GCIMS: Large-Scale MSD, Impacts, Feedbacks, and Scenario Exploration

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GCIMS SFA PI

On behalf of the GCIMS Team

August 7th 2024, EESM PI meeting

Rockville, MD

GCIMS GLOBAL CHANGE INTERSECTORAL MODELING SYSTEM

Pacific Northwest NATIONAL LABORATORY

BERKELEY LAB Lawrence Berkeley National Laboratory

Massachusetts Institute of Technology

Tufts UNIVERSITY

UCDAVIS UNIVERSITY OF CALIFORNIA

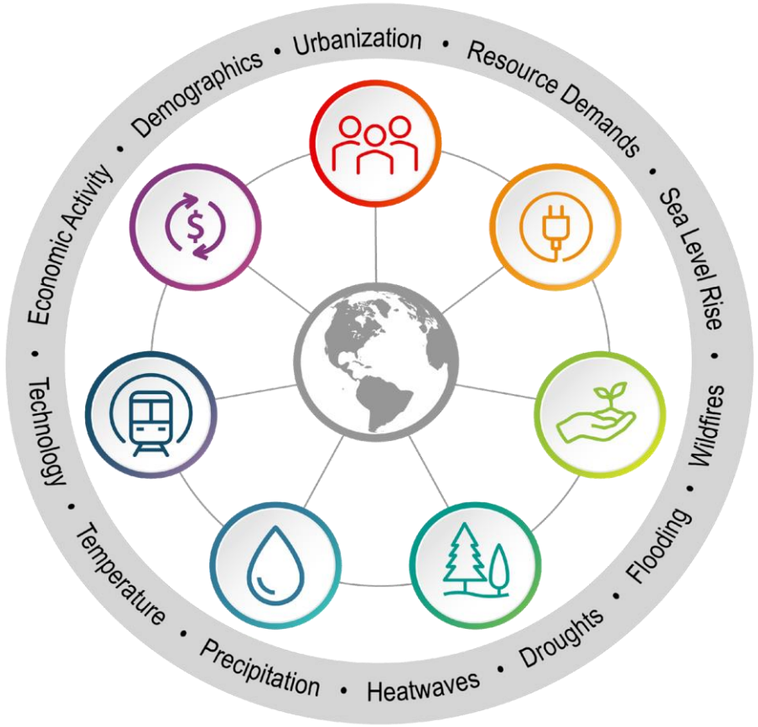
WESTERN WASHINGTON UNIVERSITY

UNIVERSITY of HOUSTON

UNIVERSITY OF MARYLAND

GCIMS Project: Vision and Team

The long-term vision is *to improve the understanding of the complex interactions among energy, water, land, climate, socioeconomics, and other important human and natural systems*



- *while capturing the evolution of the integrated human–Earth system,*
- *at regional to global scales,*
- *with an emphasis on developing and applying an internally consistent, open-source, computationally efficient modeling framework (the GCIMS).*

GCIMS is supported by the U.S. Department of Energy, Office of Science, Earth and Environmental System Modeling, MultiSector Dynamics Program Area

GCIMS: Open, Modular, Integrated Modeling

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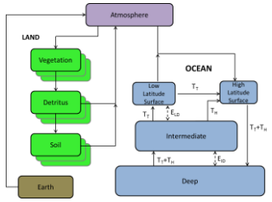
Data Development

gcamdata (consolidation)

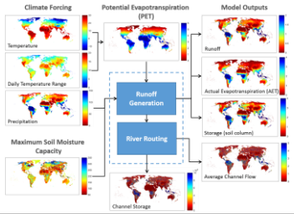
Moirai (gridded land)

Physical System Models

Hector (simple climate)



Xanthos (global hydrology)

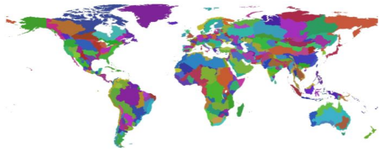


MSD Integration

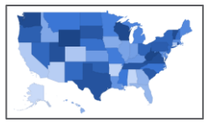
GCAM

32 Energy Economy Regions

235 Water Basins



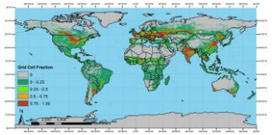
384 Land Regions



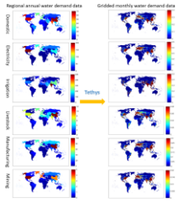
GCAM-USA (50 State)

Regional Resolution

Demeter (land)

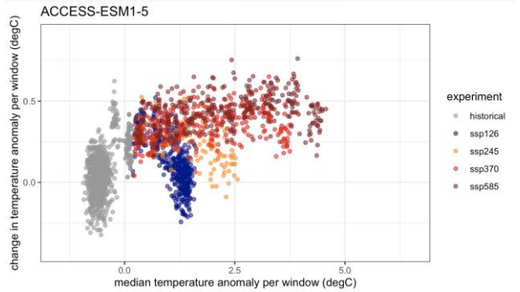


Tethys (water)



Climate Model Emulation

STITCHES



GCIMS: Global Change Intersectoral Modeling System: Not all GCIMS models shown above.

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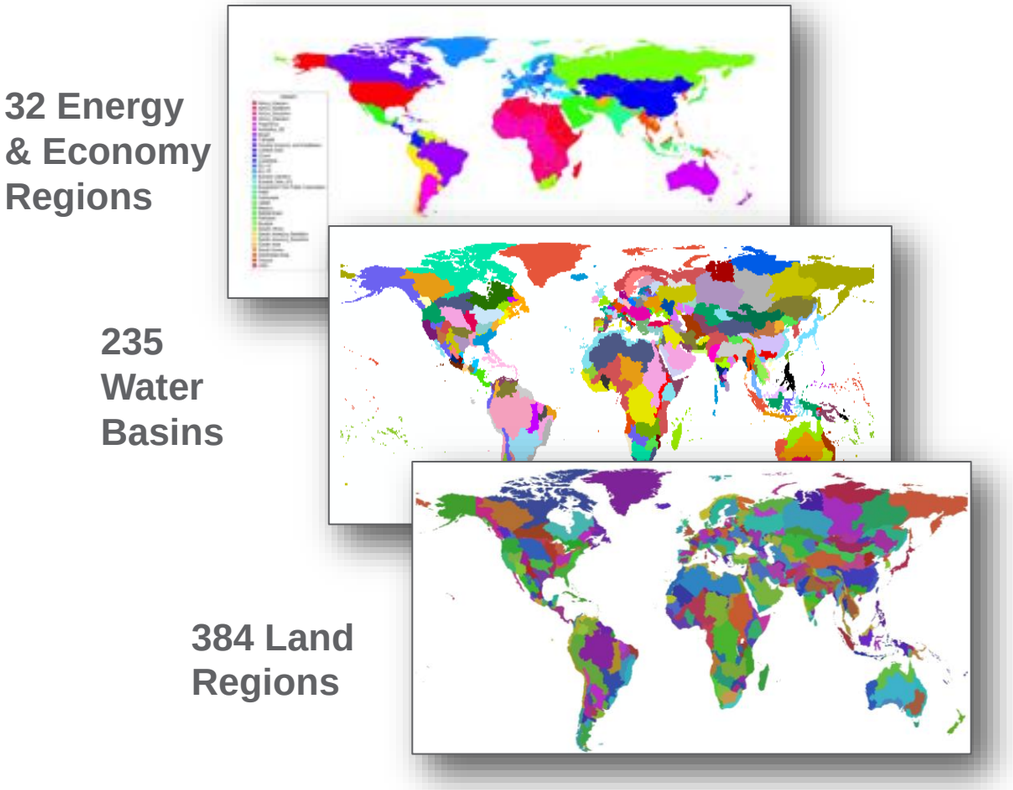
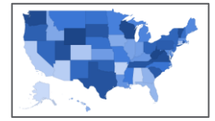
Global Change Analysis Model (GCAM)

- GCAM is a ***multisector, multi-regional, dynamic model*** focusing on the interaction among human activities, technology, and physical systems.
- GCAM ***economically and physically links*** long-term activity in **Energy, Agriculture, Land, Water, and Emissions**.
- GCAM includes ***technology and physical detail in energy*** production, transformation and final demand sectors.
- GCAM includes ***physical representation of crop management practices*** in the agriculture sector.
- GCAM includes ***dynamic economic modeling of the water*** sector linked to energy and agriculture.
- GCAM models ***dynamic international trade*** in energy, agriculture, and in a growing number of related sectors.

Global Coverage



- 32 Energy/Economic regions
- 384 Land regions based on water basins



GCAM-USA (50 State)

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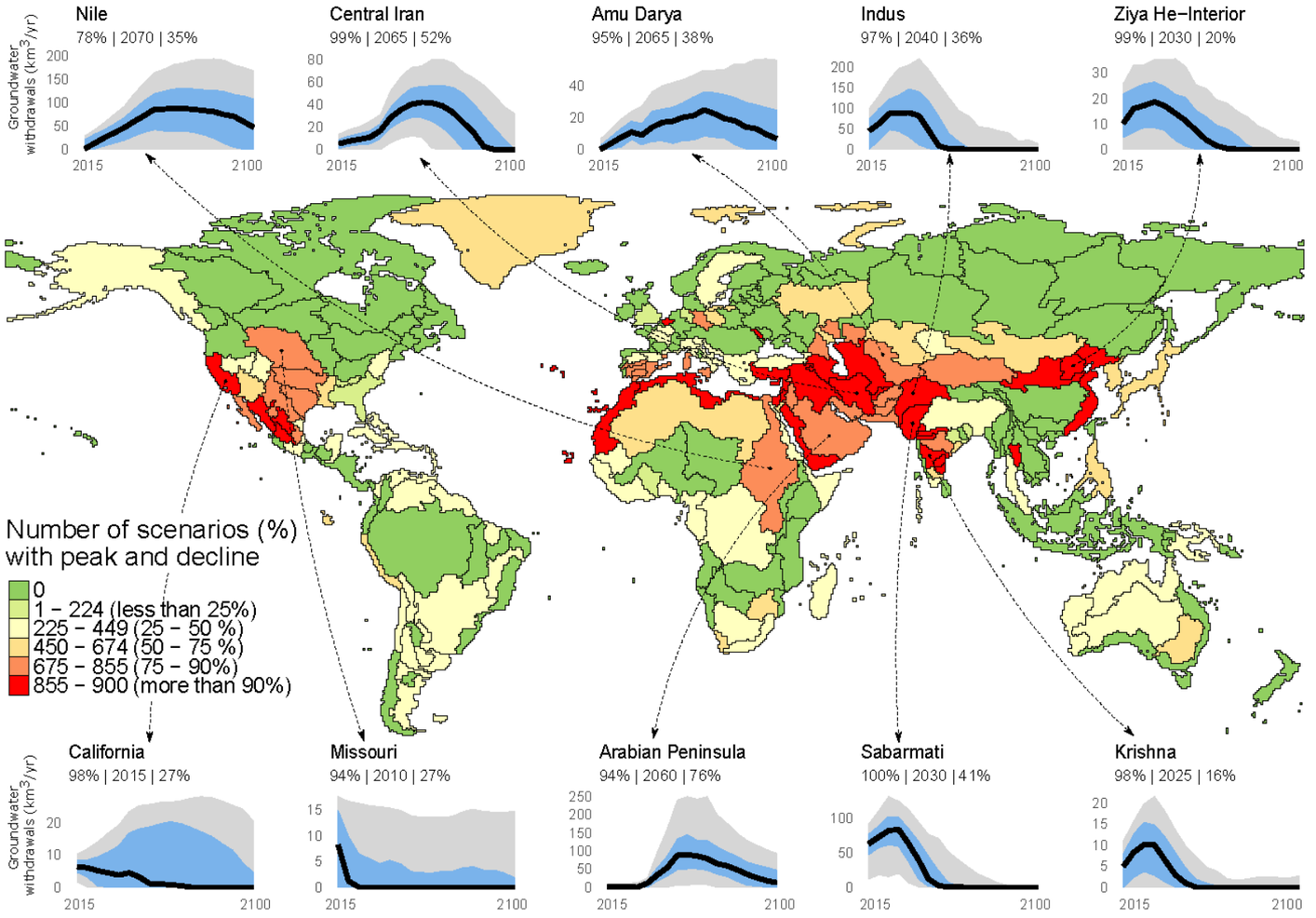
MSD Research: Future Groundwater Use

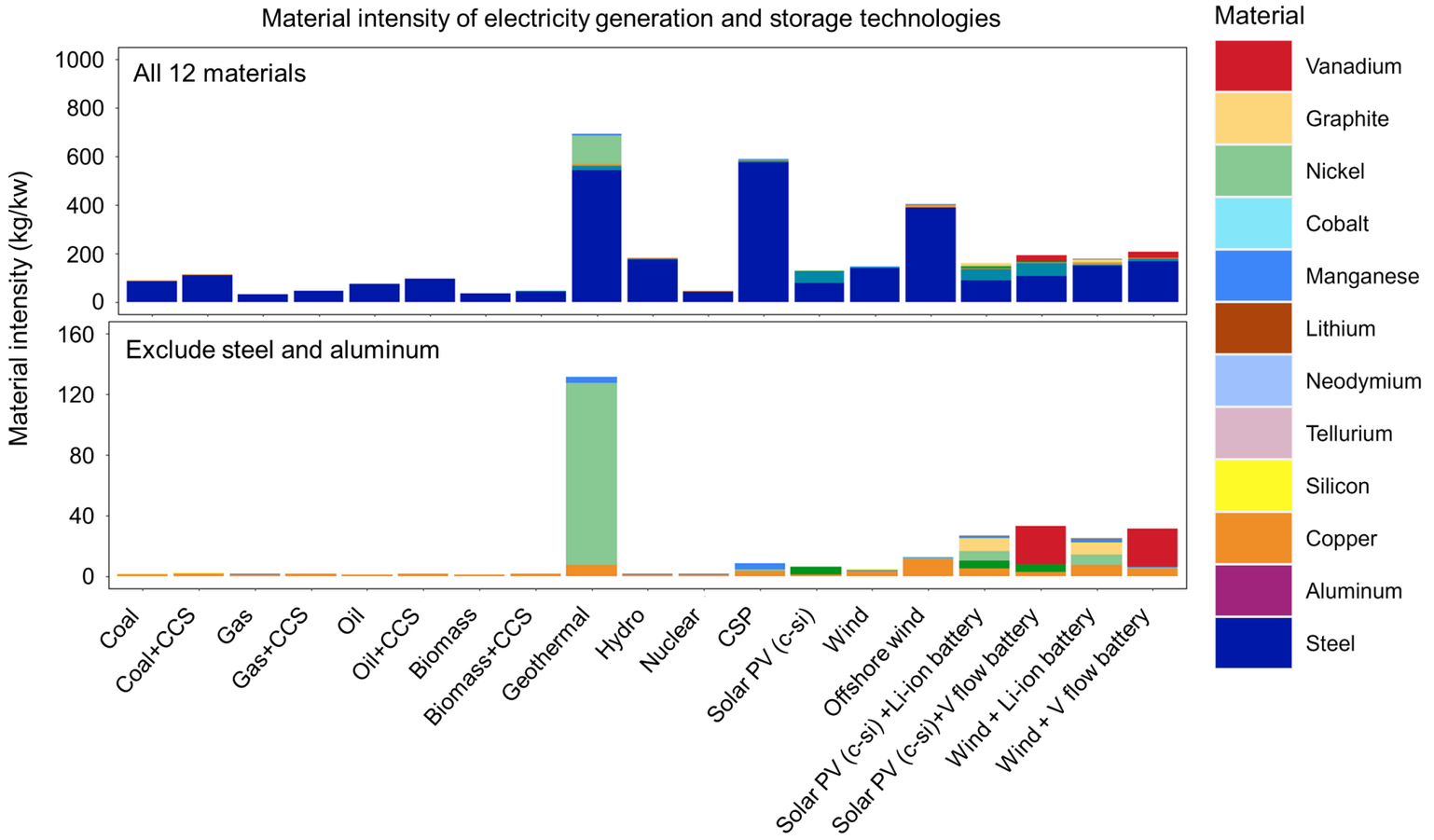
- Basins with ***peaking groundwater use*** see increasing water prices affecting regional crop prices, crop production, and trade.
- Importance of rich physical representation of ***hydrology in GCAM and Xanthos*** models.
- ***Importance of integrated modeling of water with agriculture, energy, and trade***.



Niazi, H., Wild, T., Turner, S., Graham, N., Hejazi, M., Msangi, S., Kim, S., Lamontagne, J., & Zhao, M. (2024). Global Peak Water Limit of Future Groundwater Withdrawals. *Nature Sustainability.*

Related Breakout Sessions: ***A: Water Cycle and Hydroclimate*** *and* ***F: ELW Transitions***

MSD Research: The Multisector Demand, Supply, and Trade of Critical Materials



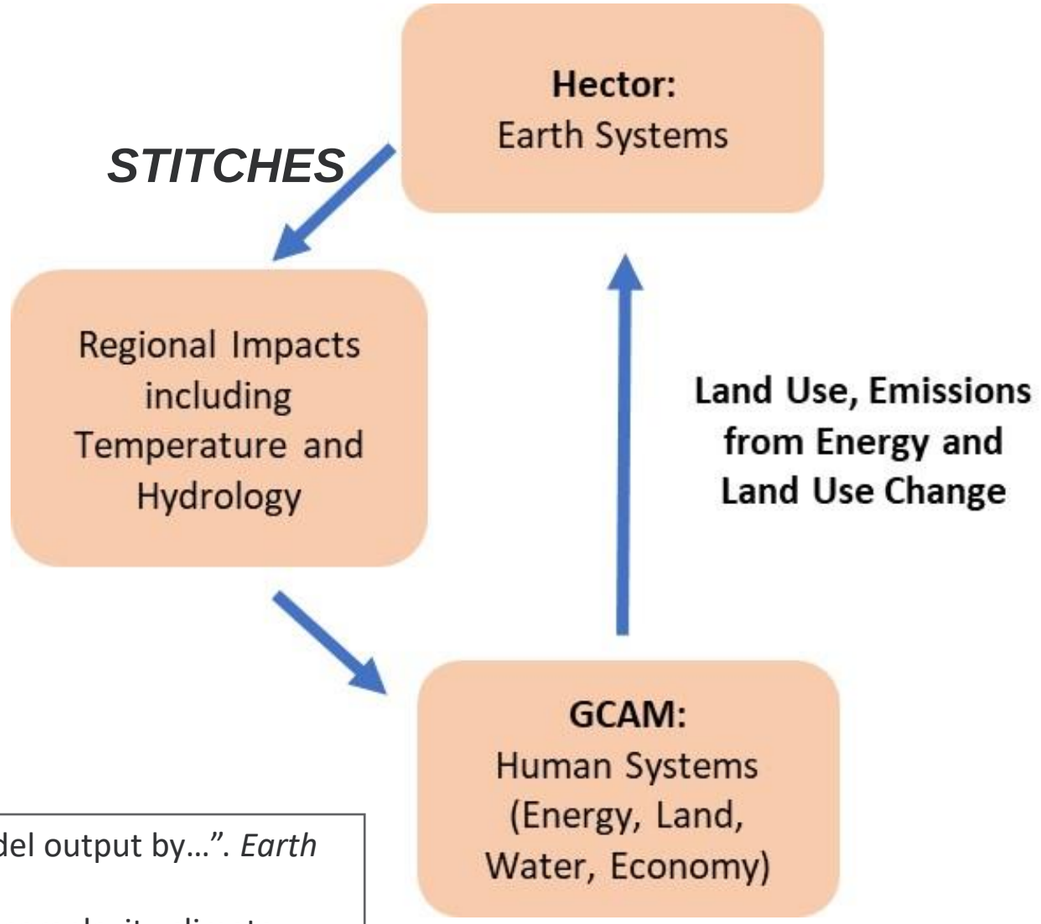
- Need for MultiSector Dynamic analysis linking energy sectors and material sectors is clear.

Qiu, Yang, Gokul Iyer, Neal Graham, Matthew Binsted, Marshall Wise, Pralit Patel, Brinda Yarlagadda (2024 in press). "The impacts of material supply availability on a transitioning electric power sector." *Cell Reports Sustainability.*

Breakout Session: ***F. Energy, Water, and Land Transitions (several GCIMS talks)***

Modeling Climate Impacts and Feedbacks: Tight Coupling and Emulators

- Tight-coupling of human-earth systems modeling for generating large ensembles of uncertain scenarios.
- Emulation of ESMs allows for efficient execution and scenario exploration.
- Advances in our **Hector** simple climate model and our **STITCHES** emulator.



Tebaldi, Snyder, Dorheim (2022). "STITCHES: Creating new scenarios of climate model output by…". *Earth Systems Dynamics.*
Dorheim et al. (2024). "Hector V3.2.0: functionality and performance of a reduced-complexity climate model." *GMD.*

Breakout Session: ***J. Strengthening EESM IM Framework and E. Biogeochemistry***

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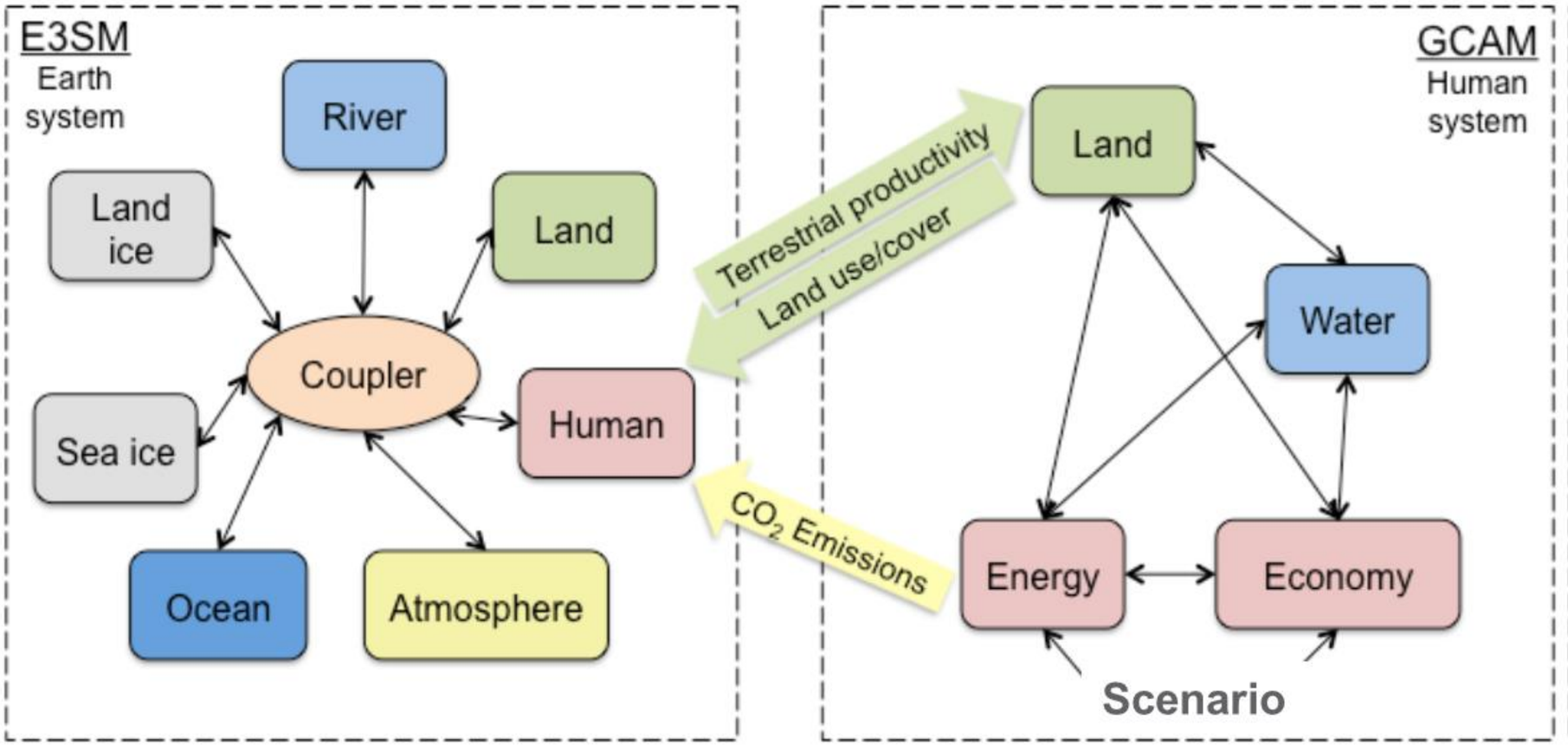
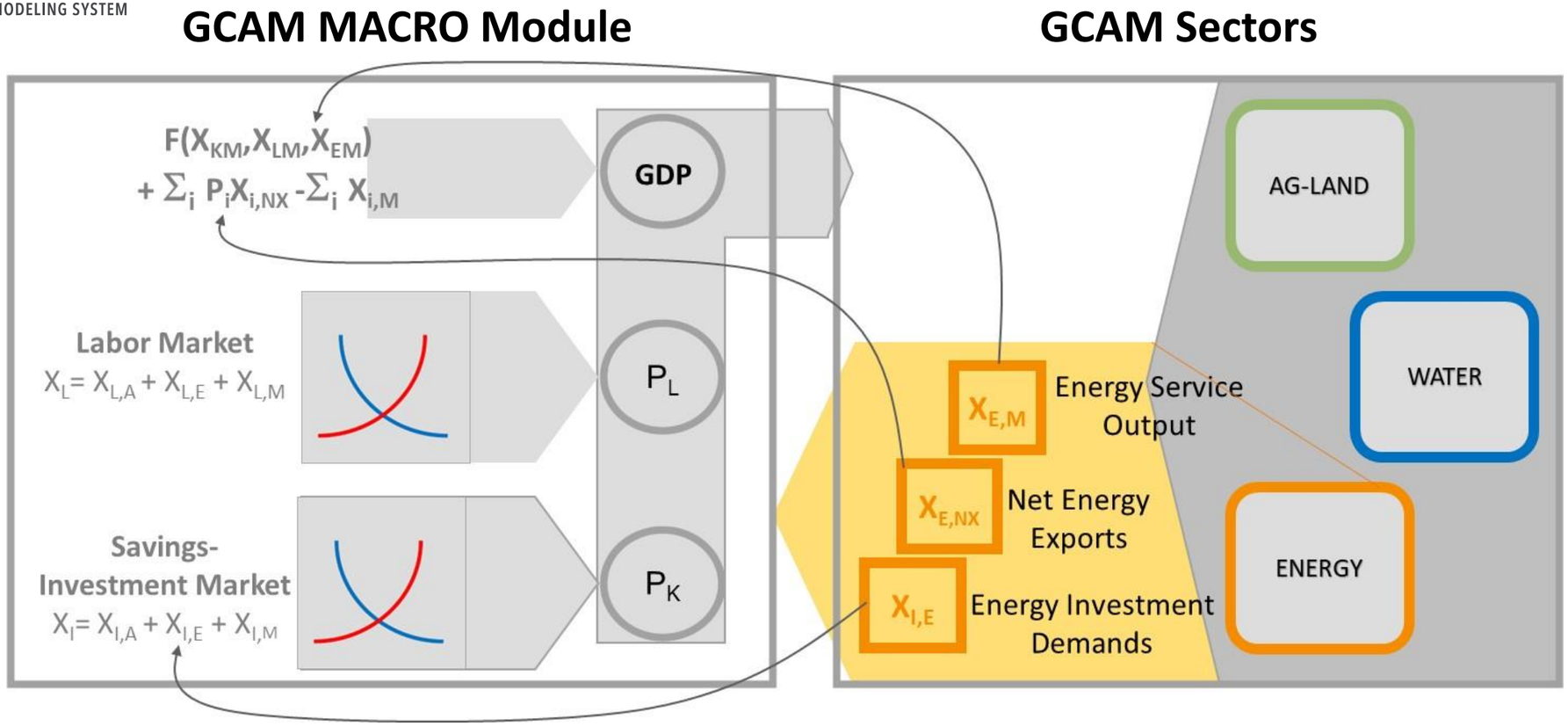
GCAM is the Human Systems Model in E3SM



- Land and Terrestrial Carbon coupling:
  - GCAM makes economic Land Use allocations based on productivity from E3SM.
  - GCAM Land Use/Cover is sent to E3SM for its terrestrial carbon computations.

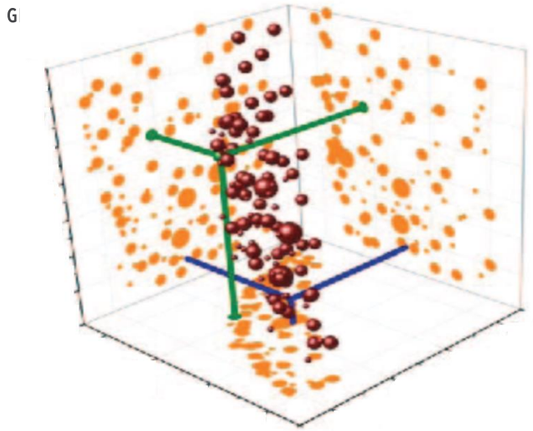
Impacts/Feedbacks to the MacroEconomy

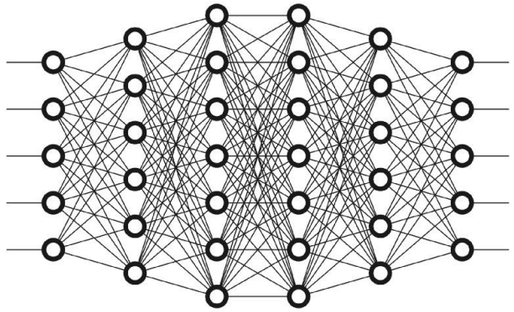


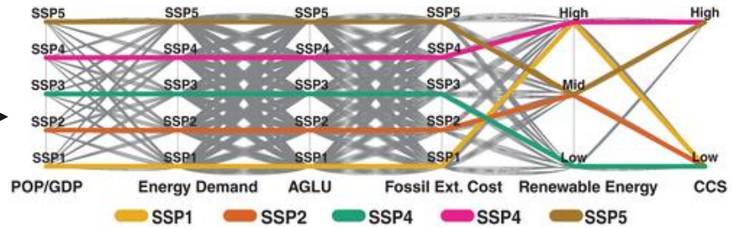
- The macroeconomy defines the scale of human activity and is one of the most important factors determining the scale of human-physical Earth system interactions.
- Physical impacts can have substantial feedback effects on the macroeconomy - as human activities change in response to these impacts.

Breakout Session: D. ***Impacts, Tipping Points…*** *– Two GCAM studies*

Scenario Exploration and Deep Learning-Aided Scenario Discovery (DL-SD)







Scenarios: Expert-elicited uncertain drivers.

DL-SD: Targeted ensemble search to identify critical drivers

Scenario Discovery: Expansive search to identify critical drivers.

- GCIMS has pushed the envelope on Scenario Discovery via the Lamontagne Lab at Tufts.
- Expert-elicited scenarios misses critical drivers, but Scenario Discovery can be inefficient
- **DL-SD:** New research area using deep learning models to emulate GCAM in order to help us target our search for interesting outcomes and get there more efficiently.

Breakout Session: ***F. Energy, Water, and Land Transitions.***

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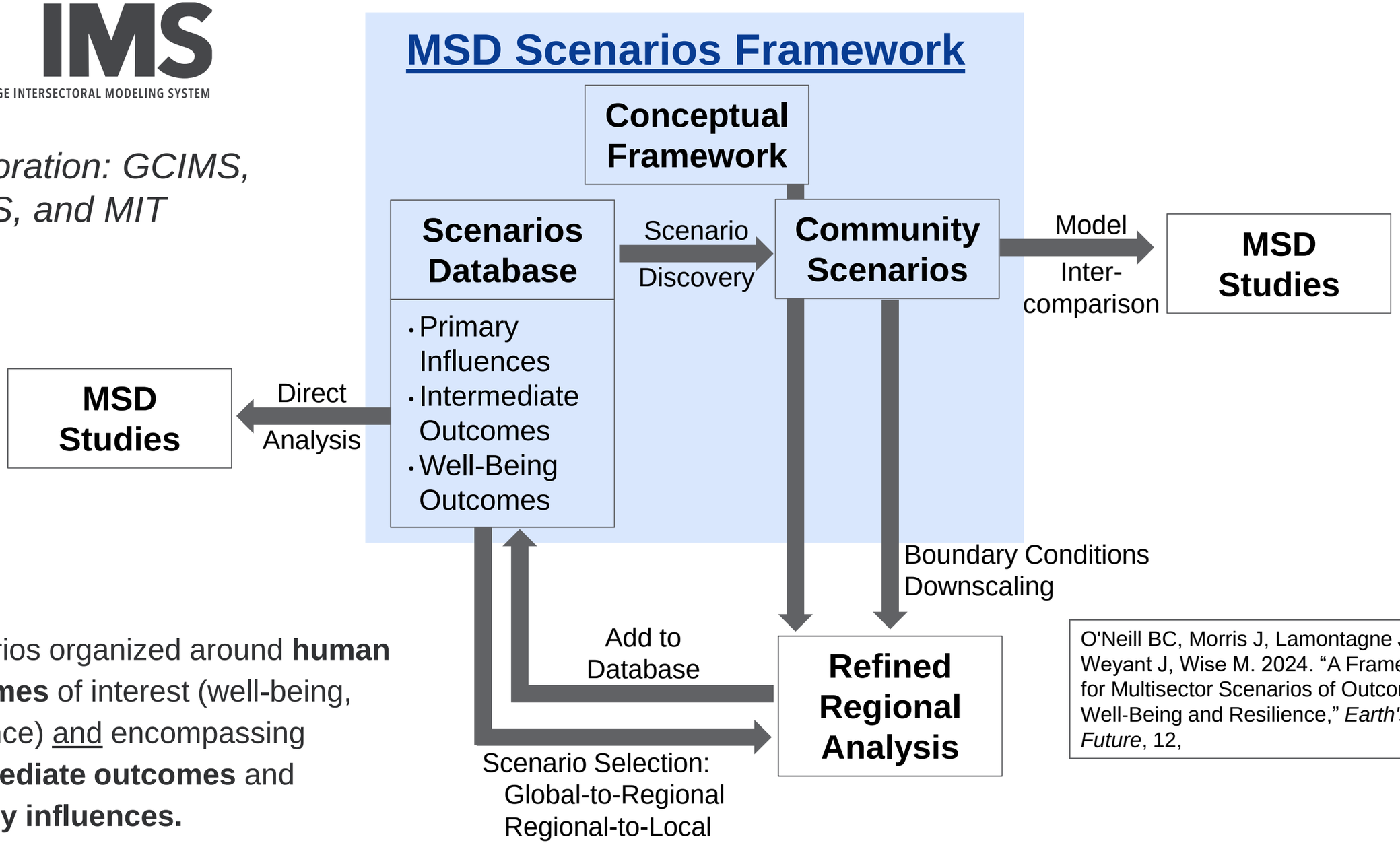
Collaboration: GCIMS, PCHES, and MIT



Scenarios organized around **human outcomes** of interest (well-being, resilience) and encompassing **intermediate outcomes** and **primary influences.**

O'Neill BC, Morris J, Lamontagne J, Weyant J, Wise M. 2024. "A Framework for Multisector Scenarios of Outcomes for Well-Being and Resilience," *Earth's Future*, 12,

Breakout Session: ***5. Model Biases, Uncertainties, and Fitness-for-Purpose.***

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GCIMS EESM Collaborations

- **IM3** – Research and modeling with GCAM-USA, Xanthos, Demeter, and Tethys.
  - 50-State electric power capacity and dispatch modeling with GCAM-USA.
- **InteRFACE** – GCAM
- MIT, ICoM – Demeter
- PCHES and MIT – MSD Scenario development focused on outcomes and well-being.
- MSD-LIVE – model/data hosting, training at the GCAM Annual Meeting, GCIMS model execution on Jupyter notebooks.
- E3SM – GCAM Coupling

THE GCIMS TEAM (2024)

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Leadership Team

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PNNL

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PNNL

Gokul Iyer
Regional Teleconnections Lead
PNNL

Jon Lamontagne
Compounding Influences Co-Lead
TUFTS UNIVERSITY

Abigail Snyder
Compounding Influences Co-Lead
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Chris Vernon
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PNNL

Stephanie Waldhoff
Human-Earth System Feedbacks Lead
PNNL

Thomas Wild
Human Responses Lead
PNNL

Guta Abeshu
PNNL

Matthew Binsted
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PNNL

Xin Zhao
PNNL

Earth System Science
Civil and Environmental Engineering
Nuclear Engineering
Ecology
Mathematics & Computer Science
Economics
Hydrology
Engineering Systems
International Relations
Environmental Science
Public Policy
Atmospheric Science
Operations Research
Statistics
Project Management
Biology
Environmental Policy

Thank you!

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