MultiSector Dynamics (MSD)

Bob Vallario

**U.S. Department of Energy
Office of Science**

**Office of Biological & Environmental Research
*Climate and Environmental Sciences Division***

**Snowmass, CO
July 2019**

Goal…worth repeating, early and often!

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*.
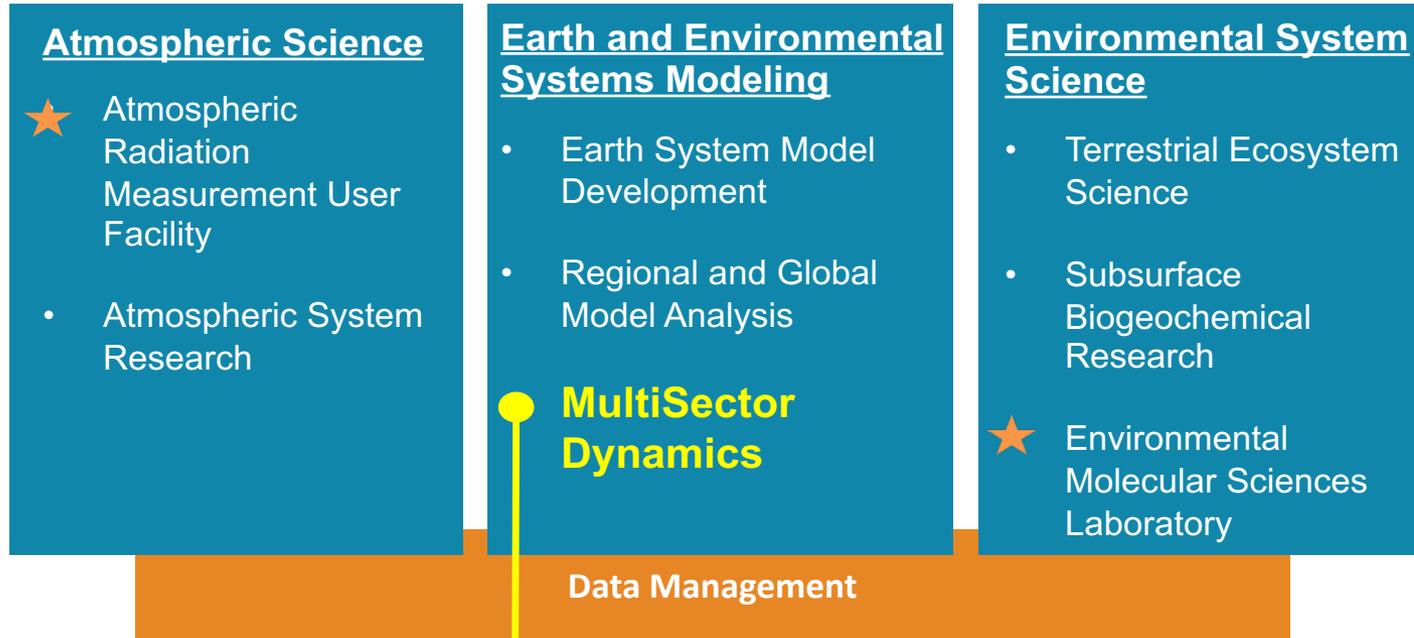
History and essential context

- Early 1990s-2009 – Early, leading work in *Integrated Assessment Research* focused on the contribution of anthropogenic and natural forcings to the climate system and evolution of the climate under a broad range of scenarios development and technology pathways.
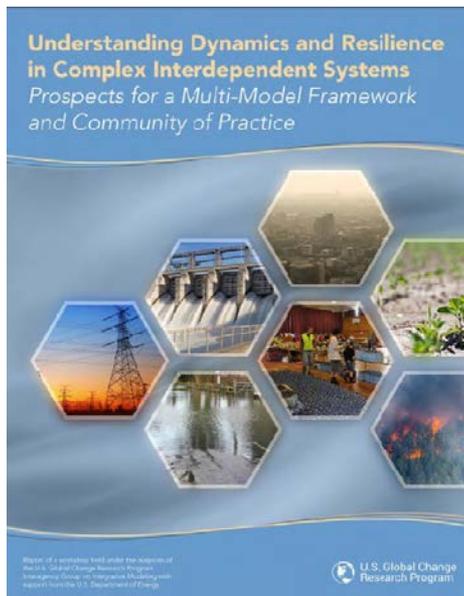
- 2009-2016 - a notable pivot with a focus on systems response to climate and weather-related extremes (impacts, adaptations, vulnerabilities), motivated by a 2009 community workshop report.

- **2016-present** - a transformational shift toward more comprehensive basic research in MultiSector Dynamics, catalyzed by a 2016 report on *dynamics and resilience in complex, adaptive systems*.

Program areas in CESD

Atmospheric Science

- ★ Atmospheric Radiation Measurement User Facility

- Atmospheric System Research

Earth and Environmental Systems Modeling

- Earth System Model Development

- Regional and Global Model Analysis

- **MultiSector Dynamics**

Environmental System Science

- Terrestrial Ecosystem Science

- Subsurface Biogeochemical Research

- ★ Environmental Molecular Sciences Laboratory

Data Management

Three program managers in the **Earth and Environmental Systems Modeling Program**

- ESMD Program Area - Sally McFarlane (acting) Corrine Hartin (detail)
- RGMA Program Area - Renu Joseph
- MSD Program Area - Bob Vallario

Funding Mechanisms for CESD…and for MSD

Laboratory Investments

- Science Focus Areas (~$1M-$22M)
- Large Projects
  - e.g., NGEE-A; NGEE-T; Ameriflux, IDEAS, ESGF, ESM SciDAC projects
- Small Projects (<1$M/year)
- Collaborators on University Projects
  - ($20K to >$1M)

University Investments

- Cooperative Agreements
  - Small ($100K) to Large ($4M)
- Large University projects
  - (~1M/year)
- Small University projects
  - (<$1M/year, PI-driven)
- Small Projects in response to SFAs
- Collaborators to Lab projects
  - Independently funding line or as sub-awards from Labs

SFAs at the National Labs and University Collaborative Agreements (with RGMA*)

MultiSector Dynamics

1. **Integrated Multi-sector, Multi-scale Modeling (IM3)**

   Pacific Northwest NATIONAL LABORATORY

   SFA PI: Ian Kraucunas/Jennie Rice

2. **Integrated Human Earth Systems Dynamics (IHESD)**

   Pacific Northwest NATIONAL LABORATORY

   SFA PI: Leon Clarke/Mohamad Hejazi

3. **Program on Coupled Human Earth Systems (PCHES)**

   Stanford University

   CA PI: John Weyant/Karen Fisher-Vanden/Rob Nicholas

4. **Integrated Global Systems Modeling (IGSM)**

   Massachusetts Institute of Technology

   CA PI: Ron Prinn /John Reilly

5. **Hyperion***

   UC DAVIS UNIVERSITY OF CALIFORNIA

   CA PI: Paul Ullrich

6. **FACETS***

   IOWA STATE UNIVERSITY

   CA PI: Bill Gutowski

NREL

Sandia National Laboratories

BERKELEY LAB

UNIVERSITY OF MARYLAND

UCAR

Cornell University

PennState

BOSTON UNIVERSITY

TEXAS A&M UNIVERSITY

UtahState University

Stony Brook University

UCLA

PURDUE UNIVERSITY

UNIVERSITY OF DELAWARE

University of New Hampshire

THE UNIVERSITY OF UTAH

SFAs…

Scientific Focus Areas -BER's way of developing and managing core lab efforts integral to the success of the division

Purpose : To encourage, facilitate, and effectively manage integrative and collaborative programs at the DOE National Laboratories to achieve scientific research and solutions of the highest quality in support of BER strategic goals.

- Coherent and cohesive programs that reflect coordination and collaboration among individual researchers and teams of investigators
- Encouraged to leverage the unique capabilities within labs to advance BER goals
- Encouraged to bring in external collaborators as needed to maximize research results
- Maximize the reliability, dependability, and availability of Science and BER User Facilities
- Expected to develop and evolve their research programs over time to identify, build and anticipate new areas of science & future research needs and challenges.
- Evolve as BER's strategic goals change and as science progresses

SFAs at the National Labs

Integrated Multi-sector, Multi-scale Modeling (IM3)

Submitted Title: Integrated Multi-sector, Multi-scale, Modeling (IM3) Scientific Focus Area

Flexible and extensible modeling capabilities that capture the dynamic multiscale interactions among climate, energy, water, land, socioeconomics, critical infrastructure, and other sectors and to use these capabilities to study the vulnerability and resilience of coupled human and natural systems from local to continental scales under scenarios that include short-term shocks, long-term stresses, and feedbacks associated with human decision-making. It will also explore how different model configurations, levels of complexity, multi-model coupling strategies, and spatial and temporal resolutions influence simulation fidelity and the propagation of uncertainties.
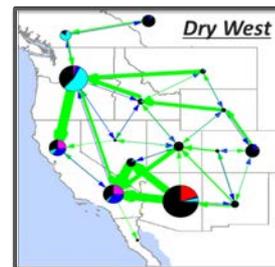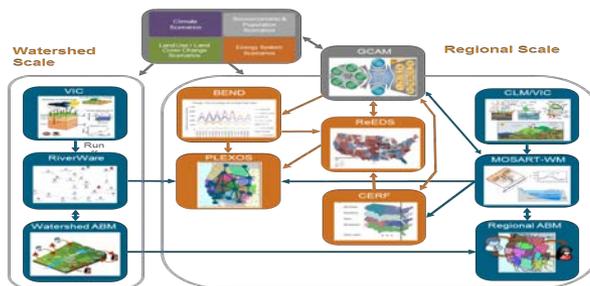
Principal Investigators:
Ian Kraucunas - Pacific Northwest National Laboratory
Jennie Rice (Interim) - Pacific Northwest National Laboratory

Collaborative Institutional Leads:
Melissa Allen-Dumas - Oak Ridge National Laboratory
Jared Carbone - Colorado School of Mines
Alejandro Flores - Boise State University
Andrew Jones - Lawrence Berkeley National Laboratory
Dan Li - Boston University
Hong-Yi Li - University of Houston
Jordan Macknick - National Renewable Energy Laboratory
Brian O'Neill - University of Denver
Patrick Reed - Cornell University
Vince Tidwell - Sandia National Laboratories
Ethan Yang - Lehigh University

Project Participants:
Christa Brelsford - Oak Ridge National Laboratory
Casey Burleyson - Pacific Northwest National Laboratory
Stuart Cohen - National Renewable Energy Laboratory
Maoyi Huang - Pacific Northwest National Laboratory
Gokul Iyer - Pacific Northwest National Laboratory
Tom Lowry - Sandia National Laboratories
Ryan McManamay - Oak Ridge National Laboratory
David Millard - Pacific Northwest National Laboratory
Z. Todd Taylor - Pacific Northwest National Laboratory
Chris Vernon - Pacific Northwest National Laboratory
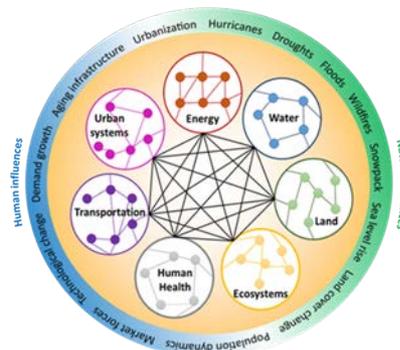Nathalie Voisin - Pacific Northwest National Laboratory

Website: https://im3.pnnl.gov/

SFAs at the National Labs

Integrated Human and Earth Systems Dynamics (IHESD)

Submitted Title: Integrated Human and Earth Systems Dynamics (IHESD) Scientific Focus Area

Examining the complex, multiscale dynamics of human systems and their interactions with the Earth system, in particular, the intersection of energy, water, land, the economy, and the environment. Centered around the Global Change Assessment Model (GCAM) and the GCAM ecosystem of models, early efforts explore, first, how climate variability and extreme events interact with evolving human systems and alter long-term human system and human-Earth system dynamics at different temporal and spatial scales; and, second, how uncertainty about economic decision making propagates through projections of land use, energy, and biogeochemical change.

Principal Investigator:
Leon Clarke – Pacific Northwest National Laboratory (PNNL)
Mohamad Hejazi - Pacific Northwest National Laboratory (PNNL)

Project Participants:
Benjamin Bond-Lamberty -Pacific Northwest National Laboratory
Katherine Calvin - Pacific Northwest National Laboratory (PNNL)
Jae Edmonds - Pacific Northwest National Laboratory (PNNL)
Corinne Hartin - Pacific Northwest National Laboratory (PNNL)
Gokul Iyer - Pacific Northwest National Laboratory (PNNL)
Son H Kim - Pacific Northwest National Laboratory (PNNL)
Page Kyle - Pacific Northwest National Laboratory (PNNL)
Robert Link - Pacific Northwest National Laboratory (PNNL)
Pralit Patel - Pacific Northwest National Laboratory (PNNL)
Steven J Smith - Pacific Northwest National Laboratory (PNNL)
Marshall Wise - Pacific Northwest National Laboratory (PNNL)
Leon Clarke - University of Maryland
Tom Wild - University of Maryland
Fernando Miralles - University of Maryland
Yuyu Zhou - Iowa State University
Jon Lamontagne - Tufts University
Pat Reed - Cornell University
Alex Ruane - Columbia University
Alan DiVittorio - Lawrence Berkeley National Laboratory
Erwan Monier - University of California Davis (UC Davis)
Ryan Sriver - University of Illinois at Urbana-Champaign
Ian Sue Wing - Boston University

Website: http://www.globalchange.umd.edu/

Cooperative Agreements at Universities

Program for Coupled Human Earth Systems (PCHES)

Submitted Title: A Multi-Model, Multi-Scale Research Program in Stressors, Responses, and Coupled Systems Dynamics at the Energy-Water-Land Nexus

Research in support of a next-generation integrated suite of science-driven modeling and analytic capabilities, and a more expanded and connected community of practice, for analyses of the stressors, impacts, adaptations and vulnerabilities of global and regional change, with emphasis in understanding energy, water, and land systems interactions and interdependent infrastructures. A particular focus of this effort is the independent development and testing of multi-model, multi-scale analytic capabilities and component models for unique research insights and for consideration by the other MSD integrated modeling teams.
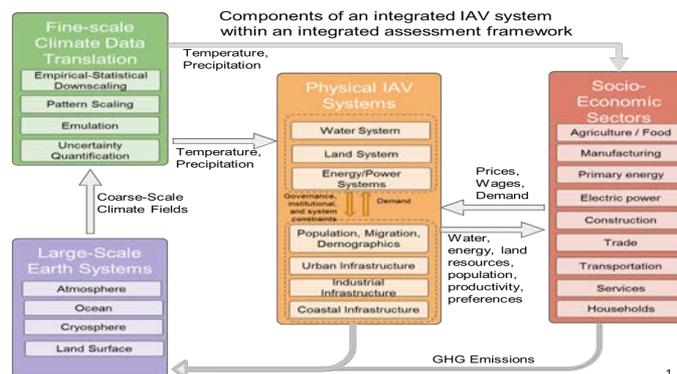
Principal Investigator:
John Weyant - Stanford University
Karen Fisher-Vanden - Pennsylvania State University
Robert Nicholas - Pennsylvania State University

Project Participants:
Noah Diffenbaugh - Stanford University
David Lobell - Stanford University
Christopher Forest - Pennsylvania State University
Murali Haran - Pennsylvania State University
Klaus Keller - Pennsylvania State University
Jim Shortle - Pennsylvania State University
Mort Webster - Pennsylvania State University
Doug Wrenn - Pennsylvania State University
Thomas Hertel - Purdue University
Ian Sue Wing - Boston University
Steve Frolking - University of New Hampshire
Richard Lammers - University of New Hampshire
Alex Prusevich - University of New Hampshire
Patrick Reed - Cornell University
Wolfram Schlenker - National Bureau of Economic Research

Website: https://www.pches.psu.edu/

MultiSector Dynamics

Integrated Global Systems Modeling (IGIM)

Submitted Title: An Integrated Framework for Climate Change Assessment

Develop and focus enhancements on the IGSM framework, built around an Earth system model, an economic model of human activity, and a growing set of components that link economic activity to natural resources affected by environmental change. In terms of IGSM framework enhancements, a major emphasis of development is on the linkages between the Earth system and economic activity through water, crops, renewable energy resources, and atmospheric chemistry. The focus will be on enhancing these linkages in the global model, but with increased fidelity on U.S. resource sectors. The economic activity component of the IGSM, built on state-level data for the U.S., maintains a focus on better characterizing trade-offs between renewable energy and other energy resources, along with linkages to water and land.
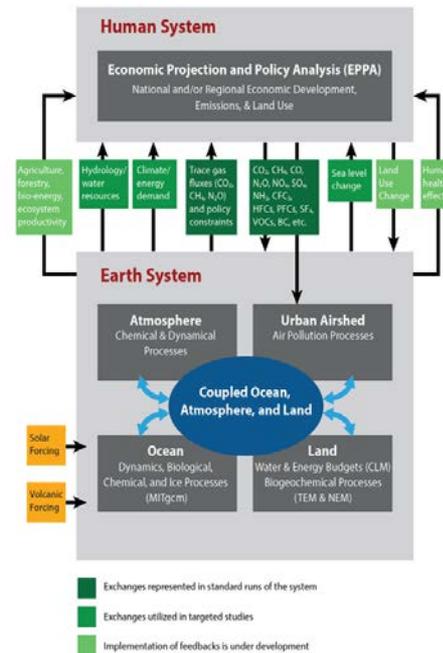
Principal Investigator:
Ron Prinn- MIT
John Reilly - MIT

Project Participants:
Adam Schlosser – MIT
Sergey Paltsev- MIT
Chien Wang- MIT
Stephanie Dutkeiwicz - MIT
Erwan Monier- MIT
Niven Winchester- MIT
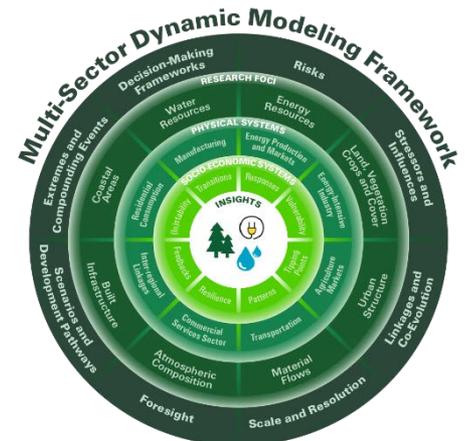
Cooperative Agreements at Universities

Hyperion

Submitted Title: An Integrated Evaluation of the Simulated Hydroclimate System of the Continental US

PI: Paul Ulrich

Development of a comprehensive regional hydroclimate data assessment capability focused on feature-specific metrics and stakeholder-relevant outcomes. Additionally, the effort seeks to leverage this assessment capability to improve our ability to predict these outcomes, by identifying the process-level drivers of outcome biases and evaluating the most appropriate and efficient ways to couple climate models, hydrologic models, and **models of human impacts (e.g., localized irrigation influences).** Co-funded by MSD and CESD's Regional and Global Model Analysis program area.

FACETS

Submitted Title: A Hierarchical Evaluation Framework for Assessing Climate Simulations Relevant to the Energy-Water-Land Nexus

PI: Bill Gutowski

Development of a hierarchical model evaluation framework informed by different uses of Earth system models and their output by climate scientists and stakeholders for planning and managing resources. Examination of a suite of different modeling methods and design structured, hierarchical experiments for regional analysis that feature baseline simulations across a range of spatial resolutions and modeling approaches. Some of these simulations will focus on the impacts of future land use and **land cover changes associated with food and bioenergy crop production and urbanization, and expansion of wind turbine deployment, which highlight specific challenges for modeling the energy-water-land nexus.** Co-funded by MSD and CESD's Regional and Global Model Analysis program area.

New: The Integrated Coast…Systems, Dynamics, & Evolution (at the Terrestrial Aquatic Interface)
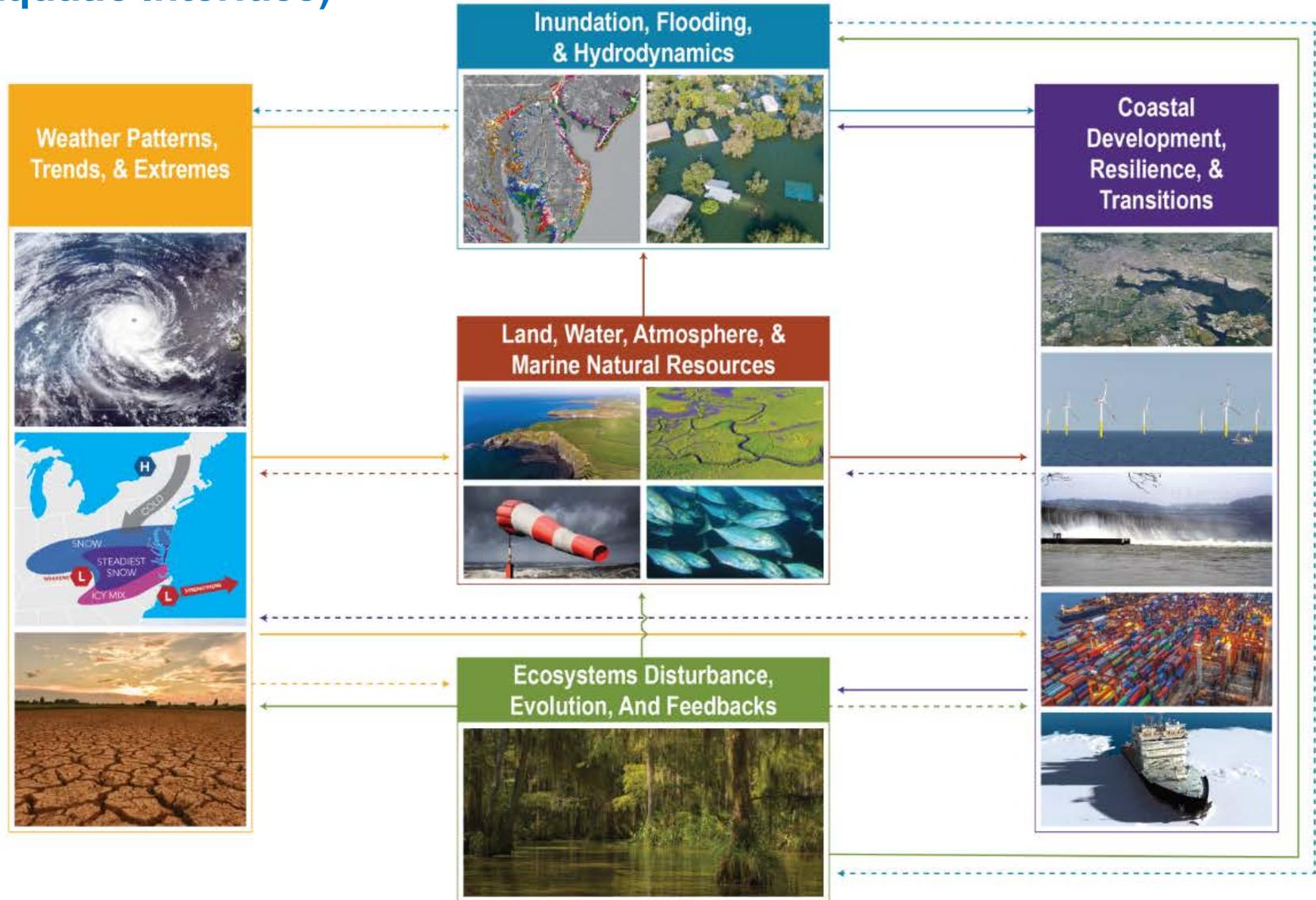
And a new business model for CESD…a federated approach to program collaboration

Illustrative CESD Capabilities and/or Interests for Research of the Integrated Coast

Inundation, Flooding, and Hydrodynamics
- Sea Level Rise and high latitude "teleconnections"
- Wave propagation (especially under weather extremes)
- Subsidence/subduction
- Watershed function, river flows, hydrodynamics, sedimentation
- Dynamic vegetation
- Permeability and land surface development (flooding)
- Infrastructure siting/placement
- Engineered and natural barriers
- Closing the water budget

Weather and Weather Extremes
- Changing ambient weather
- Tropical cyclones
- Noreasters
- Major precipitation events
- Droughts
- Temperature extremes
- Wind patterns
- Ocean temperature, chemistry, currents
- Urban climates
- Ice/snow events

Land, Water, Atmosphere, and Marine Natural Resources
- Land resources, soil chemistry, soil moisture
- Ecosystems and ecosystem services
- Groundwater supply, recharge, quality, and salt water intrusion
- Surface water quantity & quality (including temperature and drivers of hypoxia)
- Surface and groundwater interactions
- Reservoir operation
- Air quality
- Wind (as a natural resource)
- Coastal marine chemistry, biology, hypoxia, temperature, and currents (implications for marine energy systems)
- Arctic ice and passage

Ecosystems Disturbance, Evolution, and Feedbacks
- Biogeochemistry and carbon cycle feedbacks to the Earth system
- Carbon sensitive ecosystems and climate induced natural transitions (temp, precip, salinity, interface movement)
- Human-induced influences, from water management and quality to land-use driven changes in hydrology to displacement of natural ecosystems.

Coastal Development, Resilience, and Transitions
- Urban and infrastructural morphologies
- Regional and "native scale" interdependencies and teleconnections (e.g., electric grid, watersheds, agro-ecological zones, etc.)
- Population dynamics and demographics
- Sectoral interdependencies
- Demands (& depletions) of natural resources including land use and water resources
- Economic structure and regional and international interdependencies
- Disruptive technology transitions, especially energy systems
- Ports as hubs: vulnerabilities, adaptations, transitions
- Energy and water system evolutions
- Arctic passage trade
- Stressor-response instabilities and non-linear responses (cou0led model behaviors)

Earth System Modeling
Multisector Dynamics
Regional and Global Modeling
Watershed Science
Terrestrial Ecosystem Science
Atmospheric Systems Research
Data Management Sciences*

* Underpins all

MSD progress and contributions are substantial and growing…website is increasingly representative

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

"Big Deal" Annual Activities…

- **Annual Reports**

- **Annual MSD Community Meetings**

- **Annual Individual Team Meetings**

Integrated Multisector, Multiscale Modeling (IM3) Scientific Focus Area

FY 2019 Annual Report

June 2019

Pacific Northwest National Laboratory
Richland, Washington 99352

57 pages

EMF | Energy Modeling Forum

HOME ABOUT PEOPLE PROJECTS PUBLICATIONS EVENTS INDUSTRY AFFILIATES

Snowmass Workshop- Analyses of Multi-Sector Energy and Environmental Dynamics

EVENT INFORMATION

▪ Week 1 - Agenda and Presentations

Date / Time
Wednesday, July 18, 2018 to Friday, July 20, 2018

Availability: By invitation only

Location: Snowmass, Colorado

Investigator: John Weyant

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https://emf.stanford.edu/events/snowmass-workshop-analyses-multi-sector-energy-and-environmental-dynamics

Joint Global Change Research Institute

Pacific Northwest / University of MARYLAND

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2018 GCAM Community Modeling Meeting

For archived registration and venue information, please go here:

2018 GCAM Community Modeling Meeting

Agenda

October 16-18, 2018: Joint Global Change Research Institute

Day 1 – Tuesday October 16, 2018

GCAM-USA and USA Modeling: – Moderator: Sha Yu (PNNL/JGCRI)

- Sha Yu (PNNL/JGCRI): **GCAM Regional Modeling Context**
- Gokul Iyer (PNNL/JGCRI): **GCAM-USA Overview**
- Pralit Patel (PNNL/JGCRI): **US electric sector separating investment and dispatch**
- Chris Vernon (PNNL/JGCRI): **Interconnection Cost Implications of Future Electricity Capacity Expansion in the USA: A Multi-sector Approach**

http://www.globalchange.umd.edu/annual-meetings/2018_gcam_community_modeling_meeting/

Highlights…another "Big Deal"

https://climatemodeling.science.energy.gov/research-highlights?f%5B0%5D=field_funding_program%3A2

Future directions

- **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 and land systems, and non-linear responses, e.g., induced by extremes

Coastal Dynamics

Integrated Water Cycle

Connected Infrastructure

Urban/Landscape Morphology

Summary

- **A period of transitions, challenges, but ultimately, high productivity**
- **93 publications in three years (2016-2018)…with 32 already in 2019**
- **2018 Nobel Prize awarded to former long-standing MSD PI** in Economic Sciences for work performed in the 1990s.
- **Substantial volume of new, open source scientific code** (e.g., *Hector, Tethys, Xanthos, Demeter, fldgen and more)*
- **Training** on new model/analysis/data platforms…e.g., 2018 GCAM training:
  - Scientists/modelers from nearly 20 countries
  - Energy industry…from EPRI to Exxon/Mobile
  - Interagency and intergovernmental
- Major enhancements to **web presence**…a community "work in progress"
- Expanded **teaming and collaborations** (with DOE incentives) leading to a team-of-teams approach
- DOE coordinated **interagency webinars** by MSD community, e.g., by Calvin, Hartin, Hejazi, Kraucunas, Reilly, and others

Summary (contd.)

- **Launch of the MSD community-of-practice development process!**
- Strengthened **connections within the CESD family of programs/areas**…e.g., collaborative funding with RGMA and DM, as well as specific collaborative activities with E3SM and SBR
- MSD community leadership on **NCA4*, Chapter 17, Sector Interactions, Multiple Stressors, and Complex Systems***
- Early efforts in MSD community **resource/repository building** (MSD Live)
- Significant number of challenging **intra- and inter-agency activities**…IGIM, IIWG, more
- **2018 Integrated EESM PI meeting and concurrent MSD meeting.**
- Pivotal **AGU Town Hall** with DOE, NSF, NGA
- Preparation and planning for new initiatives in **Coasts and the Arctic**
- Upcoming interagency workshop on **Integrated Hydro-Terrestrial Modeling**
- **Recent COV review**