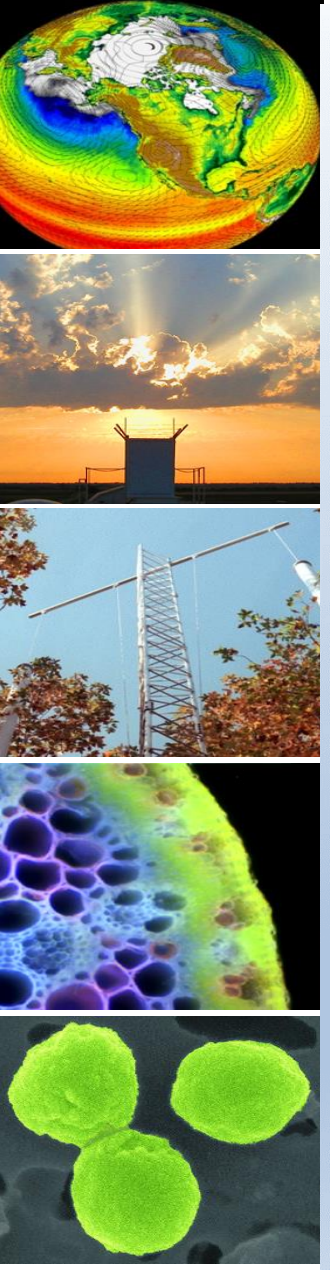


MultiSector Dynamics and Linkages with ESMD

Bob Vallario

Program Manager
MultiSector Dynamics in
Earth and Environmental Systems Modeling

EMSD PI Meeting

October 27, 2020

Goal

Explore the *complex interactions and potential co-evolutionary pathways* within the integrated human-Earth system, including natural, engineered, and socioeconomic systems and sectors.

Strategic Objectives

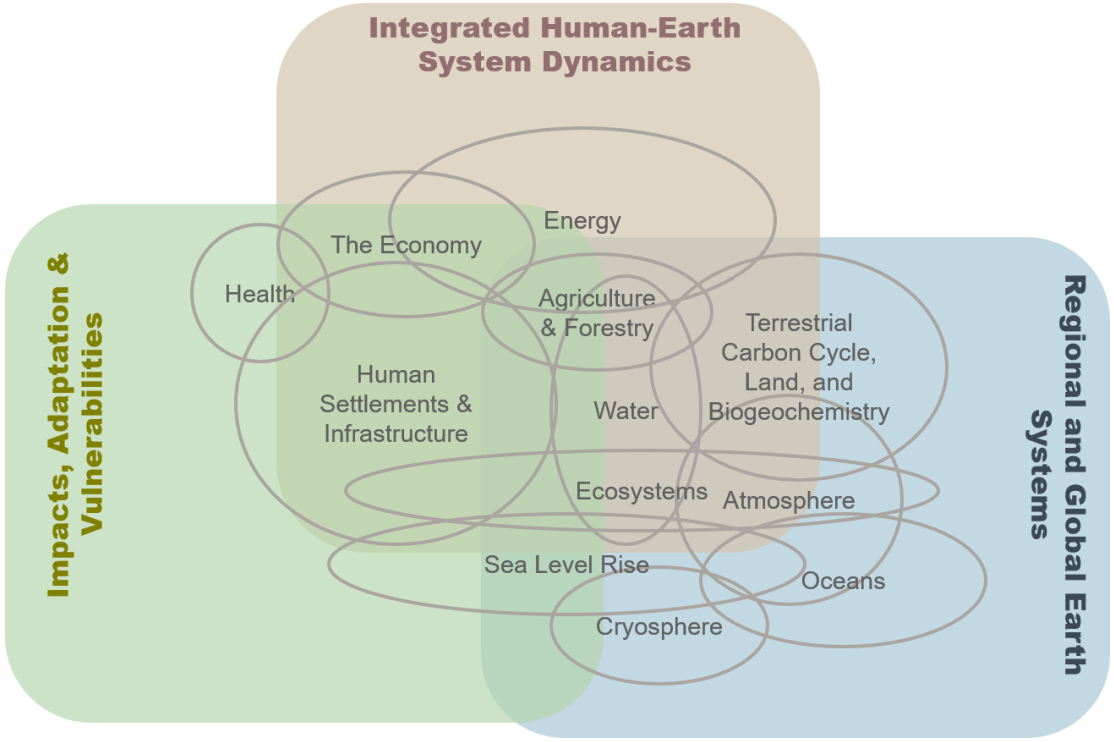
1. **Forces and Patterns.** Reveal the combination of factors, varying by geographies, that contribute most significantly to ***patterns of development in transregional, regional, and sub-regional landscape evolutions,*** including interactions and interdependencies among natural and built environments and human processes and systems.

2. **Stabilities and Instabilities.** Identify the characteristics of interacting natural and built environments and human processes that lead to ***stabilities*** **and** ***instabilities*** across systems, sectors, and scales, and deliver new insights into the role of strong interdependencies, feedbacks, and compounding influences and stressors.

3. **Foresight**. Explore how development patterns, stabilities, instabilities, and *systems resilience* may evolve within multisector, multi-scale landscapes as a result of ***future forces, stressors, and disturbances…*** and reveal what pathways, characteristics, and risk profiles may emerge from ***both gradual and abrupt transitions***.

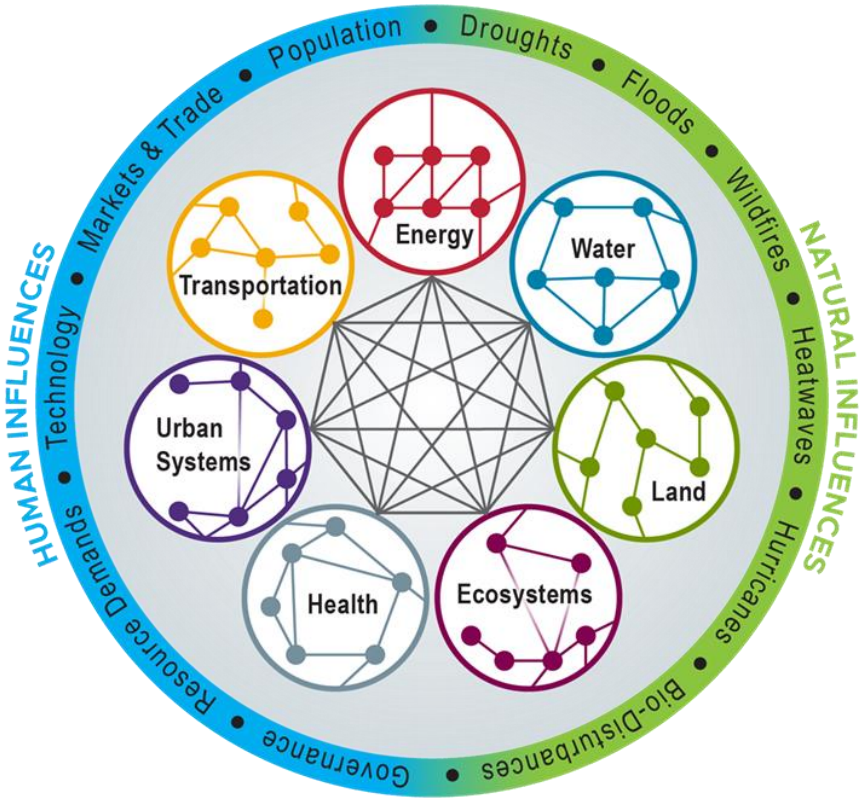
Somewhat iconic representations

Global Earth System Evolution



- Regional to Global
- Earth system drivers, impacts, and responses
- Energy and land

Regional Landscape Evolution



- Local to regional
- MSD and complex landscape evolution
- Multi-influence, multi-stressor
- Sectors, infrastructures, regional economies, natural resources

MSD Research Priorities

- **Functional, collaborative community-of-practice and working group structure**
- **Hierarchical frameworks** and use-inspired tools (emulators, sensitivity research, etc.)
- **Distributed science mechanisms** (i.e., open source models, software couplers, interoperability, modular methods, community data and computation
- **Complexity theory and science** (networks, collective behavior, evolution and adaptation, pattern formation, systems theory, machine learning, etc.)
- **Scenario methods and development** with implications for uncertainty framing/analysis, complex storylines, modeling experiments, and more.
- **Model resolution and fit-for-purpose process details** across spatial and temporal scales (e.g., energy, water, land, economics, population, land use, technology
- **Significant coupled systems behaviors**, such as found among energy, water, land and socioeconomic systems with non-linear responses, e.g., induced by extremes

MSD Major Projects: National Lab SFAs/ and Projects and University Collaborative Agreements

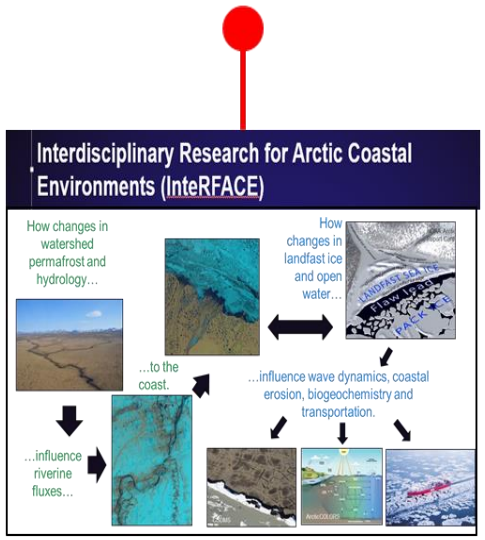
1. Integrated Multi-sector, Multi-scale Modeling SFA (IM3)
   SFA PI: Jennie Rice
2. Global Change Intersectoral Modeling System SFA (GCIMS)
   SFA PI: Mohamad Hejazi
3. Integrated Coastal Modeling (ICOM)*
   PI: Ian Kraucunas
4. Interdisciplinary Research for Arctic Coastal Environments (InteRFACE)*
   PI: Joel Rowland
5. Program on Coupled Human Earth Systems (PCHES) CA
   CA PI: John Weyant/Karen Fisher-Vanden/Rob Nicholas
6. Integrated Global Systems Modeling (IGSM) CA
   CA PI: Ron Prinn /John Reilly
7. HyperFACETS*
   CA PI: Paul Ullrich

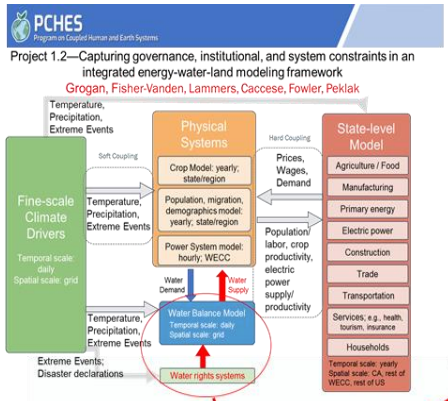
* Collaborative program funding

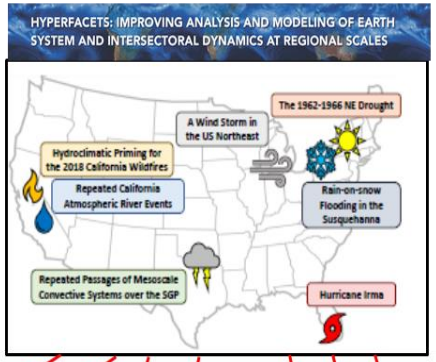
Partners (examples):

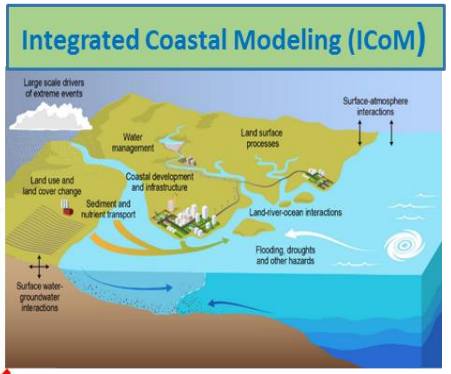
NREL
Sandia National Laboratories
Berkeley Lab
University of Maryland
UCAR
Cornell University
PennState
Boston University
Texas A&M University
Utah State University
Stony Brook University
UCLA
Purdue University
University of Delaware
University of New Hampshire
The University of Utah
Iowa State University

Some common geographies of interest

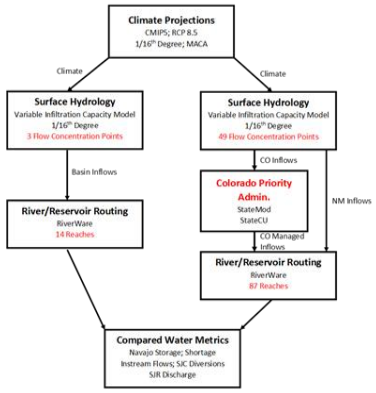








San Juan River Basin



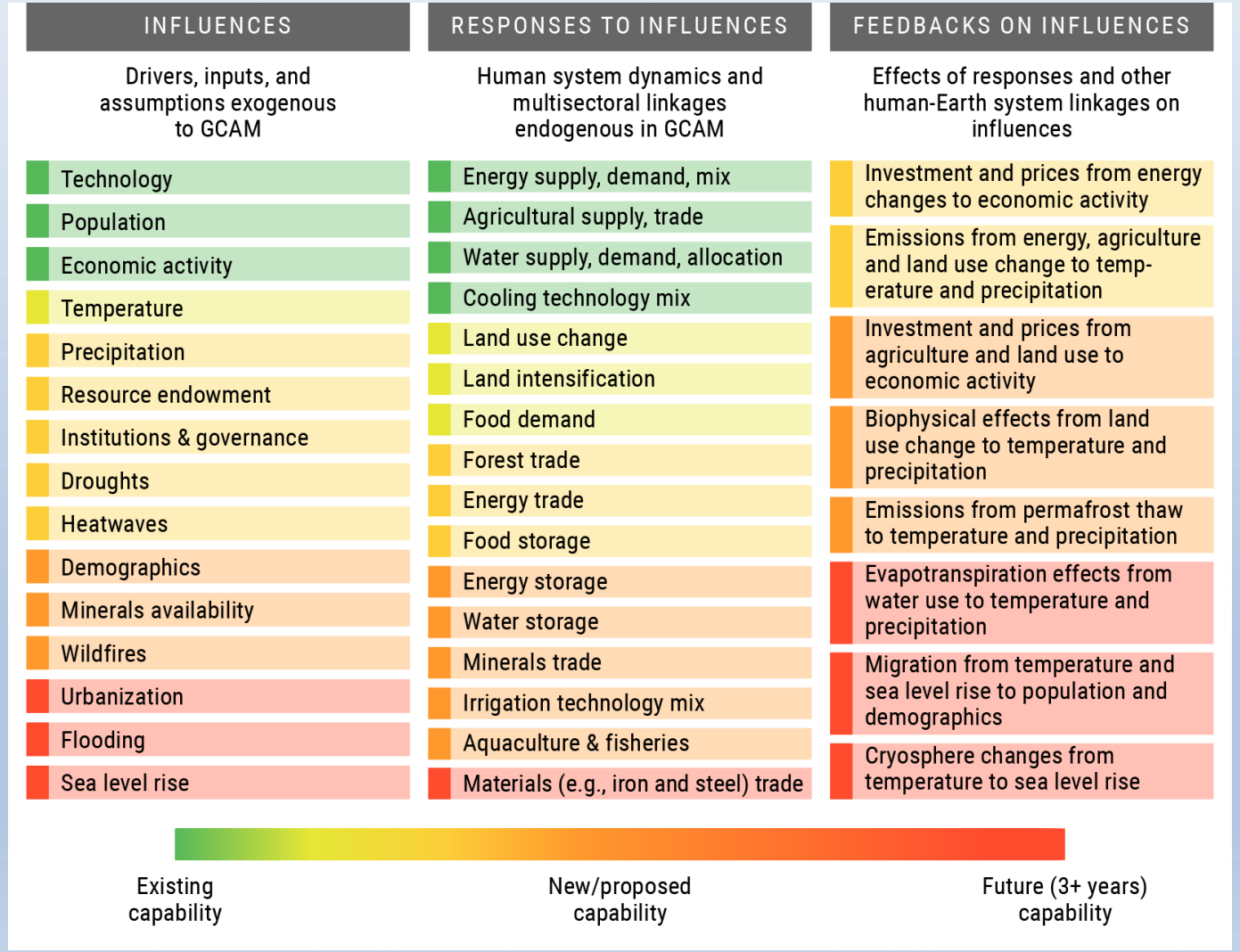
Sectoral Interactions, Stressors, and Tipping Points

MSD and ESMD connections (examples)

- Kate Calvin is Chief Scientist for MSD's GCIMS SFA and Task Leader for E3SM
- Co-support, with Renu in RGMA, Ruby Leung (E3SMs Chief Scientist) on HypeRFACETS
- Fine scale work in IM3…e.g., work on perennial bioenergy crops for the Community Terrestrial System Model (CTSM), formerly the Community Land Model (CLM) now being adapted for ELM
- Integrated Coastal Modeling (ICoM) project in the Mid-Atlantic region
- Interdisciplinary Research for Arctic Coastal Environments (InteRFACE) project
- Upcoming MSD Town Hall with Xujing as speaker/panelist on opportunities and connections within Earth and environmental systems sciences

- Focuses on long-term evolution of the coupled human-Earth system
- An integrated framework to investigate the interplay between influences, responses, and feedbacks
- Internally consistent, tightly coupled, computationally efficient framework
- Regional to global spatial scales and seasonal to multidecadal timescales
- Major research experiments:
  - Compounding Influences
  - Regional Teleconnections
  - Human Responses
  - Human–Earth System Feedbacks

gcims.pnnl.gov



Models and Tools in GCIMs SFA

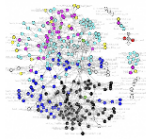
Dynamic Integration

GCAM: Global Change Analysis Model

GCAM-USA: 50 U.S.-State Version of GCAM

Cassandra: Model Coupling Framework

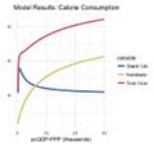
Data Development



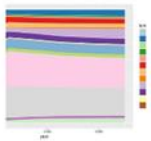
gcamdata: GCAM Data System

Moirai: Land Data Amalgamation for GCAM's AgLu Module

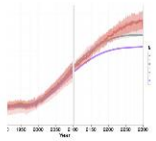
Component System



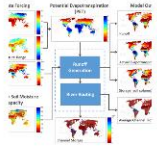
Ambrosia: GCAM Food Demand Model



gcamland: GCAM Land Allocation Model

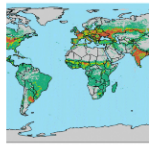


Hector: Reduced-Form Climate Model

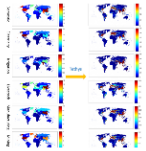


Xanthos: Global Hydrologic Modeling Framework

Disaggregation

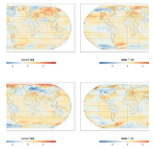


Demeter: Land Use and Land Cover Change Disaggregation

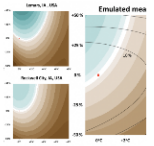


Tethys: Spatial and Temporal Sectoral Water Demand Downscaling

Statistical Emulators



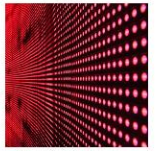
fldgen: Earth System Model Emulator for Temperature and Precipitation



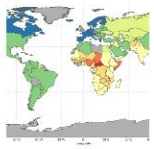
Persephone: Crop Model Yield Change Emulator

Supporting Tools

GCAM Interactive Visualization Dashboard: A Scenario Explorer

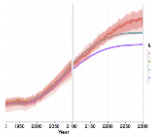


gcam_reader: GCAM Data Extraction Python Package



gcammaptools: Geospatial Visualization R Package

pygis: Python GIS Utilities



Pyhector: Python Interface for Hector

rgcam: GCAM Data Extraction R Package

rgis: R GIS Utilities

GCIMS SFA and the ESMD Connection

- In *general*…the human systems in E3SM
- GCAM (full version in coupled mode) – emissions and land use/land to E3SM with productivity from E3SM to MSD.
- Eventual plans to link GCAM's water components in E3SM (as well as GCIMS' Tethys to downscale water demand)…currently use for offline diagnostics and analysis and use GCIM's Hector to define the scenarios.
- GCAM contributed 2 scenarios to CMIP6. E3SM has not run those two scenarios but in v2, with runs starting in 2021, the BGC group will be running GCAM-generated scenarios.
- Other potential:
  - Exploring use of GCIM's Demeter to downscale land demand
  - Exploring more feedbacks in E3SM v3 such as environmental influences on energy supply/demand.
  - climate emulators developed through GCIMS to help identify which scenarios are valuable to run in expensive Earth System Models. And more broadly for ESMs…potential for human-system emulators who can't link GCAM directly (e.g., GCIMS experiment 1 relevance…for a temperature change of x, how much do emissions or land use change?)
  - GCIMs experiment 4 to explore uncertainty space and then run E3SM-GCAM for a subset of simulations to quantify potential error between the emulated response and the ESM response.

Recent Publications

2020

Humans drive future water scarcity changes across all Shared Socioeconomic Pathways

Neal T Graham; Mohamad Hejazi; Min Chen; Evan G R Davies; James A Edmonds; Son H Kim; Sean Turner

Environmental Research Letters

READ

2020

100 years of data is not enough to establish reliable drought thresholds

Robert Link; Thomas B. Wild; Abigail Snyder; Mohamad Hejazi; Chris R. Vernon

Journal of Hydrology X 7

READ | DATASET

2020

The Role of Climate Sensitivity in Upper-Tail Sea Level Rise Projections

B. Vega-Westhoff; Ryan Sriver; Corinnel Hartin; T. E. Wong; K. Keller

Geophysical Research Letters 47(6)

READ

2020

Technical note: Deep learning for creating surrogate models of precipitation in Earth system models

Theodore Weber; Austin Corotan; Brian Hutchinson; Ben Kravitz; Robert Link

Atmospheric Chemistry and Physics 20(4)

READ

2020

The critical role of conversion cost and comparative advantage in modeling agricultural land use change

Xin Zhao; Katherine Calvin; Marshall Wise

Climate Change Economics 11(1)

READ

2020

Moirai Version 3: A Data Processing System to Generate Recent Historical Land Inputs for Global Modeling Applications at Various Scales

Alan Di Vittorio; Chris R. Vernon; Shijie Shu

Journal of Open Research Software 8

READ

2019

Implications of water constraints on electricity capacity expansion in the United States

Lu Liu; Mohamad Hejazi; Gokul Iyer; Barton A. Forman

Nature Sustainability 2(3)

READ | HIGHLIGHT

2019

Impacts of Observational Constraints Related to Sea Level on Estimates of Climate Sensitivity

Benjamin Aaron Vega-Westhoff; Ryan Sriver; Corinne Hartin; Tony E. Wong; Klaus Keller

Earth's Future 7(6)

READ | HIGHLIGHT

2019

A Global Hydrologic Framework to Accelerate Scientific Discovery

Chris R. Vernon; Mohamad Hejazi; Sean Turner; Yaling Liu; Caleb J. Braun; Xinya Li; Robert Link

Journal of Open Research Software 7()

READ | HIGHLIGHT

2019

Representing power sector detail and flexibility in a multi-sector model

Marshall Wise; Pralit Patel; Zarrar Khan; Son H Kim; Mohamad Hejazi; Gokul Iyer

Energy Strategy Reviews 26

READ

2019

A crop yield change emulator for use in GCAM and similar models: Persephone v1.0

Abigail Snyder; Katherine Calvin; Meridel Phillips; Alex C. Ruane

Geoscientific Model Development 12(4)

READ | HIGHLIGHT

2019

Joint emulation of Earth System Model temperature-precipitation realizations with internal variability and space-time and cross-variable correlation: fldgen v2.0 software description

Abigail Snyder; Robert Link; Kalyn Dorheim; Ben Kravitz; Ben Bond-Lamberty; Corinne Hartin

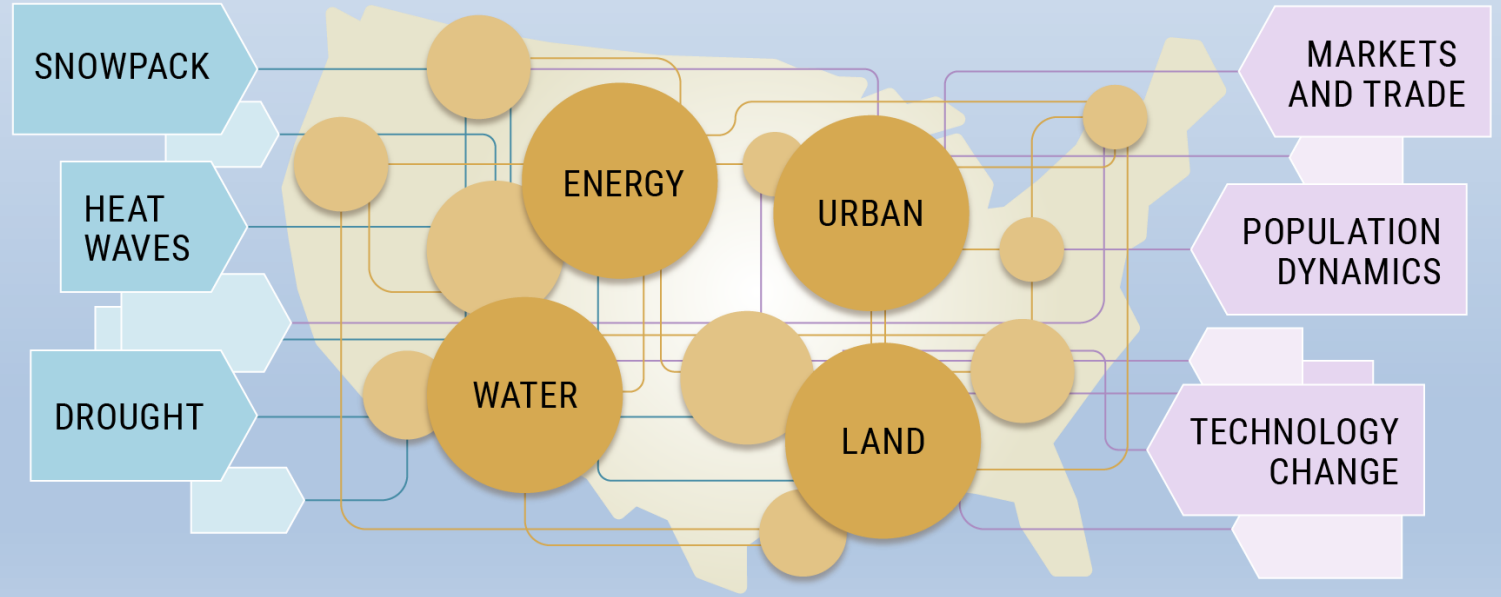
PLOS ONE 14(10)

READ | HIGHLIGHT

GCIMS.PNNL.GOV

IM3

1. **Develop flexible, open-source, integrated modeling capabilities** that capture the structure and dynamic behavior 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 due to long-term influences and short-term shocks, from local to continental scales.
3. **Explore how uncertainty** in data, model structure, model parameters, multi-model coupling strategies, and spatial and temporal resolutions influence projections of human-natural systems evolution.



im3.pnnl.gov

IM3 Research and E3SM Spinoff

Enhancing the Community Terrestrial System Model to Grow Perennial Bioenergy Crops

Scientific Challenge

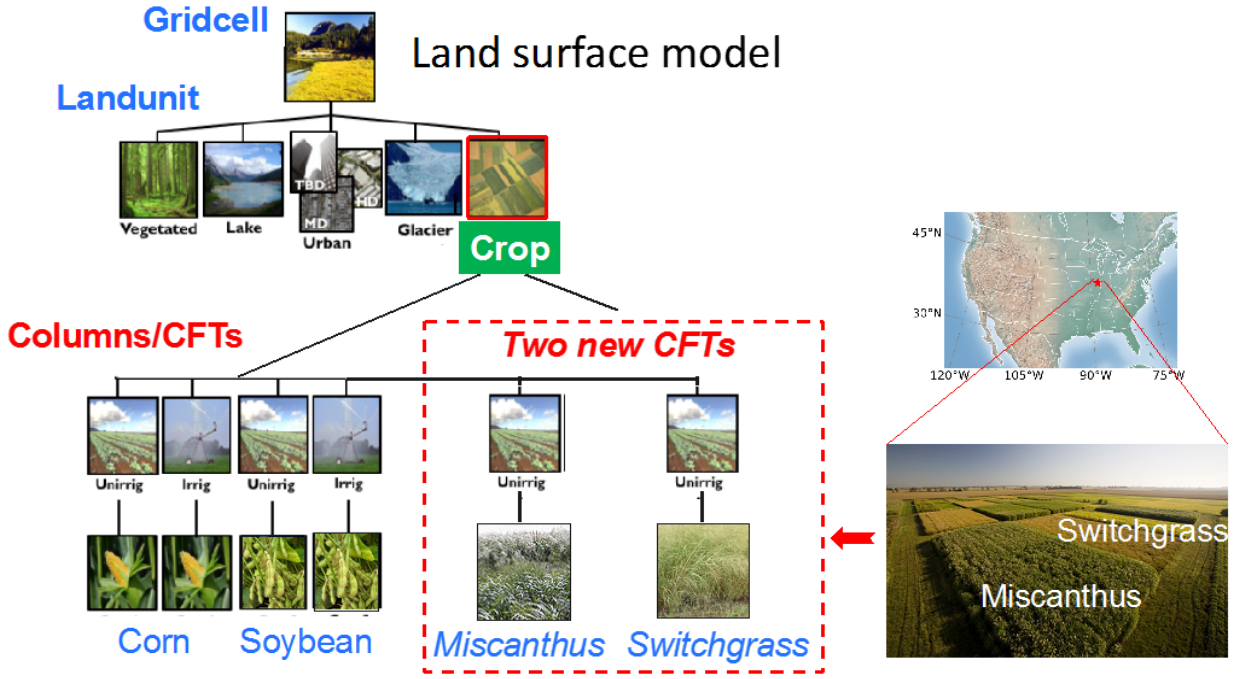
- Improve perennial bioenergy crop representation in terrestrial system models.

Approach and Results

- Implement two new perennial bioenergy crops, Miscanthus and switchgrass, into the latest version of the Community Terrestrial System Model (CTSM), previously known as the Community Land Model (CLM)
- Validate this new capability in CTSM with *in situ* observations in the Central Midwestern United States
- Demonstrate the model is capable of capturing observed patterns of energy and carbon fluxes for the two new perennial bioenergy crops.

Significance and Impacts

- Simulated perennial bioenergy crops in the CTSM land model for the first time
- Established the foundation for quantifying the effects of potential biofuel expansion on complex human-Earth system dynamics at local, regional and global scales



Effectively modeling perennial bioenergy crops is essential to understanding the effect of projected increases in biofuel production.

Cheng, Y., Huang, M., Chen, M., Guan, K., Bernacchi C., Peng, B., and Tan, Z., 2019, Parameterizing perennial bioenergy crops in Version 5 of the Community Land Model based on site-level observations in the Central Midwestern United States, *Journal of Advances for Modeling the Earth system*, 12(1), https://doi.org/10.1029/2019MS001719.

Recent publications

2020

Impact of climate change on adaptive management decisions in the face of water scarcity

Yang, YCE, K Son, F Hung, and V Tidwell

Journal of Hydrology 588

> READ | DATASET

2020

River regulation alleviates the impacts of climate change on U.S. thermoelectricity production

Zhang X, H-Y Li, LR Leung, L Liu, MI Hejazi, BA Forman, and W Yigzaw

Journal of Geophysical Research: Atmospheres 125

> READ | HIGHLIGHT

2020

Inferred inflow forecast horizons guiding reservoir release decisions across the United States

Turner SWD, W Xu, and N Voisin

Journal of Hydrology and Earth System Sciences 24

> READ | DATASET

2019

Parameterizing perennial bioenergy crops in version 5 of the Community Land Model based on site-level observations in the central midwestern United States

Cheng Y, M Huang, M Chen, K Guan, C Bernacchi, B Peng, and Z Tan

Journal of Advances in Modeling Earth Systems 12

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2019

Improving consistency among models of overlapping scope in multi-sector studies: The case of electricity capacity expansion scenarios

Iyer GC, M Brown, SM Cohen, J Macknick, P Patel, M Wise, MC Binsted, and N Voisin

Renewable and Sustainable Energy Reviews 116

> READ

2019

Sensitivity of western U.S. power system dynamics to droughts compounded with fuel price variability

O'Connell M, N Voisin, J Macknick, and T Fu

Applied Energy 247

> READ | HIGHLIGHT

2019

Interacting implications of climate change, population dynamics, and urban heat mitigation for future exposure to heat extremes

Vahmani P, AD Jones, and CM Patricola

Environmental Research Letters 14

> READ | HIGHLIGHT | DATASET

2019

A multi-layer reservoir thermal stratification module for Earth system models

Yigzaw W, H-Y Li, X Fang, LR Leung, N Voisin, MI Hejazi, and Y Demissie

Journal of Advances in Modeling Earth Systems 11

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2019

Calibration and analysis of the uncertainty in downscaling global land use and land cover projections from GCAM using Demeter (v1.0.0)

Chen M, CR Vernon, M Huang, KV Calvin, and I Kraucunas

Geoscientific Model Development 12

> READ | HIGHLIGHT

2019

Choice of irrigation water management practice affects Indian summer monsoon rainfal land its extremes

Devanand A, M Huang, M Ashfaq, B Barik, and S Ghosh

Geophysical Research Letters 46(15)

> READ | HIGHLIGHT

2019

Planning for sustained water-electricity resilience over the U.S.: Persistence of current water-electricity operations and long-term transformative plans

Voisin N, V Tidwell, M Kitner-Meyer, and F Boltz

Water Security 7

> READ | HIGHLIGHT

2019

A multi-scale calibration approach for process-oriented aggregated building energy demand models

Taylor ZT, Y Xie, CD Burleyson, N Voisin, and I Kraucunas

Energy and Buildings 191

> READ | HIGHLIGHT

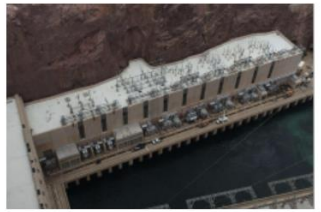
2019

The nonlinear response of storm surge to sea-level rise: A modeling approach

Wang T, and Z Yang

Journal of Coastal Research 35(2)

> READ | HIGHLIGHT



2019

Implications of water management representations for watershed hydrologic modeling in the Yakima River basin

Qiu J, Q Yang, X Zhang, M Huang, JC Adam, and K Malek

Hydrology and Earth System Sciences 23

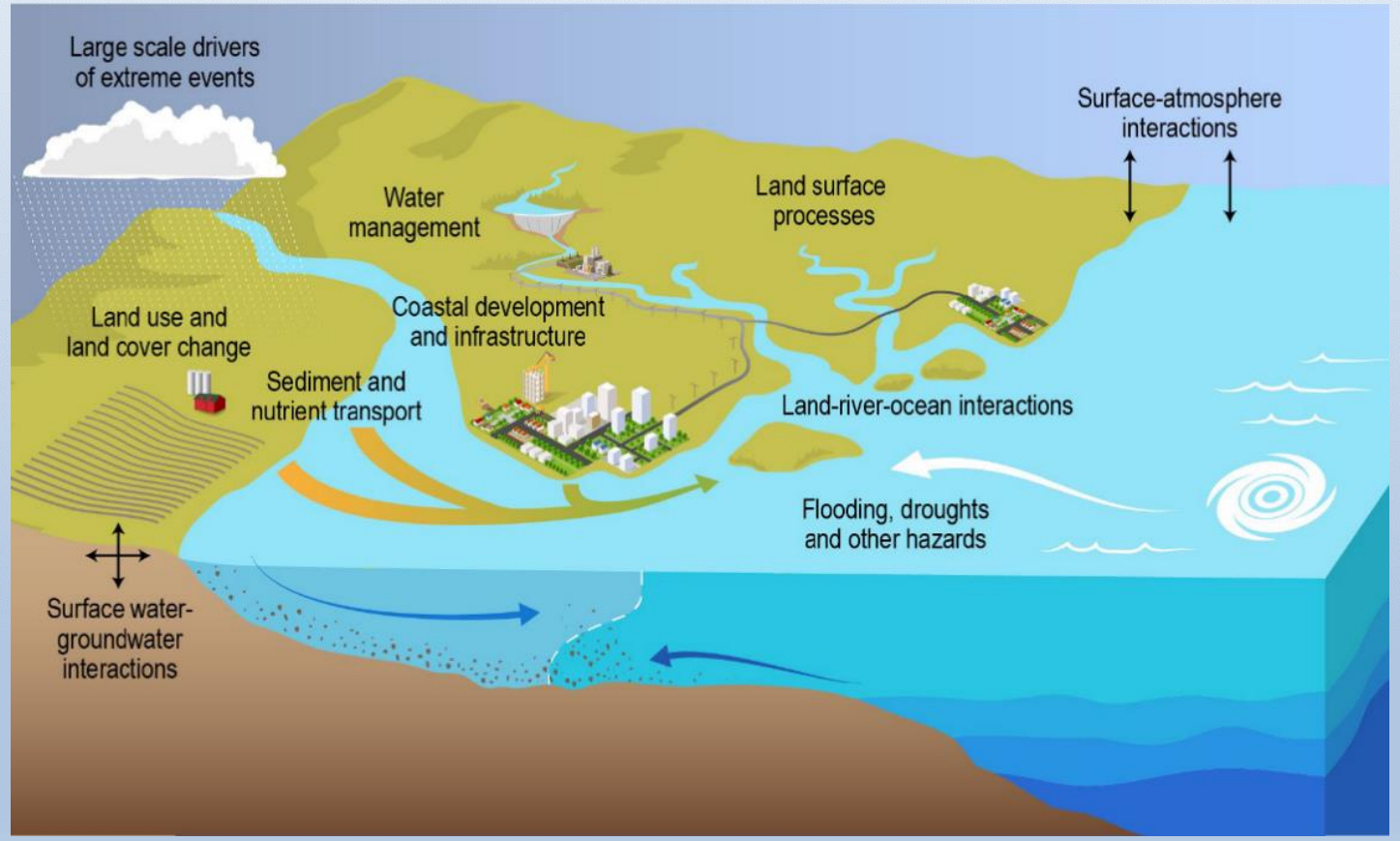
> READ

IM3 and GCIMS in Context

	IM3 SFA	GCIMS SFA
Focus	Mechanistic understanding of **stressors, vulnerabilities, resilience, and transformations in complex human-environmental landscapes** consisting of sectors, infrastructures, resources, and the natural environment.	Understanding **human drivers, responses, and feedbacks in global Earth system evolution**, with a focus on energy, water cycle, land, and biogeochemistry.
Scale	Local to Regional	Regional to Global
Focus-Relevant Partnerships	Teaming with RGMA for fine-scale analyses of local/regional interactions/dynamics (e.g., Hyperfacets) and with SBR for Watersheds and IHTM	Teaming with ESM for inclusion of humans in E3SM
Model Structure	Physics based models as well as agent-based, decision-theoretic models	Economic models with more detailed physical system emulators of energy, water, land, biogeochemistry, and climate components.
Methods	Integration and testing of best-in class component models (cross-agency)…and substitutability… within flexible, interoperable modeling frameworks	Single leadership class model (GCAM) and IHESD-developed components that are fit-for-purpose.
Leadership	PNNL - Richland, WA led multi-institutional team	JGCRI (PNNL and UMD) – College Park, MD led multi-institutional team
History	4 year history with rapidly growing domestic following, interagency interest/engagement, and emergence as a recognizable center of excellence	25 + year development with major domestic and international following and model training program
Resources	FY20 - $4.6 M	FY20 - $4.5 M

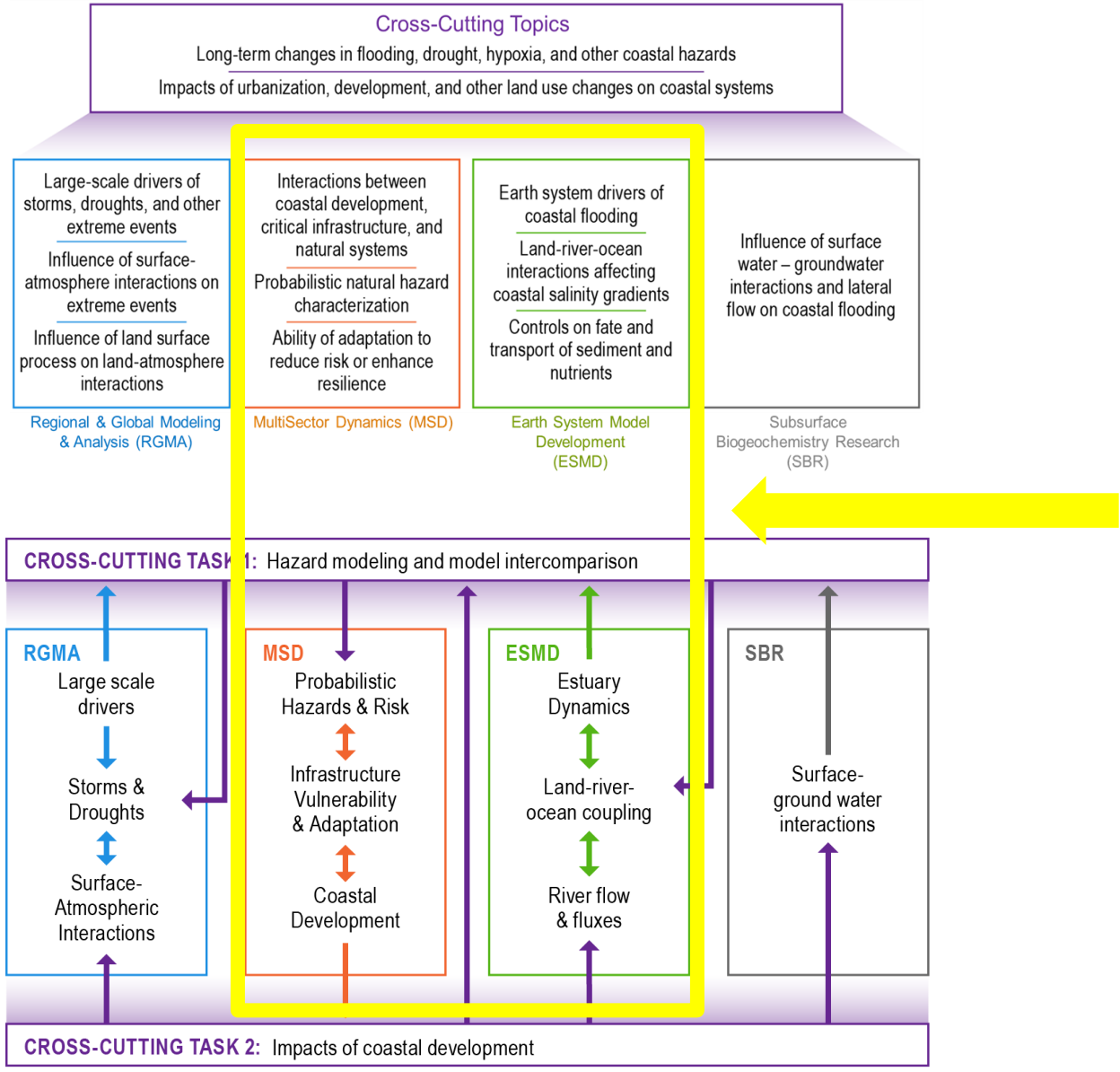
Goal: To deliver a robust predictive understanding of coastal evolution that accounts for the complex, multiscale interactions among physical, biological, and human systems.

- **Pacific Northwest National Laboratory led multi-institutional team** (LANL a strong participant)… >40% funding awarded by PNNL to others
- **Mid-Atlantic regional focus** … existing DOE capabilities, complex systems interactions, extensive data, and converging interagency activities
- **$16.2M** over three years ($5.4M/yr)
- **A "federated" approach** spanning four distinct program areas within DOE's CESD; requires foundational work in each area and substantial crosscut modeling work.
- **Informs potential follow-on observational and experimental work.**



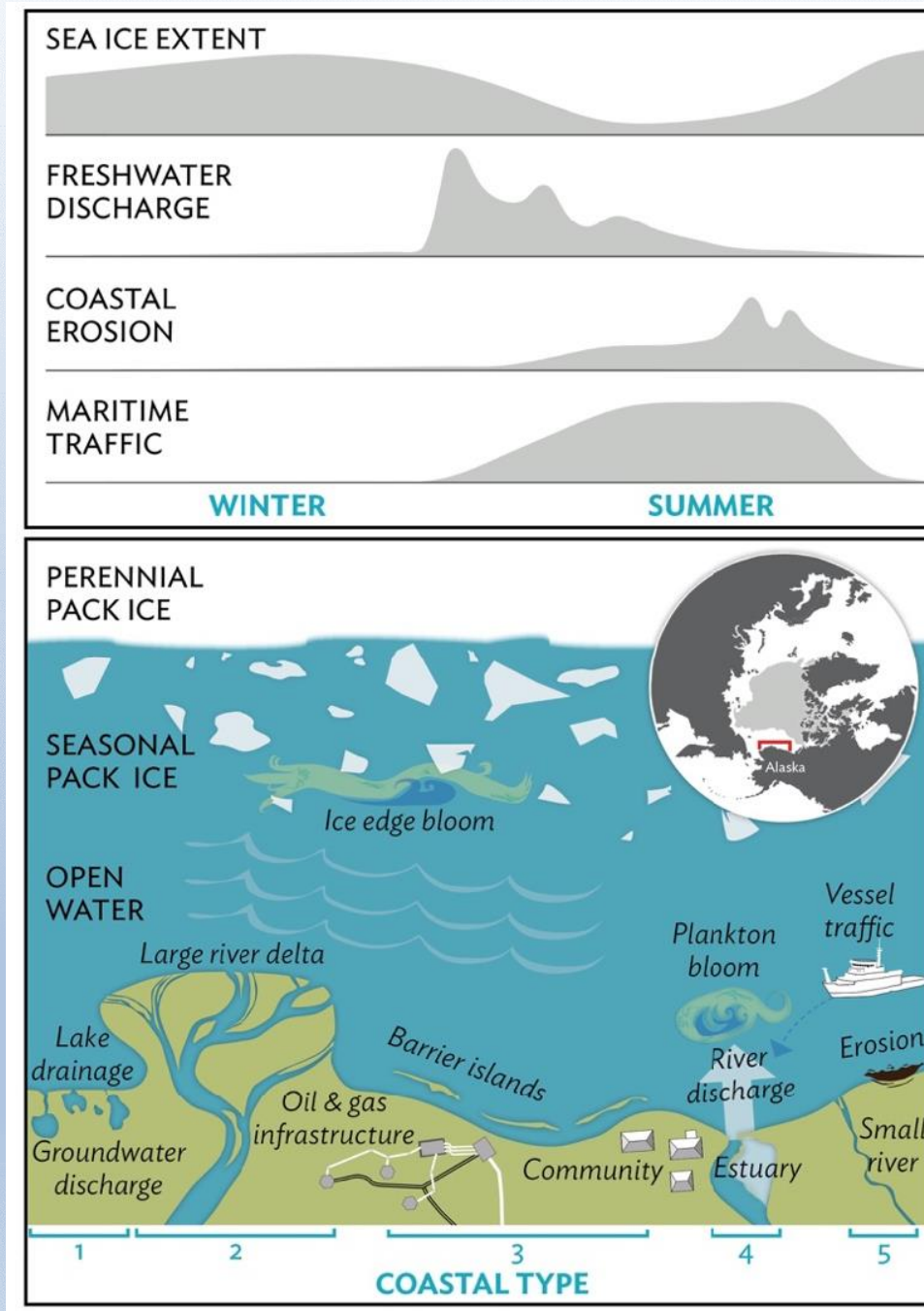
icom.pnnl.gov

Project components and study region



Enhance the understanding of interactions between natural and societal changes in the Arctic

- Co-evolution of transportation, resources development, and human systems
- Critical thresholds in this co-evolution and effects on the economy and communities
- Links of Arctic evolution to broader global dynamics



Significant Environmental Influences on Oil and Gas Development in the Arctic

Warming air and water temperatures

Ecosystem change with potential for more conflict between subsistence, conservation, oil and gas activities, and ownership (rights)

Sea ice

Affects shipping and multiple forms of transportation, subsistence hunting activity, coastal erosion

Winds & storm inundation

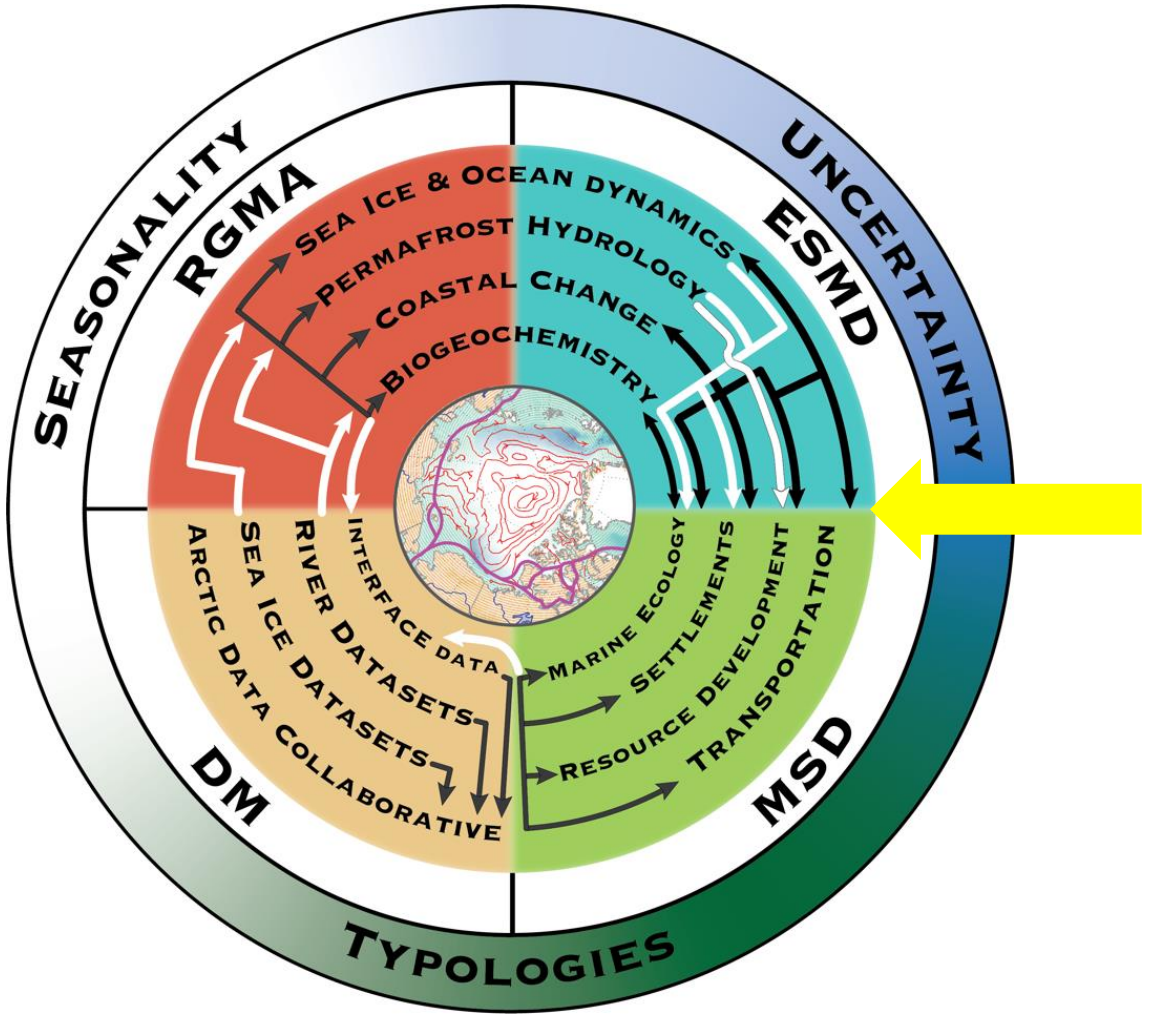
Affects coastal erosion rates and storm inundation damages infrastructure, impacts to subsistence hunting activity, danger to housing and community infrastructure

Permafrost thaw

Industry and civil infrastructure damage, food security impacts, release of methane, disease potential

Coastal flooding

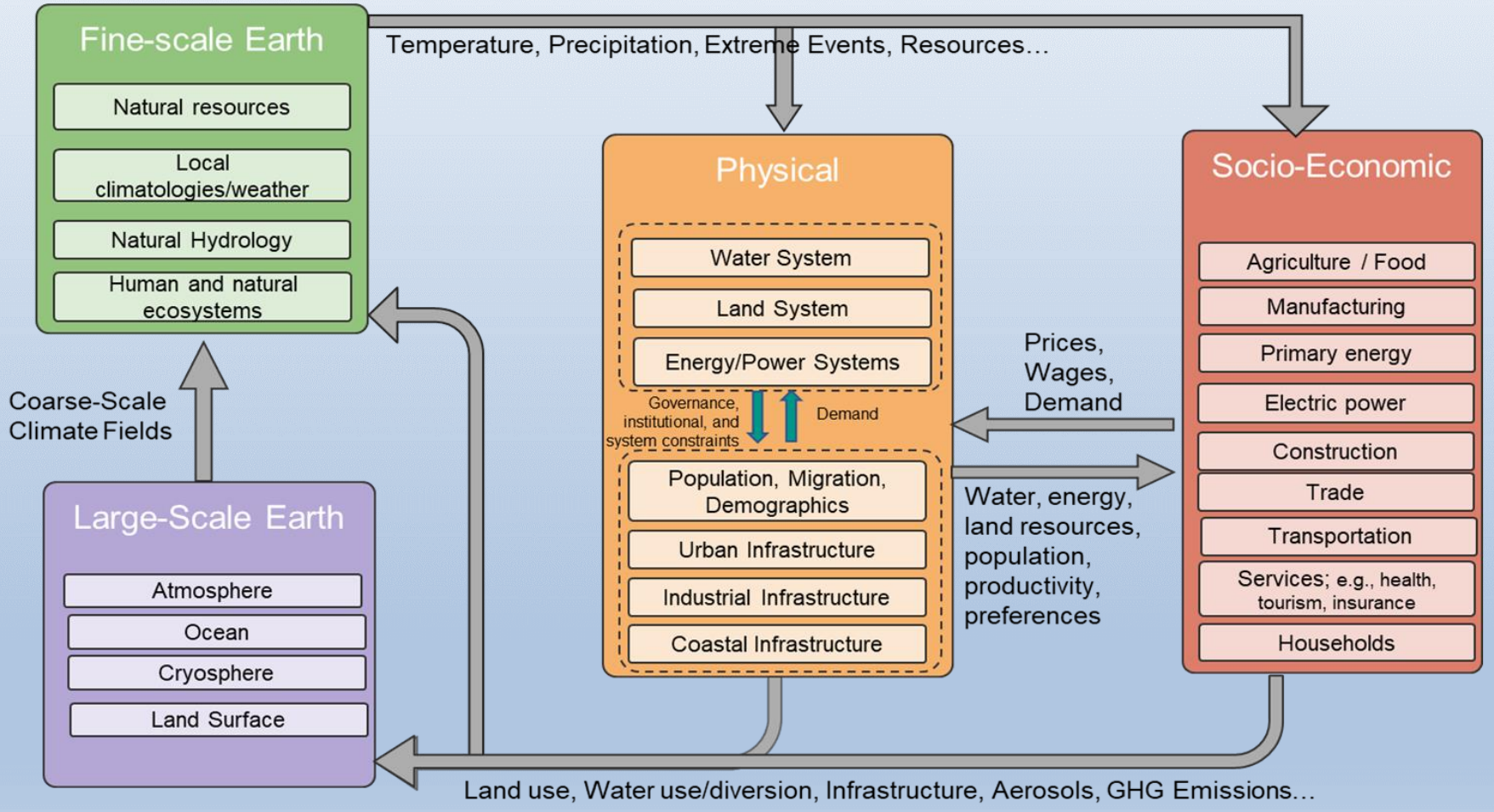
Infrastructure damage, transportation disruption, cultural dislocation (e.g. burial sites, sacred locations)



PCHES
Program on Coupled Human and Earth Systems

PennState · ILLINOIS · Stanford University · TEXAS · BOSTON UNIVERSITY · PURDUE UNIVERSITY · DARTMOUTH · COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

Goal: To build a next generation integrated suite of science-driven modeling and analytic capabilities, and a more expanded and connected community of practice, for analyses of compound stressors related to integrated Energy-Water-Land systems dynamics and interdependent infrastructures.

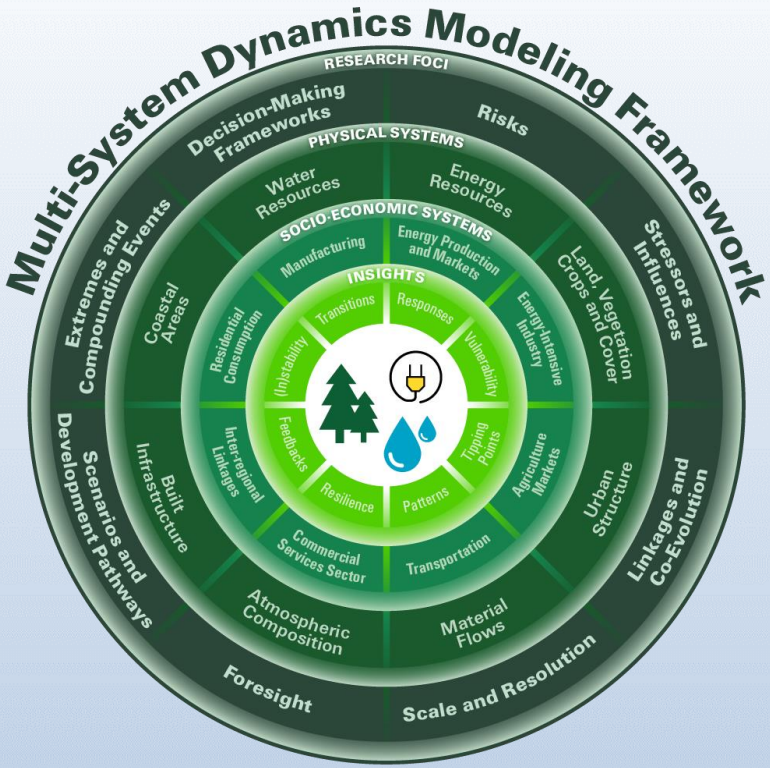


www.PCHES.psu.edu

MIT JOINT PROGRAM ON THE SCIENCE AND POLICY of GLOBAL CHANGE

ACTIVE PROJECT

An Integrated Framework for Modeling Multi-System Dynamics



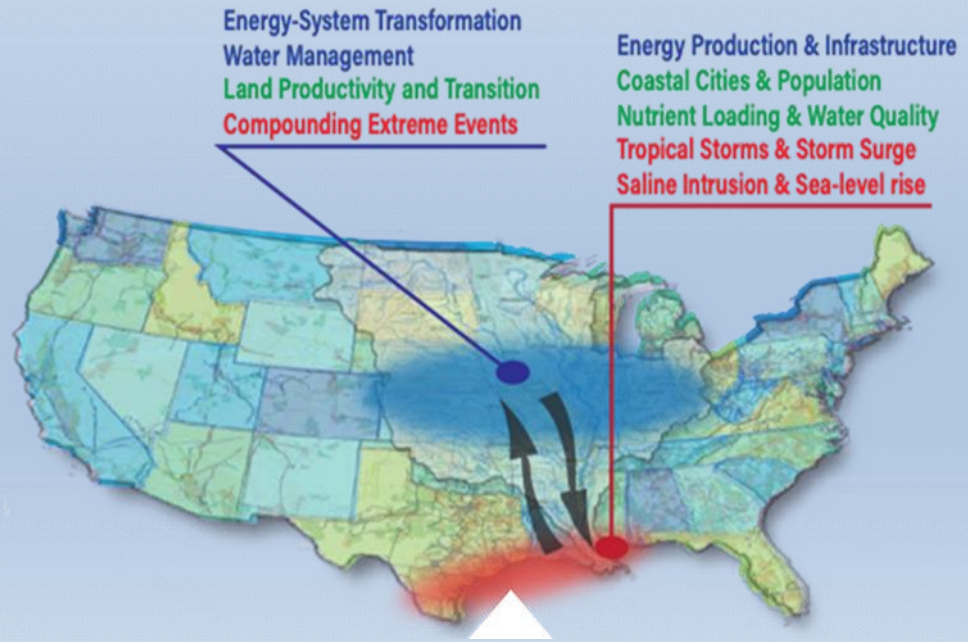
Goal: Develop a multi-system modeling framework to explore compounding stressors and tipping points at regional scales

Focus on:

Forces and patterns

Stabilities, instabilities, tipping points

Foresight and resilience



https://globalchange.mit.edu/research/research-projects/integrated-framework-modeling-multi-system-dynamics

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

niversity of California Davis
, Lawrence Berkeley National Laboratory

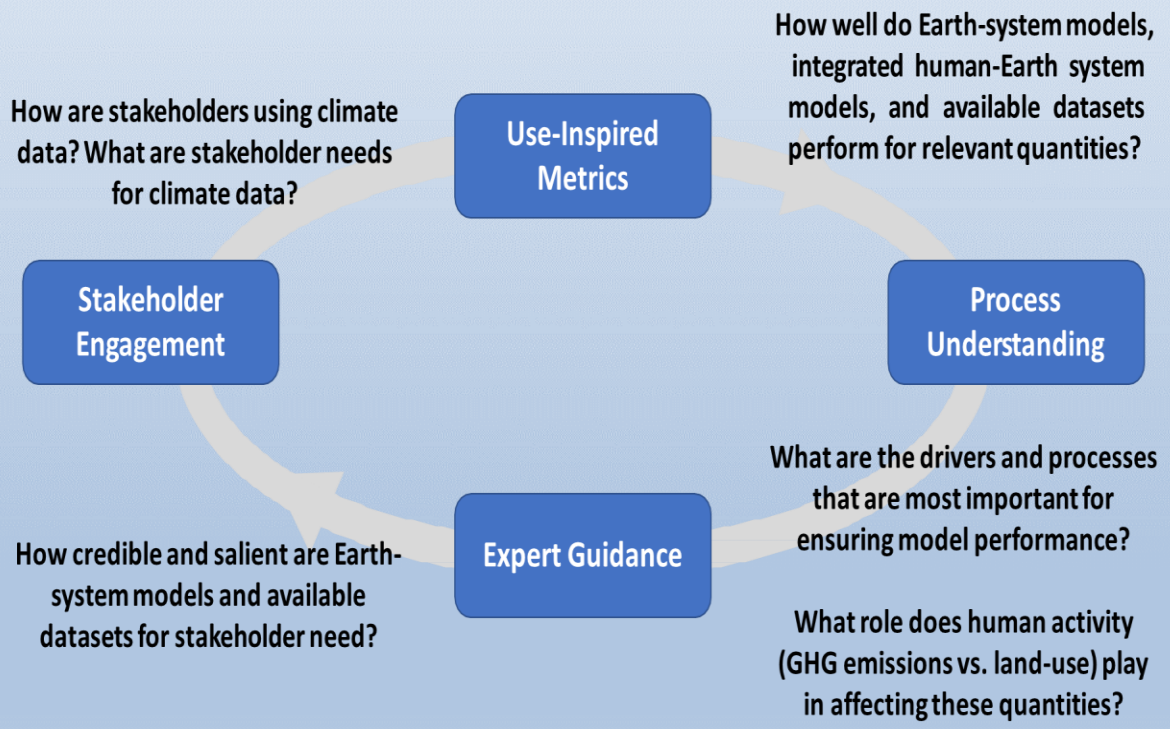
Goals

1. Advance our understanding of processes at the atmosphere-water-energy-land interface.

2. Fundamentally improve our ability to perform credible climate modeling of particular regions and the processes relevant to those regions.

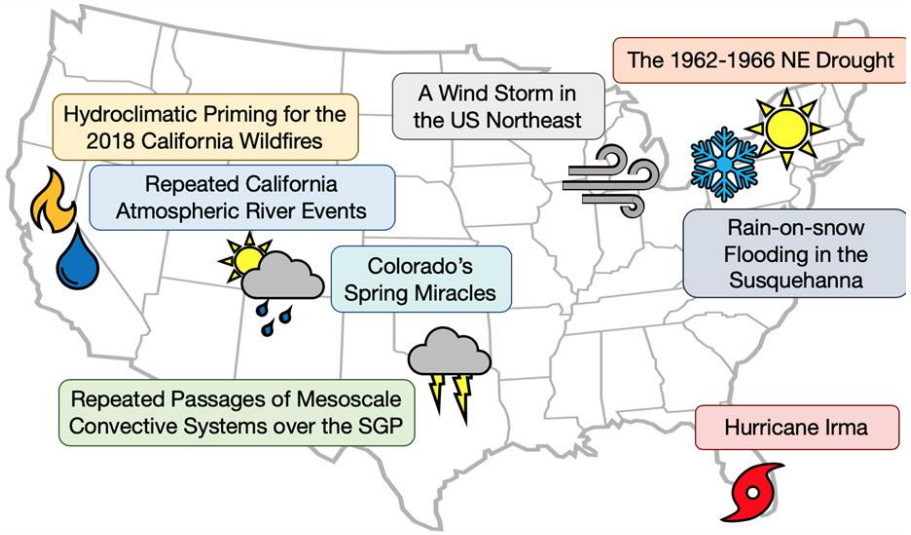
3. **Strengthen stakeholder input** in model development and evaluation. Engage effectively in **co-production:** Together enforcing the science and meeting real needs.

Process and Continuous Engagement



https://climate.ucdavis.edu/hyperfacets/

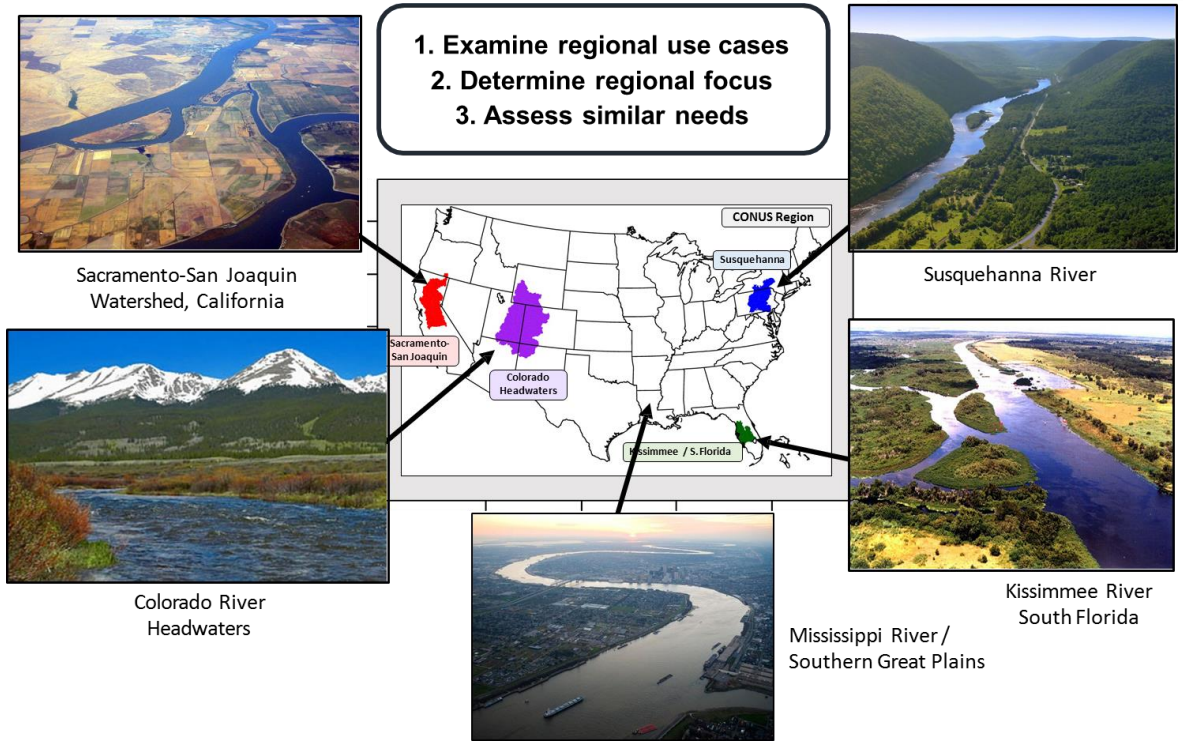
Study regions and storylines



Leverage ongoing stakeholder relationships in key case study regions.

Understand **priorities and overlapping interests** among stakeholders.

Understand needs for **planning and decision-making** in each region.



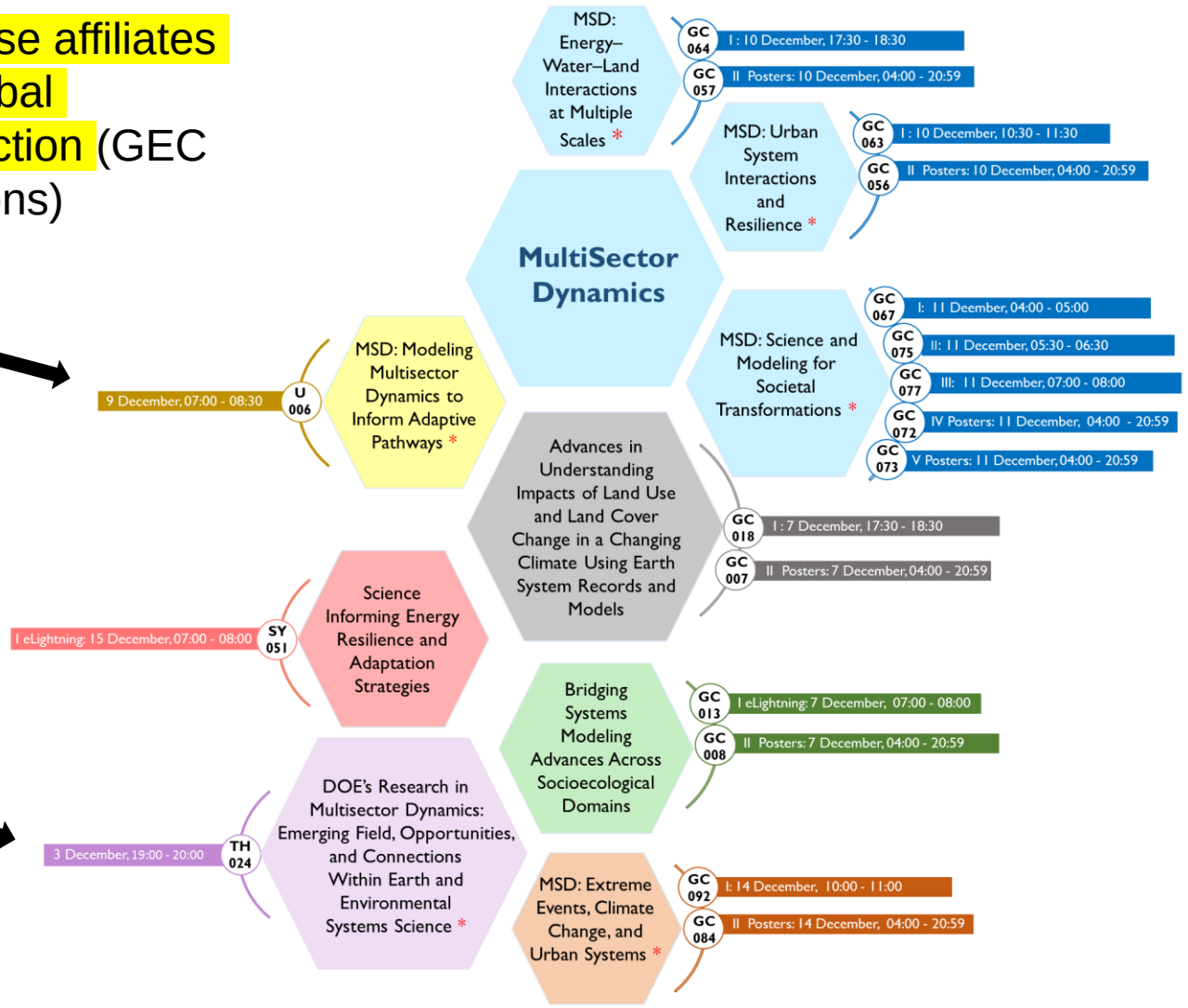
2020 AGU FALL MEETING

Click the Session Labels to go to the detailed session website (e.g., GC 064)
* Designates topics planned by the MSD Community of Practice
All times Pacific Standard Time US

MSD direct funded and close affiliates comprise 10% of 2020 Global Environmental Change Section (GEC is 4th largest of AGU Sections)

Union Session

Xujing joining as speaker/panelist in MSD convened DOE Town Hall



www.multisectordynamics.org

https://climatemodeling.science.energy.gov/program/multisector-dynamics