Earth Systems and Climate Change Hub

National Environmental Science Programme

Fire-generated thunderstorms and climate change in Australia

Fire-generated thunderstorms can produce extremely dangerous fire behaviour, with strong, erratic winds and lightning.
Image: Alex Ellinghausen

- Thunderstorms that are initiated by bushfire smoke plumes have been observed more frequently in recent years than in previous decades.
- These fire-generated thunderstorms can produce extremely dangerous fire behaviour, including erratic changes in wind. They can also start new fires from burning embers and lightning far ahead of the fire front.
- In southern Australia, human-caused climate change is increasing some risk factors associated with fire-generated thunderstorms.

Thunderstorm clouds that are initiated by bushfire smoke plumes are known as pyrocumulonimbus (pyroCb) clouds. These have occurred in many of the most destructive Australian bushfire events in recent decades, including the 2003 Canberra fires and the Black Saturday fires in 2009. They have also occurred in very destructive fires in North America in recent years. Fire-generated thunderstorms have been observed more frequently in recent years, especially in the two most recent south-eastern Australian fire seasons, including the devastating Black Summer fire season of 2019/20.

As the global climate warms in response to increasing greenhouse gas emissions, many of the impacts associated with extreme weather hazards and disasters, including those associated with extreme bushfires, are likely to increase.

Understanding extreme weather hazards and how they may change as the climate continues to warm is important for increasing Australia's preparedness and resilience.

Researchers in the Earth Systems and Climate Change (ESCC) Hub have contributed significantly to Australia's scientific knowledge of extreme bushfires and how they may change in the future. By working closely with emergency management stakeholders, the Hub has provided tailored data and information products as well as expert advice to help enhance their emergency management and long-term planning.

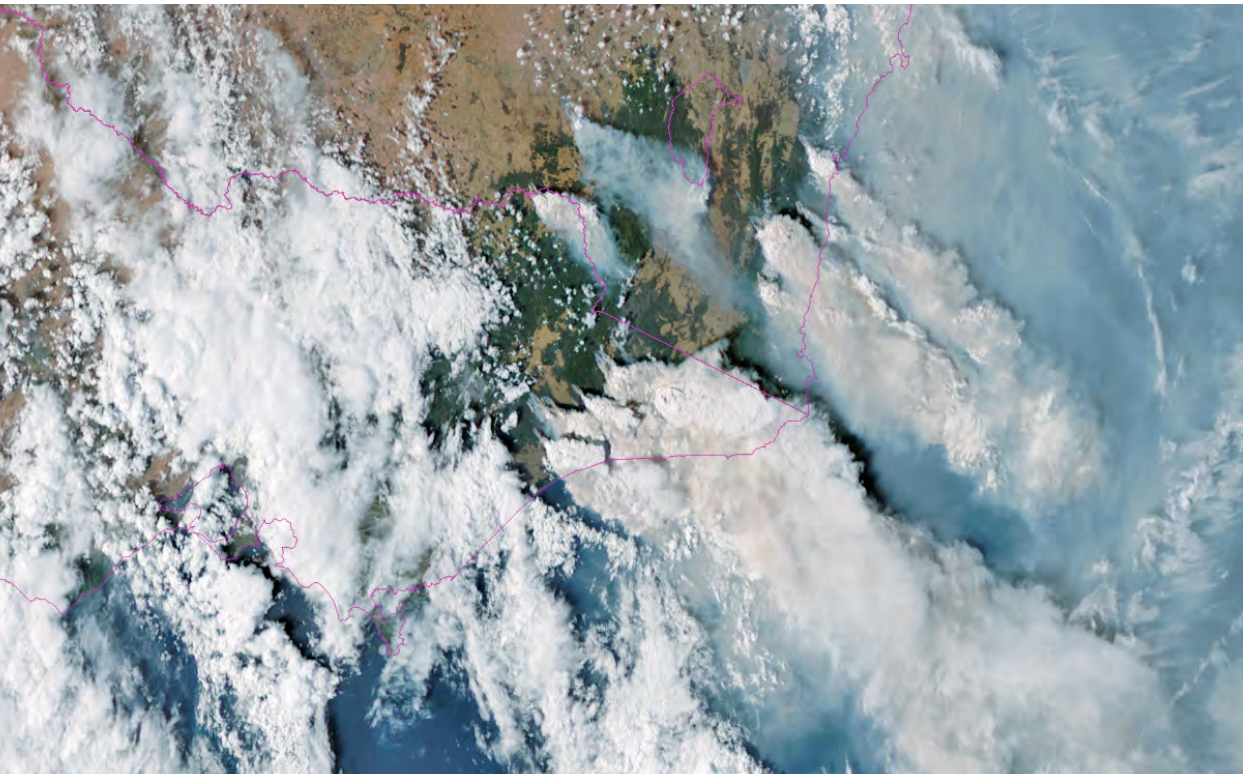

Figure 1: **Himawari satellite image of the smoke from the Black Summer fires taken over south-eastern Australia at 5 PM (Eastern DST) 30 December 2019.** Image: Japan Aerospace Exploration Agency

How do fire-generated thunderstorms form?

Fire-generated thunderstorms form when a sufficiently large and intense fire releases enormous amounts of heat causing air to rise rapidly in the smoke plume.

As the plume rises, the atmospheric pressure reduces and causes the plume air to expand and cool. If it cools enough, the moisture in the plume air can condense and form clouds.

The condensation process causes energy to be released that warms the cloud. If the surrounding air is relatively cold, the cloud is buoyant and can rise. Further expansion and cooling causes more moisture to condense, enabling the cloud to continue to rise further. If this process is strong enough a thunderstorm can form.

Evaporation of rain falling from the cloud can cool the air making it relatively heavy. This can lead to intense downbursts of strong and erratic winds that can create dangerous on-ground conditions. These strong and erratic winds can lead to more unpredictable fire behaviour that can make it very hard, if not impossible, for fire fighters to control the fire, as well as being very dangerous for fire fighter safety.

In addition, collisions of ice particles in the very cold upper parts of these clouds can cause a build-up of electrical charge, producing lightning. This lightning can then ignite new fires far ahead (as much as 100 km ahead) of the main fire front.

Fire-generated thunderstorms have some things in common with conventional thunderstorms. Both require the lifting of warm moist air into a relatively cold layer above. However, fire-generated thunderstorms have an advantage over conventional thunderstorms in that the fire adds heat and moisture to the plume that can provide a lifting mechanism and help enhance buoyancy. As a result, fire-generated thunderstorms can even occur in environments that may not support conventional thunderstorm development.

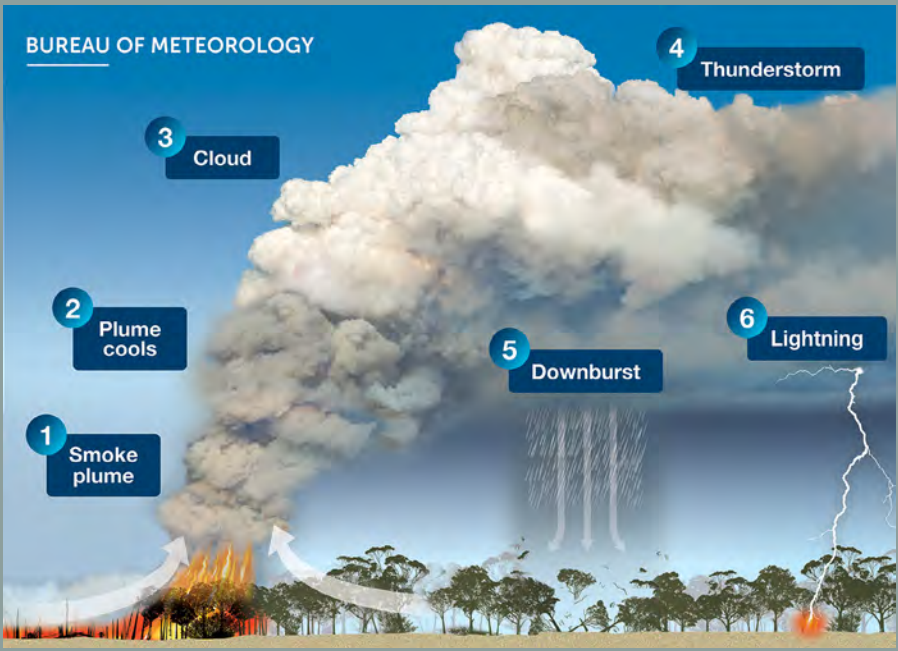

Figure 2: **Pyrocumulonimbus cloud development.**
Image: Australian Bureau of Meteorology

1. **A plume of hot, turbulent air and smoke rises above a large area of intensely burning fire.**
2. **Cooler air mixes into the plume as it rises, causing it to broaden and cool.**
3. **When the plume rises high enough, lower atmospheric pressure causes further cooling and clouds form.**
4. **In the right environmental conditions (known as a weakly-stable atmosphere) a thunderstorm may develop.**
5. **Rain from the cloud sometimes evaporates as it falls and cools when it comes into contact with dry air, producing a downburst of wind.**
6. **Lightning may be produced and can ignite new fires far ahead of the fire front.**

Lightning underneath the plume of the Dunns Rd fire during a fire-generated thunderstorm in the Murrumbidgee corridor in 2019.
Image: Helen Shimitras

When do fire-generated thunderstorms form?

Fire-generated thunderstorms form when two conditions are present: large intense fires and a weakly stable atmosphere. In recent decades these conditions have been forecast using various indices including the Forest Fire Danger Index (FFDI) and the Continuous-Haines Index (C-Haines).

These indices have been found to provide a good representation of the risk of occurrence for fire-generated thunderstorms. The two indices have also been examined in past data for recent trends, and in climate models for future changes.

Fire-generated thunderstorm formation is a complex process that can be influenced by many factors in addition to those indicated by fire weather indices. For example, specific wind patterns in complex mountainous terrain, large areas of flaming and fires at higher elevation can all favour their development. Very dry air in the middle troposphere can evaporate cloud soon after it forms in the plume, reducing the chance that a fire-generated thunderstorm will form. Additionally, the amount of heat needed for their formation can vary dramatically in different atmospheric environments.

Research by the ESCC Hub and across the research community has improved our understanding of how all these factors combine to affect fire-generated thunderstorm formation. This research also helps to enhance predictions of how the conditions conducive to their formation might change in a warmer future climate.

Interactions between winds and rugged terrain can be conducive to the expansive flaming zones associated with fire-generated thunderstorm development.

Image: iStock.com/DLMcK

Observed changes in fire-generated thunderstorms

There has been a substantial increase in the number of fire-generated thunderstorms observed in recent years, with 2019/2020 producing almost as many as were observed in the previous 35 years combined.

However, the types of observations available have changed over time which creates some uncertainties around quantification of long-term changes in the frequency of these events.

Climate change has already influenced the frequency and severity of some risk factors associated with the occurrence of fire-generated thunderstorms in some parts of Australia. This includes more dangerous fire-weather conditions near the land surface as represented by indices such as the FFDI, as well as at higher levels of the atmosphere as represented by the C-Haines index.

An analysis of the FFDI and C-Haines values for historical fire-generated thunderstorms in Australia shows that these events are more likely to occur when both of these indices are simultaneously high. A significant trend over recent decades of higher values of these indices has been found in some parts of southern Australia, especially in spring and summer. This includes an increase

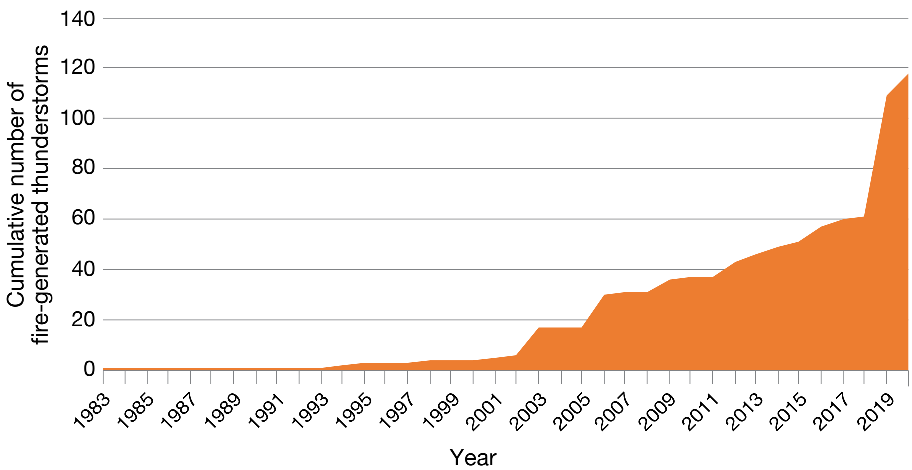

Figure 3: **Cumulative observed number of fire-generated thunderstorms.** Sourced from *Di Virgilio et al*. (2019) (updated to 2020).

in the frequency of when both indices are simultaneously high, as typically occurs for fire-generated thunderstorms events in this region.

FFDI and C-Haines are just two of many factors that influence fire-generated thunderstorm formation. Climate change may also potentially influence ignition risk from lightning occurrence, particularly for dry lightning when little rainfall accompanies the lightning.

Climate change is likely to increase the amount of fuel available for burning due to the increased atmospheric carbon dioxide concentrations enhancing vegetation growth. Prolonged drought and more frequent high temperatures may also result in drier fuels.

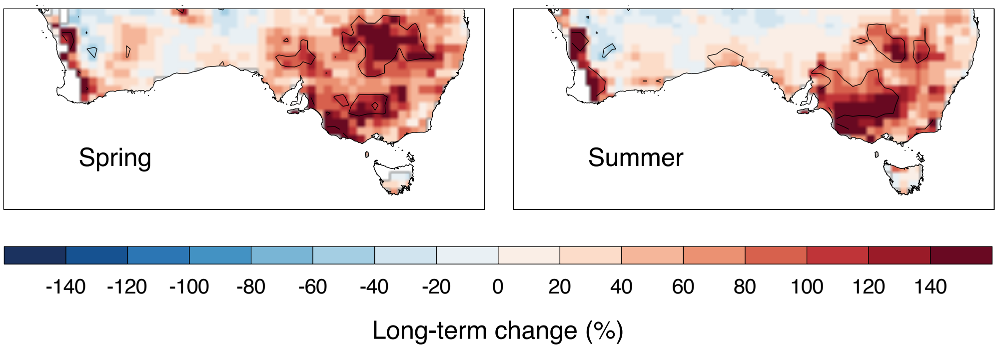

Figure 4: **Long-term increases in fire-danger days have already increased two risk factors associated with fire-generated thunderstorms.** The difference in the number of dangerous days is shown here based on the change from the time period 1979–1997 to the time period 1998–2016. This is for the number of days at a given location that both the Forest Fire Danger Index (FFDI) and C-Haines index are high (both > 95th percentile). Black contours indicate statistically significant changes at the 95% confidence level. For details see *Dowdy and Pepler* (2018).

Future changes in fire-generated thunderstorms

Climate projections under a high emissions scenario indicate a continued increasing trend for more dangerous near-surface weather conditions for bushfires in the future for many regions of Australia.

This would be exacerbated by the increased occurrence of extreme heat events as well as humidity changes that can increase the risk of dry fuel conditions.

Projections also indicate a future increase in the C-Haines index for many regions of southern Australia, while some regions in northern and eastern Australia may experience a decrease.

The combination of these changes may result in some areas, particularly in south-east Australia, experiencing an increase in the frequency of fires that become large and intense enough to generate thunderstorms.

With the increasing frequency of reported fire-generated thunderstorms and indications that they might become even more frequent in the future, there is a need for increased preparedness. This includes improved understanding of the phenomena (i.e. when do fire-generated thunderstorms become dangerous) as well as improved prediction capabilities and warning systems. Further research on these issues is needed to better understand these events and develop improved prediction tools.

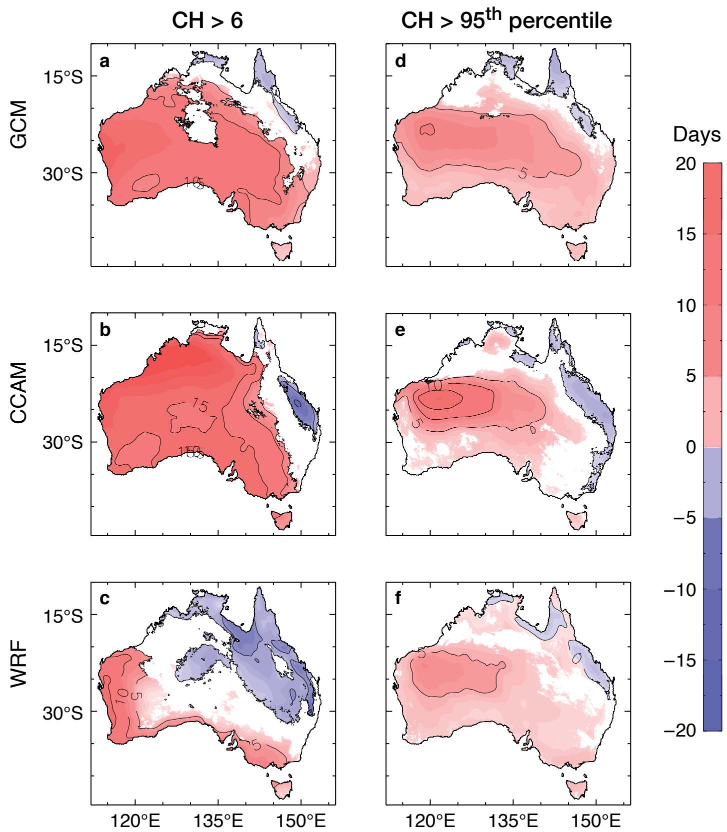

Figure 5: **Future increase in risk factors associated with fire-generated thunderstorms in southern Australia.** This is shown for three different climate modelling approaches, including global climate model (GCM) projections, the CCAM regional climate model, and a suite of regional climate models from the NARCliM project (WRF). Results are presented as the percentage change from the time period 1990–2009 to 2060–2079 in the number of dangerous days (based on C-Haines Index exceeding a value of 6, as well as based on C-Haines exceeding its historical 95th percentile) under high emission pathways (RCP8.5). Coloured regions represent locations where at least two thirds of the models agree on the direction of change. For details see *Dowdy et al*. (2019).

Climate change is likely to result in a change in seasonality for periods when the weather is suitable for conducting prescribed burns. This will have consequences for emergency management practises.
Image: Alf Manciagli/Shutterstock.com

Climate change science to inform emergency planning practices: fuel reduction burning

Climate change science information is critical to help deal with current and future impacts of extreme weather hazards, including those caused by fire-generated thunderstorms and extreme bushfires.

The Earth Systems and Climate Change (ESCC) Hub has produced data, information and provided advice on current trends and future changes to weather hazards relevant to Australian decision makers and managers.

For example, the NSW Bushfire Inquiry into the 2019/2020 fires recommended that targeted fuel-reduction burning could be performed to reduce the risk of fire-generated thunderstorms. In response, and to inform emergency planning and preparation, ESCC Hub researchers developed future projections of conditions favourable for prescribed burning.

In south-eastern Australia, current prescribed burns are conducted during autumn (March-May) and early spring (September), but rarely during winter (June-August). However, as our climate continues to warm emergency managers need to know how opportunities for conducting these burns might change in the future. This is particularly important for forest and woodland areas adjacent to populated urban areas.

Research conducted by the ESCC Hub found that in many south-eastern regions of Australia, future windows for conducting prescribed burns are projected to decrease during the months currently used for conducting burns. In contrast, burn windows are projected to generally increase in the winter months.

These are periods when current prescribed burns are less commonly conducted. This change in seasonality means that these periods could be more suitable for conducting burns in future. This information therefore provides important input into preparation and resource allocation planning for future bushfire seasons in south-eastern Australia.

>>> FURTHER INFORMATION

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- Additional details on hazardous weather phenomena in Australia's changing climate are available from the ESCC Hub website: http://nespclimate.com.au/extreme-weather-hazards-in-a-changing-climate-project-5-5/

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