Progress, challenges, and opportunities in IAM-ESM-IAV modeling, with emphasis on fine-scale spatial and temporal analysis of the energy-water-land system

Ian Kraucunas

EMF CCI/IA Snowmass 2016
Growing need for integrated multi-sector, multi-scale modeling to address climate IAV

Water quality breakout session: What combination of adaptation measures have the greatest promise for protecting aquatic ecosystems and associated ecosystem services in different regions from evolving vulnerability resulting from population growth, land use change, and climate change?
IAMs are increasingly seeking more explicit representations of climate impacts

Recent advances have focused on:

- Improving representations of climate IAV processes and feedbacks
- Increasing spatial and temporal resolution (e.g. subnational detail) to facilitate:
  1. regional analyses while maintaining global context and constraints
  2. coupling with higher-resolution sectoral models

Projected change in water withdrawals for electricity generation

Liu et al. (2015)
IAMs are increasingly seeking more explicit representations of climate impacts.

- There are opportunities to gain additional insights by coupling IAMs with high-resolution representations of additional sectors.
ESMs are increasingly accounting for the diverse and complex influences of human activities.

**Community Land Model (CLM)**
- **Hydrology**
  - Precipitation
  - Transpiration
  - Evaporation
  - Sublimation
  - Melt
  - Throughfall
  - Infiltration
  - Surface runoff

**Model for Scale Adaptive River Transport (MOSART)**
- **Runoff generation**
- **Irrigation water supply**

**Water Management Model (WM)**
- **Reservoir-induced fractional change in streamflow**

Hydrograph illustrates importance of simulating reservoir operations.

Voisin et al., 2013

Li et al., 2013
ESMs are increasingly accounting for the diverse and complex influences of human activities.

- Influence of downscaled land use/land cover projections from GCAM on CLM surface hydrology is comparable to the influence of climate change.

**Climate effect, RCP4.5**

**LULCC effect, RCP4.5**

Huang et al., in preparation.
Coupling IAMs with ESMs/sectoral models can yield new insights into potential climate impacts

- GCAM coupled with CLM+
- Water deficit projected to increase more with climate change mitigation than under unconstrained climate change (largely due to increased biofuel production)
- Water deficits are significantly underestimated if computed at coarser spatial/temporal resolution

Hejazi et al., PNAS, 2015
Coupling multiple sectoral models together can likewise yield improved IAV assessments

- Evaluated exposure to Katrina-like surges under different scenarios of storm intensity, sea level rise, and land subsidence
  - Regional climate model (WRF)
  - Hi-res storm surge model (FVCOM)
  - GIS-based exposure analysis

- New/current work:
  - Evaluate potential impacts of 0.6m sea level rise on power plant siting (CERF)

- Knowledge gap:
  - Translating exposure into impacts (both short-term and long-term)
New* multi-institution DOE-IARP project that leverages and significantly extends RIAM and PRIMA

Research Thrust Areas:
- Energy-Water Nexus
- Land Use/Cover Change
- Population Dynamics
- Framework Design and Software Engineering

* Pending successful response to review comments
Energy-Water Nexus: Could drought “break” the Western interconnection?

- 69% of generating capacity relies on fresh surface water
- Droughts in one region are typically balanced by normal or wet conditions in the other—but this may not always be the case
- Gap: tools for projecting vulnerability under different energy/climate/water scenarios

Base case:
- NW and Colorado hydrologic regions export to California
- Operating costs: $19.8 B

Drought with low hydropower:
- Larger import from Colorado River, lower import from NW
- Operating cost: $20.4 B

Drought with low hydro and thermoelectric generation:
- Unserved energy: 6%

Voisin et al., in review

July 26, 2016

Voxyx, 2010 (obs)
Representing future energy-water-climate interactions

ReEDS capacity expansion model

Water and Climate Impacts on Electricity Sector in PLEXOS Production Cost Model


Population dynamics modeling and agent-based modeling in IM³

Explore agent-based approaches for upscaling information from watershed to basin scale
Also provides mechanism for studying adaptation and other human behaviors (e.g., evolution of electric grid)

- Develop state-level and grid-scale population model for the United States
- Study influence of climate on internal migration
- Establish linkages with GCAM to study cross-sector dynamics
Community need: agree on some terminology regarding “model coupling” for IA-IAV-ESM

**Coupling (computer programming)**
From Wikipedia, the free encyclopedia

In software engineering, coupling is the manner and degree of interdependence between software modules; a measure of how closely connected two routines or modules are; the strength of the relationships between modules.

...Low coupling is often a sign of a well-structured computer system and a good design, and when combined with high cohesion, supports high readability and maintainability

<table>
<thead>
<tr>
<th><strong>FULL COUPLING:</strong> All resolved variables in both models are fully reconciled/integrated</th>
<th><strong>PARTIAL COUPLING:</strong> Some, but not all, variables are reconciled/integrated</th>
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<tbody>
<tr>
<td><strong>TIGHT COUPLING:</strong> Models/components exchange information at every time step</td>
<td><strong>LOOSE COUPLING:</strong> Models/components exchange information less frequently</td>
</tr>
<tr>
<td><strong>TWO-WAY COUPLING:</strong> Models exchange information in both directions</td>
<td><strong>ONE-WAY COUPLING:</strong> One model provides information to the other</td>
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<td><strong>HARD COUPLING:</strong> High degree of software integration (e.g., flux coupler)</td>
<td><strong>SOFT COUPLING:</strong> Low or no software integration (e.g., “sneaker-net”)</td>
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AGU Session: Multi-sector multi-scale modeling to address integrated human-Earth system dynamics

https://agu.confex.com/agu/fm16/preliminaryview.cgi/Session13689
Abstract submission deadline: 3 August 2016

Session conveners:
Ian Kraucunas, Pacific Northwest National Laboratory
Nadya Bliss, Arizona State University
Robert Vallario, U.S. Department of Energy

The integrated assessment modeling community has made efforts to fill some of these gaps by developing models that represent multiple sectors in a single modeling framework, typically with all or most sectors represented using highly aggregated methods. Increasingly, researchers from different fields are developing strategies for bringing together higher-resolution models from multiple sectors, often at regional to continental scales, to address issues that require simultaneous high-fidelity representations of multiple human and natural systems. This session will highlight the successes and challenges associated with integrated multi-sector, multi-scale modeling.
Challenges and opportunities for integrated IA-IAV-ESM-ABM approaches

- Develop more robust representations of climate *impacts* (with time-evolving vulnerability and exposure, not just hazards)
- Develop more robust representations of potential adaptation actions/options, especially human decision-making and feedbacks
- Identify key questions, dynamics, and use cases to focus on, and always be thinking about uncertainty characterization
- Understand when higher spatial, temporal, and/or process resolution is needed (versus reduced-form representations)
- Understand when full/partial, tight/loose, hard/soft coupling is needed (and define/use these terms consistently!)
- Develop more flexible, agile, and interoperable frameworks that can support all of the above
Thank you!

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