

## Replies to Referee #2

*This study projects changes in extreme fire weather across Europe under global warming levels of 2°C and 3°C using bias-adjusted RCMs. The manuscript is well-structured and methodologically thorough, making a meaningful contribution to understanding regional fire risk. However, despite the overall high quality of the manuscript, a major revision is required to address the specific points detailed below before publication in ESD.*

We sincerely appreciate the reviewer's thoughtful evaluation of our manuscript and thank them for their helpful comments. Below, we address all the issues raised by the reviewer and respond to each comment. Reviewer comments are shown in blue, our responses in black, and the proposed changes in red.

### *Major Comments:*

*1. This study utilizes the QDM method to bias-adjust the regional EURO-CORDEX model outputs. However, the rationale for not directly adjusting the FWI data remains unclear. Furthermore, the bias correction evaluation for FWI appears to be performed solely based on the 95th percentile. The authors should provide a clearer justification for this choice and discuss the potential implications of this specific threshold-based approach on the overall results.*

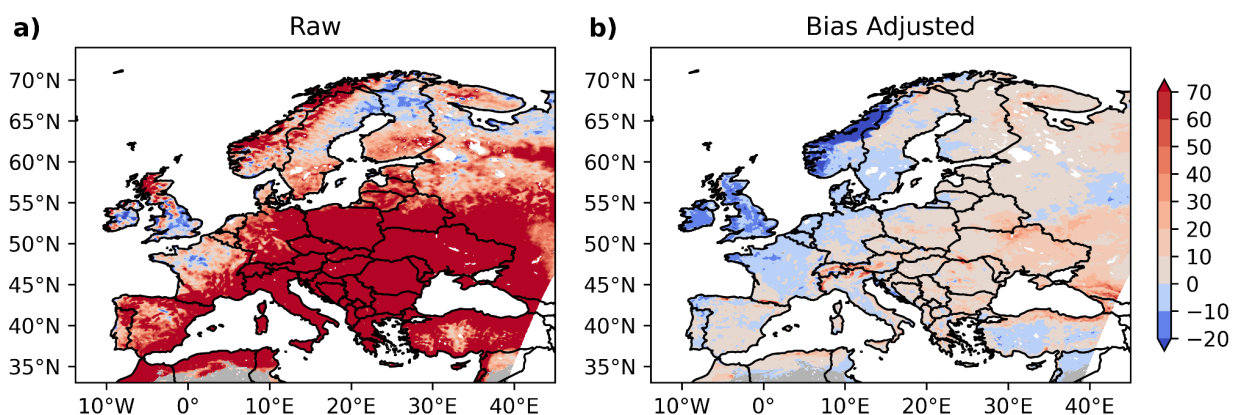
Thank you for your comment. Although it is true that one can directly adjust the FWI instead of the input variables, especially when the main objective is to improve the performance of the output variable, we decided to adjust the biases of each individual field. The rationale behind this choice is that it allows us to not only improve the performance of the FWI itself, but also to maintain physical interpretability and trace the contributions of its driving components to the projected changes under global warming. This was the objective of Figure 9 (where we analyzed the FWI subcomponents ISI and BUI) and Figure 10 (where we examined individual atmospheric fields). For these two analyses, we also used the bias-adjusted fields. Correcting only the FWI might have resulted in inconsistencies when tracing back to the physical drivers of the projected increase.

To address your concern that the rationale for this methodological choice was unclear, we will add the following paragraph to Section 2.2.2 on bias adjustment:

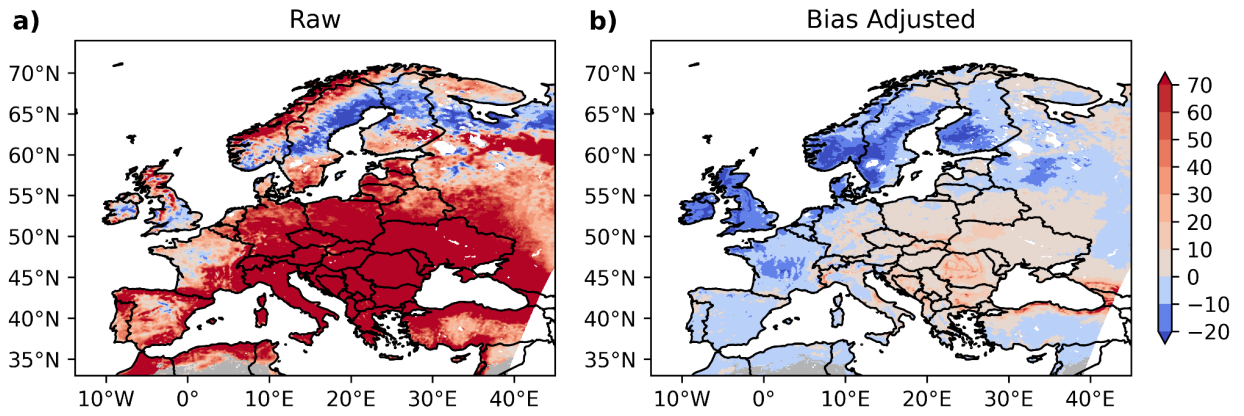
*“Here, we applied the QDM method (Cannon et al., 2015) to adjust the biases in the input fields extracted from EURO-CORDEX simulations, which were subsequently used to calculate the FWI. It could be argued that adjusting the FWI itself might be a more direct and computationally cheaper approach than adjusting the input fields, especially if the sole objective is to increase confidence in the FWI projections. However, our aim is not only to enhance confidence in the FWI projections but also to understand the physical drivers of the expected changes in FWI by tracing changes in the underlying input fields. To avoid inconsistencies that might arise from adjusting only the FWI, each individual input field was adjusted via QDM.”*

To address the reviewer’s second concern regarding the evaluation of bias adjustment only at the 95<sup>th</sup> percentile, we test several additional percentiles to assess whether the results are sensitive to the threshold selection. The results indicate that the performance improvement is not sensitive to threshold selection. Therefore, we propose keeping the 95<sup>th</sup> percentile figure in the main text as it reflects the focus of the study on local extreme fire weather conditions. In addition, we propose to include the figures for the additional tests in the Supplementary Material (please see below) and add the following sentence to the main text in Section 3.3:

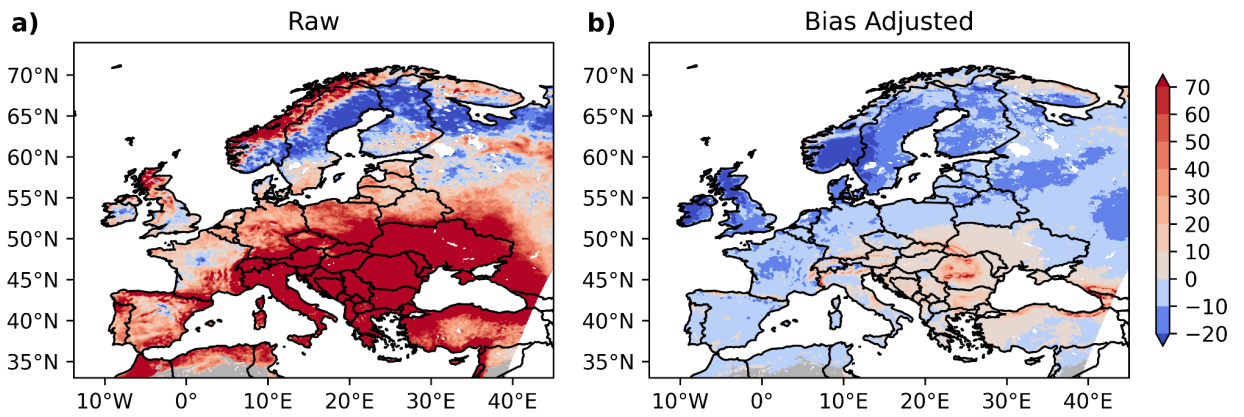
*“Sensitivity tests show that the observed spatial pattern of bias reduction is robust and largely independent of the choice of the 95<sup>th</sup> percentile threshold and exhibits qualitatively similar behavior across other parts of the distribution (Figures D6 – D10)”*.



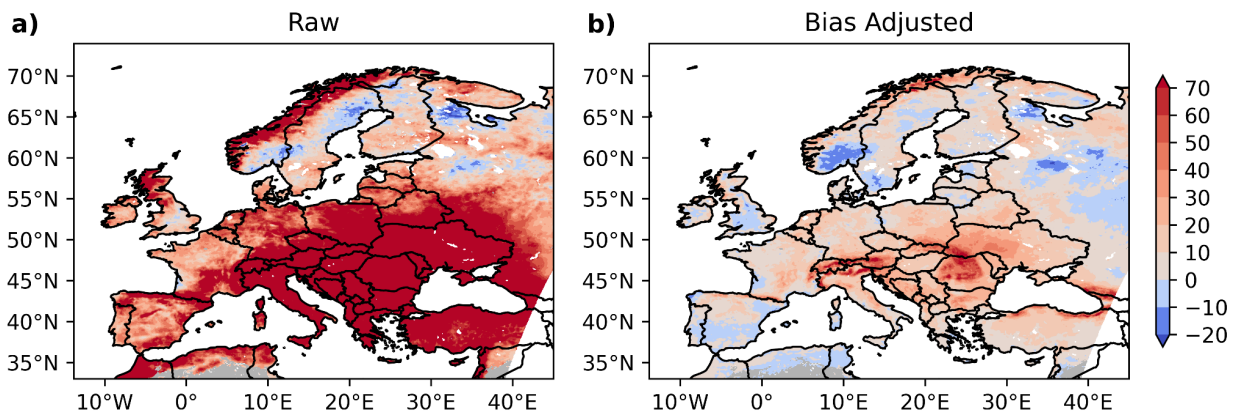
**Figure D6.** Relative percentage bias (%) in the 50<sup>th</sup> percentile of FWI for EURO-CORDEX ensemble median relative to ERA5-Land data during 1971-2000, based on **a)** raw and **b)** bias-adjusted simulations. Areas classified as unburnable are shown in gray.



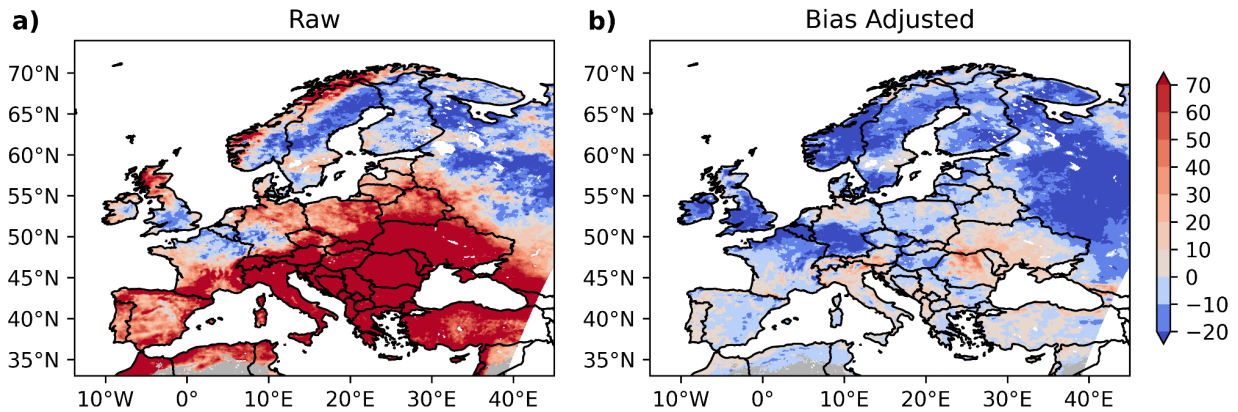
**Figure D7.** Same as in Figure D6, but for the 75<sup>th</sup> percentile.



**Figure D8.** Same as in Figure D6, but for the 90<sup>th</sup> percentile.



**Figure D9.** Same as in Figure D6, but for the 99<sup>th</sup> percentile.



**Figure D10.** Same as in Figure D6, but for the 99.9<sup>th</sup> percentile.

*2. I understand the authors' explanation regarding the unavailability of minimum relative humidity for most models. Nevertheless, it is necessary to explicitly discuss this limitation in the Discussion section. Specifically, the authors should describe how the choice of this humidity metric might influence the robustness of the conclusions.*

Thank you for your comment. As Reviewer #1 also suggested including a discussion regarding this selection, we propose adding the following text at the end of the first paragraph in Section 3.1 for the revised version (note that the first sentence was already included in the submitted version):

*“At the European scale, combinations that include mean relative humidity generally underestimate extreme fire weather danger (Figures 3a and 3b), while those that include minimum relative humidity tend to overestimate it (Figures 3c and 3d). Regarding the magnitude of the bias, using minimum relative humidity instead of mean relative humidity increases the absolute bias when the accompanying variable is maximum wind (Figures 3a and 3c), whereas it decreases the bias when the accompanying variable is mean wind (Figures 3b and 3d).”*

To address your comment, we propose adding the following paragraph in the Discussion section about the possible implications of the variable selection:

*“The proxy variable combination we selected to represent the original noon-time FWI calculation at daily resolution may have resulted in a possible underestimation of the baseline climatological values (as shown in Figure 3). However, a recent study found that all*

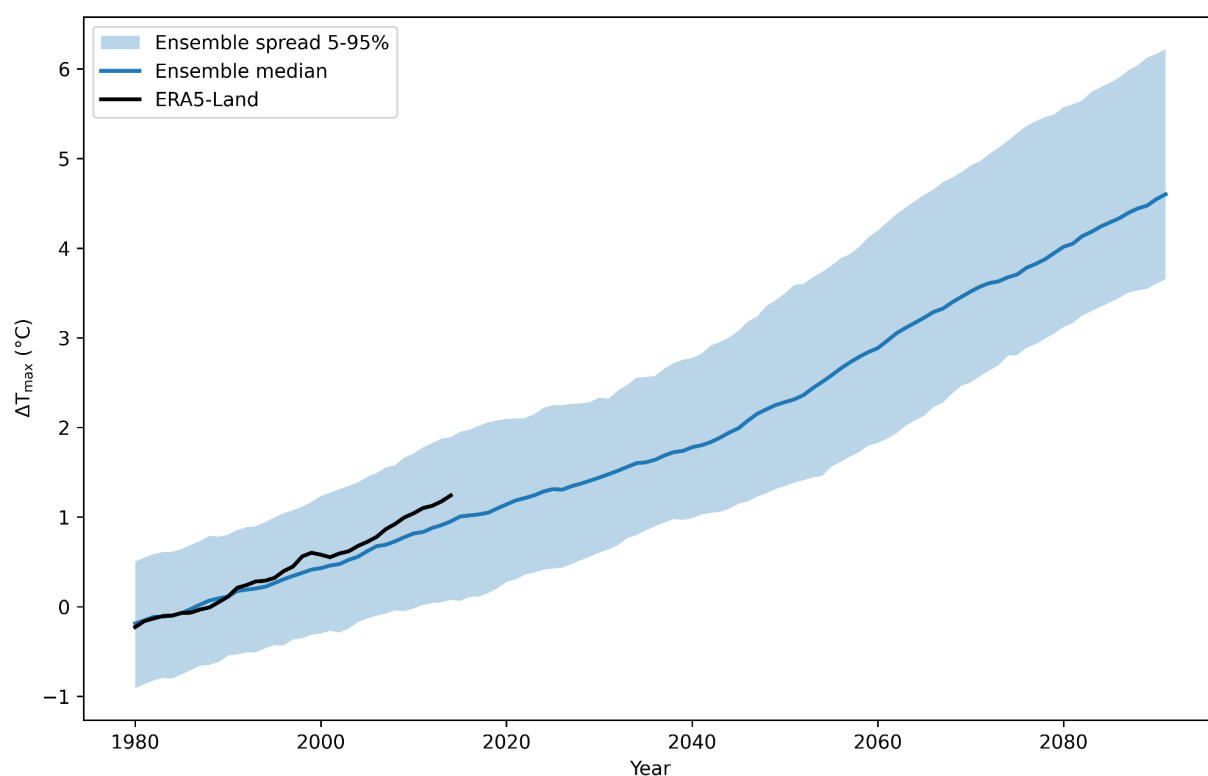
*combinations at daily resolution overestimate the trend in FWI95d relative to the original noon-time calculation (Matteo et al., 2025; note that, in addition to minimum/mean relative humidity they tested the dependence on maximum/mean temperature, whereas we tested maximum/mean wind speed). We also calculated the difference between the trends from the original calculation and those from the proxy combination selected for daily resolution and found that the daily combination overestimates the average trend in FWI95d over Europe by about 17% (results not shown). Therefore, although our analysis revealed an underestimation of the extreme portion of the FWI distribution due to the use of mean relative humidity, it is still possible that the projected trends are overestimated. Similar to Matteo et al., 2025, we therefore suggest that the next generation of climate model simulations should include more sub-daily outputs to better estimate the risks related to compound hazards in a warming climate.”*

*3. The use of (outdated?) CMIP5-based RCP8.5 scenarios warrants further justification, given that CMIP6 (and increasingly CMIP7) scenarios are already available and are widely used for future projections. Notably, since the "future" projections in RCP scenarios begin in 2005, there is now a 20-year overlap with historical observations (up to 2026). The authors should clarify whether the observed warming pathways over the past two decades align with the RCP8.5 trajectory used here. This comparison is particularly important for assessing the lower warming level of 2°C.*

Thank you for your comment. While we acknowledge that CMIP6-based SSP scenarios are increasingly used, dynamically downscaled EURO-CORDEX simulations based on CMIP6 were unfortunately not available at the time of our analysis. These simulations are still being produced, and some are expected to be available during 2026 (as mentioned in the Discussion of the manuscript).

Our study relies on a large ensemble of CMIP5-based RCP8.5 downscaled simulations, which we believe currently provides one of the most comprehensive coverage across models for FWI projections. Authors are also involved in another study about the new generation of EURO-CORDEX simulations that are downscaled from CMIP6 models in an FWI-based evaluation setting, and we do not expect an ensemble as large as the one used in this study to be available soon.

Regarding the representation of observed warming, we note that our analysis is conducted at specific Global Warming Levels (GWLs) rather than fixed time periods in the future, which makes the exact pathway of warming less critical. Nevertheless, as highlighted by the reviewer, substantial deviations between observed and simulated warming could affect the interpretation, particularly for the +2 °C GWL. Therefore, we compare the land warming trajectory derived from ERA5-Land with the bias-adjusted EURO-CORDEX RCP8.5-based land warming pathways over the study domain, and found a general trend in models towards underestimating the observed warming in the recent decades, similar to the previous studies (Schumacher et al., 2024). This information is now included in the Supplementary Material as Figure D14.



**Figure D14.** Annual mean daily maximum temperature from the EURO-CORDEX ensemble (blue) and ERA5-Land reanalysis (black), shown as changes relative to the reference period (1971-2000) and averaged over the study domain. Time series are presented as 20-year running averages to suppress high-frequency variability.

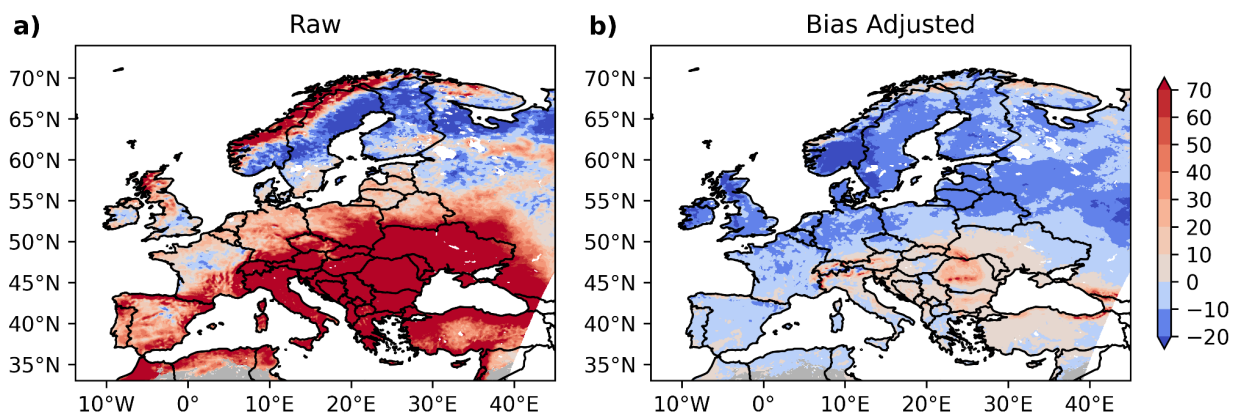
We also will add a sentence in the discussion regarding Figure D14:

*“This new generation of simulations retains the same spatial resolution as their CMIP5 counterparts, but incorporates greenhouse gas forcing scenarios based on the state-of-the-*

*art Shared Socioeconomic Pathways (SSPs) instead of RCPs, along with a consistent space- and time-varying aerosol forcing (Katrakou et al., 2024) The latter may lead to a better representation of regional extreme fire weather conditions, considering that models that do not account for time-evolving aerosols underestimate the European summer warming (Schumacher et al., 2024, note that, in our analysis, we also found that the EURO-CORDEX ensemble median slightly underestimates the warming trend in daily maximum temperature, as given in Figure D14).”*

*4. The colormaps in Figure 5 (and similarly in Figure 4) require revision. The current use of blue for FWI values ranging from 0 to 20 can be misleading to readers. Additionally, both the colormap selection and the numerical ranges in Figures 4c and 4d should be optimized to better represent the data distribution (+/-) and enhance clarity.*

Thank you for your suggestions. We would like to note that in Figure 5, the value ranges represent the relative percentage bias rather than the FWI itself. However, we fully agree that the colormap could be misleading to readers. Therefore, in the revised version, we propose to modify the colormaps as follows (blue for negative values only, red for positive values only):

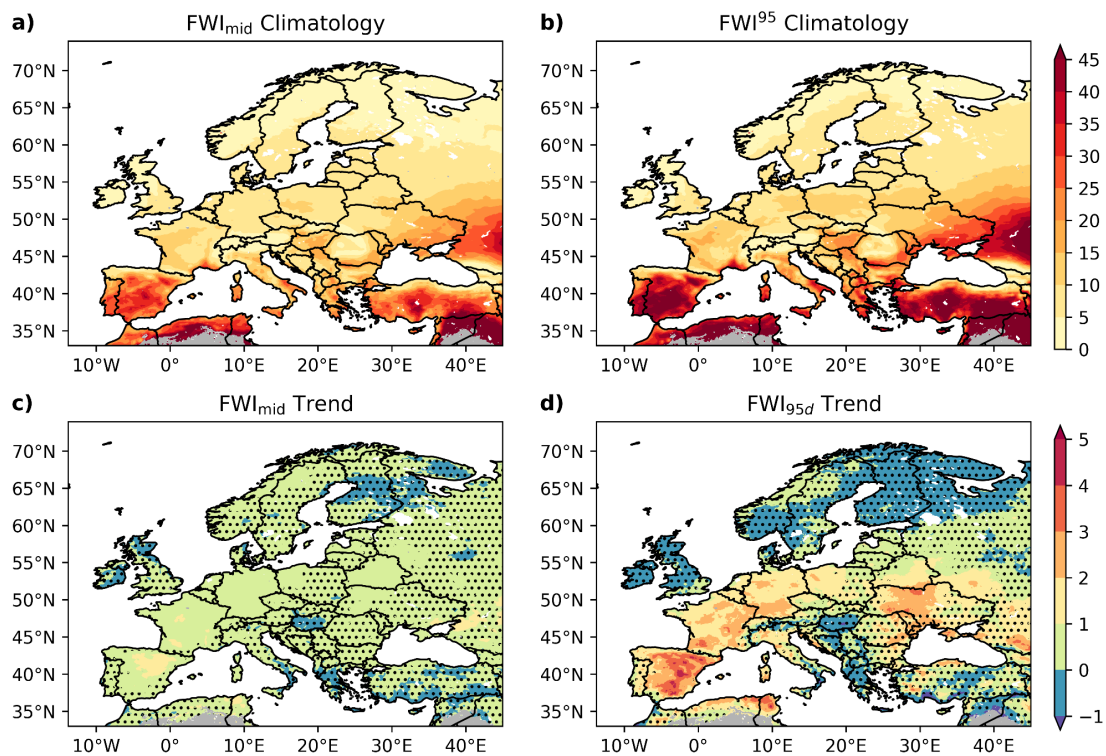


**Figure 5.** Relative percentage bias (%) in the 95<sup>th</sup> percentile of FWI for EURO-CORDEX ensemble median relative to ERA5-Land data during 1971-2000, based on **a)** raw and **b)** bias-adjusted simulations. Areas classified as unburnable are shown in gray.

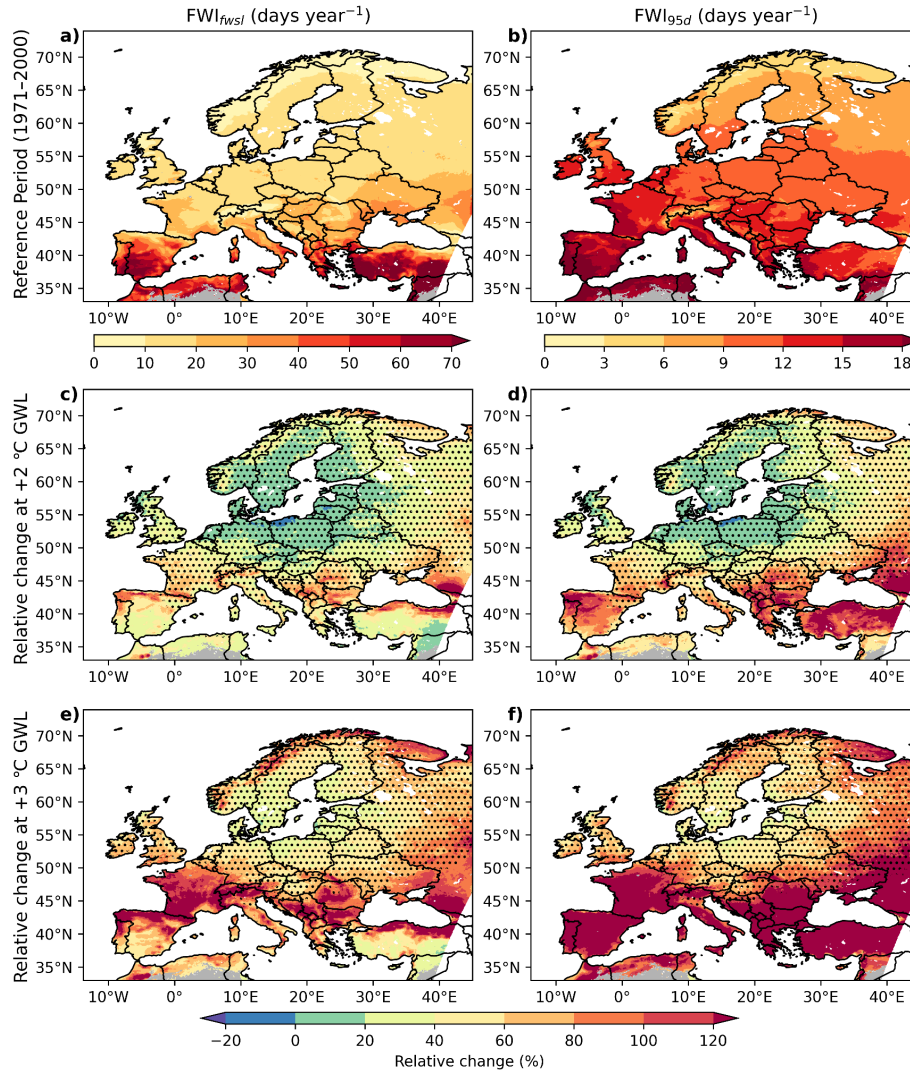
Similarly, the same colormap will be applied to the Supplementary Figures discussed in the first comment (as shown above).

Regarding Figure 4, we agree that the use of blue for FWI may be confusing to readers. To address this comment, we will revise the colormaps used in the climatology panels

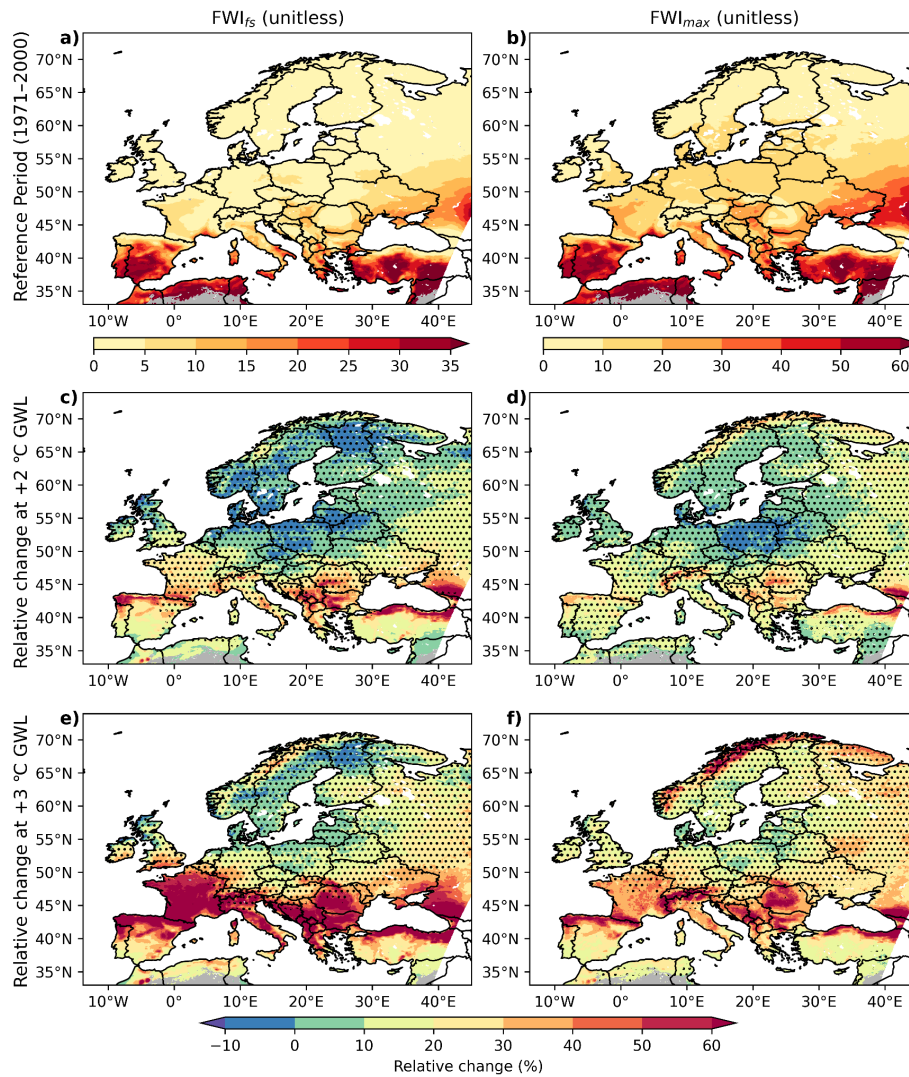
throughout the manuscript, namely in Figures 4, 6 and 7. We will also revise Figures 4c and 4d to provide a clearer representation of the data distribution:



**Figure 4.** **a)** Observed climatology of the mid-range FWI ( $FWI_{mid}$ ) and **b)** the 95<sup>th</sup> percentile FWI ( $FWI^{95}$ ) during the analysis period of 1950-2023 based on ERA5-Land reanalysis data. **c)** Observed trends (unitless decade<sup>-1</sup>) in  $FWI_{mid}$  and **d)** in the number of days per year when FWI exceeds the 95<sup>th</sup> percentile ( $FWI_{95d}$ ) relative to the reference period 1971-2000 (days decade<sup>-2</sup>) based on ERA5-Land reanalysis data. Trends are calculated using the Theil-Sen slope estimator. Areas with stippling indicate regions where the trend is not statistically significant ( $p < 0.05$ ), according to the Mann-Kendall test. The analysis covers the period 1950-2023. Areas classified as unburnable are shown in gray. Note that a single colorbar is used for both trend panels, although the units differ.



**Figure 6.** Patterns of frequency-based extreme fire weather metrics and their projected relative changes in Europe based on the ensemble median of 33 bias-adjusted EURO-CORDEX models. The left panels show the fire weather season length ( $FWI_{fwsl}$ ) and the right panels show the number of days per year exceeding the 95<sup>th</sup> percentile FWI ( $FWI_{95d}$ ) relative to the reference period (1971-2000). **a, b)** Reference period patterns with a separate colorbar shown below, **c, d)** changes relative to the reference period at +2 °C GWL and **e, f)** changes relative to the reference period at +3 °C GWL. Note that the reference period is already 0.46 °C warmer than the preindustrial period. Areas without stippling indicate regions where at least 66% of the models project statistically significant changes according to a t-test ( $p < 0.05$ ) and agree on the sign of change. Areas classified as unburnable are shown in gray.

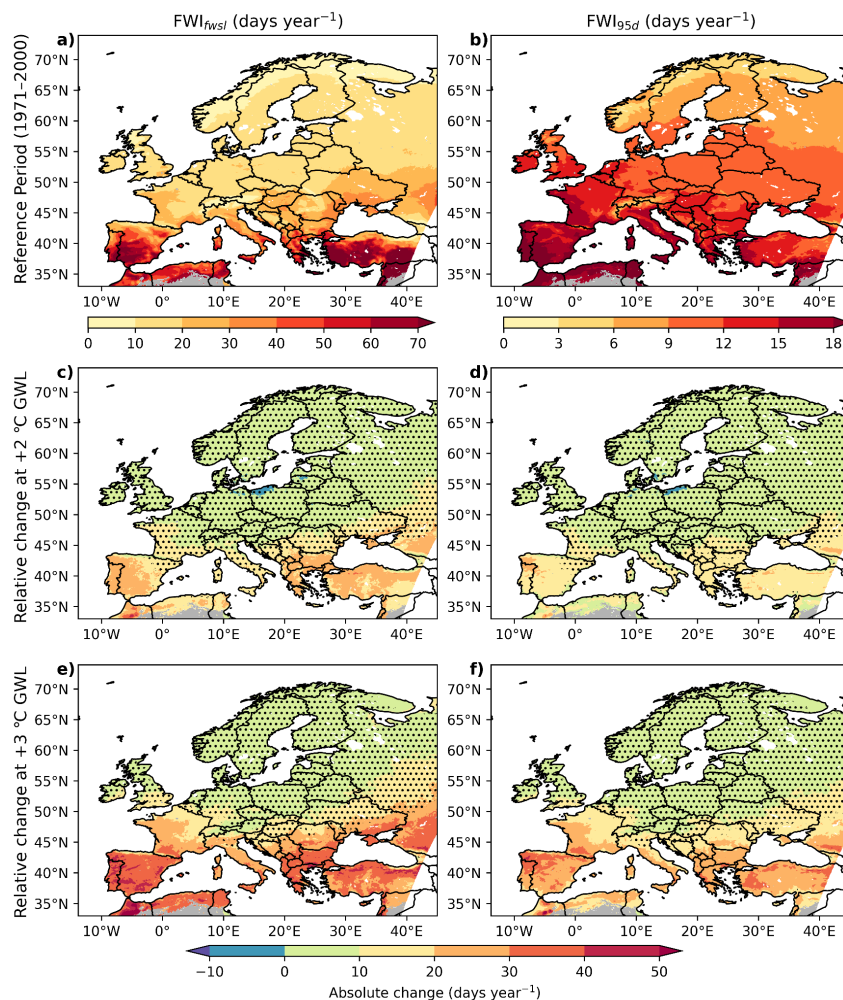


**Figure 7.** Patterns of magnitude-based extreme fire weather metrics and their projected relative changes in Europe based on the ensemble median of 33 bias-adjusted EURO-CORDEX models. The left panels show the fire weather season length ( $FWI_{fs}$ ) and the right panels show the number of days per year exceeding the 95<sup>th</sup> percentile FWI ( $FWI_{max}$ ) relative to the reference period (1971-2000). **a, b)** Reference period patterns with a separate colorbar shown below, **c, d)** changes relative to the reference period at +2 °C GWL and **e, f)** changes relative to the reference period at +3 °C GWL. Note that the reference period is already 0.46 °C warmer than the preindustrial period. Areas without stippling indicate regions where at least 66% of the models project statistically significant changes according to a t-test ( $p < 0.05$ ) and agree on the sign of change. Areas classified as unburnable are shown in gray.

5. While Figures 6 and 7 present relative changes, I recommend including the absolute changes for key results, at least in the Supplementary Materials. In high-latitude regions (e.g., Northern Europe), where baseline values are inherently low, a large relative increase does not necessarily translate into a significant rise in actual wildfire risk.

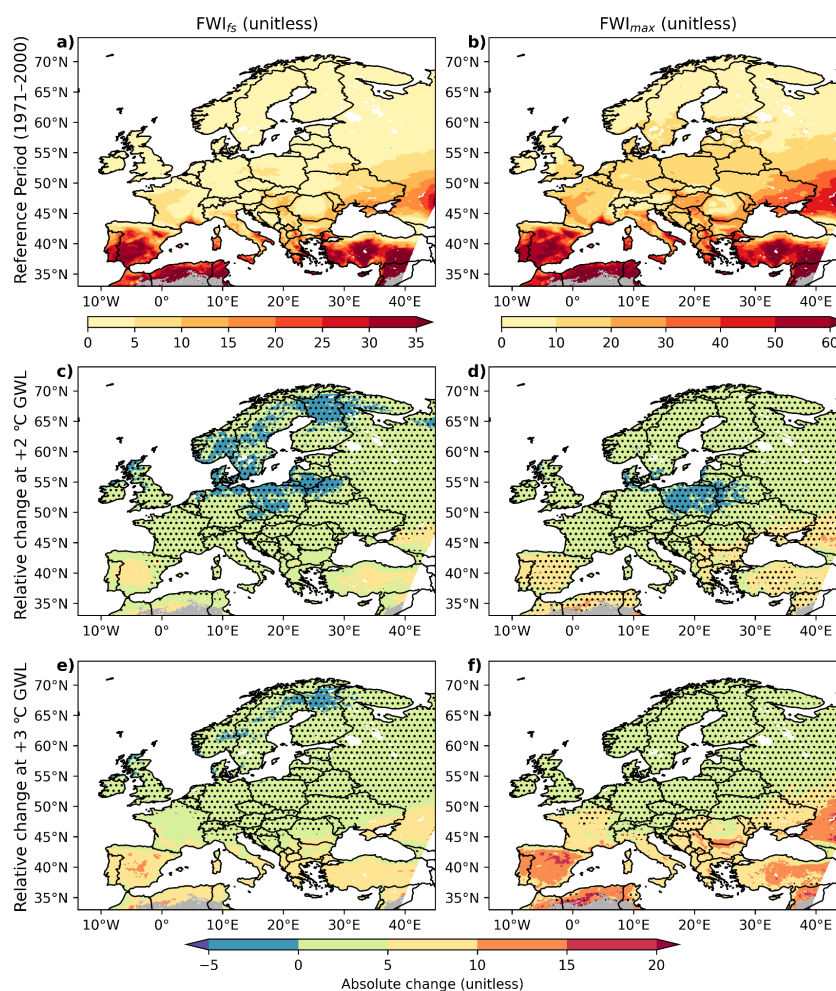
Thank you for your comment. In order to address your suggestion and Reviewer #1's last comment, we propose to include two figures in the Supplementary Materials for the absolute changes (please see below). We will also include the following sentence in the captions of Figures 6 and 7:

*“Absolute changes are shown in Figure D11 to facilitate interpretation in regions where relative changes may be amplified by climatologically low baseline values.”*



**Figure D11.** Patterns of frequency-based extreme fire weather metrics and their projected absolute changes in Europe based on the ensemble median of 33 bias-adjusted EURO-CORDEX models. The left panels show the fire weather season length (FWI<sub>fwsf</sub>) and the right panels show the number of days per year exceeding the 95<sup>th</sup> percentile FWI (FWI<sub>95d</sub>) relative to the

reference period (1971-2000). **a, b)** Reference period patterns with a separate colorbar shown below, **c, d)** absolute changes relative to the reference period at +2 °C GWL and **e, f)** absolute changes relative to the reference period at +3 °C GWL. Note that the reference period is already 0.46 °C warmer than the preindustrial period. Areas without stippling indicate regions where at least 66% of the models project statistically significant changes according to a t-test ( $p < 0.05$ ) and agree on the sign of change. Areas classified as unburnable are shown in gray.



**Figure D12.** Patterns of magnitude-based extreme fire weather metrics and their projected absolute changes in Europe based on the ensemble median of 33 bias-adjusted EURO-CORDEX models. The left panels show the fire weather season length ( $FWI_{fs}$ ) and the right panels show the number of days per year exceeding the 95<sup>th</sup> percentile FWI ( $FWI_{max}$ ) relative to the reference period (1971-2000). **a, b)** Reference period patterns with a separate colorbar shown below, **c, d)** absolute changes relative to the reference period at +2 °C GWL and **e, f)** absolute changes relative to the reference period at +3 °C GWL. Note that the reference period is already 0.46 °C warmer than the preindustrial period. Areas without stippling indicate regions where at least 66% of the models project statistically significant changes according to a t-test ( $p < 0.05$ ) and agree on the sign of change. Areas classified as unburnable are shown in gray.

*Minor Comments:*

*1. Caption of Figure 3 : "Com-4" should be "Comb-4".*

Thank you for noticing this. We will correct the typo.

**References (only those that were not included in the submitted version)**

Matteo, A., Garnés-Morales, G., Moreno, A., Ribeiro, A. F. S., Azorin-Molina, C., Bedia, J., Di Giuseppe, F., Dunn, R. J. H., Herrera, S., Provenzale, A., Quilcaille, Y., Torres-Vázquez, M. , and Turco, M.: Challenges in assessing Fire Weather changes in a warming climate, *npj Climate and Atmospheric Science*, 8, 284, <https://doi.org/10.1038/s41612-025-01163-0>, 2025.