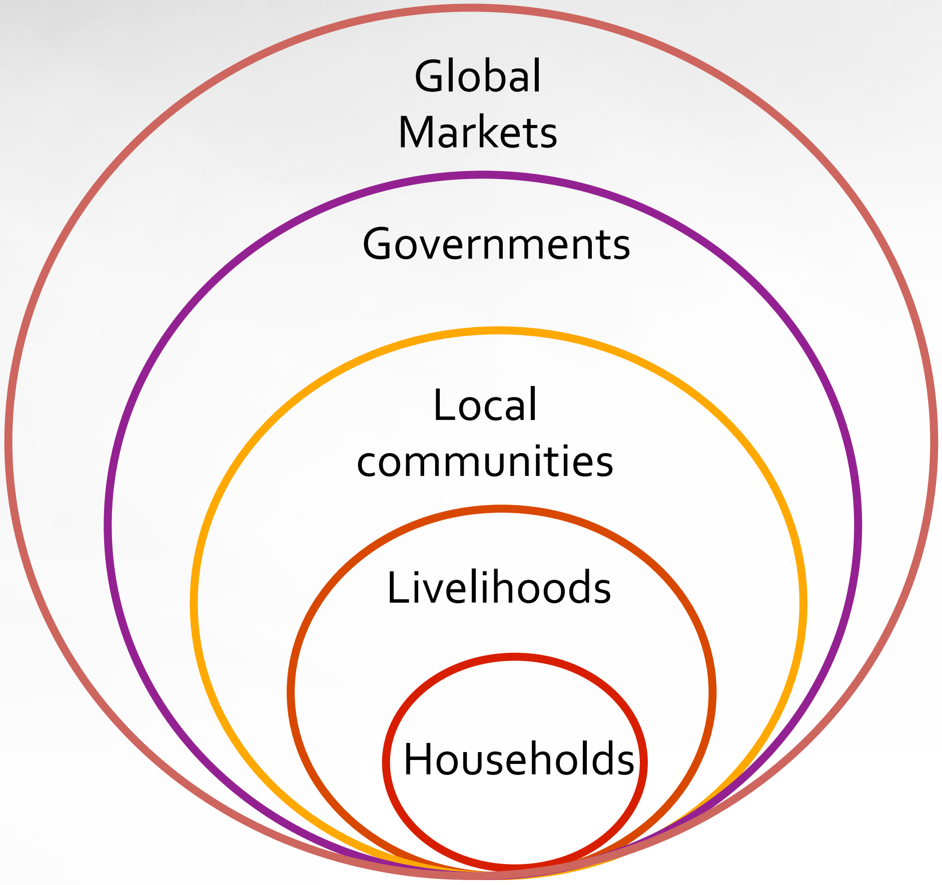
- Finer scale information needed for IAV research
- Downscaling
- IAV analysts develop scenarios nested within global set
  - Greater credibility, legitimacy, and salience
  - Based on detailed local knowledge
- "Place-based" scenario process for developing local scenarios consistent with SSPs
- Degree of coupling can vary from global to local



Scenarios in US National Climate Assessment

US National Climate Assessment and its use of scenarios

- Mandated by US Global Change Research Act, due in 2013.
- Long-term goal: establish an ongoing, distributed process.
- Uses of scenarios:
  - Provide context of range of potential future conditions.
  - Calibrate sensitivity studies.
  - Establish common assumptions for modeling.
  - Engage participants.
- Types of scenarios:
  - Four types of scenarios using existing resources based on SRES A2 and B1 scenarios:
    - Climate (Kunkel et al.)
    - Sea level (Parris et al.)
    - Land use (EPA) and
    - Socioeconomic (Census and EPA).
  - Participatory scenario planning: inventory and pilot studies.

Climate information: wide range of sources, data

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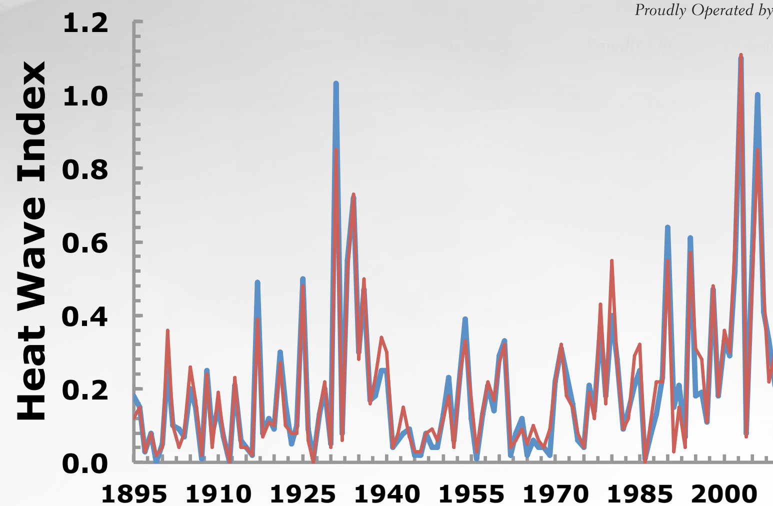
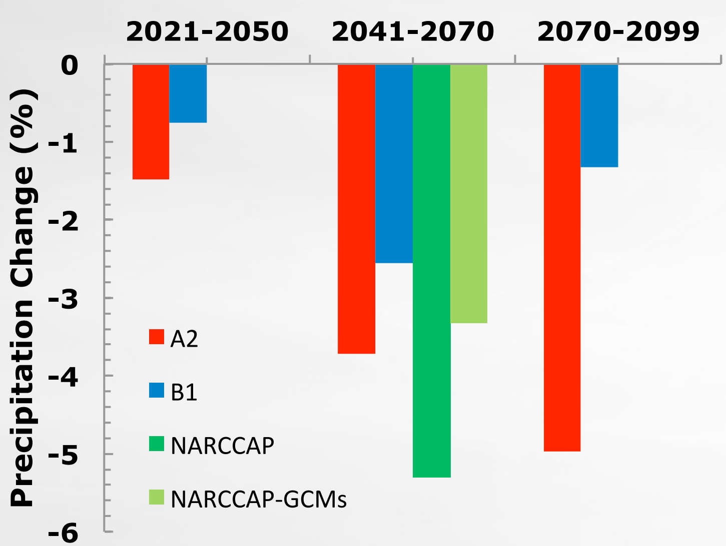
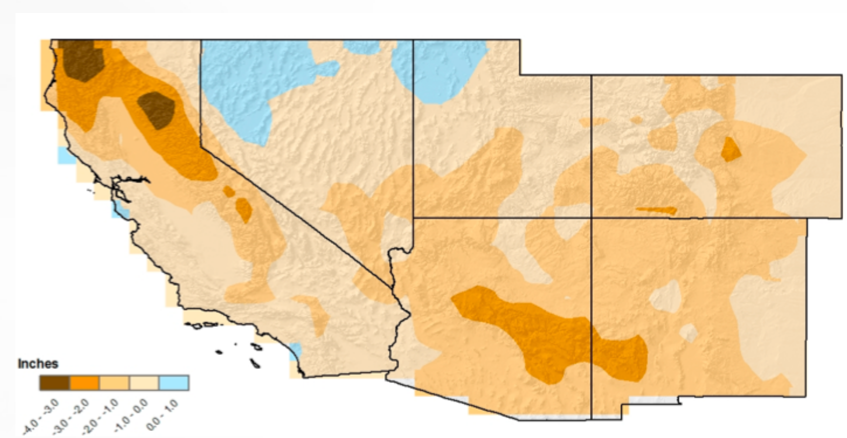
- **Narrative description** (GCMs, RCMs, climate process studies, observations)
- **Maps of mean annual temperature and precipitation.**
- **Major climatic factors, e.g., drought, heat waves, winter storms, flash floods.**
- **Trends, e.g.,:**
  - Seasonal and annual temp and precip;
  - Precipitation extremes (daily 5 year storms);
  - Temperature extremes (4 day, 1 in 5 year events);
  - Freeze-free season length.





NARCCAP, Change in Annual Precipitation 2041-2070 minus 1971-2000



National Climate Assessment
U.S. Global Change Research Program

Socioeconomic and land use data and scenarios

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PNAS

National housing and impervious surface scenarios for integrated climate impact assessments

Britta G. Bierwagen[a], David M. Theobald[b,1], Christopher R. Pyke[c], Anne Choate[d], Philip Groth[d], John V. Thomas[e], and Philip Morefield[a]

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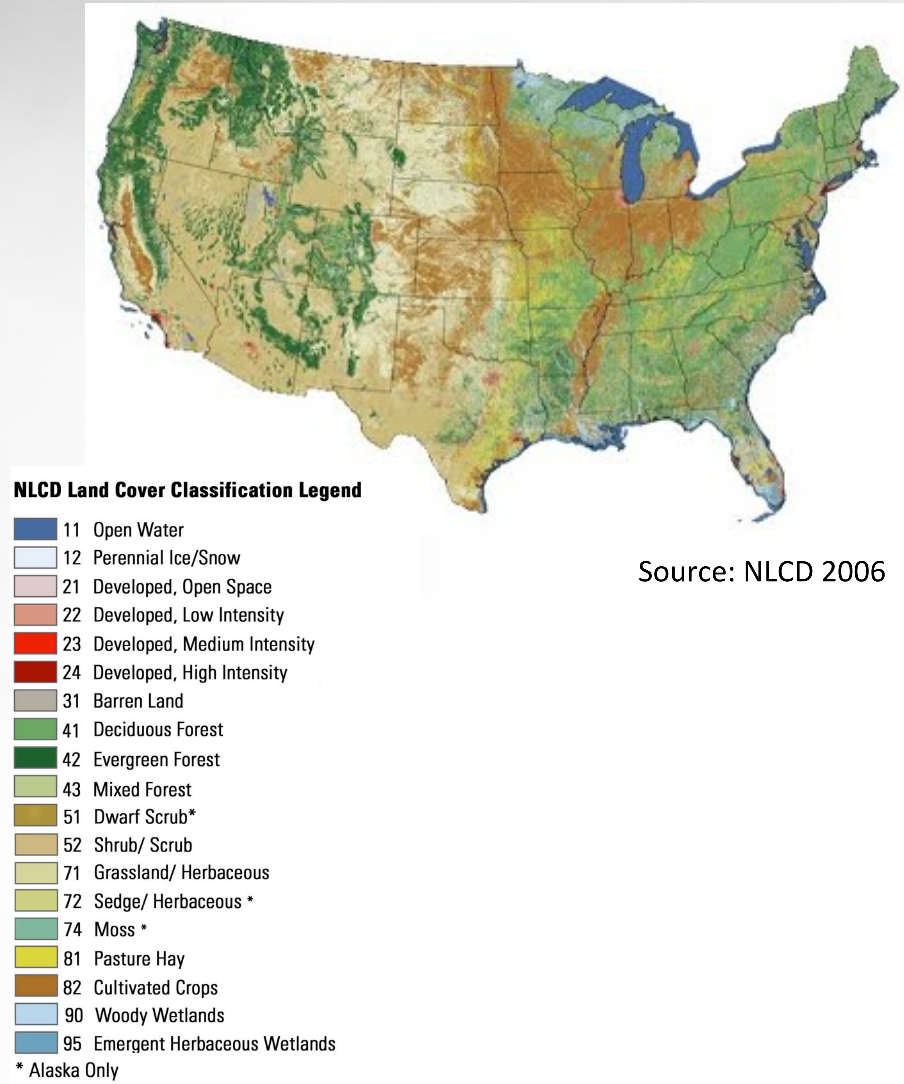
- Based on story lines derived from SRES scenarios A1, A2, B1, and B2.
- Base-case scenario consistent with the U.S. Bureau of the Census midline U.S. population.
- Projections to 2100 using:
  - A county-scale demographic model; and
  - Spatial allocation model to distribute projected population into housing units across the landscape at 1 ha scale.
- Geospatial data for conterminous U.S. available through a Web interface.



Source: NLCD 2006

National Climate Assessment
U.S. Global Change Research Program

Participatory scenario planning

- Group visioning and planning process
  - Systematic and creative evaluation of implications of uncertain forces.
  - E.g., National Park Service (with Global Business Network), Western Lands and Communities, Wildlife Conservation Society, Army Corps of Engineers, Tucson Water, ...
- 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.
  4. Assess implications for decision making.
  5. Document and evaluate the process.

NCA participatory scenario pilot studies

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Bring climate change into an existing process

- Participants conduct planning/visioning and consider ability to achieve objectives under two scenarios.
  - "*The Best Chance You'll Get*" – "B1 world": low climate change, slow population growth, high per capita GDP, high environmental concern, compact urban areas, less disruption of ecosystems.
  - "*Big Problems, Low Capacity*" – "A2 world": high climate change, high population growth, slow economic development, low environmental concern, sprawling urban development, more disruption of ecosystems.
- In second stage, participants explore adaptation *strategies* (not just technologies) for A2 conditions.

National Climate Assessment
U.S. Global Change Research Program

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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

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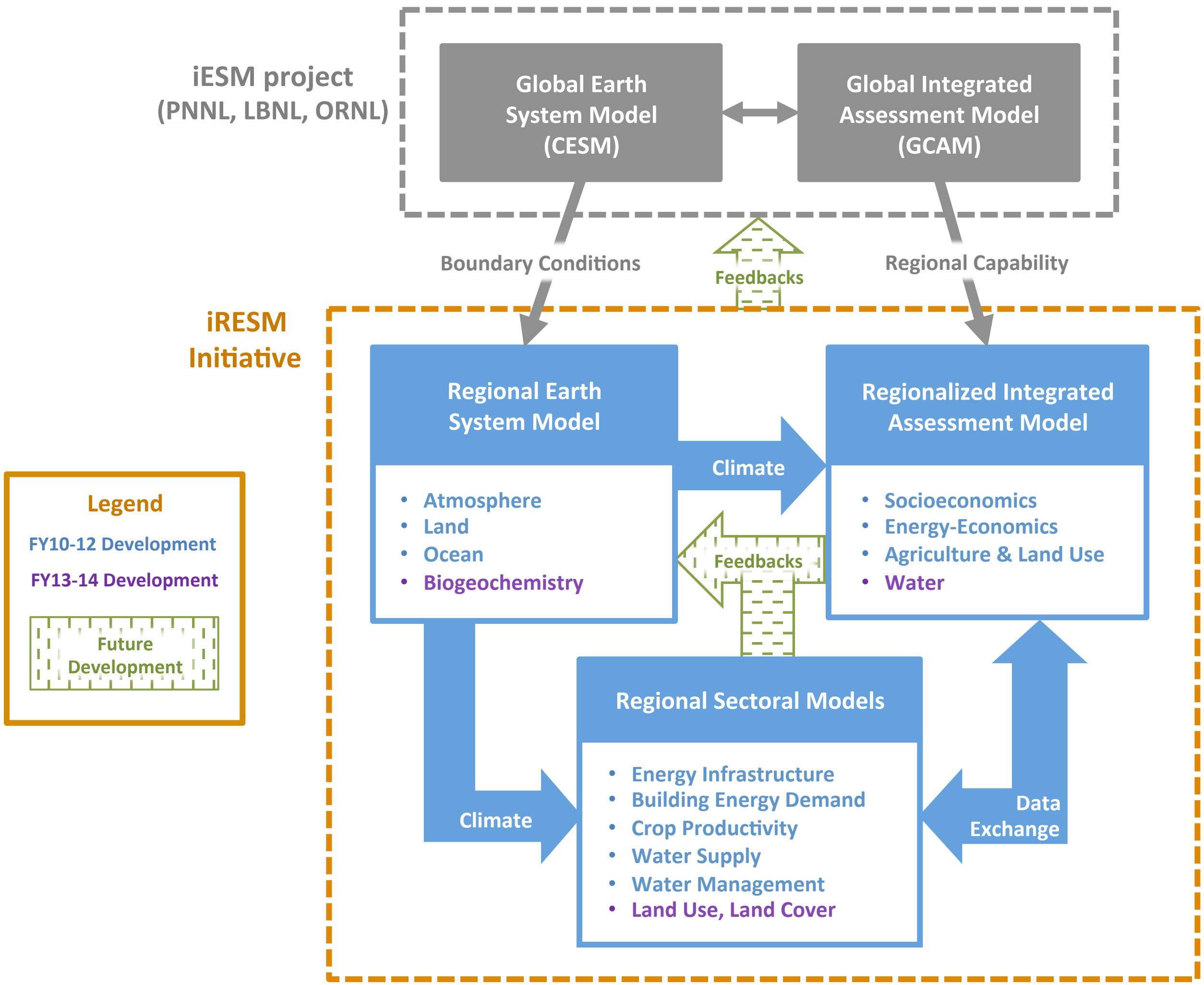
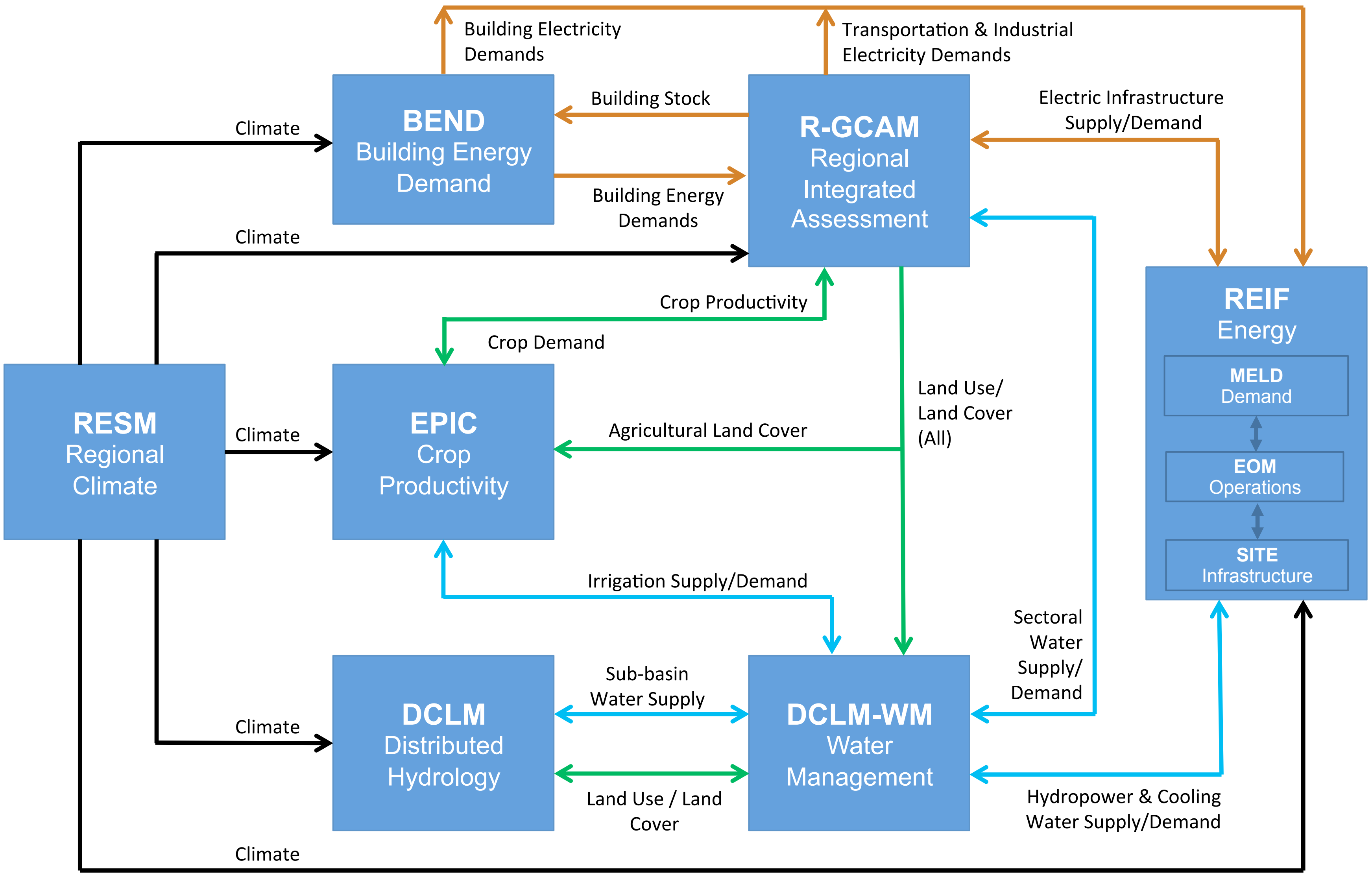


Key Attributes:

- 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

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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

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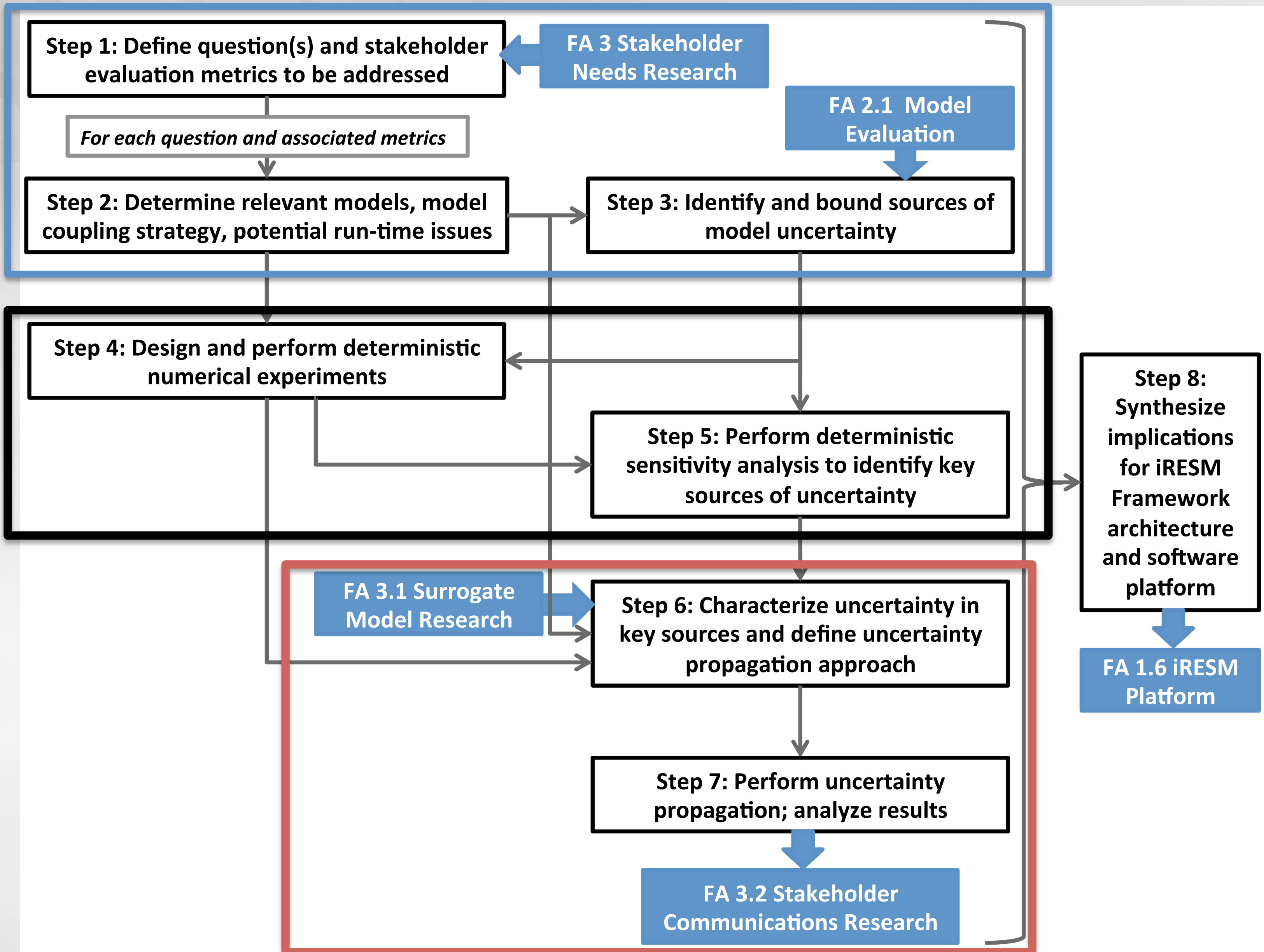
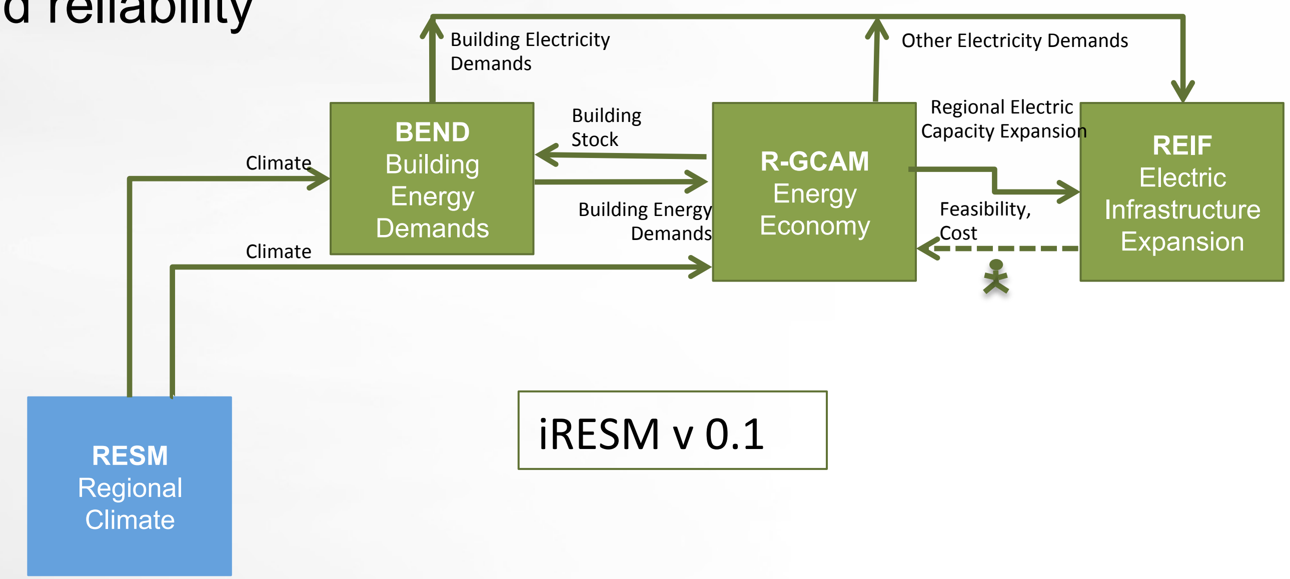


Example of decision support process

- 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



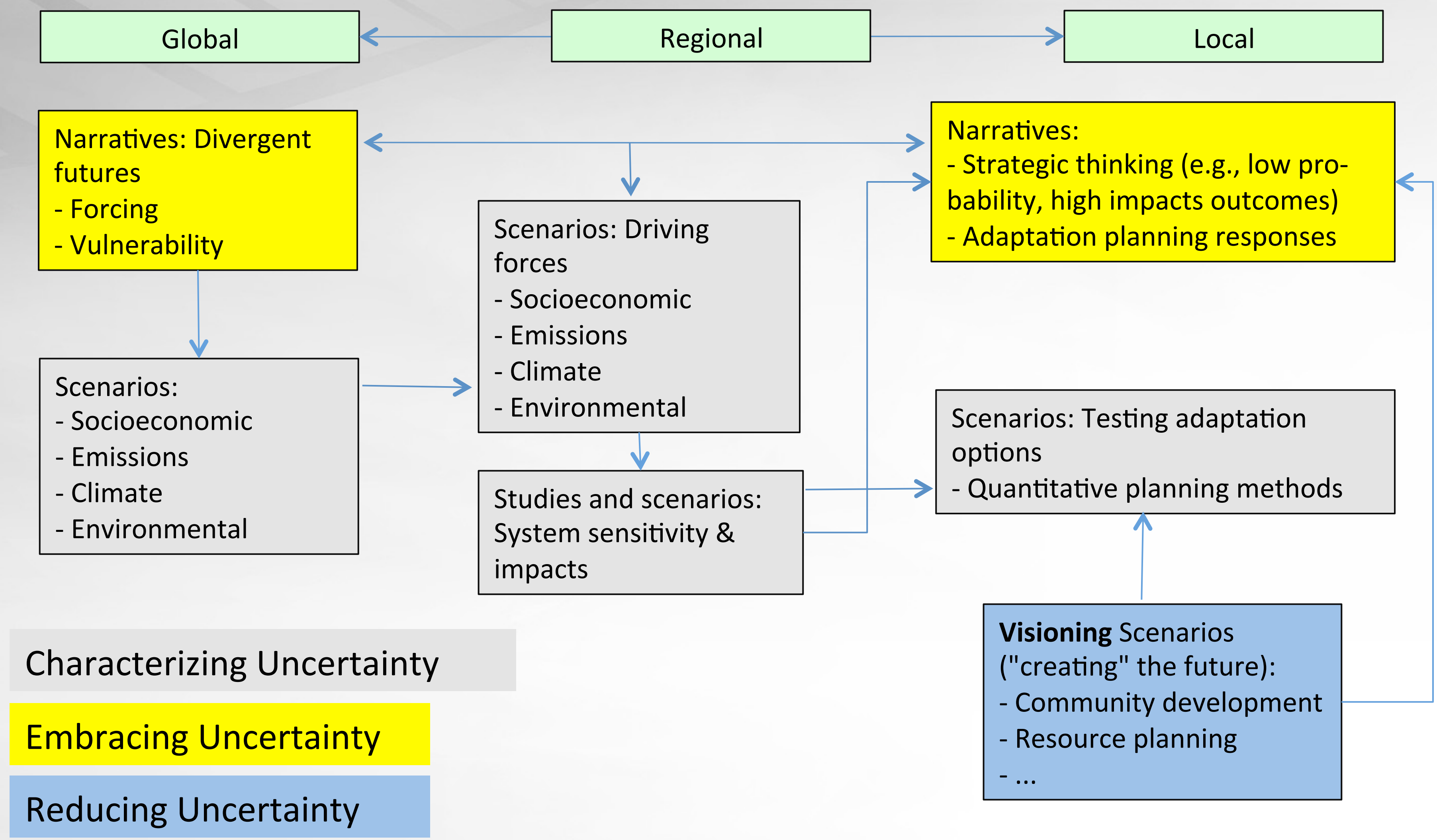
Need for development of UC methods for scientific insight and decision support

- Estimated runtimes for integrated models can be long, with implications for UC
- A flexible architecture and, for many applications, surrogate models for selected components, 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
- USGCRP Interagency Group on Integrated Modeling has reflected this need in the draft USGCRP strategic plan

Conclusion (1)

- Development and use of scenarios in climate change research, assessment, and communication are continuing to evolve.
  - New methods for developing socioeconomic scenarios.
  - Participatory scenario planning.
  - More user friendly climate information.
  - Regional modeling with stakeholder and uncertainty analysis components.
- Evolution reflects different uses of scenarios in different communities

Conceptual relationship among different types of scenarios and their uses



Hartman and Moss, in prep.

Conclusion (2)

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- Application of these techniques in the US NCA and the IPCC is beginning, but progress will take time.
- We need to better understand what scenarios should be like to connect global change science to place-based concerns and decision making processes.

Thank you

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