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Modeling Water in IAMs: Where are We and What can ESMs and IAVs Offer?

MOHAMAD HEJAZI

Joint Global Change Research Institute (JGCRI), Pacific Northwest National Laboratory (PNNL)

Snowmass, 2016

Research questions

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- How to effectively incorporate a representation of the water system in IAMs? What are the different approaches?
- What are some of the limitations with the current approaches in term of their ability to resolve certain feedbacks?
- What can IAV and ESM provide to overcome some of the gaps in modeling water in IAMs?

Source: https://www.carbontrust.com

- Gaps in input data: what can't we get that we need to model water in IAMs?
- Gaps in tools: Downscaling and upscaling routines to exchange information to & from IAV/ESM

Approaches for incorporating water in IAMs

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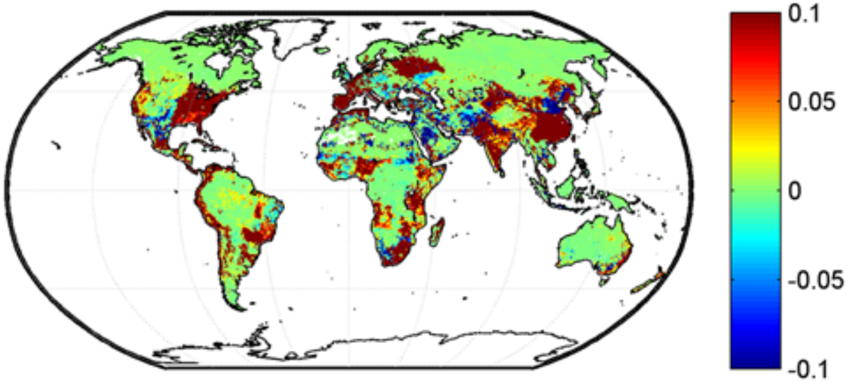
- Employing existing water models (1-way exchange of information)
- Incorporate representations of water demand/supply/allocation endogenously to account for their feedbacks to IAMs (2-way exchange)

Model	Home Institution	Hydrologic model
AIM Asia Integrated Model	National Institutes for Environmental Studies, Tsukuba Japan	**H08**
GCAM Global Change Assessment Model	Joint Global Change Research Institute, PNNL, College Park, MD	**GCAM-Hydrology**
IGSM Integrated Global System Model	Joint Program, MIT, Cambridge, MA	**CLM-WSM**
IMAGE The Integrated Model to Assess the Global Environment	PBL Netherlands Environmental Assessment Agency, Bildhoven, The Netherlands	**LPJmL**
MESSAGE Model for Energy Supply Strategy Alternatives and their General Environmental Impact	International Institute for Applied Systems Analysis; Laxenburg, Austria	**GLOBIOM**
REMIND Regionalized Model of Investments and Technological Development	Potsdam Institute for Climate Impacts Research; Potsdam, Germany	**LPJmL**

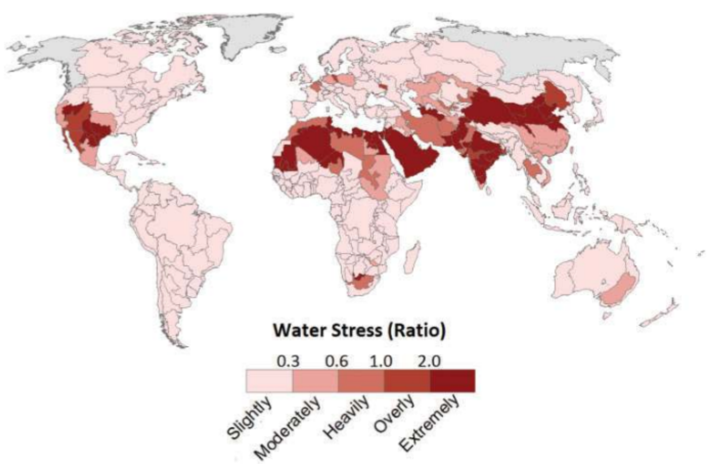
1-way coupling: Linking IAMs to existing water supply and demand models

Change in water scarcity (GCAM-Hydrology)



Hejazi et al. 2014. Hydrology & Earth Sys. Sc.

Water scarcity (IGSM-WSM)

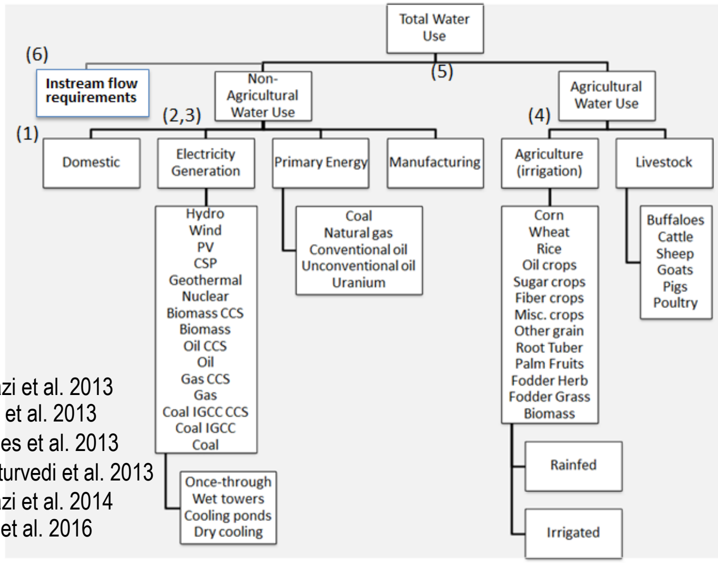


Schlosser et al., 2014. Earth's Future

- Takes advantage of existing modeling capabilities in the water sphere (ESMs, macro scale global hydrologic models, and global water management models)
- Assumes that unmet water demands have come from non-renewable resources ➔ unable to capture the feedbacks of water constraints and the cost of water to the IAM decision makings
- Past efforts are mainly limited to passing info from IAMs to ESMs/IAVs, but not vise versa

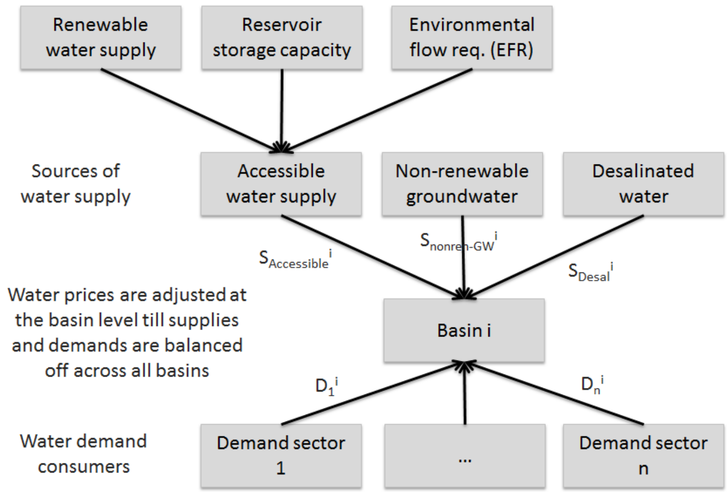
2-way coupling: Endogenous representation of water systems in IAMs (e.g., GCAM)

IAM water demands



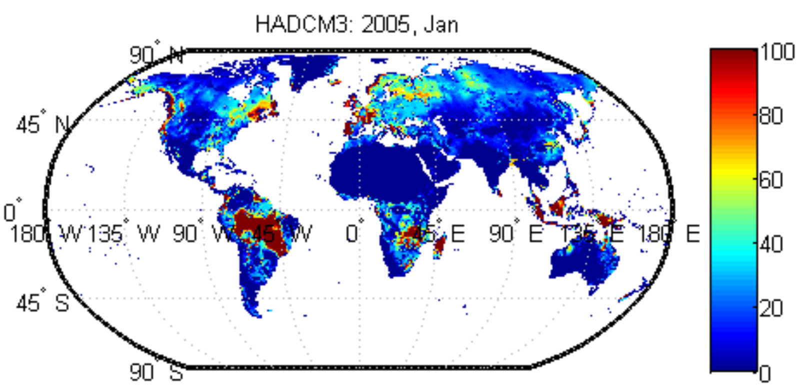
1) Hejazi et al. 2013
2) Kyle et al. 2013
3) Davies et al. 2013
4) Chaturvedi et al. 2013
5) Hejazi et al. 2014
6) Kim et al. 2016

IAM water allocations



Kim et al. (2016). Climatic Change

IAM water supplies



Hejazi et al. 2014. Hydrology & Earth Sys. Sc.

- Tailor-build simple and efficient water models within the IAM framework with dynamic feedbacks
- Opened a huge can of worms in term of building many more arrows of how water systems connect with the other IAM systems (e.g., energy and land)

2-way coupling: Endogenous representation of water systems in IAMs (e.g., GCAM)

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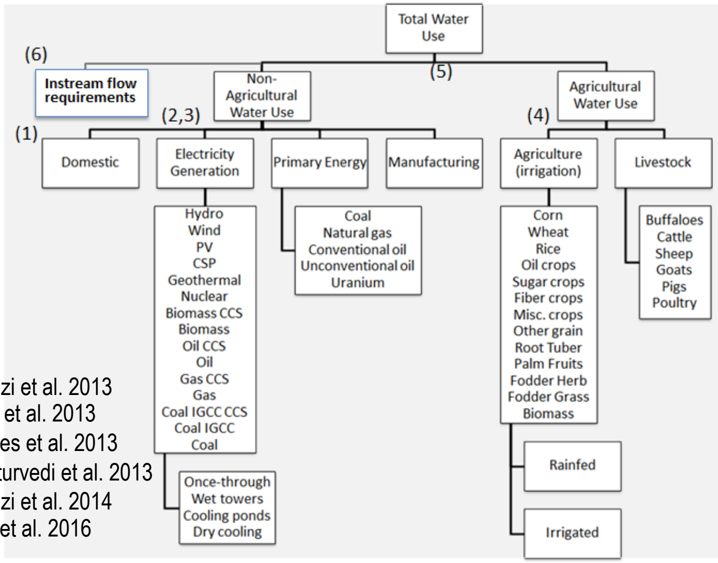
IAM water demands



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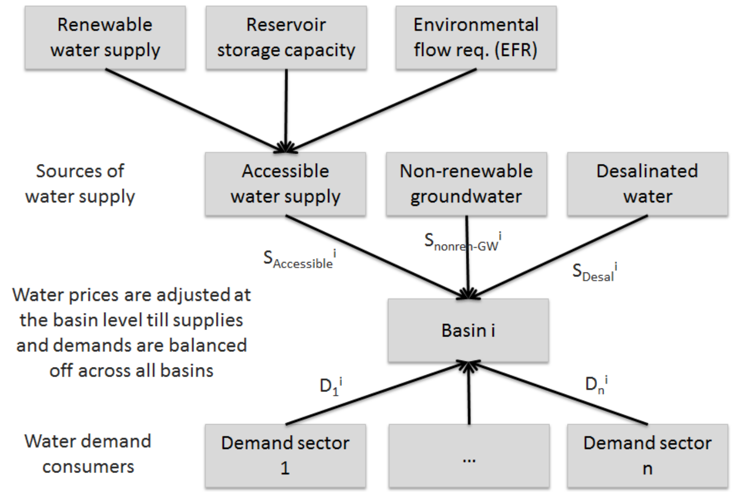
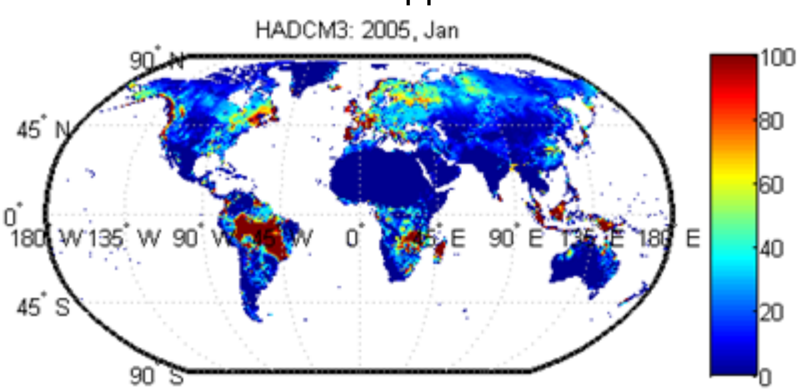


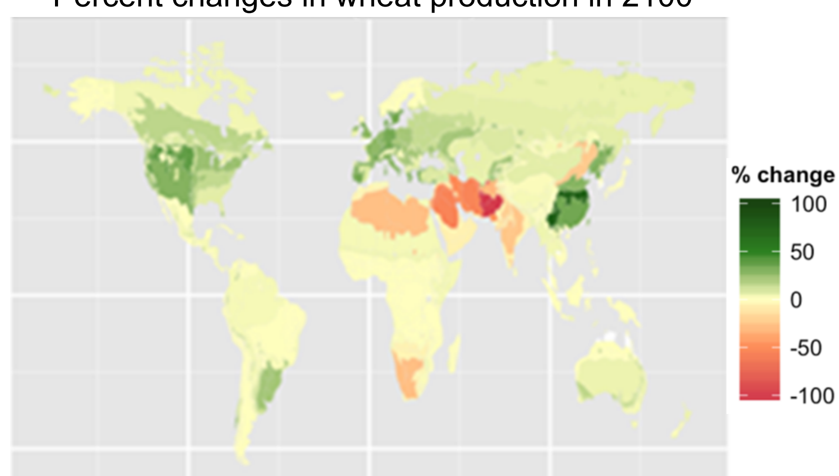
Kim et al. (2016). Climatic Change

IAM water supplies



Hejazi et al. 2014. Hydrology & Earth Sys. Sc.

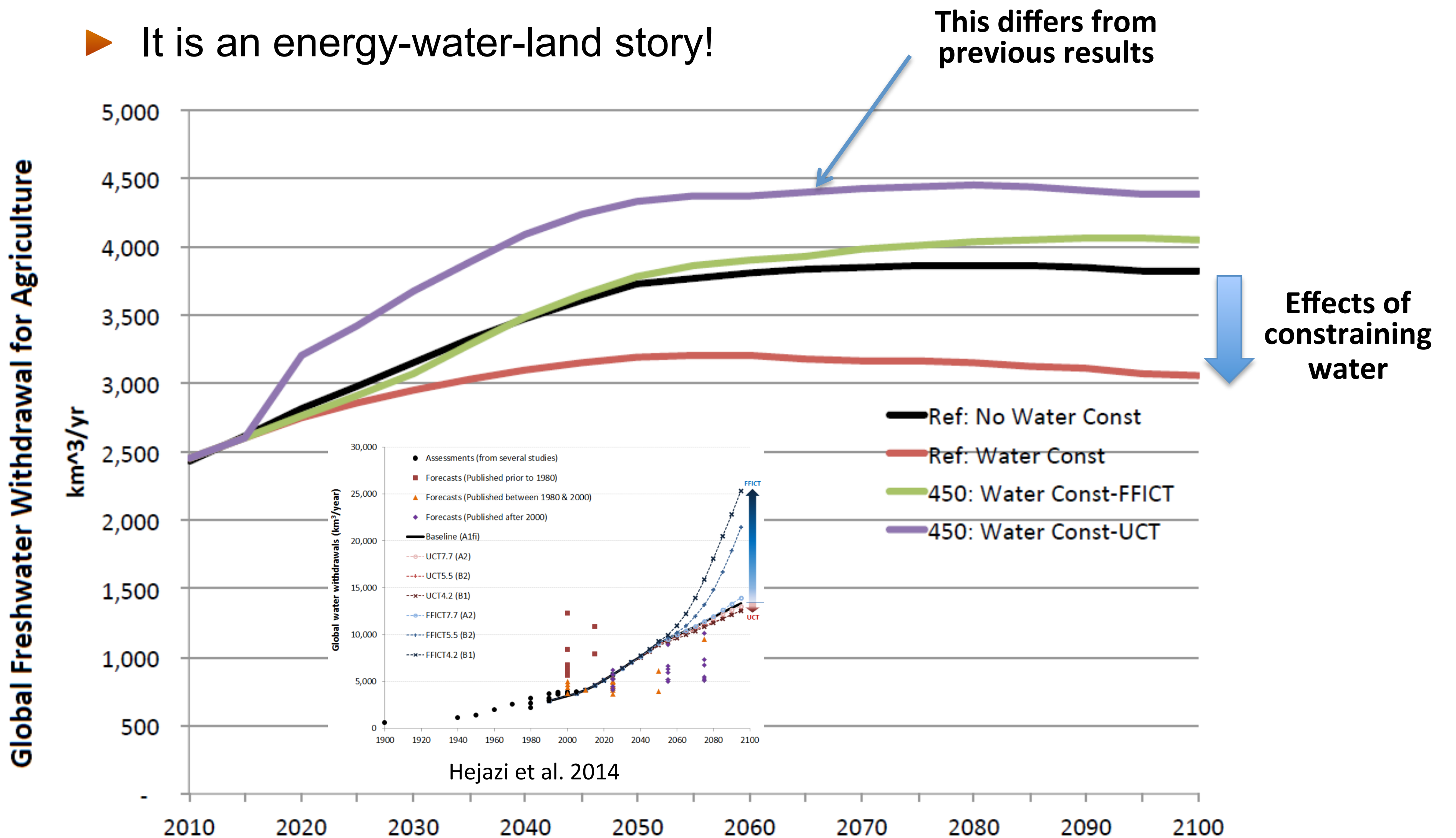
Percent changes in wheat production in 2100



Kim et al. (2016). Climatic Change

How will constraining water alter the story?

- It is an energy-water-land story!



Looking under the hood of a 2-way coupling framework

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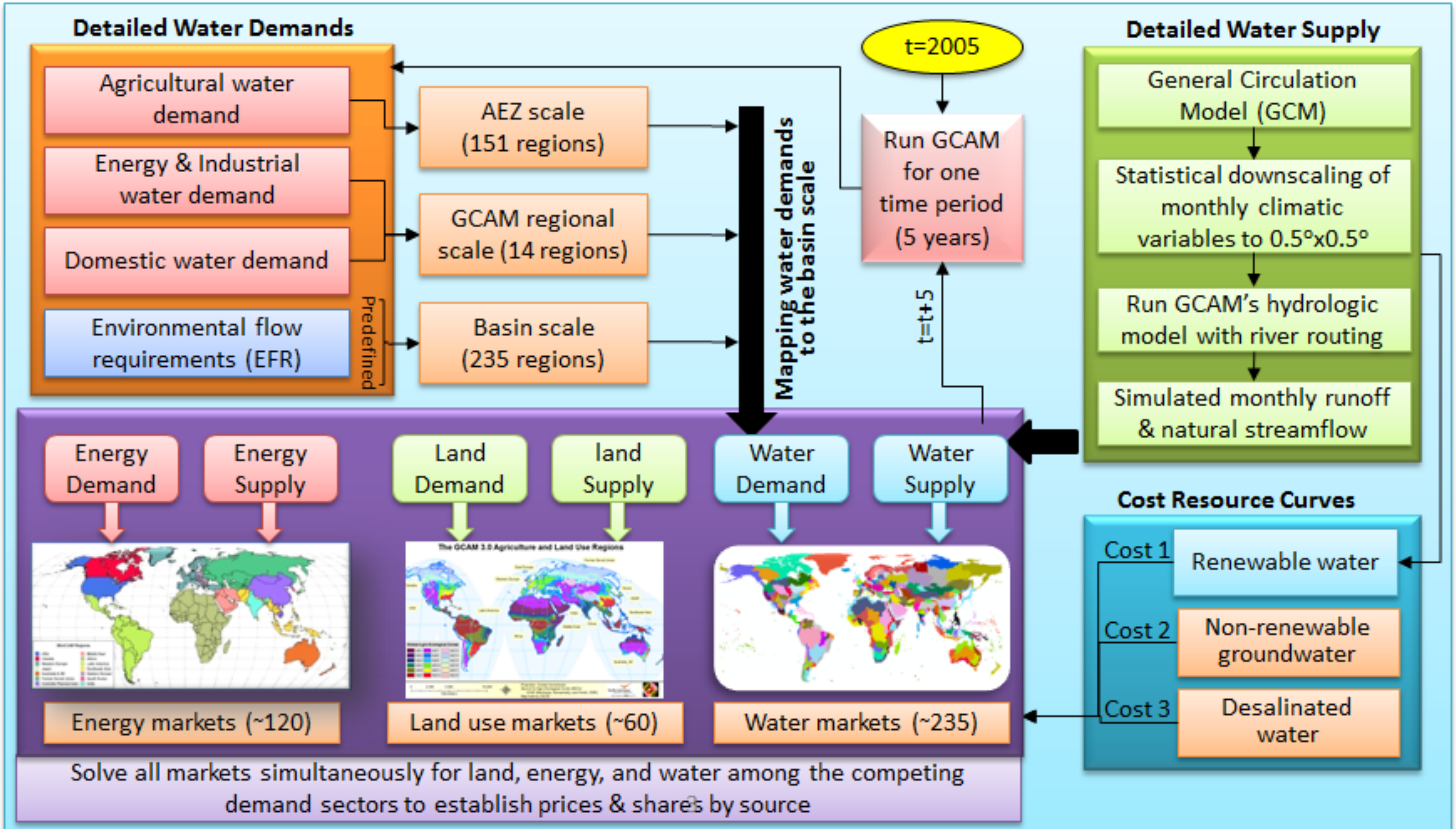
Schematic of the overall market-based approach across all goods and services in GCAM



Challenges and gaps in modeling water in IAMs: what can IAV-ESM offer?

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Model evaluation over history (e.g., 1975-2010) is a prerequisite to publish water modeling results

Water use at sub-annual scale or even at annual scale is hardly available

Mapping between geopolitical regions, AEZs, and river basins

Time period in IAMs is too coarse to capture the inter- & intra-variability in water

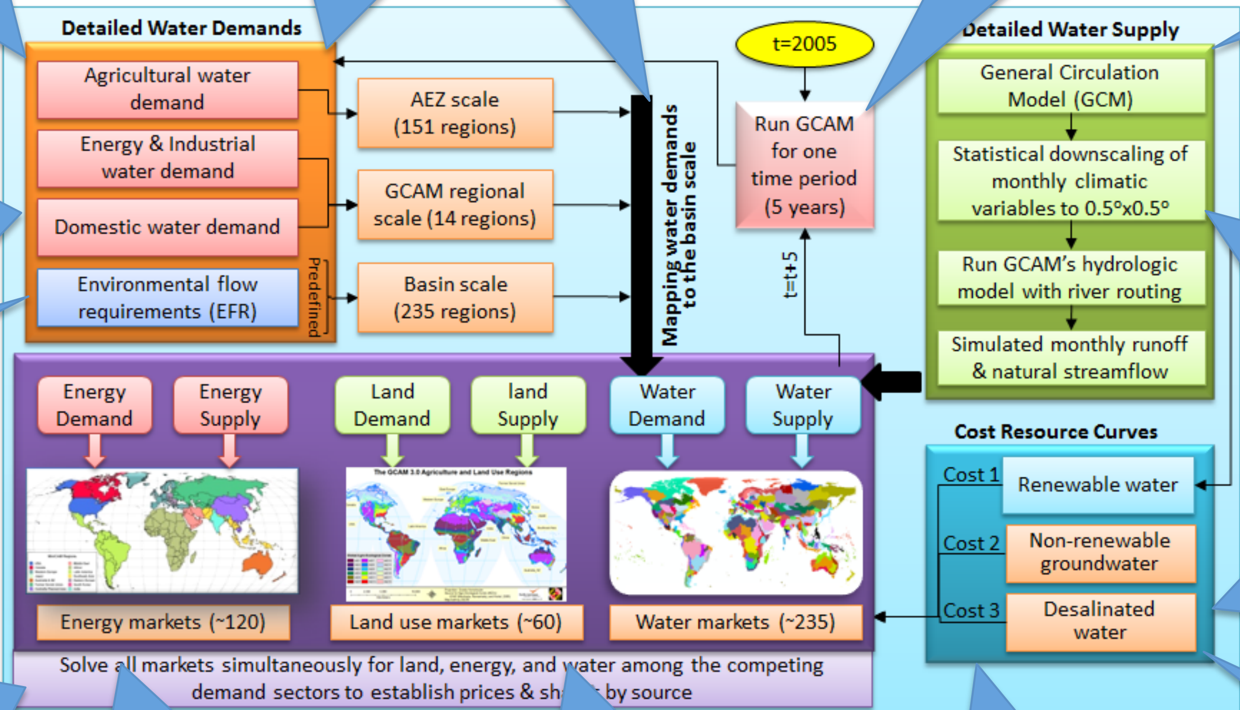
Limited to the 4 RCPs for which there exists GCM simulations

The ability to store water (reservoirs) and reuse water

GCM outputs come at various spatial units and require downscaling and bias-correction

The impact of climate changes on water demands, and hydropower

Developing resource curves for the various sources of water and their historical use



The role of adaptation (irrig., cooling tech). How quickly can adaptation come in the future?

Water regulations are heterogeneous and water allocation are often not based on markets

Water is heavily subsidized in many regions and different sectors face different water prices

How much gw water is available and how much has already been depleted?

Energy use associated with extraction and treatment of water

Let's look further at the issues of data exchange and scale in coupled frameworks

- Overlapping processes across models (water cycle in CLM & GCAM)
- Potential inconsistency among models
  - different land use and crop representations,
  - how to handle irrigation (rule-based, ranking, competitiveness)
- Lack of tools to downscale & upscale data to pass information at the appropriate scale across models – this is partially a data issue as well
- Scale (global–regional–local; decadal–annual–monthly–daily)
  - GCAM water allocation (annual accessible water vs monthly)
  - Reservoir operations (individual vs lumped)
  - Trends vs variability (e.g., monthly to multiple-year droughts)
- Withdrawal vs consumption
  - return flow, water reuse
- Economic vs physical frameworks
  - Water subsidies, costs, economically available resources, etc.

Examples of linking IAV-ESM and IAMs: GCAM-USA (IAM) → CLM-MOSART-WM (ESM)

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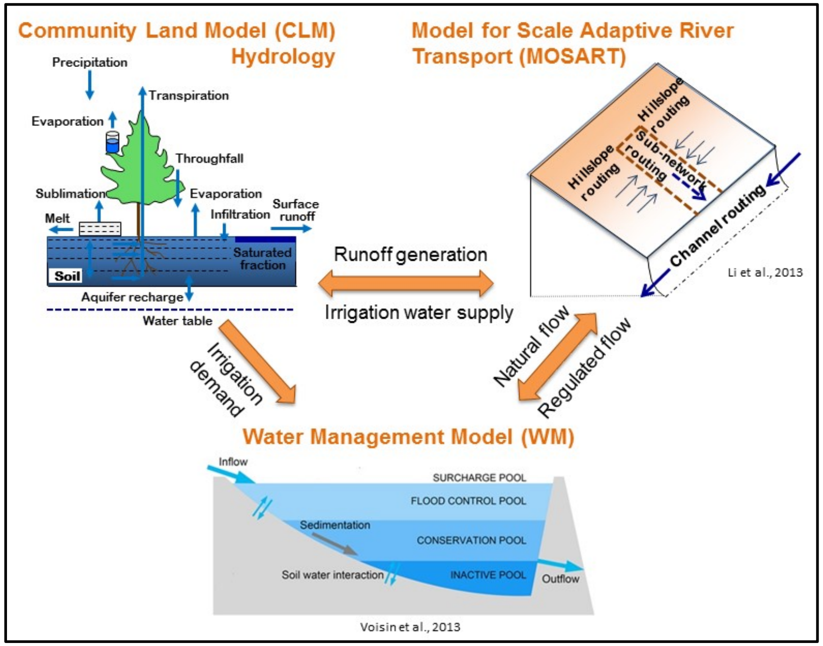
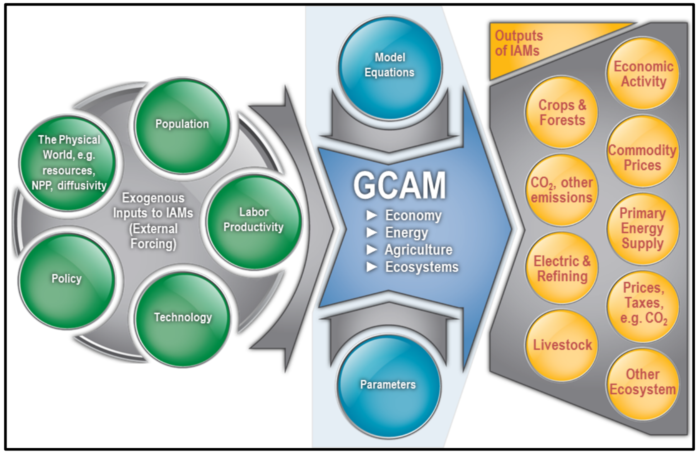
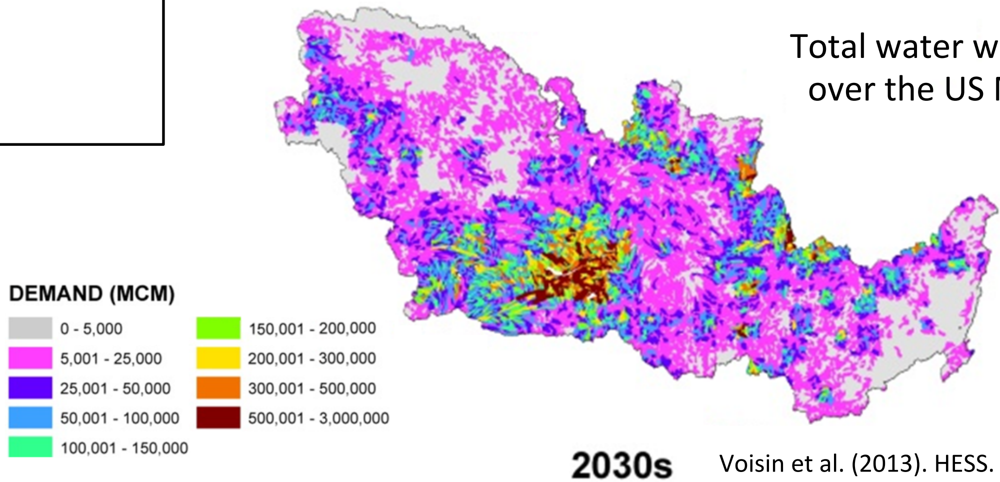
Water supply: CLM-MOSART-WM



Water demand: GCAM (downscaled to daily/grid scale)



Total water withdrawal over the US Midwest

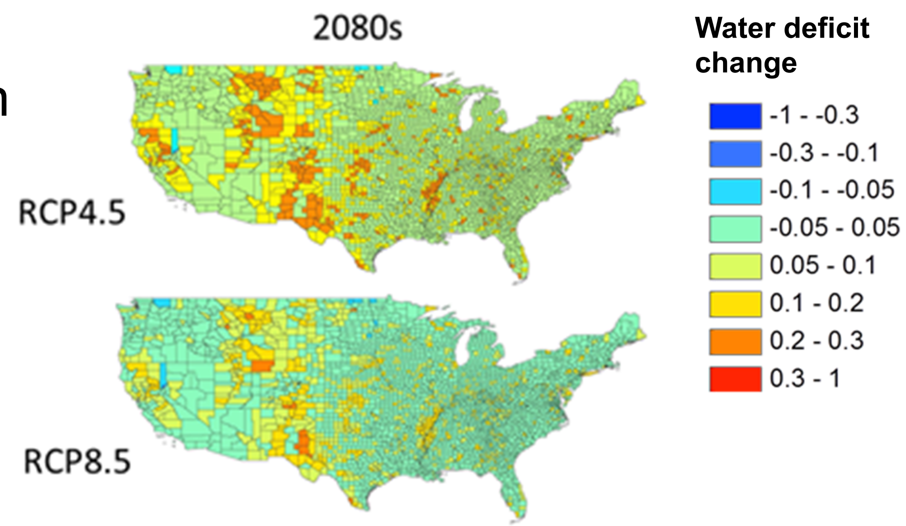


Voisin et al. (2013). HESS.

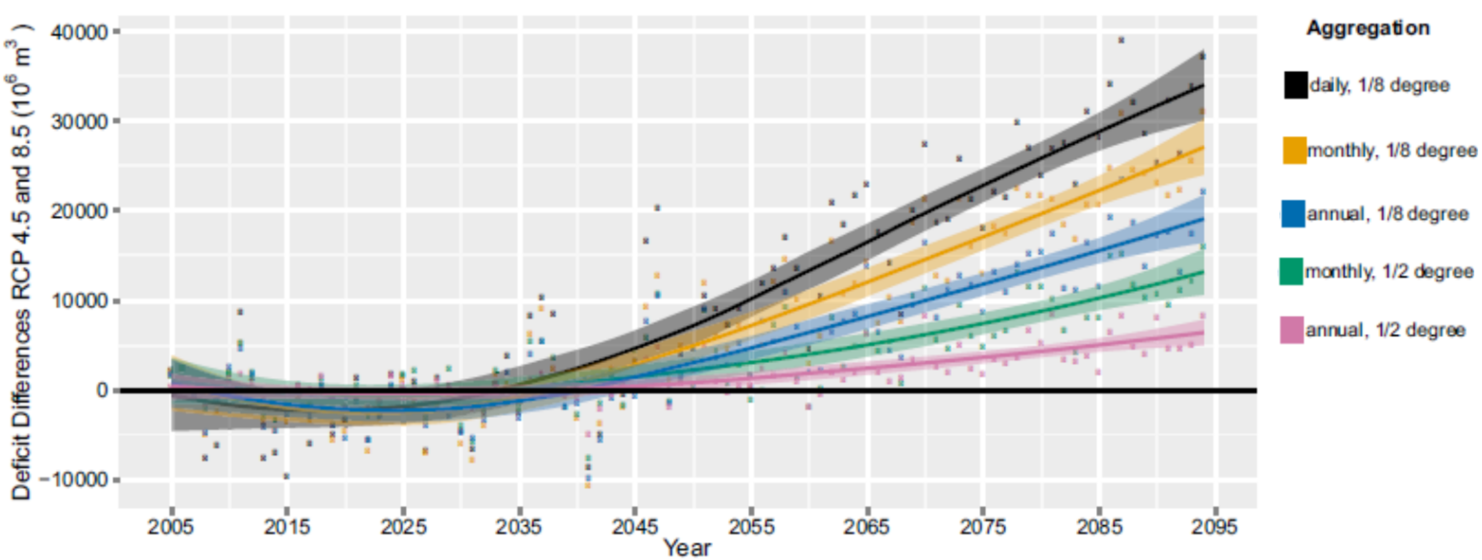
A coupled modeling framework: Focusing on regional water scarcity through model coupling

Multi-model frameworks offer unique insights into system dynamics and the importance of scale

- Water deficit projected to increase more with climate change mitigation than under unconstrained climate change (largely due to increased biofuel production)
- Water deficits are significantly underestimated if computed at coarser spatial and temporal resolution

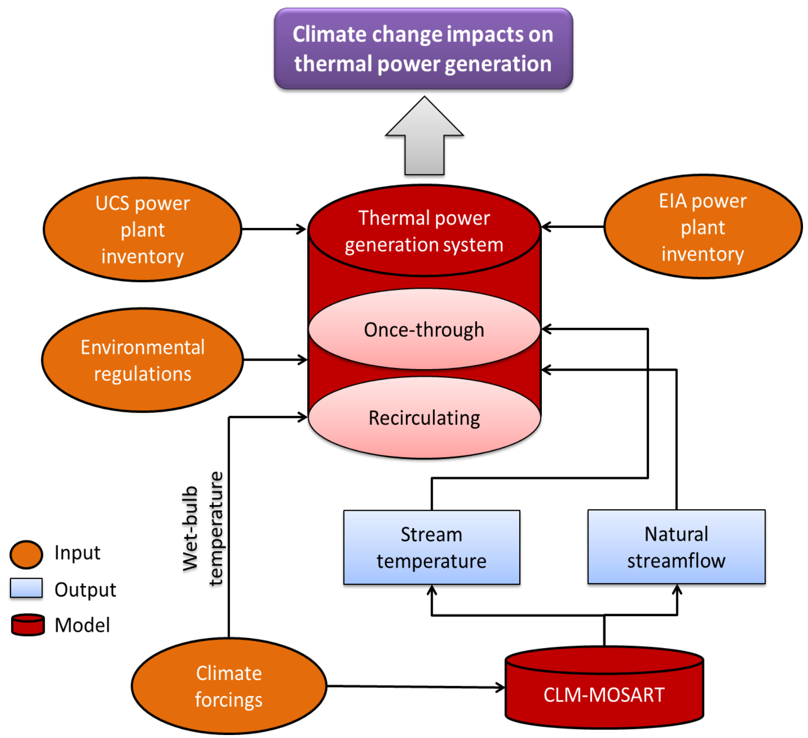


Hejazi et al. (2015) PNAS

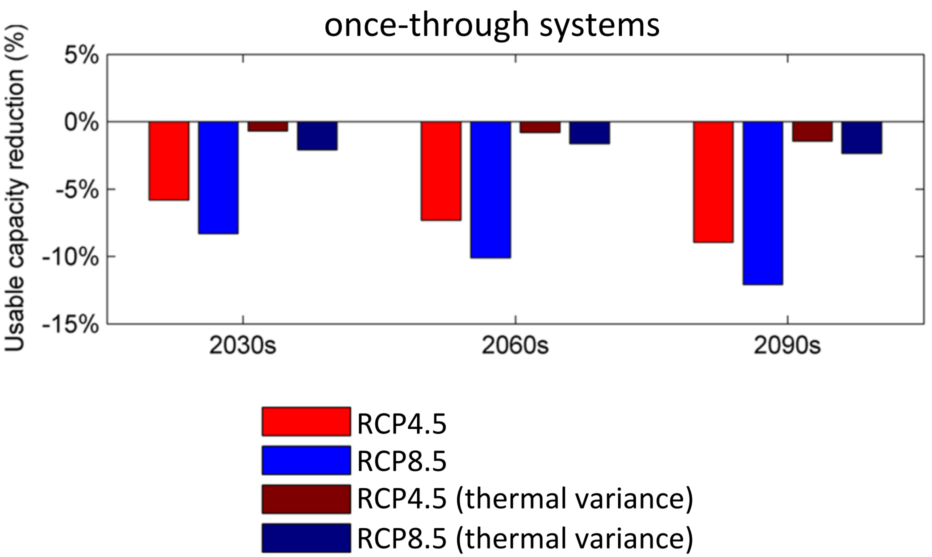


Examples of linking IAV-ESM and IAMs: water temperature & power plant modeling over the US

Schematic of modeling framework



Comparison of projected mid-century usable capacity reduction under different scenarios



1) efficiency loss due to temperature fluctuations
2) water availability constraints for wet-cooling towers
3) regulatory constraints on thermal effluent

Questions!

Mohamad I. Hejazi, Ph.D.
Research Scientist
Joint Global Change Research Institute
Pacific Northwest National Laboratory
5825 University Research Court, Suite 3500
College Park, MD 20740
www.globalchange.umd.edu
mohamad.hejazi@pnnl.gov