

# ***Interactive comment on “One-way coupling of an integrated assessment model and a water resources model: evaluation and implications of future changes over the US Midwest” by N. Voisin et al.***

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We would like to thank reviewer #2 for the thorough review and constructive comments that have led to an improved manuscript.

Comment 1.: I think the paper would be benefited if the authors clarifies further why this specific regions was chosen. The paper uses global models (GCAM), but it is not so clear the rationale behind the choice of the region, as water demand (human influences) appears not to be a major factor contributing to the increase in future water

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supply deficit over the region (only locally). As noted by the authors, climate change appears to be the dominant factor affecting the water supply deficit over the region.

Response: We clarified the choice of the region:

“The U.S. Midwest region is chosen for the first application of the integrated models. The domain includes the Missouri, Upper Mississippi and Ohio River basins (Figure 1), hereinafter denoted as the Midwest Region. The crop in the region is mostly rainfed especially over the Upper Mississippi and Ohio, and northern Missouri and has been shown, at least over the Upper Mississippi (Frans et al. 2013, Mishra et al. 2010), to be more sensitive to climate change than to land use change. However this region is chosen because it represents many crosscutting issues on climate, energy, land use, and water, including water quality. For example, the Midwest is a major area for bioenergy resource, representing potential conflicts between food and fuel. In addition, the Midwest is of primary importance for regional and international water markets, and hence represents an interesting test case for our modeling framework that aims to model global water transfer in the future.”

Comment 2: Page 6362-6363: The authors mentioned that “This region is chosen because it represents many crosscutting issues on climate, energy, land use, and water. For example, the Midwest is a major area for bioenergy resource, representing potential conflicts between food and fuel.” How does your model consider the interaction between food and fuel production? I understand that irrigation water demand was prescribed by the outputs from another model. How is rainfed crop treated in your model?

Response: GCAM is a dynamic-recursive model that is solved in five-year time steps to 2095 by establishing market-clearing prices for energy and agricultural commodities for each modeling period. As such, food and fuel production and their interactions/competition are modeled in this framework. The model’s methodology has been documented through a series of publication (Wise et al., 2009, Kim et al., 2006, Clarke

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et al., 2007b, Brenkert et al. 2003). Also, for more details on the irrigation water demand module in GCAM, the readers are referred to the following papers (Chaturvedi et al. 2013, Hejazi et al. 2013a,b). GCAM estimates both the total biophysical water requirement of crops and also the total withdrawal and consumptive demands for irrigation.

In this framework, the irrigation demand is what is being passed to the routing-WM model. The rainfed crop is simulated within the land surface hydrology model. The moisture lost through evapotranspiration by the rainfed crop is then not available for routing. This analysis does not assess the change in demand and supply to rainfed crop but rather focuses on irrigation and other water demands.

We added in a paragraph clarifying the irrigation demand and rainfed crop. “CLM simulates the full energy and water balances for a mosaic of rainfed vegetation classes, including crop. CLM provides the runoff and baseflow into the water management model “

At the beginning of section 3 we added: “A one-way coupling between GCAM and SCLM-MOSART-WM is the focus of this paper, where GCAM provides the water demand and SCLM-MOSART-WM computes the water availability and estimates the actual water supply. “

Comment 3:. I would suggest to include more literature review over the region or part of the region. For example, Frans, C., E. Istanbuluoglu, V. Mishra, F. Munoz-Arriola and D. P. Lettenmaier (2013), Are climatic or land cover changes the dominant cause of runoff trends in the Upper Mississippi River Basin?, *Geophys. Res. Lett.*, 40, 1104–1110, doi:10.1002/grl.50262.

Response: Thanks for the suggestion. We added the suggested reference in the literature review discussion, see previous comment #1.

Comment 4:. Only one climate scenario (SRES B1) was applied to simulate potential

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future water supply. I would prefer to see at least two scenarios to comprehend the climate uncertainty, which gives a wider implication of your results. What is the benefit of selecting this specific scenario for your assessment? How was the bias in the climate projection treated? Any statistical bias-corrections were performed?

Response: We added another emission scenario, A2. Those two emission scenarios were chosen because they are the only ones available through the CAScADE dataset and both represent an optimistic and a pessimistic climate emission scenarios simulated by a medium sensitivity global circulation model. The Cascade dataset is derived using an analog approach as described in section 2.2.2, which is a statistical downscaling method alternative to the Bias Correction Spatial Disaggregation (BCSD) method. Figures 7, 8, 9, and 12, and Tables 2, 3 and 4 have been updated accordingly.

Comment 5: Page 6367: “. . .an inter-dependency database that allows managing the request of water to reservoirs and the distribution of supply to grid cells.” How is this done? Could you explain it in more details?

Response: We added: “an inter-dependency database that assigns to each reservoir a list of subbasins that can receive water from that reservoir and controls the weighted distribution of the supply, and similarly assigns to each subbasin the list of reservoirs it can request water from and controls the weighted distribution of the demand to each reservoir. (Voisin et al. 2013)”

Comment 6. Page 6369: Sectoral water demands were downscaled to 0.5o by 0.5o grid. But the hydrological simulation was conducted at 0.05o. And the climate forcing was prescribed at 1/8 degree resolution. I guess all the assessments were performed at a 0.5o grid? The authors should make clearer about the spatial resolution of the assessment and upscaling/downscaling employed in this study. Are there any finer spatial data (for water demand) available over the selected region?

Response: We clarify the spatial resolutions of the dataset and model set ups in Figure 2, the schematic of the modeling chain. In the text when presenting the different models

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and datasets, and their spatial resolution, we also refer to figure 2 now. It indeed better supports the need for upscaling of CLM parameters and GCAM demand downscaling in the modeling chain. Basically, The atmospheric forcing is at 1/8th degree. The water demand is temporally and spatially downscaled to 0.5 degree, then further remapped to the subbasins for different sectors. The hydrology simulations are performed at the subbasin resolution ( $\sim 1/8$ th degree). The parameters for the LSM are aggregated from their native resolution of 0.05 degree to the subbasin mask. The analysis is mostly performed regionally although we also look into the spatial analysis at subbasin (1/8th degree) for localizing regions of highest vulnerability.

The USGS water demand is available at the county level. The state level dataset was used to spatially disaggregate the GCAM water demand. Using finer spatial resolution data is the subject of further research. Readers are referred to Hejazi et al. 2013a and 2013b for further details on the spatial disaggregation.

Comment 7. Irrigation water demand was prescribed by the GCWM model. Does the seasonal course of irrigation water demand change per year? Or the seasonal trend remains always the same as the present during the future simulation? How does climate change affect the seasonal irrigation water demand? The GCWM model calculates irrigation water demand at 0.083333..o. Why not use the finer spatial resolution data? The uncertainty of irrigation water demand arising from a specific model is substantial (for example, multi-model projections and uncertainties of irrigation water demand under climate change, doi: 10.1002/grl.50686). How was the uncertainty arising from irrigation water demand treated?

Response: Thank you for the GRL reference. We agree that there is substantial uncertainty in the projected water demand depending on the crop model adopted. As described previously (see our responses to the first reviewer's comments 7, 8, & 14), this modeling study does not yet account for climate change on irrigation water demand and focuses on the implications of climate mitigation policies, socioeconomic drivers, and technological change implications on water demands (more human centric). So

the seasonal trend remains the same during the future simulations. We provide the rationale for this approach and acknowledge its limitation in the manuscript.

We have added the following sentence to clarify that climate change impacts on water demands are not accounted for in this study:

“The adopted IAM simulates water demand by sector (irrigation, domestic and industrial, etc) driven by socio-economic factors, technologically detailed energy and food demands, and climate mitigation targets in a fully integrated system, but does not account for climate change impacts on water demands. The modeling of water demands are focused mainly on the implications of climate mitigation policies, socioeconomic drivers (population, income, food and energy demands, etc.), and technological change implications. In this study, climate change impacts are primarily captured through changes in water availability, and consequently in water deficits.”

Comment 8. I think it would be interesting to show the relative impacts of climate change and water demand increase on future water-supply deficit (for example, Table 3, Figure 8, etc).

Response: Table 3 is replaced by a more complete table showing the relative changes in demand, supply, supply deficit, flow and regulated flows for A2 and B1 future periods (see main changes in general response to reviewers). We also show elasticities to further support the sensitivity of the actual supply and supply deficit to changes in flow and demand. Elasticities quantify the sensitivity of the supply deficit to changes in flow and demand. Elasticities are the ratios of the relative changes in supply deficit over the relative change in either natural flow or demand.

Comment 9 . Page 6376: “. . .the supply deficit is around 3%....1.5%...” How accurate are these numbers? What is the uncertainty on these values? I would suggest to include validation or comparison with other studies of water demand estimates. The USGS provides water use estimate per county; <http://water.usgs.gov/watuse/>

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Response: We added a paragraph at the beginning of the results section to explain that each modeling component of the system is individually validated, including the GCAM demand with respect to the mentioned USGS demand in the dataset section.

“The GCAM demand has been evaluated with respect to the USGS demand with a close agreement in the previous section. The land surface hydrology model (SCLM-MOSART) simulation is evaluated with respect to the naturalized observed flow. The water resources management model (SCLM-MOSART-WM), in particular the effect or extraction and regulation with respect to the natural system, is evaluated by comparing the observed and simulated differences between the natural and regulated flows. The term supply is usually associated with available water, i.e. flow. The actual supply is the water that is first extracted locally and from the reservoir releases according to reservoir operation rules and environmental constraints, in order to satisfy the requested demand to that reservoir. The actual supply is a function of the demand and the natural flow, this is the met demand. We refer to supply deficit as the difference between the demand and the actual supply, the unmet demand.”

Our estimated supply deficit with respect to the observed water use over the historical period takes into account i) that we do not simulate groundwater pumping at this time and ii) forcing and modeling errors.

Comment 10: It is know that over this region climate tends to be a dominant factor affecting water supply (e.g., Frans et al., 2013). It is not so clear why this study was conducted over this region considering change in water demand and climate, and the implications therein, since the cropland is mostly for rainfed, rather than irrigated crops.

Response: We complemented the section describing the region by: “The crop in the region is mostly rainfed especially over the Upper Mississippi and Ohio and Northern Missouri and has been shown, at least over the Upper Mississippi (Frans et al. 2013, Mishra et al. 2010), to be more sensitive to climate change than to land use change. However this region is chosen because it represents many crosscutting issues on cli-

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mate, energy, land use, and water, including water quality. For example, the Midwest is a major area for bioenergy resource, representing potential conflicts between food and fuel. In addition, the Midwest is of primary importance for regional and international water markets, and hence represents an interesting test case for our modeling framework that aims to model global water transfer in the future.”

Comment 11. Page 6381: “Socio-hydrology”. . .suddenly appeared in Conclusions. Some more background information is needed and the relevancy to this study is not so clear.

Response: This has been removed from the text.

Comment 12. The authors should at least address further about the importance of groundwater pumping over the region.

Response: Groundwater is addressed in multiple locations in the paper, especially in the discussion section.

Section 3: “As discussed later, the supply deficit is localized in the southwest Missouri basin where deep groundwater pumping is used and over the urban areas around the Great Lakes, which can also be used as additional freshwater source. “

Section 5.1” “The area is relying significantly on groundwater pumping ; “ We added “26% , 11%, 7% of withdrawals over the Missouri and Upper Mississippi and Ohio respectively come from groundwater(Kenny et al. 2005), although this is not specified how much come from unconfined deep aquifers.” “[. . .]. The sensitivity to the fraction of irrigation groundwater use is the focus of further research.”

Section 5.2 on the water balance: “We need to quantify how much groundwater comes from unconfined aquifer and how much comes from return flow for adjusting the demand on the surface water system. Similarly, in order to use withdrawals more research focused on the full coupling of the water resources management model with the land surface hydrology model is needed.”



Comment 13: Figure 3: Could you provide in normal scale? We plotted figure 3 in normal scale, see below. The normal scale does not allow looking at outliers for the low and high values properly. We believe that the log scale shows best how GCAM and USGS compare over a range of values. (see figure at the end of the document)

Comment 14: Figure 5: It is good that the authors show the monthly water demand, but it is quite difficult to see the seasonal trends from this figure.

Response: The seasonal trend is shown in figures 4 for individual demand sectors. The regional seasonal total demand trend is shown in figure 8. The figure 5 is already very busy and adding a zoom in snapshot would make it cumbersome to read.

Comment 15 . Figure 11: I think this figure is benefited with different colour scheme, for example, blue-tone colour for water supply, red-tone colour for water demand. The colour scheme for water supply deficit may remain the same.

Response: We updated the colors for demand and supply. In order to make the difference between periods more clear, we use rainbow and red to blue like colors. The red-only tones and blue-only tones were making it difficult to see the evolution of the demand and supply.

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Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 10, 6359, 2013.

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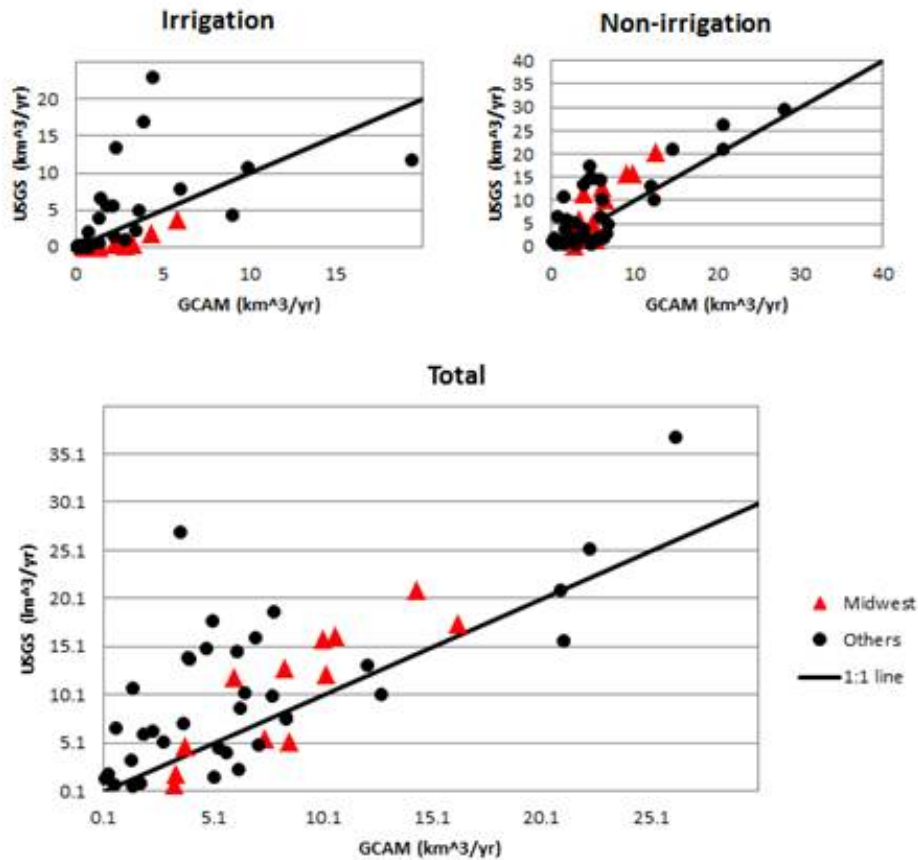


Fig. 1.

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