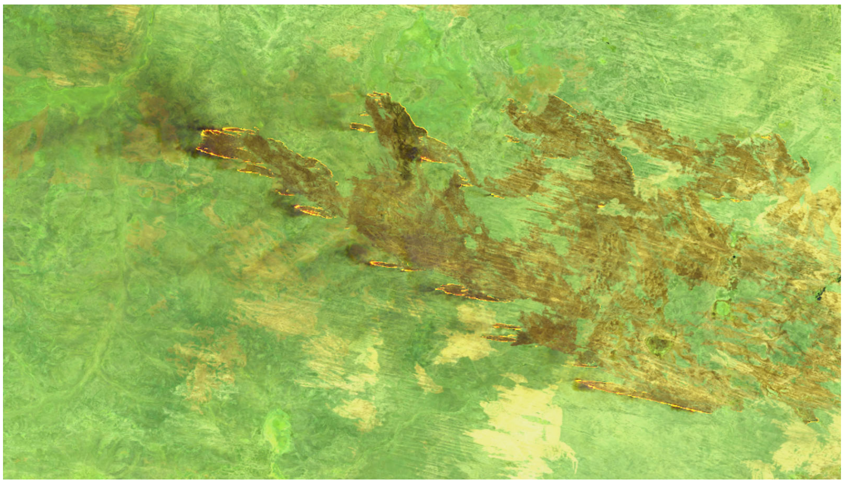
BLACK SUMMER: LESSONS FOR RAPID ADAPTATION



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BLACK SUMMER: LESSONS FOR RAPID ADAPTATION

This report details operationally significant outcomes from studies into the eastern Australian 20919-2020 Fire Season, known as Black Summer.

The work has been conducted by Adjunct Professor Rick McRae of the University of New South Wales, Canberra School of Science, located at the Australian Defence Force Academy. He has over 30 years of high level operational experience, including arson investigation, Level 3 Planning Officer, Fire Behaviour Analyst (including interstate and international deployments) and risk analyst. He has been conducting scientific studies into wildfires for 34 years. He has been involved in organising national workshops and conferences and international conferences.

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BLACK SUMMER: LESSONS FOR RAPID ADAPTATION

The 2019-2020 East Australian fire season, termed Black Summer (or BS for short), showed that many of the principles used to mitigate wildfire risk to the community are no longer valid during such fire seasons.

While fire crews did extraordinary work tackling each fire during BS, the overview of the season raises alarming prospects about where climate change will take us in future years. Managing fires in such scenarios will require a recognition that rapid adaptation is essential.

While the principles of fire fighting that have been used in past decades are still fully valid most of the time, there are events where new principles apply, and new tools must be used. As things worsen over time (Figure 1S, the use of the old tools will have increasing undesirable consequences.

The Operational Tools described below come together to form what is called the Hierarchical Predictive Framework. This is a nested set of four tools, each working on a finer spatio-temporal scale

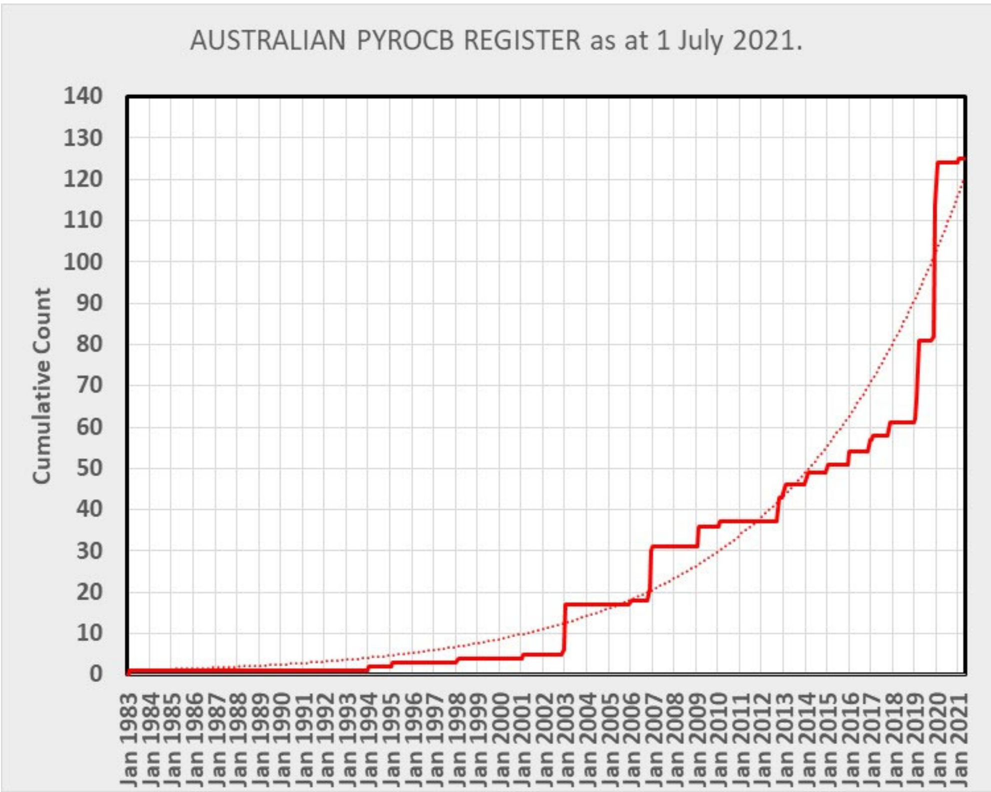


Figure 1. The cumulative count of Australian fire thunderstorm events (pyroCbs). An indicative exponential trend line has been added. The count doubled over Black Summer. (Data: Australian PyroCb Register, http://www.highfirerisk.com.au/pyrocb/register.htm)

OPERATIONAL TOOLS

It is vital that studies are conducted whenever there are fires with undesirable outcomes. Often it is suitable for fire services to conduct post-incident analyses with the aim of identifying lessons-learned that can be included in training programs to avoid future repeat of those outcomes. This also serves to reinforce operational doctrine, building a sturdier foundation for confident fire suppression operations.

Black Summer exceeded anything experienced in eastern Australia, in terms of the number of major fires, the extent of the burned area, the types of forest burnt, the intensity of the fires and their impact on the atmosphere. At their peak (Figure 2), almost 100,000 hectares were consumed per hour, at a fire power of almost a million MegaWatts. This is beyond the scope of post-incident analyses.

A number of scientific studies into BS are yielding important results. Rather than wait for the peer-review process to work, key findings are collated here.

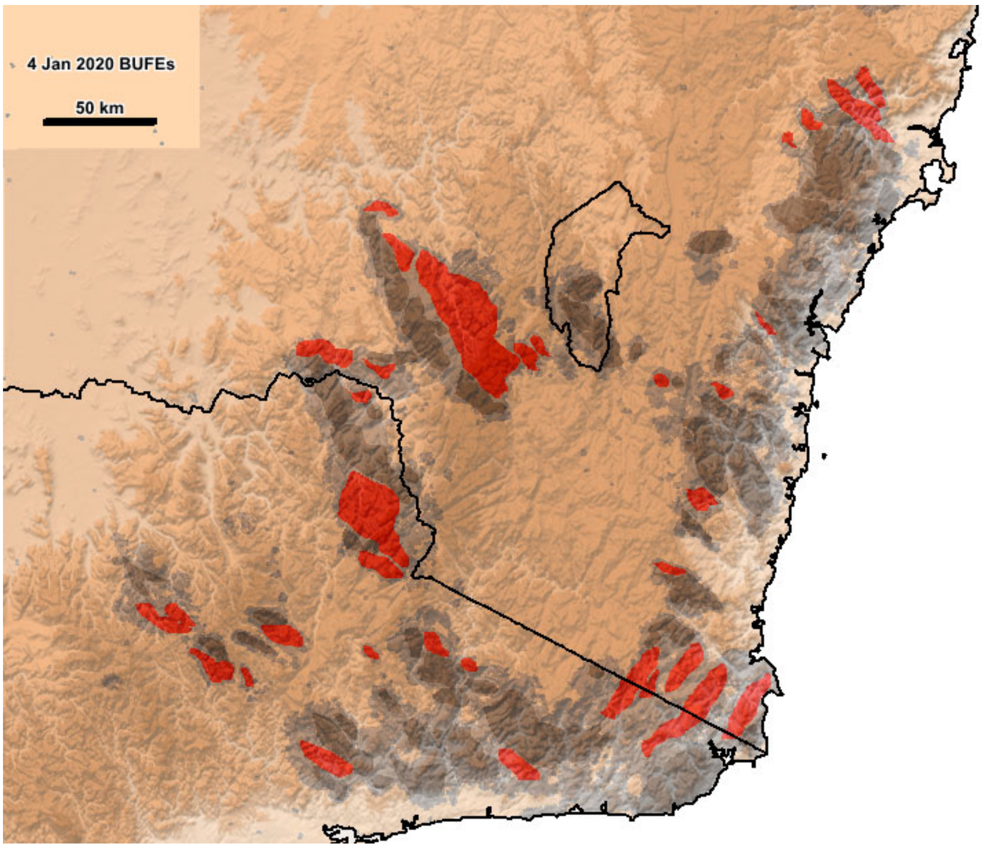


Figure 2. Areas that burnt during 4th January 2020 are shown in red. Areas in darker grey burnt in BUFEs on other days, while lighter grey shows all other areas burnt during BS.

HIERARCHICAL PREDICTIVE FRAMEWORK

Overview

There are a number of very effective systems for assessing wildfire outlooks. These are all based on quasi-steady state fire behaviour – where, if you know the fuel, the terrain and the weather you have a good idea of what a fire could do. Extreme wildfires, and BUFEs in particular are now known to follow different rules. This requires tailored predictive tools.

The Hierarchical Predictive Framework was developed from operational l4essons and applies to the forested landscapes of the South-East.

See:

McRae, R.H.D. (2023). Operational prediction of extreme wildfires. *Australian Journal of Emergency Management*, **38(4)**: 67-76.

McRae, R.H.D. (2024). Results for predicting blow-up fire events using the Hierarchical Predictive Framework. *Australian Journal of Emergency Management*, **39(4)**: 139-142.

The Framework has four nested levels, each valid over different time frames, as shown in Figure 3.

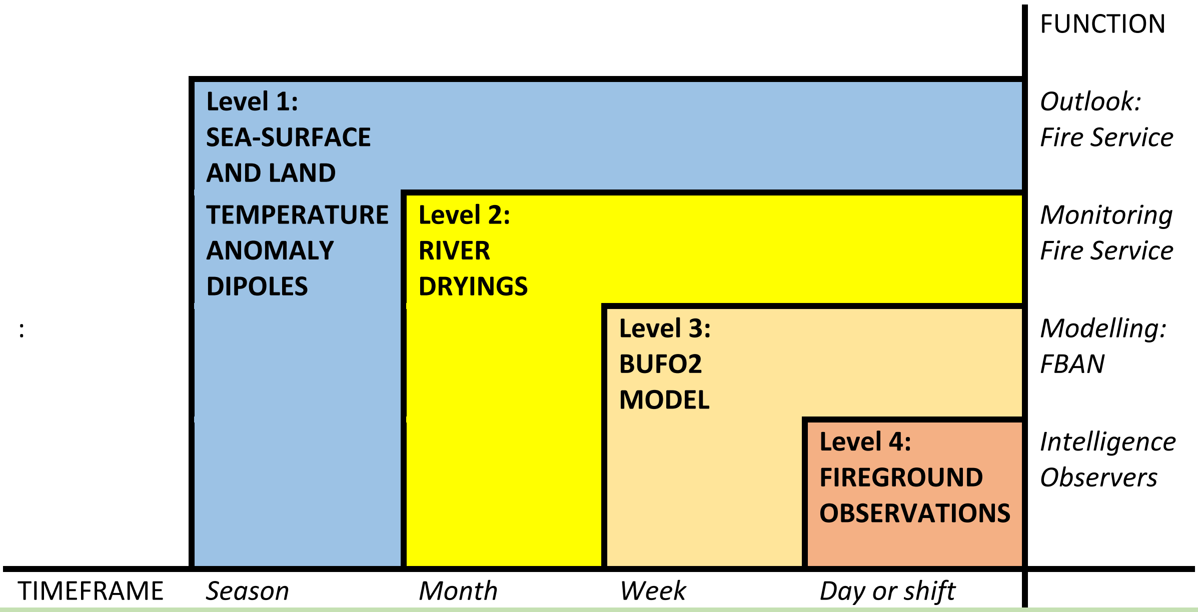


Figure 3. The Framework.

Level 1: On a seasonal level, the outlook is based on temperature anomalies. While there is over four decades of experience with seasonal outlooks looking at sea surface temperature anomalies (SSTAs), especially the ENSO, these do not resolve times when BUFEs are a problem, rather they work for times of elevated fire danger (which is used in Level 3 as a boundary condition only).

Instead, the Framework uses a dipole – the difference between 12-month averaged temperature anomalies at Canberra and a nearby part of the Tasman Sea. If this meets three criteria, then an alert is issued for conditions amenable to BUFE formation. A Level 1 alert requires a Level 2 analysis.

Level 2: On a monthly basis river flows are monitored. It has been found that when river flows decay in a particular way, or cease altogether, deep soil drainage has ceased. This means that there is no moisture input into fine fire fuels from the soil at all. It also indicates that large downed-fuels (such as logs) are also fully flammable. This facilitates the occurrence of fuels dry enough to aid the formation of deep flaming and thus of fire coupling with the atmosphere above. This forms dynamic fire behaviour, which features feedback loops which in turn cause rapid fire escalation into a BUFE. A Level 2 alert requires a Level 3 analysis, and switch in emphasis from agency preparedness to the management of one or more fires.

Level 3: The BUFO2 (Blow-Up Fire Outlook) model looks at forecasts or observations to see if there is a potential for BUFE or pyroCb occurrence. It relates the seven known causes of deep flaming to the synoptic setting. BUFO2 can be run for a single time or for a time-series of weather data. BUFO2 can be run for a hypothetical fire using certain assumptions. A Level 3 alert requires a focus on Level 4 field intelligence gathering.

Level 4: There sets of phenomena or weather patterns that are known to be associated with the potential for or the occurrence of BUFEs due various drivers. Those tasked with field observations need to be familiar with these and able to report them back into the Incident Management Team. Such staff may be from the Operations, Planning or Safety units on the IMT. Communications staff need to able to accurately report technical terms, and appreciate their priority.

A Level 4 alert should be used immediately by the Incident Management Team for a relevant fire to ensure that the IAP remains relevant, to conduct a dynamic risk assessment and to ensure the safety of fire crews and the affected community.

Details

Each level is described in detailed separately below.

LEVEL 1: Canberra Dipole

Overview

The Canberra Dipole is a predictive outlook index, designed to indicate conditions suitable for both BUFEs and pyroCbs across southeast Australia. It forms Level 1 of the Hierarchical Predictive System.

If certain conditions are met, then a Level 1 alert is issued for the coming month, and then (and only then) Level 2 needs to be considered.

Details

The Canberra Dipole is an index that compares temperature anomalies at Canberra Airport and offshore from the south coast of NSW. In both cases the anomaly is the actual monthly average temperature minus the climatological mean temperature (Figure 4).

Both are climbing over the decades due to climate change. They tend to warm up for some years, reach a "crescendo" (as happened during Black summer) and then plummet into negative conditions for a couple of years before climbing back to the previous warming trendline. The plummets correspond to major La Nina events, but the peaks are no longer linked to El Nino events.

Typically swings in the ocean lag behind swings on land by about 8 months, although the ocean swing after BS was quite minor.

The Dipole produces an alert when all of the following conditions are in place:

Condition 1: It is summer or close to summer, and…

Condition 2: the dipole is positive, and…

Condition 3: the dipole is not falling.

If so, then an alert for seasonal conditions amenable to BUFEs is issued.

This can be further qualified if there are River Drying Events in place at the time. If there are, then the alert is upgraded to seasonal conditions suggesting BUFEs are imminent.

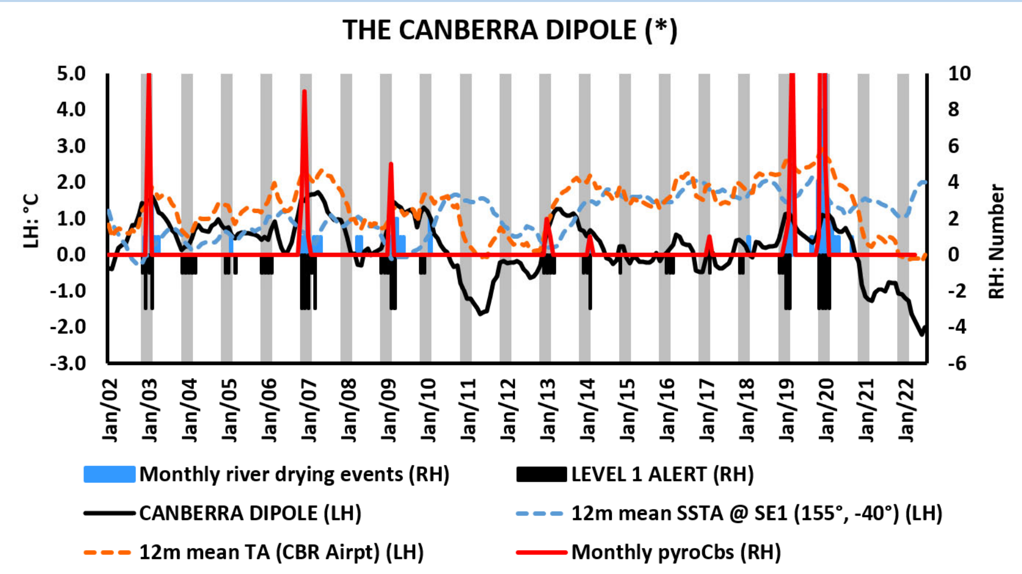


Figure 4. 20 years of Canberra Dipole data, showing the level of association between alerts (green bars) and extreme wildfire events (red line).

Canberra Airport was chosen because (a) it is near the centre of the activity pattern seen in the ANYSO event during BS, (b) it is not far from, and downwind of, the Wagga radiosonde launch site, and (c) a lot of other data are available for Canberra, providing a deeper context.

The sea surface temperature anomaly is based on a region not far off-shore from Narooma, centred at 155° -40°.

The dipole can be explained simply. If the TA is larger than the SSTA, the land is prone to heatwaves and tends to form heat lows. Thus, as isobars cross the coast from offshore, they will tend to turn right on the south coast (or left further north). This is equivalent to a ridge offshore and a trough onshore, both parallel to the coast. These alter the nature of sea breezes. They also interact with approaching synoptic troughs, producing complex semi-closed systems that recirculate smoke, creating operational hazards and public health risks. If the SSTA is larger than the TA, there opposite occurs. The isobars turn left, creating onshore ridges and off-shore troughs. These can brew up into an East Coast Low and bring extreme rainfall events.

Data

BoM monthly mean maximum temperature data for Canberra Airport (Station 070351) are accessed at:

http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=36&p_display_type=dataFile&p_startYear=&p_c=&p_stn_num=070351

Note that the climatology for this site also includes data for the old Canberra Airport site and for the transitional comparison site.

SSTA data are from NOAA's Coral Reef Watch service, accessed at:

https://coralreefwatch.noaa.gov/data_current/5km/v3.1_op/daily/png/ct5km_ssta_v3.1_global_current.png

LEVEL 2: River dryings

Overview

The monitoring of river flows is a monitoring index, designed to indicate the onset of conditions suitable for both BUFEs and pyroCbs across southeast Australia. It forms Level 2 of the Hierarchical Predictive System.

River flows, conceptually an inverse of Drought Factor, typically spike after useful rain, and then decay as a "concave" curve to a base level (Figure 5). In wet seasons that decay is often interrupted by another rain spike. This reflects upper soil moisture content. When that dries out, the base level reaches a critical level. Beyond that further decay follows a "convex" trend (Kulik 1990). This process indicates that the soil profile has dried out and that large dead-and-down fuel is fully flammable.

If certain other conditions are met, then a Level 2 alert is issued for the coming week, and then (and only then) Level 3 needs to be considered.

Details

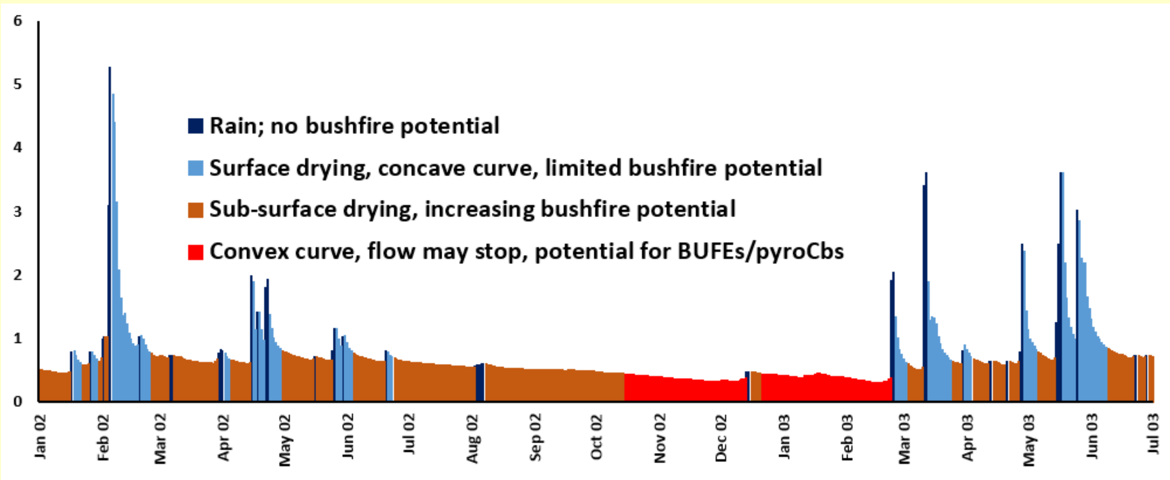


Figure 5. An example of river flow dynamics. During rain (dark blue) river levels rises and there is no bushfire potential – DF=0. Immediately after rain (light blue) there is a rapid fall of river levels back towards a base flow, and minimal bushfire potential – DF < 2. In the ensuing rain-free period (brown) there is a steadily increasing bushfire potential as the number of days since last rain increases. This reflects the drying-out of the upper soil layers and the decrease of soil moisture input into surface fine fuels – DF up to 10. After a critical level is reached (red) the river may case flowing of dry out rapidly, indicating the cessation of deep soil drainage, and the full drying out of all surface fuels – no measured by DF.

Reference: Kulik, V. (1990). Bushfire Hydrology: Runoff as an indicator of critical fire danger. Water Resources Development, 6, 44-54

Monitoring currently occurs across a reference set of 18 river monitoring stations .

Data are from BoM:

A Level 2 alert is issued if the following conditions are met:
- Number 1: 20% or more of the reference set are dry (i.e. below the flow level in Table 2).
- Number 2: The number of dry sites is rising.

It is expected that this would only be occurring during summer or autumn (in the absence of an autumn break). Nevertheless the seasonal context should always be reviewed.

Figure 6. Location map. Black dots are sites in Table 1.

Table 1. *Streamflow site metadata.*

No.	Site Code	Name	Latitude	Longitude	Owner	1st date on record	Minimum level (m)
1	216002	Clyde River at Brooman	-35.4681	150.2394	NSW DILW	8/07/1960	0.17
2	212021	MacDonald River at Howes Valley	-32.8611	150.8611	NSW DILW	9/02/1976	-0.20
3	41000261	Goobarragandra River at Mac's Crossing	-35.4183	148.4357	NSW DILW	13/06/2012	0.86
4	225219	MacAlister River at Glencairn	-37.5162	146.5665	Vic DELWP	7/04/1967	0.25
5	220004	Towamba River at Towamba	-37.0715	149.6593	NSW DILW	5/04/1970	0.35
6	212260	Kowmung River at Cedar Ford	-33.9481	150.2431	NSW DILW	17/05/1968	0.17
7	204014	Mann River at Mitchell	-29.6931	152.106	NSW DILW	10/05/1972	0.35
8	204051	Clarence River at Paddys Flat	-28.7198	152.4198	NSW DILW	26/03/1976	0.60
9	207015	Hastings River at Mt Seaview	-31.3683	152.2425	NSW DILW	31/05/1984	0.55
10	208001	Barrington River at Bob's Crossing	-32.0284	151.4671	NSW DILW	31/01/1944	0.47
11	410535	Murrumbidgee River above Tantangara Reservoir	-35.7706	148.5703	Snowy Hydro	2/05/1960	0.45
12	401554	Tooma River above Tooma Reservoir	-36.1	148.26	Snowy Hydro	19/09/1968	0.44
13	215208	Shoalhaven River at Hillview	-35.1845	149.9536	NSW DILW	6/11/1973	0.37
14	410734	Queanbeyan River at Tinderry	-35.6144	149.35	Icon Water	2/08/1966	0.65
15	403221	Reedy Creek	-36.3109	146.6012	Vic DELWP	11/11/1964	0.25
16	218007	Wadbilliga River at Wadbilliga	-36.257	149.6926	NSW DILW	12/06/1974	0.65
17	410731	Gudgenby River at Mt Tennent	-35.5722	149.0683	Icon Water	12/11/1964	0.35

LEVEL 3: BUFO2

Overview

BUFO2 is predictive tool for BUFEs and pyroCbs. It evolved from the original BUFO model based on new findings from BS.

BUFO2 works by tabulating forecast or observed processes that could lead to deep flaming, a key requirement for a BUFE – a fire coupling with the atmosphere.

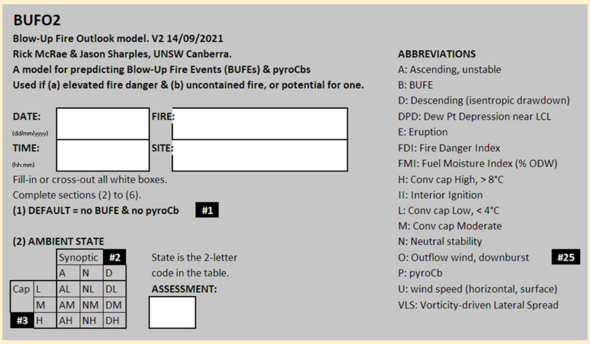
Details

BUFO2 can be run in two modes: A detailed analysis for a single time or a spreadsheet analysis for a forecast fire weather time series. The concepts are clear in the single time worksheet. There are six steps in the process.

(Step 1) DEFAULT = no BUFE, no outflow & no pyroCb.

Note the antecedent conditions required for the model to be run:

- Elevated Forest Fire Danger (although it seems that the cut-off may be as low as 40).
- An uncontained wildfire, or the potential for one.



BUFO2

Blow-Up Fire Outlook model. V2 14/09/2021

Rick McRae & Jason Sharples, UNSW Canberra.

A model for prepdicting Blow-Up Fire Events (BUFEs) & pyroCbs

Used if (a) elevated fire danger & (b) uncontained fire, or potential for one.

DATE: (dd/mm/yyyy) **FIRE:**

TIME: (hh:mm) **SITE:**

Fill-in or cross-out all white boxes.

Complete sections (2) to (6).

(1) DEFAULT = no BUFE & no pyroCb **#1**

(2) AMBIENT STATE

		Synoptic	#2	
		A	N	D
Cap	L	AL	NL	DL
	M	AM	NM	DM
#3	H	AH	NH	DH

State is the 2-letter code in the table.

ASSESSMENT:

ABBREVIATIONS

A: Ascending, unstable

B: BUFE

D: Descending (isentropic drawdown)

DPD: Dew Pt Depression near LCL

E: Eruption

FDI: Fire Danger Index

FMI: Fuel Moisture Index (% ODW)

H: Conv cap High, > 8°C

II: Interior Ignition

L: Conv cap Low, < 4°C

M: Conv cap Moderate

N: Neutral stability

O: Outflow wind, downburst **#25**

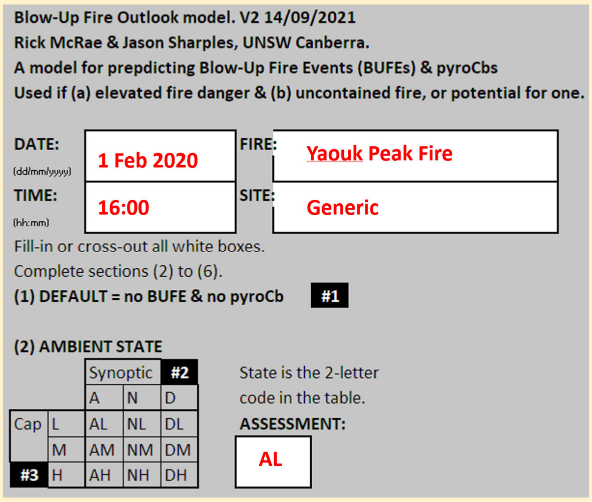
P: pyroCb

U: wind speed (horizontal, surface)

VLS: Vorticity-driven Lateral Spread

(Step 2) Ambient state

- How is the atmosphere above the fire configured?
- Synoptic state = [A]scending air; [N]eutral air; [D]escending (subsiding) air.
- Cap = [L]ow (up to 4°C); [M]edium (4 to 8°C); [H]igh (over 8°C)



Blow-Up Fire Outlook model. V2 14/09/2021

Rick McRae & Jason Sharples, UNSW Canberra.

A model for prepdicting Blow-Up Fire Events (BUFEs) & pyroCbs

Used if (a) elevated fire danger & (b) uncontained fire, or potential for one.

DATE: (dd/mm/yyyy) **1 Feb 2020** **FIRE:** **Yaouk Peak Fire**

TIME: (hh:mm) **16:00** **SITE:** **Generic**

Fill-in or cross-out all white boxes.

Complete sections (2) to (6).

(1) DEFAULT = no BUFE & no pyroCb **#1**

(2) AMBIENT STATE

		Synoptic	#2	
		A	N	D
Cap	L	AL	NL	DL
	M	AM	NM	DM
#3	H	AH	NH	DH

State is the 2-letter code in the table.

ASSESSMENT:

AL

(Step 3) Observations or forecasts

What do recent observations or current forecasts suggest might be in play around the fireground?

Column headings, grouped by data source:

Terrain data (from HighFireRisk website):

- Trench / gully? → eruptive growth
- VLS-prone land? → VLS potential

From radiosonde Skew-T plots:

- Dew Pt depression? → mixing down of dry air

From IMT or related sources:

- Fire nearby? → Fire in the feedback loop

Fuel state:

- Low FMI? → easy spotting
- Varying FMI? → unburnt areas can ignite later

Fire weather forecasts or observations:

- U > 25km/hr? → lee-slope eddy winds
- U > 40km/hr? → strong winds
- Wind change? → flanks become headfires

(Step 4) Drivers

- Are any of the seven causes of deep flaming possible (all tick boxes in a row are ticked)?
- Any [Yes] assessment causes a preliminary change from the default state (which is no BUFE + no pyroCb) to [Yes] for BUFE.

(3) OBSERVATIONS or FORECASTS Tick boxes if observed or predicted. **(4) DRIVERS**

Trench / gully?	VLS-prone landform?	Dew Pt depression?	Fire nearby?	Low FMI?	Varying FMI?	U > 25km/hr?	U > 40km/hr?	Wind change?		Tick if all requirements (3) in place.
✗			✓						Eruptive growth	✗
	✓		✓	✓		✓			Vorticity-driven lateral spread	✓
							✗		Fresh winds	✗
								✗	Wind change	✗
			✓		✗				Interior ignition	✗
	✓		✓	✓					Burnout	✓
		✓							Dew point depression	✓
Terrain (HFR)		Skw-T	IMT etc	Fuel state		Fire Wx				

(Step 5) Assessment qualifiers

- How does the ambient state alter the result of any drivers being present?
- Here we have AL…

(4) DRIVERS

(5) ASSESSMENT QUALIFIERS
If any drivers are present, then…
start with B, vary as directed. Ref [2] and [4]

	Tick if all requirements (3) in place.	AL?	AM?	NH? Or DH?	NH?	DH?
Eruptive growth	✗	Add P	Add P			
Vorticity-driven lateral spread	✓	Add P	Add P			
Fresh winds	✗	Add P				
Wind change	✗	Add P		None		
Interior ignition	✗	Add P			Add O	None
Burnout	✓	Add P			Add O	None
Dew point depression	✓	Add P			Add O	None

(Step 6) Result

- The key part.
- Data from observations or forecasts is turned into information about the drivers of events, which is then turned into intelligence about what the IAP has to address.

None?	No	(Y or N)
(B) BUFE?	Yes	
(P) PYROCB?	Yes	
(O) OUTFLOW?	No	

In this example, deep flaming could arise from:
---VLS if the fire is in VLS-prone landforms for the forecast winds,
---mixing down of dry air aloft if a hot uphill run is allowed or
---by over-zealous use of drip-torches.

A BUFE should be anticipated. If so, instability could allow a pyroCb to form.

It must be noted that fuel load is not included in this model. It has an implicit role through the need for a prior wildfire.
The worksheet includes a Glossary:

NOTES FOR BUFO2 MODEL

#1	The starting point is that boundary conditions exist, but there is no indication of a BUFE. The goal is to change that.
#2	Synoptic patterns affect the vertical air flow. Ascending air flow is most common ahead of troughs or fronts. Neutral is common with subsidence inversions under high pressure cells. Descending air flows are common zonal set-ups in the lee of high country.
#3	The scale of the Convective Cap is gained from the most appropriate radiosonde trace. Modelled profiles are often inaccurate on this matter.

#4	The literature on eruptive fire spread makes clear that it is dependent on a trench-shaped feature inclined above about 26°. (#18)
#5	VLS requires a break in slope aligned roughly at right-angles to the prevailing wind. See www.highfirerisk.com.au (HFR) for details. It also requires dry fuel to support dense spotting (#8)
#6	Dry air within 100hPa of the LCL can be mixed down to replace air made to rise in a vigorous convective column. This can increase fire behaviour, leading to a BUFE.
#7	In forecast mode, BUFO considers what a fire might do in the future, especially in terms of terrain (e.g. will it be on VLS-prone terrain when the wind exceeds 25km/hr? - see #10)
#8	Low fuel moisture is a requirement for dense spotting. A value below 5% of oven-dried weight is the cut-off.
#9	For a campaign fire, fuel moisture can vary with time, making previously unburnt patches flammable, allowing deep flaming to form.
#10	Lee-slope eddy winds tend to start when the prevailing winds exceed 25 km/hr. This is a requirement for VLS.
#11	Winds above 40km/hr may create deep flaming due solely to high headfire rate of spread.
#12	Wind changes have been known to create deep flaming.
#13	Terrain data includes more than slope, aspect and elevation. The VLS model should be used.
#14	This is extracted from Skew-T Log-P aerological diagrams.
#15	This requires fire spread predictions. It can include uncertainty (success of suppression, chance of spotting, etc). Data from IMTs, fire services, web sites, etc.
#16	Fuel state involves assessment of fuel availability - Drought Factor and fuel loads for forests fuels, or curing and fuel load for grasslands.
#17	Fire weather refers to the standard forecast products.
#18	Eruptions, or eruptive fire growth, is rapid acceleration due to fire entrainment in trench-like landforms. It includes ember storms at the top of that feature.
#19	VLS is the most efficient known process for forming deep flaming and the coupling of a fire with the atmosphere.
#20	Fresh winds can produce deep flaming, especially associated with uphill runs.
#21	Wind changes make a flank into a new headfire. Mostly this produces separate fingers of fire, but at times deep flaming can result.
#22	Interior Ignitions occurs where unburnt islands within previously burnt areas later acquire flammability and ignite. This can add up to deep flaming.
#23	Inappropriate use of incendiaries (under the auspices of an IAP) is an increasingly significant cause of BUFEs. It is especially important not to light into VLS prone landforms, and not light in a deep flaming pattern.
#24	Dew Point Depression events can cause rapid spikes in fire danger on the fire ground. The mixing down required often occurs after intense uphill runs.
#25	A fire on high ground can be quite close to the LCL. A hot uphill run can produce a plume that pushes hard against the cap. A rebound can produce an outflow wind, pushing the fire dangerously downslope.

References:

McRae, R.H.D. & Sharples, J.J. (2014). Forecasting conditions conducive to blow-up fire events CAWCR Research Letters, 11, 14-19.

McRae, R.H.D. & Sharples, J.J. (2013). A process model for forecasting conditions conducive to blow-up fire events. In J. Piantadosi, R. S. Anderssen, & J. Boland (Eds.), MODSIM2013, 20th International

Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand. Adelaide.

Tools

Application

Feedback

Expansion

HPF is optimised for forested areas of the south-east. It is not yet known how the concepts can be applied to other regions. Its application to Tasmania is being studied, while others are exploring the region between Melbourne and Adelaide. Of particular interest is SW Western Australia.

LEVEL 4: Field Intelligence

Overview

If a Level 3 alert has been issued for a specific fire or for a fire-affected area, it will be usually based on forecasts and outlooks. It becomes critical to set up field observation and information gathering capability to (a) detect the precursor signs of key expected events; (b) detect expected events and (c) confirm the occurrence of expected events.

If, for example, the Incident Controller has an intelligence need "Is this Watch-out situation likely?", then the information products required need to be developed and on-hand. This in turn drives data collection systems for that operational shift.

Details

From studies in Black Summer events, the following Watch-out situations are key:

New Watch-outs

- Cliff-top VLS, discovered in NSWRFS linescans.
- Dry air mixing down, a by-product of studies of CH data from BS.
- Beheaded fire vorticity, an explanation for some serious events during BS.
- Drumskin outflows

Existing watch-outs

- VLS
- Eruptive growth

They are described in detail below.

Cliff-top VLS

Overview

Evidence from the Green Wattle Creek Fire during Black Summer shows a new and potentially serious safety hazard for field fire crews. This hazard is a novel form of Vorticity-driven Lateral Spread (VLS), the most common cause of dangerous fire escalations.

The fire burnt around Lake Burragorang, in the Warragamba catchment, west of Sydney. This wilderness area consists of a sandstone plateau dissected by numerous deep, cliff-lined gullies and valleys.

On December 5th, 2019, the fire spotted across the stored water, heading easterly, and burnt up a west-facing slope to the base of, and over, the west-facing cliff. On reaching the clifftop, VLS occurred on a further west-facing but less steep slope, spreading sideways as well as spotting downwind for some kilometres.

Thanks to NSWRFS linescans, this is the first confirmed case of VLS not involving a change in aspect.

A new model for VLS uses second-order differentials to detect the changes in slope that initiate eddy winds and VLS. It provides a greater discrimination of areas that Operations Officers need to keep fire out of to avoid sudden escalation.

Such an escalation could rapidly create sudden loss of egress options and serious burnover conditions. It is likely that some past hallmark burnover case study fires have involved this process, but the awareness of the physics was not then available. This emphasises the need to revisit past fires as new fire behaviour studies are published.

Photos of this are not known. These ABC helicopter views show: [TOP] fire spreading laterally on a cliff-top, and [BOTTOM] the dark smoke column on the leading edge of a cliff-top VLS event. In this case the wind was towards the camera, but the watch-out guidance is still relevant.

[https://www.abc.net.au/news/2019-12-21/wind-fans-ferocious-flames-in-blue-mountains-np/11821338]

Details

Stylised example:

STEP 1: a fire is burning upslope with the wind towards the escarpment.

STEP 2: A fire crew drives into the area as lookouts (orange dot).

STEP 3: A spotfire starts on the clifftop, the fire crew drives up to the flank, maintaining a safe egress route.

STEP 4: The fire starts travelling sideways just above the clifftop. This is cliff-top Vorticity-driven Lateral Spread.

STEP 5: The VLS is established. The diagnostic dark smoke column appears. New spotfires start downwind.

STEP 6: The lateral spread and spotfires are entrapping the fire crew.

Tools

WATCH-OUT

A wind-driven spotfire above a cliff may suddenly spread sideways along the cliff-top while spotting downwind.
The wind at the fire needs to exceed 25 km/hr and the fuel must be dry (FMC < 5%).

Safe egress may suddenly be lost. Heavy smoke and dense spotting may cause loss of situational awareness. Lookouts are vital.

Dry air mixing down

Overview

Weather balloon flights are becoming increasingly common, with NSWRFS leading the way into a new era after recommendations from the Coronial Enquiry into the Wambelong Fire. Many FBANs use them to for the Continuous Haines-Index (CH), which is a measure of the potential for dangerous fire activity. CH considers two elements: the lapse rate and the dewpoint depression. BS showed that on many occasions when a BUFE occurred the lapse rate was high, leaving dew point depression was the key variable.

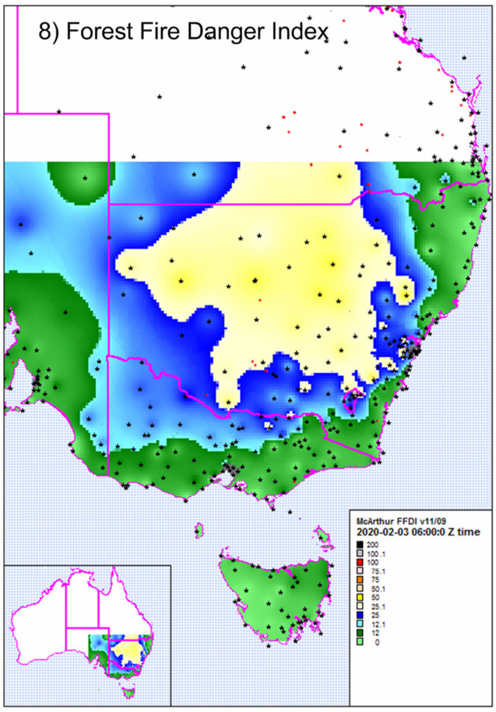
There were two main scenarios involved: if surface T & DP are widely separated, then the LCL is very high. Dry fine fuel is guaranteed once the nocturnal moisture and inversion have burnt off. In the other surface conditions did not lead to very dry fuel, but if dry air (due to a large dew point depression event at the 850 hPa pressure level) could mix down then dry fuel could occur. Leading to a rapid and perhaps unforecast increase in fire intensity.

It is now possible to anticipate this problem.

Details

This issue is best described by means of an example.

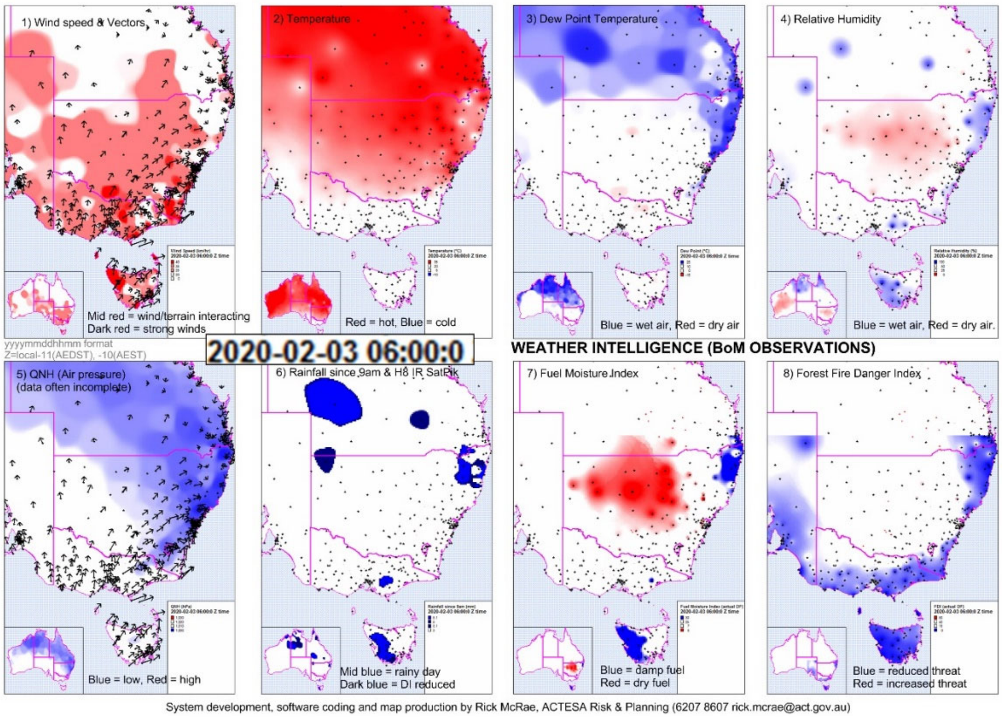
At 5pm on the 3rd of February, 2020, the FFDI in the Brindabella Ranges is High.



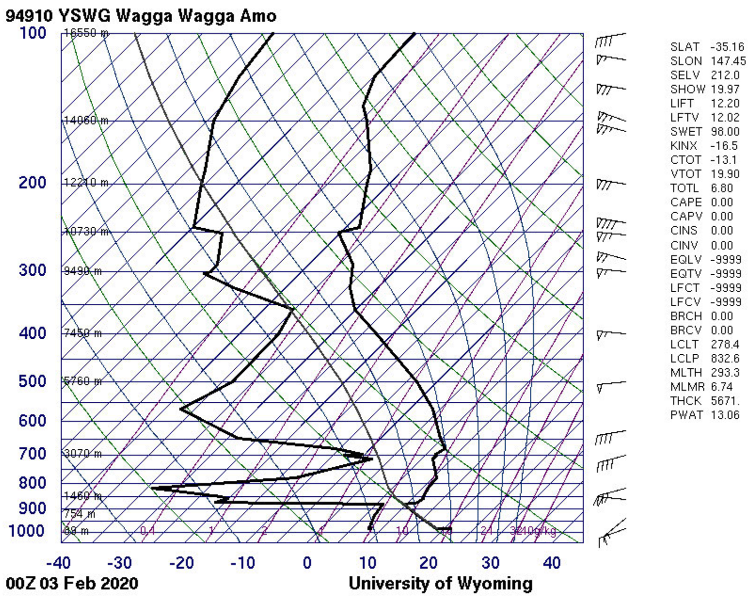
This reflects:

- Raised wind speeds, part of a predominately SW across SE Australia after the passage of a cold front.
- Warm temperature with an intermediate dew point and relative humidity.
- The Drought Factor is 10.

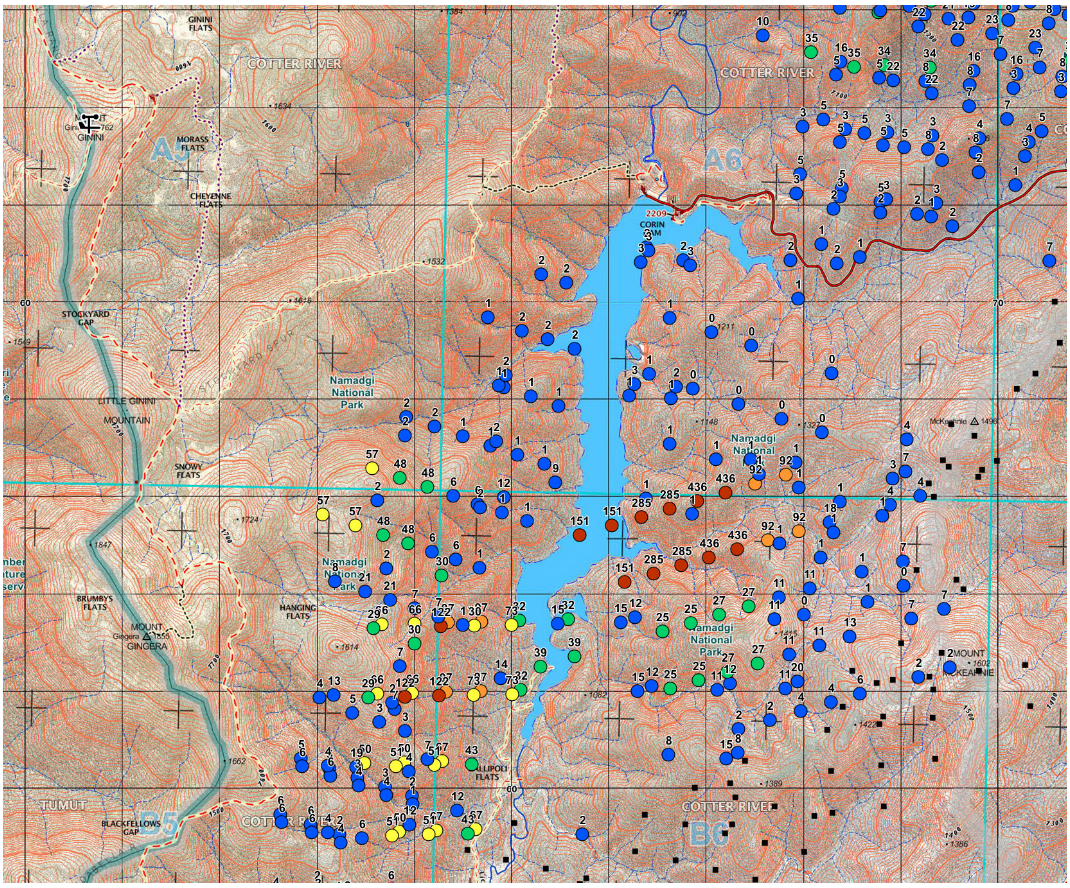
As a result the FMI is over 15%, not dry and not conducive to easy spotting.



The radiosonde data shows a major dew point depression event at about 870 hPa, or about 1400m ASL. Associated with this is a major convective cap.



Fire had been backing down off the plateau to the SE over the preceding days (1st February – black dots; 2nd February – no fire hotspots for that day in this area). On the 3rd fire was in a deep valley, with a lot of potential for hot uphill runs. The convected air needs to be replaced, but the valley constrains where it can come from. Thus air is forced to mix down from aloft. The dew point on the surface could fall as low as -20°C, making the RH as low as 6%. The FMI could fall to 6%, with easy spotting becoming a real potential. The FFDI could increase up to 2.5-fold.



The round dots are coloured to match the Fire Radiative Power from the VIIRS hotspot data. Blue = 0 to 25 MW; green = 25 to 50 MW; yellow = 50 to 75 MW, orange = 75 to 100 MW, red = over 100 MW. Mt Ginini AWS is at 1760 m ASL, above the dry air, while the hottest fire activity was at around 1200m ASL, hundreds of metres below the dry air.

The resultant fire behaviour is seen in the photo below, from Mt Stromlo Observatory.

This level of fire intensity is not what was expected from the baseline High FFDR, but is exactly as expected if the DP fell as described. Note the top of the plume – the large convective cap would make this a foehn driven plume, and violent pyro-convection would not be expected. However its absence should not be interpreted as indicating a lack of elevated fire intensity.

The RH at 850 hPa is about 12%. This is highly correlated with a raised CH, but, importantly, RH850 can be measured from an operational aircraft. Monitoring RH850 allows a useful lead-time for dangerous conditions associated with fire in deep valleys.

WATCH-OUT

On a day with High or Very High FFDR, an uncontained fire able to make a hot uphill run, especially in a deep valley, has the potential to cause dry air aloft to mix down, causing a sudden and dangerous rise in fire intensity. This is a form of feedback loop, and can suddenly reduce fire crew safety.

If the relative humidity at 1 or 1.5 km above the fire (monitored by operational aircrew) is at low values (or similar values to surface RH), then either (a) fire must be prevented from making the initial uphill run or (b) if this is not practical, fire crews should be withdrawn from the area (noting that the spread direction of a breakway would reflect prevailing wind direction, upper wind direction and terrain steering).

Tools

A tool is available to calculate the critical RH850 and advise air observers.

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Application

The tool works off surface weather observations and forecasts, and advises observers on critical values at 850 hPa. It can be used without a nearby radiosonde flight, but works better if one is available.

Weather models also produce maps of forecast RH850.

Beheaded fire vorticity

Overview

A hot forest fire burning downslope to a flat, grassy valley floor can suddenly lose its headfire intensity. Without the headfire, the recurved winds that have flowed around each flank can form intense vortices. These may separate from the fire and threaten fire crews and the community in the valley.

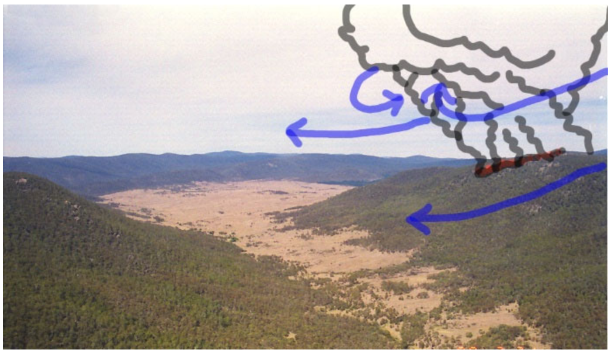
Beheaded fire whirl, 2006. (USFS)

Beheaded fire whirl, ACT, 2006. [McRae]

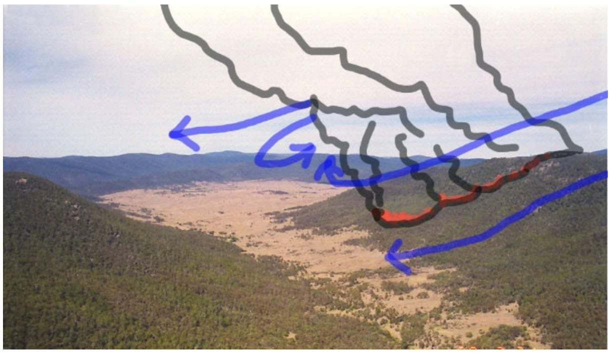
Details

This is best explained by means of a hypothetical example. Here, in the Gudgenby Valley in Namdgi National Park in the southern ACT, the winds are blowing from right to left.

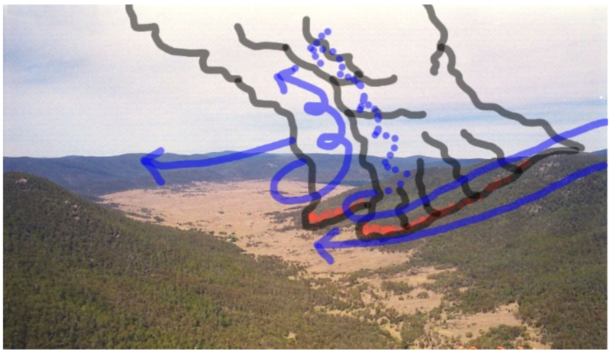
An intense forest fire crests the ridge and starts burning downslope towards the valley floor, which carries 100% grass curing. The vigorous convection column causes the winds to flow around it, swirling back in on the lee side – basically forming two vortices. Each rises rapidly. This is similar to the principle used by fire investigators, looking at charring on the lee side of tree trunks – which is higher than on the windward side for the same reason – rising vortices form on each side as the winds swirl into the lee side of the trunk.



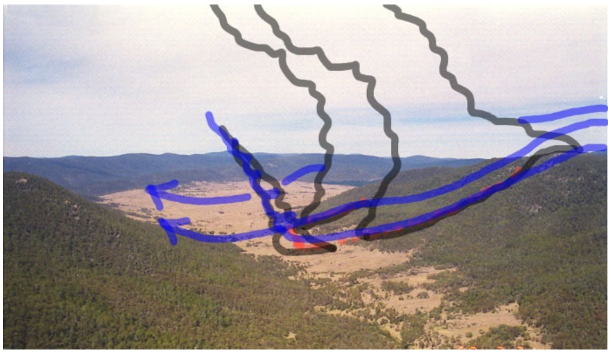
The fire progresses downslope. Even though it is a downslope run, the forest fuel loads maintain a raised intensity.



As the fire reaches the valley floor, the slope and fuels change at the same time. The grass fire has much lower intensity. The lee-vortices of the column can now swirl back into the burnt area, and form complete circulations around the ends of the more intense firelines on the flanks. This results in two isolated vortices on the foot of the downslope.



As the flanks ease, the vortices are able to detach and move downwind into the grasslands. This can create suddenly dangerous situations for field crews in such locations:



This process is not due to the fire coupling with the atmosphere to form dynamic fire behaviour. It is a consequence of the way that convective plumes form over hot forest fires.

Tools

WATCHOUT

Field crews should use extreme caution in the following situation:

- A day of elevated fire danger.
- A forest fire has moved down a steep slope onto a flat grassy valley floor.
- As the headfire rapidly abates due to the change in fuel, vortices on the end of the still hot flanks can separate and move downwind into the grassed area – even moving ahead of the fire.

It should be noted the low-level smoke can jeopardise both situational awareness and air operations.

Drumskin (outflow winds)

Studies of many plumes during Black Summer provided additional insights into plume dynamics that may affect the fire ground.

Many plume effects occur after the plume has risen many kilometres, during which time it will have advected tens of kilometres downwind. These effects are well outside the source fireground.

Some occur locally. These reflect the size of the convective cap around the LCL (Figure 8).

- If the cap is absent of small (indicatively 0°C to 4°C), then the plumes continues to rise freely, until it reaches either an upper-level inversion or the UTLS. The latter produces a pyroCb.
- If the cap is large (indicatively over 8°C), then the plumes cannot rise and are “trapped” at the LCL. This produces a smoke shield with or without towering pyroCu.
- If the cap is intermediate, then the plume gets mixed out trying to pass the cap, and no violent pyro-convection results.

Critically if the cap is just above 4°C there appears to be rebound at the LCL. The upward part creates pyroCu clouds, while the downward part can affect a fire, particularly if terrain brings the fire closer to the LCL. This involves outwash winds, which can drive a fire in unexpected directions, and downslope in a hot run if in rugged terrain.

This notion is founded on post-fire imagery (NDVI) which shows elevated intensity where a steep downslope run occurred. Other data then suggests that an outflow event occurred. More data and case studies are required to confirm this, but the fireground risks are so high that this being presented in its current form.

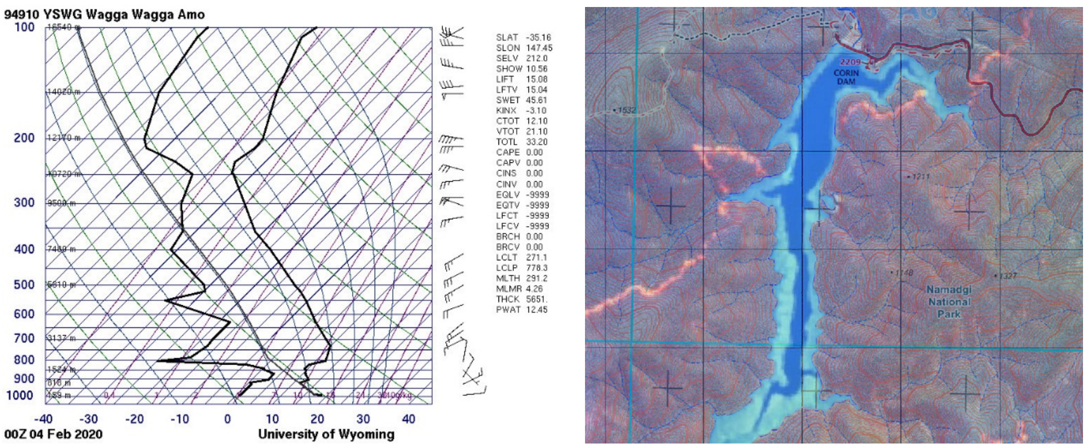


Figure 7. On 4 Feb 2020, a day with a large convective cap just under the LCL, which had been in place for ten days, and with a broadly southerly wind, the fire moved down off the plateau and crossed the dam. This type of dangerous behaviour is generally not anticipated.

This effect is item #25 in the BUFO worksheet.

WATCHOUT

Field crews should use extreme caution in the following situation:

- A day of elevated fire danger.
- A convective cap of around 4°C to 6°C near the LCL.
- Fire making a hot run, particularly if terrain brings it closer to the LCL.

This could result in outflow winds, pushing the fire in many directions, even downslope.

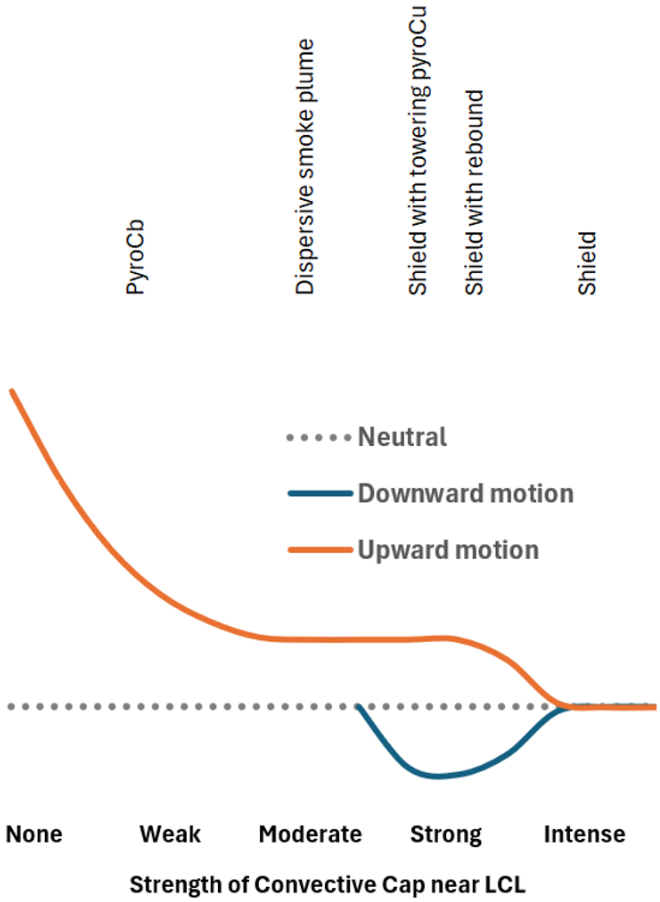


Figure 8. Changes in stability with convective cap size near LCL.

The following two Watch-outs were known before Black Summer, but their limited uptake so far makes it important to add them to this list. Both had major roles in Black Summer.

VLS

Vorticity-driven Lateral Spread is the most serious cause of dangerous fire conditions in rugged terrain. As it was only discovered in 2003, it was not considered for past landmark fire events. It is now likely to have been significantly involved in the following:

Hobart 1962;
Grays Point 1983;
Gudgenby 1983;
Ash Wednesday 1983;
Berringa 1995;
Wingello 1998;
Linton 1998;
Black Saturday 2009;
Black Summer 2019-2020.

VLS is item #19 in the BUFO worksheet.

WATCHOUT

Field crews should use extreme caution in the following situation:

- A time with Fine Fuel Moisture Content below 5%, facilitating easy spotting.
- Prevailing wind speeds over 25km/hr.
- Fire reaching a ridge top.

In these conditions fire will enter a lee-slope eddy wind and do two things simultaneously:

(a) Spot downwind for some kilometres;

(b) Move sideways along the lee crest, spotting downwind as it goes.

This forms deep flaming and a Blow Up Fire Event. This can be very dangerous for fire crews due to rapid development and sudden loss of situational awareness.

Any potential for this or occurrence of this requires the Incident Action Plan for affected sectors have the single objective of saving lives. This can last for up to three hours before reassessment.

Eruptive Growth

Eruptive wildfire growth was first recognized over two decades ago. It, in turn, has been linked to an historical fire in the Kings Cross Underground station in London. It concerns fire in a sloping trench-like landform. If that slope exceeds roughly 26° then the flames attached to the floor and can continue accelerating without limit until the trench ends. Thus, as has been seen on numerous occasions, a mild fire can enter a trench under relatively mild conditions and suddenly become dangerous to nearby fire crews. It is now likely to have been significantly involved in the following:

Ku-ring-gai 2000;
Canberra 2003;
Mansfield burnover 2006

Eruptive growth is item #18 in the BUFO worksheet.

Figure 9. Windrow trenches due to persistent effects on vegetation from the extreme intensity of post-2003 slash burns met the criteria for causing eruptive fire behaviour. Note the unburnt trenches in the foreground for comparison. (Air observer photo)

WATCHOUT

Field crews should use extreme caution in the following situation:

- A fire enters a steep, trench-like gully or canyon.

In these conditions fire may attached to the trench floor and develop eruptive growth. It will continue accelerating without limit until the trench ends. Flames and embers will blow close to the ground, making shelter difficult.

This can happen under mild conditions and develop suddenly. Situation awareness can be lost, especially under a forest canopy.

This can form deep flaming and a Blow-Up Fire Event, especially if an ember storm forms at the trench top. This can be very dangerous for fire crews due to rapid development and sudden loss of situational awareness.

Any potential for this or occurrence of this requires the Incident Action Plan for affected sectors have the single objective of saving lives. The priorities are (i) aiding crew who have escaped by running along contours; and (ii) confirming and locating any burn-over situations.

WEB SITE

An operational outlook service has been created:

http://www.highfirerisk.com.au/hpf/

This will be updated from time-to-time.

It must be noted that this is a draft product. All of the material reflects research that shows that the framework has performed well against data from the last twenty years. As we proceed it is important that monitoring is conducted to ensure that it continues to track well.

Feedback is important. Any feedback on performance of the system should be passed on to:

r.mcrae@unsw.edu.au

Of note HPF also indicates conditions amenable to heavy rainfalls

As the sites uses simple HTML coding, is should work well on all browsers, although has not been specifically designed for hand-held devices.

DATA

Temperature Anomaly:

BoM monthly mean maximum temperature data for Canberra Airport (Station 070351) are accessed at:

http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=36&p_display_type=dataFile&p_startYear=&p_c=&p_stn_num=070351

Note that the full analysis for this site also includes data for the old Canberra Airport site and for the transitional comparison site. The climatology used is the BoM-defined "climate normal", generated over the 30-year period 1 January 1961 to 31 December 1990.

Sea Surface Temperature Anomaly:

SSTA data are from NOAA's Coral Reef Watch service. Current maps are accessed at:

https://coralreefwatch.noaa.gov/data_current/5km/v3.1_op/daily/png/ct5km_ssta_v3.1_global_current.png

Maps for the first day of a specified month (with "mm" for the month and "yyyy" for the year) are at:

https://www.star.nesdis.noaa.gov/pub/sod/mecb/crw/data/5km/v3.1_op/image_browse/daily/ssta/png/yyyy/ct5km_ssta_v3.1_global_yyyymm01.png

For example, the map for January 2022 is at:
https://www.star.nesdis.noaa.gov/pub/sod/mecb/crw/data/5km/v3.1_op/image_browse/daily/ssta/png/2022/ct5km_ssta_v3.1_global_20220101.png

River flows:

BoM Water data on-line at:

http://www.bom.gov.au/waterdata/

BUFO2 Ambient state:

Ask your Fire Wx Met or the BoM duty meteorologist, or discuss it with your FBAN. This needs to cover the atmospheric profile, using skew-T plots, and the synoptic pattern, using Mean Sea Level Pressure (MSLP) plots.

MSLPs

Terrain:

First order filtered terrain modelled data can be found on the HighFireRisk website at:

http://www.highfirerisk.com.au/maps/index.htm

An on-line tool for second-order terrain filtered data is under development.

Skew-T:

Skew-T log-P profile plots are based on data from weather balloon (radiosonde) flights or from high-resolution atmospheric models. Current flight data are accessed from BoM:

http://www.bom.gov.au/aviation/observations/aerological-diagrams/

(Note that as this is part of BoM's Aviation Weather Service, there may be a dialog box warning of the need to be careful in applying the data operationally).

For archival data, the University of Wyoming site may be useful:

http://weather.uwyo.edu/upperair/sounding.html

Note also that the NSW Rural Fire Service flies its own fire related weather balloons, and other services and researchers may do so as well.

Fire:

Information on a fire's extent and on its dynamics are available from a range of sources:

- The primary source is, of course, the IMT.
- A very good source of high precision data is multispectral (or infrared, if that is what is available) linescans.
- Satellites are also useful, depending on the mix of repeat time and resolution available. (See the Table 2 below.)

Table 2.

Satellite	Repeat time	Resolution	Bands	Sources
LandSat 8&9	16d each, 8d combined.	15m/30m/100m	Vis/NIR/IR	LS
Himawari-8	Geostationary	0.5km/1km/2km	Vis/NIR/IR	RE, SL, H8, HFR, BoM
Sentinel-2A&B	10d each, 5d combined.	10m/20m/60m	Vis/NIR/IR	SH, GA
Aqua	12 hours roughly			WV
Terra - Nearing end-of-life				WV
VIIRS – NOAA-20				WV, SL
VIIRS - NPP			Safe mode	WV, SL
Fire hotspots from Terra, Aqua, NPP & NOAA-20	Daily+	Varies	Algorithm output	F, GA

SOURCES:
[BoM] https://satview.bom.gov.au/
[F] https://firms.modaps.eosdis.nasa.gov/
[GA} https://hotspots.dea.ga.gov.au/
[H8] https://himawari8.nict.go.jp/
[HFR] http://www.highfirerisk.com.au/imr/AUS_H8_10.htm
[LS] https://landsatlook.usgs.gov/
[RE] https://realearth.ssec.wisc.edu/
[SH] https://apps.sentinel-hub.com/sentinel-playground/
[SL] https://rammb-slider.cira.colostate.edu/
[WV] https://worldview.earthdata.nasa.gov/

GLOSSARY

BT: Brightness Temperature, referring to the emitting object's thermodynamically derived temperature, based on its properties in specific infra-red bands. Here, this refers to data derived from satellite imagery of fires, clouds, and plumes. This data should be managed by technical specialists.

BTD: The difference in the derived BT for two infra-red bands. This can provide valuable intelligence about smoke and aerosol load of plume-tops. This data should be managed by technical specialists.

BUFE: A Blow-Up Fire Event (BUFE) occurs when part of a fire forms deep flaming (discussed above).

Complex: When multiple large fires are burning in close proximity it may be necessary to manage them as one event. Fires in a such a complex may share the potential for BUFEs to form.

Division: In large fires, Sectors may need to be grouped in Divisions to avoid exceeding span-of-control limits and to avoid issues with communications and logistics.

Dynamic fire behaviour: Dynamic fire behaviour is when the fire stops responding to the typical set of drivers (terrain, surface weather and fuel) and instead reflects the terrain, the atmospheric profile and the fire itself. The fire ground risk profile radically alters when this transition occurs.

Glaciation: Glaciation refers to the freezing of water droplets within a cooling cloud or plume. As a pyrocloud has many condensation nuclei, this is generally considered to occur when it cools below -40°. At this stage pyrogenic lightning is considered to be possible.

IAP: Incident Action Plan, lays out. For each shift, the incident Objectives, Strategies, and Tactics.

IC: The Incident Controller has over all Control of the implementation of the IAP.

IMT: The Incident Management Team are specialists who assist the IC in implementing the IAP.

LCL: Lifted Condensation Level, where air lifted above the ground reaches 100% relative humidity, and possibly clouds start to form. It is important to note that air inside a fire's plume will have different properties to the surrounding air.

Megafire: A mega fire is one that spreads over a large landscape over a protracted time, defying intensive containment efforts. They are best considered to be quasi-steady-state fires.

Quasi-Steady-State fire behaviour: This is the "normal" form of fire behaviour, where (with some exceptions) terrain, fuel, and weather determine the behaviour of fire.

Sector: An operational sub-division of a fire's perimeter that allows optimised tactics, planning, and logistics.

UTLS: the Upper Troposphere-Lower Stratosphere, the height at which the atmosphere's dynamic changes from cooling with height to warming, preventing or impeding further convective rise.

VPC: Violent Pyro-Convection, a broad term for the visible manifestation of a fire that has coupled with the atmosphere above, producing dynamic fire behaviour.

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.