Referee #1

Thank you for all the comments and questions. Please find below our responses to your comments:

Referee comments	**Answers**
'-The irrigation prescription is idealized. The irrigation timing varies by region and crop. For example, the authors acknowledge that night irrigation is common in the Ebro basin, while their irrigation occurs at 05 UTC. This is not a minor uncertainty: the timing of irrigation controls the partitioning between evaporation, sensible heat, boundary-layer development, and potentially convection. At 3-km resolution, timing becomes particularly important because irrigation can influence the diurnal boundary layer. I would quantify the uncertainty in the magnitude of irrigation and uncertainty in the timing and diurnal distribution of irrigation, which can alter the atmospheric response even if the annual irrigation volume is correct.	We agree that the timing of irrigation is a significant source of uncertainty, especially for the diurnal land-atmosphere response. Therefore, we have added some text in the revised manuscript (Lines 262-268 in the Author's track changes file), which states that previous model sensitivity experiments provide evidence that realistic changes in irrigation timing mainly influence the diurnal cycle, with negligible effects on average soil moisture, sensible heat, or upward moisture fluxes (Valmassoi et al., 2020). Also, we state in the conclusions section that our irrigation scheduling is a source of uncertainty (Lines 559-561).
'-The paper uses maize as the representative crop while their irrigation map contains irrigated croplands generally, not maize-specific irrigated areas. So, there is a conceptual mismatch? Different European crops have varying rooting depths and seasonal water requirements, which can strongly influence the calculated RAW and, in turn, the irrigation volume.	We agree that crop type is an important source of uncertainty in estimating irrigation water requirements. Different crops have different rooting depths, growing seasons, and water requirements. This, of course, affects the calculation of readily available water (RAW). We selected maize as a representative irrigated crop and applied its rooting depth since crop types cannot be distinguished in TERRA. We already acknowledge the uncertainty associated with prescribing a constant rooting depth and the absence of crop-specific representation in the manuscript (Lines 430–440 of the previous manuscript). Now, we have added in the revised manuscript that our prescribed irrigation amount should be interpreted as a reference irrigation amount based specifically on soil available water, rather than a real estimate of crop-specific irrigation requirements, since we

	use a constant root depth and soil hydrologic parameters (Field capacity and permanent wilting point). Please find this in lines 568-570 of the Author's track changes file.
'-What is the actual irrigation water applied? Can the authors show the annual irrigation amount by region and compare with independent irrigation water use estimates? Otherwise, it is difficult to know whether the climate response is physically realistic.	Thank you for this observation. We already presented the irrigation amounts for the Alps, Mediterranean, and Mid-Europe in Figure A1 (Appendix). However, a comparison with an independent irrigation dataset is still missing. Therefore, we have now compared our May - August accumulated irrigation water with independent estimates of irrigation water use from the Global Crop Water Model (GCWM; Siebert and Döll, 2010) for the Alps, Mediterranean, Iberian Peninsula and Mid-Europe. We have included this dataset in the same, Figure A1, in the revised manuscript. The comparison shows that our prescribed irrigation water is higher than the values estimated by GCWM. However, the two irrigation datasets are not exactly equivalent. As stated in the methodology, the irrigation amount in our simulation is a prescribed amount based on the available water of a specific soil type. In contrast, the GCWM calculates evapotranspiration of blue crop water. In our case, not all irrigation amount is used for evapotranspiration since part of it may be stored in the soil profile or contribute to surface and ground runoff. We find it valuable to compare our irrigation amount with the GCWM estimates, although this should not be considered as a direct validation. Moreover, since we found large differences between the irrigation datasets, we have now emphasized in the manuscript that our prescribed irrigation is an important source of uncertainty when interpreting the simulated climate response. Please find the new text about this dataset in lines 173-181 and 558-561. Siebert, S. and Doll, P. (2010). Quantifying blue and green virtual water contents in global crop production as well as potential production losses without irrigation. Journal of Hydrology, 384(3):198–217. Green-Blue Water Initiative (GBI).

	https://doi.org/10.1016/j.jhydrol.2009.07.031
'-The irrigation water is sourced externally and is not subtracted from other water reserves. This means the experiment is adding water to the terrestrial system without accounting for river withdrawal, groundwater depletion, reservoir storage, etc. For an atmospheric irrigation-impact experiment, this can be acceptable if the purpose is specifically to isolate the atmospheric response to irrigation. Still, the paper sometimes discusses the results as if they represent realistic irrigation. The distinction needs to be much clearer.	We already acknowledge this simplification in the manuscript, stating that we considered an external water source. However, we agree that this distinction was not stated from the beginning. Therefore, we have revised the manuscript and added this explicitly in the methods section, lines 170-172. Moreover, we have revised other statements that might communicate that we introduce irrigation realistically.
'-The paper uses Siebert et al. (2013). Does this mean that the experiment doesn't capture the expansion of irrigation during the recent period? What about changes in crop type and irrigation technology?	Yes, we agree that the use of the Siebert et al. (2013) dataset results in a static representation of irrigated areas throughout our simulations. Similarly, we did not account for transient crop type and irrigation practices information. Our manuscript already discussed, as future work, the need for different crop types and the use of high-resolution irrigation datasets. However, we agree that we did not explicitly mention the importance of applying transient crop, irrigation area, and irrigation practices maps. Since this is relevant in long-term simulations, we have revised the manuscript and mentioned this limitation in lines 580-586 of the Author's track changes file.
'-Does an irrigated grid cell become entirely "irrigated cropland"? At 3 km, many grid cells may contain cropland, forest, grassland, water, and non-irrigated agriculture. Replacing the land-cover class could introduce a land-use perturbation that is not irrigation alone.	Thank you for the observation. TERRA represents surface heterogeneity within a grid cell using the tile approach, and we irrigate only the irrigated cropland tile within a grid cell. Moreover, other tiles or surface types do not receive irrigation water. We agree that this information was not clear in the original manuscript. Therefore, we have added some text in the methods section (Lines 136-139) to specify that irrigation is applied only to the irrigated cropland tiles.
'-The paper validates the simulations against 3-hourly quality-controlled observations from ICON DREAM reanalysis. But ICON-DREAM is a reanalysis, not an observational dataset. More	We use the WMO-WIS observations, the same as ERA5 (Hersbach H., et al. 2020). The density and temporal distribution are already described in ERA5 (and commented on the WMO

details are required on which observation network, stations, number of stations, spatial distribution, and whether the station observations are independent of the reanalysis.	documentation/historical records). The quality control done refers to well-accepted procedures already applied in observations reprocessing work (e.g. Copernicus Climate Change Service, Climate Data Store, 2025 and EUMETSAT, 2021), where the reanalysis provides the background information for the assessment of the observation itself. This is commonly done to avoid verifying against faulty/unrepresentative observations, even if this process does not always ensure a correct removal of such observations, e.g. ECMWF, 2026 with the ERA5T issue in snow depth. We have revised the manuscript and added this information in lines 220-225 and 230-232. We also show some spatial observation plots per region in Figure A2 for July, 2011. Regarding the validation, we are aware that the observations might not be considered independent from the reanalysis, as they are assimilated with a cycled frequency; see the discussion in the ERA5 paper about its validation. Furthermore, in our approach we used an observational dataset; the only difference is how the quality control, but not bias-correction, on the observations themselves is done, and here it is done by ICON-DREAM. Therefore, the observations are only checked for consistency, but their observed quantity is not altered. As note, the aforementioned radiosonde dataset, which is both validated and bias-corrected with ERA5, will be assimilated in ERA6. Our approach offers a distinct level of independence compared to many validation procedures that validate ERA5-forced downscalings against ERA5 itself. In our approach, the observations are only checked for orography mismatches and physical consistency. While 2-meter temperature and relative humidity are quality controlled and assimilated, they do not directly influence the analysis increments fed to the reanalysis system given the fact that those are diagnostic variables (not prognostic ones). Now, we also acknowledge in the revised manuscript that the observations are not fully independent of the reanalysis.

	- Hersbach H, Bell B, Berrisford P, et al. The ERA5 global reanalysis. Q J R Meteorol Soc. 2020; 146: 1999–2049. https://doi.org/10.1002/qj.3803 - Copernicus Climate Change Service, Climate Data Store, (2025): Comprehensive upper-air observation network from 1901 to present. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). DOI: 10.24381/ba504f7a (Accessed on 24-08-2026) - EUMETSAT (2021): Atmospheric Motion Vectors Climate Data Record Release 2 - MFG and MSG - 0 degree. V. 2. EUMETSAT. (dataset). https://doi.org/10.15770/EUM_SEC_CLM_0020 - European Centre for Medium-Range Weather Forecasts (2021). ERA5T issue in snow depth. https://confluence.ecmwf.int/spaces/CKB/pages/242084340/ERA5T+issue+in+snow+depth. Accessed: 2026-08-24

Referee #2

Thank you for all the comments and questions. Please find below our responses to your comments:

Referee comments	**Answers**
1) The authors should improve the English throughout the manuscript. For instance, there are many writing issues on the first page alone. The methodology section is also poorly structured. I list specific issues below in the Specific Comments section.	Thank you for the careful revision. We appreciate the addressed observations and questions. We agree that the manuscript required some improvements, especially in the abstract and methods. Therefore, we have solved the specific issues and improved the clarity of the text.
2) The motivation for using convection-permitting experiments is unclear. The authors do not explain why they chose the	Thank you for this observation. We agree that the justification for using convection-permitting resolution was not completely clear in

convection-permitting scale, which is computationally expensive. What added value does this model configuration provide in this study? The analysis of the model output focuses primarily on several near-surface variables. It would be more meaningful to include analysis of precipitation.	the original manuscript. Our main motivation was the spatial representation of irrigation and the intensity of the impact, which is mentioned in the introduction (first and second paragraphs). The spatial resolution is important across Europe since irrigated areas are highly heterogeneous and localized. Also, as mentioned in Chen & Dirmeyer, 2019, coarse resolution simulations usually aggregate multiple small irrigated areas within individual grid cells, which limits the representation of local irrigation and its impacts. We have added this statement in the revised manuscript, Author's track changes file, lines 33-36. Moreover, we have also clarified this motivation in the model set-up, lines 184-186, due to the importance of 3 km resolution for the tile approach in TERRA LSM. Regarding precipitation, we agree that the convection-permitting set-up also benefits the representation of deep convection. Therefore, we have added a section to analyze precipitation (See section 4.4). In general, we found no statistically significant results for precipitation when using both the two-sided Student's t-test and the false discovery rate for field significance over the 12 year simulation. However, we found localized precipitation responses in some regions using the two-sided Student's t-test. Therefore, we analyzed these results in the manuscript, but we do not consider them evidence of a robust irrigation impact on precipitation. We have added this analysis in section “Impact on precipitation and its interannual variability” (section 4.4, lines 476-516) and mentioned this also in the conclusions, lines 542-550.
3) The model evaluation is based on the ICON-DREAM reanalysis, which also provides the boundary conditions for the irrigation experiments. The authors should consider using other observation-based datasets to assess model performance.	Thank you for this observation. We would like to clarify that ICON-DREAM was not used as the dataset for comparison. Instead, we used ICON-DREAM dataset as the initial and boundary conditions. For the model evaluation, we used quality-controlled observations assimilated into the ICON-DREAM. While 2-meter temperature and relative humidity are assimilated, they do not

	directly influence the analysis increments fed to the reanalysis system given the fact that those are diagnostic variables (not prognostic ones). Now, in the revised manuscript, we have added text acknowledging that these observations are not fully independent of ICON-DREAM. Moreover, we have added more information about these observations in lines 219-225. For instance, they are obtained from the WMO-WIS observation network, consistent with the observational data used in ERA5 (Hersbach et al., 2020), and for the quality-control procedures, ICON-DREAM reanalysis provided the background information to identify potentially erroneous or unrepresentative observations, following approaches commonly used in observational reprocessing (e.g., Copernicus Climate Change Service, 2025; EUMETSAT, 2021). Besides this evaluation, we have evaluated the performance of our simulations against external reference datasets in our recent intercomparison study (Roque et al., 2026, https://doi.org/10.1002/joc.70554). In this paper, 2-m temperature, precipitation and evapotranspiration were evaluated against E-OBS, GPCC and GLEAM, respectively, over the period 2011-2019 for two highly irrigated basins, the Ebro and Po basins. Now, we have added a reference to this evaluation in the revised manuscript (Author's track changes file, lines 494-498). - Hersbach H, Bell B, Berrisford P, et al. The ERA5 global reanalysis. Q J R Meteorol Soc. 2020; 146: 1999–2049. https://doi.org/10.1002/qj.3803 - Copernicus Climate Change Service, Climate Data Store, (2025): Comprehensive upper-air observation network from 1901 to present. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). DOI: 10.24381/ba504f7a (Accessed on 24-08-2026) - EUMETSAT (2021): Atmospheric Motion Vectors Climate Data Record Release 2 - MFG and MSG - 0 degree. V. 2.

	EUMETSAT. (dataset). https://doi.org/10.15770/EUM_SEC_CLM_0020 - European Centre for Medium-Range Weather Forecasts (2021). ERA5T issue in snow depth. https://confluence.ecmwf.int/spaces/CKB/pages/242084340/ERA5T+issue+in+snow+depth. Accessed: 2026-08-24 - Roque, J. L., Lopes, F. D. S., Giles, J. A., Gutknecht, B. D., Schalge, B., Zhang, Y., Ferro, M., Friederichs, P., Goergen, K., Poll, S., and Valmassoi, A. (2026). Intercomparison of a Regional Climate Model Ensemble for Selected European Catchments, International Journal of Climatology, e70 554, https://doi.org/https://doi.org/10.1002/joc.70554
4) The irrigation scheme “integrates irrigation water into grid-scale precipitation before it is passed to the land surface.” This is a typical representation of sprinkler irrigation. It is unclear why the authors chose this irrigation method. Can sprinkler irrigation adequately represent actual irrigation practices across Europe?	Thank you for this observation. We agree that the parameterization and TERRA description were not completely clear about why we selected this method and how TERRA treats irrigation water. TERRA does not represent canopy interactions yet; therefore, even though we add irrigation water to grid-scale precipitation, there are no irrigation water-canopy interactions. As a result, our parameterization closely resembles surface irrigation, which is among the most used methods in southern Europe (Masseroni et al., 2017), including Portugal, Catalonia, and northern Italy. We have added this text in lines 102-105. Regarding irrigation methods, we are aware of their diversity across different irrigated regions of Europe. We briefly mentioned this in lines 201-203 for the Ebro basin. However, since this is another source of uncertainty, we have revised the conclusions section and added some text about it in lines 554-556. Moreover, we have included a description of ICON and TERRA in the methodology, section 2.1.

5) Although the title refers to irrigation impacts “across the European continent,” the analysis focuses only on three subregions: the Alps, the Mediterranean, and Mid-Europe. According to the irrigation map, there are also large irrigated areas in the Iberian Peninsula. Why were these areas not considered?	We agree that the Iberian Peninsula contains highly irrigated regions, such as the Ebro basin. Therefore, we have expanded our results section to include this sub-region in subsections 4.2.1, 4.2.2, and 4.2.3. Initially, we focused on three sub-regions to show the irrigation impact across different evapotranspiration regimes (soil moisture-limited or energy-limited) and the exceptional events occurring in specific years.
L1: Revise “advancing and becoming more relevant.”	We have revised the sentence and changed it to “Irrigation is an important anthropogenic activity that can impact surface and atmospheric conditions” (Lines 1-2).
L4: Change “Therefore” to “However.”	Thank you for the observation. We have changed “Therefore” to “However”.
L6: Spell out ICON or remove the acronym.	We have included the whole name and acronym.
L10: It would be better to include a concluding sentence.	Yes, we have added a concluding sentence: “Our results highlight the importance of representing irrigation in climate models across Europe, given its region-specific impact and increasing relevance, especially as the frequency of extreme events such as droughts and heat waves is projected to increase.”
L12: Revise “The role of irrigation in research” to “Research on irrigation impacts.”	We have revised the sentence (Line 17).
L17: “Biases”: biases in what?	We referred to temperature biases. We have added this into the revised manuscript (Line 22).
L17: Revise “overcome this lack.”	We have revised the sentence to "To overcome this limitation, early

	research included irrigation into EMS through long-term simulations" (Line 23).
L72: Why are evaporation sources discussed here?	Thank you for this observation. We agree that only mentioning the evaporation source was not clear enough. We added this sentence to highlight that in our scheme, irrigation water also contributes to evaporation from the land-atmosphere interface. This differs from other irrigation schemes that add water directly to the soil and do not include this evaporation source. We have revised this sentence in Lines 99-101.
L71: In the Methodology section, the authors should include a section describing the ICON model. Subsections 2.1 and 2.1.x should be at the same hierarchical level.	Thank you for this observation. Based on a previous reply, we have added a section (2.1) in the methodology to describe ICON and TERRA. We have also corrected the hierarchical level of the subsections.
L173: Revise "Model discussion."	We have changed the section title to "Model evaluation", so it better describes the content of the section.
L227: Use consistent formatting for the section title.	Thank you for this observation. We have corrected the title's format.
L240: I assume that the model uses negative values to represent upward fluxes. This convention should be clearly explained. The current figures show negative values for changes in LHF, which could be misleading because negative values are typically interpreted as a decrease in LHF.	We agree that the sign convention for LHF and SHF should be clarified. Therefore, we have added a description of this to the results section and explained the interpretation of the corresponding LHF and SHF results (Lines 305-307).