IM3: INTEGRATED MULTISECTOR, MULTISCALE MODELING OF FINE TO REGIONAL SCALE HUMAN-NATURAL SYSTEM DYNAMICS

The Integrated Multisector, Multiscale Modeling (IM3) Scientific Focus Area (SFA) develops flexible, open-source, integrated modeling capabilities that capture the structure, dynamic behavior, and emergent properties of multiscale interactions within and between human and natural systems, at scales ranging from local (~1km) to the contiguous United States (CONUS).

IM3 prioritizes coupling process-based models to resolve key interactions and feedbacks in response to short-term shocks, long-term changes, and compound stressors (such as droughts and heatwaves occurring together), and effects on vulnerability and resilience.

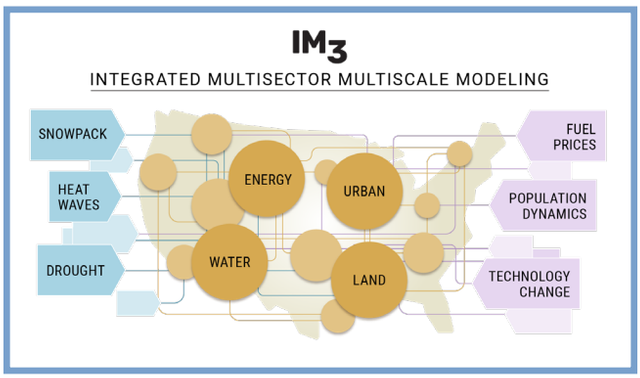
Launched in 2017, IM3's research through FY20 includes:

- Energy and water system dynamics modeling, at scales ranging from watershed to regional to simulate water availability interactions with electricity system operations
- Modeling of the complex, multiscale linkages between land use and land cover change (LULCC), hydrology, and regional climate
- Development of high-resolution U.S. population projections sensitive to state-level demographic projections and climate
- Scalable building energy demand modeling responsive to population, building technology, and weather
- Agent-based modeling to simulate emergent behavior in water management, crop planting, and urban-rural transition decisions

Funding and Participating Institutions

IM3 is sponsored by DOE's Office of Science through its MultiSector Dynamics program area. As of FY21, the IM3 team consists of four national laboratories and 6 universities:

- Pacific Northwest National Laboratory
- Lawrence Berkeley National Laboratory
- Oak Ridge National Laboratory
- Sandia National Laboratory
- Baylor University
- Boston University
- Cornell University
- North Carolina State University
- University of California, Davis
- University of North Carolina at Chapel Hill



The Integrated Multisector, Multiscale Modeling (IM3) project is developing flexible and extensible coupled modeling capabilities that capture the dynamic, multiscale interactions among energy, water, land, urban, and other systems.

- City-specific and CONUS-scale studies of urban heat islands, anthropogenic heat feedbacks, and adaptation strategies
- Developing best practices for multi-model coupling, version control, and uncertainty characterization
- Founding a community of practice to support the MultiSector Dynamics research community

CHALLENGES

The IM3 SFA has the following long-term objectives:

1. Develop flexible, open-source, integrated modeling capabilities that capture the structure, dynamic behavior, and emergent properties of the multiscale interactions within and between human and natural systems.
2. Use these capabilities to study the evolution, vulnerability, and resilience of interacting human and natural systems and landscapes from local to continental scales, including their responses to the compounding effects of long-term influences and short-term shocks.
3. Understand the implications of uncertainty in data, observations, models, and model coupling approaches for projections of human-natural system dynamics.

IM3 RESEARCH AREAS

M3 has identified the following research gaps to address in its current phase (FY21-FY23):

Heat Waves and Urban Vulnerability

- Population vulnerabilities to the impacts of extreme heat at a subnational scale remain underrepresented.
- Previous regional-scale electricity demand projections have not addressed the impacts of heatwaves on building thermodynamics.

Drought and Adaptation

- Previous studies have not addressed multiscale dynamic interactions and conjunctive management of surface water and groundwater resources under compound natural and human influences.
- There is a lack of representation of human adaptation to water scarcity in terms of both water use and water management decisions.
- LULCC and its impact on water demand/supply are not yet propagated through other sectors nor across scales.

Compound Effects of Heat Waves and Drought on the Electric Grid

- Current electricity infrastructure expansion models are unable to simultaneously address short- and long-term stressors with the spatial and temporal resolution necessary to demonstrate that the future infrastructure can meet future demand with sufficient reliability and reasonable cost.
- There is little understanding of how the compound influences of drought and heatwaves interact to create cascading failures and non-linear responses.

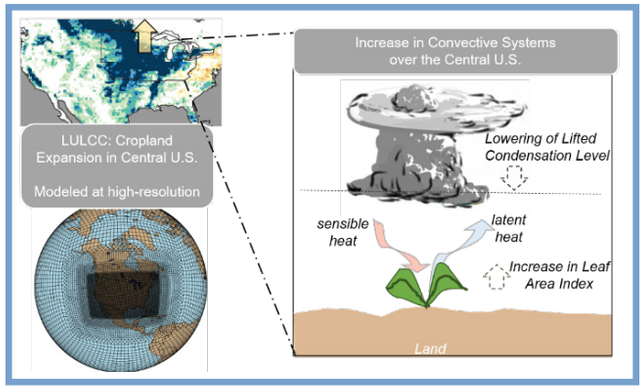
Uncertainty Characterization

- There is a lack of guidance for confronting the computational and conceptual challenges of multi-model uncertainty characterization (UC) workflows.

IM3 is pursuing these research gaps with different degrees of spatial, temporal, and process resolution and at the following scales: CONUS, electricity grid interconnection, watershed, and urban.

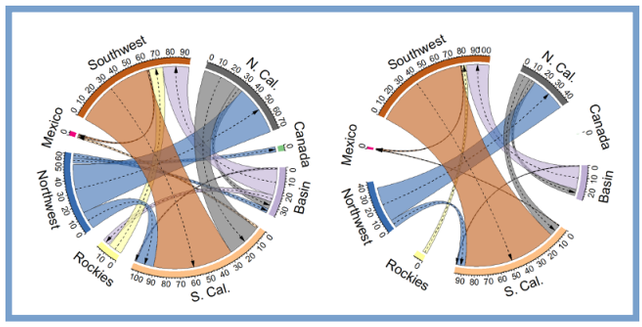
FUTURE WORK

IM3 will continue to expand the variety of sectors and long- and short-term influences addressed in its research. Future potential research areas include wildfire, flooding, transportation, human health, and ecosystems. IM3 will also continue to address uncertainty in multisector dynamics modeling at multiple scales and degrees of resolution to improve coupled model fidelity for projecting vulnerability and resilience.



The expansion of croplands over the Central U.S. shifts the thermodynamic environment, making it more conducive to convection and resulting in an increase in the number of mesoscale convective system-like features.

Devanand A, M Huang, D M Lawrence, C M Zarzycki, Z Feng, P J Lawrence, Y Qian, Z Yang. "Land use and land cover change strongly modulates land-atmosphere coupling and warm-season precipitation over the Central United States in CESM2-VR," *Journal of Advances in Modeling Earth Systems*, 12, e2019MS001925, (2020). DOI: 10.1029/2019MS001925



Net interchange between region pairs for wet and drought year conditions in TWh/year. Power generation in the Desert Southwest alleviates changes in Northwest water availability to support electricity demand in Southern California. The sensitivity of regional dependency paths to water-availability is conserved under climate change conditions.

Voisin, N., Dyreson, A., Fu, T., O'Connell, M., Turner, S. W. D., Zhou, T., & Macknick, J. (2020). Impact of climate change on water availability and its propagation through the Western U.S. power grid. Applied Energy, 276, 115467. doi: https://doi.org/10.1016/j.apenergy.2020.115467

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