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Comment on hess-2021-329

Anonymous Referee #2

Referee comment on "Historical simulation of maize water footprints with a new global gridded crop model ACEA" by Oleksandr Mialyk et al., Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2021-329-RC2, 2021

General Comments:

Basically, the authors describe important new model developments for the ACEA model and show novel findings that are of interest for different scientific communities. The results are well described and well illustrated.

In my opinion, paper readability should be increased before publication. Therefore, redundancies should be removed from the text. Units are sometimes separated with a blank and sometimes not. Please be consistent throughout the text.

Different declarations e.g. about spatial resolution are confusing and the downscaling approach that has been applied is not described in the manuscript.

Important model assumptions and approaches are not described and referred to literature instead. Please summarize the most important model assumptions and approaches, so that this paper stands for its own and the reader doesn’t have to read multiple other papers to understand the ACEA model.

Generally, I am not sure if one can say that ACEA is a biophysically based mechanistic process model, such as LPJmL or DSSAT. The crop yield calculation is based on AquaCrop-OS, which - to my understanding - is not a very physically based model, since it works with Penman-Monteith and some rough scaling factors.

The authors claim several time and in different context that they are the first, which is

incorrect every time. I therefore suggest to be a little more modest and careful in the statements, because it could give the impression that you may not be familiar with existing data or literature.

Model results are compared against other models, but the study lacks in a model validation (e.g. of ET), as e.g. done in Kimball et al. (2019): https://doi.org/10.1016/j.agrformet.2019.02.037.

Overall, I would suggest major revisions for the submitted paper.

Specific Comments:

Line 14: The term 'high agricultural development' same as 'low agricultural development' (Line 16) could be misleading, since it is not clear what 'high development' exactly means. I'd suggest using instead 'highly intensive'.

Line 16: Abbreviation CV (coefficient of variation) could be written out at first appearance to make it easier for the reader.

Line 17: has reduced by 34.6% until which year? 2016?

Line 25: I would be careful with this statement, because the increasing demand is certainly a driver but not the reason for environmental degradation.

Line 25: I would keep the term 'planetary boundaries' from the reference instead of using 'environmental limits', since this concept is commonly known under the term 'planetary boundaries'.

Line 26: There are also large uncertainties and different values exist for the global water consumption of 'crop production'. It would be interesting for the reader and also nice for the introduction (also with respect to your new approach) to describe the range from different approaches (maybe between 70 and 90%). Another question in this context: Do you mean agriculture or exclusively 'crop production' here?

Line 51: The coupling of grid cells is only required if it is necessary to consider lateral water flows, what you don't do?

Line 51: Since there is a lot of new literature available for GGCMs, I'd suggest to additionally cite the following publications here to give a broad overview of existing models and latest approaches:

- Zabel F, MuÌ□ller C, Elliott J, et al. Large potential for crop production adaptation depends on available future varieties. *Glob Change Biol*. 2021;00:1–13. https://doi.org/10.1111/gcb.15649
- Minoli, S., Müller, C., Elliott, J., Ruane, A. C., Jägermeyr, J., Zabel, F., Dury, M., Folberth, C., François, L., Hank, T., Jacquemin, I., Liu, W., Olin, S., Pugh, T. A. M. (2019): Global response patterns of major rainfed crops to adaptation by maintaining current growing periods and irrigation. - Earth's Future, 7, 12, 1464-1480. https://doi.org/10.1029/2018EF001130
- Müller, C., Franke, J., Jägermeyr, J., Ruane, A. C., Elliott, J., Moyer, E., Heinke, J., Falloon, P., Folberth, C., Francois, L., Hank, T., Izaurralde, R. C., Jacquemin, I., Liu, W., Olin, S., Pugh, T., Williams, K. E., Zabel, F. (2021): Exploring uncertainties in global crop yield projections in a large ensemble of crop models and CMIP5 and CMIP6 climate scenarios. - Environmental Research Letters, 16, 3, 034040. https://doi.org/10.1088/1748-9326/abd8fc

Line 52: I'd suggest to mention the Global Gridded Crop Model Initiative (GGCMI) within the Agricultural Model Intercomparison and Improvement Project (AgMIP). In the context of climate impact assessments, it would be great to include Jägermeyr et al. (2021), in which the new CMIP6 scenarios are applied to a large ensemble of global gridded crop models. The publication is currently still under review in Nature Food but could be accepted soon.

Line 50-54: I disagree that GGCMs have never been used so far to estimate WFs. Maybe that depends on the definition of a GGCM and also of what you mean with WFs. Since a general definition of a GGCM does not exist, this is difficult. In general, a GGCM must not necessarily be physically based. There are a lot of studies that look e.g. at Evapotranspiration (ET) for crop models, e.g. Lui, W. et al. (2016): Global investigation of impacts of PET methods on simulating crop-water relations for maize. *Agricultural and Forest Meteorology*, *221*, 164-175. https://doi.org/10.1016/j.agrformet.2016.02.017.

In GGCMI, models have simulated ET in phase 1, phase 2 and the latest phase 3. There has been approaches, e.g. by Jägermeyr et al. to investigate water flows, irrigation demands, and crop water productivity with crop models. Deryng et al. e.g. investigated crop water productivity in context with increasing CO2 concentrations:

- Jaegermeyr, J. et al. Reconciling irrigated food production with environmental flows for Sustainable Development Goals implementation. Commun. 8, 15900 doi: 10.1038/ncomms15900 (2017).

- Jaegermeyr,J. et al. (2015): Water savings potentials of irrigation systems: global simulation of processes and linkages. HESS, 19, 3073–3091, 2015 . doi:10.5194/hess-19-3073-2015
- Deryng D. et al. (2016): Regional disparities in the beneficial effects of rising CO2 concentrations on crop water productivity. Nature Climate Change. DOI: 10.1038/NCLIMATE2995

Line 78: I am not sure if one can say that ACEA is a process-based model, such as LPJmL or DSSAT. Crop yield calculations are based on AquaCrop-OS, which - to my understanding - is not a biophysical process based mechanistic crop model.

Line 78: Redundant. The model abbreviation ACEA has already been introduced, so not necessary to do it again. Same with the abbreviation GGCM. Please only write out the complete name at first use and use the abbreviation in the following (without the abstact, in which abbreviations should generally be avoided).

Line 79: What means high temporal resolution? In line 92, you say daily. Most GGCMs use daily temporal resolution, but some global gridded crop models run at hourly resolution. Accordingly, what means 'high' in your sentence? I would suggest to delete high and write daily instead. Finally, to reduce redundancy, this should be deleted in line 92.

Line 86 and Figure 1: Since the 'scenarios' only refer to different water supply systems, I'd suggest to call them 'water supply' or 'water supply scenarios' or 'water supply assumptions' instead of 'scenarios'.

Line 89: Is fertilizer (N,P,K) a possible input for management in ACEA?

Line 91: Why are grid cells iterated, when lateral flows are not considered? You could parallelize the grid cells (as you actually say in line 65).

Line 92: How is crop growth simulated? What approaches are used? I think it is required to describe the main approaches and processes of the model (e.g. how is atmospheric CO2 concentration considered?). The reader has to understand the most important underlying approaches without having to read the other Aquacrop publications!

Line 94: Redundant, parallelization is already mentioned in line 65.

Line 107: Since there are many different GDD approaches available, which one has been

implemented to the model?

Line 150ff: Is this correction factor, derived by a bias correction of yields, used also to scale evapotranspiration? This is not explained here. But if yes, is a linear relationship between yield and ET realistic?

Line 159: The assumption that maize harvested areas experienced the same dynamics as croplands seems arbitrary to me and must lead to large regional errors. Is there any evidence that maize areas behave similar than total cropland areas? The term 'extrapolation' in this context seems wrong as it seems to be a scaling. To me, the procedure is not yet clear. Does the irrigation fraction in each pixel remain constant in your scaling approach? If not, can you explain where the change in irrigation fraction comes from? If all values are scaled with FAOSTAT in the end, why not directly scaling MIRCA2000 with FAOSTAT trends for maize for each country?

Line 165: Why do you use a three year moving average and not 5 or 10-year? Have you made a sensitivity analysis or is there any assumption that gives arguments for taking a 3-year average?

Line 178: Now I am confused. In line 13 (abstract) and in line 78, you said that you allied the model at 5 x 5 arc minutes. Now you say, you run ACEA at 30x30 arc minutes. What is correct?

Line 179: Please be aware that MIRCA2000 harvested areas for the maize class includes maize (corn), maize for forage and silage, and pop corn. How do you deal with the different maize usages that also go along with different plant characteristics and harvest characteristics (e.g. for silage, the complete overground biomass is harvested)?

Line 180: When you consider harvested areas according to MIRCA2000, you implicitly consider multiple growing seasons that are included in the harvested area (if a physical area of 1 ha is harvested twice per year, the harvested area is 2 ha).

Line 185: Is the GSWP3-W5E5 data is based on bias-corrected reanalysis data? If yes, that would be important to mention here.

Line 190: The same methodology is also used within GGCMI, you could refer to Minoli et al. (2019):

- Minoli, S., Müller, C., Elliott, J., Ruane, A. C., Jägermeyr, J., Zabel, F., Dury, M., Folberth, C., François, L., Hank, T., Jacquemin, I., Liu, W., Olin, S., Pugh, T. A. M. (2019): Global response patterns of major rainfed crops to adaptation by maintaining current growing periods and irrigation. - Earth's Future, 7, 12, 1464-1480. https://doi.org/10.1029/2018EF001130

Line 205: I know studies that assume irrigation to be triggered below 70% of field capacity. There seems to be some a range of values in the literature that could be discussed as another source of uncertainty.

Line 207: To be clear: You always assume full irrigation and don't consider e.g. deficit irrigation, right?

Line 210: How is the downscaling applied? If you downscale the results to 5x5 arc minutes, you cannot say that the model is applied at 5x5 arc minutes (see e.g. abstract).

Figure 3: For the right panel of Fig. 3, I would suggest to use an area weighted mean to consider the different maize areas (e.g. the US corn belt should weigh more than small areas), instead of using the median of all data points along the latitude. Is the color bar logarithmically scaled? Please explain in figure caption. Additionally, I think the 10^{th}percentile is the correct formulation (10% percentile would be doubled).

The Table 2 is good to have and helpful.

Line 293ff: There seems to be high uncertainties about global maize areas and expansion.

Figure 7 and 10: For improving this figure, one could set the dot size relative to the maize area or maize production in the country to visualize the importance of the respective country.

Line 343: Please be aware that the applied crop calendar also includes high uncertainties, and regions have been identified that do not well represent local phenological data from observations. A new updated crop calendar is currently being processed in ISIMIP.

Line 346: Can you explain why it is less accurate to calculate green and blue CWU in the post-processing? Isn't that a question on how it is implemented?

Line 382: I would be careful with this statement. The fact that you don't know any study that has shown this doesn't mean that no other GGCM can do this, as most existing GGCMs have the ability to simulate that on a daily base.

Line 394: Again, it is not explained, which downscaling methodology is applied. If this is just interpolated, I wouldn't call it a 'downscaling' approach.

Line 396: Actually all data except the crop calendar are available at 5x5 arc minutes. For climate input, one could use e.g. WFDE5, HWSD soil data is also available at 0.00833° spatial resolution.

Line 398: Indeed, this is a strong limitation, since cultivar variations and improvements over time play a big role, especially for maize.

Line 410: Please delete this statement. An extrapolation of historical maize areas based on FAO trends has been performed e.g. by Iizumi, T., Sakai, T. The global dataset of historical yields for major crops 1981–2016. *Sci Data* **7,** 97 (2020). https://doi.org/10.1038/s41597-020-0433-7.

Line 423: What means high spatial and temporal resolution? Please avoid subjective statements such as 'good', 'big' or 'high' in scientific articles.

Line 423ff: To me, the conclusion mainly reads like a summary and can be shortened.