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Modes of pyroCb development in southeast Australia

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Abstract: Pyrocumulonimbus (pyroCb)—bushfire-generated thunderstorms—have been associated with extreme fire behaviours during some of Australia's most notorious and destructive bushfire events, including Ash Wednesday 1983, Canberra 2003, Black Saturday 2009, and the Black Summer of 2019-20. PyroCb are increasingly common in Australia. Since the first recorded pyroCb in 1983, 144 events have been recorded, with over 100 of those occurring just since 2010. The southeast mainland (Victoria, New South Wales, and the Australian Capital Territory) is particularly vulnerable (McRae 2025).

The collective understanding of conditions favourable for pyroCb is still somewhat limited, but an ever-increasing number of case studies has provided substantial insights into the variety of atmospheric conditions in which pyroCb develop. One such insight is that at least two modes of pyroCb development are common in southeast Australia. In one mode, pyroCb development is dependent on the passage of a surface boundary—such as a cold front or trough. In the other, pyroCb development occurs independent of a boundary passage, typically in conditions more favourable for conventional thunderstorm development that change more subtly, though specific circumstances for this type of event have varied (Fig. 1).

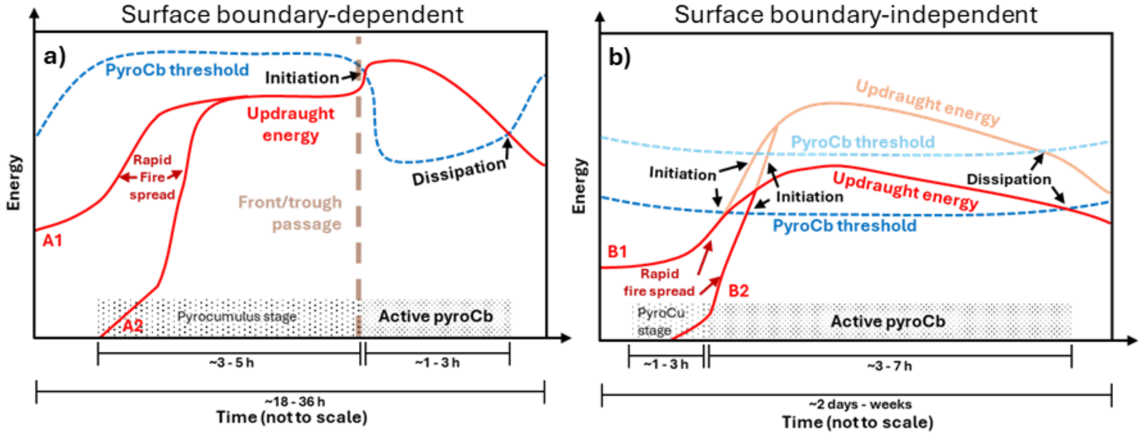

Figure 1. Schematic time series for: a) surface boundary-dependent and b) surface boundary-independent pyroCb events. Updraft energy is influenced by the fire's heat release, its size and shape, and ambient atmospheric buoyancy. A1/B1 and A2/B2 represent mature fire-induced pyroCb events and same-day ignition-pyroCb development events, respectively. In (b), light blue/light orange correspond to relatively dry events where the fire must contribute more energy for pyroCb to initiate, while red/dark blue correspond to relatively moist events with a lower pyroCb threshold.

Here we detail two pyroCb events in southeast Australia, each representing one of the two common modes of development: the 2017 Sir Ivan fire and pyroCb in New South Wales (boundary-dependent) and the 2019 Licola fire and pyroCb pair in Victoria (boundary-independent). For both cases, high-resolution numerical weather modelling was used to simulate atmospheric conditions across the fireground and surrounding areas from the lead-up to pyroCb initiation through to dissipation.

The Sir Ivan fire began 11 February 2017. Overnight and into the following day, the fire spread rapidly under extreme fire weather conditions. In the mid-afternoon of 12 February, a pre-frontal surface trough passed over the fireground, rapidly bringing slightly cooler and significantly moister near-surface conditions. Because the surge in low-level moisture outpaced the decrease in surface temperature, significant instability was introduced to the fireground. Almost immediately upon the trough's arrival, a long-lived pyrocumulus emanating from the fire grew explosively into a pyroCb that exhibited supercell thunderstorm behaviour (Terrasson et al. 2019). The pyroCb lasted approximately 2 hours before dissipating under increasingly cooler, more stable conditions.

The 3 March 2019 Licola pyroCb pair were part of a multi-day pyroCb outbreak in the Gippsland region of Victoria. These pyroCb formed well ahead of an approaching synoptic-scale surface trough, in an environment that was conditionally favourable for thunderstorm development and remained so throughout much of that day. The pyroCb were both long-lasting, with the eastern pyroCb lasting over 5 hours. Both pyroCb dissipated before the arrival of the surface trough.

Given the potential dangers that pyroCb pose to anyone in their vicinity, better understanding the variety of atmospheric environments associated with different modes of pyroCb development is of great importance. Such insights may be highly useful in developing a conceptual framework for pyroCb development in Australia's most pyroCb-prone region. This framework could in turn be useful to researchers, fire weather forecasters, fire behaviour analysts, and decision-makers at the fireground itself by providing important context for interpreting and anticipating future events. Furthermore, a clearer understanding of pyroCb development modes sheds more light on the complex relationships between the key components of pyroCb formation—including weather conditions near the surface and aloft, fire dynamics (e.g., fire behaviours and the size, geometry, and intensity of flaming regions (Badlan et al. 2021a, 2021b), and the feedbacks between these factors. As Australia's climate continues to change and pyroCb become more frequent and potentially more destructive, a clearer grasp of the modes of pyroCb development is essential.

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