Scientific Drivers, Needs, and Trends in Integrated Human-Earth System Modeling at the Energy-Water-Land Nexus

Bob Vallario
Program Manager, Integrated Assessment Research

July 25, 2016

Snowmass 2016 – Week 2
Snowmass, CO

Three communities evolving individually and collectively – where are we headed and why?

1. What are the key information exchanges presently or potentially for these model forms and communities – **IAMs, IAVs,** and **ESMs (and RGCMs)**…and demographics, hydrology, and other specialized modeling domains.

2. Interest in building off of current and emerging USGCRP and agency priorities, e.g., Energy-Water-Land (or Food) systems, and more broadly through IGIM: 1) drought stressed regions and 2) connected, concentrated infrastructure (including urban).

3. Importance and focus on modeling and understanding cross-sectoral and broader system dynamics… *not just physical but socio-economic as well*.

4. Particularly important to understand disruptive events…extremes, system shocks, vulnerabilities and adaptations.

5. Where and why might hard versus soft couplings be useful? Where do they need to be coupled? Two way exchanges?

6. Scale matches and mismatches?

Three communities evolving individually and collectively (contd.)

7. Implications of adaptive grids and/or other “telescopic” capabilities?

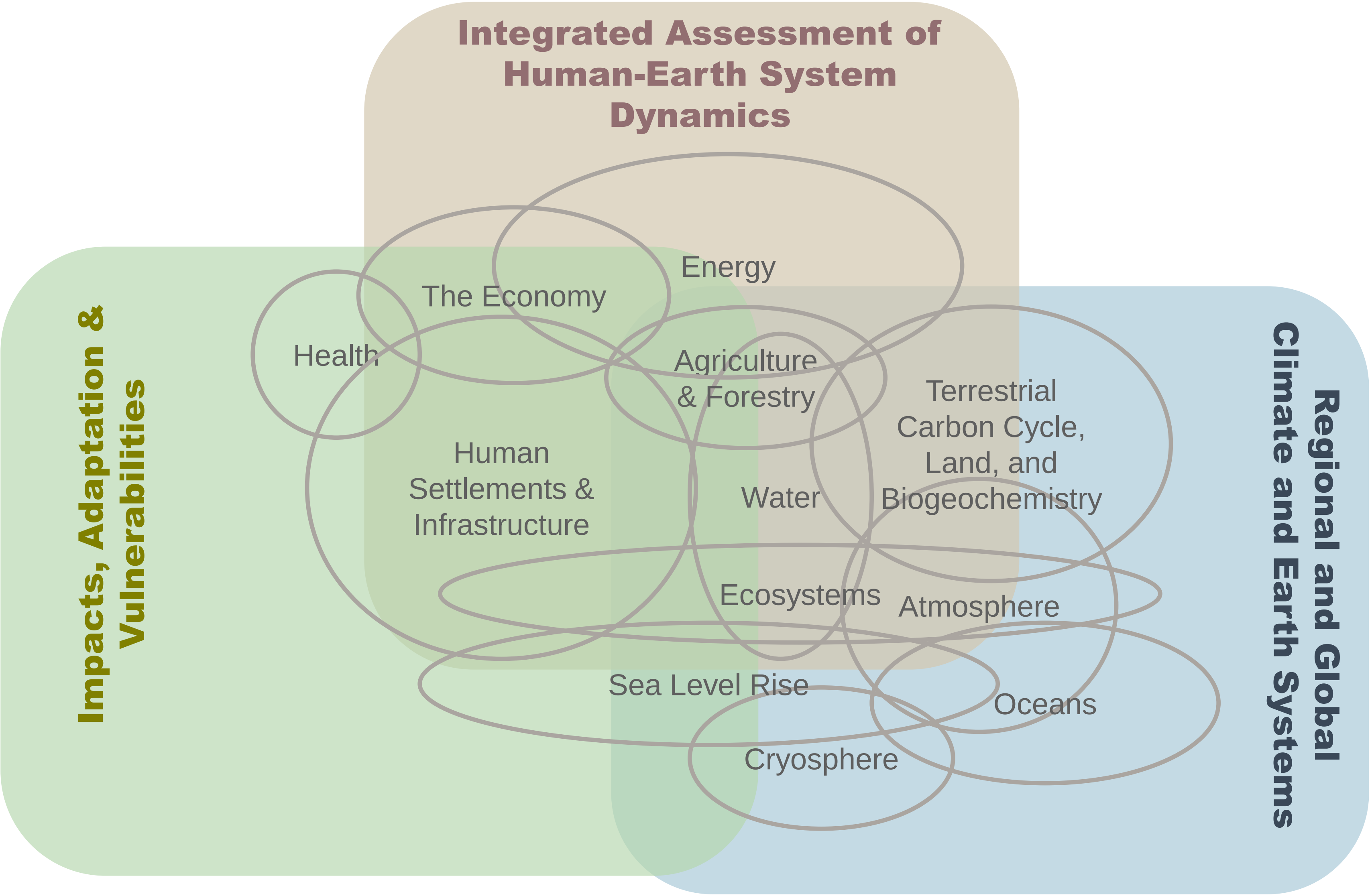
8. Typology of uses and users. What makes sense given uncertainties and/or data limitations for key questions and user-driven needs?

9. Differences for one pass deep dives versus highly iterative analyses tied to uncertainties and options (e.g., human decisions)?
    1. More complexity doesn’t always mean better predictability
    2. Use of emulators?
    3. How do we test and incorporate what really matters for key questions of interest? (Not all detail matters)

10. How do we transfer place-based learning to more generalized models and simulations?

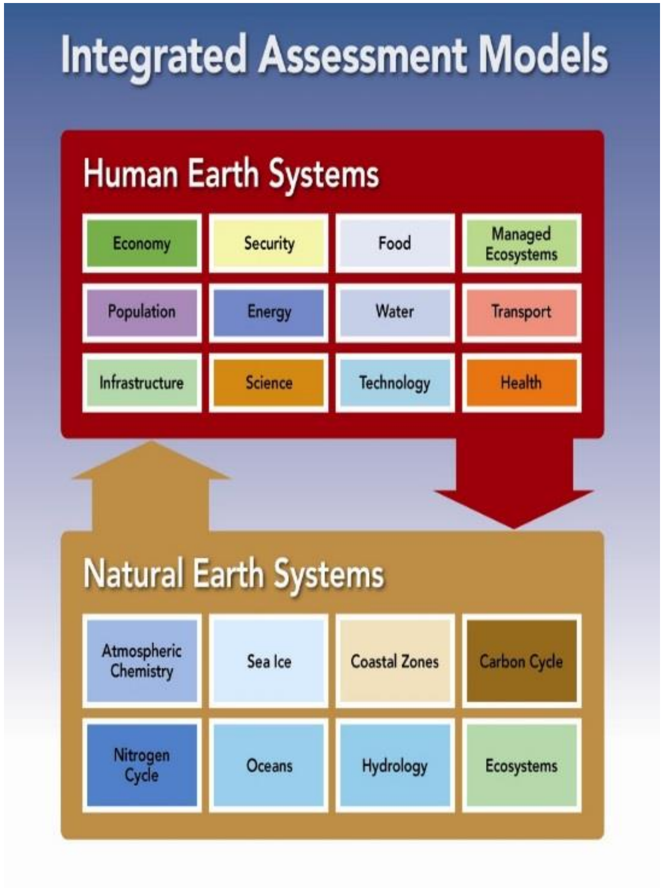
11. Modeling and scenarios… in both directions?

Modeling & analysis: a convergence of communities driven by needs/opportunities



Edmonds with modifications

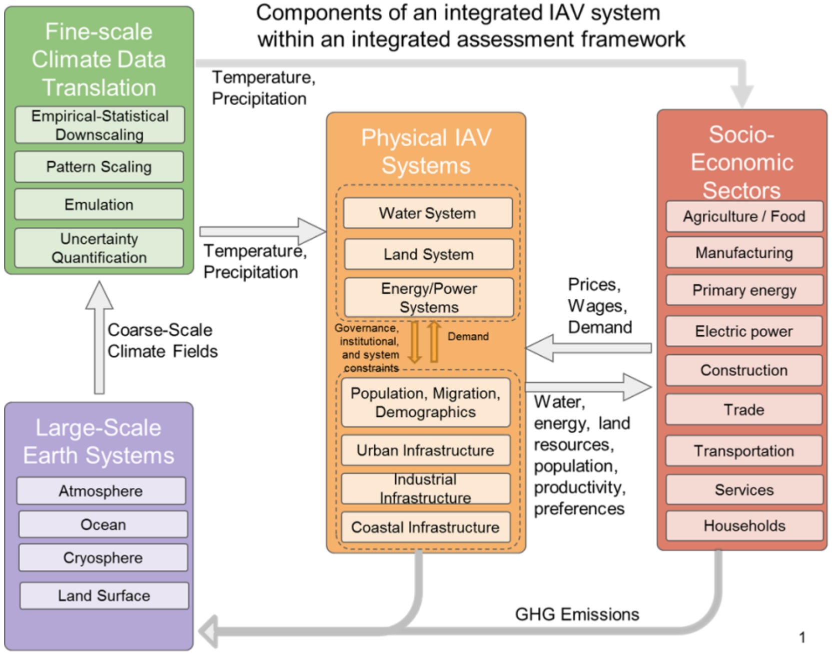
Three significant emphases are emerging in Integrated Assessment Research



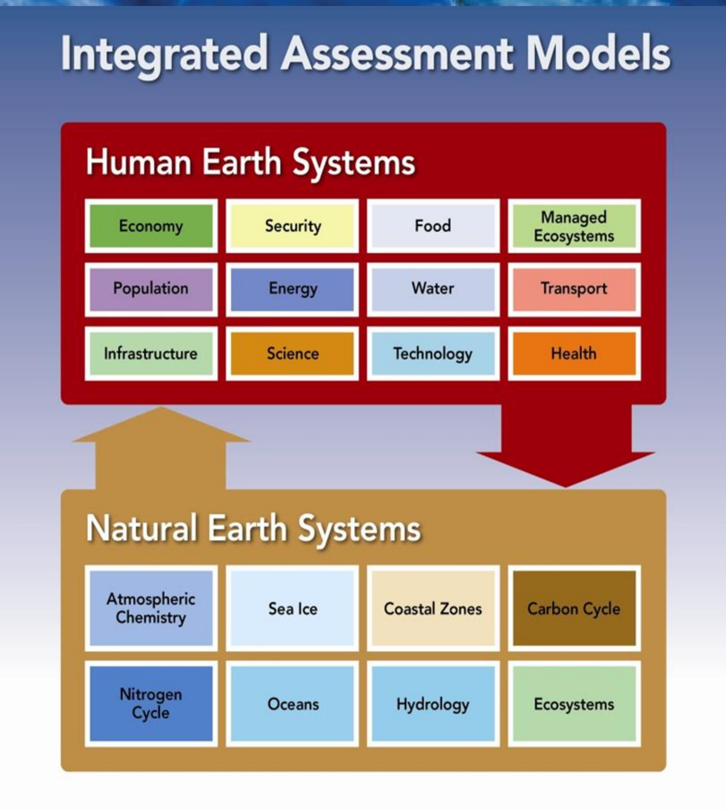
IAMs

EWN and IAV Data-Knowledge Systems

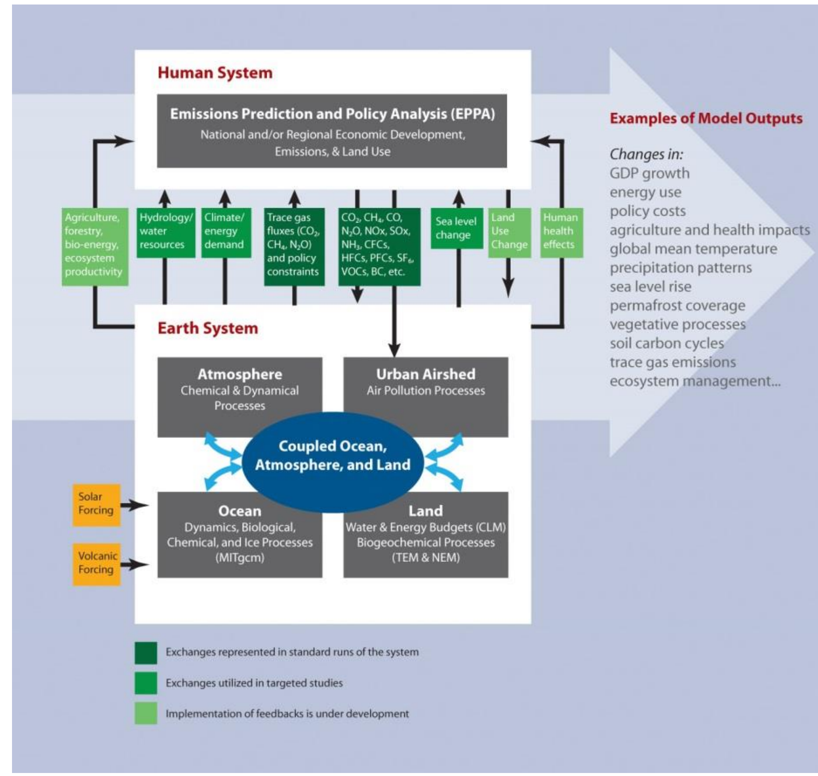
Multi-Sector, Multi-Scale IAV Models



Just a reminder…different approaches, complexities, and scales for IAMs



GCAM - EMIC based. Evaluating a new emulator that can reflect impacts, adaptations, and feedbacks.



IGSM - EMIC based on dialed back and adapted major components of CESM.

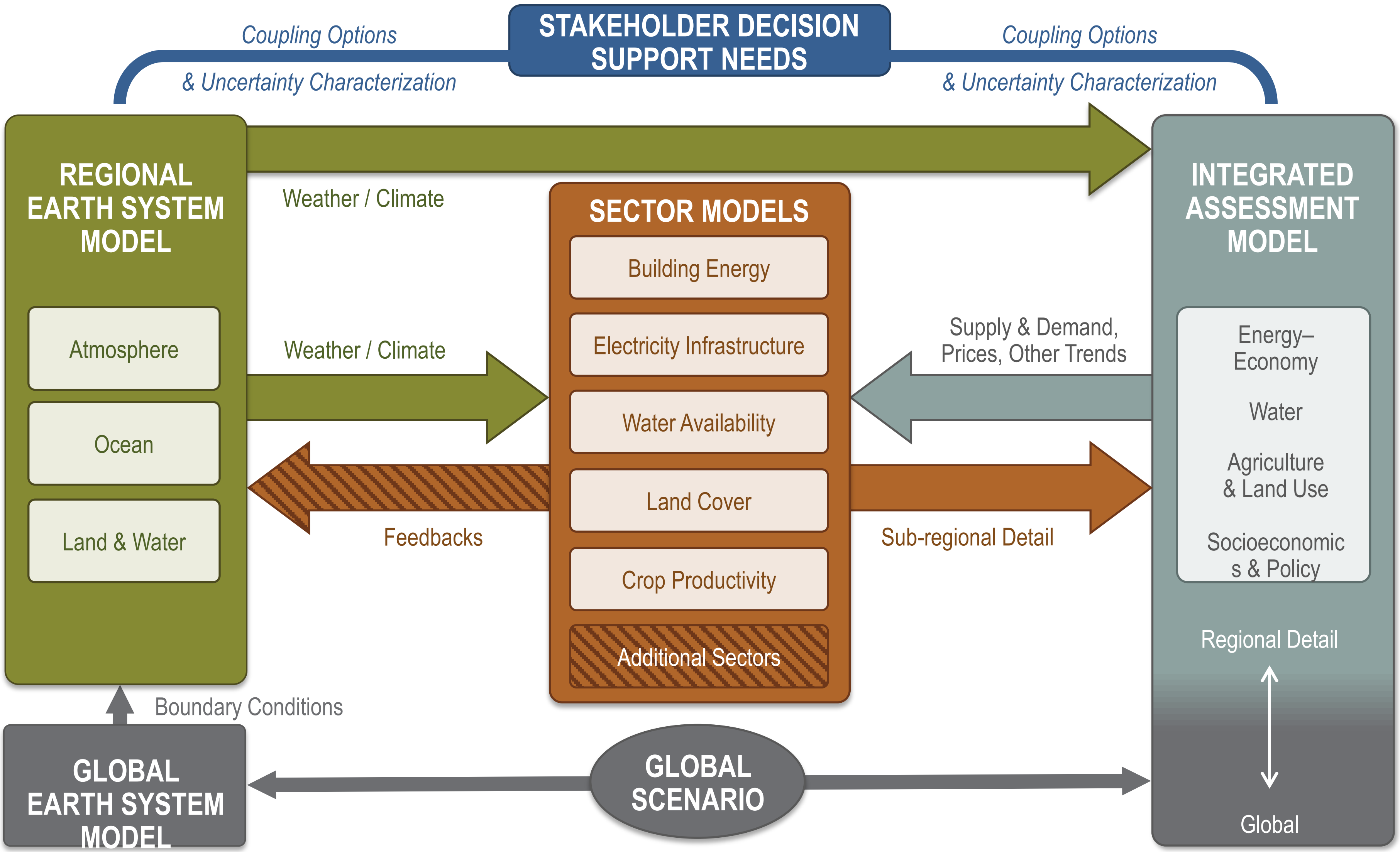
And basic models such as PAGE, DICE, FUND

Partial motivations for an integrated framework

Relevance of factors and processes at range of scales from local to international – not encompassed in any single model or currently linked models

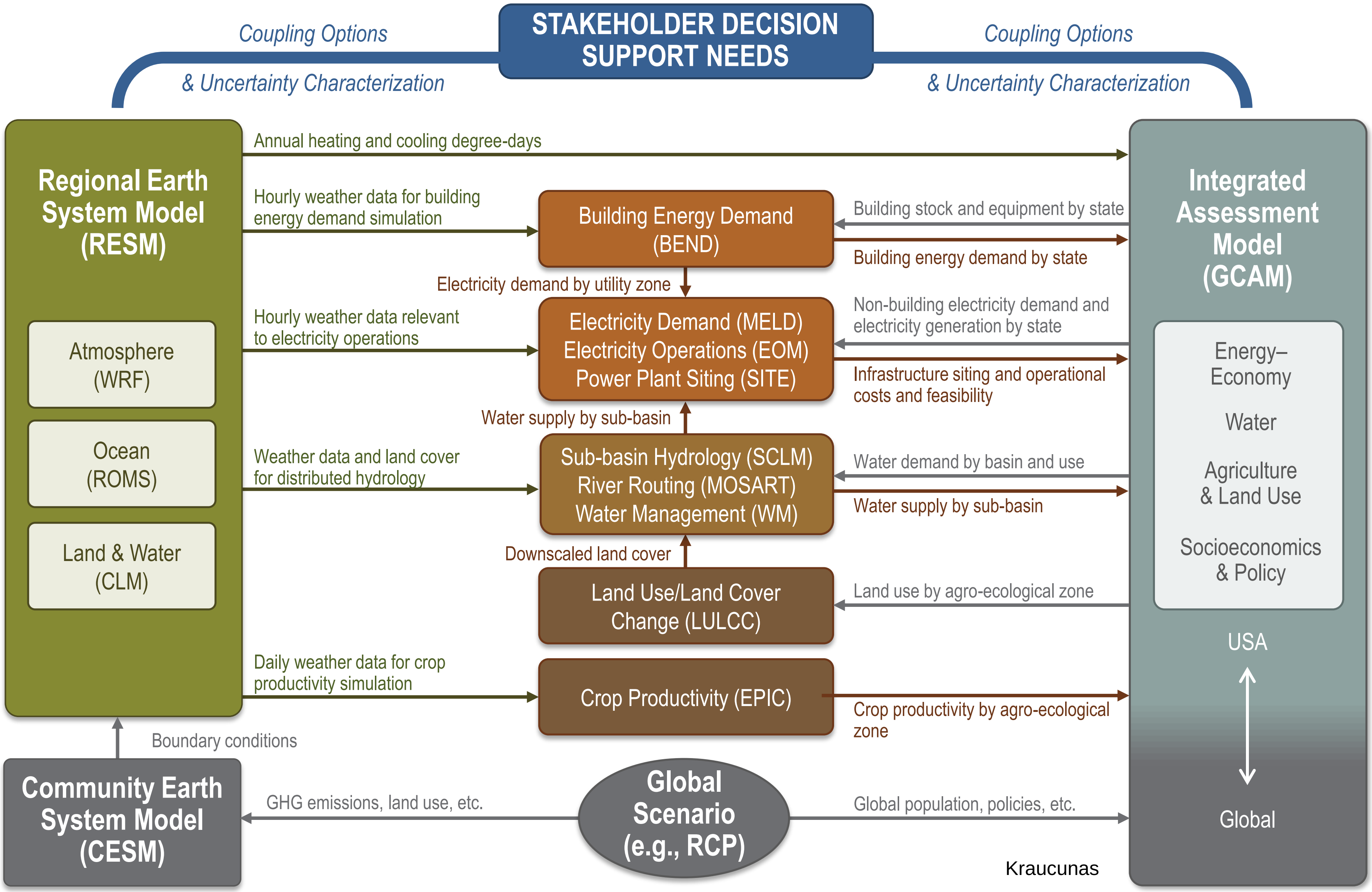
- IAMs have international scale and can factor supply/demand at national and international scales; however coarse resolution within a region is insufficient for understanding infrastructure-specific issues or local supply/demand dynamics
- Technology or sector-specific models can capture sub-national to regional dynamics but cannot examine influences of international or cross-sectoral interactions
- Current representation of climate (and other) shocks is inadequate in most models
- Limited capacity for consistent multi-criteria tradeoff analysis

An illustrative endpoint: PRIMA



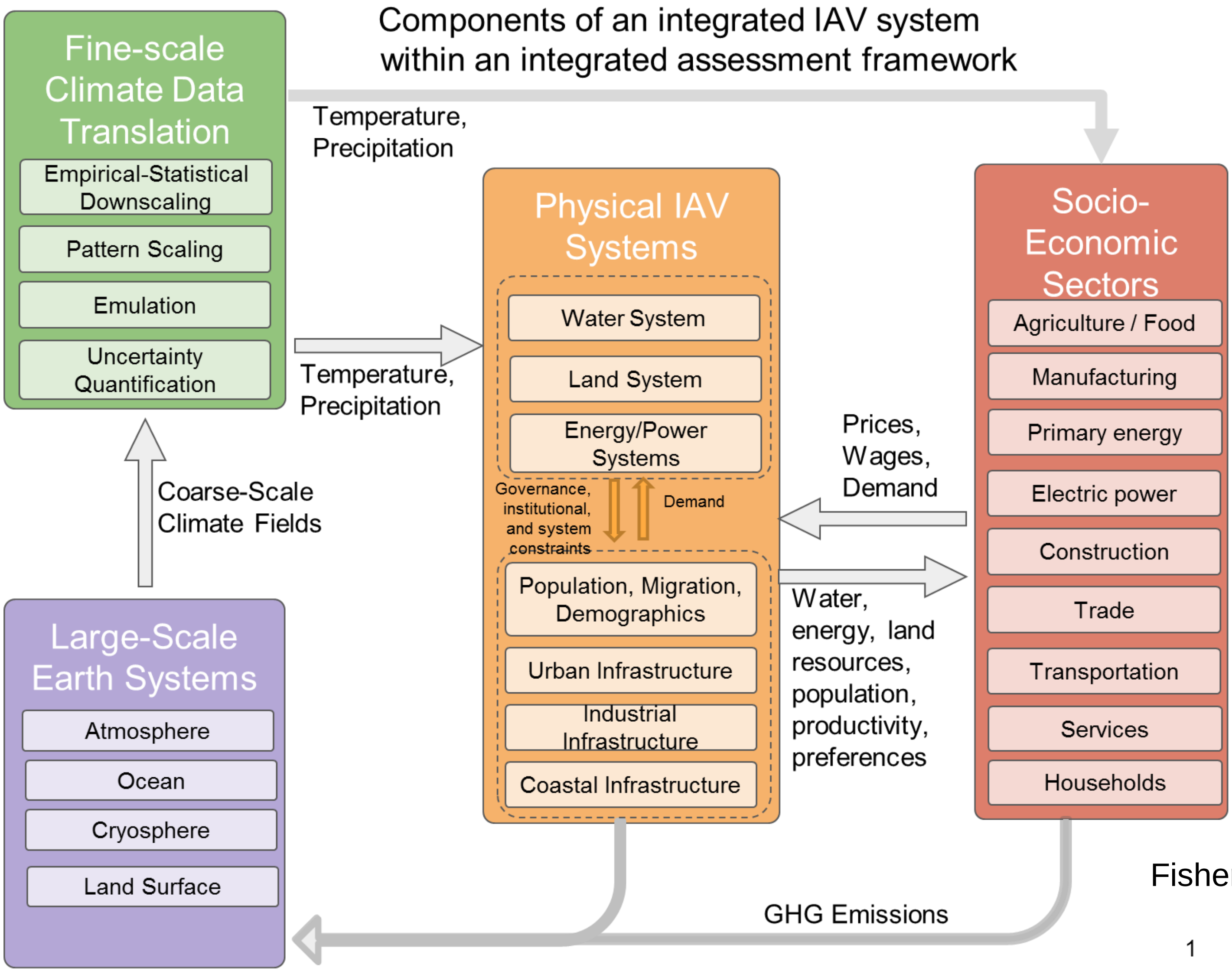
Kraucunas

In greater detail… note the coalescence of models and model forms!



Kraucunas

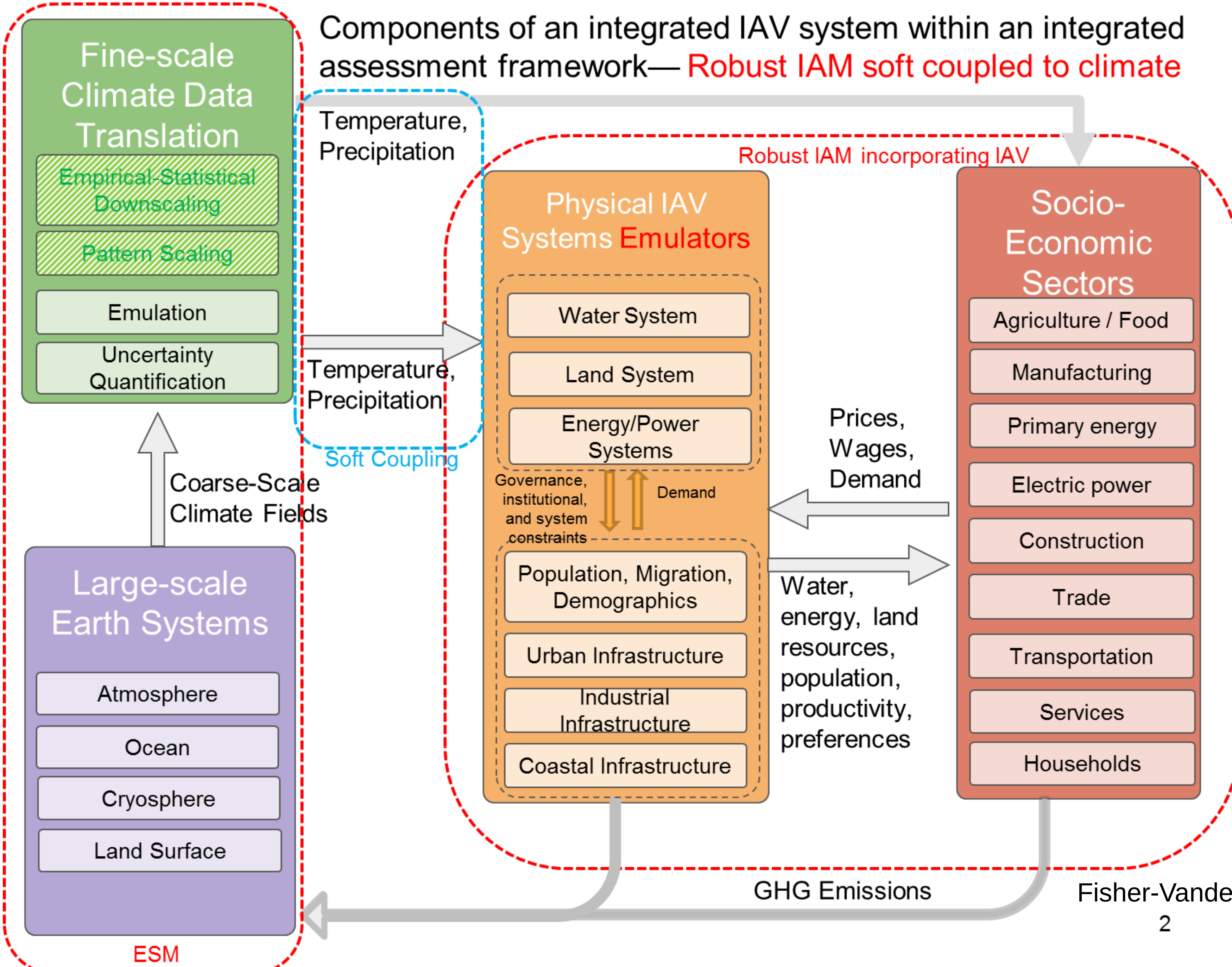
Exploring framework structures…what matters for what questions?



Fisher-Vanden

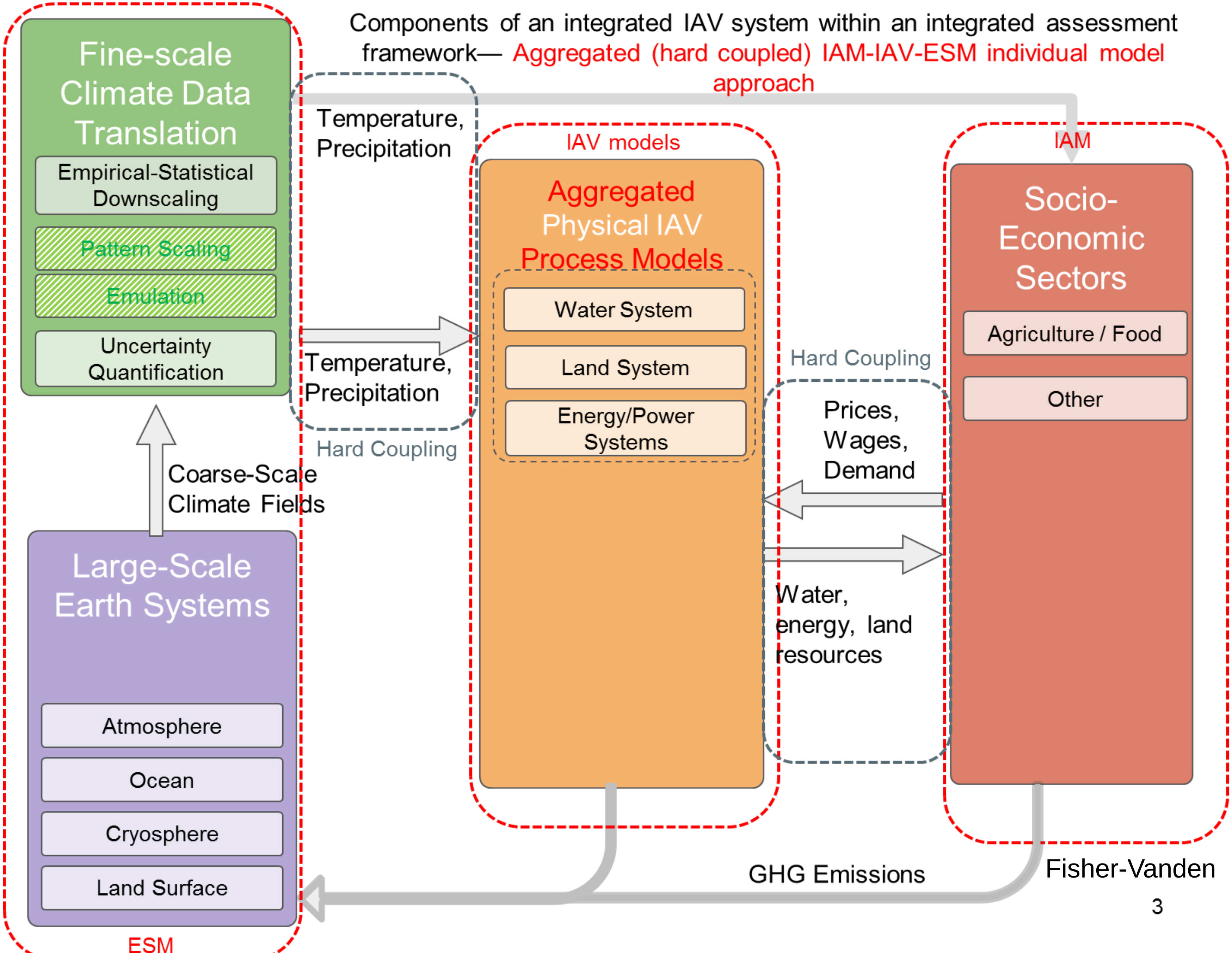
1

Components of an integrated IAV system within an integrated assessment framework— Robust IAM soft coupled to climate

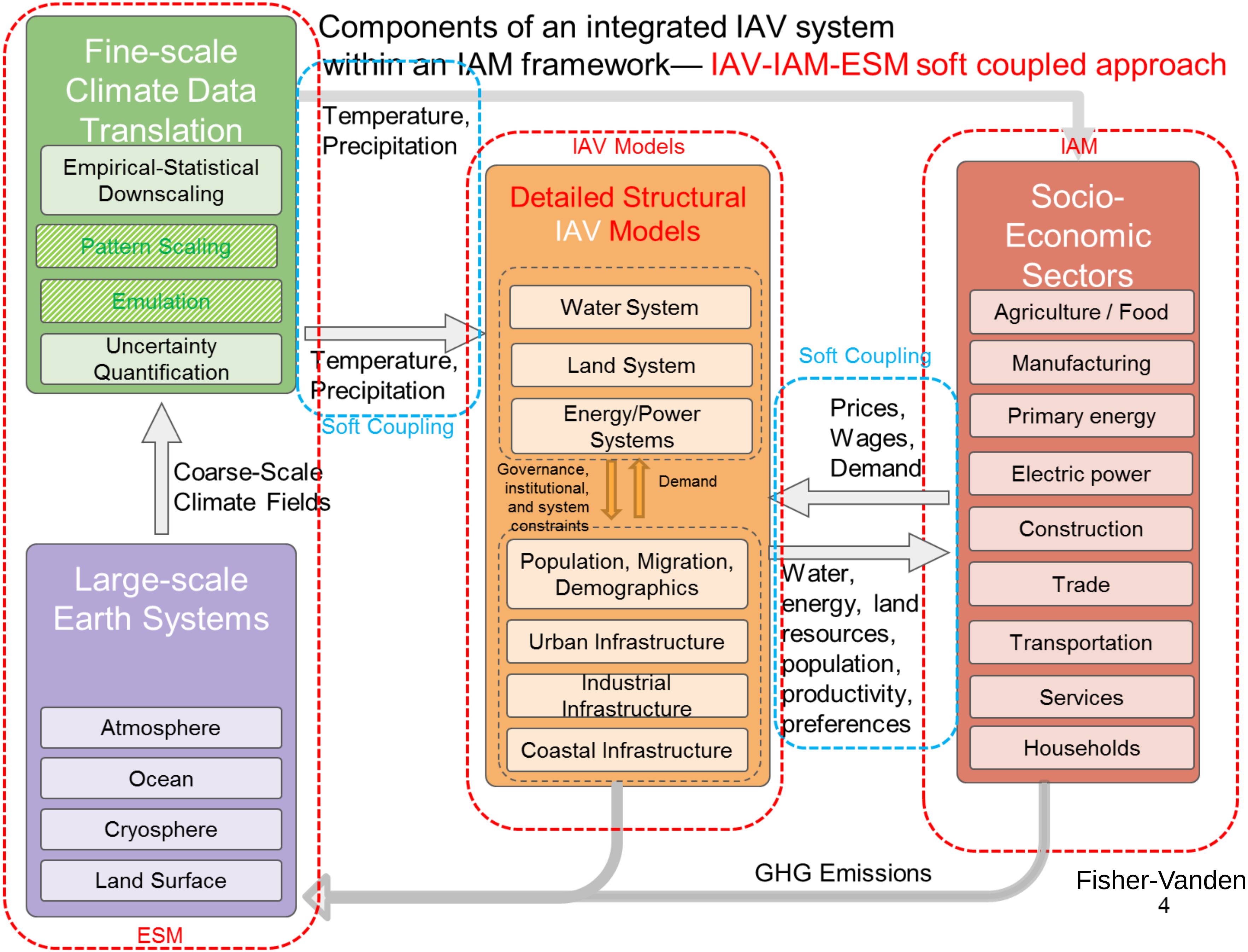


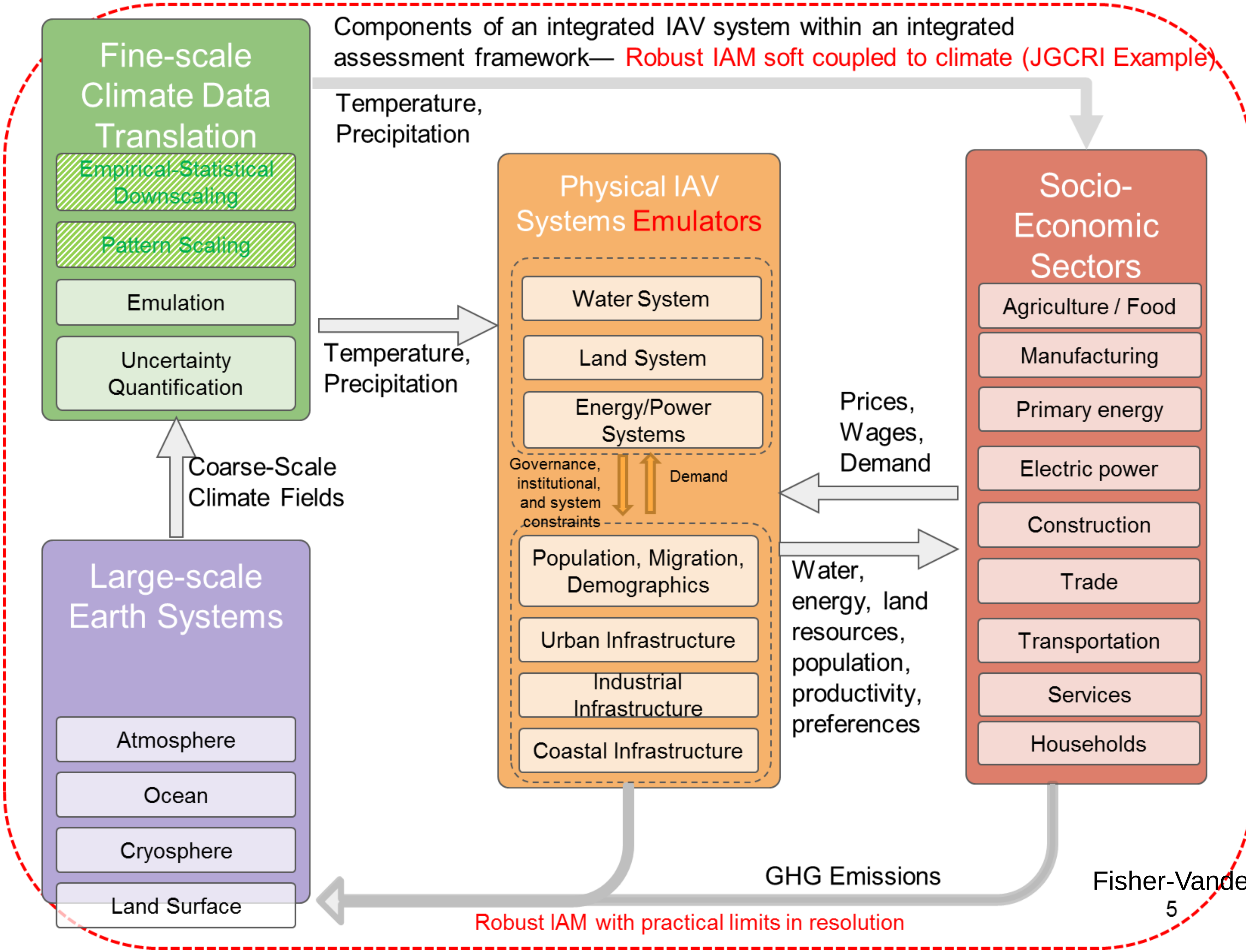
Fisher-Vanden

Components of an integrated IAV system within an integrated assessment framework— Aggregated (hard coupled) IAM-IAV-ESM individual model approach



Fisher-Vanden


Components of an integrated IAV system
within an IAM framework— IAV-IAM-ESM soft coupled approach
Fine-scale Climate Data Translation
Empirical-Statistical Downscaling
Pattern Scaling
Emulation
Uncertainty Quantification
Temperature, Precipitation
Temperature, Precipitation
Soft Coupling
Coarse-Scale Climate Fields
Large-scale Earth Systems
Atmosphere
Ocean
Cryosphere
Land Surface
ESM
IAV Models
Detailed Structural IAV Models
Water System
Land System
Energy/Power Systems
Governance, institutional, and system constraints
Demand
Population, Migration, Demographics
Urban Infrastructure
Industrial Infrastructure
Coastal Infrastructure
Soft Coupling
Prices, Wages, Demand
Water, energy, land resources, population, productivity, preferences
IAM
Socio-Economic Sectors
Agriculture / Food
Manufacturing
Primary energy
Electric power
Construction
Trade
Transportation
Services
Households
GHG Emissions
Fisher-Vanden
4



Components of an integrated IAV system within an integrated assessment framework— Robust IAM soft coupled to climate (JGCRI Example)
Fine-scale Climate Data Translation
Empirical-Statistical Downscaling
Pattern Scaling
Emulation
Uncertainty Quantification
Temperature, Precipitation
Temperature, Precipitation
Physical IAV Systems Emulators
Water System
Land System
Energy/Power Systems
Governance, institutional, and system constraints
Demand
Population, Migration, Demographics
Urban Infrastructure
Industrial Infrastructure
Coastal Infrastructure
Socio-Economic Sectors
Agriculture / Food
Manufacturing
Primary energy
Electric power
Construction
Trade
Transportation
Services
Households
Prices, Wages, Demand
Water, energy, land resources, population, productivity, preferences
Coarse-Scale Climate Fields
Large-scale Earth Systems
Atmosphere
Ocean
Cryosphere
Land Surface
GHG Emissions
Robust IAM with practical limits in resolution
Fisher-Vanden
5

Some desired characteristics for a framework

- Problem-driven: user needs drive framework structure and applications
- Modular: delete, add, or substitute components
- Flexible coupling approach: software environment facilitates changing components and their resolution
- Tractable uncertainty characterization: address multiple sources and focus on subset of uncertainties
- Embedded in consistent global boundary conditions: take advantage of parallel process
- Regionally-transferable: requires data to parameterize, initialize, and evaluate relevant components

Ultimately, enabling tools and capabilities are needed and taking center stage

- Multi-model frameworks and flexible couplings
- User-driven typologies
- Software development and modular designs
- IAV representations (within IAMs and separately)
- Spatial and temporal scales that matter for IAV
- "Telescopic" capabilities
- System shocks and extreme events
- Hindcasting and model evaluation.
- Emulation
- Uncertainty characterization
- Sensitivity studies and interpretation of results
- Scenarios
- Data science, data analytics, and data fusion methods.

And funding is moving to meet the needs… FY16 through the IARP

- **PNNL-JGCRI Triennial Review of Scientific Focus Area (SFA)** aligned around EWL, funding augmented in key areas.
- **MIT Cooperative Agreement (CA) supplemented** for EWL interactions.
- **New Stanford led-multi-institutional Cooperative Agreement awarded** for multi-scale, -sector modeling framework
- **New PNNL-led multi-lab and university SFA reviewed and established** on regional scale EWL IAV modeling.
- **Two new CAs competed and awarded for university led multi-institutional teams addressing fine-scale climate analysis and human feedbacks for EWL**
- **ORNL led data-knowledge system proposal reviewed and initiated** with collaborators: ANL, NASA DAAC (Columbia), others

Pacific Northwest National Laboratory
Oak Ridge National Laboratory
NREL
Sandia National Laboratories
Argonne National Laboratory
Berkeley Lab

Stanford University
Massachusetts Institute of Technology
PennState
UCAR
Iowa State University
University of Maryland
Boston University
UC Davis University of California
Cornell University
Stony Brook University
Purdue University
University of New Hampshire
UtahState University
UCLA
University of Delaware
Texas A&M University
The University of Utah

And funding is moving to meet the needs… FY16 through the IARP (Contd.)

- National laboratory team created and working data-knowledge system planning under three co-chairs (ORNL, BNL, Sandia).
- Interagency workshop at Univ. of MD and report in preparation on economic methodologies and scenarios for EWN and IAV.
- AGU Town Hall, collaborative CESD workshops/PI meetings with Koch, Joseph, TES
- CERC (DOE-wide) funding received by LBNL and gains traction on the energy-water nexus
- Broader interagency engagements
- EWL interagency (IGIM) activity launched last year at Snowmass
- And yes, this Snowmass-2016 workshop

Pacific Northwest National Laboratory
Oak Ridge National Laboratory
NREL
Sandia National Laboratories
Argonne National Laboratory
Berkeley Lab
Stanford University
Massachusetts Institute of Technology
PennState
UCAR
Iowa State University
University of Maryland
Boston University
UC Davis University of California
Cornell University
Stony Brook University
Purdue University
University of New Hampshire
UtahState University
UCLA
University of Delaware
Texas A&M University
The University of Utah

A "coalition of the willing" forms around Snowmass - 2015

- Half a dozen agencies and about a dozen scientific leaders from the community assembled for a meeting during the IAV week of EMF's *The Climate Change Impacts and Integrated Assessment (CCI/IA) Workshop XXI (2015)*
- Developed a detailed prospectus, early shared vision of general needs and opportunities, and plan for next steps
- Organized under IGIM as a more expansive Interagency Coordinating Group
- Helped put in place a scientific steering group to help shape and plan the May 24-26th workshop.
- Detailed scientific workshop report that will serve as input to an interagency coordination plan (a.k.a. roadmap).

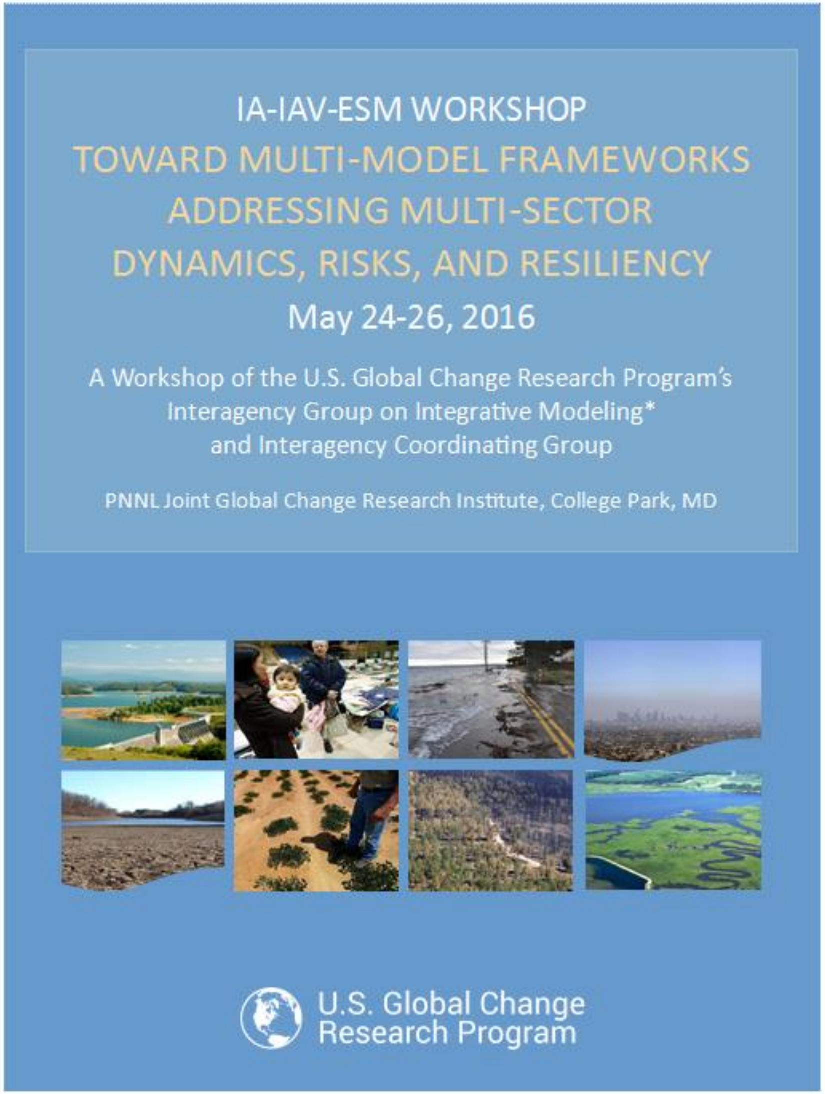
May 2016 Workshop

Interagency Coordinating Group

Gary Geernaert, U.S. Department of Energy/ USGCRP (Vice-chair)
Bob Vallario, U.S. Department of Energy (ICG chair)
Greg Anderson, National Science Foundation
Jeff Arnold, U.S. Army Corps of Engineers
John Balbus, National Institutes of Health
Hoyt Battey, U.S. Department of Energy
Diana Bauer, U.S. Department of Energy
Charles Covel, U.S. Department of Homeland Security
Ben DeAngelo, U.S. Global Change Research Program
Anne Grambsch, U.S. Environmental Protection Agency
Margaret Lange, National Geospatial-Intelligence Agency
Jia Li, U.S. Environmental Protection Agency
Jim McFarland, U.S. Environmental Protection Agency
Bob O'Connor, National Science Foundation
Marilee Orr, U.S. Department of Homeland Security
Alex Ruane, National Aeronautics and Space Administration
Ron Sands, U.S. Department of Agriculture

Workshop Scientific Steering Group

Karen Fisher-Vanden, Pennsylvania State University (co-chair)
Richard Moss, Joint Global Change Research Institute (co-chair)
Scott Backhaus, Los Alamos National Laboratory
Chris Barrett, Virginia Tech
Budhu Bhaduri, Oak Ridge National Laboratory
Ian Kraucunas, Pacific Northwest National Laboratory
Pat Reed, Cornell University
Jennie Rice, Consultant
Karen Seto, Yale University
Ian Sue Wing, Boston University
Claudia Tebaldi, National Center for Atmospheric Research



Workshop focus…with more details to be discussed by others

- Use-case driven, multi-sector
- Shared components to inform the framework
- Systems and cascading system vulnerabilities, especially to rapid change and extreme events
- Influences and impacts across scales – time and space
- Implications of multiple stressors and evolving regional landscapes
- Tensions and tradeoffs in complex, dynamic systems
- Physical and economic consequences
- Implications and uncertainties of decision options

Agency Example Uses: Drought and Increased Variability of Water Supply

1. **Reservoir resilience affected by droughts, floods, and changing**

2. **State economies, including agriculture, affected by drought**

3. **Planning for wildfire impacts and management under changing climate, environmental, demographic, and policy futures**

4. **Surface water quality and ecosystem services affected by droughts, floods, and changing land use/land cover trends**

Agency Example Uses: Concentrated and Connected Infrastructure

1. **Electric system reliability and demands affected by water quantity/quality**

2. **Health services affected by cascading infrastructure failures and interdependencies**

3. **Coastal city inundation affected by sea level rise and extreme weather events |**

4. **Urban socioeconomic systems and vulnerable communities affected by heat waves and air quality**

Summary

- A lot to consider.
- Separately, the three communities are evolving to answer new and emerging questions in impacts, adaptations, vulnerabilities
- Feedbacks matter…when they matter!
- Increasingly, different forms of model couplings (hard and soft) are evolving to respond to questions and needs not easily or capably addressed by single modeling communities.
  - Where is this happening and why?
  - Where is it likely to head?
  - What of the "art of the possible" is most meaningful? We're not going to be able to address every question and need.

Summary (Contd.)

- Is there value in beginning to view this as a system of models, with potential for more agile interactions and combined capabilities spanning systems, detail, and spatial and temporal scales?
- How best to guide our efforts by aligning with a typology of users, a couple of use cases, and related scientific questions, and analytic needs?
- How can we make the march forward most agile and adaptable to changing needs and questions?