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

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Research questions

- 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?
- 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

Source: https://www.carbontrust.com
Approaches for incorporating water in IAMs

- 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)

<table>
<thead>
<tr>
<th>Model</th>
<th>Home Institution</th>
<th>Hydrologic model</th>
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<tbody>
<tr>
<td>AIM</td>
<td>National Institutes for Environmental Studies, Tsukuba Japan</td>
<td>H08</td>
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<td>GCAM</td>
<td>Joint Global Change Research Institute, PNNL, College Park, MD</td>
<td>GCAM-Hydrology</td>
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<td>IGSM</td>
<td>Joint Program, MIT, Cambridge, MA</td>
<td>CLM-WSM</td>
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<tr>
<td>IMAGE</td>
<td>PBL Netherlands Environmental Assessment Agency, Bildhoven, The Netherlands</td>
<td>LPJmL</td>
</tr>
<tr>
<td>MESSAGE</td>
<td>International Institute for Applied Systems Analysis; Laxenburg, Austria</td>
<td>GLOBIOM</td>
</tr>
<tr>
<td>REMIND</td>
<td>Potsdam Institute for Climate Impacts Research; Potsdam, Germany</td>
<td>LPJmL</td>
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1-way coupling: Linking IAMs to existing water supply and demand models

- 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 vice versa


Schlosser et al., 2014. Earth’s Future
2-way coupling: Endogenous representation of water systems in IAMs (e.g., GCAM)

- 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)

IAM water demands

IAM water supplies

- Hejazi et al. 2014
- Kyle et al. 2013
- Davies et al. 2013
- Chaturvedi et al. 2013
- Hejazi et al. 2014
- Kim et al. 2016

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

IAM water demands

IAM water allocations

Percent changes in wheat production in 2100

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


Kim et al. (2016). Climatic Change
How will constraining water alter the story?

It is an energy-water-land story!

This differs from previous results

Effects of constraining water

Global Freshwater Withdrawal for Agriculture

Hejazi et al. 2014

Ref: No Water Const
Ref: Water Const
450: Water Const-FFICT
450: Water Const-UCT
Looking under the hood of a 2-way coupling framework

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?

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.

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

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

The ability to store water (reservoirs) and reuse water.

The impact of climate changes on water demands, and hydropower.

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)

Water supply: CLM-MOSART-WM

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

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

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

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

once-through systems

- RCP4.5
- RCP8.5
- RCP4.5 (thermal variance)
- RCP8.5 (thermal variance)
Questions!

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