Author Responses to Referee RC1 (Minor Revision)

Manuscript: EGUSPHERE-2026-136

All page and line numbers refer to the latest submitted manuscript after Major Revision.

Review of Zhu et al. "Quantifying the current and future likelihood of the 2022 extreme wildfire weather conditions in France with anthropogenic climate change"

Summary

Zhu et al. presented an extensive revision of their manuscript in which they addressed all my previous concerns. Besides a few technical corrections, I would advise the editor to accept the manuscript for publication in NHESS.

We sincerely thank the reviewer for their careful evaluation of our revised manuscript and for acknowledging that the revision has addressed the previous concerns. We are grateful for the reviewer's positive recommendation for publication in NHESS. We have also carefully considered the remaining technical corrections and revised the manuscript accordingly.

Minor comments

L11-L13 "we examined how ACC has modified and will modify the probability of such fire weather conditions between 1950 and 2100. We found that by 2022, ACC at least doubled the likelihood of those FWI conditions, and will make them, by the end of the century" compared to 1950? Please make it clear in the Abstract what the baseline is for the doubling by 2022.

Response: We agree that the original wording could be misread as implying a comparison between 2022 and 1950. This was not our intention. In our attribution analysis, the reference is not a historical baseline period but the NAT-only counterfactual climate, i.e., a climate with natural forcings only. The risk ratio is defined as p_{ALL} / p_{NAT}, where ALL includes both anthropogenic and natural forcings and NAT includes natural forcings only. We have revised the Abstract accordingly. In addition, following the reviewers' comments, we have adjusted the wording to clarify that the reported increase refers to the multi-model median estimate.

Revised text p. 1, L10-14: "Using climate simulations from the Coupled Model Intercomparison Project Phase 6 (CMIP6), we examined how ACC has modified and will modify the probability of such fire weather conditions over the period 1950–2100. The multi-model median suggests that, in 2022, FWI conditions of the same exceedance probability as the 2022 wildfire-related conditions were approximately 2 to 10 times more likely under anthropogenic and natural forcings combined than under the natural-forcing-only counterfactual climate, depending on the spatiotemporal scale, with considerable inter-model spread. By the end of the century under the Shared Socioeconomic Pathway 2-4.5 (SSP2-4.5), these same-rarity FWI conditions are projected to become roughly one to two orders of magnitude more probable, with still large inter-model uncertainty."

L28 "in Landiras burned over 12,552 hectares over 14 days" two times "over"

Response: We have modified to avoid the repetition.

Revised text p. 2, L28: "in Landiras burned 12,552 hectares over 14 days"

L61 "more or less likely due to human-induced climate change in 2022" Again, please specify the baseline (reference) period associated with the statement.

Response: We agree that the wording in the Introduction was also ambiguous. As clarified above, the attribution statement refers to a comparison between the ALL-forcing climate and the NAT-only counterfactual climate for 2022, rather than to a comparison with the 1959–2023 observational period or any other historical baseline. We have revised this sentence accordingly to explicitly state the reference climate.

Revised text p. 3, L60-62: "...and (iv) estimate the extent to which those fire weather conditions have become, in 2022, more or less likely under anthropogenic-plus-natural forcings than under the natural-forcing-only climate, and how this contrast is likely to further increase in the future."

L332 "during those wildfires exceed what would be expected in a natural climate" also here, please specify the baseline (reference) period associated with the statement.

Response: Consistent with the changes made in the Abstract and Introduction, we have revised this sentence.

Revised text p. 17, L331-334: "Finally, attribution metrics indicated that FWI conditions of comparable rarity to those observed during the wildfires were substantially less likely under the natural-forcing-only climate, and that anthropogenic climate change made those conditions approximately 2 to 10 times more likely in 2022. Under a moderate-emissions pathway, those same-rarity FWI conditions are projected to become roughly one to two orders of magnitude more probable by the end of the century, although substantial uncertainty remains across and within models."

Author Responses to Referee RC2 (Minor Revision)

Summary

I appreciate the revisions/responses and find the manuscript to be improved. I have two follow-up comments below.

We thank the reviewer for their constructive assessment of our revised manuscript and are pleased that the revisions and responses have improved the manuscript. We also appreciate the reviewer's additional follow-up comments, which have helped us further refine the paper.

I would recommend a check of the wording in the abstract, in particular, to be careful about how the reported RRs may be quoted and interpreted. Phrasing in the abstract of "at least doubled" implies a consideration of the uncertainty range, but to my understanding this is just considering the best estimate and the spread of this best estimate across scales. The multi-model uncertainty range is not greater than 1, though this is somewhat influenced by one model that is lower than the other three. Given the small sample sizes and small spatial scales, it is not surprising that the uncertainty ranges are large and that the attribution is not always significant. But I think some of the phrasing here implies overconfidence. I also find the "at least 10-100" phrasing to imply more precision than was perhaps intended (looking at the figures, it was not obvious how this exact range was extracted).

Response: We agree that the original wording in the Abstract could be improved. We indeed did not sufficiently distinguish between multi-model median best estimates and the broader uncertainty range across models and bootstrap intervals. We have revised the Abstract accordingly. The wording 'at least doubled' has been replaced and 'at least 10–100 times more probable' has been rephrased as an approximate order-of-magnitude projection with an explicit acknowledgment of large inter-model uncertainty. Corresponding adjustments have been made in the Conclusions to ensure consistency throughout the manuscript.

Revised text p. 1, L12-14: "The multi-model median suggests that, in 2022, FWI conditions of the same exceedance probability as the 2022 wildfire-related conditions were approximately 2 to 10 times more likely under anthropogenic and natural forcings combined than under the natural-forcing-only counterfactual climate, depending on the spatiotemporal scale, with considerable inter-model spread. By the end of the century under the Shared Socioeconomic Pathway 2-4.5 (SSP2-4.5), these same-rarity FWI conditions are projected to become roughly one to two orders of magnitude more probable, with still large inter-model uncertainty."

Revised text p. 17, L333-334: "Under a moderate-emissions pathway, those same-rarity FWI conditions are projected to become roughly one to two orders of magnitude more probable by the end of the century, although substantial uncertainty remains across and within models."

Revised text p. 15, L276-280: "This increase is evident across temporal and spatial scales in the multi-model median, although its magnitude and timing differ substantially among models. Likewise, the timing at which the RR exceeds 1 and remains above that threshold is broadly consistent with the emergence of anthropogenic signals in simulated fire weather indices since the late twentieth century in southern Europe (Abatzoglou et al., 2019). Our study suggests that the multi-model median probability of such conditions increased by approximately 2–10 times in 2022 and is projected to increase by roughly one to two orders of magnitude by the end of the twenty-first century under a medium-level radiative forcing scenario."

Revised text p. 12, L227: "The multi-model median RR lies between ≈ 2 and 10 in 2022 across the four scales."

The description added to the text and caption has helped clarify the intent of Figure 6. However, I am still not understanding the logic for applying this to Figure 7. The caption describes RRs of FWI conditions for those fires, but if p_{ALL} and thus p_{OBS} are fixed through time, then this implies considering more severe FWI conditions in the future (assuming FWI increases with time). I would suggest either changing the calculation to reflect the FWI conditions of those fires or to change the description to clarify RRs of FWI conditions of the same rarity as the 2022 fires (and then add a brief description on why this is the better question to ask).

Response: We thank the reviewer for pointing out this ambiguity. We agree that, under our current calculation, p_{ALL} is fixed to p_{OBS} by construction, so the corresponding FWI_{ALL} threshold varies with year. Therefore, Fig. 7 should not be interpreted as tracking the future probability of the same absolute FWI value observed during the 2022 wildfire. Instead, it quantifies the risk ratio for FWI levels that have the same exceedance probability—and thus comparable rarity—as the 2022 wildfire-related FWI conditions in the ALL climate of each year; the corresponding threshold is then evaluated under the NAT climate to compute p_{NAT} and RR.

We have retained this probability-based framework for two reasons. First, our attribution metric relies on within-model ALL/NAT comparisons at the native resolution of each CMIP6 model; directly applying the absolute SAFRAN-observed FWI threshold to each model would introduce model bias and resolution mismatch issues. Second, the fixed-probability approach is a commonly used framing in event-attribution studies (e.g., Philip et al., 2020) and provides a more internally consistent and numerically stable comparison under non-stationary climate conditions. A fixed threshold would become extremely rare in the ALL and NAT distributions during earlier periods, leading to numerically unstable RR estimates.

To clarify, we have made the following revisions:

(1) In Section 2.7, we added a clarifying sentence stating that FWI_{ALL} is year-dependent and represents the FWI level in the ALL climate with the same exceedance probability as the observed 2022 wildfire-related FWI, making explicit that the analysis is probability-based rather than threshold-based.

(2) In the Figure 7 caption, we changed "FWI conditions associated with Landiras-1 wildfire" to "FWI conditions of the same exceedance probability as those associated with the Landiras-1 wildfire."

(3) In the Results section, we revised the description of the future RR trend to clarify that the increasing RR reflects the growing inability of the NAT climate to produce FWI conditions that remain at the same extreme quantile in the evolving ALL climate, rather than a fixed 2022 FWI threshold becoming more probable in the future.

Revised text p. 7, L150-154: "For the GEV distribution fitted to the ALL-scenario simulated annual maxima of the MA-FWI time series, we inverted its cumulative distribution function (CDF), $F_{ALL}(x)$, for each year to find the FWI level in the ALL scenario such that $1-F_{ALL}(FWI_{ALL}) = p_{OBS}$. We then applied this year-specific threshold FWI_{ALL} to the GEV distribution fitted to the NAT-scenario simulated annual maxima of the MA-FWI time series – using its CDF $F_{NAT}(x)$ – to compute $p_{NAT} = 1 - F_{NAT}(FWI_{ALL})$. Note that FWI_{ALL} is therefore year-dependent and represents the FWI level in the ALL climate with the same exceedance probability as the observed 2022 wildfire-related FWI; the analysis is probability-based rather than based on a fixed absolute FWI threshold. Because the attribution metric relies on the within-model ratio between p_{ALL} and p_{NAT}, no spatial downscaling was required."

Revised caption (Fig. 7): "Figure 7. Risk ratio (RR) of FWI conditions of the same exceedance probability as those associated with the Landiras-1 wildfire, from four CMIP6 models (IPSL-CM6A-LR, CanESM5, MIROC6, NorESM2-LM) and the multi-model median (black) across different scales: (a) regional over 30-day window; (b) regional over 14-day event duration; (c) local over 30-day window; (d) local over 14-day event duration. Shaded envelopes denote 90 % parametric-bootstrap confidence intervals for individual models. All panels use a logarithmic y-axis. The horizontal dashed line indicates RR = 1 (no anthropogenic influence)."

Revised text p. 12, L227-228: "In the latter half of the century, this ratio reaches the range of one to two orders of magnitude, reflecting the growing inability of the NAT climate to produce FWI conditions that remain at the same extreme quantile in the warming ALL climate."

Author Responses to Editor

Please ensure that the colour schemes used in your maps and charts allow readers with colour vision deficiencies to correctly interpret your findings. Please check your figures using the Coblis – Color Blindness Simulator (https://www.color-blindness.com/coblis-color-blindness-simulator/) and revise the colour schemes accordingly with the next file upload request. => Figs. 4, 5, 7, 8, S2, S3, and S6.

Response: We agree with the editor's comment. We have checked Figs. 4, 5, 7, 8, S2, S3, and S6 using the Coblis Color Blindness Simulator and have revised the colour schemes accordingly to improve readability for readers with colour vision deficiencies. We also revised the colour scheme in Fig. 1, as it appeared to present a similar potential issue.

Revised figure (Fig. 1):

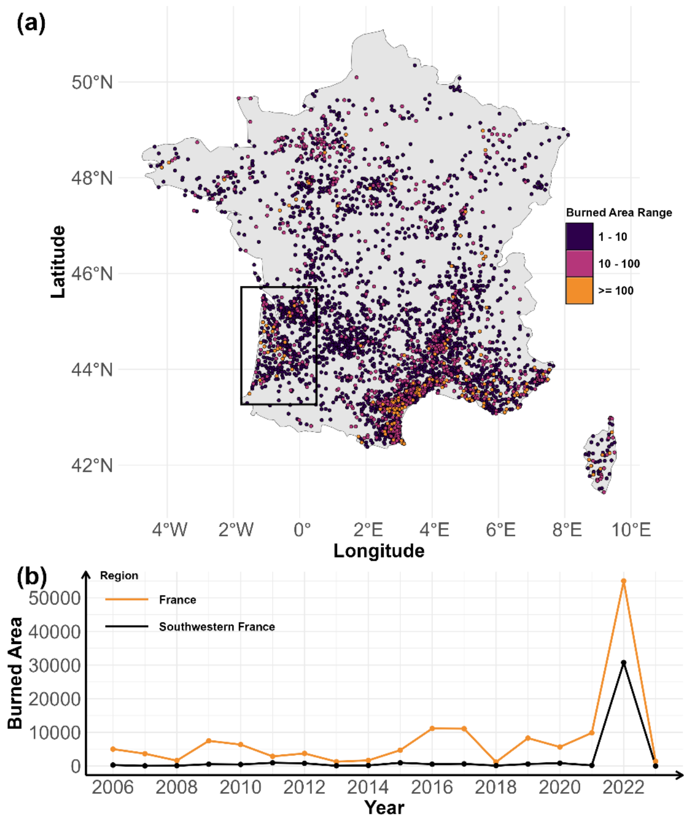

Figure 1. (a) Wildfires ⩾ 1 ha recorded in the BDIFF database from 2006 to 2023. Color denotes burned area (BA) classes and the black box delineates the southwestern France region (~ 4.9 × 10^4 km^2). (b) Total burned area during the warm fire season (May–September) for France (orange line) and the southwestern region (black line).

Revised figure (Fig. 4):

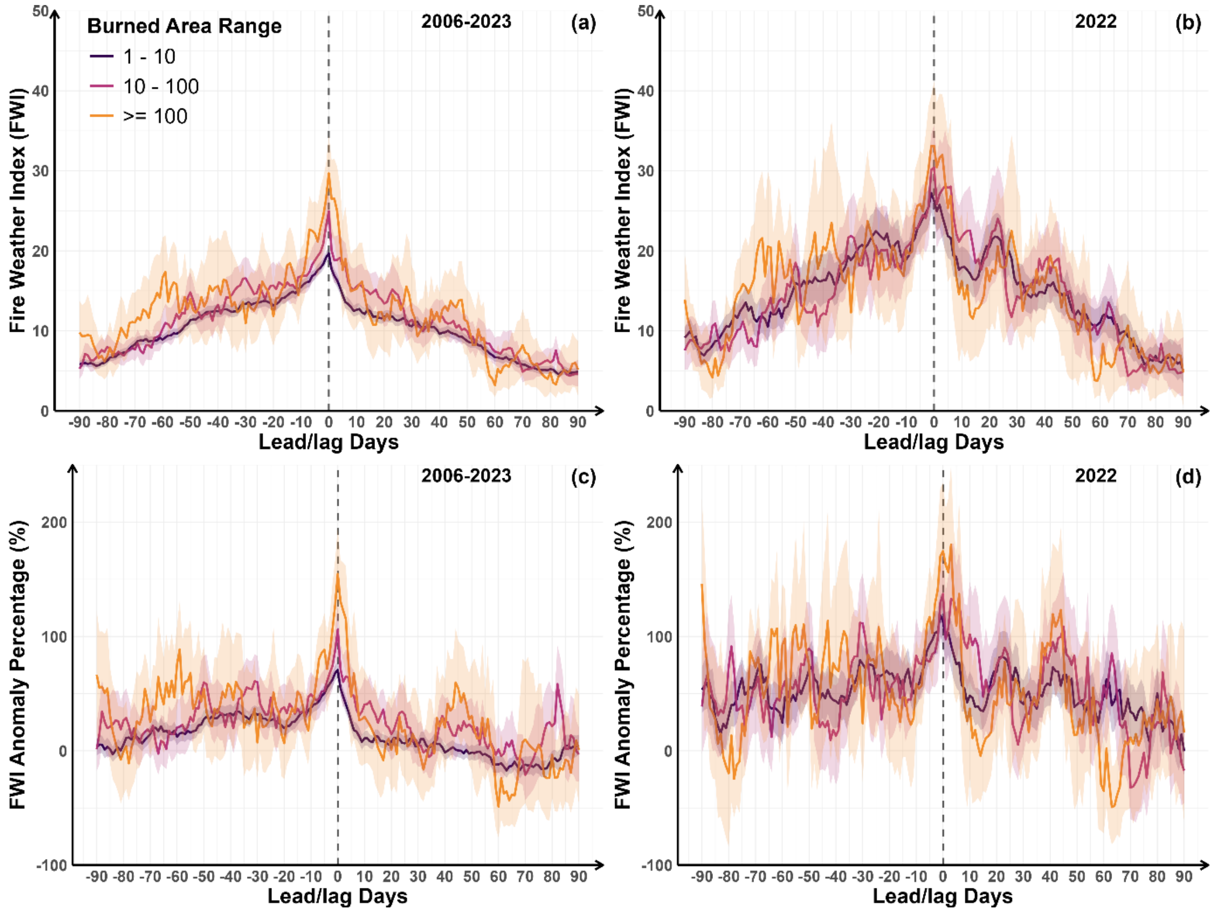

Figure 4. Lead–lag time series of FWI (a,b) and percent anomalies (c,d) relative to wildfire dates for three fire size classes over 2006–2023 (a,c) and 2022 only (b,d) in SW France. Anomalies were computed relative to the long-term (1959–2023) mean local seasonal cycle. Curves denote the three burned-area classes: BA = 1–10 ha, BA = 10–100 ha, and BA ≥ 100 ha, as indicated in the legend. Shaded bands indicate 95 % bootstrap confidence intervals. The x-axis shows lead/lag days from −90 to +90 relative to the wildfire starting day (day 0; vertical dashed line).

Revised figure (Fig. 5):

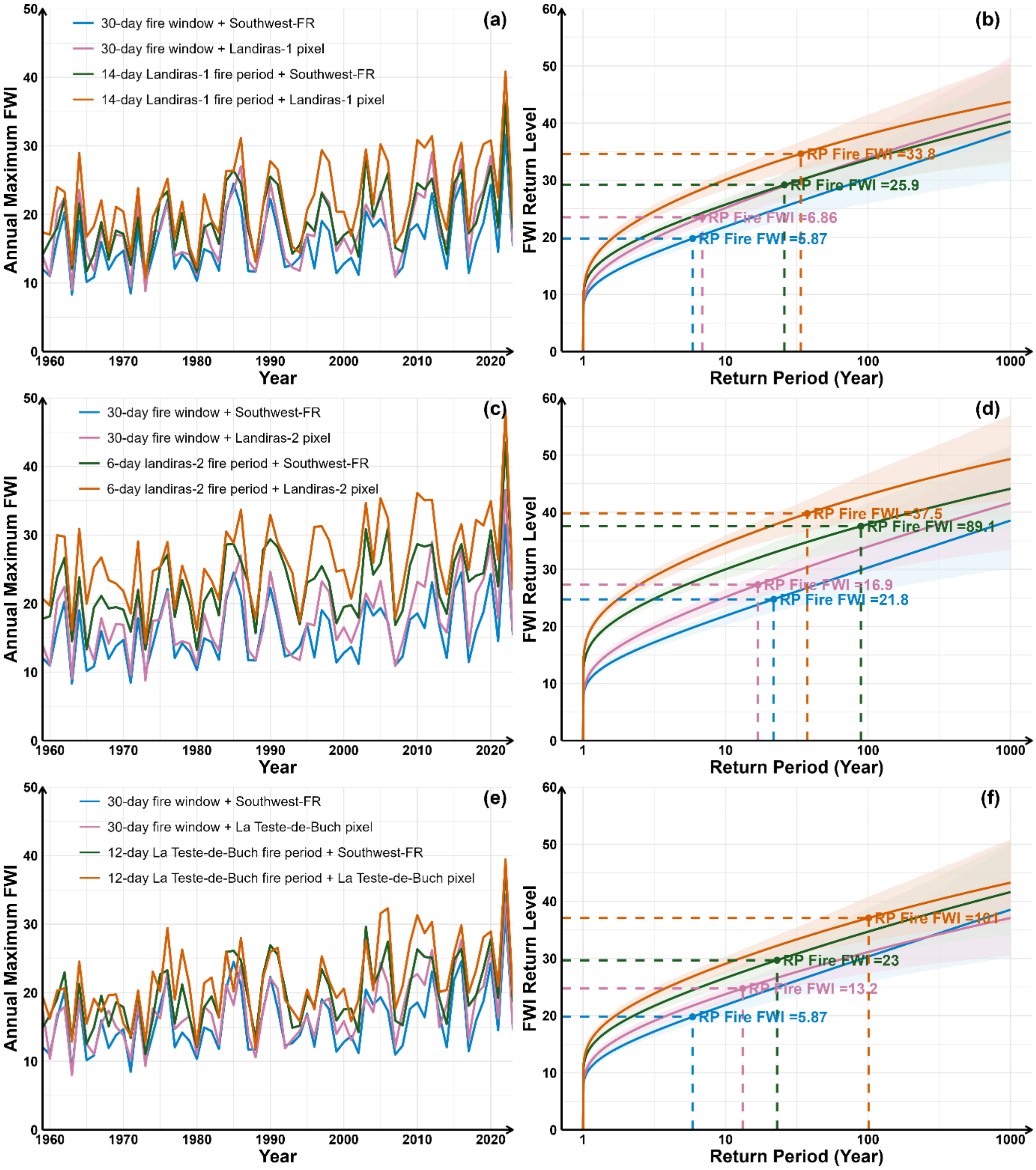

Figure 5. Annual maxima of moving-averaged FWI at multiple spatiotemporal scales (left) and return-levels (right) associated with Landiras-1 (a-b), Landiras-2 (c-d), and La Teste-de-Buch (e-f). Return levels on the right (logarithmic x-axis from 1 to 10^3 years) were estimated by fitting a GEV distribution to the annual-maximum moving-averaged FWI. Shaded envelopes indicate 80 % parametric-bootstrap confidence intervals. Dashed lines indicate the estimated return periods of the FWI level observed for each wildfire.

Revised figure (Fig. 7):

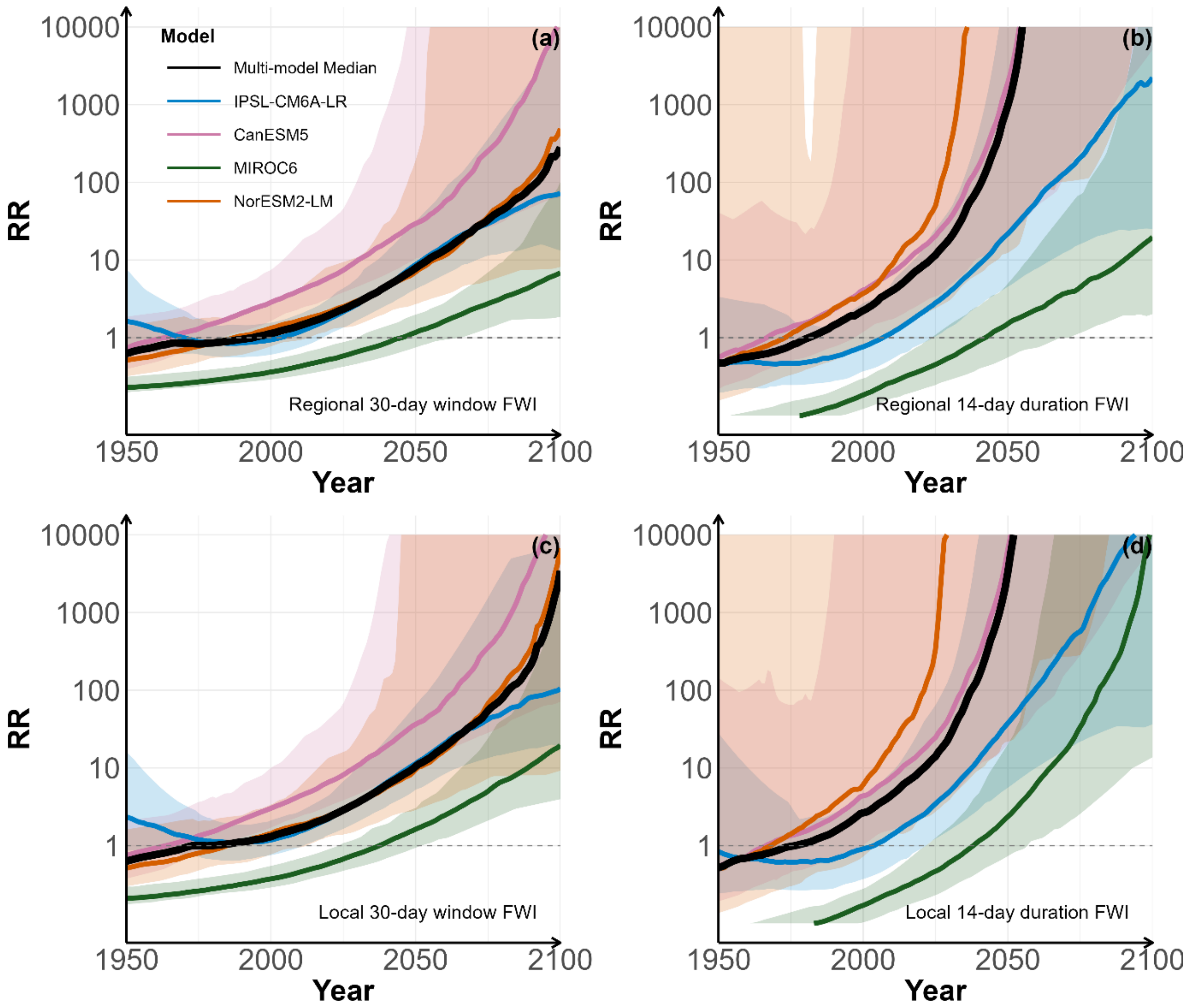

Figure 7. Risk ratio (RR) of FWI conditions of the same exceedance probability as those associated with the Landiras-1 wildfire, from four CMIP6 models (IPSL-CM6A-LR, CanESM5, MIROC6, NorESM2-LM) and the multi-model median (black) across different scales: (a) regional over 30-day window; (b) regional over 14-day event duration; (c) local over 30-day window; (d) local over 14-day event duration. Shaded envelopes denote 90 % parametric-bootstrap confidence intervals for individual models. All panels use a logarithmic y-axis. The horizontal dashed line indicates RR = 1 (no anthropogenic influence).

Revised figure (Fig. 8):

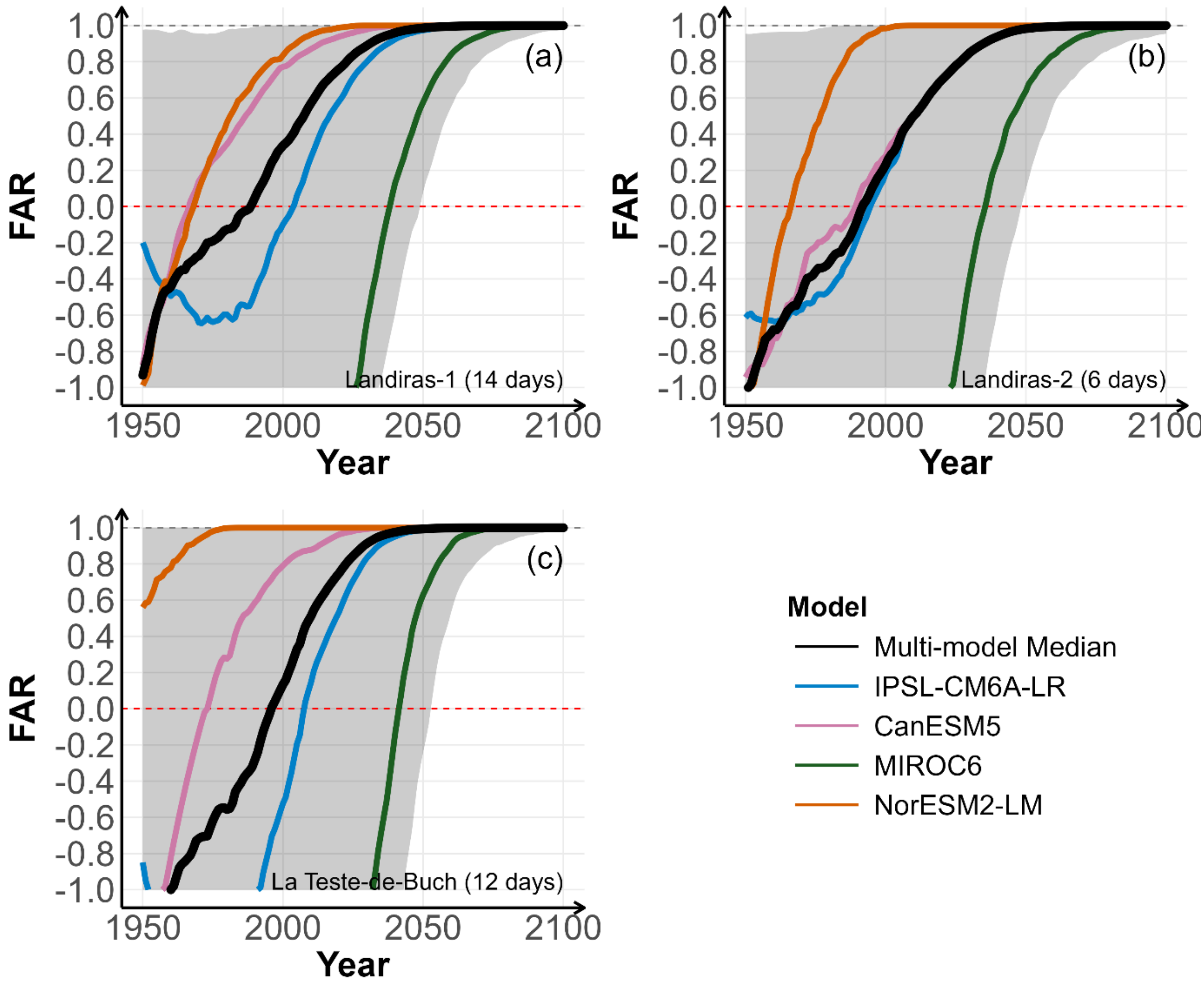

Figure 8. Fraction of attributable risk (FAR, 1 – 1/RR) using the local FWI over the event-duration window for (a) Landiras-1 (14-day), (b) Landiras-2 (6-day), and (c) La Teste-de-Buch (12-day). The black curve shows the multi-model median across models. The y-axis is truncated to [−1,1]; horizontal dashed lines indicate FAR = 0 (no anthropogenic contribution) and FAR = 1 (fully attributable). The shaded envelope indicates the 90 % pooled ensemble uncertainty range for the multi-model median, obtained by pooling the bootstrap replicates from the four models and taking the 5th and 95th percentiles of the pooled distribution. This approach captures both within-model sampling uncertainty and inter-model spread.

Revised figure (Fig. S2):

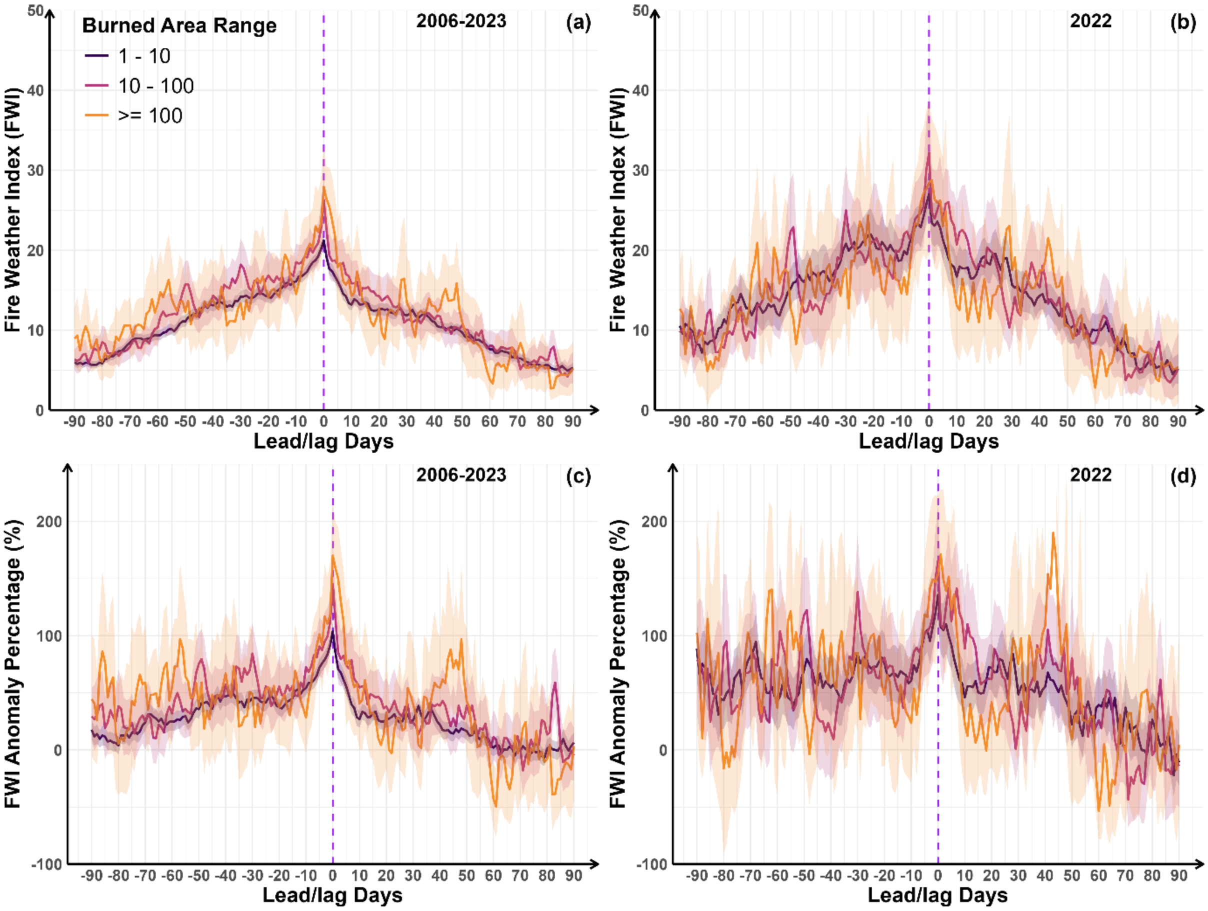

Figure S2. Same as Fig. 4 except that the Fire Weather Index (FWI) was derived from the ERA5 dataset

Revised figure (Fig. S3):

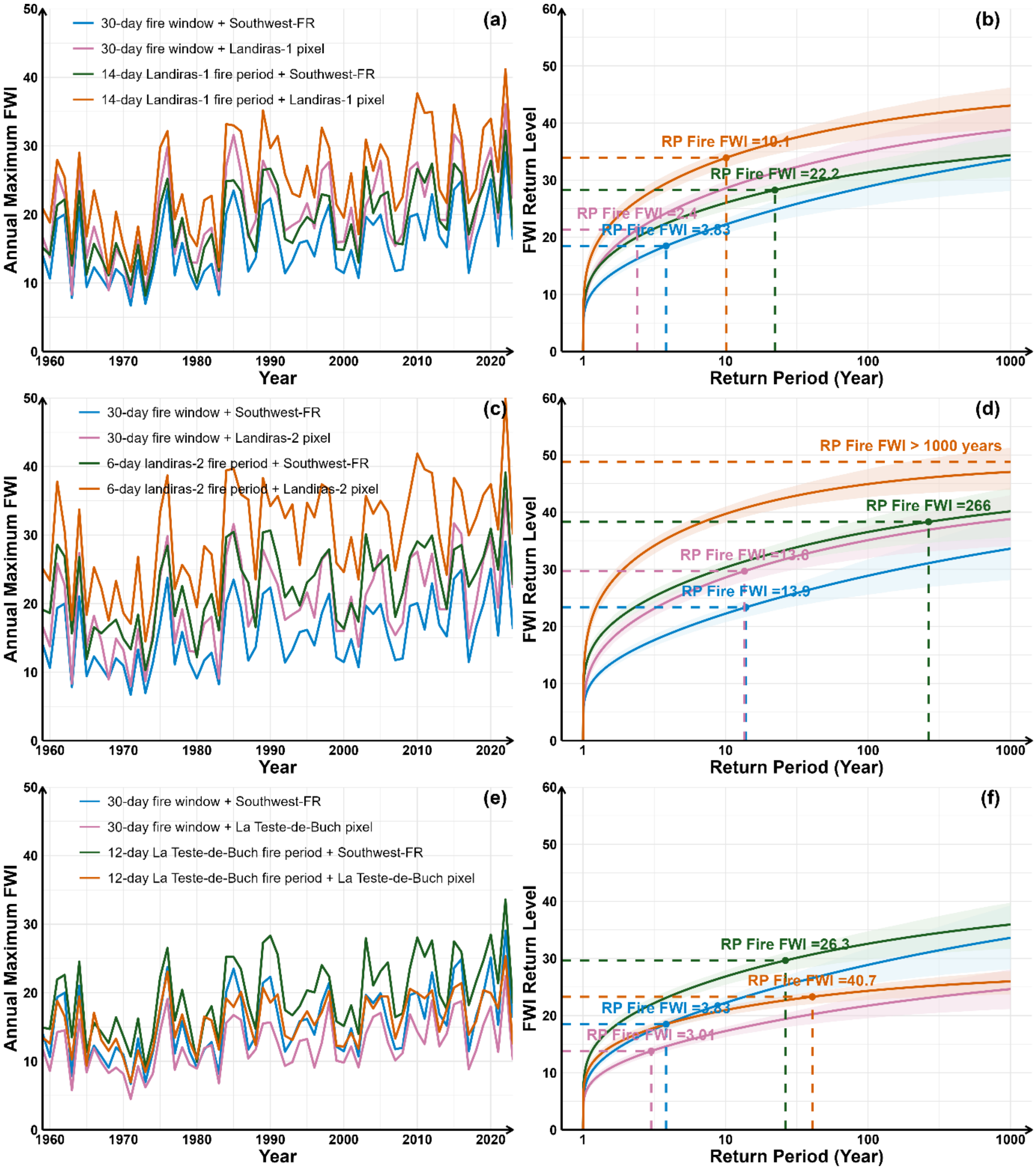

Figure S3. Same as Fig. 5 except that the Fire Weather Index (FWI) was derived from the ERA5 dataset.

Revised figure (Fig. S6):

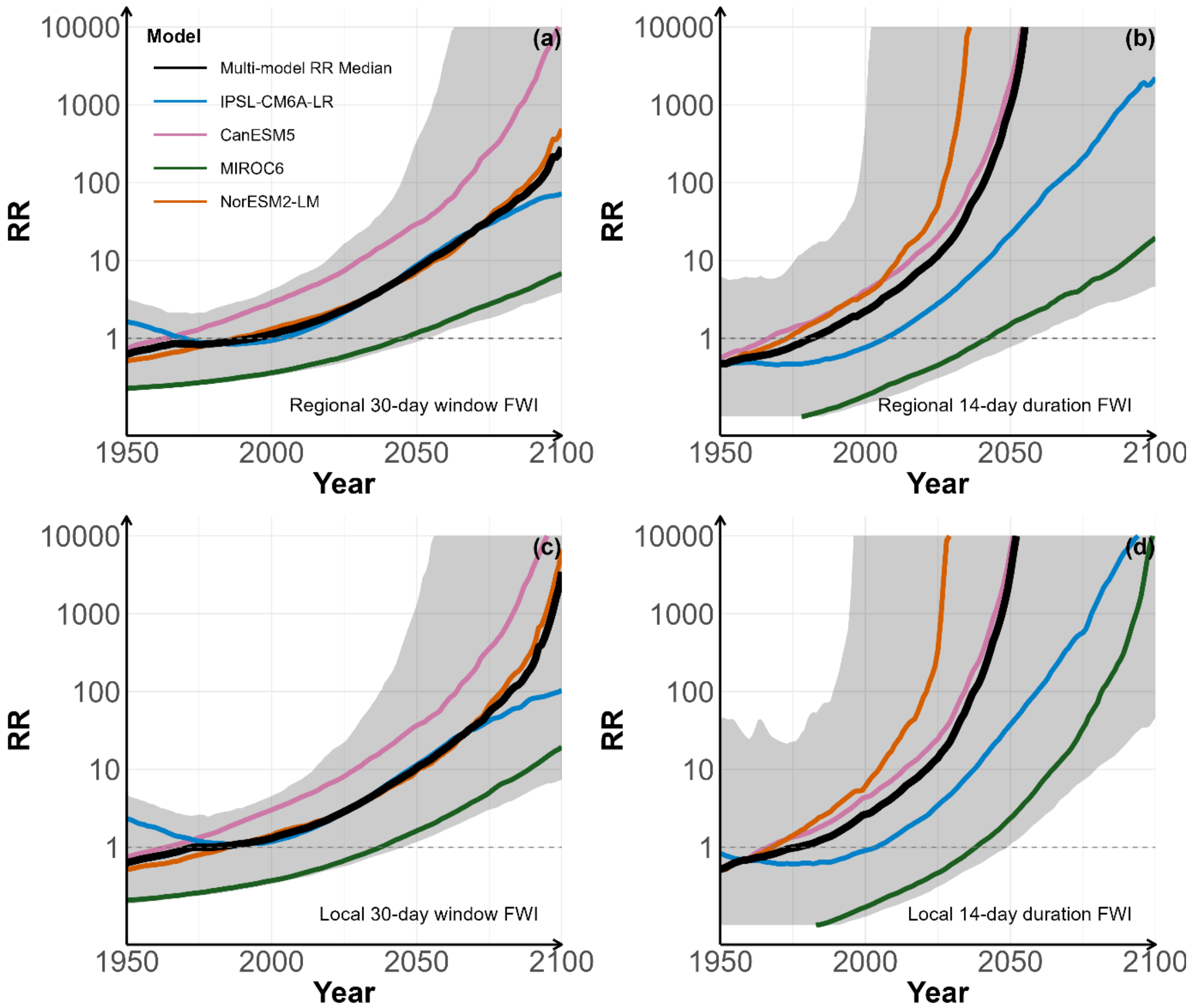

Figure S6. Same as Fig. 7 except that the uncertainty range was computed for the multi-model median RR. For each year, the grey shaded envelope denotes the corresponding 5th–95th percentile range of the pooled bootstrap replicates from four models (4×100 = 400 samples). This pooled range reflects both within-model sampling uncertainty and inter-model spread.