Hydrol. Earth Syst. Sci. Discuss., 11, C3403–C3410, 2014
www.hydrol-earth-syst-sci-discuss.net/11/C3403/2014/

Hydrology and Earth System Sciences
Discussions

Interactive comment on "On inclusion of water resource management in Earth System models – Part 1: Problem definition and representation of water demand" *by* A. Nazemi and H. S. Wheater

J. Polcher (Referee)

jan.polcher@lmd.jussieu.fr

Received and published: 27 August 2014

I am very supportive of this paper as it is essential to motivate the community to take more interest in this anthropogenic pressure on the water cycle. Human water usage affects our ability to predict future water resources and has the potential of inducing climate feedbacks. I would like to see this paper published but I believe that the authors will need to revise some aspects as key constraints in Earth System Model development have been neglected. Thus in the following review I will detail my concerns regarding the description of irrigation parametrisations and then continue with minor comments which will hopefully help make this review paper more complete. The domi-

nant doctrine in Earth System Modelling (global or regional) is mass, water and energy conservation. There are good reasons for that and the most pragmatic one is that the model can run forever without any numerical problems. But our philosophy of science dictates that a closed system, as the Earth is to a good approximation, should conserve water. Thus irrigation has to use water which is already in the system and available without extra energy. Most of the parametrisations presented in this paper (tables 1 and 2) do not conserve water. If one wants to consume water for irrigation it has to be available in the grid box of the model, thusÂăthe water cycle needs a more detailed representation and the complexity of the model increases. On the other hand new feedbacks are introduces which are realistic and relevant for studying the interactions with climate variability and change. Water conservation in the models is also the link to the water supply problem. I would like to detail this with the case of ORCHIDEE (de Rosnay et al. 2003). We had to start by developing a routing scheme which works on the same grid as the evaporation calculation so that there were no interpolations involved when determining if the irrigation needs could be fulfilled with the water in the streams or aquifers of the current grid box. Once this was achieved we could use the procedure recommended by the FAO and limit the gross irrigation by the water available (as documented in de Rosnay et al. 2003). Since then (and thanks to evolutions in the photosynthesis part of the model) we found that we can by PDF (i.e. each crop present in the grid box) determine the water missing to optimise the transpiration and produce much better estimations of irrigation needs (Guimberteau et al. 2012). There is another issue we are currently working on and that is the role of the horizontal resolution (Documented in the Polcher et al 2013 reference used by the authors). When working at the global scale with coarse resolutions, there is always a river or an aquifer to provide enough water to sustain a realistic irrigation. Once the resolution falls below 50km, we cannot any more reproduce the observations in all regions as the "local water" is insufficient. Men have built reservoirs and channels which transport water over these distances. Thus, in regional climate applications and future resolutions of global models, our routing scheme will have to represent as well these man made modifications of the water transport in order to reproduce reasonably well irrigation. This is a direct consequence of our ambition that irrigation does not corrupt water conservation in the model. If one thinks a step further, we will have to consider the usage of geological water for irrigation which is outside of our definition of the climate system and thus breaks our assumption of the Earth Climate being a closed system. Or our definitions for the Earth System will have to be extended to include some hydrogeological aspects. Because we have chosen to preserve the water conservation in ORCHIDEE, the irrigation parametrisation can be used in any circumstance and has been used for more scientific studies that I dare to count, even if it is not always explicitly mentioned in the papers. I will provide some references to papers where this is the case in the specific comments below. With this, I do not wish to disqualify irrigation parametrisations which are not integrated in the water conservation of the model. They have their usefulness and should be considered as excellent tools for looking at surface atmosphere interaction problems. But there is a fundamental difference between these 2 classes of parametrisations which I think should be reflected in the paper.

Specific comments :

8242, 19 : for me the first attempts to include routing in LSMs (I prefer the Land Surface Model term so that in Earth System modelling the land is at the same level as the ocean and models. Who would dare speak about an ocean or atmosphere scheme ?) are : Miller et al, 1994 J. Clim, Hagemann and Dümenil, 1998, Climate Dynamics, Oki and Sud, 1998, Earth Interactions.

8245, 7 : In the list of possible effects of irrigation and water usage on the climate system, the impact on ocean circulation should be mentioned. This is of particular concern for closed oceans and the polar environment where a change in fresh water input can modify the oceanic circulations and thus feedback on continental rainfall. A recent review of literature showed a few nice examples for the Mediterranean : E. J. Rohling and H. L. Bryden (1992) Man-induced salinity and temperature increases in western Mediterranean deep water. J. Geophys. Res., 97(C7), 11191–11198 M.

Vargas-Yàñez et al. (2010) Climate change in The Western Mediterranean Sea (1900-2008). Journal of Marine Systems 82(2010) 171-176. N. Skliris and A. Lascaratos (2004) Impacts of the Nile River damming on the thermohaline circulation and water mass characteristics of the Mediterranean Sea. Journal of Marine Systems 52(1–4), 121–143.

8245, 15 : A recent study which shows (from one specific model !) the regions where irrigation triggers an atmospheric feedback in the water cycle and those where rainfall is not affected : Guimberteau et al. (2012) Global effect of irrigation and its impact on the onset of the Indian summer monsoon, Climate Dynamics, Volume 39, Issue 6, pp 1329-1348

8245, 24 : I would already write in the abstract that this review paper is in line with GEWEX's ambition to strengthen activities on human-water interactions and raise the awareness on this issue.

8246, 9 : Yes, there are still fundamental obstacles to include water resources in large scale models, but I would say that it does not matter if this is on-line or off-line. The nature of the coupling to the atmosphere is not affected by irrigation as it is only evaporation and the surface energy balance which are changed. I would say that in the "water conserving approach" to irrigation, we have to deal with the fundamental problem that man is also modifying the transport of water and tapping non renewable water sources which are outside of the climate system.

8252, 20 : In the this discussion of the usage of ETP one has to take into account that LSMs define potential evaporation in a quite different way from FAO, Penman-Monteith or others. Thus using simply the FAO guidelines for estimation irrigation needs will induce inconsistencies at various time scales with the evaporation estimated by the model. This is of particular concern for water stressed surfaces which is the case when we expect irrigation to occur. This problem is limited to LSMs which resolve the diurnal cycle and does not occur in GHMs which use anyway some empirical estimates of ETP for evaporation. This issue is well documented in : Milly, P. C. D.: Potential evaporation and soil moisture in general circulation models (1992), J. Climate, 5, 209–226 Barella-Ortiz, A., et al. (2013) Potential evaporation estimation through an unstressed surface-energy balance and its sensitivity to climate change, Hydrol. Earth Syst. Sci., 17, 4625-4639

8254, 5 : Using the extra information available in LSMs we can now do better and the concerns raised here are behind us. The irrigation need can be estimated using potential transpiration. This is the transpiration which would occur should the plan not be water stressed. If this is implemented together with a sub-grid soil moisture division (i.e. bare soils and non-crop PFTs have different soil moisture reservoirs) then the irrigation taken from the water reservoirs optimises photosynthesis and is only evaporated by the crops and not used by other surface types. Furthermore the potential transpiration takes into account the CO2 fertilisation, the adaptation of the plants to the climatic conditions or crop groth cycles as far as the LSM represents them. This is now present in ORCHIDEE and documented by Guimberteau et al. (see above for the full reference). The next step in the uncertainty is whether the irrigation is sprinkled on the crop, and thus induces some interception loss, or localized and limited to soil moisture processes. But this far beyond the current state of our models and would require knowledge on the irrigation techniques used in each region of the world.

8254, 19 : This evolution toward potential transpiration is partially explained in this paragraph but does not address the issue of having to treat separately in the grid box the irrigated vegetation from the rest. Most LSMs today define multiple plant functional types (PFTs) in each grid box and can thus distinguish the various water needs. But as long as all PFTs share the same soil moisture reservoir this does not help. Irrigation will increase the soil moisture of all PFTs and thus reduce water stress for forests as well as crops and in particular increase bare soil evaporation. Thus too much water will be used for irrigation and the evaporation increase overestimated.

8254, 21 : The projection of irrigative demand is closely linked to the infrastructures

which can be put into place to adducts water to the area where farming occurs. There is some pioneering work being done by economists and which is able to predict which regions can be irrigated and how the irrigation can be sustained in a changing climate. The modelling is purely based on the economical cost of bringing the water from the regions where it is available (generally mountains because of the amount of rainfall and the available potential energy) to those where the farming occurs (sedimentary plains and urbanized areas). The thesis of Hypatia Nassopoulos : http://halshs.archives-ouvertes.fr/pastel-00838516/, her papers and more generally the group at CIRED are at the forefront of this research. I know the thesis is in French and I am not sure if the part on the model to predict dam operations and water adduction has been published. But Hypatia Nassopoulos can be contacted.

8259, 7 : In this discussion of the irrigation-induced (or irrigation-displaced) rainfall the rôle of the conservation of water needs to be taken into account. For a model which limits irrigation by the available water stabilising feedbacks can be envisioned. Should irrigation for instance displace rainfall into the neighbouring valley/catchment, then the originally irrigated farmland cannot be sustained as the basin total rainfall might become to low to support the activity. This is perhaps far fetched, but it is a process which can limit irrigation and is not available to parametrisations which do not close the water balance. Thus I would classify these studies into the general topic of surface/atmosphere feedback studies where the surface energy balance perturbation is irrigation. As far as I could verify, none of the studies referred to in Table 3 include the feedbacks generated by water conservation.

8259, 28 : The studies presented here on the surface/atmosphere interactions are all analysed on the simple scheme of whether evaporation increase can favour moisture convergence or on the contrary reduce it. This has to be linked in some way to the wealth of literature where deforestation (or more academic perturbations) and its impact on evaporation are discussed. But I feel there is a recent evolution which is being missed here. It is now accepted that landscape contrasts (transitions between wet and cool and dry and hot areas) are critical in generating rainfall. Irrigation has a huge effect on this type of mechanisms as it creates sharp contrasts in evaporation and surface temperature. But models are known to be limited in their ability to generate the atmospheric perturbations caused by these processes and thus sensitivity experiments have to be analysed with caution. I would suggest that the authors take a look at this part of the literature of which I only highlight 2 recent publications : Taylor (2009) Feedbacks on convection from an African wetland, GRL, VOL. 37, L05406 (These African wetlands are just naturally irrigated areas !) Taylor et al. (2012) Afternoon rain more likely over drier soils, Nature, 489, 423–426

8260, 18 : Some LSMs have included irrigation in all of their studies as it simply was available in the model and provided more realistic river discharge values on many of the basins considered. One of these cases are the studies performed by Thanh Ngo-Duc during his thesis. When validating his atmospheric forcing over large basins, looking at the water exchanges between continents and oceans or validating ORCHIDEE with GRACE, the irrigation parametrisation of de Rosnay et al. was used but its impact not specifically analysed. The references are : Ngo-Duc T. et al. (2005) 53 years forcing data set for land-surface models, J. Geophys. Res., 110:D06 116 Ngo-Duc, T. et al. (2005): Effects of land water storage on global mean sea level over the past 50 years. Geophysical Research Letters, 32:L09704 Ngo-Duc, T. et al. (2006): Validation of the land water storage simulated by ORCHIDEE with the GRACE data, role of the routing scheme. Water Resources Research, 43(4):W04427

8264, 17 : I believe that in this section the authors mix different aspects of spatial resolution. First there is the spatial resolution needed to represent properly the irrigation processes. This can be achieved either by running the LSM at a higher resolution than the atmospheric component or by obtaining a higher effective resolution at the surface by using tiling approaches. As I pointed out above, if the crop PFTs have their own soil moisture reservoir the impact of irrigation on their evaporation can be quite well represented. The second issue is the adequate resolution to represent the impact of

increased evaporation and surface flux contrasts onto the atmospheric processes. For this problem, I do not know of any study as it is probably strongly regionally and seasonally dependent. But this issue of resolution is not independent of the complexity of the parametrisation of irrigation. As the resolution of the surface increases more processes need to be included in order to ensure water conservation within the model as else not enough water is available in each grid box to sustain the enhanced evaporation.

8266, 4 : The uncertainty of the demand linked to the potential evaporation is not that much of an issue as long as the same assumption is used for reference evaporation (or ETP) in the calculation of the crop evaporation and the irrigation demand. If the GHM uses Pristley-Taylor then the FAO guideline has to be re-interpreted accordingly. For the LSM more options are available as ETP or potential transpiration consistent with the surface energy balance can be derived in the model (but significantly different from Penman-Monteith as pointed out above). Thus if the consistency of the model is preserved, then the uncertainty of the irrigative demand linked to ETP is the same as that of the evaporation.

8266, 4 : To me the largest uncertainty in the parametrisations currently available is the limitation of irrigation by the available water. If the irrigation is limited by the water available within the grid box then we are hindered by our ability to describe water transports and the role played by humans and our lack of geological water used in some regions.

8293, Table 1 : de Rosnay et al. was implemented globally and only analysed over the Indian Peninsula. So it should probably move to table 2.

8295, Table 3 : Guimberteau et al. 2013 is missing.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 11, 8239, 2014.