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**Version:** Revision

**Title:** Changing European Hydroclimate under a Collapsed AMOC in the Community Earth System Model

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# Point-by-point reply to reviewer

July 28, 2025

We thank the reviewer for their careful reading and for the useful comments on the manuscript.

*This study investigates the hydroclimatic response over Europe under eight climate scenarios featuring different AMOC (Atlantic Meridional Overturning Circulation) strengths, including AMOC collapse cases, across pre-industrial (PI), RCP4.5, and RCP8.5 conditions. The authors use the CESM model, which has sufficiently high resolution for this kind of regional hydro-climatic analysis. They focus on daily water balance analysis by examining daily averaged precipitation and potential evapotranspiration (PET), from which they derive the potential precipitation deficit (PPD). The results indicate that while precipitation dominates the PPD, it does not fully explain the spatial variations, and PET also plays a role—particularly as PET rates increase with warming. The study shows that AMOC collapse leads to drier conditions and increased drought extremes across all climate scenarios, with the drying effects becoming more severe under RCP4.5 and RCP8.5. Particularly noteworthy is the comparison between RCP4.5 scenarios with and without AMOC collapse, which illustrates how radiative forcing combined with an AMOC collapse significantly intensifies drying by extending the dry season.*

*Overall, this is a compelling and timely contribution, especially given the increasing interest in AMOC-related tipping points. The authors have done an excellent job in designing and executing a set of carefully structured experiments. The clarity of figures, particularly those showing the combined* *impacts of AMOC and warming scenarios, is commendable. With minor revisions, I believe this study is well-suited for publication in HESS.*

General Comments

1. *It is intriguing that an AMOC collapse occurs under PI radiative forcing with a freshwater flux of 0.18 Sv, but not under RCP4.5 with the same flux. Further elaboration on this outcome would enhance the reader's understanding, as it suggests interesting non-linear behaviour and sensitivity to background climate states.*

   **Author's reply:**

   The description on the different simulations was confusing in the manuscript. The PI simulations were obtained from the AMOC hysteresis experiment. In this experiment, the AMOC was forced under the slowly-increasing $F_H$ at a rate of $3 \times 10^{-4}$ Sv yr$^{-1}$ (up to $F_H = 0.66$ Sv) and the AMOC collapses around $F_H = 0.525$ Sv. The $F_H$ was then reduced back to zero at the same rate and the AMOC recovers around $F_H = 0.09$ Sv. This results in a broad multi-stable AMOC regime for 0.09 Sv $< F_H <$ 0.525 Sv. Within this multi-stable regime, four simulations were branched off under constant $F_H$ and constant PI radiative forcing conditions, which are the two 'AMOC on' states and two 'AMOC off states'.

   The climate change simulations were initiated from the two AMOC on states. The RCP4.5 under the 0.18 Sv hosing did not cross the basin boundary of attraction and hence the AMOC did not collapse; this simulation was discussed in greater detail in van Westen et al. (2024, https://arxiv.org/abs/2407.19909). We do expect that a collapsed AMOC state exists under RCP4.5 and 0.18 Sv hosing, which will look similar to the collapsed AMOC state under RCP4.5 and 0.45 Sv hosing. This discussion is beyond the scope of this manuscript and is being addressed in van Westen et al. (2025, https://doi.org/10.5194/egusphere-2025-14).

   **Changes in manuscript:**

   We will rewrite section 2.1 in the revision and clarify how the different simulations were obtained.

2. *The distinction between AMOC "ON" and "OFF" states needs clarification. Figures and text indicate that both states include freshwater fluxes of 0.18 Sv and 0.45 Sv, raising questions about how the AMOC is still "ON" under such forcing. More detail on how the AMOC states are defined would be useful.*

   **Author's reply:**

   The description was confusing here (see also point #1 above). We will adopt a different naming convention to streamline the manuscript, e.g., $\mathrm{PI}_{18}^{\mathrm{on}}$. The simulation name includes the radiative forcing conditions, where the subscript indicates the $F_H$ strength (in units of $\times 10^{-2}$ Sv) and the superscript whether the AMOC is in its strong northward overturning state (i.e. 'on') or in its collapsed state (i.e., 'off').

   **Changes in manuscript:**

   We will rewrite section 2.1 in the revision. All the relevant text and figures will be changed accordingly.

3. *Much of Section 3.3 reads more like methodological description and could be moved to the Methods/Data section. Additionally, justification for the use of the k-means clustering approach should be strengthened. How do the results differ from a traditional analysis of MSLP changes, and why is clustering more appropriate or insightful in this case?*

   **Author's reply:**

   Yes, agreed. The $k$-means clustering methodology should be introduced more clearly. Part of the $k$-means clustering can be moved to the Methods.

   **Changes in manuscript:**

   We will incorporate these changes and provide a better justification for the $k$-means clustering in the revision.

4. *The Discussion section includes very little comparison with other studies that examine hydroclimate or European climate changes in response to AMOC shutdown. It would also be helpful to discuss how the results might change if CESM model biases were accounted for or removed.*

**Author's reply:**

Agreed, we will expand the discussion on hydroclimate responses to an AMOC shutdown. However, we note that only a few studies have provided an in-depth analysis of European hydroclimate responses

**Changes in manuscript:**

We will incorporate more literature in the revision. We will also expand the discussion on the CESM model biases.

Specific Comments

1. *Line 17–18: Replace vague or journalistic terms like "hot topic" or "major tipping point" with more scientific language.*

   **Author's reply:**

   Agreed.

   **Changes in manuscript:**

   Will be rewritten in the revision.

2. *Line 30: Specify how the seasonal cycle shifts.*

   **Author's reply:**

   There is a delayed response in the season cycle over the northern part of the Amazon Rainforest.

   **Changes in manuscript:**

   This will be clarified in the revision.

3. *Lines 26–32: It might be worth adding Saini et al., 2025 (https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2024PA004967) here, as they examine the impact of AMOC shutdown on Australian hydroclimate. They also use a comparable higher-resolution model, and this could be another interesting region where AMOC impacts are transmitted via planetary-scale dynamics.*

**Author's reply:**

Thank you for bringing this study to our attention, this is indeed a relevant study.

**Changes in manuscript:**

The study will be incorporated in the revision.

4. *Line 62: Should read "details on how..."*

   **Author's reply:**

   Agreed.

   **Changes in manuscript:**

   Will be corrected.

5. *Line 195: Should read "a factor of 3.5."*

   **Author's reply:**

   Agreed.

   **Changes in manuscript:**

   Will be corrected.

6. *Lines 235–237: Grammar needs correction here. Consider rephrasing for clarity and correct sentence structure.*

   **Author's reply:**

   Agreed.

   **Changes in manuscript:**

   Will be rewritten in the revision.

7. *Lines 303–305: Please indicate which scenario (e.g., RCP8.5) is being discussed to ensure clarity.*

   **Author's reply:**

   Agreed.

**Changes in manuscript:**

The two RCP8.5 scenarios will be mentioned here.

8. *Lines 332–333: This sentence appears to repeat the introductory paragraph of the section. Consider removing or rephrasing to avoid redundancy.*

   **Author's reply:**

   Agreed.

   **Changes in manuscript:**

   Sentence will be removed in the revision.