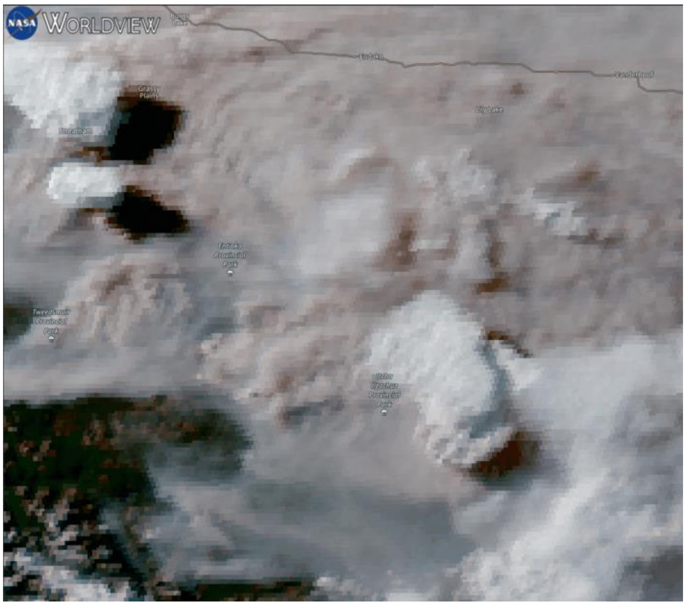
-THE LEGACY OF BLACK SUMMER-

The context of, and lessons from, Australia's Black Summer bushfires in 2019-2020.

A TAXONOMY OF VIOLENT PYRO-CONVECTION



ABI sunset view of a pyroCb cluster (type 7), British Columbia, 13 July 2023 0250UTC.

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PREAMBLE

When a fire forms deep flaming, it can rapidly change its behaviour, and become dangerous to fire crews and the community. When such a Blow-Up Fire Event (BUFE) occurs, it typically lasts up to three hours and defies all attempts at suppression. Containment efforts often make matters worse. The only incident objective then must be to save lives. It is therefore essential that we do everything that we can to understand these events.

For decades there has been a global scientific collaboration looking at the most obvious manifestation of BUFEs, the fire thunderstorm, or pyroCb. These are readily seen in satellite imagery, and have been logged for many years. Increasingly, fire services are paying attention to pyroCbs.

There are a number of forms of pyroCb that can be distinguished. Being able to distinguish these using remote sensing allows at times a better understanding of events on the fire ground that caused them – and, critically, the potential for more events in the near future. This is a valuable lesson-learning process, which at times requires significant changes in the existing thinking of fire services.

Significantly, there are also other forms of BUFE that are not readily discriminated in satellite imagery. There is a need to routinely use radiosonde profiles, weather radar, and any other sources of information that may be to hand. The distribution of critical elements over the landscape and over time are needed to fully resolve fire dynamics and the resulting Violent Pyro-Convection (VPC). The dichotomous key below uses that data.

A new BUFE forecasting tool for south-east Australia is available:
https://www.highfirerisk.com.au/hpf/

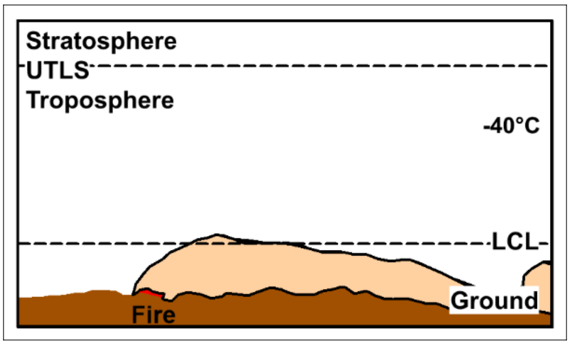
VIOLENT PYRO-CONVECTION (VPC)

A fire's local intensity determines the local behaviour of the smoke plume above it. Very low intensity produces sluggish, white, wispy smoke that rapidly mixes out with the surrounding air. As intensity increases, the smoke gains in density and persists longer, while rising, before mixing out. As defined by Brian Potter, there are series of stages as a plume builds. Here we will look at two end stages.

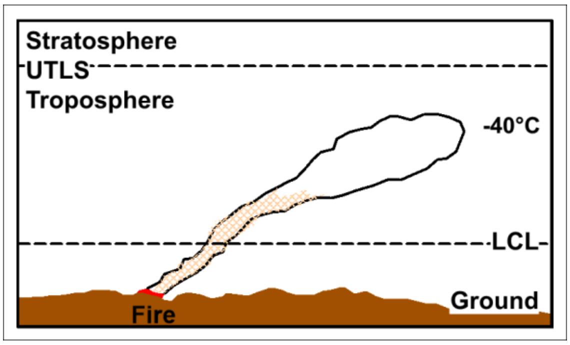
VPC Scenario 1. At very high intensities, the plume resists mixing out as it rises, and punches out of the mixed layer. The plume rises well above the top of that layer (the Lifted Condensation Level, LCL, or cloud base). Above the LCL there will be a pyrocloud within the plume.

VPC Scenario 2. At very high intensities, the plume is trapped below a low-level inversion and moves downwind under that cap. Typically no pyrocloud forms, apart from some localised pyroCu.

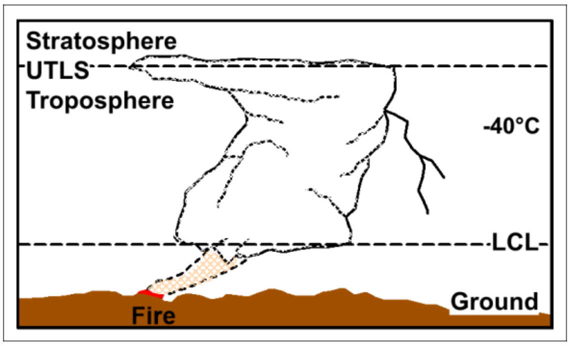
Note that events that fail both (a) and (a*) are not VPC events – they are likely steady-state fire events, not covered here.



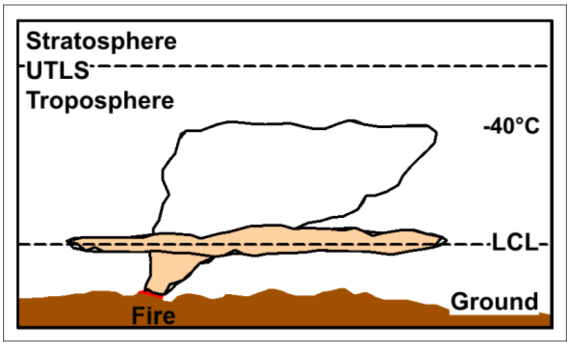
Type 1: Foehn effect event.



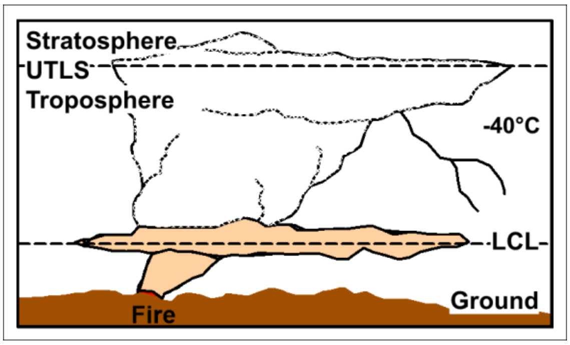
Type 2: Pyro-puff event.



Type 3: Fire enhanced ambient Cb event.



Type 4: Tier 2 event.



Type 5: PyroCb event.

Idealised depictions of key types of violent pyro-convective events.

a) Very stable profile (more than 8°C convective cap).

With a strong convective cap a kilometre or so above the fire ground (typically below the LCL), convection is limited while advection dominates. Most events are isentropic drawdown, so are in the lee of high country and feature downslope laminar flow. There is also a hydraulic jump, up to 100 km downwind, which while rarely above the fireground, could produce dangerously unpredictable fire behaviour.

These events have long been common in, for example, California and the Mediterranean basin. They recently became newsworthy in Hawaii. They were not recorded in Australia prior to 2010, and yet were behind half of major fire events during Black Summer.

These fires spread by dense short and medium range spotting, and are thus poorly held (if at all) by most containment options (even with no fuel for 1.5 km). They present significant safety risks for fire crews, especially if the occurrence of dense spotting is not anticipated.

Type 1. Foehn-effect fires

a*) Unstable profile (less than 4°C convective cap).

When VPC initiates without a convective cap, the plume is typically over a deep flaming

event. The heat from this causes radiative forcing of the aerosol-filled plume. Airborne infrared imagery above the BUFE shows reflection, scattering and re-radiation underway for up to 2 km above the fire. This aids vigorous convection with little mixing out.
Prior to initiation of VPC, there may be a "bow wave" cloud – a horse-shoe shaped lenticularis – wrapped around the upwind edge of the plume. The bow wave may also be detectable in satellite water vapour imagery.

b) No pyroCb produced.

c) Short-lived towering pyroCu, minimum average cloudtop temperature above -40°C. These events are typically due to a hot uphill run of a fire, but with insufficient mixing down of dry air aloft to sustain it after that run concludes. Potentially, burn-out ignition patterns could be involved, via pyrogenic potential. If this is possible, then such ignitions should be halted immediately. The duration of core plume generation is less than the time taken for the plume to reach maximum altitude.
Normal fire ground safety protocols should apply during such hot uphill runs, with monitoring for enhanced feedback developing.

Type 2. Pyro-puff (towering pyro-Cu)

c*) Prolonged VPC occurs.

d) Cbs occurring or about to occur within (typically) 50km of fire ground. The smoke plume can then be entrained into a Cb's inflow.
BUFEs are commonly linked to trough lines, as are Cbs - so it is not unexpected that in some cases there is an ambiguity between a Cb or pyroCb label. Evidence suggests that North American pyroCbs occur preferentially in conditions conducive to Cbs, whereas there is no evidence for this in Australia.
If the anvil has a cloud-top infrared Brightness Temperature (BT) anomaly, or is discoloured by aerosol, then it is a pyroCb (go to b*).
Beyond the normal fire-ground safety issues from Cbs, there is some evidence that extra care is needed on the fireground as fire behaviour is directly affected by these events.

Type 3. Fire-enhanced ambient Cb

d) Towering pyroCu blocked by inversion between LCL and UTLS. While outwardly resembling a pyroCb, these do not reach the required altitudes. Therefore, the cloudtop temperatures are not low enough, inhibiting in-cloud glaciation and lightning. The stronger the cap, the more the plume-top can visually resemble a pyroCb's anvil.
There can be interaction between fire weather and the plume, especially if the plume top is at high altitude, allowing strong convective dynamics near the fireground.

Type 4. Tier 2 event

b*) PyroCb produced.
PyroCbs reach the UTLS, and the resulting plume cloud has an anomalous BT temperature (i.e., 3.0 µm BT – 10.3 µm BT exceeding 50°C) due to the aerosol within it. Reaching the UTLS guarantees glaciation and lightning. Strong convection creates indraft winds that dominate fire behaviour. On reaching the LCL, the condensation of water vapour (from indrafts and from combustion) releases latent heat of condensation, which may be up to three times the heat from the fire. This enhances convection. For a large range of altitude the plume will be thermally expanding, and thus resisting mixing

out. This often gives the plume a cauliform appearance.
PyroCbs can often occur nocturnally, if the fire's energy release can negate the nocturnal inversion. Mixing down of dry air aloft or nocturnal low-level jets can be involved, as can burn-out ignition patterns.
PyroCbs can be initiated when a passing soliton breaks down the convective cap.

PYROCB:
A pyroCb has all of the following properties: 1) reaching the Upper Troposphere / lower Stratosphere (UTLS); (2) Cb morphology, including an anvil, sometimes an overshooting top, and a cauliform texture to the basal parts; (3) glaciation (and perhaps subsequent lightning generation) when average cloud-top BT falls below -40°C; and (4) an unambiguous linkage to convection immediately above the fire. The duration of core plume formation exceeds the time taken to reach the UTLS, so the anvil is clearly linked to the fire.
The fire needs to form deep flaming under an unstable atmospheric profile.
These fires spread by dense short and medium range spotting, and are thus poorly held (if at all) by most containment options (even with no fuel for 1.5 km). They present significant safety risks for fire crews, especially if the occurrence of dense spotting is neither forecast nor detected.
The pyroCb event may emerge from only a small part of the fire's extent – the rest must not be overlooked.

A fire that creates a pyroCb: radically changes winds around the fire edge; impedes situational awareness; creates major vorticity events; causes low oxygen combustion; and, as a result, creates ember storms. All of these are dangerous for fire crews. Pyrogenic lightning may cause new ignitions downwind (based on upper steering winds, nit surface winds).

e) Event with no context, likely isolated.
Due to the impacts on fire behaviour that they signify, it is important to further classify pyroCbs, below. Sometimes there is insufficient information to do so.
The affected Division should be treated as dangerous for fire crews for, nominally, three hours, with continuing re-assessment.

Type 5. PyroCb (no context)

e*) Event with context, either singular or in a group.

f) VPC initiation spans less than 2 hours.

g) VPC initiation spans less than 100km.
This is likely to be from a single fire or fire complex, and likely from a single Division. After initiation, the BUFE typically lasts around three hours.
The affected Division should be treated as dangerous for fire crews for, nominally, three hours, with continuing re-assessment.

Type 6. PyroCb event

g*) VPC initiation spans more than 100km.
On a landscape with multiple fires, or fire complexes, conditions amenable to

BUFEs may occur nearly simultaneously on more than one fire. This is sensitive to spacing across the landscape, and often shows passage of a trough, wind change event, or the sudden removal of a convective cap (such as by the removal of dense smoke).
All sectors and divisions of all fires involved should be treated as dangerous for fire crews for a minimum of three hours, with continuing re-assessment.

Type 7. PyroCb cluster

f*) VPC initiation exceeds 2 hours.

h) VPC initiation spans less than 100km.
Many events produce a series of pyroCbs from a common source area, whose size needs to consider the rate of expansion of the fire. The cause of these pulses has proven difficult to ascertain, but may be due to terrain patterns or to unstable feedback loops between the fire and its environment. Some or all pulses are pyroCbs, some may be Tier 2 events.
Pulses act to extend the window of dangerous conditions beyond those of single pyroCb events – perhaps for an entire shift - with continuing re-assessment.

Type 8. PyroCb Pulse

h*) VPC initiation spans more than 100km.

i) VPC initiation spans less than 200km or less than one day.
An outbreak is, simply, a combination of a cluster and of pulsing. Not all events in a cluster need to pulse.
All sectors and divisions of all fires involved should be continually assessed for danger to fire crews, with changes to incident objectives implemented as and when required.

Type 9. PyroCb outbreak

i*) VPC initiation spans more than 200km and one day.
This applies to regional conditions amenable to large numbers of BUFEs over a number of days. There has been only one recorded super outbreak – in southeast Australia between 28 December 2019 and 4 January 2020. This was associated with branched inshore troughs ahead of a stalled cold front. A low-pressure recirculation formed, keeping fire behaviour elevated.
All sectors and divisions of all fires involved should be continually assessed for danger to fire crews, with changes to incident objectives implemented as and when required.

Type 10. PyroCb super outbreak

FOOTNOTE: This does not include “MegaFire”, the often misunderstood steady-state fire concept.

FOOTNOTE: Terms like “pyro” and “pyro-convection” are being used operationally for VPC in some areas, but have little value, as both can be correctly applied to a candle flame.