IM3

INTEGRATED MULTISECTOR MULTISCALE MODELING

Exploring Vulnerability and Resilience in the U.S. Across Interacting Energy, Water, Land, and Urban Systems

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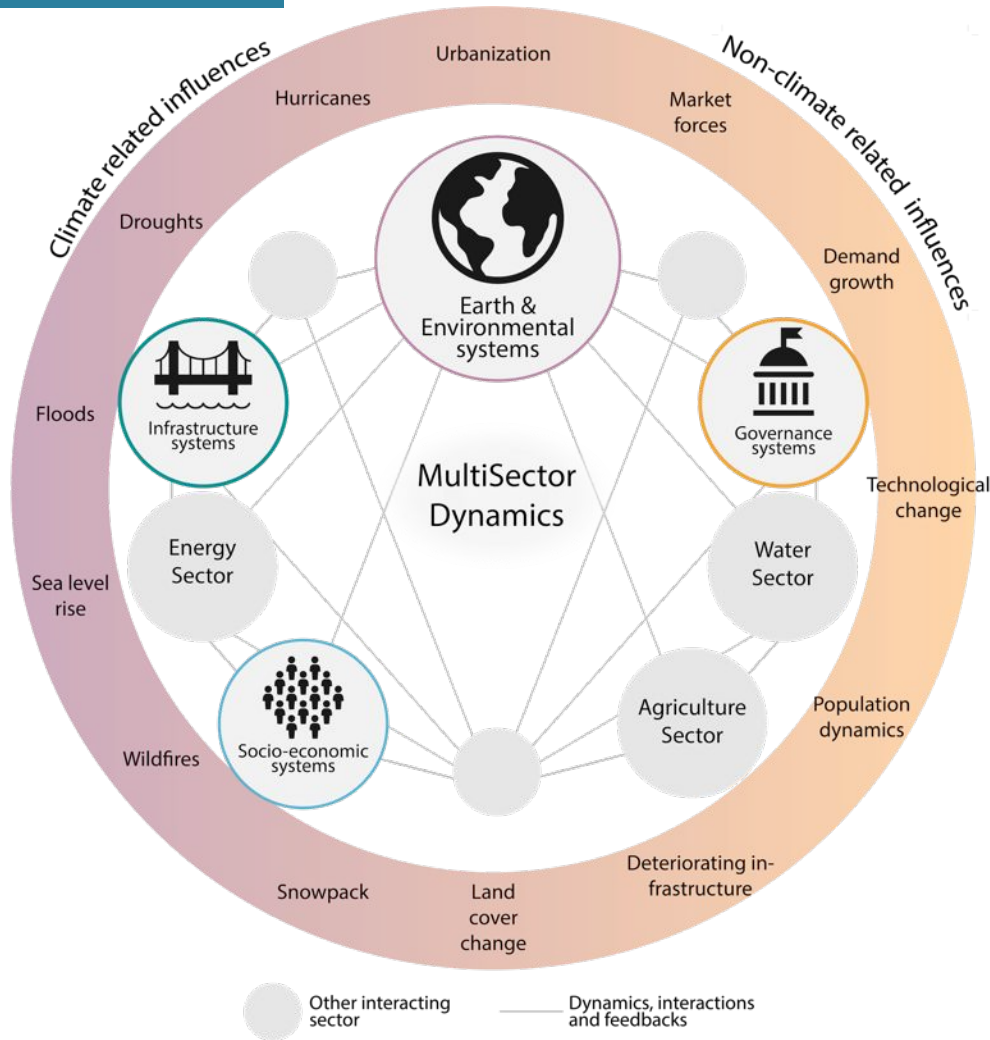
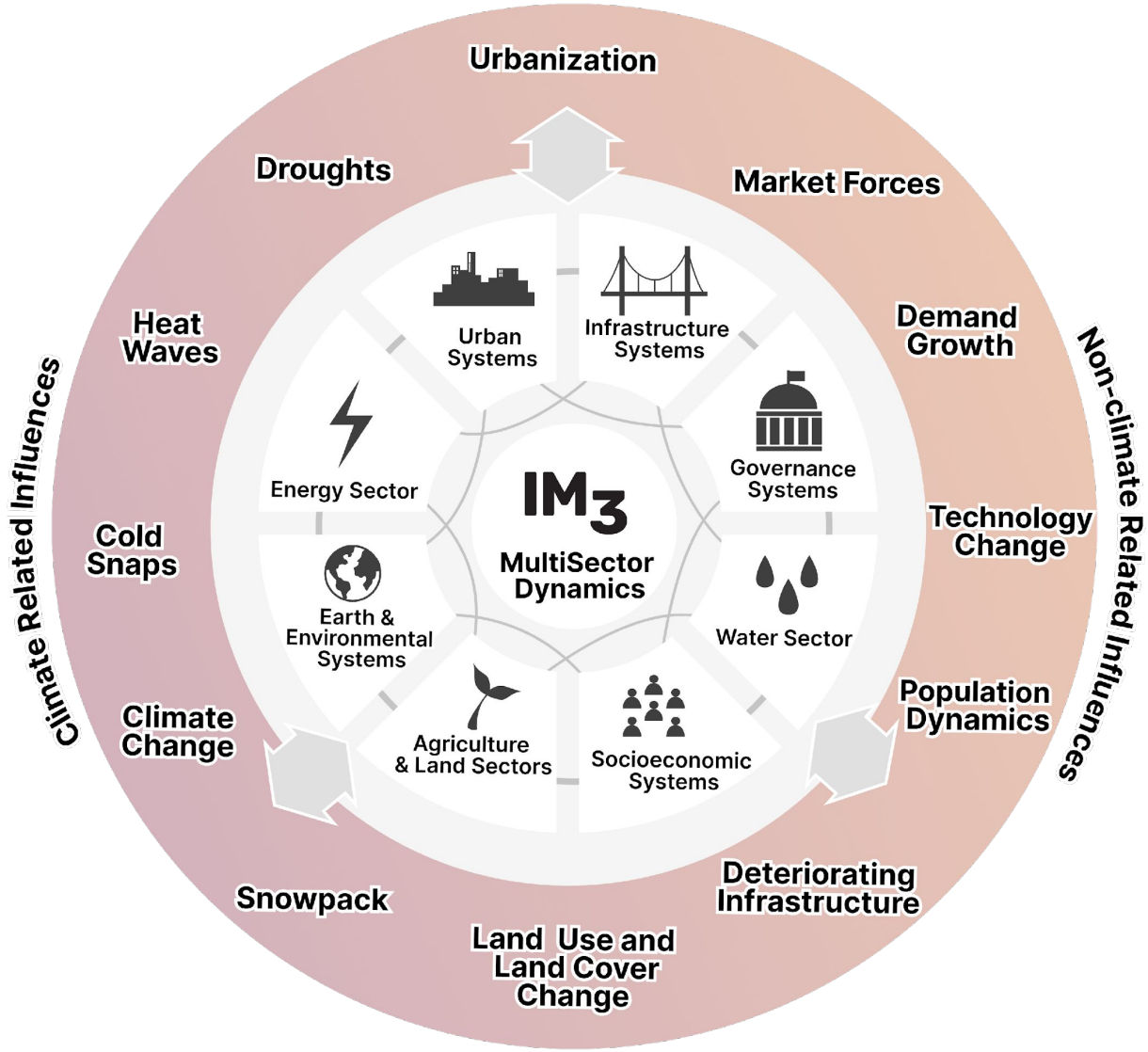
Senior Research Scientist
IM3 Principal Investigator

On behalf of the entire team

This research is supported by the U.S. Department of Energy, Office of Science, as part of research in MultiSector Dynamics, Earth and Environmental System Modeling Program

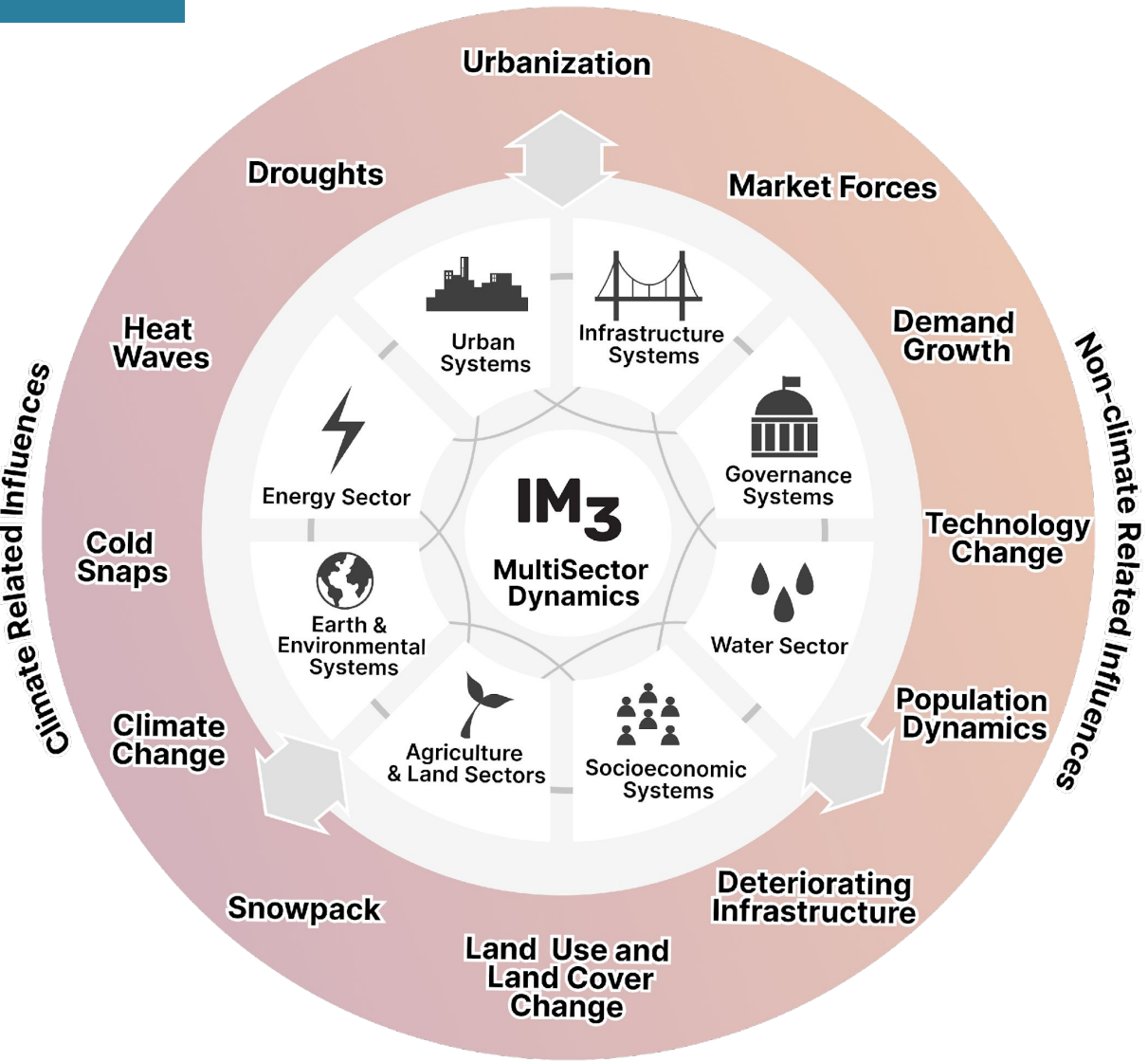
The IM3 Science Focus Area is supported by the MSD Program Area





Reed, Patrick M., Antonia Hadjimichael, Richard H. Moss, Christa Brelsford, Casey D. Burleyson, Stuart Cohen, Ana Dyreson et al. "Multisector Dynamics: Advancing the Science of Complex Adaptive Human-Earth Systems." *Earth's Future* 10, no. 3 (2022): e2021EF002621.

Overarching Science Questions



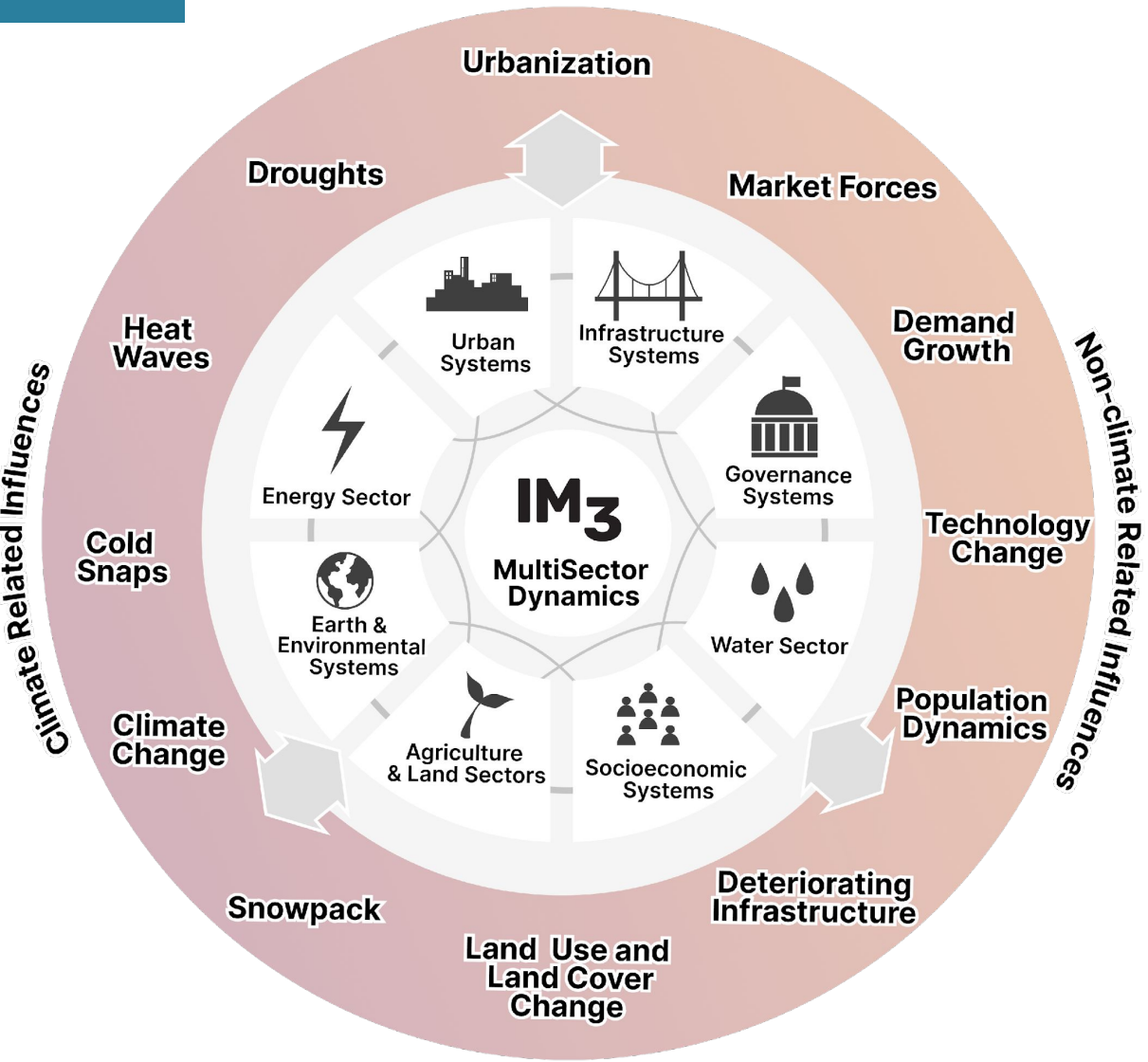
From local to continental U.S. scales:

1. How do short-term shocks and long-term changes compound to create **vulnerabilities and risks to energy, water, land, and urban systems**, and what are potential **adaptive responses?**

2. What degree of **spatial, temporal, and process resolution** is necessary to capture multisector, multiscale dynamics?

3. What are the **implications of uncertainty** in data, observations, models, and model coupling approaches for projections of human-natural system dynamics?

Modeling Approach for Co-Evolving Human-Earth System Interactions in the U.S.



Develop, enhance, and couple

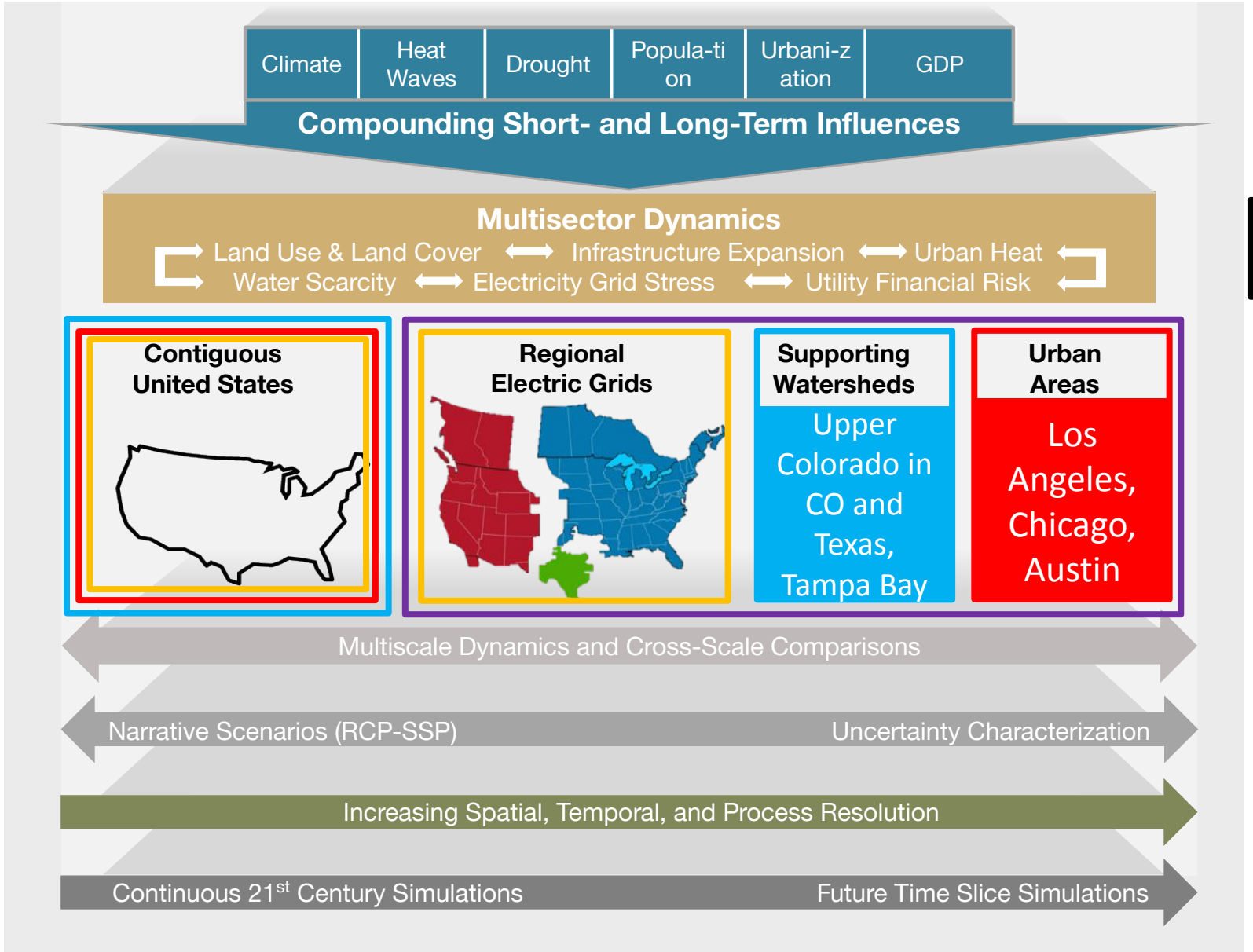
- **best-in-class sectoral models** such as:
  - AI/ML
  - Physics-based
  - and other process-based models (such ABMs)
- **and datasets**

across scales

All open-source data, models, and tools to ensure reproducibility

Research Design (FY21- FY24)

https://github.com/IMMM-SFA



Experiment Groups

How will **heat stress** in urban and rural areas evolve; how effective are green or white roofs?

How will **electricity infrastructure and grid stress** evolve with climate and energy system transitions?

How will **land use** and **water availability** evolve; what role can **adaptive water management** play?

Enabling Capabilities

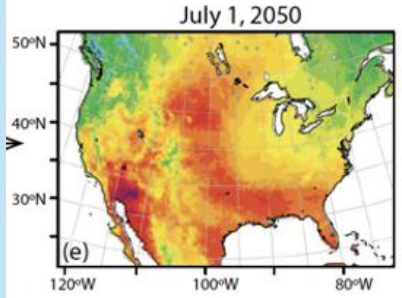
MSD Community of Practice Facilitation Team

Open-Source Data, Software, and Collaboration Team

Uncertainty Characterization Team

Integrated Multisector, Multiscale Modeling Example

How will the price of electricity, power outages, and the infrastructure landscape be affected by future climate, energy system transitions, multisectoral energy-water-land-economy interactions, and socioeconomics?



Thermodynamic Global Warming Scenarios

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HYPERFACETS

A Framework for Improving Analysis and Modeling of Earth System and Intersectoral Dynamics at Regional Scales

Socioeconomic Projections (SSP3 and SSP5)

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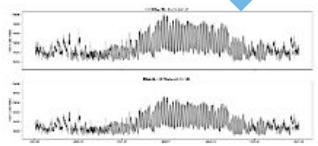

TELL: Total ELectricity Loads Model

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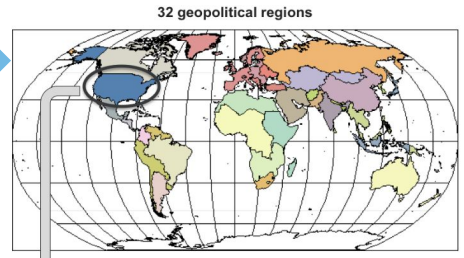
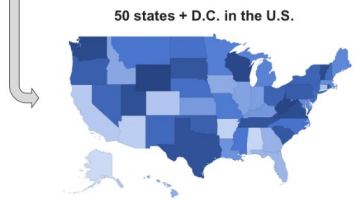
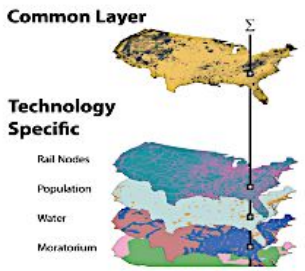


GCAM-USA

GCIMS





CERF: Infrastructure Siting

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GOWEST: Grid Operations West

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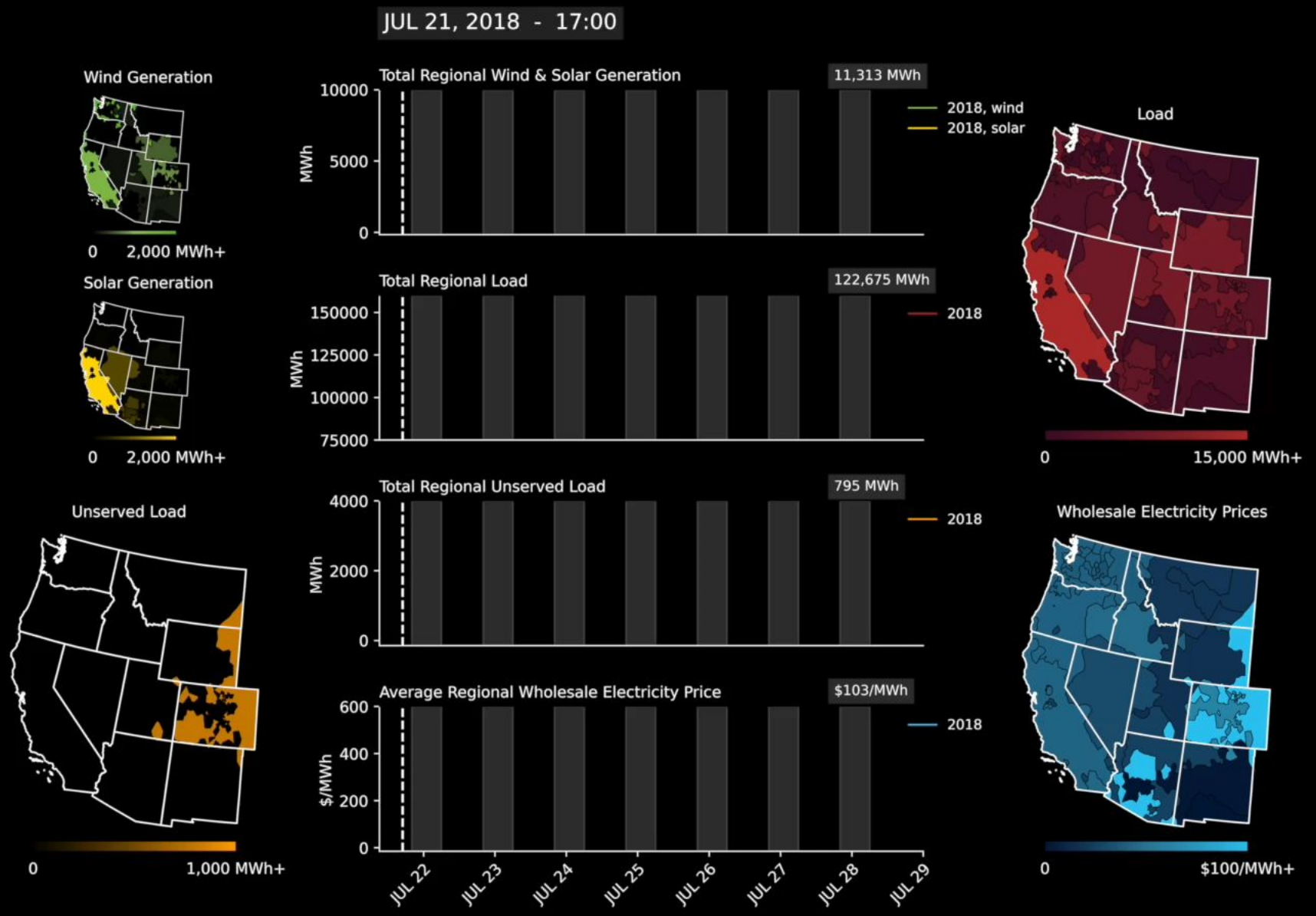
Global/ National

Local

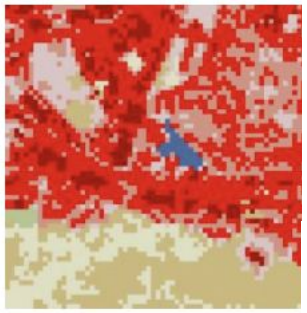
Mongird et al. in prep; Akdemir et al. in prep; Wild et al. in prep

Hourly, coincident impacts of a heat wave on solar and wind resources, electricity demand, and grid stress metrics in the Western U.S.



Modeling Heat Waves in Urban Areas

Model Coupling



NATURF: Neighborhood Adaptive Tissues for Urban Resilience Futures

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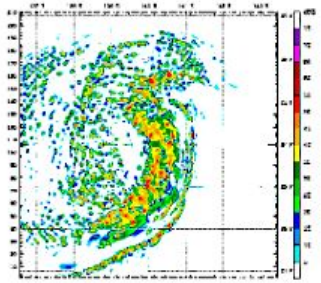
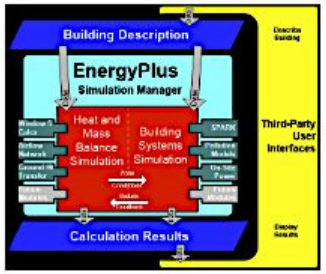
Building morphology



WRF: The Weather Research and Forecasting Model (UCM)



EnergyPlus: Building performance simulation

1M Buildings modeled in Los Angeles

Anthropogenic heat from buildings in Los Angeles County: A simulation framework and assessment
Xu Y, Vahmani P, Jones A, Hong T, July 2024, Sustainable Cities and Society

Some Recent Publications

2023

Large ensemble diagnostic evaluation of hydrologic parameter uncertainty in the Community Land Model Version 5 (CLM5)

Yan, H, N Sun, H Eldardiry, TB Thurber, PM Reed, K Malek, R Gupta, D Kennedy, SC Swenson, Z Hou, Y Cheng, and JS Rice

Journal of Advances in Modeling Earth Systems 15, e2022MS003312

> READ

2024

Multisectoral analysis of drought impacts and management responses to the 2008–2015 record drought in the Colorado Basin, Texas

Ferencz, SB, N Sun, SWD Turner, AB Smith, and JS Rice

Natural Hazards and Earth System Sciences 24

> READ | CODE

2024

Dynamic urban land extensification is projected to lead to imbalances in the global land-carbon equilibrium.

McManamay, RA, CR Vernon, M Chen, I Thompson, Z Khan, and KB Narayan

Communications Earth & Environment 5, 70

> READ | CODE | DATASET

2024

Using Financial Contracts to Facilitate Informal Leases Within a Western United States Water Market Based on Prior Appropriation.

Zeff, H, A Hadjimichael, PM Reed, and GW Characklis

Earth's Future 12(5)

> READ | CODE

2024

statemodify: a Python framework to facilitate accessible exploratory modeling for discovering drought vulnerabilities.

Gupta, RS, CR Vernon, TB Thurber, DF Gold, ZM Hirsch, A Hadjimichael, and PM Reed

Journal of Open Source Software 9, no. 96

2024

Persistent urban heat

Li, D, L Wang, W Liao, T Sun, G Katul, E Bou-Zeid, and B Maronga

Science Advances 10(15)

> READ | HIGHLIGHT | CODE | DATASET

2024

Representing farmer irrigated crop area adaptation in a large-scale hydrological model

Yoon, J, N Voisin, C Klassert, TB Thurber, and W Xu

Hydrology and Earth System Sciences 28, 4

> READ | HIGHLIGHT | CODE | DATASET

2024

An open-source framework for balancing computational speed and fidelity in production cost models

Akdemir, KZ, K Oikonomou, JD Kern, N Voisin, H Ssembatya and J Qian

Environmental Research: Energy 1, 015003

> READ | CODE | DATASET

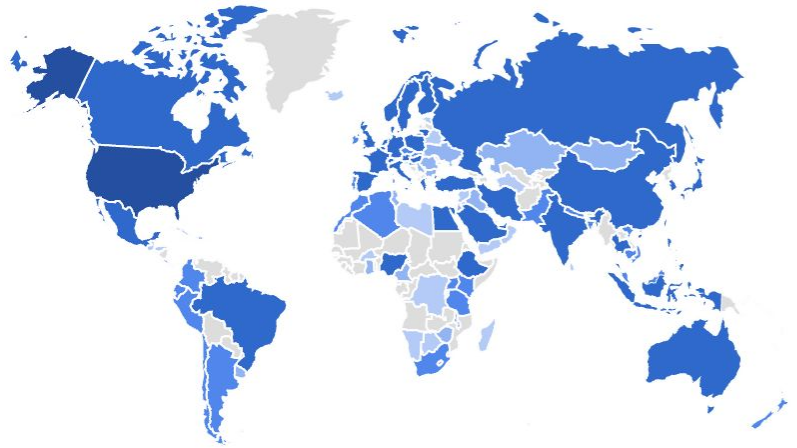
Uncertainty Characterization E-Book, uc-ebook.org

***"I found it to be an extremely effective teaching tool**, enabling active learning in a short period of time", Sarah Fletcher, Assistant Professor, Stanford University*

Interactive Tutorials

- Factor Discovery
- Model Calibration
- Sobol Sensitivity Analysis
- Factor Mapping using Logistic Regression
- Time-evolving scenario discovery for infrastructure pathways
- A Hidden-Markov Modeling Approach to Creating Synthetic Streamflow Scenarios

Unique visitors, last 12 months

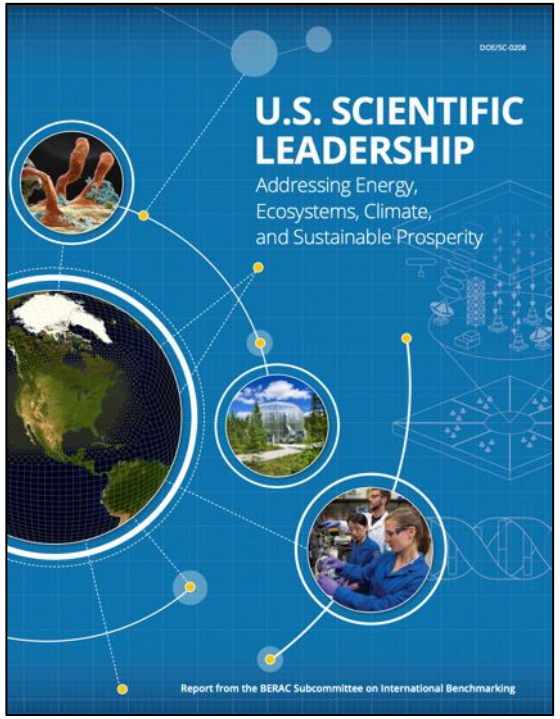


COUNTRY	USERS
United States	2.4K
Germany	368
China	225
United Kingdom	222
India	175
Canada	158
Netherlands	153

In use at:

- Cornell University
- Dartmouth University
- Penn State University
- Rice University
- Stanford University

IM3 Supports the MSD Community Of Practice Facilitation Team



BERAC. 2022. U.S. Scientific Leadership Addressing Energy, Ecosystems, Climate, and Sustainable Prosperity: Report from the BERAC Subcommittee on International Benchmarking, DOE/SC-0208. M. McCann and P. Reed, eds. Biological and Environmental Research Advisory Committee. DOI:10.2172/1895129.

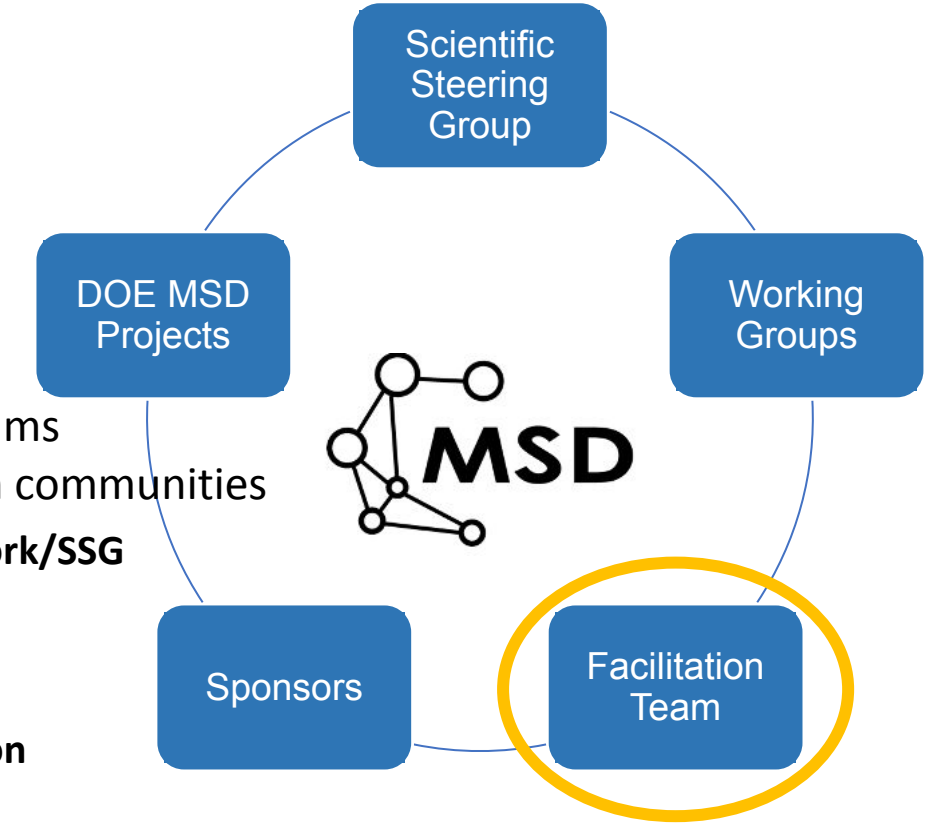
"BER has supported **innovative research on coupled human-Earth systems** with world-renowned researchers and tools. For example…the recently established **MultiSector Dynamics community of practice**, a multidisciplinary collective of university and national laboratory researchers working at the interface of human and natural systems."

Communication
- Website
- Newsletter
- Webinars
- Outreach

Coordination
- Workshops
- Conference forums
- Linking research communities

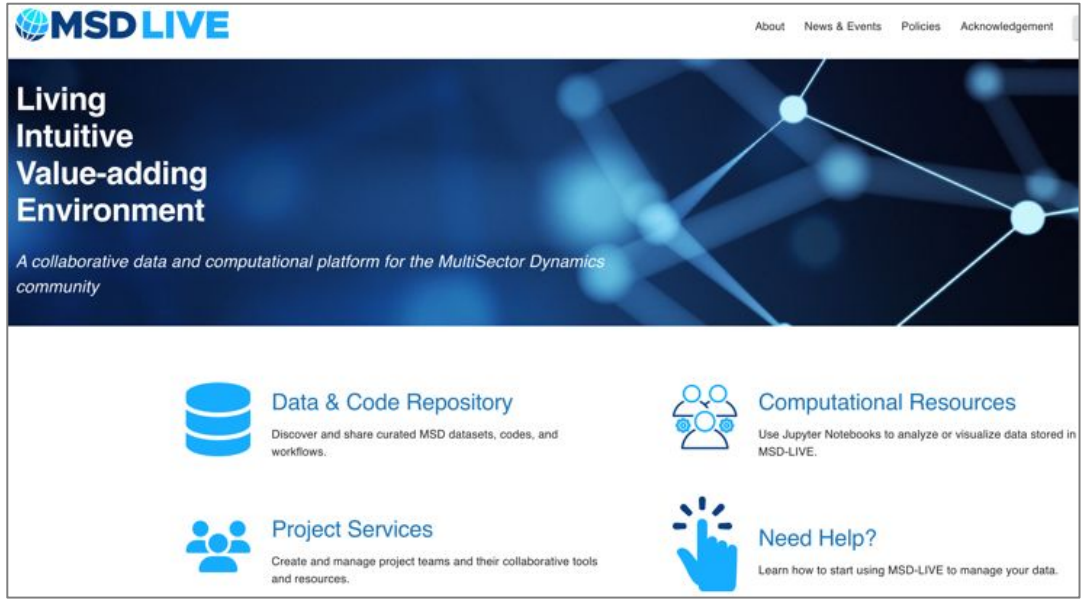
Conceptual Framework/SSG
- Vision reporting
- FT & SSG drafting
- Review process

Technical coordination
- Working groups



Leading Open Source and Fair Data Approaches for MSD Community

- IM3 requires all open-source code, data, and tools – no exceptions
- IM3 ideas and data management objectives led to MSD-LIVE project led by Casey Burleyson



- IM3 developed the concept of a "meta-repository" to accompany each submitted manuscript (Vernon, C.R. 2023)

Input data

Dataset	Repository Link	DOI
GCAM-USA Output	https://data.msdlive.org/records/43sy2-n8y47	https://doi.org/10.57931/1989373
TGW Weather Forcing	https://data.msdlive.org/records/cnsy6-0y610	https://doi.org/10.57931/1960530

Output data

The output of the TELL model is stored in the data repository linked below. The post-processed files (resulting from the analysis scripts itemized below) are stored in the /data directory in this meta-repository.

Dataset	Repository Link	DOI
TELL Output	https://data.msdlive.org/records/r0rvc-kjw89	https://doi.org/10.57931/2228460
Post-Processed Data	https://github.com/IMMM-SFA/burleyson-etal_2023_applied_energy/tree/main/data	https://doi.org/10.5281/zenodo.10278502

Contributing modeling software

Model	Version	Repository Link	DOI
GCAM-	v5.3	https://data.msdlive.org/records/r52tb-	https://doi.org/10.57931/1960381

Reviewer feedback: *"I agree that this paper should be deemed fully reproducible and given the* ***highest rating for reproducibility.****"*

MSD CoP Webinar on meta-repositories presented in February 2024

Future Collaboration Opportunities

- **Collaborate with RGMA and ESMD (e.g., CASCADE & E3SM)**
  - High-resolution urban- and basin-scale climate for impacts modeling
  - Model extreme events in addition to heat waves and drought, such as wildfire
- **Expand collaboration with other MSD projects**
  - Incorporate fine-scale results (e.g., Puget Sound hydropower availability, ICoM land use change) into IM3 models
  - Continue active collaborations with GCIMS on dynamic urban land, groundwater modeling, water demand downscaling from GCAM-USA
  - Plan with GCIMS for joint activities to propose in SFA renewals
- **Continue to interact with other agencies (e.g., USGS)** to help facilitate use of IM3 models and data and open-source integrated modeling approaches
- **Continue to gather feedback from applied research activities leveraging IM3 research** on foundational science gaps that need to be filled **(R2O2R)**

E3SM Energy Exascale Earth System Model

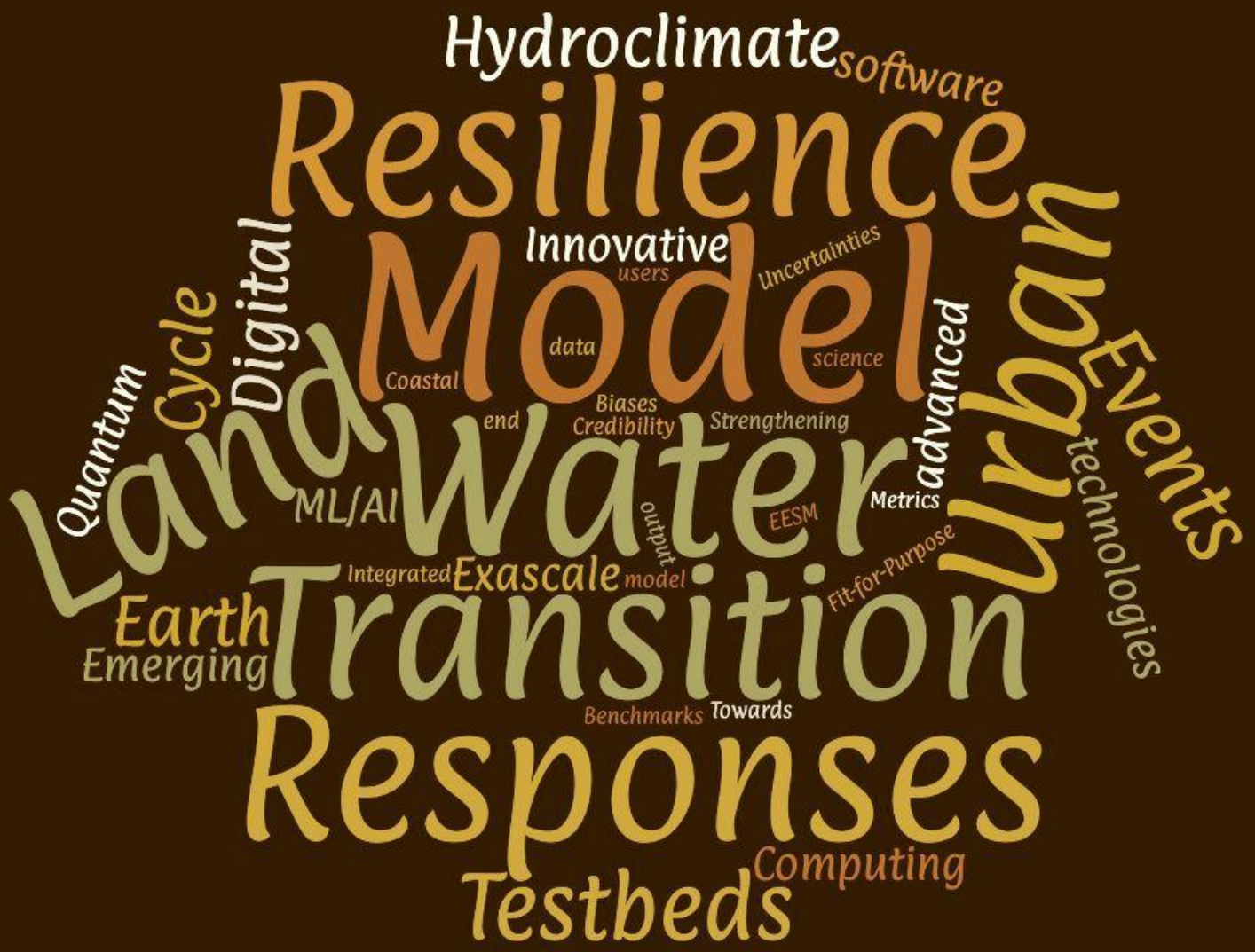
IM3 GCIMS ICOM

U.S. Department of Energy | Office of Science
HYPERFACETS
A Framework for Improving Analysis and Modeling of Earth System and Intersectoral Dynamics at Regional Scales

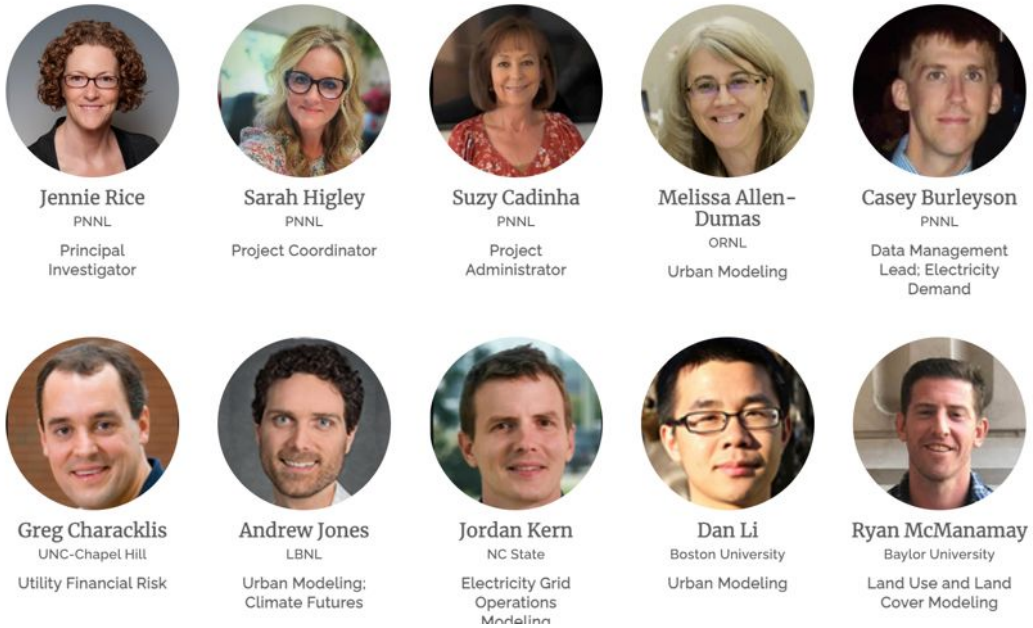
USGS science for a changing world

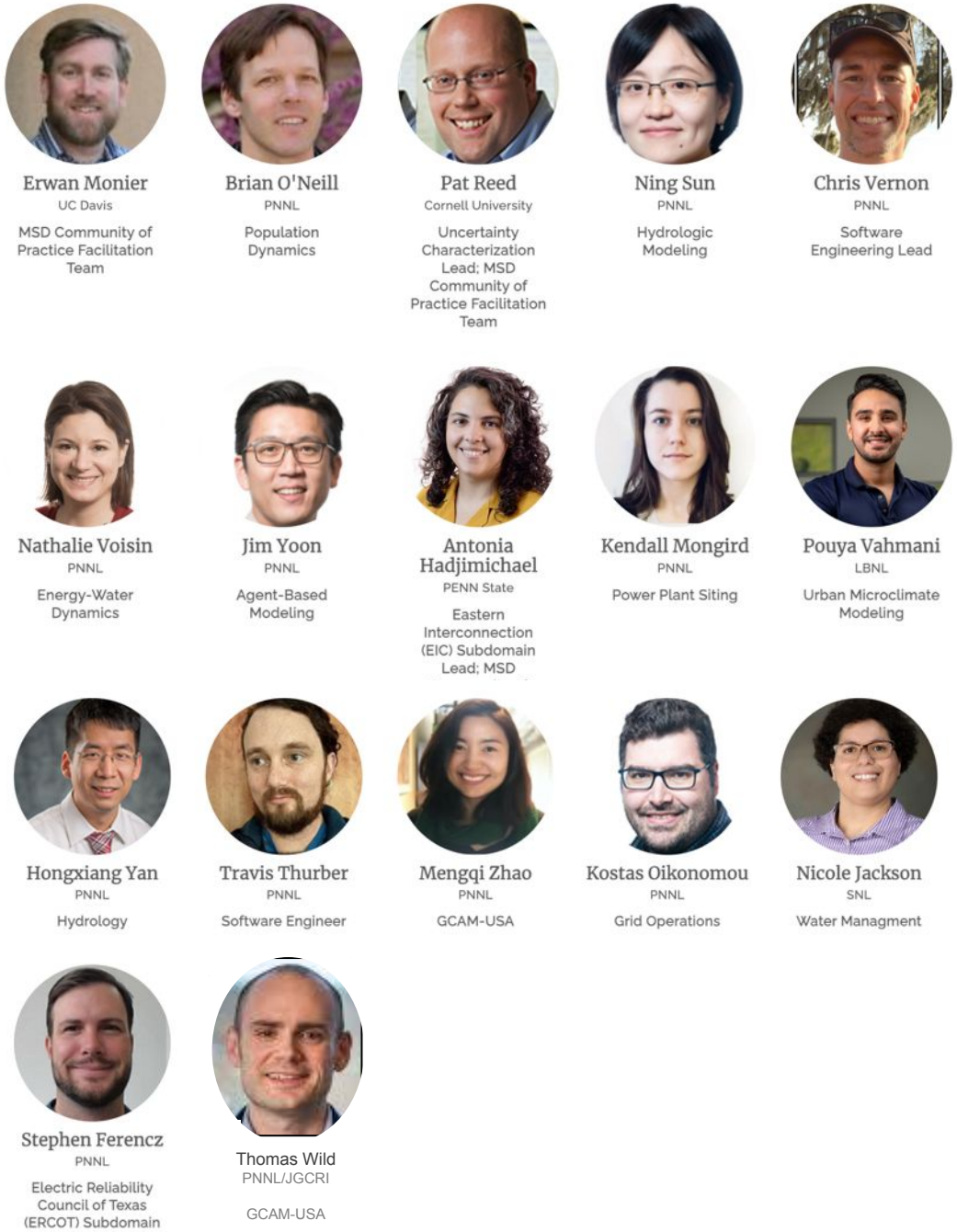
U.S. DEPARTMENT OF ENERGY
Applied Offices

IM3 at the EESM PI Meeting



IM3 Leadership





- Full team is about 60 people across institutions (~30 at PNNL)

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INTEGRATED MULTISECTOR MULTISCALE MODELING

Thank you

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This research is supported by the U.S. Department of Energy, Office of Science, as part of research in MultiSector Dynamics, Earth and Environmental System Modeling Program

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