

15th Oct 20

Dear Professor Abram,

Once again, please allow me to apologise for the delay in sending a decision on your manuscript titled "Connections of climate change and variability to forest fire disasters in southeast Australia". It has now been seen by our reviewers, whose comments appear below. In light of their advice I am delighted to say that we are happy, in principle, to publish a suitably revised version in Communications Earth & Environment under the open access CC BY license (Creative Commons Attribution v4.0 International License).

We therefore invite you to revise your paper to address the points raised by our reviewers. At the same time we ask that you edit your manuscript to comply with our format requirements and to maximise the accessibility and therefore the impact of your work.

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Please review our specific editorial comments and requests regarding your manuscript in the attached "Editorial Requests Table". Please outline your response to each request in the right hand column. Please upload the completed table with your manuscript files.

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We hope to hear from you within about two weeks; please just let us know if you need more time.

Best regards,

Heike Langenberg, PhD

Chief Editor

Communications Earth and Environment

On Twitter: @CommsEarth

REVIEWERS' COMMENTS:

Reviewer #1 (Remarks to the Author):

This comprehensive review by Abram et al examines the many factors and complex interactions of climate variability and change in altering forest fire risk in south east Australia.

The manuscript initially covers the important and essential ingredients for large and extreme forest fires in Australia. The manuscript then explains the role of a range of climate conditions that leads to greater forest area burnt including synoptic conditions, drought, covariability between temperature and precipitation and the phases of climate drivers that are fire promoting. The fire metrics used to cover fire risk include forest area burnt, Forest Fire Danger Index, fuel moisture index, radiative power, Continuous Haines and the number of PyroCb events. The manuscript even considers the longer term records through paleoclimate reconstructions. The manuscript ensures the reader is left in no doubt of the role of climate variability and change on the 2019/20 fire season in relation to forest burnt areas.

The novel aspects of this study include:

- Comprehensive and completeness in explaining the climate variables influencing large scale forest area burnt
- the link of large forest burnt areas when two or more drivers are in fire-promoting state and the important climate change influence on these drivers such as the southern annular mode in relation to fire risk
- that the dangerous fire weather in southeast Australia has emerged outside of the range of historical experience.

While the manuscript was long I felt that the content was necessary to cover the number of factors and the complex interactions between the variables. One concern for the authors to be aware of is the use of the term 'fire risk' – most of this paper focuses on extensive forest burnt areas and not on impact, therefore there are many other factors to consider in the term 'fire risk'. I think acknowledging and clarifying that there are high impacting fires that fall outside of this study and that there are a range of other factors that contribute to fire risk will alleviate concerns. Overall this is a much-needed comprehensive manuscript that can be used by readers and researchers as a reference paper on the role of climate variability and change in altering forest fires risk.

Specific comments

Title: The term 'disaster' should not be used in the title as the focus of the paper is not on disasters but on area burnt and other fire metrics linked to fire risk in forested areas of Australia.

Line 8: I am not what 'acted upon' means in this context - is there a better way to explain this?

Line 18: Can the word 'possibility' be replaced with 'likelihood'?

Line 36: were the impacts just 'ecological' or should this be replaced with 'environmental'?

Line 51-53: I think citation of 14 should instead be 25 as this statement is about expected increase in fire risk metrics (FFDI and instability) which is what 25 covers rather than 14.

Line 61: The sentence and the figure do not align. The sentence is about 'fire risk' but the figure points identifies Fig. 1c which is about area burnt not fire risk. Might be better to refer to Figure 1 as a whole rather than point out Fig 1c.

Line 72-80: The differentiation between 'normal' and 'extreme' conditions is not clear. Are these the accepted terms more broadly to differentiate? Is the occurrence of a pyroconvective event the difference? The authors also refer to 'normal forest fires' and 'extreme fires'. Do these occur only occur with the respective 'conditions'.

Line 75: Is there a more technical or scientific describing word that could replace 'violent'?

Line 89: add an appropriate citation

Line 92 and 93: add an appropriate citation to the end of both sentences

Line 111: is 'pyrocumulonimbus storms' the correct term? Doesn't pyrocumulonimbus mean fire generated storm so therefore the word 'storm' should not be added?

Line 142: Is the historical mean period 1911-1940 a typical historical reference level to compare to?

Lines 263: Just a note - Ash Wed fires (1982/83 fire season) had co-occurrence of drivers but the area burnt wasn't as great as the impact.

Line 317: suggestion only - instead of 'suppression of fires' the terms 'fire and land management' might better capture the point being made.

Lines 596-614: This paper focuses on climate change and forest fire risk – I think the conclusion section on Response Options is outside the scope of what was presented in the body of the manuscript.

Lines 606-614: The authors should not overstate the use of these results. Land and fire managers are well aware of the flammability of the forest and a bigger challenge is predicting impact where and when fires eventuate.

Methods:

The limitations of FFDI are well covered in this manuscript but KBDI and FMI limitations are not adequately explained.

Line 1050: for consistency change 'Feb' to 'February'

1133: replace 'data was' with 'data were'

1134: replace 'data is' with 'data are'

1160: Should make point that high impacting fires still occur outside of these periods of 'extensive fires'

Reviewer #2 (Remarks to the Author):

The manuscript of Abram et al. "Connections of climate change and variability to forest fire disasters in southeast

Australia" is a very nice review that analyze several relevant and concise Remote sensing dataset to explain the connection between the historical climate at different temporal scales (from yearly climate data to paleoclimate data) and fire occurrences in southeast Australia, with a focus on specific extremes events (big fire years) and a particular focus in the extreme fire season 2019-2020. The authors present an interesting reconstruction of recent and past fire patterns in a globally important fire sensitive ecosystem. This paper is very pertinent in the current global burning scenario, and give a huge contribution to understand fire-climate relationship with a large perspective.

The manuscript is well organized and easy to follow, figures are well organized. The methods (despite to be separated as supplementary material), the results and the interpretation, together with a very interesting discussion increase the international interest of the manuscript.

From my point the view, this paper represent more a research paper rather that a review paper. The statistical and remote sensing analyses are very robust, and I don't have any major concern for publication in is current form.

Some specific comments and minor concerns:

1) I found a little weird the citation of figures and the "methods" in the introduction. Probably the methods should be referred as Supplementary material rather than "methods" across the manuscript. I insist, this paper could be accepted as research paper, because most of the information and presented data were analyzed by the own authors, and it is not a simple review.

2) My only main concern is about a biased argument across the manuscripts that highlight the effects of climate changes and fire risk on changes in fuel dryness and fire weather. According with your data, at a yearly, decade, or paleoclimate time series scale, a decrease in rainfall has been observed and is also expected, and consequently a decrease in fuel build-up is expected, particularly in fire fuel build-up limited regions as should be the case of several regions in Australia. So this reduction of rainfall could reduce or limit fires.

3) in the methods section, authors forgot to mention what was the final spatial resolution of the remote sensing data. Because all original dataset probably have different spatial resolution, it is important to mention the final grid cell size that you used to aggregate the data.

Response to reviewer comments

We thank both reviewers for their considered and constructive comments on our manuscript. We have used these comments to revise the manuscript, and provide a response (in blue text) to each comment below.

Reviewer #1 (Remarks to the Author):

This comprehensive review by Abram et al examines the many factors and complex interactions of climate variability and change in altering forest fire risk in south east Australia.

The manuscript initially covers the important and essential ingredients for large and extreme forest fires in Australia. The manuscript then explains the role of a range of climate conditions that leads to greater forest area burnt including synoptic conditions, drought, covariability between temperature and precipitation and the phases of climate drivers that are fire promoting. The fire metrics used to cover fire risk include forest area burnt, Forest Fire Danger Index, fuel moisture index, radiative power, Continuous Haines and the number of PyroCb events. The manuscript even considers the longer term records through paleoclimate reconstructions. The manuscript ensures the reader is left in no doubt of the role of climate variability and change on the 2019/20 fire season in relation to forest burnt areas.

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- that the dangerous fire weather in southeast Australia has emerged outside of the range of historical experience.

While the manuscript was long I felt that the content was necessary to cover the number of factors and the complex interactions between the variables. One concern for the authors to be aware of is the use of the term 'fire risk' – most of this paper focuses on extensive forest burnt areas and not on impact, therefore there are many other factors to consider in the term 'fire risk'. I think acknowledging and clarifying that there are high impacting fires that fall outside of this study and that there are a range of other factors that contribute to fire risk will alleviate concerns.

R: This is a very good point and we agree. We have modified the end of the introduction to specify that this paper is examining fire risk related to climatic factors that lead to large and extreme fires, and that other factors that determine the impact of fires on people and ecosystems fall outside of the scope of this review. The revised text reads:

“The range of interacting climate factors which contribute to fire risk confound attempts to attribute changing fire risk to any single factor (Box 1, Box Fig. 1). At the same time, multiple climatic influences raise the possibility that climate change could have a non-linear effect on forest fire risk. In this review, we examine the ways that climate variability and climate change are altering the risk of large and extreme forest fires in southeast Australia, acknowledging that the ultimate impact of fires on people and ecosystems is also determined by a range of non-climatic factors that fall outside of the scope of this review. Our assessment includes an examination of the confluence of climate factors that resulted in the 2019 climate extremes and the Black Summer mega forest fires.”

Overall this is a much-needed comprehensive manuscript that can be used by readers and researchers as a reference paper on the role of climate variability and change in altering forest fires risk.

R: Thank you for your positive and constructive comments.

Specific comments

Title: The term ‘disaster’ should not be used in the title as the focus of the paper is not on disasters but on area burnt and other fire metrics linked to fire risk in forested areas of Australia.

R: We have changed the title to “Connections of climate change and variability to large and extreme forest fires in southeast Australia”

Line 8: I am not what ‘acted upon’ means in this context - is there a better way to explain this?

R: We have clarified the wording as: “The combination of climate variability and long-term climate trends generated the climate extremes experienced in 2019...”

Line 18: Can the word ‘possibility’ be replaced with ‘likelihood’?

R: Done

Line 36: were the impacts just ‘ecological’ or should this be replaced with ‘environmental’?

R: We have changed “ecological” to “environmental”

Line 51-53: I think citation of 14 should instead be 25 as this statement is about expected increase in fire risk metrics (FFDI and instability) which is what 25 covers rather than 14.

R: Thank you for picking this up. We have replaced the Dowdy 2018 reference at this point with Dowdy et al 2019 that examines future fire risk metrics.

Line 61: The sentence and the figure do not align. The sentence is about 'fire risk' but the figure points identifies Fig. 1c which is about area burnt not fire risk. Might be better to refer to Figure 1 as a whole rather than point out Fig 1c.

R: Apologies for this error. In revising the manuscript we have moved the panel that should have been referred to here as a figure in Box 1. The revised manuscript text now points to Box 1 and Box Fig. 1 here.

Line 72-80: The differentiation between 'normal' and 'extreme' conditions is not clear. Are these the accepted terms more broadly to differentiate? Is the occurrence of a pyroconvective event the difference? The authors also refer to 'normal forest fires' and 'extreme fires'. Do these occur only occur with the respective 'conditions'.

R: We have removed reference to "normal" conditions. This text now appears in Box 2, giving a clearer discussion of the requirements for large fires, and the escalation to extreme fires characterised by pyroconvective events.

Line 75: Is there a more technical or scientific describing word that could replace 'violent'?

R: We have replaced "violent" with "powerful"

Line 89: add an appropriate citation

R: We cite here Nolan et al., 2016 and Box Fig. 1

Line 92 and 93: add an appropriate citation to the end of both sentences

R: We have now cited De Kauwe et al 2020 for these sentences.

Line 111: is 'pyrocumulonimbus storms' the correct term? Doesn't pyrocumulonimbus mean fire generated storm so therefore the word 'storm' should not be added?

R: We have changed "pyrocumulonimbus storms" to "pyrocumulonimbus events"

Line 142: Is the historical mean period 1911-1940 a typical historical reference level to compare to?

R: We have added a sentence that says: "The 1911-1940 reference interval is the earliest standard climatology possible for the national temperature dataset (Methods), and is used here as the closest approximation to pre-industrial conditions in Australia."

Lines 263: Just a note - Ash Wed fires (1982/83 fire season) had co-occurrence of drivers but the area burnt wasn't as great as the impact.

R: We have added "high impact" to describe the Ash Wednesday fires. The burn area in 1982/83 was not as very large, but still reached the 0.5 MHa level used to define large fire seasons in our study.

Line 317: suggestion only - instead of 'suppression of fires' the terms 'fire and land management' might better capture the point being made.

R: We have altered the wording to "fire occurrence and spread is also influenced by land clearing and landscape management, and by the direct human influence on fire ignition and suppression", which we feel addresses the reviewer's suggestion while also capturing the information from the references cited here.

Lines 596-614: This paper focuses on climate change and forest fire risk – I think the conclusion section on Response Options is outside the scope of what was presented in the body of the manuscript.

R: We have opted to retain this section as we feel it gives important context to our review, including the context of other non-climatic factors that determine the impact of fires, and important context on adaptation and mitigation response options for managing increasing climate-related fire risks.

Lines 606-614: The authors should not overstate the use of these results. Land and fire managers are well aware of the flammability of the forest and a bigger challenge is predicting impact where and when fires eventuate.

R: This is a very valid point. We have revised the wording here to point to options for early warning and preparedness, without implying that land and fire managers don't use this type of information already.

Methods:

The limitations of FFDI are well covered in this manuscript but KBDI and FMI limitations are not adequately explained.

R: We have expanded the methods text as follows to provide more specific information about limitations in FMI and KBDI:

"FMI is not effective for describing wet fuels and does not incorporate effects of rainfall on fuel moisture, and should not be considered as giving a quantified estimate of fuel moisture content without the use of a scaling factor¹³⁰. But it is simple to calculate making it easy to implement operationally, is effective at emulating the predictions of more complex process-based fuel moisture models for different types of fuels¹³⁰, and does not lose sensitivity at low fuel moisture levels, and so may be a better indicator than other models of the critically low fuel moisture conditions that are an important factor in the development of extreme fires.

"

"The KBDI used within the drought factor term has also been shown to be a poor proxy for fuel moisture alone, and should not be viewed as a substitute for specific estimates of fuel moisture¹²⁸."

Line 1050: for consistency change 'Feb' to 'February'

R: Done

1133: replace 'data was' with 'data were'

R: Done

1134: replace 'data is' with 'data are'

R: Done

1160: Should make point that high impacting fires still occur outside of these periods of 'extensive fires'

R: We have added clarification here that reads: "noting that this assessment does not preclude smaller but high impact fires."

Reviewer #2 (Remarks to the Author):

The manuscript of Abram et al. "Connections of climate change and variability to forest fire disasters in southeast Australia" is a very nice review that analyze several relevant and concise Remote sensing dataset to explain the connection between the historical climate at different temporal scales (from yearly climate data to paleoclimate data) and fire occurrences in southeast Australia, with a focus on specific extremes events (big fire years) and a particular focus in the extreme fire season 2019-2020. The authors present an interesting reconstruction of recent and past fire patterns in a globally important fire sensitive ecosystem. This paper is very pertinent in the current global burning scenario, and give a huge contribution to understand fire-climate relationship with a large perspective.

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From my point the view, this paper represent more a research paper rather that a review paper. The statistical and remote sensing analyses are very robust, and I don't have any major concern for publication in is current form.

R: Thank you for these positive comments

Some specific comments and minor concerns:

1) I found a little weird the citation of figures and the "methods" in the introduction. Probably the methods should be referred as Supplementary material rather than "methods" across the manuscript. I insist, this paper could be accepted as research paper, because most of the information and presented data were analyzed by the own authors,

and it is not a simple review.

R: The intention is that the methods section will appear at the end of the manuscript rather than in a separate supplement. Because of this we have continued to refer to “Methods” rather than “Supplementary material”.

We agree with the reviewer that there is new analysis within this manuscript, but this analysis has been done as a means of synthesising a range of concepts covered in other papers. We feel that overall our manuscript is better suited as a review rather than a research article.

2) My only main concern is about a biased argument across the manuscripts that highlight the effects of climate changes and fire risk on changes in fuel dryness and fire weather. According with your data, at a yearly, decade, or paleoclimate time series scale, a decrease in rainfall has been observed and is also expected, and consequently a decrease in fuel build-up is expected, particularly in fire fuel build-up limited regions as should be the case of several regions in Australia. So this reduction of rainfall could reduce or limit fires.

R: We are unaware of strong, published evidence for this in southeast Australian forests, but acknowledge the possibility. We have adapted a sentence in the future changes section of the text to now read: “In the short-to-medium term, fuel loads could also increase in association with forest dieback in response to declining cool season rainfall and increased heat stress, while climate-related forest dieback might ultimately reduce fuel loads in the longer-term in some currently forested regions.”

3) in the methods section, authors forgot to mention what was the final spatial resolution of the remote sensing data. Because all original dataset probably have different spatial resolution, it is important to mention the final grid cell size that you used to aggregate the data.

R: We have provided information on the resolution of the ACORN-SATv2, AWAP and MODIS products to the methods text.

Additional revisions

We have added information from, and citation to, two new relevant publications:

*Khaykin et al., 2020 (Comms Earth and Environment) on the radiative effect of stratosphere-penetrating bushfire smoke from the Black Summer fires.

*The Royal Commission into National Natural Disaster Arrangement Report, released on 28 October 2020. This addition has been made to the text in the second last paragraph of the main text (on adaptation response options).