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Title: Temporal variations and change of forest fire danger in Europe in 1960–2012
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Referee #1

We would like to thank the Referee for the constructive comments. The main changes made in the document based on the comments of Referees are: cross –correlations between FWI and burned area are now calculated also for Finland, sensitivity studies were taken out, thresholds for calculation of high fire danger days were changed and some of the figures were edited to be more informative and easier to read. We also have added a map depicting the trend of FWI in each grid box. As well, an error that made FWI values systematically too low was corrected. This correction has no impact on the conclusions of this study. Detailed replies to the comments are given in "Italics" after the comments given in the beginning of this document.

General comments

This manuscript aims to assess the impact of recent climate change on fire danger in Europe, along with a validation and a sensitivity analysis of the selected fire danger index. Innovative techniques for the trend and breakpoint analysis are used and the manuscript is generally suitable for publication in NHESS.

The introduction (especially the general part) is very good and the analysis was done in a sensible way. Figures and tables are adequate but may need adaptation to revised methods. The language is generally very good except for some minor points listed below. However, there are several approaches in the analysis and in its description that should be reconsidered. These include a more detailed explanation of the FWI, the division of Europe into regions, as well as the methods used for statistical analysis and the validation and sensitivity analysis. More details on this can be found in specific comments.

I suggest major revisions to the analysis and the manuscript before the paper's publication in NHESS. Please note that as I think the topic is very interesting and challenging, I have included a rather long list of suggestions for further or refined analyses. These are mere suggestions and I do not expect the authors to carry out all of them.

Specific comments

1) The division of Europe into the four regions north, west, east and south (Fig. 1, p. 6296 ll. 3-5) is very arbitrary and artificial for a climate change study. While a certain generalization is certainly necessary at the European scale, I would have expected an approach that is at least partially based on the climatic regions of Europe.
2) In addition to these four regions, there are a sensitivity analysis based on station data from Finland and validations/FWI-burned area cross-correlations based on state-wide data from Spain and Greece. It is not made clear why these specific locations were selected and how they tie up with the European analysis. Regarding the cross-correlations, one example for each region would be preferable to two examples for the southern region.
3) Although fire danger indices in general and the FWI in particular are mentioned in the Introduction and in Material and Methods, no clear description about its calculation (within the Canadian Forest Fire Danger Rating System) is given. As only one index is used and even a sensitivity analysis is carried out later on, such information would be vital. The current descriptions (p. 6296 ll. 5-9) do not show whether calculations were only performed for March-September each year or whether they were done based on continuous data and only the values for March-September were selected for the analysis as well as which starting values were used. This is important because the FWI is a cumulative index and there may be carry-over effects from the previous weeks or even the previous fire season. Additionally, these aspects and the more general concept of calculating FWI from the ERA data could be covered in a dedicated chapter of Material and Methods.

4) On page 6293 lines 9-10 the authors state that "Fire weather danger indices are used to assess fire potential". This is not necessarily the case. Other points of view may include difficulty of suppression, potential ignitability etc.
5) If I understood correctly, the mean of the FWI data for each region and fire season (March-September) was calculated and analyzed. There are a range of problems associated with this type of calculation:

a) According to Van Wagner (1987) and Van Wagner (1985), the FWI is not meant to be used for spatial or temporal averaging and the Daily/Seasonal Severity Rating (DSR/SSR) should be used instead. This issue should be observed or at least duly discussed.
b) The FWI was calculated using UTC and a fixed fire season length despite the fact that the area under analysis is very big. While it is true that only trends are analyzed and a definition of fire season length is hard to obtain for all grid points, this form of calculation can be expected to produce spurious results. For example, data from at least three different time zones are averaged, which have all been calculated based on the time of the westernmost time zone. Thus, some kind of systematic error can be expected. A suggestion would be to calculate standardized trends on a grid point-basis and then to compare and to average these. This would also allow for a preparation of trend maps. The easiest way to avoid the fire season problem would be to consider the whole year instead of limiting the analysis to a fire season that may or may not be appropriate for a particular grid point.
c) In the Discussion (p. 6304, ll. 21-22), the authors mention that contrary to the whole study area and to Spain, annual FWI is used for Greece in the cross-correlation analysis. This is neither explained in Material and Methods nor in the respective results section but may obviously have an influence on the comparability of results.
6) Considering the analysis, trends of mean FWI for each region as well as the number of values over fixed thresholds were used. Breakpoint analyses were carried out additionally. The following points should be considered:
a) For the south-Mediterranean level, the ERA40/ERA Interim data were extended to cover the whole period under analysis. I wonder why this was not done for all regions and the European level as well.
b) The techniques used for the analysis (e.g. Mann-Kendall-Test and Sen's slope estimate) should be explained at some greater length (i.e. are they parametric/non-parametric etc.).
c) While the analysis regarding trends was done in a sensible way, it should be considered whether the distribution of annual FWI values can be solely represented by its mean. Quantile regression techniques may be better suited to show FWI trends for different levels of fire danger.
d) The fixed thresholds chosen for the additional analysis hardly make sense for the large area under consideration. This is stated by the authors in p. 6269 ll. 9-11 ("In Southern Europe FWI values larger than 30 are common, whereas in the rest of Europe they occur only very occasionally."). In Fig. 5 it seems that a threshold of 10 was used for all regions and the threshold of 30 was used only for Southern Europe additionally, although this is not mentioned explicitly in the text. A suggestion would be to use one or more selected quantiles as thresholds which would dynamically adapt to each grid point or region (e.g. the FWI corresponding to 90% of the FWI distribution for each grid point). Additionally, extreme value theory (e.g. peak over threshold) can also be used to analyze this type of data and to obtain e.g. return levels and return periods for a certain FWI value in a certain area.
e) The breakpoint analysis is an interesting approach; however it was done only for south Europe and Spain. It would be nice to have this done for the other areas and for the whole of Europe as well and to check if there is a match of breakpoints between the different regions and between FWI and its input parameters (cf. p. 6303 ll. 18-22).
f) Apparently, the breakpoint analysis was also used to obtain trend-free periods for crosscorrelations of FWI and burned area (p. 6303 ll. 15-18). This is not explained in Material and Methods.
7) The sensitivity analysis of FWI to meteorological parameters is a bit odd as FWI itself is calculated from these parameters and the methods of calculation are known. As pointed out before, these methods of calculation should be described at some length. If a sensitivity analysis remains necessary at all, the authors should consider a more structured approach, e.g. calculating the FWI for the station data presented and repeating this for several steps of (simulated) temperature increase. Otherwise, statements such as the one given in p. 6302 ll. 18-20 are not valid.
8) The cross-correlation analysis is quite limited. While it is good to relate the fire danger indices to actual fire data, the following points should be considered:

a) Expansion of the analysis to (in the ideal case) at least one state per region
b) Integration of the number of fires in the analysis (as area burned is highly sensitive to local fire-fighting policies and other factors)
c) Expansion of the analysis to integrate cross-correlations on a day-to-day and/or local basis (e.g. concerning the FWI on the day a fire ignited in the area a fire ignited)

9) Discussion pp. 6306/6307 ll. 29-2:
How is it possible that social events favor fuel conditions? Please explain or give an example.

Technical corrections

1) p. 6292 l. 2: fire-weather danger indices *change to: fire danger indices*
2) p. 6292 l. 3: … forest fire activity is important in changing climate. *Insert a changing climate*
3) p. 6292 ll. 6-7 *Try to rephrase this sentence.*
4) p. 6292 l. 14 Our results show that, fire risk… *remove ","*
5) p. 6292 l. 18 … global temperatures in the world increased… *leave out "in the world"*
6) p. 6292 l. 22 During the recent 50 yr, … *Check if yr is the correct abbreviation for this journal and whether yrs should be used.*
7) p.6292 l. 23 … north-eastern Europe, and mountainous regions; … *Add and in mountainous regions*
8) p. 6293 ll. 8-9 fire weather danger *change to: fire danger*
9) p. 6293 l. 8-9 did … changed in Europe…? *change to: did ... change in Europe...?*
10) p. 6293 l. 9 fire weather danger indices *change to: fire danger indices*
11) p. 6293 l. 10-12 *try to rephrase this sentence/statement*
12) p. 6294 ll. 8-10 *This statement is a bit confusing. Please try to rephrase.*
13) p. 6294 l. 27 … like the end of slush and burn farming … *Do you mean slash and burn farming?*
14) p. 6295 l. 2-3 … must be taken into account too. *Please change to: must be taken into account, too.*
15) p. 6295 ll. 15-16 … it still remains as one of the key factors … *remove "as"*
16) p. 6298 l. 6 … were ln transformed … *change to: were ln-transformed*
17) p. 6298 ll. 6-7 … and the cross-correlation with FWI were estimated … *change to: cross-correlation was estimated or cross-correlations were estimated*
18) p. 6300 l. 2 … and wind speed in a single locations like shown in Fig. … *change to: in a single location as shown in*
19) p. 6300 ll. 18-22 *Very long and complex sentence. Please rephrase.*
20) p. 6300 ll. 22-26 … no trend is observed … indicating that the observed positive trends … results from the last couple of decades. *Change to "result" or rephrase the whole sentence.*
21) p. 6302 l. 18 (Chirstensen et al., 2007) *Spelling error in the author's name.*
22) p. 6303 l. 7 … shows a trend to decline after 80's which is confirmed … *change to: after the 80's, which*
23) p. 6303 l. 21 and l. 23 … in early 70s and middle 90s … *insert "the" twice and use consistent notation (cf. comment p. 6303 l. 7)*
24) p. 6304 l. 5 long term *change to: long-term*
25) p. 6304 l. 5 It should be noted though that… *change to: It should be noted, though, that*
26) p. 6304 ll. 12-17 … on the one side … on the other side *change to: on the one hand, ... on the other hand ... Additionally: check sentence structure.*
27) p. 6304 ll. 17-21 *Check this sentence.*
28) p. 6304 l. 21 These difference … *change to These differences*
29) p. 6304 ll. 23-25 *Check this sentence.*
30) p. 6305 l. 28 Socio economic … *change to: Socio-economic*
31) p. 6305 l. 29 … could directly linked to … *could be directly linked to OR could directly link to?*
32) p. 6306 l. 2 fie *fire or fires?*
33) p. 6306 l. 12 … we found that a changes … *change to: a change*
34) p. 6306 ll. 12-13 … fire weather danger indices … *remove "weather"*
35) p. 6306 l. 13 … and are burned … *change to area burned*
36) p. 6306 ll. 15-17 *Check this sentence.*

37) Figs. 2+5: *Some of the colors used are hard to distinguish. Try using different line types (e.g. dashed, dotted) for ERA 40/ERA Interim.*

Authors replies:

Below are our replies to the comments.

1. *The selection of four regions used in the study. The division is based on crude climate division. The southern region represents Mediterranean warm climate, the eastern region continental climate, western area more humid Atlantic climate and the northern region cool Fennoscandian climate. To illustrate detailed spatial variation of trend we have now added figures showing the FWI trend of each grid cell.*
2. *The cross correlation was calculated for Greece and Spain because of available national level burned area data. We have added now similar calculations also for Finland representing a different climatic region. The sensitivity analyses was taken away, they did not really add the values of this study.*
3. *The calculations were made for the whole year and the values for March-September were then selected for more detailed analysis. We have added more detailed description of the method.*
4. *Text has been changed "Fire weather danger indices are used to estimate the impact of weather conditions on the occurrence of fires."*
5.
    a. *Use of FWI instead of DSR/SSR, we have added discussion on this matter in the revised manuscript. FWI has earlier been used in comparable studies e.g. by Moriondo et al., (2006); Wastl et al. (2012) so we consider the use of FWI justified. The main goal was to examine the temporal variation of fire danger induced by climate variation and change. In that sense, FWI stands out as a widely used alternative, taking also into consideration that Wastl et al. (2012) showed different fire danger indices give relatively similar results.*

    References: Moriondo, M., Good, P., Durao, R., Bindi, M., Giannakopoulos, C., and Corte-Real, J.: Potential impact of climate change on fire danger in the Mediterranean area. ClimRes., 31, 85-95, 2006.

    Wastl, C., Schunk, C., Leuchner, M., Pezzatti, G., and Menzel, A. Recent climate change: Long-term trends in meteorological forest fire danger in the Alps. Agricultural and Forest meteorology, 162– 163, 1– 13, 2012.

    b. *We have calculated the trend for each grid cell and this is now depicted in the new figures we have included. Nevertheless, for the cross-correlations, the availability of fire data at the national scale only forced us to spatially aggregate also the FWI values to the respective national scale.*
    c. *We have calculated the FWI also for Greece and Finland and used the same time period June-September.*
6.
    a. *Extension of ERA/ERA Interim to cover the whole period 1960-2012. The extension in case of break point analyses and cross correlation calculation was needed to be done in order to make the analysis possible. The extension of the time series, since it is an internal process (depends on the data itself), only shifts and modify the measurements systematically. This correction only marginally modifies the outputs of the long term variation and change analyses and so, we decided to perform them on the original data.*
    b. *We now present the methodological approaches more in depth.*

c. *The use of fixed thresholds is justified as the aim is to study the temporal variation. Moriando et al. (2006) used value 45 for Mediterranean region. Lehtonen et al. (2013) selected limits based on Tanskanen et al. (2005) study and the limits were FWI>32 (extreme risk), 17-32 (high risk), 16-31) medium risk), <8 low risk. These limits were for boreal forest conditions. This is to indicate that the calculations can be done using various limits. We feel that when we examine temporal variation and change it is feasible to use the limits applied in this study. We have changed the limits to be 45 for Southern Europe and 20 for the rest of the Europe to make the analyses easier to compare with other research. We have added text that limit 45 was used only southern and the whole Europe.*

References: Moriondo, M., Good, P., Durao, R., Bindi, M., Giannakopoulos, C., and Corte-Real, J.: Potential impact of climate change on fire danger in the Mediterranean area. ClimRes., 31, 85-95, 2006.

Lehtonen, I., Ruostenoja, K., Venäläinen, A., and Gregow, H.: The projected 21st century forest fire risk in Finland under different greenhouse gas scenarios. Boreal Environ. Res., (in press), 2013.

Tanskanen, H., Venäläinen, A., Puttonen, P. and Granström, A.: Impact of stand structure on surface fire ignition potential in Picea abies and Pinus sylvestris forests in southern Finland. Can. J. For. Res,. 35, 410–420, 2005

d. *The analyses of return levels and return periods for a certain FWI value in a certain area would be possible. However, we feel that it would be a subject for another study concentrating in the frequency of extreme fire danger conditions.*
e. *Breakpoint to different region. We have added analyses of Finland representing northern Europe. There is no break point like also seen from the FWI time-series. The same result is obvious also for western Europe.*
f. *The explanation has been added to the text.*

7. *We have deleted that part of text.*
8.
    a. *We have added Finland to cross-correlation analyses.*
    b. *Similarly to the (valid) argument that area burnt depends on additional biotic and abiotic parameters, the variable 'number of fires' is not independent to exogenous triggers. Socio-economic conditions, distance from settlements and transportation network is only an example of some of the parameters that are associated to the fire ignition. We believe that the inclusion on the number of fires in our analyses would be of interest, though we do not agree that this variable has a more straightforward relationship to weather in comparison to area burnt. Especially when the lack of a cross-country, standardized approach to compile fire number statistics is considered, the use of this variable would hamper the validity of our comparative outputs.*
    c. *This might give good results but we consider it is out of scope of this study*
9. *How is it possible that social events favor fuel conditions? Please explain or give an example. We changed the "major social events" to "as for example rural migration and urbanization followed by land abandonment"*

Technical corrections

They have taken into account