OFFICE OF BIOLOGICAL AND ENVIRONMENTAL RESEARCH
Earth and Environmental System Modeling

U.S. DEPARTMENT OF ENERGY | Office of Science

AN INTEGRATED FRAMEWORK FOR MODELING MULTI-SYSTEM DYNAMICS

Socioeconomic forces and environmental changes variably affect natural resources and physical systems—land, water, energy—across the United States.

To manage these resources under changing conditions, decision-makers in communities, regions, and states require the ability to identify particularly vulnerable infrastructure and populations.

They also need robust strategies for infrastructure development aligned with economic development plans.

By focusing research on risks of extremes and compounding events through integrated modeling of physical and socioeconomic systems, we gain insights on the vulnerabilities and resilience in a region, potential tipping points, and responses and feedbacks throughout these systems *(see Figure 1)*.

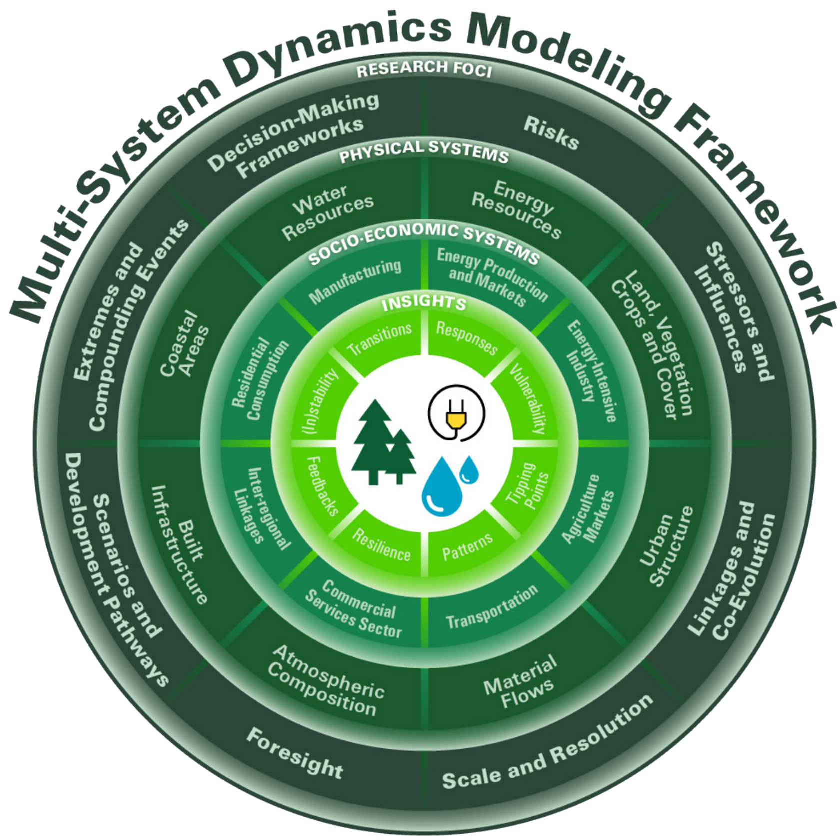

Figure 1. A complex "system of systems" comprises the MIT Joint Program's research vision for future modeling studies and defines the scope of this project.

A REGIONAL FOCUS

This project focuses on two regions in the United States (the Lower Midwest and Gulf Coast), three systems (water/land, energy infrastructure, and coastal communities) and four economic sectors (transportation, agriculture, industry, and energy)—all subject to compounding extreme events and more gradual transitions driven by long-term forces and patterns of development.

The regional boundaries for this research are variable. Some systems require a broad geographic focus (e.g., the entire Mississippi River basin to consider flooding or global agricultural markets for pressures on land-use change within the regions of interest) while others may require focus on specific communities/facilities (e.g., risks to port facilities or to specific urban infrastructure).

The chosen regions provide interesting natural (river), built (levee system, transportation network), and economic (fuels, electricity, transportation, ports) connections between the regions.

CHALLENGES

This project addresses two central science questions:

- Could changes in the severity, frequency, and intervals of extreme and/or compounding events significantly exceed the resilience of the coupled regional water, land, and energy systems *(see Figure 2)* and/or alter the trajectories of regional and sub-regional multi-sector dynamics and economic activity?
- What insights can be gained from a focus on these events, such as coastal and inland flooding from tropical storms, extreme heat, ice storms and droughts, accompanied by significant changes involving water, energy, land use, populations and the built environment?

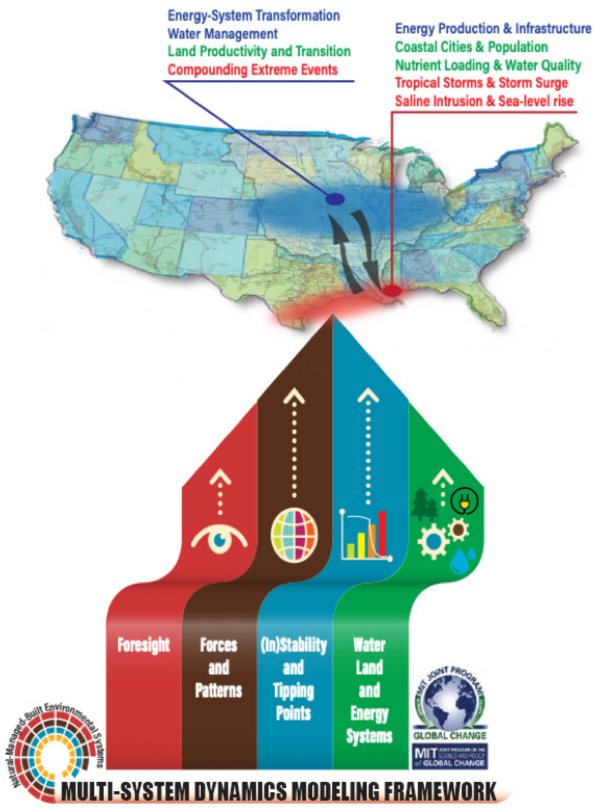

Figure 2. The modeling framework projects instabilities and tipping points—each driven by long-term forces and patterns—among interconnected water, land and energy systems at the regional level.

APPROACH

To address these questions, researchers enhance and apply tools, including:

- A land-water system model that simulates how precipitation, temperature, geomorphology and land cover affect water runoff and river flow, including metrics of water resource quantity and quality;
- Large ensembles of the evolution of the global atmosphere and climate system under varying economic conditions and ranges of earth-system response, with various downscaling techniques to improve the simulation of changes in the likelihood of extreme events at local and regional levels;
- Various stochastic dynamic program approaches that can represent a variety of decision-making behaviors;
- Large ensembles of scenarios of regional economic development representing different patterns and levels of population and productivity growth, technological development, and household consumption patterns; and
- Coupled models of agriculture, energy, transportation, industry, and services including links to household consumption patterns and income sources.

OUTCOMES

This project will serve as a testbed for several hypotheses about the co-evolution of biophysical systems and socioeconomic sectors in their response to multiple environmental stressors and economic and demographic influences, including:

- Uncertainty quantification and risk assessment can lead to more stable and resilient development pathways.
- Scale of decision-making contributes to the stability of systems, with independent optimal local decisions potentially adding instability to larger systems while optimal system-level decisions could create greater stability.
- Level of foresight factored into decision-making affects the resulting stability and resilience of systems.
- Accounting for regional, sectoral, and system connections leads to more resilient response strategies.
- Considering risks jointly with their compounding influences and stressors, rather than in isolation, results in more resilient response strategies.

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