Authors Response to the open discussion on „Modeling and evaluating the effects of irrigation on land-atmosphere interaction in South-West Europe with the regional climate model REMO2020-iMOVE using a newly developed parameterization“ - egusphere-2023-890

Response to Anonymous Referee #1 (RC1)
Response by the authors in blue (AC), the text from the revised manuscript is *italic* and the new text is **bold.**

RC1: Pg 6, line 170-171. Do this account for soil irrigation history? I mean, if you initialize the simulation the 15th, it accounts for the irrigation on the 14th?
AC: I am not sure if I understand your question. In line 170 we describe the order of the physical processes called in every timestep in REMO2020-iMOVE. During the initialization, there is no irrigation carried out. The irrigation is only defining and adding the new irrigated fraction to the model. We added more details in the text to clarify the call structure and we give more details of the soil initialization following your comment to line 308.
We added in line 169: *“**The irrigation module, which accounts for a check for irrigation requirement and the water application, is called every time step exclusively for the irrigated land fraction. These irrigation processes are carried out after the hydrological processes of the soil from the previous time step (t-1). In this way, the irrigation processes are applied to the soil hydrology inherited from t-1. After the irrigation processes, the vegetation processes start, which are strongly influenced by the moisture content in the soil and in the atmosphere of the same time step (t).**“*

RC1: I would suggest transform the abbreviations in lowercase in italics, in order to differentiate them from the normal text. Ex: line 176 irrht, line 195 wsmx
AC: Thank you for your suggestions. We applied it. However, we kept the names of the analysis regions in capital letters, since these are rather names than abbreviations and are defined in Fig. 3.
We changed it in whole text, eg., line 179: threshold (***irrthr***), line 118: maximum water-holding capacity (***wsmx***), line 119: land surface parameters (***LSP***), etc.

RC1: Line 196-197: Why is this relaxation applied?
AC: Since this approach of our parameterization is based on a soil moisture target rather than on an absolute irrigation water amount as in the prescribed scheme, we have to take into account the soil moisture changes not related to irrigation during the irrigation time. The relaxation approach allows us to reach our target value slowly within the prescribed time simulating the increasing soil moisture during irrigation process. We improved our text and pointed out the advantages.
We added in line 199: *„The "adaptive irrigation" is also based on a prescribed soil moisture target and a prescribed, limited irrigation time. Again, for each grid cell, the water amount is calculated that is necessary to reach the soil moisture target. The water amount added every time step follows a relaxation approach (Eq. 1), **which simulates the increase of soil moisture during the time steps of irrigation and simultaneously, considers the changes of soil moisture not related to irrigation. Further, our relaxation approach takes into account the number of irrigation time steps remaining. Using this approach the soil moisture increases until the irrigation target is exactly reached during the prescribed irrigation time.“***

RC1: Pg 13 Line 288: please, define again the regions here, to make it easy the reading.
AC: Thank you for your suggestion. We applied it.
We added: *„Fig. 7 shows the evolution of the meteorological conditions from April until August in the three analysis regions, IT **(Italy)**, CF **(Central France)**, and SF **(Spain-southern France)** (Fig. 3).“*

RC1: Line 308: Is the soil moisture initialized by the reanalysis? Orthere is a surface model that is computed offline?

AC: The initialization of the experiments is explained in section 4.1 Experiment Setup. Therefore, we improved our description here. To clarify: Soil conditions in RCMs need a long spin-up time until they are in equilibrium state. Therefore, for the initialization of the model, the soil variables from a previous, > 10 year long REMO simulation for the the same date as the starting date of the simulation (01/01/2017) are used. Except for the soil variables, the initialization of all other variables is based on reanalysis data (ERA5) (see Table 2). This is a common method in regional climate modeling to safe computation time. After the initialization, soil moisture is calculated by REMO2020-iMOVE, including evapo(transpi-)ration, infiltration, runoff, drainage, and for the irrigated simulations irrigation. We improved our text and tried to clarify.

In the text in *line 219: "S0 and S1* ***start from 01/01/2017. We initialized S0 and S1 with ERA5 (Table 2), except for the soil conditions. Since soil conditions have a long spin-up time in RCMs, we initialize the soil variables with a previous, long-term (> 10 years) REMO simulation to get the soil variables in an equilibrium state. This method is also known as "warm-start" (Pietikäinen et al., 2018)****."*

RC1: Line 309-310: why is the irrigation applied during the day hours? I though irrigation is typically done in the evening, night or or early morning. Do you have data to reference the applied daytime hours of irrigation?

AC: Thank you for your comment. The timing of irrigation depends on the irrigation method, the region and on the plant. We base our assumption of irrigation techniques and conditions based on findings from irrigation in the Po Valley, since it is the largest irrigated area in my model domain. There, channel irrigation (furrow irrigation) is one of the most common irrigation techniques which can take up to 24 h (Bjorneberg, 2013, Zucaro et al. 2014) until the channels are filled with sufficient water. In addition, in the Po Valley, irrigation is politically regulated with a rotational supply in predetermined shifts to its users (Zucaro et al. 2014). Therefore, irrigation is possible/necessary during daytime hours. We also found the same irrigation start time in Valmassoi et al. 2019 who investigated the Po Valley as well and tested different starting times. We improved our references and the description of irrigation details in the text in subsection 3.2 Irrigation module and water application schemes, as well as in 4.1. Experiment setup and in 5 Discussion.

In the text in 3.2. in line 178: *„Using an adjustable threshold (irrthr) on the soil moisture, the irrigation module determines the grid cells with irrigation requirements and creates a daily irrigation mask* ***at 7 AM LT as the starting time for irrigation in our parameterization following Valmassoi et al. (2019) .“***

In the text in 4.1 in line 231.: ***„****Following Bjorneberg (2013)* ***and Zucaro (2014)*** *channel irrigation is performed* ***for up to 24 hours depending on the channel width and length, we chose 10 h irrigation time for our experiment. With the irrigation start time at 7 AM LT (subsection 3.2), irrigation is applied during daytime in our experiment.“***

In the text in 5. in line 554: *„The underestimation of T2Max can be traced back to our experiment design which shows maximum irrigation effects. And therefore, it might overestimate irrigation effects. First, our irrigated fraction is based on the area equipped for irrigation that is not completely irrigated in reality. Second, in our experiments, we keep the soil moisture at very high levels (higher than 0.75 of wsmx) at which plants do not experience any water stress and the potential transpiration by plants is reached.* ***And third, we irrigate at daytime hours leading to strong effects on variables with a distinct diurnal cycle as the surface fluxes, evapotranspiration as well as T2Max. The effect of irrigation timing was analyzed by Valmassoi et al. (2019), who showed a rather low impact of irrigation timing on the development of irrigation effects.****“*

RC1: Line 319: “The strongest cooling effect in the soil occurs…”

AC: We applied your more defined suggestion.

In the text in line 330: *„ The strongest cooling effect **in the soil** occurs in the Ebro Basin and in the southern Po Valley with -4 K as a mean value in AMJ. “*

RC1: Figure 8 caption. Please, explain it better, what is delta_m?
AC: Thank you for pointing out the unclarity. We changed the label of the y-axes and legends and to keep only the unit in square brackets in all figures showing irrigation effects as differences.
In the revised manuscript we renewed Fig. 8, Fig. 9, Fig. 10, Fig. 11, Fig. 12, Fig. 13, Fig. 14, Fig. 15.

RC1: Line 356: Bowen ration does not have units
AC: Thank you for pointing out this mistake. We corrected it.
RC1: Figure 9: again Bowen ration does not have units
AC: Thank you for pointing out this mistake. We corrected it and renewed Fig. 9.

RC1: Figure 9 captions: Instead of “Effects on surface..etc” please, explain what you compare, what is delta, etc.
AC: Thank you for pointing out the unclearity. We improved the captions for all figures showing irrigation effects.
In the text:
*„Figure 8. **Irrigation effects based on the difference between the simulation with irrigation (S1) and the simulation without irrigation (S0)** on soil and surface processes ....*
*Figure 9. **Irrigation effects based on the difference between the simulation with irrigation (S1) and the simulation without irrigation (S0)** on surface fluxes ...*
*Figure 10. **Irrigation effects based on the difference between the simulation with irrigation (S1) and the simulation without irrigation (S0)** on the surface energy balance ...*
*Figure 11. **Irrigation effects based on the difference between the simulation with irrigation (S1) and the simulation without irrigation (S0)** on the atmosphere ...*
*Figure 12. **Irrigation effects based on the difference between the simulation with irrigation (S1) and the simulation without irrigation (S0)** on summed precipitation ...*
*Figure 13. **Irrigation effects based on the difference between the simulation with irrigation (S1) and the simulation without irrigation (S0)** on vegetation ...*
*Figure 14. Development of a) LAI and c) NPP, and the **irrigation effects based on the difference between the simulation with irrigation (S1) and the simulation without irrigation (S0)** ...*
*Figure 15. Delayed **irrigation effects based on the difference between the simulation with irrigation (S1) and the simulation without irrigation (S0)** on 2 m temperature ...*
*Figure 16. Development of delayed **irrigation effects based on the difference between the simulation with irrigation (S1) and the simulation without irrigation (S0)** during the heat wave …“*

RC1: Line 367: First sentence should be rewritten: “The effects of irrigation propagate to the atmosphere through land-atmosphere interactions, in particular through fluxes.”
AC: We applied your suggestion.
In the text in line 378: “**The effects of irrigation propagate to the atmosphere through land-atmosphere interactions, in particular through fluxes**.”

RC1: Fig. 11: could you plot outliers less thick?
AC: Thank you for your suggestion. Less thick was not possible, but we selected another marker and changed the color and transparency of the outliers. In addition we increased the line width of the box and whiskers to make clear what is important. We believe, these changes improved the readability of the diagram.

In the revised manuscript we renewed the Fig. 11.

RC1: Fig 11 caption. Please, explain what limits indicate the boxplots in the box, whiskers and outliers.
AC: We applied your suggestion.
In the text: *„Figure 11. Irrigation effects based on the difference between the simulation with irrigation (S1) and the simulation without irrigation (S0) on the atmosphere above irrigated areas as a and d) spatial distribution of mean values of AMJ, b and e)* ***mean diurnal cycle in AMJ with the box spanning from the 1st to the 3rd quartile, the red line showing the median, the whiskers showing the 5th and 95th percentile, and outliers as values outside of these limits****, and c and f) as annual cycle of mean values for a-c) 2 m temperatures and d-f) 2 m relative humidity*."

RC1: Line 443: Why do you think there is the decrease in the daily accumulated precipitation in the irrigated simulation? Please, give an hypothesis, or a hint.
AC: Referring to Fig. 16c, we show only specific dates of the simulations. For the 05/08/ precipitation increases through irrigation, for the 06/08/ decreaes and for the 07/08/ showing no effect for our analysis region IT during the heat wave. As showing also in Fig. 12, the effects of irrigation on precipitation are not clear in our simulations. For the 06/08/ we can only give a hypothesis. Irrigation does not only increase the moisture in the soil and atmosphere, through changes in the temperatures it has the potential to also affect the wind conditions. Analyzing limiting areas gives the option, that the increased humidity from the evapotranspiration in the irrigated simulation could have been advected to adjacent regions causing a decrease of precipitation. Another explanation could be that the cooler surface temperatures through irrigation lead to less convective processes above the irrigated areas. In the end, precipitation-irrigation effects are more complex than eg. irrigation-temperature effect and require a different experiment setting as we pointed out also to the comment of Jozsef Szilagyi (https://doi.org/10.5194/egusphere-2023-890-CC1).
We added these hypotheses in our text.
In the text in line 452: *„In IT, precipitation (Fig. 16c) occurs on the 2nd and 3rd of August at very low rates, which can be neglected, and on the 5th, 6th, and 7th of August at higher rates up to 4.5 mm day-1 in the non-irrigated simulation and 2.5 mm day-1 in the irrigated simulation. However, these precipitation rates are very low and affect the soil moisture with a small increase from 0.45 of wsmx to 0.47 of wsmx in the non-irrigated simulation on the 5th of August.* ***As in subsubsection 4.4.2, the effect of irrigation on precipitation is unclear during the heat wave. In Fig. 16c precipitation increases on the 5th, decreases on the 6th, and stays the same on the 7th of August. A possible explanation for the precipitation increase might be the higher evapotranspiration rate and higher relative humidity (as shown in subsubsection 4.4.2). However, the temperature changes through irrigation can also affect wind patterns, so that the humidity is advected outside our analysis region IT. Further, the cooling effect of irrigation on the surface temperature and near-surface temperature leads to less convective processes, which might have developed in the not-irrigated simulation on the 6th of August.*** "

RC1: Figure A1. Too small, please, make it horizontal
AC: Thank you for your suggestion. We applied it.
In the revised manuscript, we rotated and increased Figure A1.