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?
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?
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
- **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

- **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**

<table>
<thead>
<tr>
<th>Brief statement of conclusion, referenced to report or chapter:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Framing and stakeholder information needs</td>
</tr>
<tr>
<td>One or more types of stakeholder decisions (or uses of the information) have been considered in formulating the conclusion.</td>
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<tr>
<td>Yes</td>
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<tr>
<td>2. Initial evaluation of evidence</td>
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<tr>
<td>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:</td>
</tr>
<tr>
<td>Strong</td>
</tr>
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<td>3. Preparation of conclusion</td>
</tr>
<tr>
<td>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,</td>
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<tr>
<td>Fully</td>
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<td>4. Identification of key uncertainties</td>
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<tr>
<td>Sources of uncertainty and steps for improving the information base have been identified.</td>
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<tr>
<td>Fully</td>
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<td>5. Assessment of confidence based on evidence and agreement</td>
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<tr>
<td>In light of the potential uses of the information, a confidence level has been assigned.</td>
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<tr>
<td>High</td>
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<tr>
<td>6. Indication of how likely it is that an outcome or event will occur</td>
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<td>If you indicate how likely an event is to occur, the standardized numerical ranges and likelihood words have been used.</td>
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<tr>
<td>&gt;9 in 10 Very Likely</td>
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<td>7. Traceable account:</td>
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# National climate assessment confidence terms

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

► 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?

- 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)

- 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")
  - 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

SOCIO-ECONOMIC SCENARIOS
- Population
- GDP
- Energy
- Industry
- Transportation
- Agriculture
- ...

EMISSIONS SCENARIOS
- Greenhouse gases (CO₂, CH₄, N₂O, ...)
- Particles and chemically active gases (SO₂, BC, OC, CO, NOx, VOCs, NH₃O)
- Land use & land cover

RADIATIVE FORCING SCENARIOS
- Atmospheric concentrations
- Carbon cycle – including ocean and terrestrial fluxes
- Atmospheric chemistry

CLIMATE SCENARIOS
- Temperature
- Precipitation
- Humidity
- Soil moisture
- Extreme events
- ...

IMPACT, ADAPTATION, VULNERABILITY STUDIES
- Coastal zones
- Hydrology and water resources
- Ecosystems
- Food security
- Infrastructure
- Human health
- ...

Source: Moss et al. 2010
Socioeconomic narratives to radiative forcing
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
New scenarios: "Parallel Process"

**Current task**

*Socioeconomic pathways*

Vulnerability: exposure, sensitivity, adaptive capacity

Emissions drivers, mitigative capacity

**Ongoing (CMIP5)**

*Integrated Analyses*

Mitigation, adaptation, impacts

*Earth System Model Simulations*

Climate change, climate variability

*Radiative Forcing: Representative Concentration Pathways*

GHGs, other gases, and particle concentrations over time; land cover W/m² in 2100

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FOUR RCPs

Source: Moss et al., 2010
Forcing Agents

**GHG Emissions and Concentrations from IAMs**

- Greenhouse gases: $\text{CO}_2$, $\text{CH}_4$, $\text{N}_2\text{O}$, CFCs, HFCs, PFCs, $\text{SF}_6$
- Emissions of chemically active gases: $\text{CO}$, $\text{NO}_x$, $\text{NH}_4$, VOCs
- Derived GHGs: tropospheric $\text{O}_3$
- Emissions of aerosols: $\text{SO}_2$, 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)
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

<table>
<thead>
<tr>
<th>Scenario Characteristics</th>
<th>Pop6</th>
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<tbody>
<tr>
<td><strong>MDG+ “Sustainability”</strong></td>
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<tr>
<td>- Rapid transition to sustainability</td>
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<tr>
<td>- Social progress</td>
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<td>- Low fertility</td>
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<tr>
<td>- High int’l trade and cooperation</td>
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<tr>
<td><strong>MDG-Derailed Development</strong></td>
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<tr>
<td>- A shock derails initial positive trends</td>
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<tr>
<td>- Economic, population, and environmental collapse</td>
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<tr>
<td>- Highly inequality both within and across countries</td>
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<tr>
<td><strong>MDG+ Conventional Market-oriented Growth</strong></td>
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<tr>
<td>- Sustained social progress</td>
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<tr>
<td>- Rapid market-oriented economic growth</td>
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<tr>
<td>- Moderate pop growth</td>
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<tr>
<td>- Conventional (fossil) fuels dominate</td>
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<tr>
<td><strong>MDG-Muddling Through</strong></td>
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<tr>
<td>- Stagnation</td>
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<tr>
<td>- Sporadic economic growth</td>
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<tr>
<td>- Apathy about the less fortunate and the environment</td>
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<td>- Mixed technological progress</td>
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<tr>
<td><strong>MDG+ Hustle</strong></td>
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<tr>
<td>- Traditional cultural values and life styles</td>
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<tr>
<td>- High pop growth</td>
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<tr>
<td>- Good economic growth</td>
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<tr>
<td>- Engineered ecosystems</td>
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<td>- Social cohesion</td>
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<tr>
<td><strong>MDG-Chaos</strong></td>
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<tr>
<td>- Mired in problems</td>
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<td>- High population growth, low migration</td>
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<td>- Slow economic growth</td>
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<td>- Conventional technologies</td>
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<td>- Resource competition</td>
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<td>- Slow diffusion of technology</td>
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Application in user-driven impacts research: nested scenarios – working across scales

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
Scenarios in US National Climate Assessment
US National Climate Assessment and its use of scenarios

- 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
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

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
Conceptual relationship among different types of scenarios and their uses

Global

- Narratives: Divergent futures
  - Forcing
  - Vulnerability

Regional

- Scenarios: Driving forces
  - Socioeconomic
  - Emissions
  - Climate
  - Environmental

- Studies and scenarios: Climate & impacts

Local

- Narratives:
  - Strategic thinking (e.g., low probability, high impacts outcomes)
  - Adaptation planning responses

- Scenarios: Testing adaptation options
  - Quantitative planning methods

- Visioning Scenarios
  - "creating" the future:
    - Community development
    - Resource planning
    - ...

Characterizing Uncertainty

Embracing Uncertainty

Reducing Uncertainty

Hartman and Moss, in prep.

Richard Moss, Joint Global Change Research Institute
Stakeholder driven uncertainty characterization in regional modeling
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.”
Key Attributes:
- Open source
- Flexible and modular
- Capable of simulating interactions and resolving impacts at high resolution
- Uncertainty characterization for stakeholder questions and issues
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 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
**Key iRESM model outputs from stakeholder perspective:**

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

Step 1: Define question(s) and stakeholder evaluation metrics to be addressed

For each question and associated metrics:

Step 2: Determine relevant models, model coupling strategy, potential run-time issues

Step 3: Identify and bound sources of model uncertainty

Step 4: Design and perform deterministic numerical experiments

Characterization Research

Step 5: Perform deterministic sensitivity analysis to identify key sources of uncertainty

Step 6: Characterize uncertainty in key sources and define uncertainty propagation approach

Step 7: Perform uncertainty propagation; analyze results

FA 3.1 Uncertainty Characterization Research

FA 3.2 Decision Support Research

FA 2.1 Model Evaluation

FA 3.1 Uncertainty

FA 1.6 Architectural Software Development

Step 8: Synthesize implications for iRESM framework architecture and software platform
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 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
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**

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**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
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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