

Author Responses to Referee RC1

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All page and line numbers refer to the originally submitted manuscript.

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

Summary

Zhu et al. present an analysis of the climatic conditions surrounding the extreme 2022 wildfire season in the Southwest of France. The authors use a country-level fire dataset, two different climate re-analysis derived fire weather index (FWI) datasets and CMIP6 model output to quantify how exceptional the 2022 climatic conditions were and how anthropogenic climate change (ACC) has made (and will make) these conditions more likely. The authors find that with increasing spatial-temporal resolution of the FWI, the signal becomes stronger and return period lengths increase by decades, suggesting that aggregating FWI over longer time periods (compared to the time of burning) and larger spatial scales will average out the FWI signal. Furthermore, the climate attribution analysis indicates that already ACC made the FWI conditions during the 2022 fires more than twice as likely compared to the “only natural forcings” run and that by the end of the century these conditions will be 10 to 100 times more likely to occur.

The study presents a nice concise analysis well within the scope of NHESS that is relevant for local stakeholders in the France as well as those in the wider European context. I do not have any concerns with the methods, assumptions or the interpretation of the results. The methodology is not entirely novel as studies of FWI on large spatial scales are common and attribution studies on extreme fire years have also been published before. However, I still think the study presents a scientific advance on the local and regional scale. I have a few major and minor comments which are listed below.

[We thank the reviewer for this positive and very comprehensive review of our work. We appreciate all the suggestions and tried to clarify as much as possible the text, where needed.](#)

General comments

One of the general comments is that there is almost no mention of ignition sources in the manuscript (except a little in the discussion about the ignition of the Landiras-2 fire from peat smoldering). It is not technically the scope of the paper to focus on ignitions because it focuses on the fire weather conditions surrounding these fires, if there are no ignitions sources there will be no fire. It would increase the novelty of the paper dramatically if these were taken into account in the analysis, even if it was a very simple approximation. For example, by making “ignition probability” a function of FWI.

[We agree with the reviewer’s suggestion that the ignition source is indeed a crucial component of wildfire activity and would definitely add to the scientific literature.](#)

However, as the reviewer also pointed out, ignition (whether anthropogenic or natural) is not the main focus of our study. Also, Ganteaume and Guerra (2018) showed that the fire cause is known in only 34% of cases. Nevertheless, we intend to examine this research question in a future study by using the ignition-related functionalities of the Firelihood model (Pimont et al., 2021) that takes into account the fire weather index as well as land use and land cover variables to provide the ignition probability, regardless of the cause. We expanded the discussion section.

Inserted at p. 16, L291: “Second, our analysis does not explicitly consider ignition sources and their spatiotemporal variability. In France, approximately 95 % of ignitions are related to human activities (Ganteaume and Guerra, 2018), and the realized fire activity therefore reflects the interplay between human pressure and fire-weather conditions. As a simple approximation, the “fire start probability” could be expressed as a monotonically increasing function of the FWI (i.e., an ignition probability conditional on fire weather) using a probabilistic framework such as the Firelihood model (Pimont et al., 2021) combining FWI with land use and land cover information.”

Ganteaume, A. and Guerra, F.: Explaining the spatio-seasonal variation of fires by their causes: The case of southeastern France, *Appl. Geogr.*, 90, 69–81, <https://doi.org/10.1016/j.apgeog.2017.11.012>, 2018.

A second major comment concerns the readability of the paper. Generally, the manuscript is written in a very technical style that does not help with reaching a wider readership. If a single sentence in the results contains three abbreviations “FWI”, “PC1” and “EOF” that were explained somewhere in the methods, you will lose possibly interested readers. The Conclusions section (5) was surprisingly accessible and I would urge the authors to use the writing style of this section and apply it to the entire manuscript, especially the Abstract and Results sections. It would also help if concepts like PC1 and EOF are shortly explained somewhere in the results, just to inform the reader why these metrics are important and what we can learn from them. The manuscript would benefit from a thorough language revision. I have provided several suggestions in the specific comments, although these are not exhaustive.

We agree with the reviewer’s comments. The frequent use of technical terms (including abbreviations) may make it difficult for readers. We revised the text accordingly where needed and limited as much as possible the use of acronyms in the text, figures and captions to improve readability. We hope the text reads better now.

Specific comments

Title: “extreme wildfires weather”, either pick “extreme wildfires in France” or “extreme wildfire weather conditions in France”. Both apply to the study.

Response: The title has been revised as “Quantifying the current and future likelihood of the 2022 extreme wildfire weather conditions in France with anthropogenic climate change”

L7-10 ‘Our results show that the extremeness of FWI conditions generally increases with the spatiotemporal resolution, with the associated return periods increasing from

6 to 34 years, from 22 to 89 years, and from 6 to 101 years when moving from the coarsest to the finest spatiotemporal scale for the Landiras-1, Landiras-2, and La Teste-de-Buch wildfires, respectively. This sentence is not clear. How does resolution relate to extremeness?

Response: We agree that the phrasing was ambiguous. In the revised text, we explicitly defined "increasing spatiotemporal resolution" as the transition from larger to smaller grid cells and from longer to shorter time steps. Furthermore, we replaced "extremeness" by "rarity (return periods)". The revision now states that moving from coarse to fine scales reveals rarer FWI conditions (i.e., longer return periods).

Revised text: "Our results demonstrate that the rarity (return period) of FWI conditions is generally the highest at fire location and fire duration scales with the associated return periods increasing from 6 to 34 years, from 22 to 38 years, and from 6 to 101 years when moving from the coarsest to the finest spatiotemporal scale for the Landiras-1, Landiras-2, and La Teste-de-Buch wildfires, respectively".

L17 "California in 2025", far more area burned in 2020 in California compared to 2025 (>8 times more, see <https://www.fire.ca.gov/incidents/2025> and <https://www.fire.ca.gov/incidents/2020>) but more infrastructure was damaged in 2025 compared to 2020. I would at least mention 2020 in this sentence.

Response: We agree that the 2025 fires were particularly notable for their impacts on infrastructure while the 2020 California wildfire season was actually record-breaking in terms of burned area.

Revised text: "The past decade has witnessed a number of unprecedented extreme wildfires across parts of the world (e.g. Australia in 2019–2020, Canada in 2023, or California in 2020 and 2025), causing widespread impacts on societies, ecological environments, and human life."

L22 "[...] and more than 14 times larger than the average in SW France (Fig. 1b)." Please revise this sentence. Separate the stats for France and SW France or rewrite in a different way to make the distinction clearer.

Response: We agree that the distinction between national and regional statistics was ambiguous. We have revised the sentence to clearly state that the 55,000ha national total represents a 6–7 fold increase over the national mean, whereas the 14-fold refers specifically to the burned area in SW France relative to its own average.

Revised text: "Across France, more than 55,000 hectares of forests and other natural vegetation were burned (IGN and MASA, 2025)—an area 6 to 7 times larger than the national average over the preceding decade. In SW France specifically, the burned area was even more than 14 times larger than the regional average (Fig. 1b)."

L23 "a small number of wildfires" suggestion: "a small number of large wildfires"

Response: Agreed.

Revised text: “This extensive burned area resulted in substantial biomass losses in Atlantic pine forests (Vallet et al., 2023) and was largely driven by a small number of large wildfires.”

L27 “due to frequent wind shifts causing spread in multiple directions.” Might need a reference, local source?

Response: The *Office National des Forêts* wrote a short experience report regarding those wildfires. Unfortunately, the report is not available online. Also, we double checked with ERA5-Land reanalysis and found similar abrupt wind changes during those wildfires.

Revised text: “La Teste-de-Buch wildfire burned approximately 6,000 hectares over 12 days, while the second one in Landiras burned over 12,552 hectares over 14 days, due to frequent wind shifts causing spread in multiple directions (Office National des Forêts, personal communication).”

L29-30 “largest wildfire in France since the 1940s.” Please cite a reference here, what is the source?

Response: Actually, there is no reliable fire dataset in France extending so far. This assessment was based on historical archives and media reports. We clarified this in the text.

Revised text: “When combined, the Landiras-1+2 wildfire burned over 19 776 ha, which makes it the largest wildfire in France since the Landes forest fire of August 1949 (Sarrau and Yagoub, 2025).”

Sarrau, J. and Yagoub, M. M.: Documentation of Historical Forest Fires and Hazard: Case of Gironde and Les Landes, France, ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., X-G-2025, 771-778, <https://doi.org/10.5194/isprs-annals-X-G-2025-771-2025>, 2025.

L37 “contributed to reduce fuel moisture content” to a reduced fuel moisture content?

Response: Thanks. We have revised the sentence.

Revised text: “This warmer atmosphere and elevated atmospheric aridity has contributed to a reduced fuel moisture content, thereby increasing landscape flammability.”

L94 “To quantify how unusual were those conditions” please rephrase

Response: Done.

Revised text: “To quantify the departure from the climatology (i.e., normal conditions), [...]”

L168-169 “Figure 3 illustrates the first two modes of May–September FWI over the observational 1959–2023 period with the spatial distributions of EOF loadings (left panel) and their corresponding principal components (right panel).” This is a very technical description of the first results that might be improved by bringing the results

a bit more descriptive, what is the EOF loading saying and why is it relevant? And why are their PC important? Please rephrase this first section of the results to make it more accessible.

Response: We have revised the description of Figure 3 to better contextualize the findings for non-specialists. Specifically, we added brief, plain-language definitions of the EOF loadings and Principal Components (PCs), explaining their physical meaning.

Revised text: “Figure 3 illustrates the first two dominant modes of May–September FWI variability over the 1959–2023 period, with the EOF loadings (left panels) and their corresponding PCs (right panels). The loadings characterize the spatial structure of a given mode, identifying regions where FWI anomalies vary either in phase (same sign) or in opposition. The PCs reflect the temporal evolution of each mode, highlighting years during which the associated spatial structure is either amplified or dampened. In other words, the initial FWI time series in a specific grid cell featuring a high positive loading will strongly look like the associated PC. A negative loading will in turn indicate that the FWI time series varies in opposition to the PC.”

L184-185 “(note that 100% indicates FWI was twice larger than what we would expect from the average local conditions)” please rephrase, FWI is higher not larger. For example: “FWI is twice as high as expected under average local conditions.”

Response: We corrected.

Revised text: “Figure 4c shows positive anomalies 3 months before fires (note that 100% indicates that FWI was twice as high as expected from average local conditions), reaching 71 %, 106 %, and 155 % for small, medium, and large fires, respectively.”

L186 “FWI anomalies were that time stronger during” stronger anomalies? Higher or lower please but not stronger.

Response: We corrected.

Revised text: “A similar signal was observed in 2022 (Fig. 4b,d), but FWI anomalies were that time higher during the previous months and were 119 %, 137 %, and 180 % higher than mean conditions on the starting days of small, medium and large wildfires, respectively (Fig. 4d).”

L190 “indicates that annual maxima of the MA FWI” MA FWI is already maximum annual right? Please rephrase.

Response: We apologize for the ambiguity. Here, “MA” stands for “Moving Average” rather than “Maximum Annual.” The MA is calculated as the arithmetic mean of daily FWI values over a sliding temporal window. This process smooths out the raw time series and reduces short-term variability. We then selected the annual maximum value from this smoothed series for our analysis. To prevent any oversight or misunderstanding by future readers, we explicitly reiterate the full name here.

Revised text: “Figure 5 (left panels) indicates that the annual maxima of the moving-average (MA) FWI are consistently highest when computed at the finest spatiotemporal resolution (i.e., the fire-duration window at the 64 km² SAFRAN grid cell fire level). These

maxima decrease when the temporal window is lengthened to 30 days or when FWI conditions are spatially averaged over the SW France region ($\sim 4.9 \times 10^4 \text{ km}^2$).

L207 “We then computed the RR” please write in full again first time in the results: risk ratio (RR)

Response: Done.

Revised text: “We then computed the risk ratio (RR) for the Landiras-1 wildfire (Fig. 7) using all models.”

L225-226 “Indeed, we found that PC1 was strongly correlated with both temperature and rainfall anomalies over a large portion of western Europe (see Fig. S4 in the Supplement).” Interesting but this is a new result in the Discussion section, please move to results.

Response: We agree with the reviewer. We have moved this statement (including the reference to Fig. S4) from the Discussion to the Results section.

L232 “45°N (see Fig. S5 in the Supplement).” Again a new result in the Discussion, these need to be introduced in the Results.

Response: Done. We moved it to the Results section.

L241 “The unprecedented levels of FWI in 2022” please rephrase to something like: “The exceptionally high FWI values observed [...]” in the original it is not clear if it is high or low.

Response: Yes, we clarified the direction of the anomaly. The text now reads as:

Revised text: “The exceptionally high FWI values observed in 2022 in southwestern France, whether sampled locally or regionally, were conducive to a series of wildfires, with larger wildfires associated with larger FWI anomalies.”

L243 “their highest amplitude on the day or week of the wildfires” please rephrase, the day or week of ignition? As stated before, some of these larger fires burned for multiple weeks so it is important to be clear here.

Response: Right. The lead/lag plot is relative to the starting day of wildfires. We have revised the sentence to clarify that FWI peaks typically coincide (on average) with the day of ignition or the week surrounding it.

Revised text: “We found that FWI levels reached their highest amplitude on the day of ignition (or the week surrounding it), boosted by either synoptic-scale heat waves or local wind bursts, as shown in previous studies over southern Europe (Ruffault et al., 2020) and France (Barbero et al., 2020; Pimont et al., 2021).”

Figures

Figure 1 Please write burned area (BA) in full in the legend title and y-axis label in panel b. Please remove the coordinates of the bounding box in panel a, they partly overlap with the fire locations and some are unreadable.

Response: Thanks for those suggestions that improved the figure.

Revised figure (Fig. 1):

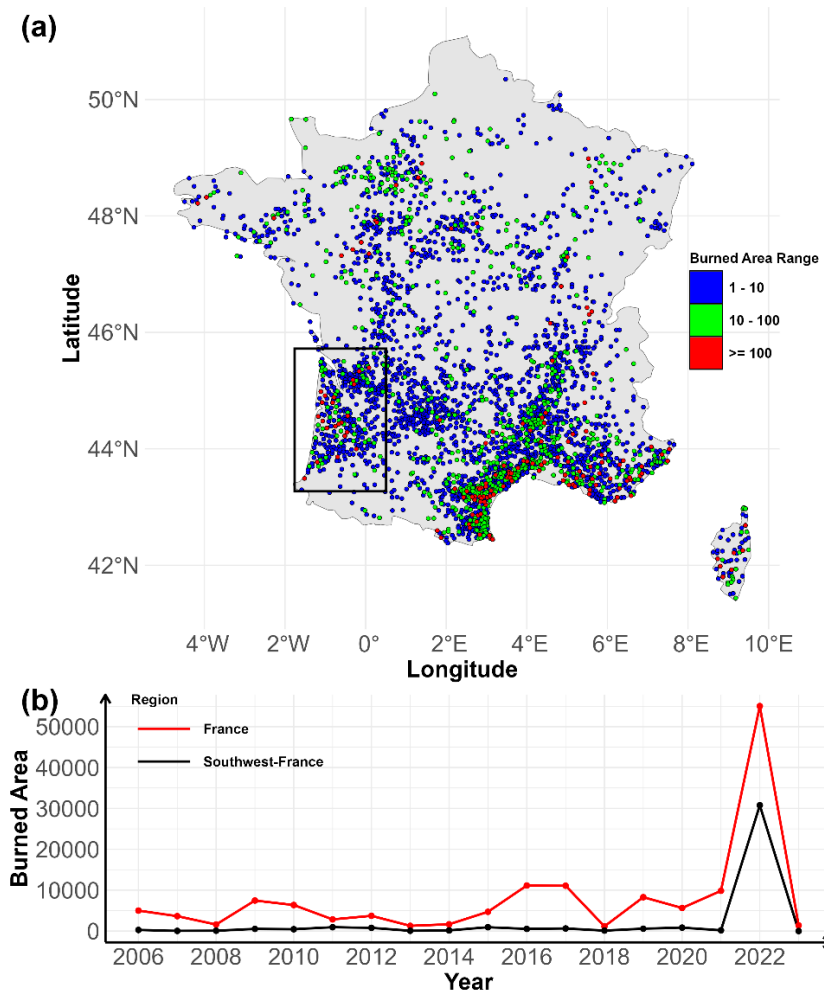


Figure 1. (a) Wildfires ≥ 1 ha recorded in the BDIFF database from 2006 to 2023. Color denotes burned area (BA) classes and the black box delineates the southwestern France region ($\sim 4.9 \times 10^4$ km²). (b) Total burned area during the warm fire season (May-September) for France (red line) and the southwestern region (black line).

Figure 3 many abbreviations in the figure make it very hard to interpret, EOF FWI PC#1, it makes it unnecessary technical. Please reconsider changing the text in this figure that a wide range of audiences immediately can grasp what the figure is showing. Also, it is totally unclear to me what a high EOF or low EOF means.

Response: We understand the suggestion but for the sake of readability, we prefer to stick with acronyms and provide the full term in the caption, otherwise the figure would

be too busy. Regarding the meaning of EOFs, we clarified this point above (see L168-169).

Revised caption (Fig. 3): Leading two modes of mean May–September Fire Weather Index (FWI) over France from 1959 to 2023. (a) First empirical orthogonal function (EOF) (variance explained 62%) with (b) its corresponding principal component (PC1) time series. (c) Second EOF (variance explained 13%) with (d) its corresponding PC2 time series.

Figure 4 Please write FWI in full on y axis (fire weather index)

Response: Done.

Revised figure (Fig. 4):

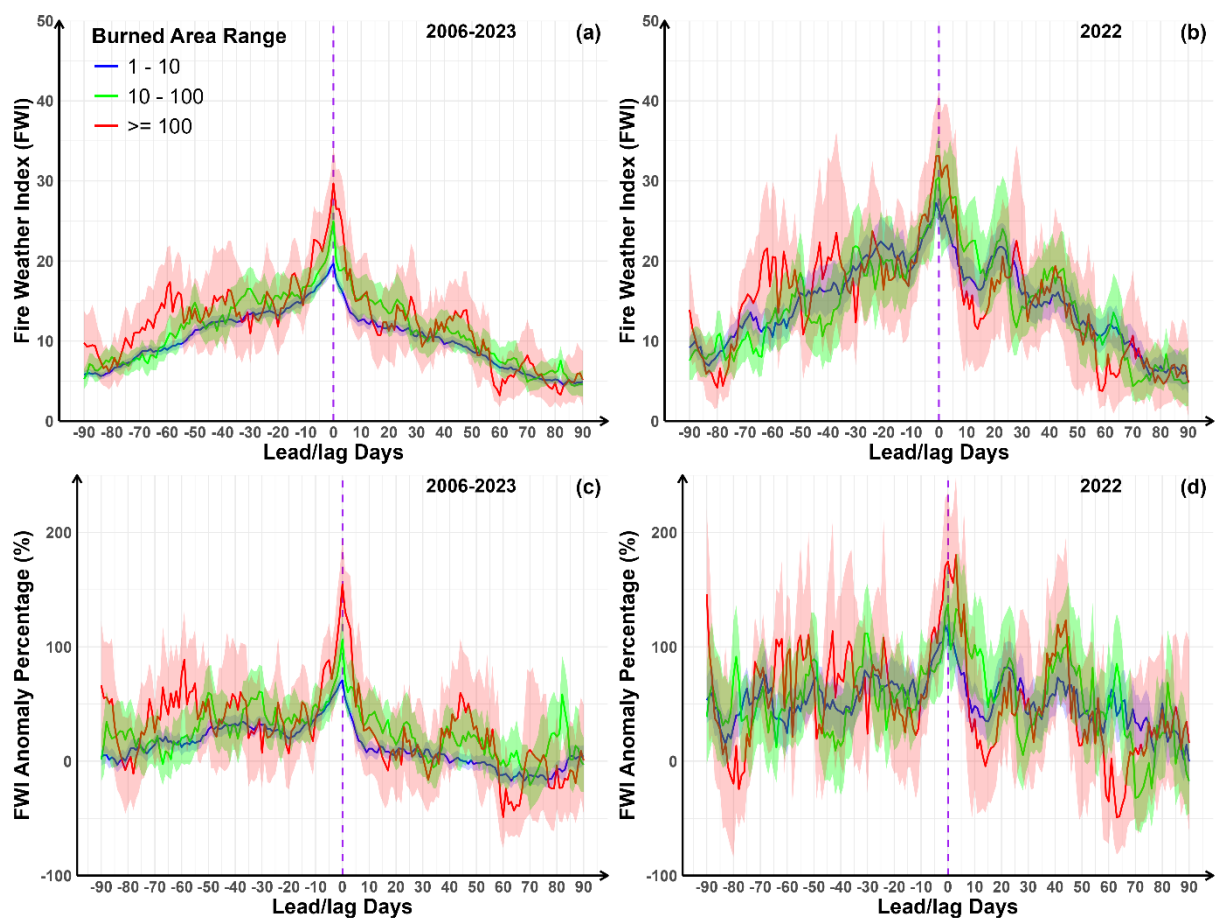


Figure 4. Lead-lag time series of FWI (a, b) and percent anomalies (c, d) relative to wildfire dates for three fire size classes over 2006–2023 (a, c) and 2022 only (b, d) in SW France. Anomalies were computed relative to the long-term (1959–2023) mean local seasonal cycle. Blue, green, and red curves denote BA = 1–10 ha, BA = 10–100 ha, and BA ≥ 100 ha, respectively. 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; purple dashed line).