Program on Coupled Human and Earth Systems (PCHES)

www.PCHES.psu.edu

A five-year Cooperative Research Agreement with the Department of Energy's Office of Science (Biological and Environmental Research Program).

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 the stressors related to integrated Energy-Water-Land systems dynamics and interdependent infrastructures.

Participants: ~20 investigators, ~8 post-docs, and ~15 grad students from 10 institutions

Research Program Elements:

I. Develop Integrated EWL Modeling Frameworks
II. Develop Model/Module Integration Methods
III. Develop/Recommend Model Uncertainty Characterization, Evaluation and Inter-comparison Methods
IV. Create a Community of Practice for This Kind of Research

PCHES Team

www.pches.psu.edu

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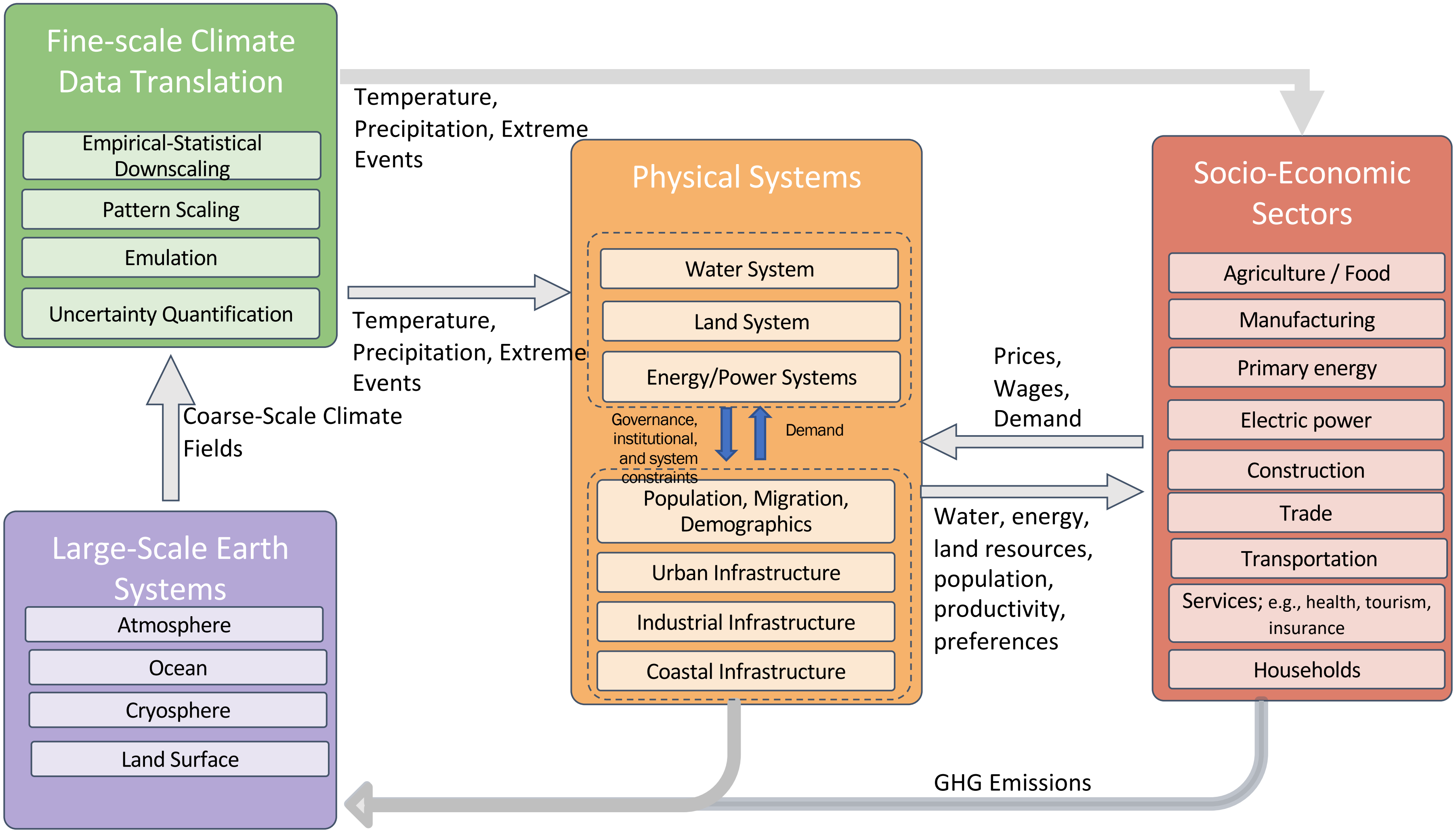
Integrated Energy-Water-Land systems dynamics and interdependent infrastructures

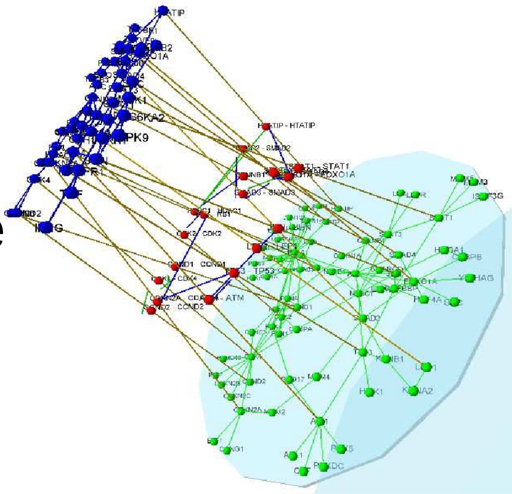


Framing

- Overlapping and Interacting Networks of Natural and Human Systems
- Each System has Distinct Spatial and Temporal Variability
- "Impacts" occur when these patterns converge at specific locations/times

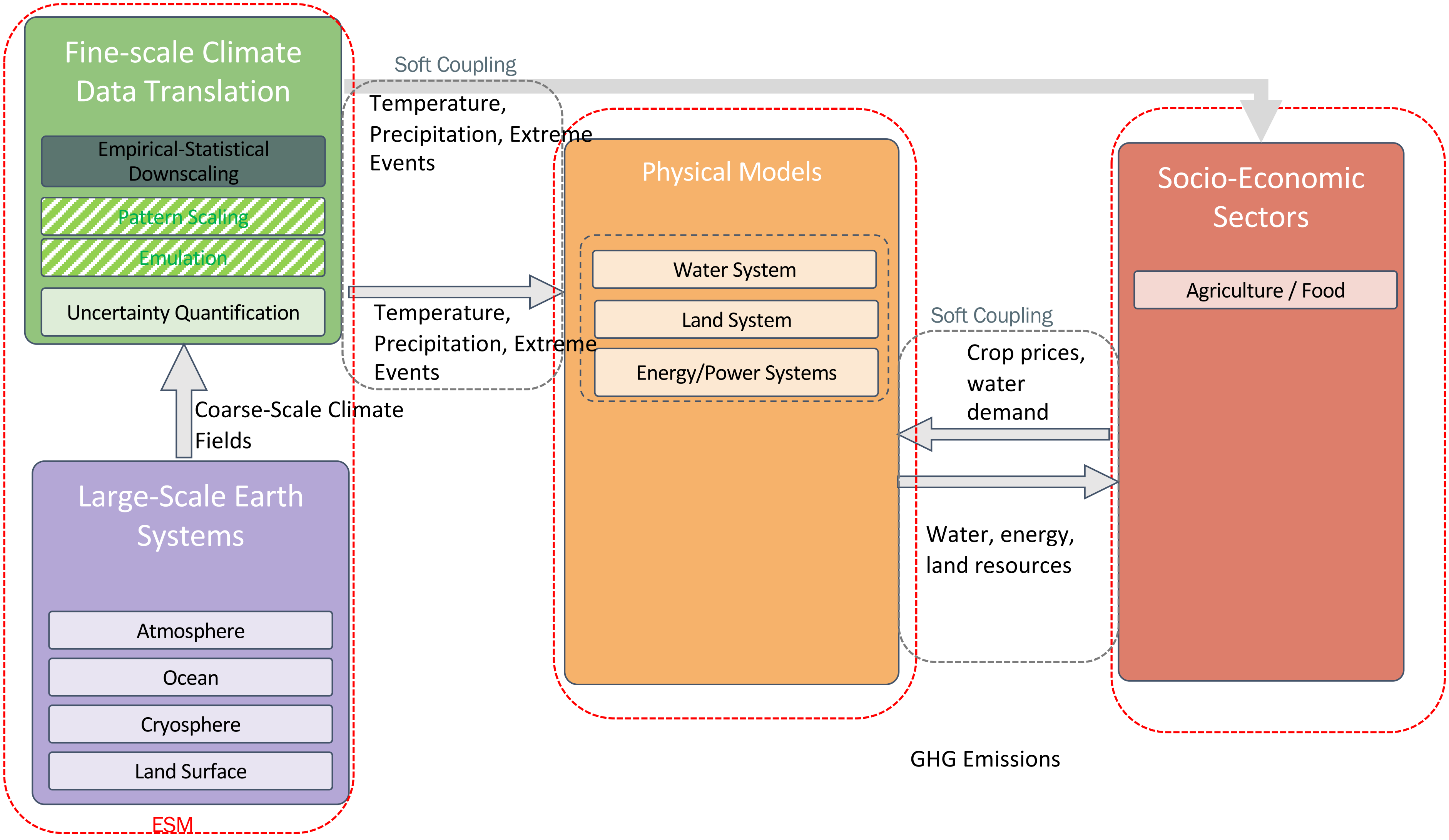
- **Science Questions:**

1) What are the necessary spatial/temporal resolutions in each subsystem model and in coupled frameworks to characterize the impacts of interest?
2) How does this inform resiliency and vulnerability?



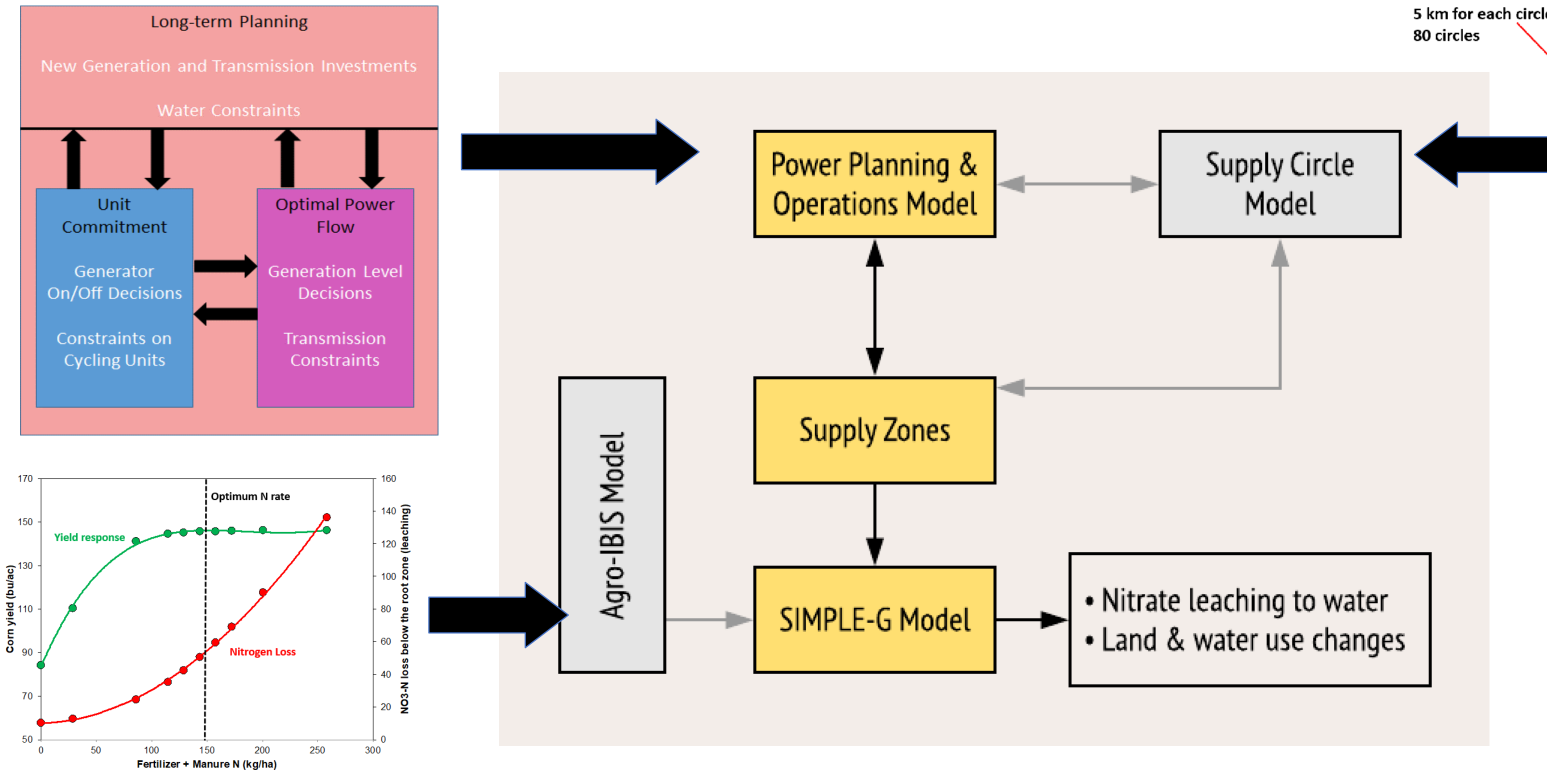
Project 1.1—Gridded modeling of integrated energy-water-land systems dynamics

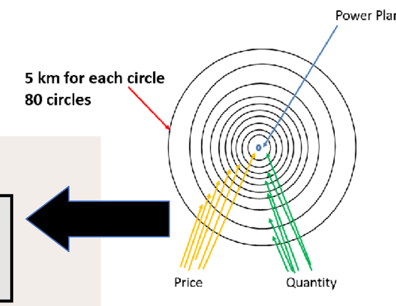
Hertel (lead), Grogan, Haqiqi, Lammers, Liu, Schlenker, Sun, Valqui, Webster



Electricity-Land-Water System Dynamics in the MISO region

⇒ *What if states adopt biomass co-firing of coal units to meet RPS?*



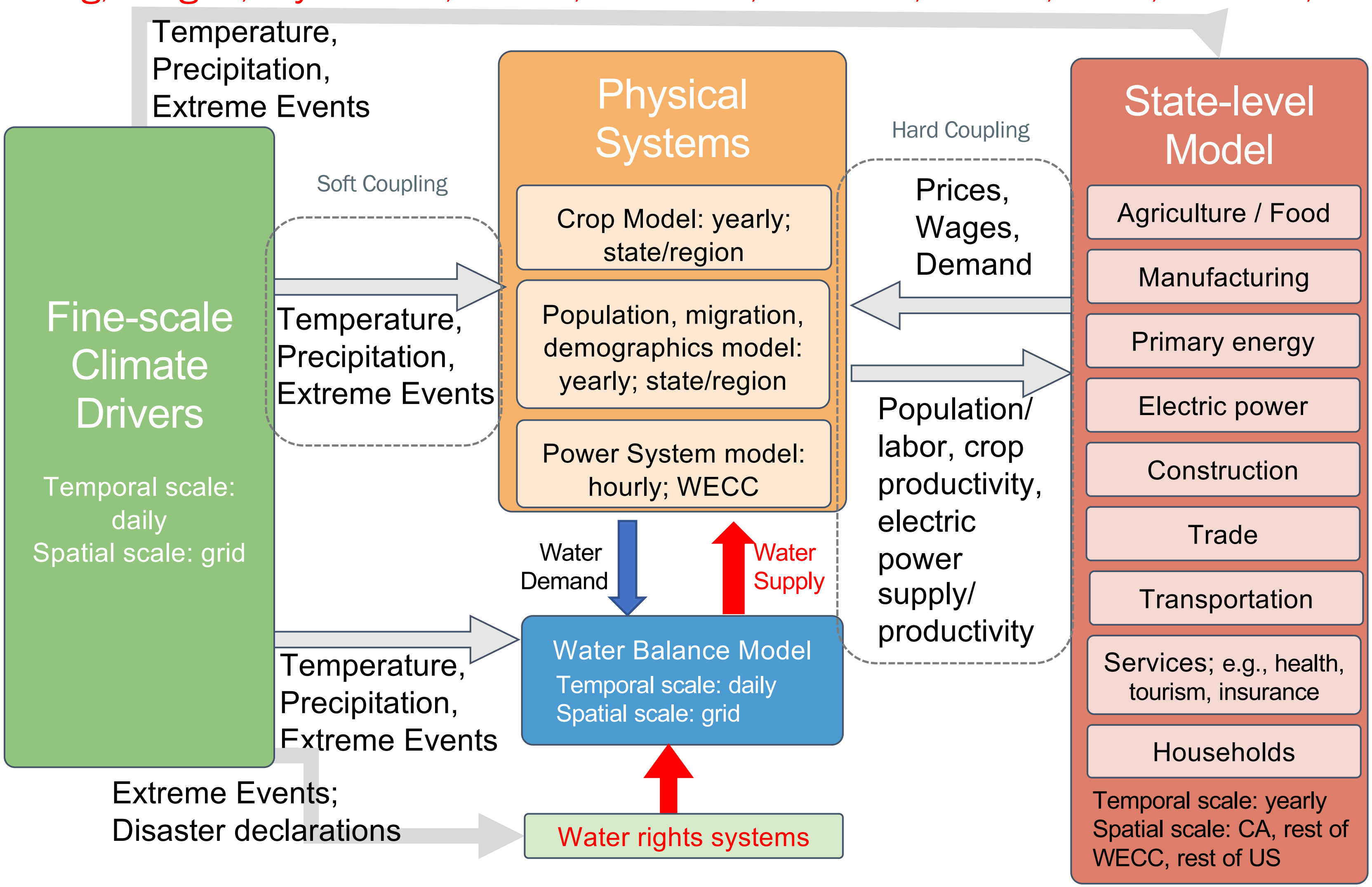


Highlights importance of fine-scale resolution in determining the joint outcome between the spatial distribution of power generation and the spatial distribution of water quality impacts from biomass.

Other Subproject 1.1 fine-scale related research

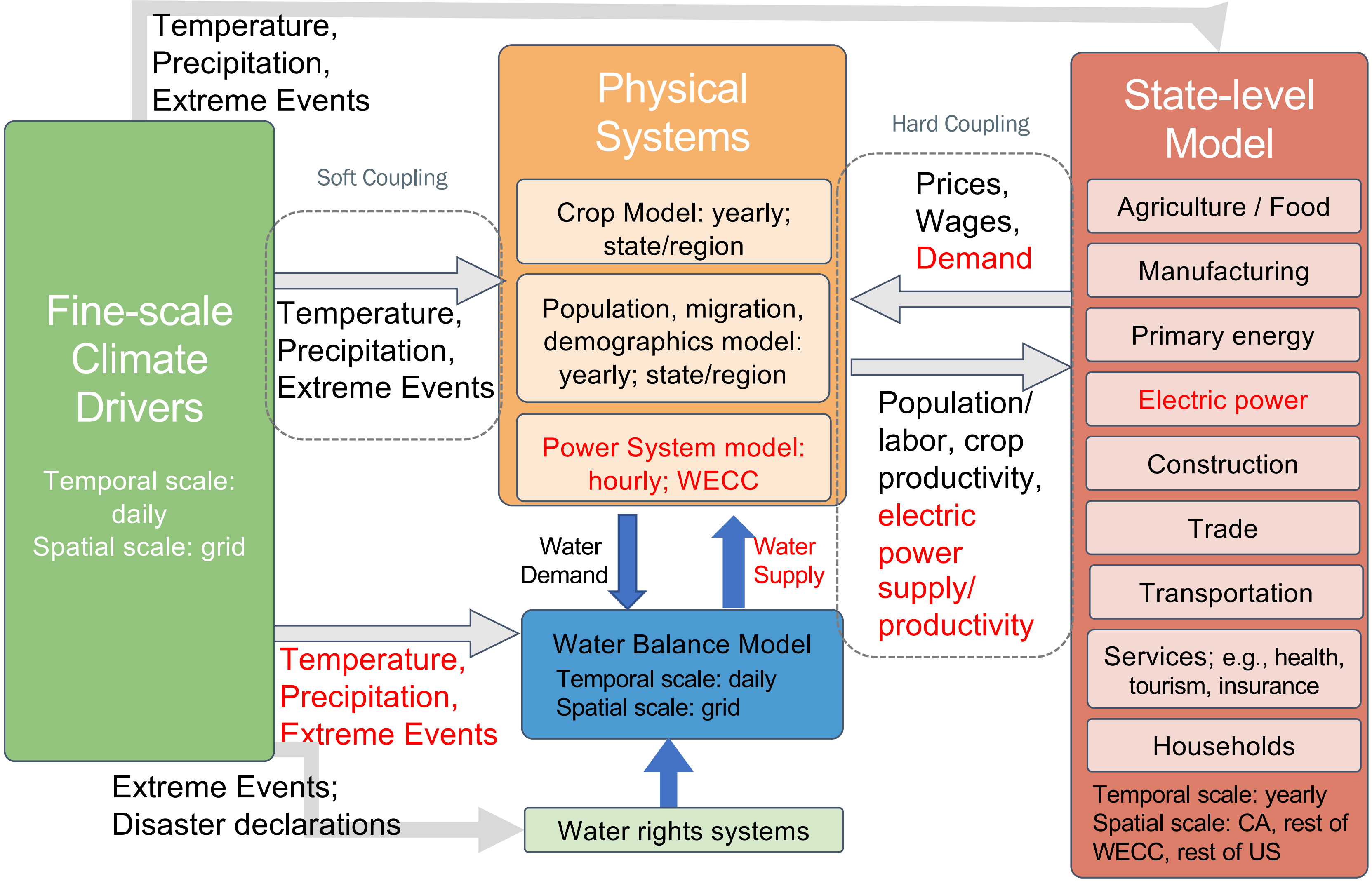
- Soil moisture and crop yields
  - Combine statistical crop yield response model of Schlenker and Roberts (2009) with UNH's Water Balance Model
  - Using WBM model output for soil moisture as an explanatory variable for crop yields dominates previous estimates based on precipitation and allows for better estimates of supplementary irrigation requirements
- Technology Adoption: hybrid corn adoption
  - Did adopting hybrid seeds affect avg yields and *sensitivity* to extreme weather?
  - Key findings: Hybrid corn significantly increased heat tolerance and adoption seems endogenous to weather shocks.
- Climate Extremes and Resilience
  - Can CMIP5 and NEX-GDDP products simulate extreme GDD variables?
    - We provide a useful framework for diagnosing/evaluating model uncertainties using ag-relevant extreme temperature metrics
  - Does Yield Volatility imply Price Volatility?
    - Increased volatility makes crop storage more profitable. Developed optimal storage model under different expectation scenarios

Project 1.2—Capturing governance, institutional, and system constraints in an integrated energy-water-land modeling framework Fisher-Vanden (lead), Caccese, Fowler, Frolking, Grogan, Jayasekera, Kumar, Lammers, Nicholas, Peklak, Perla, Webster, Wrenn

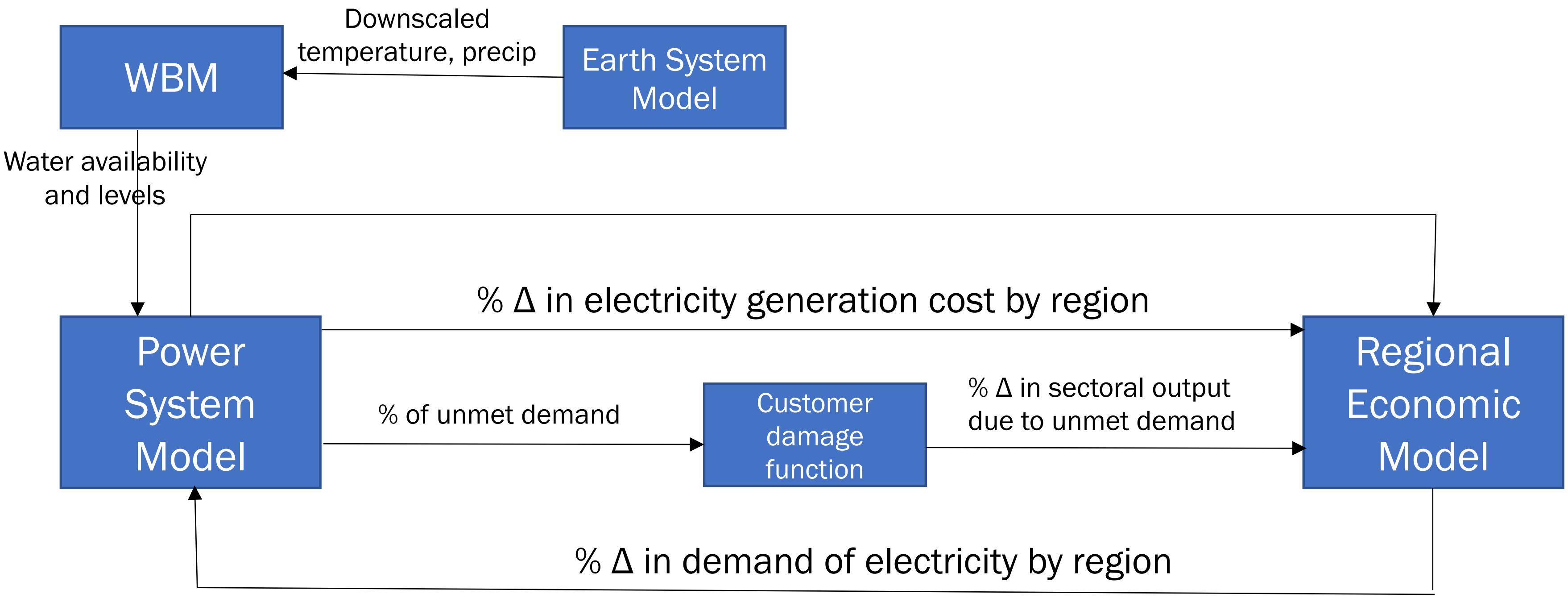


Project 1.2—Capturing governance, institutional, and system constraints in an integrated energy-water-land modeling framework

Fisher-Vanden, Kumar, Webster, Lammers, Perla



Hydrology-Electricity-Economy Coupling Methodology

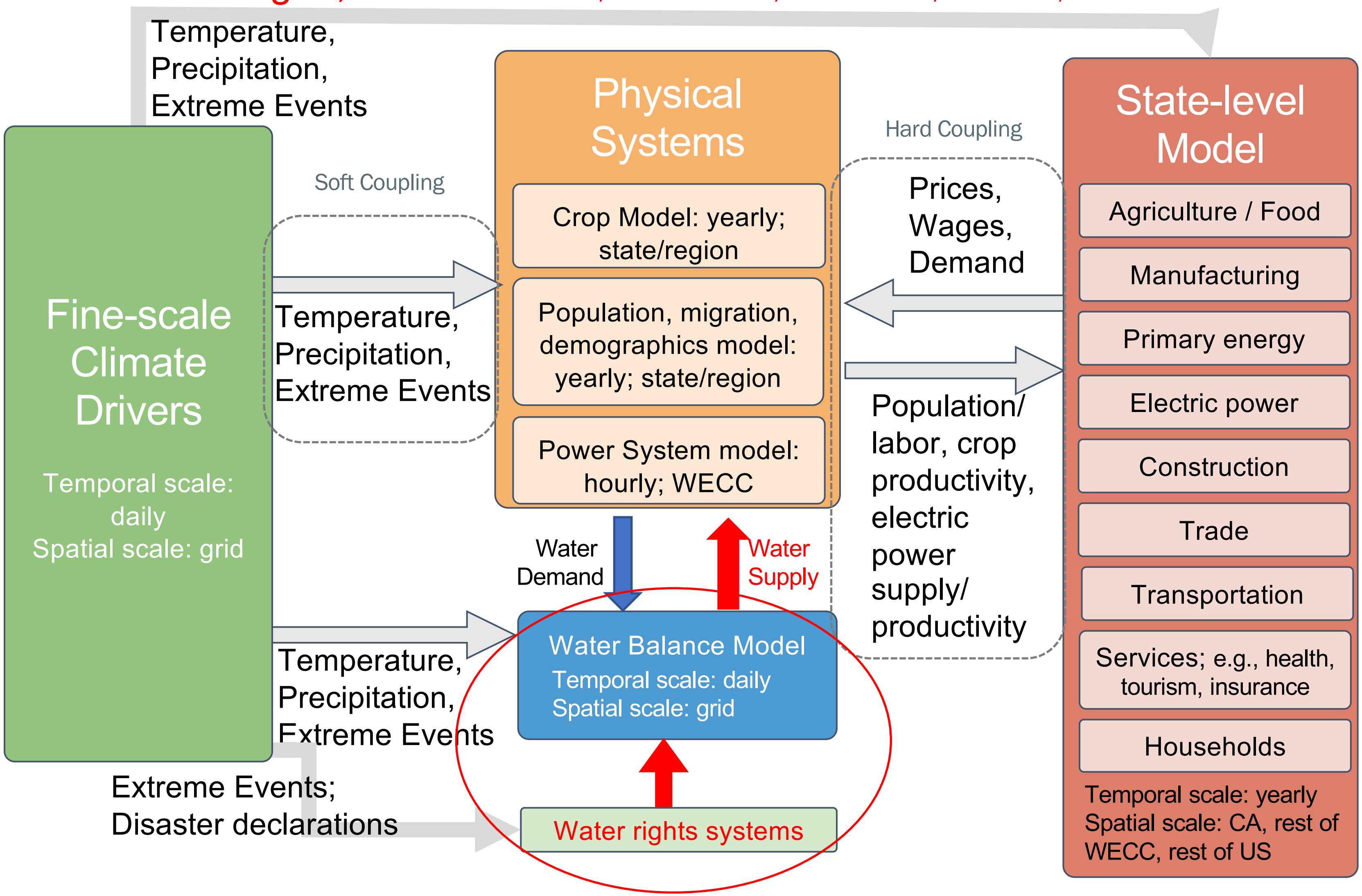


Key findings:

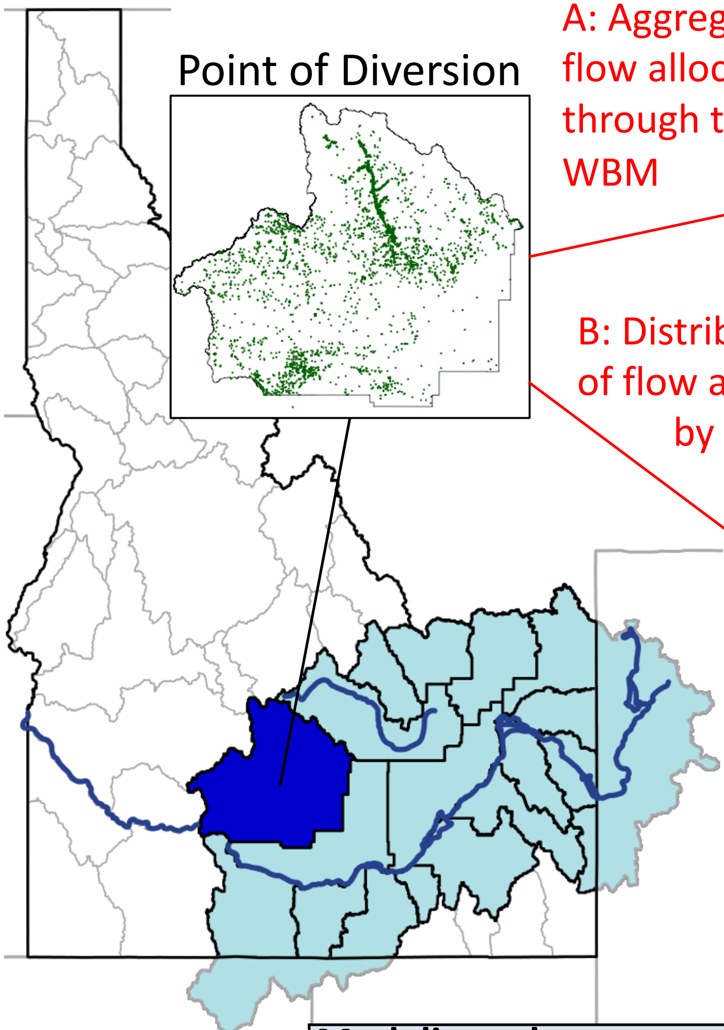
- Hourly detail of PSM important for capturing productivity impacts of outages due to water shortages
- Demand feedbacks in response to higher electricity prices significantly dampens economic impacts of outages

Project 1.2—Capturing governance, institutional, and system constraints in an integrated energy-water-land modeling framework

Grogan, Fisher-Vanden, Lammers, Caccese, Fowler, Peklak

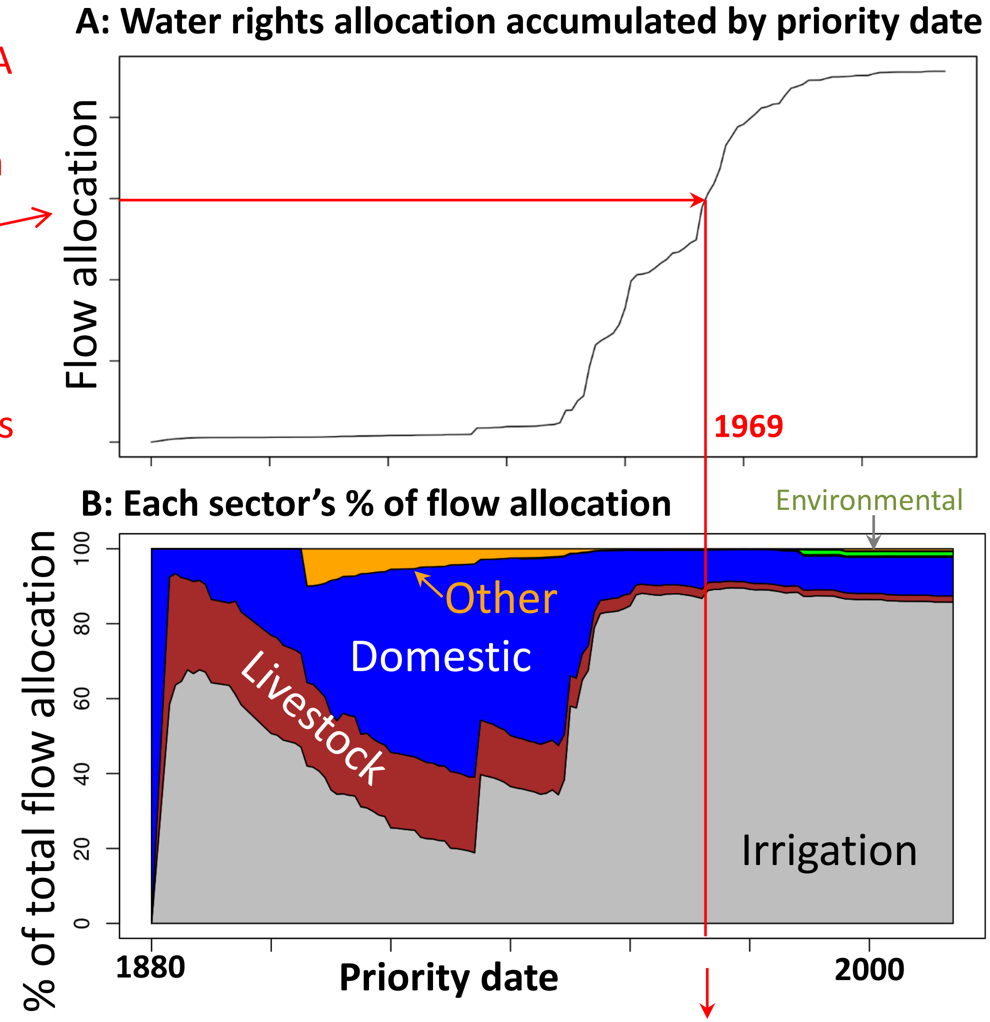


Methods: Aggregate to WMA-level representation



A: Aggregate WMA flow allocations through time from WBM

B: Distribution of flow allocations by sector



Irrigation gets 85%
Livestock gets 3%
Domestic gets 10%
Other gets 2%
Environmental gets 0%

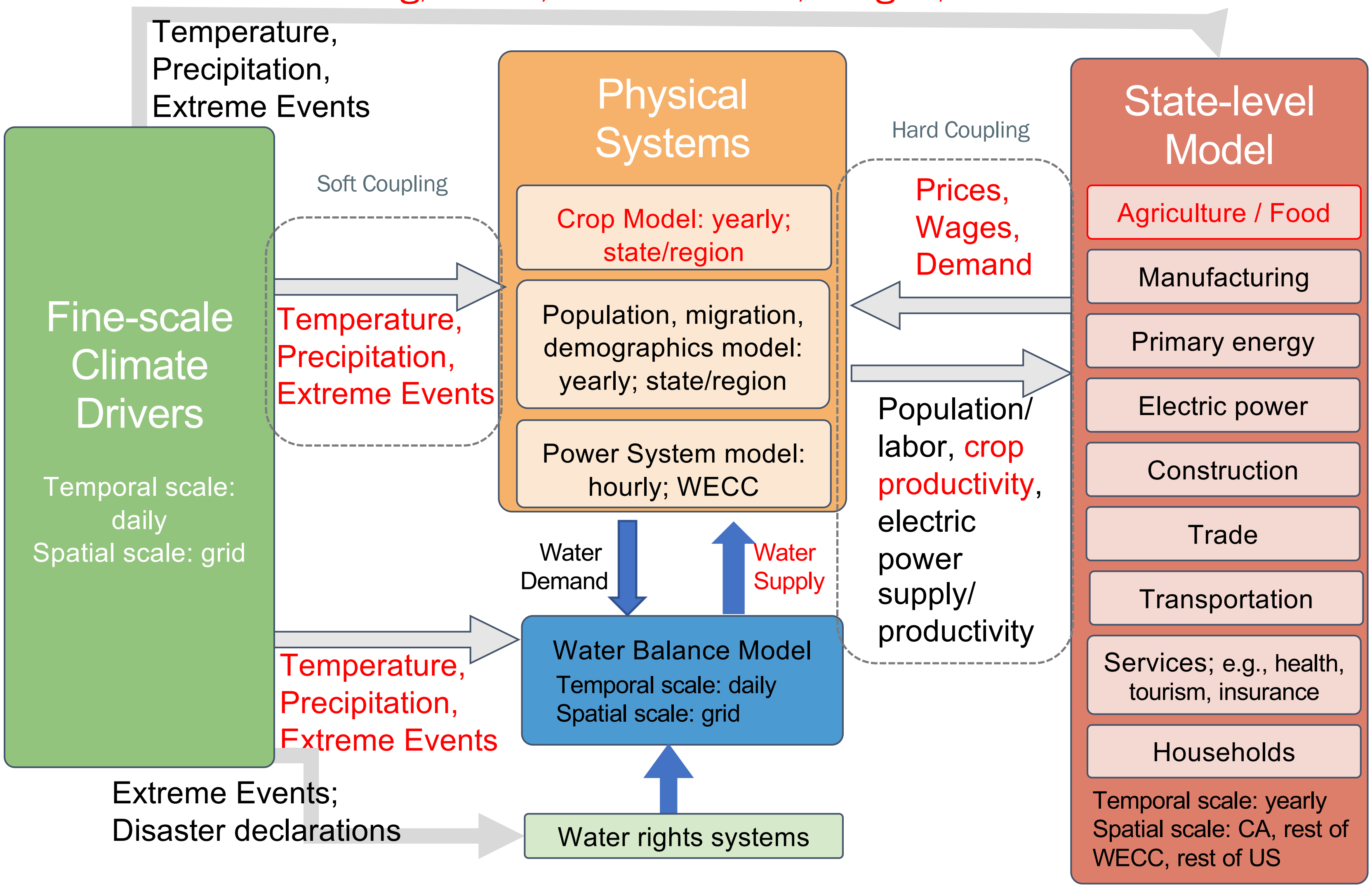
Modeling scheme:

Water demand & supply	Simulated by WBM
Water distribution	Volume-dependent rules based on water rights data

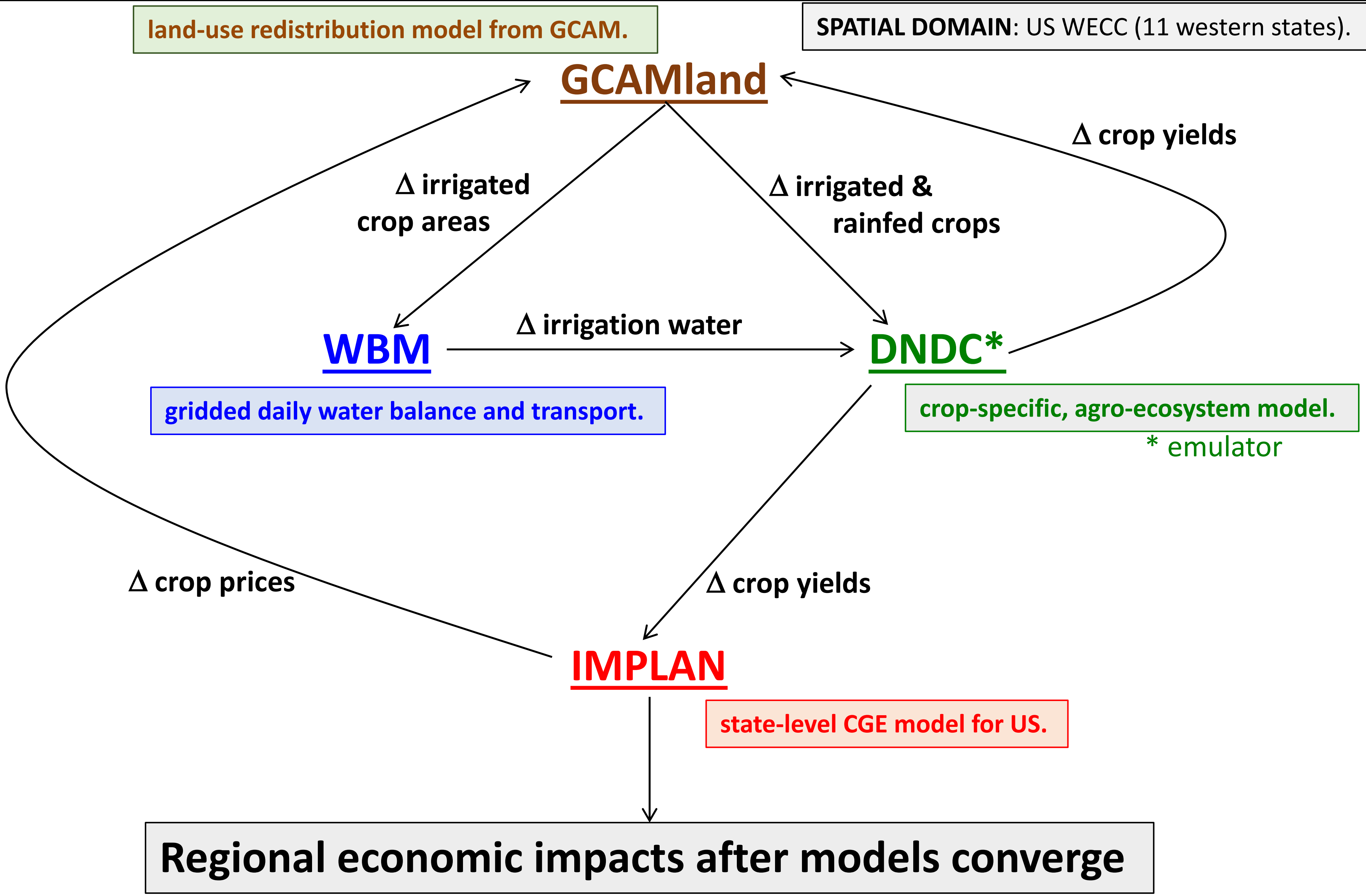
Water sector distribution is applied across WMA by WBM

Project 1.2—Capturing governance, institutional, and system constraints in an integrated energy-water-land modeling framework:

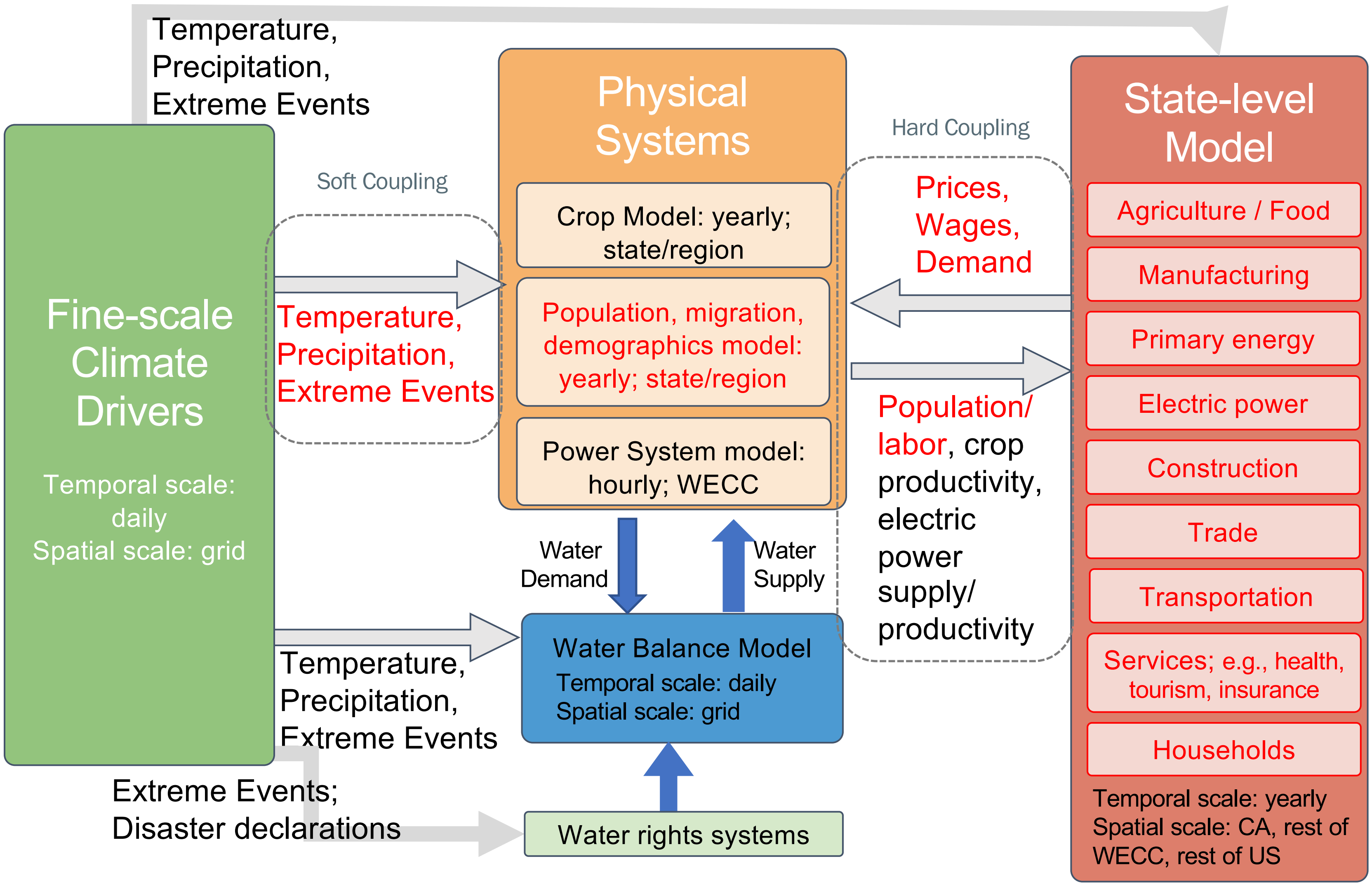
Frolking, Calvin, Fisher-Vanden, Grogan, Lammers



OBJECTIVE: couple four process models → regional economic impacts of water limitations in US West.

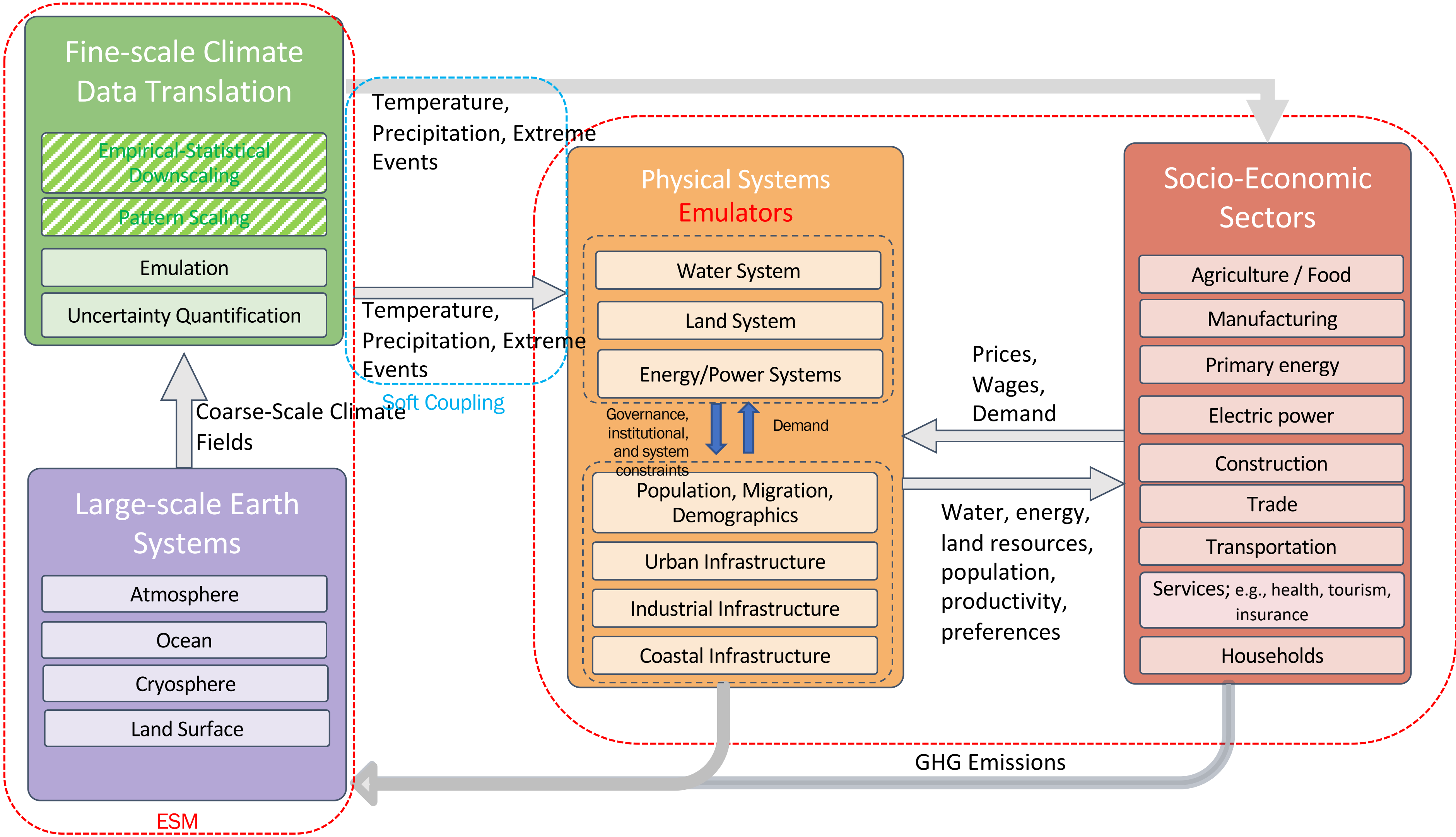


Project 1.2—Population Dynamics: Wrenn, Jayasekera, Fisher-Vanden, Carbone



Project 1.3--Global modeling of integrated energy-water-land systems dynamics

Sue Wing (lead), Mansur, De Cian, Mansur, Mistry, van Ruijven



Emulators of Climate Change Impacts

- Objectives
  - Simplify the process of incorporating climate change impacts into a diverse range of models
  - Represent shifts in key human system endpoints due to future climate change in a computationally efficient and empirically grounded manner
- Approach
  - Estimate empirical models of endpoint responses to meteorology using historical data
  - Combine fitted models with outputs of climate models at different spatial/temporal scales
  - Incorporate resulting "shocks" into various IAM and IAV models to assess primarily economic effects

Energy

- US counties (*Sue Wing, in prep*): Shocks to hourly per capita electricity demand under RCP 4.5/8.5 scenarios simulated by 21 climate models, ca 2050
- Global, gridded (*De Cian and Sue Wing, 2019; Van Ruijven, De Cian and Sue Wing, 2019*): Shocks to demand for petroleum, natural gas, electricity in agriculture, residential, commercial, industrial sectors under RCP 4.5/8.5 scenarios simulated by 21 climate models, ca 2050

Agriculture

- US counties (*Sue Wing et al, 2015):* Maize, wheat, soybean, sorghum, cotton yield changes under 3 warming scenarios simulated by MIT IGSM, ca 2050, 2090
- Global, countries (*Waldhoff et al, in review):* Changes in yields of 12 crops under RCP 4.5/8.5 scenarios simulated by 4 climate models, decadally to 2100
- Global, gridded (*Sue Wing, De Cian and Mistry, in review*): Maize, wheat, soybean, yield changes under RCP 4.5/8.5 scenarios simulated by 21 climate models, ca 2050, 2090

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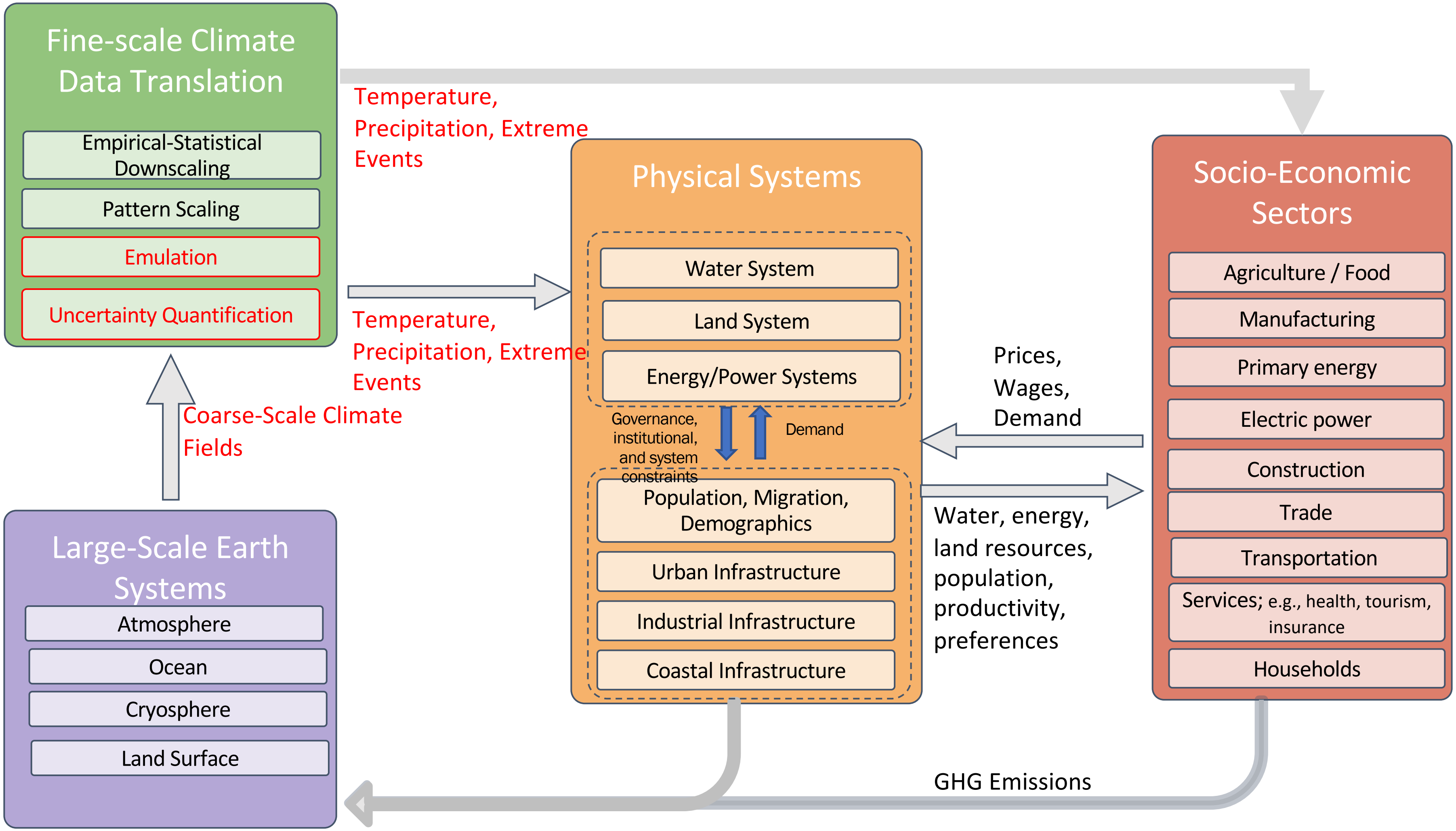
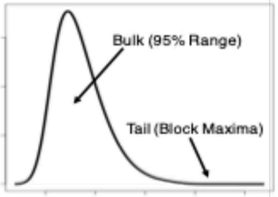
Project 2.2—The influence of uncertainties on the tails of climate projections on decision-relevant spatial and temporal scales:

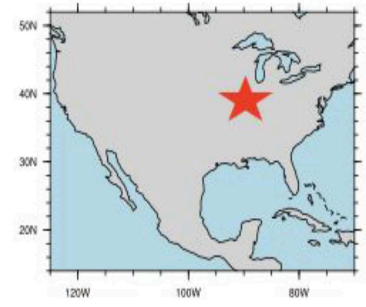
Keller, Haran, Lee, Nicholas, Srikrishnan, Sriver, Ye



Recent Results:

Do global climate models capture extreme temperature?



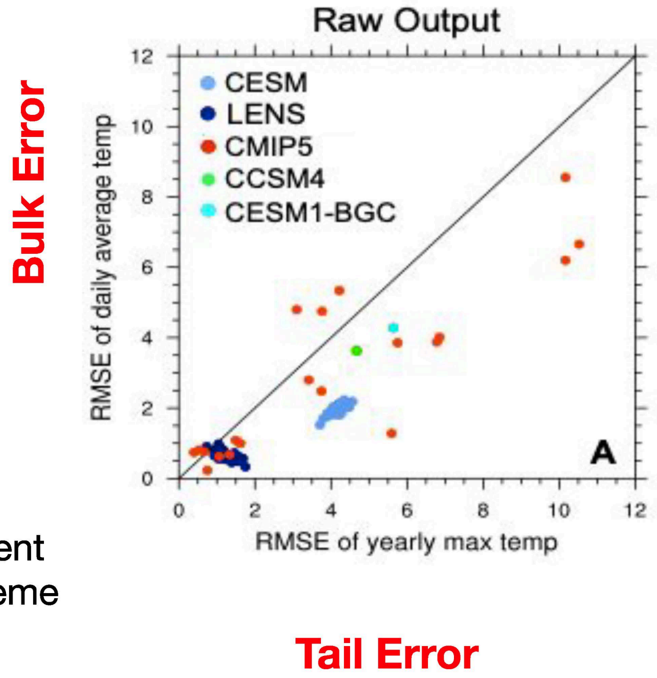


Objective

Analyze mean and extreme temperature at regional scales in global climate model ensembles and evaluate skill based on the historical period

Approach

- Utilize a block maxima approach to analyze extreme temperature distributions across spatial scales
- Quantify effects of internal variability, resolution, and different model structures on temperature distributions (bulk vs tails)

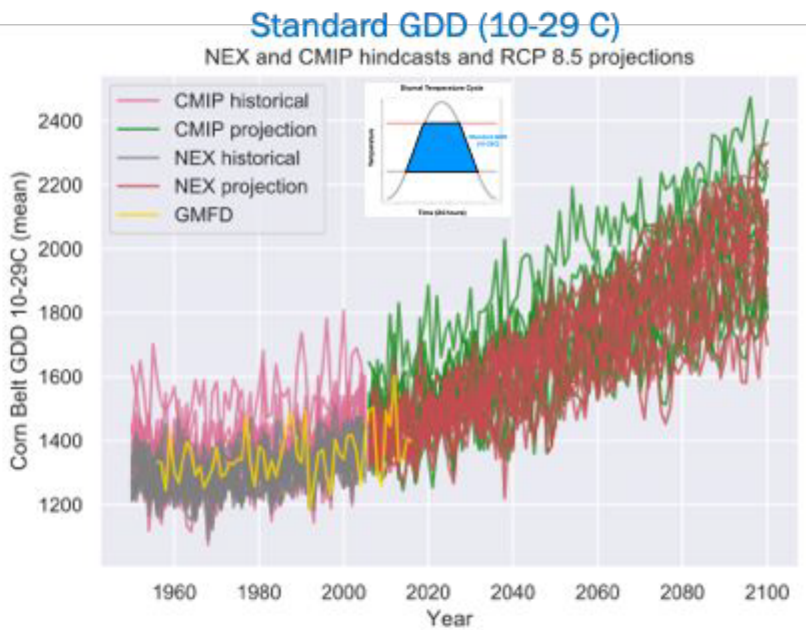


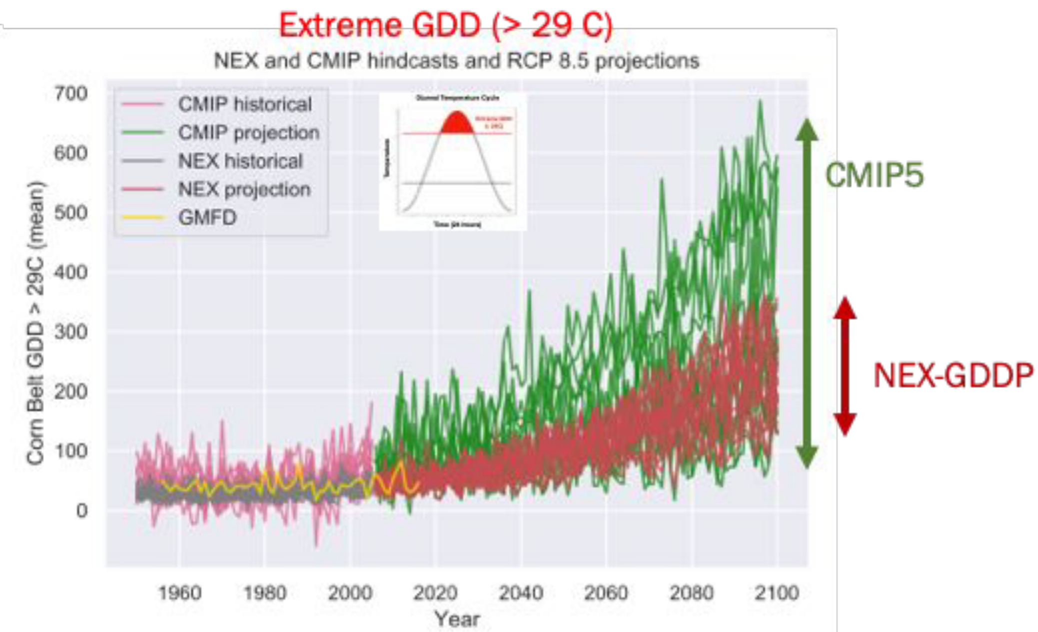
Impact

- Daily average and extreme temperatures vary widely between different models and ensembles, which influences skill in both bulk and extreme temperature distributions

Hogan, E. E., Nicholas, R. E., Keller, K., Eilts, S., and Sriver, R. L. (2019), Representation of US warm temperature extremes in global climate model ensembles, Journal of Climate, doi://10.1175/JCLI-D-18-0075.1

Growing Degree Days in CMIP5 and NEX-GDDP
- Focus on the US Corn Belt





- Historical variability significantly reduced in NEX-GDDP compared to CMIP5
    - Major implications for extreme GDD projections

Lafferty, Sriver, Haqiqi, Hertel, Schlenker, Nicholas, and Keller (In prep), Extreme temperature in downscaled hindcasts and projections, Journal of Climate.

Improving the climate realism of crop-yield projections

Ongoing Work:

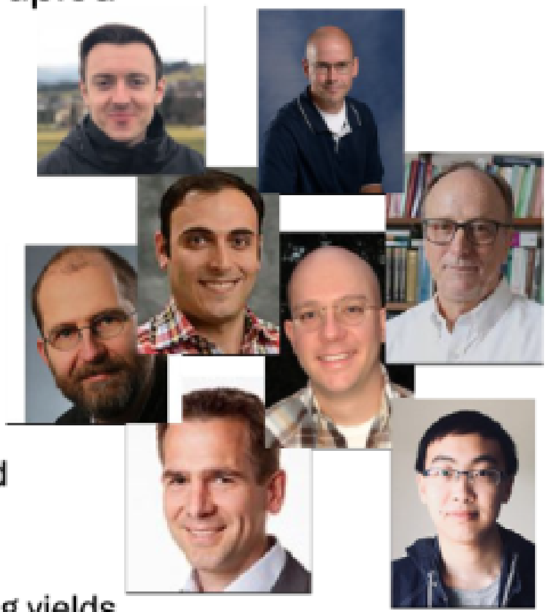
Assessing the suitability of downscaled projections for coupled human-environment analysis

David Lafferty & Ryan Sriver, University of Illinois

Iman Haqiqi and Tom Hertel, Purdue University

Klaus Keller, Rob Nicholas and Haochen Ye, Penn State

Wolfram Schlenker, Columbia University



Characterize ag-relevant temp uncertainties in global climate models and downscaled products

- Uncertainty Propagation:
  - Global Models (CMIP5) → downscaled products (NEX-GDDP) → Ag yields
- Extension of analysis developed under PCHES2.2 (Hogan et al., 2019)
  - Diagnose intermodel differences and quantify effects of bias-correction and downscaling on regional extremes

Data-Driven Agent-Based Modeling

Many see a "problematic relationship between AB models and empirical data" (e.g., Fagiolo et al, *Comp. Econ.*, 2007)

Why use statistical calibration?

- Which hypothesis is best supported by the data?
- **Which operation rule best describes the agent behaviors (e.g., in reservoir management)?**
- **How do households respond to repeated flooding events?**

Research question: How much data are required to calibrate ABMs?

Computer Model Calibration

Motivation:

- Computer models are used to project future hazards
- Key model parameters ("inputs") are often uncertain

Calibration:

- Estimate parameters using model outputs and observations

Key problems:

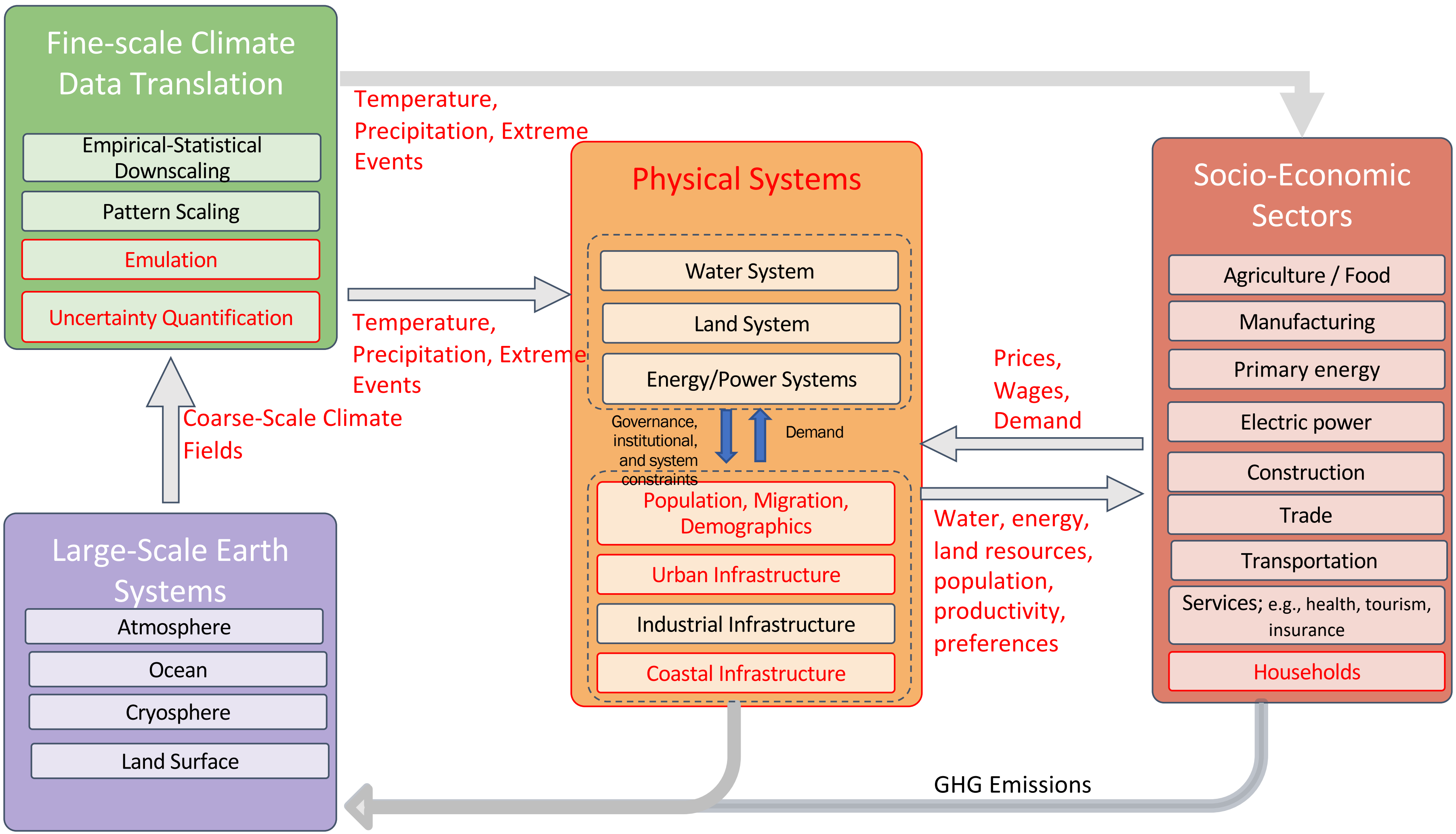
- Current calibration methods can be slow

Our approach:

- A fast particle-based approach for computer model calibration
    - Lee, B. S., Haran, M., Fuller, R., Pollard, D., and Keller, K. (2019). A fast particle-based approach for calibrating a 3D model of the Antarctic ice sheet. *Submitted to the Annals of Applied Statistics.*

Use Case for Project 2.2—Modeling Flood Risk:

Olmstead (lead), Keller, Plough, Wrenn, Zarekarizi



Flooding Proximity and Housing Market Outcomes, a Multi-city Study

Olmstead, Wrenn and Plough

- Local resilience to increasing flood frequency/magnitude depends on property buyers'/sellers' ability to accurately assess flood risk.
- Global costs associated with coastal flooding are high and rising, but housing markets may not fully capitalize flood risk (Beltran et al 2017).
    - Published estimates range from steep discounts to (counterintuitively) small premiums (McCoy & Zhao 2016, Bin & Landry 2013).
- To test whether these inconsistent results are due in part to misspecification of prior flood exposure, we develop a spatially-refined measure of exposure and use that measure to estimate flood risk discounts in two coastal housing markets: Houston, TX and Tampa, FL.
- Preliminary estimates suggest variation across cities in flood risk capitalization, with promising results for our spatially-refined prior exposure measure.

FLOPIT: Flood Probability Interpolation Tool

Keller, Zarekarizi

FEMA flood maps

+

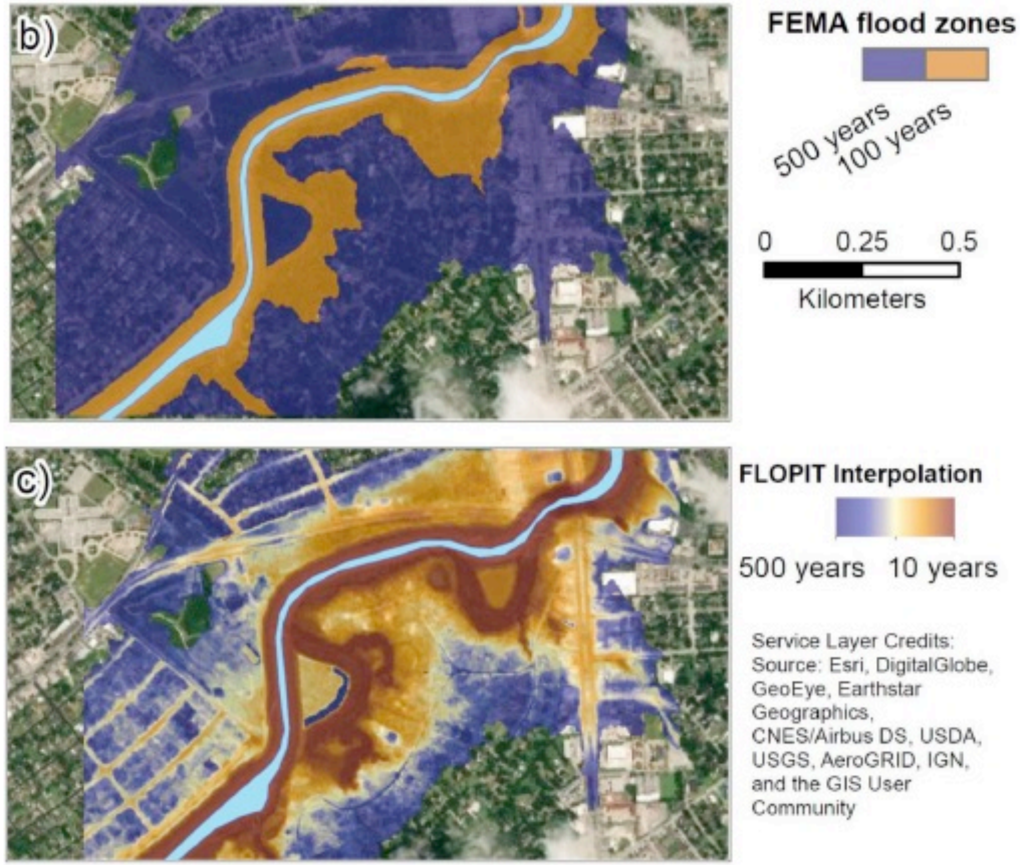
Digital Elevation Model

↓

FLOPIT

↓

Probabilistic flood maps



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Project 3.1: Base Research Program for Developing Evaluation Tools for MSD Modeling Frameworks

Weyant (lead), Merrick, Reed

Two emergent research projects

1. Towards a framework for model evaluation – how to know a "better" model when you see one
   - Initially focused on assessing model aggregation assumptions (temporal, spatial, etc.) in normative models
   - Development analogous to "information bottleneck" concept from information theory
   - Conditionally unavoidable in a couple of dimensions, but has qualitative and frequently quantitative value
   - Can also be applied to scenario choice

2. Towards a systematic approach to model development, uncertainty quantification, risk management & diagnostics
   - Basic approach has roots in statistics, bayesian decision theory and machine learning
   - Implemented in a general stochastic network framework
   - Two biggest challenges are non-stationarity and representing human behavior
   - Explicitly considering data driven versus structural assumption driven methods in and across disciplines
   - Initial demonstation project is on extreme event supply chain impacts-paper early June

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Project 4.1: Community Engagement Activities

- Extended PI Meetings
  - December 2016 - Stanford, California (Combined Agric Methods/PIAMDDI/PCHES)
  - July 18-21, 2017 - Snowmass, Colorado (combined with Outreach Meeting)
  - May 21-22, 2018 - PSU
  - May 14-15, 2019 - PSU
- Oureach Meetings
  - July 18-21, 2017 – Snowmass, Colorado (combined with PI Meeting)
  - July 18-20, 2018 - Snowmass, Colorado
  - July 16-18, 2019 - Snowmass, Colorado (multi-MSD team format)
- Coordination With US Based Research Groups
  - IARP Supported Research Groups
    - MIT: John Reilly, Adam Schlosser, Erwan Monier
    - IHESD: Leon Clarke, Kate Calvin, Mohamad Hejazi, Richard Moss,
    - IM3: Jenny Rice, Ian Kraucunas, Brian O'Neill, Jordan Macknick
  - Other DOE National Labs
    - LBNL: Bill Collins, Andy Jones, Susan Hubbard
    - LLNL: Ben Santer, Karl Taylor
    - LANL: Scott Bachus, Nathan Urban
    - PNNL: Ruby Leung, Dave Judi
  - Other US Based Labs
    - NASA-GISS: Alex Ruane

Project 4.1: Planned Research Community Engagement Activities

International Outreach & Coordination

- Projects
  - Coordination with EU PESETA & ISI-MIP Projects: Fisher Vanden
  - Coordination with AgMIP International Consortium: Fisher-Vanden
  - October 2016 EU ADVANCE Study Final Meeting - Brussels: Weyant
  - December 2016 EU CD-LINKS Study Meeting - Beijing: Weyant
  - December 2016 IAMC Annual Meeting - Beijing: Weyant
  - May 15-17 CD-Links Study Meeting – Potsdam: Weyant
  - December 5-7, 2017 IAMC Annual Meeting – Brazil: Weyant
  - March 20-22, 2018 EU CD-LINKS study Meeting – New Dehli: Weyant
  - November 13-15, 2018 IAMC Annual Meeting – Seville, Spain
  - March 19-22, 2019 EU CD-LINKS study Meeting – Rio: Weyant
  - December 2-4, 2019 IAMC Annual Meeting – Tsukuba, Japan
  - New ENGAGE, NAVIGATE & PESETA EU Studies, 2020

- Coordination with Individual Research Groups
  - PBL (Netherlands), IIASA (Austria), PIK (Germany), NIES (Japan)
  - COPPE (Brazil), Roberto Schaeffer, IIM/TERI (India): ERI/Quinhua Univ. (China):