**Hydrology and
Earth System
Sciences**

Open Access

Discussions

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.

N. Voisin et al.

nathalie.voisin@pnnl.gov

Received and published: 22 August 2013

We thank the reviewer for the thorough review and constructive comments which resulted in an improved manuscript.

Comment 1: Statements like "The supply deficit seems to be driven by the change in flow. . ." seem so obvious that it is unclear why any experiment would be needed to ascertain this. I cannot understand what the last sentence is trying to say. Much later in the paper (for example, conclusions part 2b) there are things that were found here

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

that would not be easy to discover with other techniques, illustrating the advantage of coupling an IAM to a water model. If the abstract clearly stated why this coupled model is needed, and featured more of these sorts of unique insights into the response of the water supply and demand, that would be an improvement.

Response: We have clarified the abstract to ramp up the motive to illustrate the value of the coupling. We have also clarified the last sentence of the paragraph. The new changes are as follow:

"The linkage of the Global Change Assessment Model (GCAM) and a subbasin implementation of the Community Land Model (SCLM) facilitates the propagatation of human decisions pertaining to water demand per sector and technology from the assessment decision framework to SCLM at the appropriate temporal and spatial scales. This coupling constitutes a key step toward establishing a consistent, integrated framework of water modeling that is portable, consistent with global modeling and analyses, and provides significant improvements and insights into the interaction of human decisions and climate changes at regional scales."

We modified "The supply deficit seems to be driven by the change in flow" by :

Most of the changes in supply deficit and the supply are driven primarily by the change in flow over the region, rather than by the change in demand. The integrated framework further shows that the supply deficit is at least twice as sensitive as the supply to changes in flow and demand."

We also have replaced the last sentence in the abstract with the following:

The Spatial analysis demonstrates the relationship between the supply deficit and the change in demand over urban areas not along a main river or with limited storage. This analysis also identifies areas upstream of groundwater dependent fields, which have an overestimated surface water demand since groundwater demand is not represented in the current model."

Comment 2: p. 6365, line 9, the 'pseudo grid cell' of each subbasin represents on average 120 km2. It might be worth noting that this is roughly the same as a 1/8-degree grid cell, making the resolution comparable to the NLDAS effort, which shows up later in the paper.

Response: Agree. We added " The study area was delineated into 18681 subbasins with ~120 Km2 average size, equivalent to 1/8th degree grid cells making it comparable to the North American Land Data Assimilation System (NLDAS2) (Cosgrove et al. 2003)."

Comment 3: Section 2.2, the modeling chain is discussed, which is somewhat confusing. The CLM implementation is discussed, along with its atmospheric forcing data (sect. 2.2.2). While some of the shortcomings are discussed in Section 5, it would be helpful to explain why there is a land surface model used, when there is already a land surface component in the IAM. Some mention should be made regarding the types of errors that may be introduced when taking one set of output from an IAM and feeding it into a one-way coupling that includes a component (the CLM) that can no longer feedback into the earth system dynamically. Is there any correspondence between the land use in the IAM and that in the CLM? It should also be clarified why atmospheric forcing data were needed, since up to this point it sounds like that would be obtained from the IAM.

Response: The IAM model is run at a much coarser spatial and temporal resolution than the needed scale for SCLM-MOSART-WM. The atmospheric forcings used in SCLM-MOSART-WM are consistent with the climate representation in GCAM with regard to total radiative focings. However, GCAM does not usually use daily climate data as needed by SCLM-MOSART-WM. GCAM uses such data only when a hydrology module (runoff generation and routing) is used, but this feature is not used in the present study (turned off). In the described experiment, the CASCaDE data is only used in a postprocessing step to guide the temporal downscaling of GCAM simulated water demand. The land representations among the models are conceptually different;

and one of the shortcomings in this experiment is the lack of spatial downscaling of the land use in GCAM to enforce a matching representation of land use in SCLM. This is described in the manuscript and our team is working on addressing this issue for future improvement of the integrated modeling framework.

These are briefly discussed in section 3 in the manuscript:

"A one-way coupling between GCAM and SCLM-MOSART-WM is the focus of this paper. There is, however, a mismatch in scale both spatially and temporally among the models. GCAM is solved on a 5âĂŘyear time step and operates at the regional scale (14 geopolitical regions & 151 AEZs) which are much coarser than what would be required by SCLM-MOSART-WM. The temporal and spatial disaggregations to the subbasin and daily resolution of MOSART-WM need to represent spatio-temporal variations of use over the basin."

We have added the following sentences to explain the rationale for the atmospheric forcings, the land surface model, and the level of consistency between the models:

"Although the atmospheric forcings used in SCLM-MOSART-WM are consistent with the climate scenarios in GCAM with regard to the total radiative forcings, GCAM does not explicitly use any gridded climate data as input. The CASCaDE data is simply used to guide the temporal downscaling in a post-processing step of the GCAM simulated water demand from annual to daily scale, as will be discussed in section 3.2."

"Due to the lack of available tools to downscale land use from the 151-AEZ scale in GCAM to the grid/subbasin scale, SCLM-MOSART-WM uses the same land use in the future as defined by the current conditions. Reconciliation of land use between the global and regional models is an on-going research for future improvement of the modeling framework."

Comment 4: p. 6366, line 15, calling the B1 scenario "middle of the road" is incorrect. It is a very optimistically low projection, and the lowest of the SRES scenarios.

Interactive
Comment

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

Response: We corrected it to:

"The GFDL-B1 and GFDL-A2 climate scenario portrays the B1 and A2 emissions scenarios (optimistic and pessimistic) as modeled by the GFDL CM2.1 model that has climate sensitivity in the medium range among the IPCC AR4 models. The B1 emission scenario corresponds to the lowest increase in surface temperature among the different greenhouse gas emission scenarios. Economically, it focuses on global environmental sustainability. The A2 scenario concentrates regional economic development and is one of the scenarios with the largest temperature increase. (AR4, Fourth climate change assessment report)"

Comment 5: p. 6367, line 13, Similar to prior comments, the questions raised by assumptions should be at least mentioned up front, rather than relegating them to the end of the paper. Specifically, "return flow is not explicitly simulated" would seem to be a serious shortcoming, as in some basins this is a significant component of the managed water supply.

Response: We agree that return flow is a significant component of the managed water supply. We are investigating the two-way coupling and in particular the effect the uncertainties in the localization of the extraction and the redistribution of water will have on the overall modeling as future work. Even though GCAM already simulates withdrawals and consumptive use water demands, we chose in this one-way coupling to only extract the consumptive use. We changed the sentence to"The return flow is however implicitly simulated as we only extract the GCAM consumptive use rather than the withdrawals. The dynamic coupling is an area of research and in particular we investigate the effect the uncertainties in the localization of the extraction and the redistribution of water will have on the overall modeling."

Comment 6: Section 3 I found confusing. It is explained that the IAM operates at a 5-year timestep. In the temporal downscaling (sect 3.2) annual water demand is linearly interpolated to obtain annual demand values. But then irrigation (section 3.2.1, p. 6370,

line 13) demands are apparently computed on an annual basis using estimated crop coefficients. Are the demands obtained from the IAM only lumped values at 5-year intervals? Is the separation by source (the remained of section 3) only used to allocate the totals from the IAM?

Response: We clarify the text. The temporal downscaling is performed independently for each water use sector in GCAM to downscale the GCAM water use results from annual to monthly, and then to daily. For the irrigation in GCAM, the crop irrigation water demand is simulated on an annual time scale, instead of on a monthly time scale in Chatuverdi et al. (2013). This allows deriving the annual crop demand when running the IAM and deriving annual outputs every 5 years (GCAM is run with a 5-year time interval). We have clarified the text in Section 3 by adding the following statement:

"GCAM estimates annual irrigation demands every five years (GCAM is run with a 5-year time interval)."

Comment 7: Another concern regarding the 5-year IAM timestep and the linear allocation of demand between time steps is how cyclical events would be smoothed. For example, ENSO variability is largely removed with a 5-year aggregation. Changes in intensity, extent, or duration of, for example, 2 year wet or dry periods, with their concomitant changes in water demand (as farmers dynamically adjust some demand to accommodate supply) would be missed completely by this analysis, it would seem.

Response: IAM models generally focus on long term trends and are typically run over multi-year time periods. We agree that the use of linear interpolation is somewhat simplistic and one could potentially improve the adopted assumptions to capture some of the effects of climate change on water demands in GCAM. However, as we indicated previously, the current study does not address climate change impacts on water demands. The focus is mainly on the implications of climate mitigation policies, socioeconomic drivers, and technological change implications on water demands (more human centric).

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

We have added the following sentence to clarify this in the manuscript:

"We implement a subbasin configuration of a land surface model to simulate water supply (runoff and baseflow) coupled with a river routing model and a water management model, and a global integrated assessment model (IAM). 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: p. 6370, line28, Similar to comment 7, the monthly distribution of irrigation demand would change with variation of temperature and precipitation from year to year. Is that simulated here?

Response: We agree with the reviewer that irrigation demand would change with variation of temperature and precipitation over time. Ideally, we would capture that by using a detailed crop growth model like GCWM (Siebert and Doell 2008) that captures the climate effects on crop water demands. However, this would also require capturing the crop land evolution in GCAM to model future water demands. This obviously would require us to downscale GCAM land use results to 1/8th grid scale, a capability that we don't yet have in our tool kit. This approach is consistent with the overall approach of GCAM in which climate change impacts are not explicitly accounted for in water demands, energy demands, or land use. the adopted experiment only captures climate impact on the supply side in the SCLM-MOSART-WM components. We have ongoing efforts to incorporate climate information in GCAM, which would represent important advancements for the framework.

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."

We also added: Also, adopting the use of a gridded physically-based crop growth model would require downscaling of the evolution of land use (e.g., cropland expansion) in GCAM for future time periods; a capability that is not available and requires future research.

Comment 9: Equation 1, the subscripts do not seem to be used consistently. The subscript I is for month, but does that mean there are 12 of them, or one for each month is the simulation? Should Ratio have a subscript of i as well? We have corrected all the time indices for all equations 1 through 7. Thanks for pointing out the inconsistencies. These are the updated equations:

(see attached pdf)

Comment 10: Equation 7, similar to eq. 1, T is monthly temperature; should it have an i subscript too?

Response: Please see our response to the previous comments.

Comment 11: ne 20, the operating rules are stated as static into the future. Again, some mention of this is included later in the paper, but a justification at this point would help. Since adaptation of reservoir operation is already being promoted for relicensing

(e.g. Viers, 2011. JAWRA 1-7. DOI: 10.1111/j.1752-1688.2011.00531.x) this is not realistic. It should be justified as a necessary simplification at this point.

Response: We added the sentence to:

"Future water resources, i.e. future regulated flow and water supply, are affected not only by changes in natural flow and water demands, but also climate change adaptation in the operating rules of the reservoirs (Viers 2011). As a simplification however, operating rules based on historical flow and demand are kept unchanged throughout the future simulation (see discussion section)."

Comment 12: p. 6375, section 4.1, historic changes over the period 1984-1999 are evaluated for the coupled modeling system. Analyzing changes over this short period would be highly vulnerable to natural variability. Furthermore, since it represents just 3 IAM timesteps, looking at changes over that period would not seem to be a very meaningful exercise. Or is it just the variability that is being analyzed?

Response: We agree with the reviewer that this is a short period for evaluation of the model. However we are limited to the available processed USGS from Moore et al. (2013) for the validation, which spans the 1982-1999 period. We presently evaluate the model with respect to the historical climatology. County level USGS data is available every five years on an annual time scale. IAM is constrained to that time step. We added in the text:

"We evaluate the change in the 1984-1999 monthly flow climatology due to the human activities including regulation and extraction of water over the three regions." And "The historical regulated flow and water supply climatologies serve as the reference for evaluating the effect of climate change."

Comment 13: p. 6376, line 5, regulation drives a 24% loss in annual discharge, which seems far too large – is that including diversions?

Response: The estimated loss in annual discharge does not take into account any

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

diversions and most importantly we do not take into account groundwater pumping at this time. The effect of regulations is minimal in two of the basins (Ohio and the Upper Mississippi) but more substantial in the Missouri due to the more pronounced level of water demands for irrigation (the biggest consumer of water).

We added: "Based on the analysis of observed regulated and naturalized flows, the regulation and extraction result in an observed estimate of 16% loss in annual discharge over the Missouri over the 1984-99 period. Our higher simulated estimate of 28% is explained by the fact that i) we do not take into account groundwater pumping at this time and ii) the simulated natural flow underestimates the observed naturalized flow.

Comment 14: Section 4.2.1, Some more information on these changes would be helpful. For example, for the Missouri, demand increases up to 60% over the irrigation season. Is that driven by expanded area, higher temperatures creating increased PET? Are changes in irrigation efficiency included? Direct effects of CO2 on stomatal conductance? There are so many things wrapped up in these numbers, an expanded interpretation of what is driving these changes would show some of the value of using these models. Similarly, section 4.2.3 could be expanded to provide a deeper understanding of the projected changes.

Response: As we indicated previously (response to comment 7), the current study does not address climate change impacts on water demands. The focus is mainly on the implications of climate mitigation policies, socioeconomic drivers, and technological change implications on water demands (more human centric). We clarify in section 3.1.1 how the irrigation demand is computed in GCAM, in particular how this is linked to changes in food demand and prices, and irrigation efficiency. The model is however simplistic to allow for an annual estimate and does not simulate the more complex interactions with CO2 effect on stomatal resistance, change in crop type, etc. It does take into account a progressive performance improvement in irrigation efficiency. Readers are referred to Chaturvedi et al. (2013), Hejazi et al. 2013a and 2013b for further in

depth details. For the newly added text, please refer to our responses to comments 7 and 8.

Comment 15: p. 6380, line 24, as in the abstract, the line "changes in supply deficit are driven by a combination of changes in demand and runoff" (repeated in conclusion number 2d) is too bland and general. How much of the deficit is driven by changes in demand vs supply? How has this study provided clues to this response that have not been available with the tools used for climate-water impacts up until now?

Response: In order to quantify the combination of changes in demand and flow and how they drive the changes in supply deficit, we added elasticities metrics in Table 3. The elasticity of the supply deficit with respect to natural flow is the ratio of the relative changes. An elasticity larger than 1 indicate that the supply deficit is that much sensitive to changes in natural flow. We then evaluate this elasticity with respect to the elasticity of the supply deficit with respect to changes in demand. The elasticities provide supporting evidence that changes in supply deficit are mostly driven by changes in flow. However over the Missouri basin, the difference between the elasticities is the smallest which indicates that changes in demand has a higher impact than in the other regions.

Our regional integrated modeling framework allows revising previous estimates based on irrigation only- simulated as evaporative deficit derived from crop models - by integrating other type of demands. Our added spatial analysis of elasticities complements this regional analysis and allows identifying the urban areas as most vulnerable to changes in demand.

Comment 16: p. 6382, line 14, the "regulated flow is projected to increase" and the next line down says " supply is also projected to increase." Aren't these essentially the same thing?

Response: We clarified in the text the terms supply and supply deficit. "The term supply is usually associated with available water, i.e. flow. The actual supply is the water

that is first extracted locally and next 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."

Comment 17: A final thought – a lot of flow regulation in this area is done for barge navigation purposes. How are requirements/demand for navigation represented in the IAM or in the offline models coupled to it?

Response: The introduction of the region says : "Reservoir regulation for navigation is a priority in the Ohio River basin, the Upper Mississippi River basin, and along the main stem of the Missouri River. In our generic water resources model detailed below, operating rules differ for i) irrigation only, ii) combined irrigation and flood control, and iii) other usages. The operating rule for other usages is consistent with navigation with the aim to have a uniform flow throughout the year. However, over the main stem of the Missouri the priority is given to irrigation, which prescribes seasonality in the monthly releases."

We added: "Control for navigation requires joint operations between reservoirs of different storage capacity, with coordination for withdrawals over multiple time scales. WM does not perform joint reservoir operations. However at a monthly time scale, the effect or reservoir regulation on streamflow matches reasonably well the observed regulated flow as shown in Voisin et al. (2013) and in the next sections".

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

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

$$W_{ij} = W_j \times Ratio_{AEZ_{ij}} \qquad (1)$$

Here i indicates the ith month in year j.

$$E_{ij} = E_j \times (0.05 \frac{HDD_{ij}}{\Sigma HDD_{ij}} + 0.15 \frac{CDD_{ij}}{\Sigma CDD_{ij}} + 0.8 \times \frac{1}{12}) \qquad (2)$$

$$HDD_{ij} = \Sigma_1^n \left(18 - T_{d_{ij}}\right) \forall \; T_{d_{ij}} < 18℃ \qquad (3)$$

Here d indicates the dth day in ith month in year j, n indicates the number of days in ith month in year j.

$$CDD_{ij} = \Sigma_1^n \left(T_{d_{ij}} - 18\right) \forall \; T_{d_{ij}} > 18℃ \qquad (4)$$

$$E_{ij} = E_j \times (0.74 \times (0.05 \frac{HDD_{ij}}{\Sigma HDD_{ij}} + 0.15 \frac{CDD_{ij}}{\Sigma CDD_{ij}} + 0.8 \times \frac{1}{12}) + 0.26 \times \frac{1}{12}) \qquad (5)$$

$$W_{ij} = W_j \times \left(0.74 \times \left(0.05 \frac{HDD_{ij}}{\Sigma HDD_{ij}} + 0.15 \frac{CDD_{ij}}{\Sigma CDD_{ij}} + 0.8 \times \frac{1}{12}\right) + 0.26 \times \frac{1}{12}\right) \qquad (6)$$

$$W_{ij} = \frac{W_j}{12} \left[\left(\frac{T_{ij} - T_{avg_j}}{T_{max_j} - T_{min_j}} R\right) + 1.0\right] \qquad (7)$$

Fig. 1.