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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

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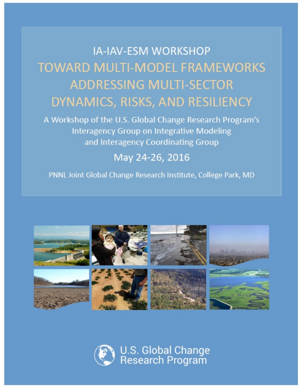


Water quality breakout session: What combination of adaptation measures have the greatest promise for protecting aquatic ecosystems and associated ecosystem services in different regions from evolving vulnerability resulting from population growth, land use change, and climate change?

Climate/Weather (precipitation extremes, also temperature)—affects most other boxes also

Water diversions, transfers

Toxic / legacy waste (e.g. in sediments)

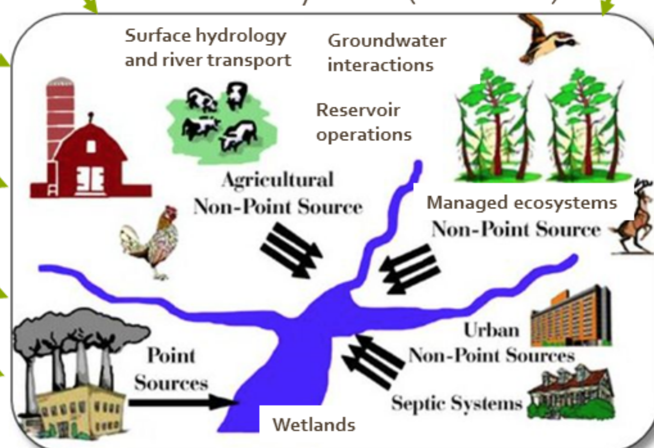
Atmospheric deposition and acidification

Agricultural practices (e.g., overfertilization, irrigation, CAFO)

Saltwater intrusion

Energy production

Water Quality Model (watershed)



Land use and land cover change

Wildfire, invasive species, and other disturbances

Changes in urban environment (e.g., green infrastructure)

Big picture drivers/influences:
Population movement
Technology changes
Socioeconomic and behavioral trends
Agricultural trends (e.g., biofuel production)
Regulatory environment

Direct metrics:
dissolved oxygen
water temperature
pH, N, P, salinity
pathogens, toxics, & pharmaceuticals
sediments

Outcome metrics:
hypoxic zones & algal blooms
ecosystem changes
fishable/boatable/swimmable
adverse health outcomes
drinking water supply

Resilience measures (some have co-benefits or primary driver is non-climatic):
Waste treatment
Water management
Conservation/recycling/fit for use water
Forest management
Green infrastructure

IAMs are increasingly seeking more explicit representations of climate impacts

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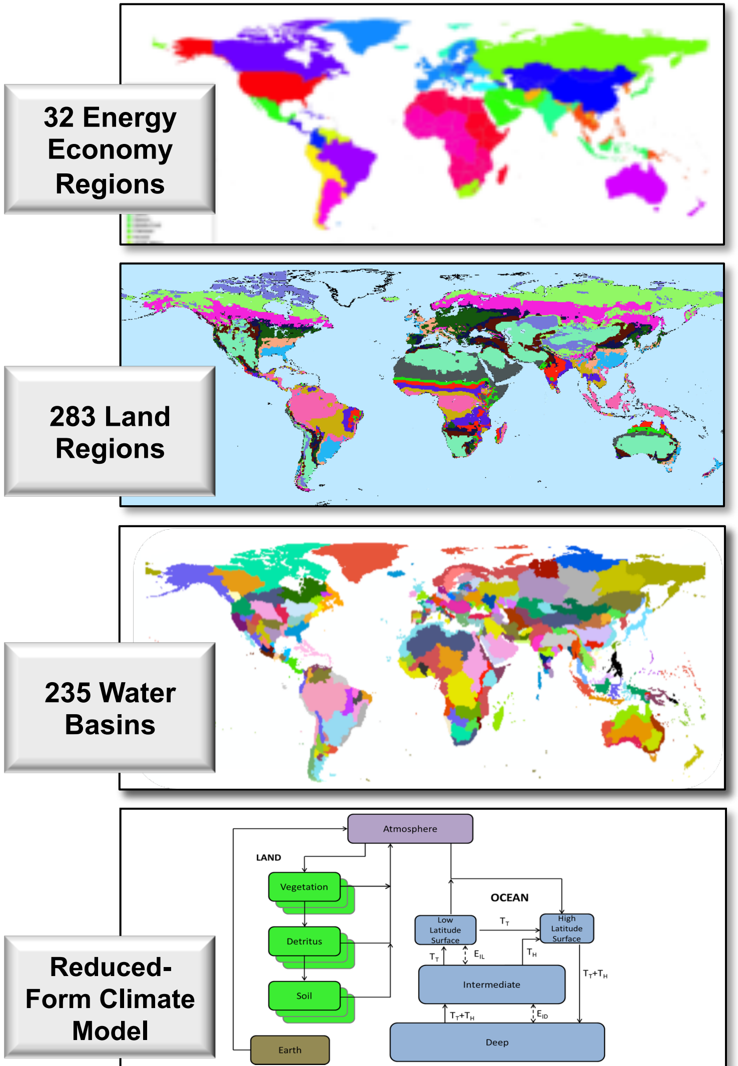
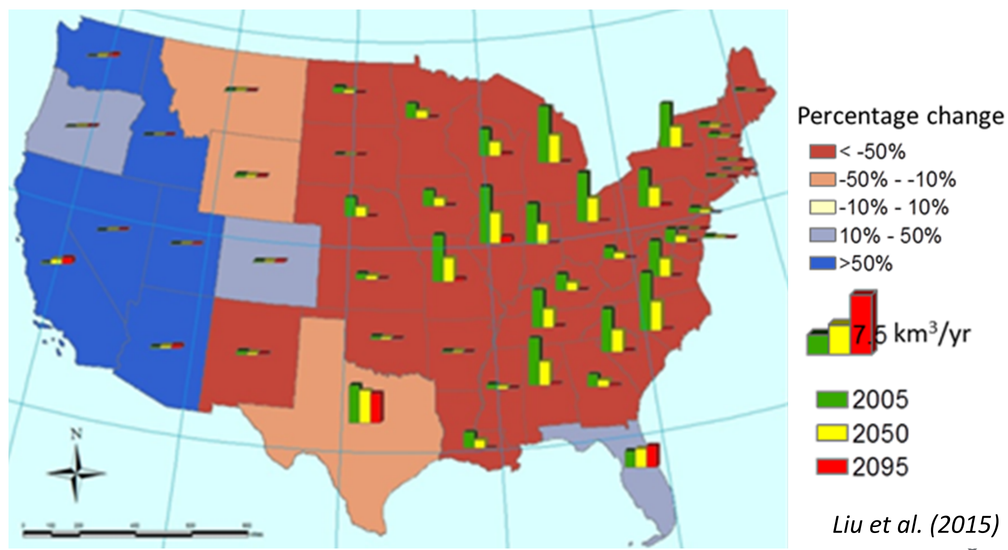
Global Change Assessment Model



Recent advances have focused on:

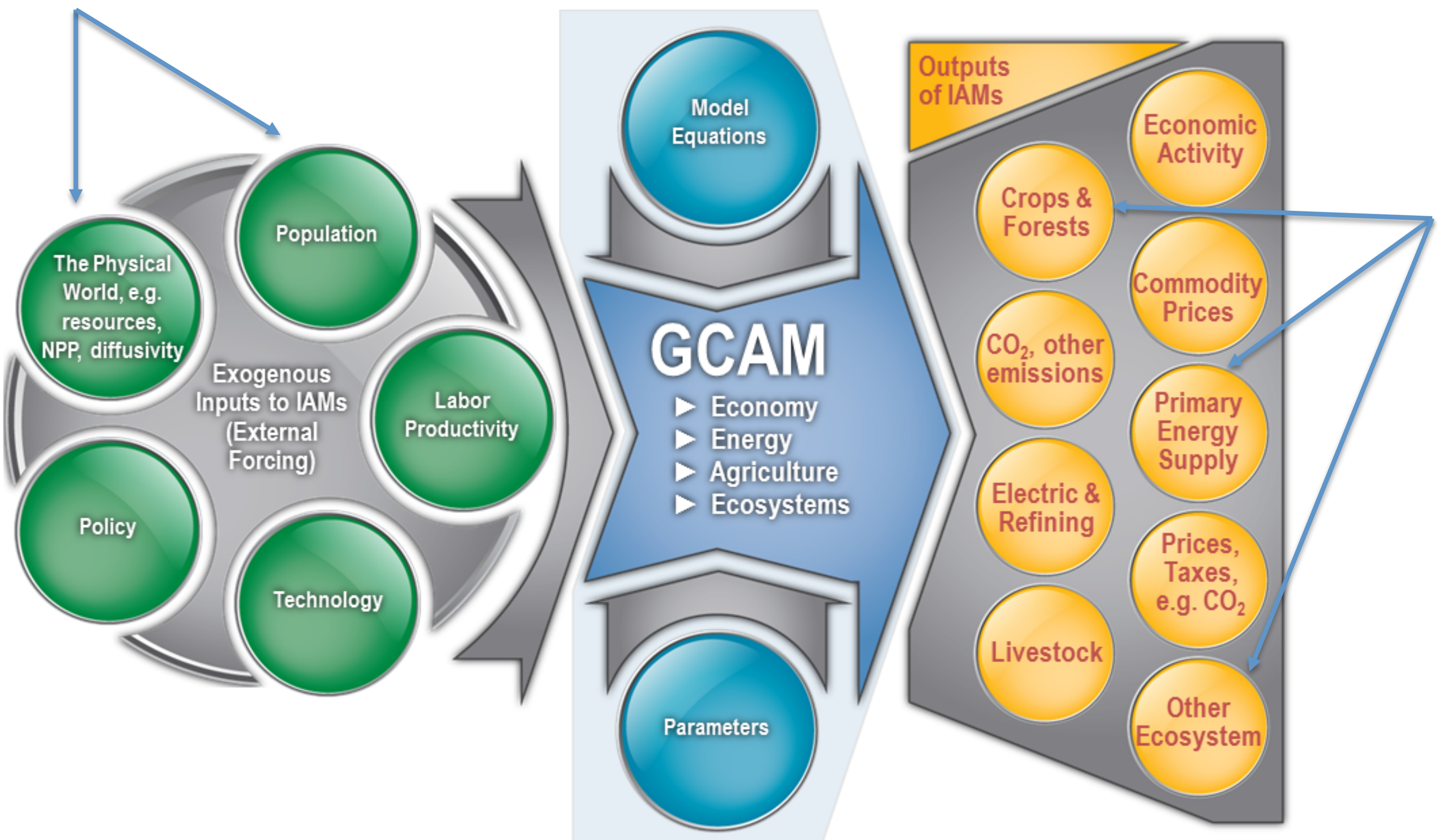
- Improving representations of climate IAV processes and feedbacks
- Increasing spatial and temporal resolution (e.g. subnational detail) to facilitate:
  (1) regional analyses while maintaining global context and constraints
  (2) coupling with higher-resolution sectoral models



Projected change in water withdrawals for electricity generation

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

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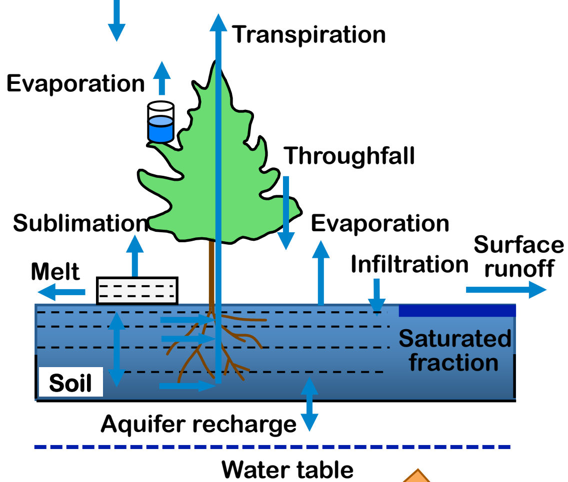
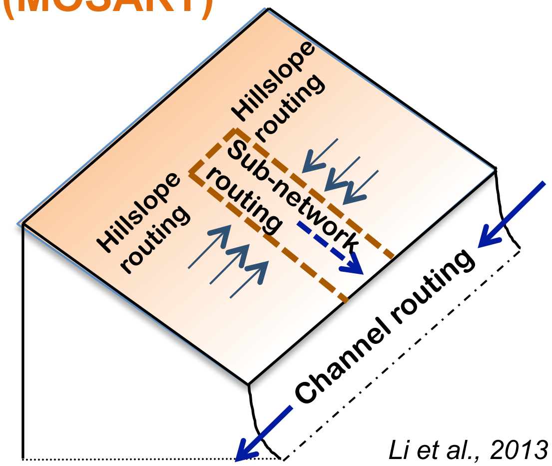
Community Land Model (CLM) Hydrology



Model for Scale Adaptive River Transport (MOSART)



Li et al., 2013

Runoff generation

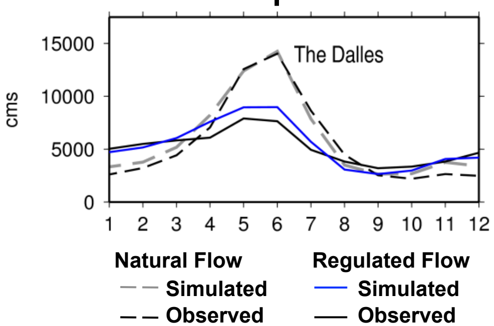
Irrigation water supply

Irrigation demand

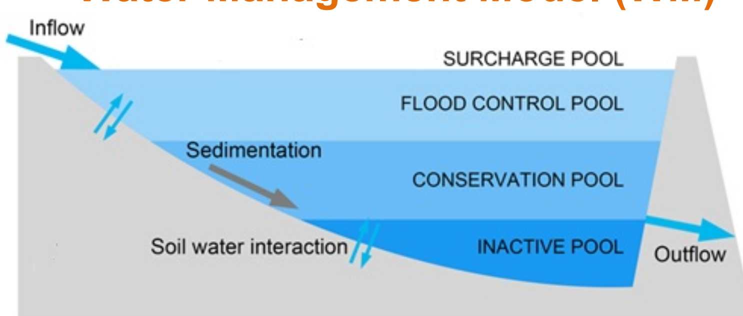
Natural flow

Regulated flow

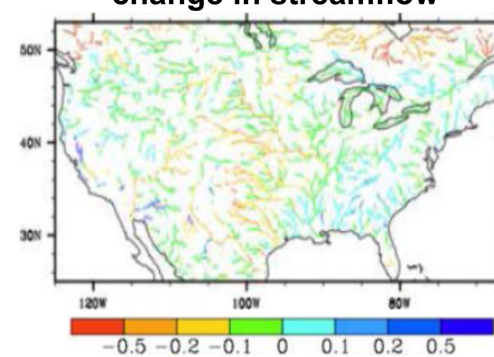
Hydrograph illustrates importance of simulating reservoir operations



Water Management Model (WM)



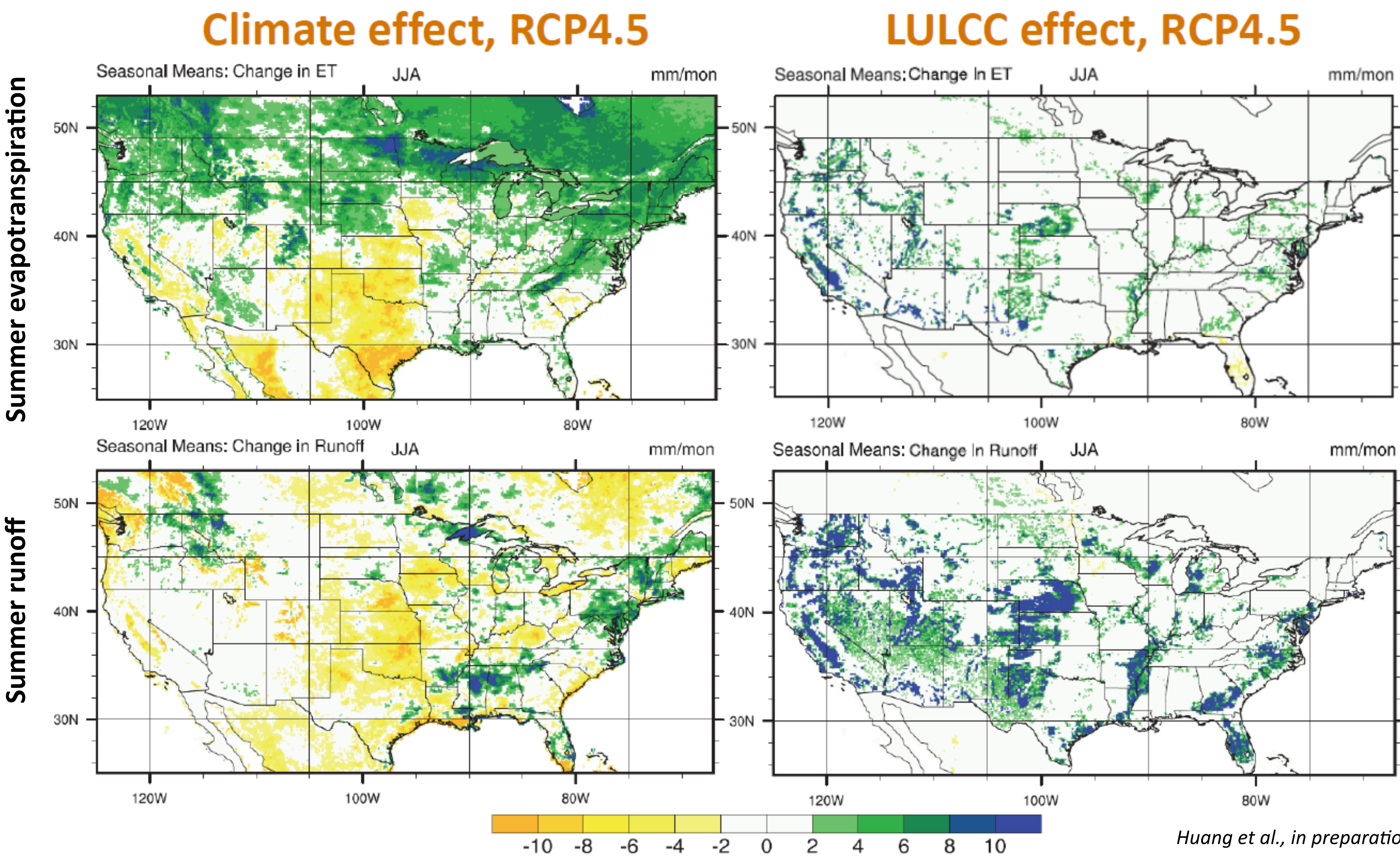
Reservoir-induced fractional change in streamflow



Voisin 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



Huang et al., in preparation

Coupling IAMs with ESMs/sectoral models can yield new insights into potential climate impacts

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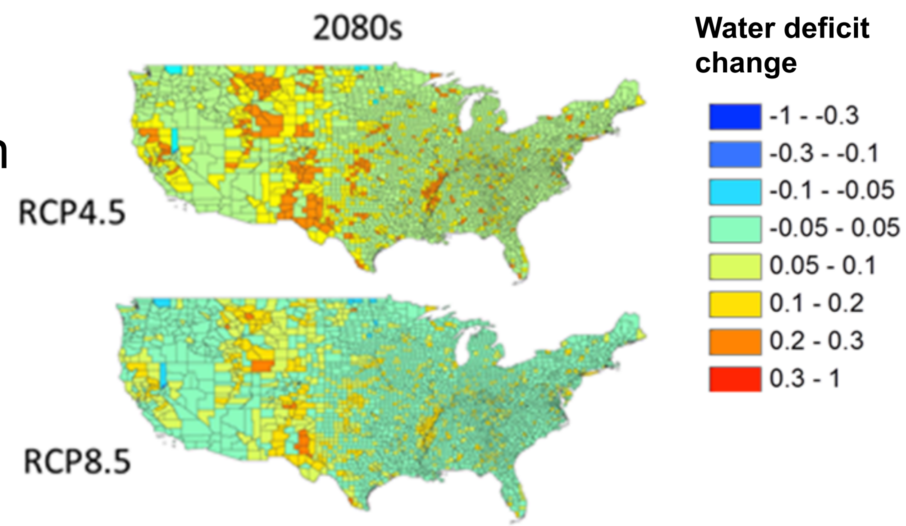
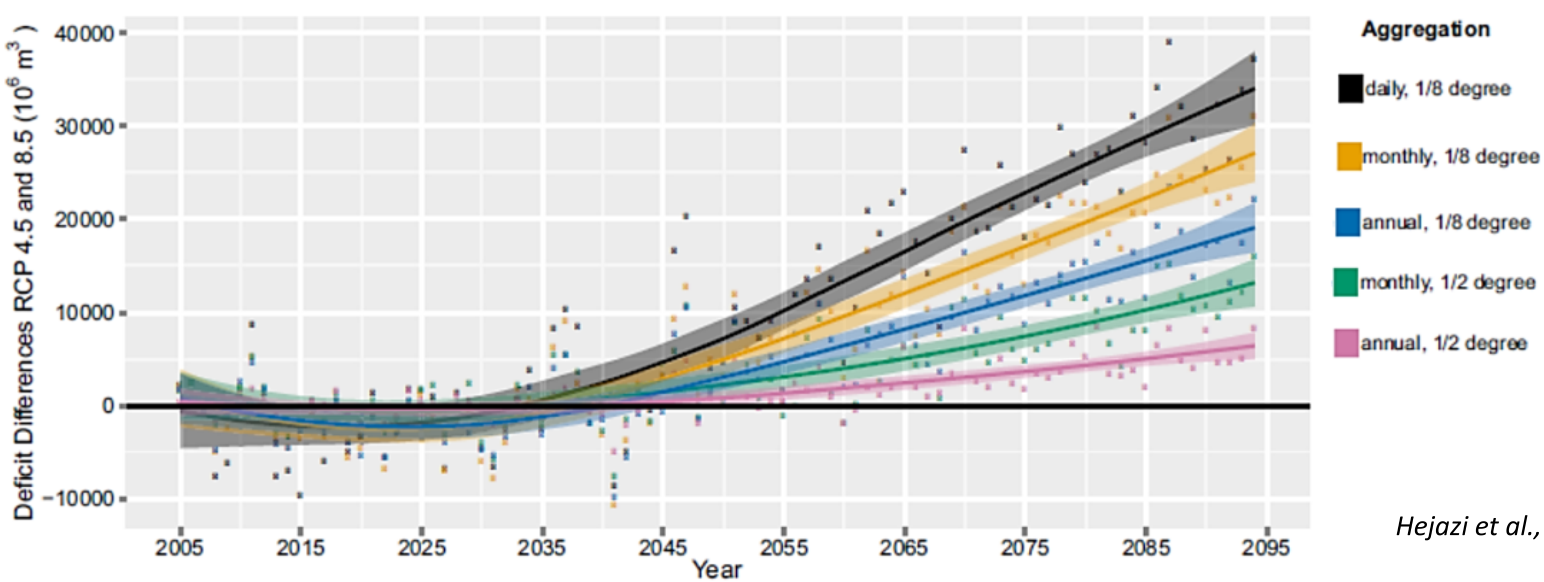
- GCAM coupled with CLM+
- Water deficit projected to increase more with climate change mitigation than under unconstrained climate change (largely due to increased biofuel production)
- Water deficits are significantly underestimated if computed at coarser spatial/temporal resolution

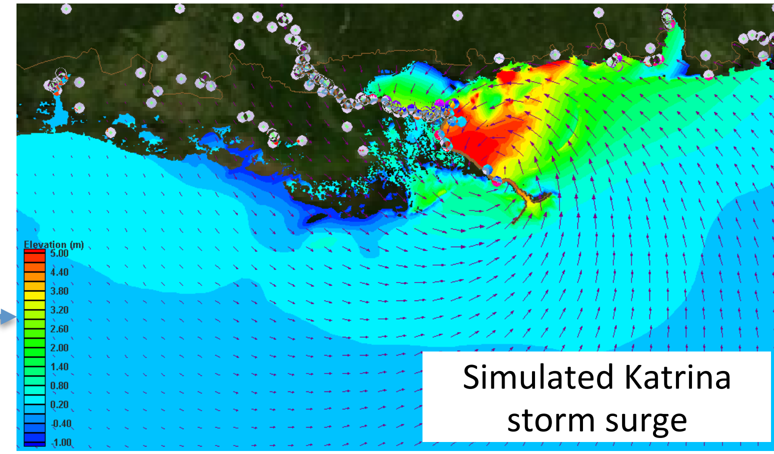




Hejazi et al., PNAS, 2015

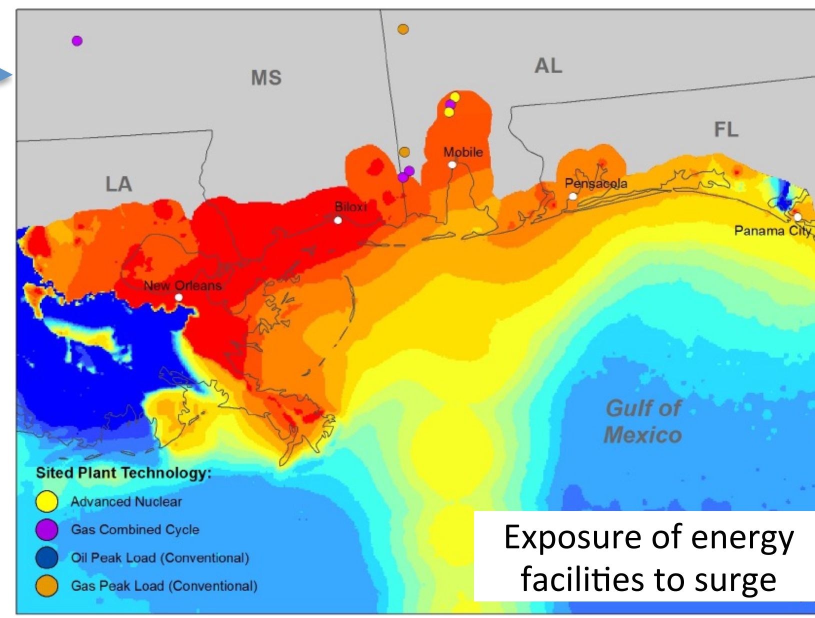
Coupling multiple sectoral models together can likewise yield improved IAV assessments

- 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)**



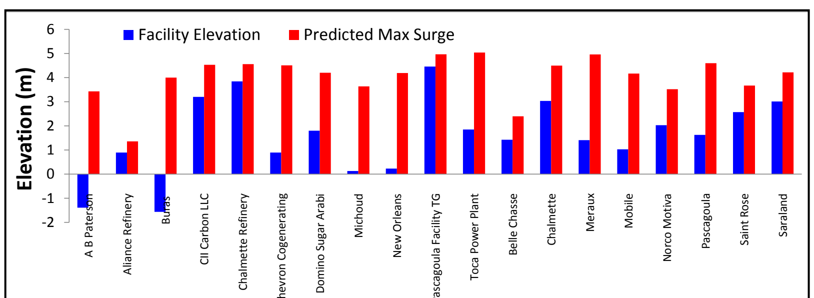
Simulated Katrina storm surge

Yang et al., 2014



Exposure of energy facilities to surge

Vernon et al., in preparation



Energy Facility Exposure to Inundation

Integrated Multi-sector, Multi-scale Modeling (IM^3)

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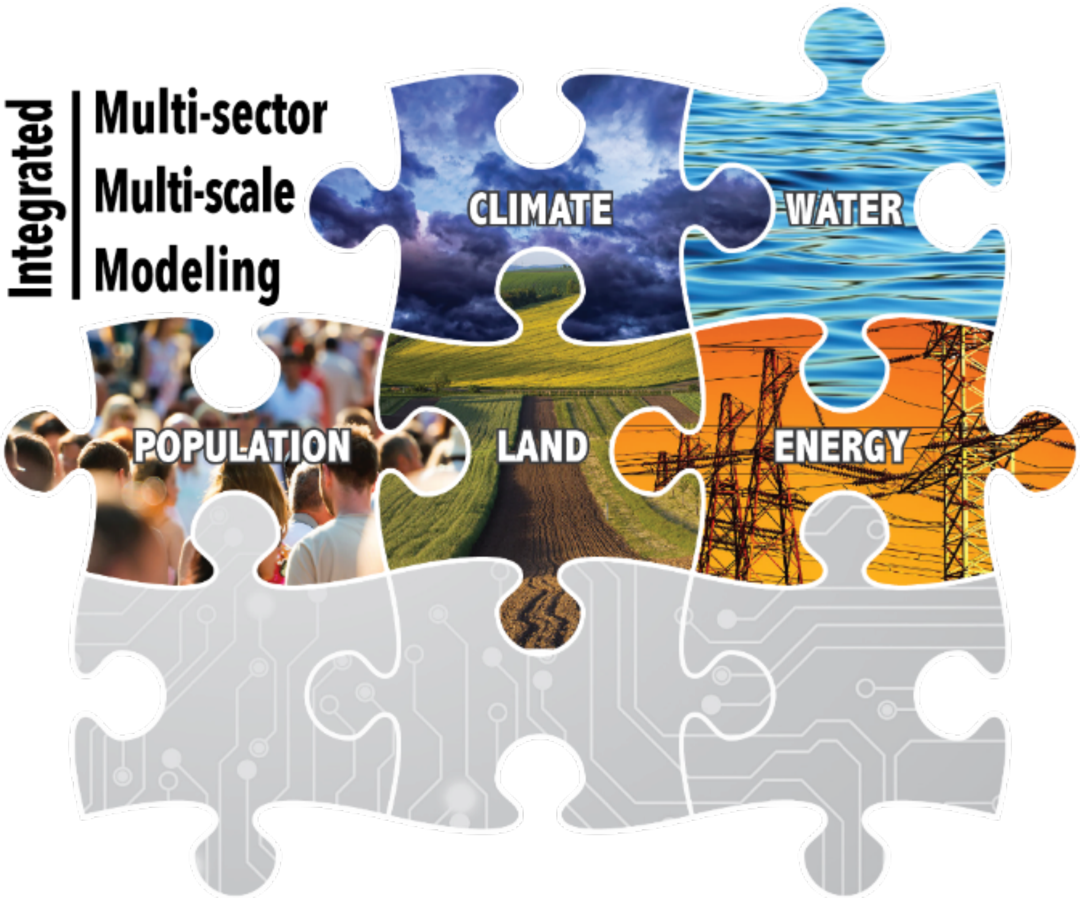

New* multi-institution DOE-IARP project that leverages and significantly extends RIAM and PRIMA

Research Thrust Areas:

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

* Pending successful response to review comments

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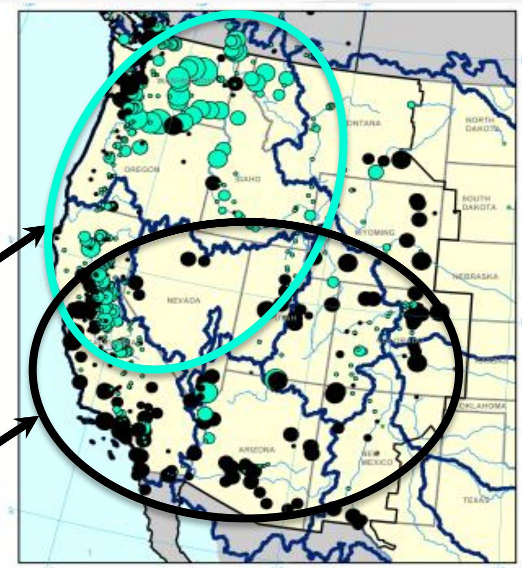
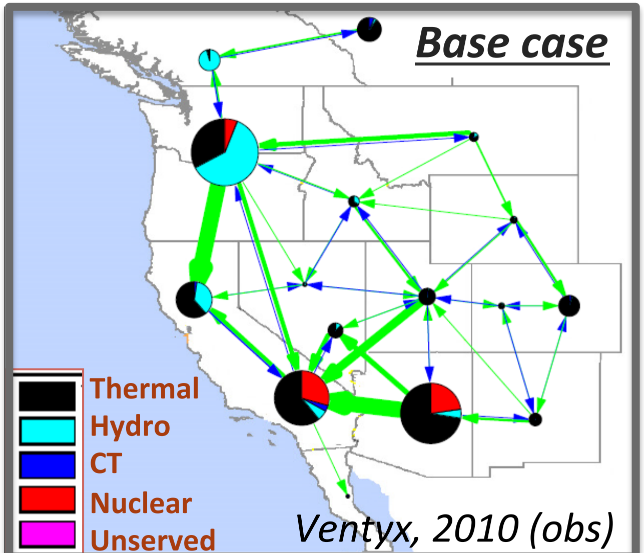
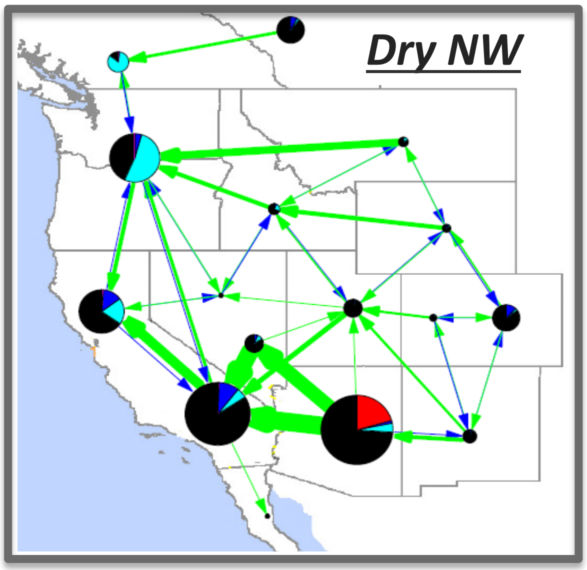
Energy-Water Nexus: Could drought "break" the Western interconnection?

- 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**

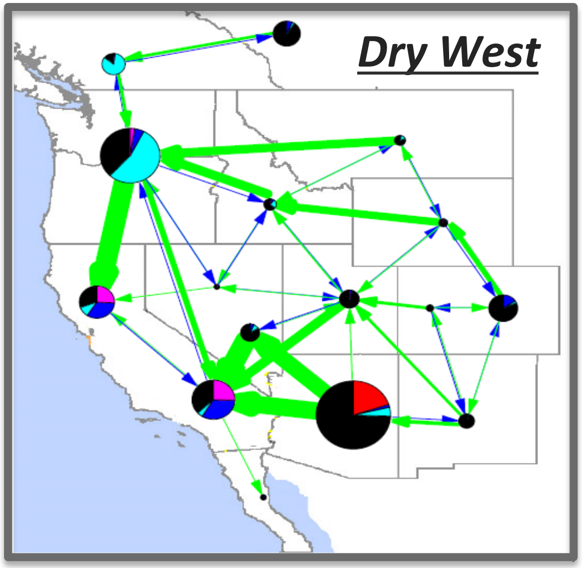




Base case:
- NW and Colorado hydrologic regions export to California
- Operating costs: $19.8 B



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

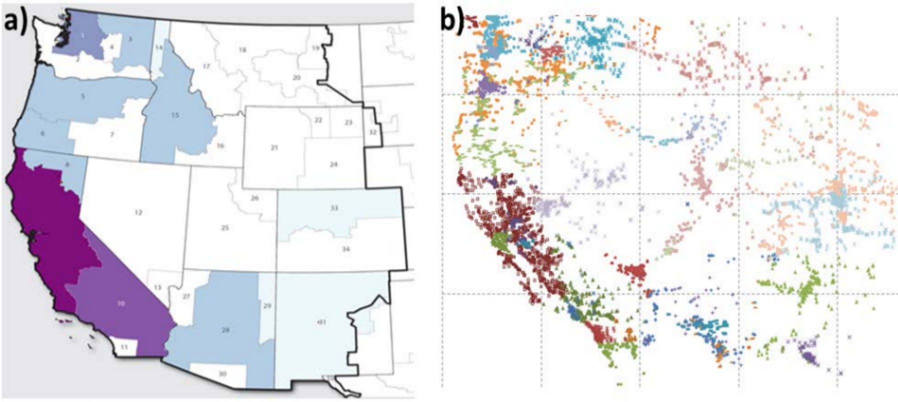


Drought with low hydro and thermoelectric generation:
- Unserved energy: 6%

Voisin et al., in review

Representing future energy-water-climate interactions

ReEDS capacity expansion model

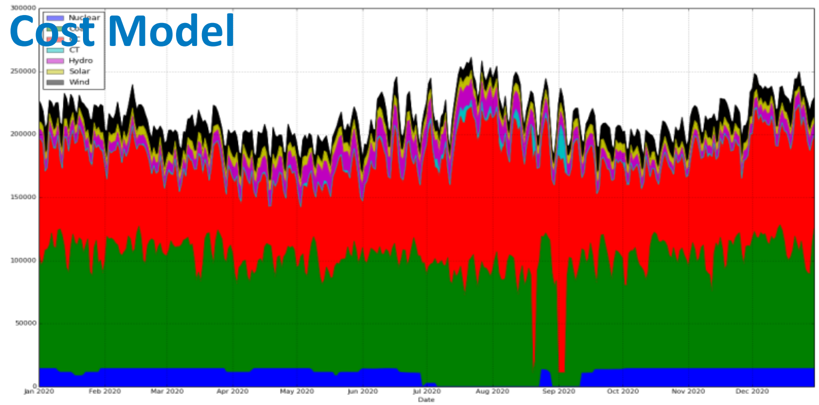


Geospatial representation for the Western Interconnect

a) ReEDS regions: numbered and differ in colors
b) PLEXOS buses: represented as points, balancing authorities differ in colors

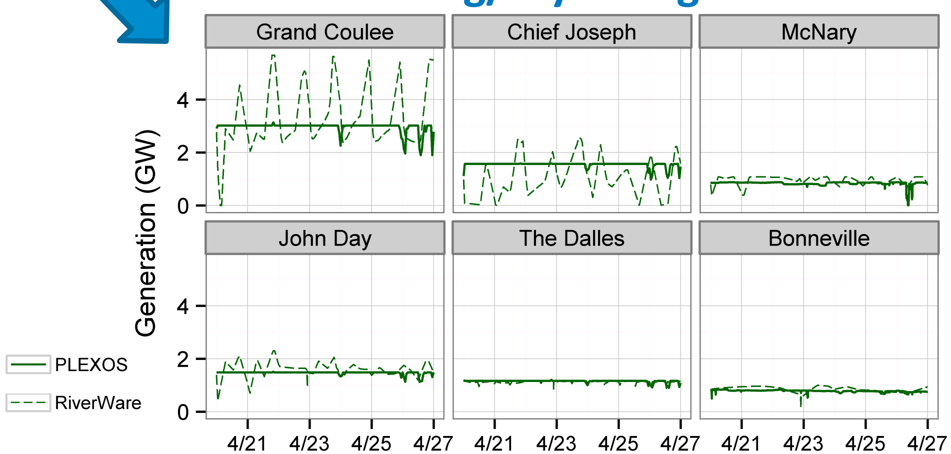
Diakov, V, W Cole, P Sullivan, G Brinkman, and R Margolis. 2015. "Improving Power System Modeling: A Tool to Link Capacity Expansion and Production Cost Models." NREL/TP-6A20-64905.

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



Macknick, J., Zhou, E., Miara, A., Ibanez, E., O'Connell, M., Hummon, M., Brinkman, G. "Impacts of cooling system choices and demand response measures on operating costs and reliability in a water-constrained electric system." *forthcoming*

River Routing/ Hydrologic Models



Ibanez E, T Magee, M Clement, G Brinkman, M Milligan, and E Zagona. 2014. "Enhancing Hydropower Modeling in Variable Generation Integration Studies." *Energy*. 74. 518–528.

Population dynamics modeling and agent-based modeling in IM³

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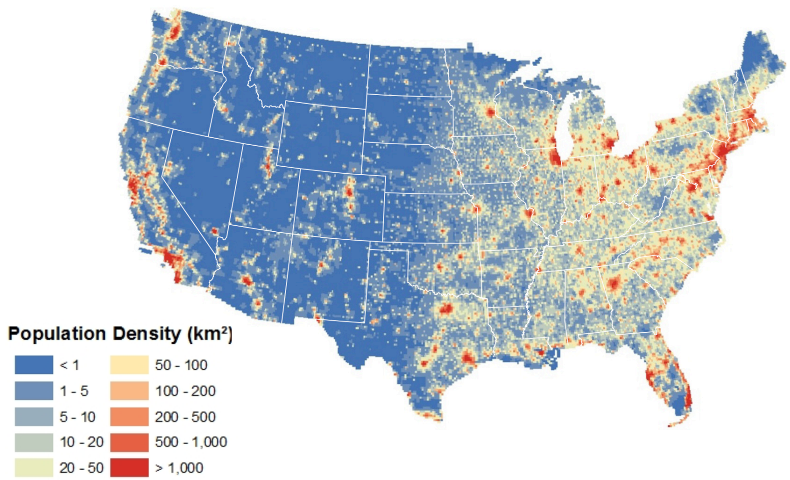
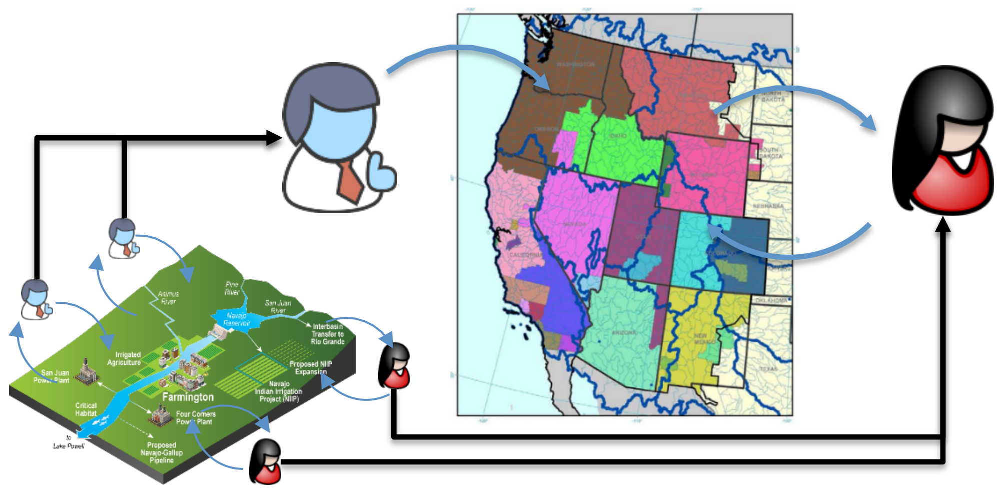


- Explore agent-based approaches for upscaling information from watershed to basin scale
- Also provides mechanism for studying adaptation and other human behaviors (e.g., evolution of electric grid)

- 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



Watershed Scale **Interconnection Scale**

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

A possible starting point (rough draft)

FULL COUPLING: All resolved variables in both models are fully reconciled/integrated	**PARTIAL COUPLING:** Some, but not all, variables are reconciled/integrated
TIGHT COUPLING: Models/components exchange information at every time step	**LOOSE COUPLING:** Models/components exchange information less frequently
TWO-WAY COUPLING: Models exchange information in both directions	**ONE-WAY COUPLING:** One model provides information to the other
HARD COUPLING: High degree of software integration (e.g., flux coupler)	**SOFT COUPLING:** Low or no software integration (e.g., "sneaker-net")

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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

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Thank you!

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