ABSTRACT

Textbox Australia's emergency managers are in the grips of climate change. The climate is changing in Canberra, where I work. In turn that is affecting the spectrum of incidents that we as emergency managers are responding to. This involves the community through the risks to the community (that we seek to mitigate).

I seek to explore this through my direct experiences on the job: as an emergency manager, as a technical expert and as a research scientist. Our climate in Canberra has changed, and has changed dramatically, starting with the 1997 El Niño event when our climate started following what is termed the "Hockey Stick Curve" (Mann et al, 1999). A typical summer now involves: extreme heat, extreme atmospheric moisture, extreme storms and extreme raised dust. By using the hockey stick concept it is clear that this is not the "New Norm", rather that the situation may deteriorate quickly.

Looking more widely, across the nation, we have seen challenging wildfire outbreaks in Queensland, Tasmania (twice) and other areas. My work as a fire behaviour analyst (FBAN) makes it clear that our prior expectations are losing their validity. What do we replace them with? Looking globally, I have deployed to Canada as an FBAN and I am collaborating as part of a global atmospheric research project looking at the growing impact of fire thunderstorms (pyroCbs). This required monitoring of smoke impact on the Greenland Ice Cap, and its potential impacts. I was in the IMT for two of the world's most significant pyroCb events. We are seeing this new wildfire problem occur in new regions, starting with Australia in 2001, but now expanding rapidly every year.

Staggering changes, devastating impacts and massive challenges - are we adapting correctly? I offer some take-home messages to help, covering observing, sharing, preparing and adapting.

Peer-reviewed article

Experiences with the global impacts of climate change

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Discussion

I am an emergency manager and, among other things, my publication records suggests climate change scientist. I would like to review my direct experiences with global climate change and discuss how significant these are. I would like to use my personal experiences to highlight how we should not downplay where climate change is taking us in Australia.

To start with, I have seen a number of fires that have burnt through a peat, or organic, soil layer in highland swamps, down to the basement gravel. In the 1980s I was involved in geomorphology studies in the Blue Mountains of NSW (Holland, et al., 1992a & 1992b). We took peat samples and had them radiocarbon dated. East Australian peatlands started forming at the end of the last ice age (Hope, et al., 2017). Modern fires are burning peat soils that have lain in place for ten thousand, and perhaps up to fifteen thousand years. That is unsustainable.

Speaking of peat soils, I have been deployed as a Fire Behaviour Analyst to serious wildfires in northern Tasmania on two recent occasions. On both there were "unprecedented" fires burning in or near World Heritage listed areas, with remnants of the vegetation of the ancient Gondwana supercontinent. This vegetation is definitely not meant to carry hot wildfires.

We hear a lot about the world nearing a 1.5 degree warming threshold. Average temperature over the whole year over the whole globe may be doing this, but what is happening locally and seasonally – and driving emergency incidents - can be a very different picture. Many years back I worked out an expected, sinusoidal daily maximum temperature curve for Canberra Airport. I have software that looks at daily departures from this. It looks at running average departures over 30 and 90 day windows through the summer, spanning back eighty years. I was dismayed when it showed that over some recent years we had reached a 90 day average departure of over 4°C. If you look at summer days over the last 12 months the average departure reached 4.5°C - see Figure 1.

That suggests a serious problem for Canberra with heatwaves. In recent years the Bureau of Meteorology has used the Extreme Heat Factor, or EHF, to measure heatwave severity (Nairn & Fawcett, 2013). Typically in a Canberra summer there will be a few runs of up to a week where the EHF is positive. I talk with duty officers from ACT Ambulance Service and ACT Health about how close we are to the activation trigger for the Extreme Heat Sub-Plan of the ACT Emergency Plan (now reviewed in 2019). Usually we get close, but do not reach the trigger point. Community advisory messages may be issued by ACT Health.

In the 2018-2019 summer we exceeded the trigger for a four day period (Figure 2). This was the most extreme heatwave on record for Canberra (Bureau of Meteorology, 2019).

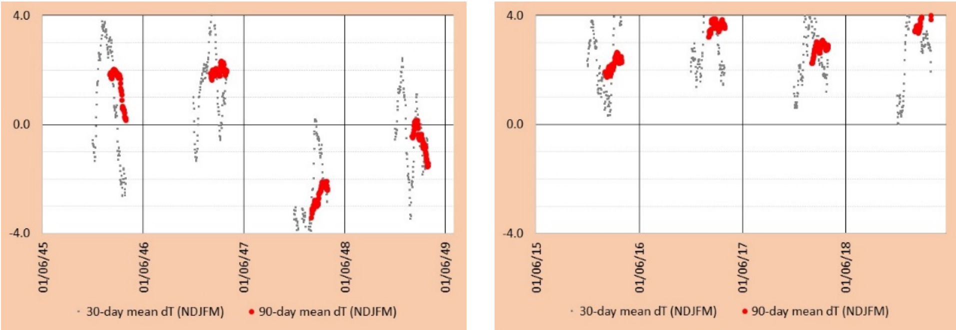

Figure 1: A comparison of summer temperature anomaly (dT) trends for Canberra Airport across two four year blocks. [Data: BoM, Plot: McRae]. (A) The past: temperature anomaly fluctuations vary around a mean of zero degrees, using data for July 1945 to June 1949 as a representative interval. (B) Modern reality: temperature anomaly fluctuations vary around a higher, and rising mean. (Maxima: 30d to 7.4°C, 90d to 4.5°C) Data for July 2015 to June 2019.

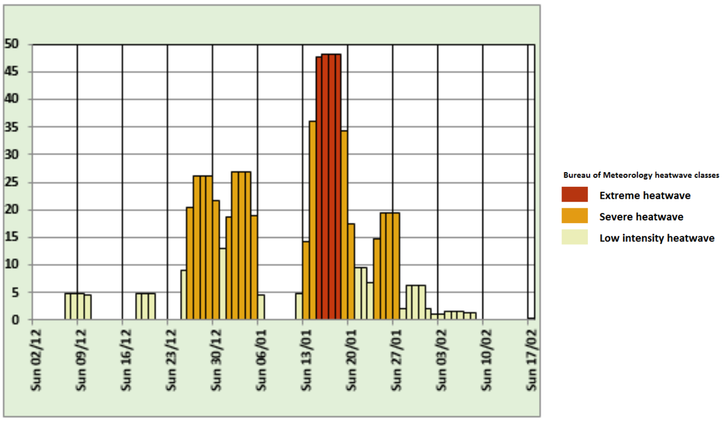

Figure 2: Canberra EHF plot fort summer 2018-2019, showing 54 days over 0 in 3.5 months. [Data: BoM, Plot: McRae]

Canberra's record temperature is 42.2°C, recorded on 1st February 1968. In eighty years of records we had logged fifteen 40°C days. In one month, January this year, we logged five more. The underlying frequency of 40°C days can be modelled mathematically, and this shows roughly a doubling every 9 years since 1997.

Climate scientists coined the term "hockey stick graph" for a depiction of the onset of new, hotter trend in the global climate. (See discussion on this at https://www.newscientist.com/article/dn11646-climate-myths-the-hockey-stick-graph-has-been-proven-wrong/) Data modelling from the US (berkeleyearth.org) shows that for many sites in south-eastern Australia climate data trends could be colloquially termed to be hockey stick curves, and that their inflection points occurred during major El Niño events, such as 1997. The 1997 inflection point in Figure 3 makes it look like a hockey stick graph. We can look at the impacts of the hockey stick on 40°C days by referring to the 1939 to 1997 frequency (Figure 3). The trends since 1997 are very significant (Figure 4).

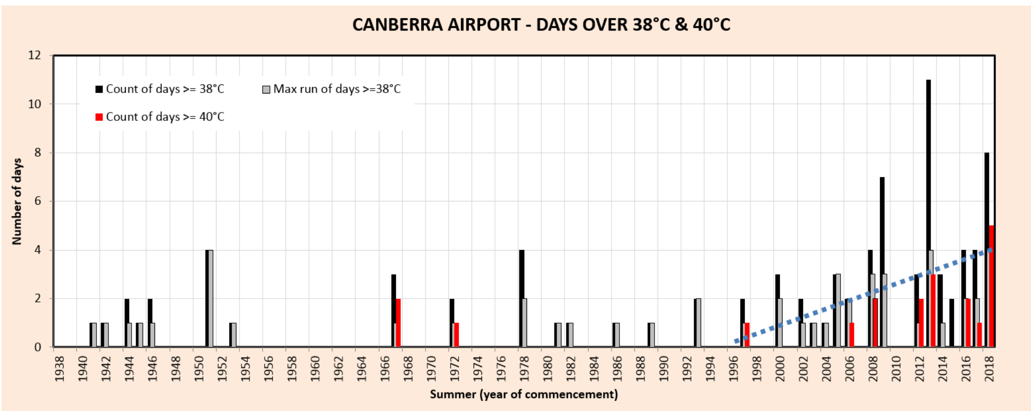

Figure 3: Annual counts of hot days for Canberra Airport [Data: BoM].

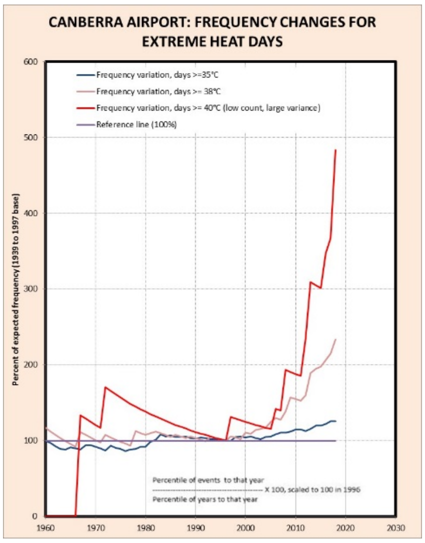

Figure 4: Canberra hot day relative frequencies, with 1997 values set at 100%. Compared to that baseline: 35°C days are now 30% more common, 38°C days are now 133% more common, and 40°C days are now 383% more common [Data: BoM, Analysis & plot: McRae].

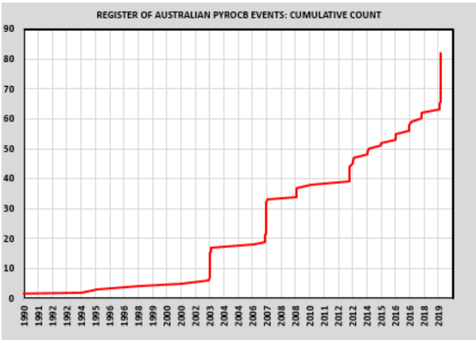

Figure 5: Australian pyroCb register [Di Virgilio, et al., 2019].

The frequencies hot days are rising so quickly that there is now room to fit a 45°C day. A key thing about hockey stick curves is that there is no new normal. Over the next 9 years there could be some major new records set for Canberra.

When people think heat in Australia, they naturally think bushfires. There is a clear and widespread expectation of major impacts on bushfire activity. Thinking in terms of a McArthur Meter (Luke & McArthur, 1978), hotter weather means rotating the dials clockwise, giving higher FDI values. Easy. Alas, there are some important reasons why it is not easy.

Globally there has been detailed scrutiny of wildfire blow-up events. These happen when fires couple with the atmosphere overhead (Sharples, et al., 2016). This involves processes not found on a McArthur Meter. Normally if you know the weather, the terrain and the fuel you can predict what the fire will be doing. This is called steady-state fire behaviour. In dynamic fire behaviour, interactions occur between the weather, the terrain and the fire. These can produce very different fire behaviour. In an unstable atmosphere, coupling between the fire and the atmosphere allows the plume to push to high levels and perhaps reach the Stratosphere (Fromm, et al., 2010). This most extreme form of wildfire behaviour is known as a fire thunderstorm, pyro-cumulonimbus or pyroCb.

In 1978, a global monitoring project commenced with the launch of the NIMBUS 7 weather satellite. Ever since, scientists have looked for injections of aerosol into the otherwise clean upper atmosphere (Fromm, et al., 2010). While looking for volcanic ash and the signs of nuclear tests, they also picked-up wildfire smoke in the Stratosphere. This is the tell-tale sign of a pyroCb.

From 1978 until 2001, Australia had experienced two confirmed pyroCbs and two other possible events (McRae, et al., 2015). Since 2001 another 78 events have been logged (Figure 5). That includes a 33% increase during 2019.

This staggering shift in frequency is a major challenge for Australia. In 2003 Australia's fire services knew very little about pyroCbs, or of the blow-up events that cause them. Then the 2003 ACT fires impacted on Canberra (Fromm, et al., 2006). I was the Planning Officer on the 18th of January, and it was clear in hindsight that we had no idea what was going on. The lack of knowledge about extreme fire behaviours and their complex interactions with the environment meant that inquiries set up to review the 2003 ACT fires were limited in their ability to explain how the fires behaved and why that behaviour was not predictable. It was only in later years that the science was done and formalised. The previously unknown fire behaviours identified in the 2003 ACT fires made those fires amongst the most scientifically important wildfires in Australia. That is a big claim but it is easily justified.

First documentation of the impacts of an Australian pyroCb on the atmosphere (Fromm, et al., 2006).

First ever confirmed pyro-tornadogensis event (McRae, et al., 2013).

The discovery of Vorticity-driven Lateral Spread, a main driver of blow-up fire events (Sharples, et al., 2012).

Validation of the Nuclear Winter Hypothesis (Fromm, et al., 2006).

The 2003 fires were closely scrutinised by the global science community. I co-authored a prominent science paper on them along with colleagues from Australia, the US, Canada and Israel (From, et al., 2006). They were among the most severe fire events ever logged, so Australia had gained international attention.

Six years later the Black Saturday fires in Victoria became the most intense fire event ever recorded (see for example Dowdy, et al., 2017), and then Australia became the source of a series of key case studies (such as Fromm, et al., 2012 and McRae, et al., 2015).

Canada, the US and north-eastern Asia (mainly Siberia and Mongolia) have long experienced pyroCbs during major fires in the boreal forests. In 2001 Australia joined them in routinely producing pyroCbs. In 2010 western Russia joined term, followed by Europe and South America in 2017. It is likely that southern Africa joined in 2018. This is a rapid expansion of a major problem (McRae, 2019).

To summarise the problem in Australia, the risks to the community from steady-state bushfires is, and has long been, well managed by fire services. So, in rough terms, 5% of the damage comes from these 95% of the fires. The other 5% of fires, driven by dynamic fire spread processes, cause 95% of the damage.

I deployed to British Columbia as an FBAN in 2017. They were having their worst ever fire season. On the 12th of August they experienced the most severe wildfires ever recorded, globally (Peterson, et al., 2018, Struzik, 2019). So for the second time in my career I was in the IMT for a globally significant wildfire.

In Quesnel we were sitting for day after day in heavy smoke. We could see parts of the fire ground from the air, but there were large tracts that were no-fly due to a lack of visibility. There were days when it was clear that the fires would be exhibiting extreme behaviour and that fire crew safety was a priority. I knew that satellites could see a lot more of a fire when a blow-up events occurs, and that there was potential for this happen. I alerted my global research collaborators and satellite images were given close scrutiny.

Since 1978 Stratospheric aerosol loads had been measured on the 0 to 15 scale for the Aerosol Index (AI). On the 12th of August AI got to 45. Systems had to be re-designed to handle it (Colin Seftor, pers. comm., 2017).

As the smoke load was cleared by a wind shift, the clear air had no convective cap, and free-convection occurred in eight separate plumes in the next few hours. This smoke was injected to high altitudes and moved north. Unfortunately just to the north, close to Great Slave Lake there was an east-west line of fire over 250km wide that was injecting massive smoke loads to lower levels. So north of GSL the air had elevated smoke concentrations across most of the troposphere (Figure 6).

What damage could this do? It crossed the North Pole and entered Russia. It crossed the Greenland Ice Cap. One of the reasons that the north polar ice cap is melting is discoloration of the ice. In briefings we discussed how pumping over it the largest smoke injection ever seen cannot be a good thing (Thomas, et al. 2017 & Hsu, et al., 1999), and how this may contribute to climate change. There were settlements in the Yukon and North West Territories where, for three days in a row, the skies were darkened and there was none of the expected cycling of temperature through the day. This same effect had been demonstrated from the 2003 Canberra fires (Mitchell, et al., 2006 & Fromm, et al., 2006).

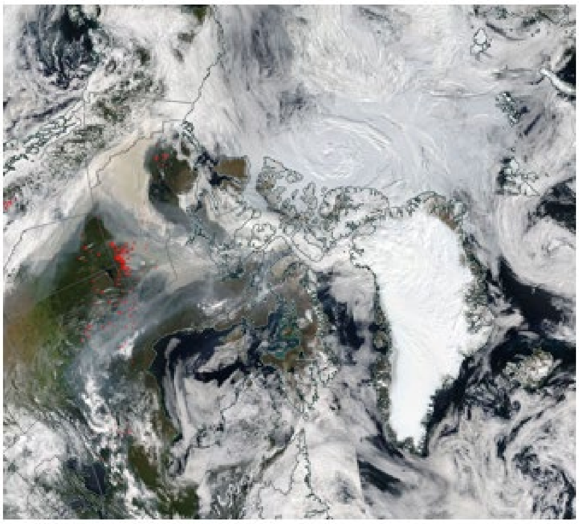

Figure 6: Fire hotspots (red dots) and smoke, northern Canada, 13th August 2017 [Image & Data: NASA WorldView].

Just before I travelled to Canada, there was on-line discussion of a wildfire burning in Greenland (see Earth Observatory website). No life or assets were under threat from this fire, but it was a clear sign that things were getting unusual. Recently, there were more wildfires there, near Sisimiut.

I wish that I would see no more clear signs of global climate change while I work. I suspect, however, that I will. The 2018-2019 fire season had a number of key aspects to it that supports this conclusion.

The fire outbreak in SE Queensland was unprecedented. While satellite imagery often hinted at coupled fire-atmosphere events (see links on http://www.highfirerisk.com.au/h8_videos.htm), these did not produce pyroCbs. The combination of drought and weather caused fire impacts in places and in vegetation types that are not meant to see wildfires. The burning of tropical rainforest is likely to cause long-term damage.

The Kimberley region saw some widespread fire activity (Figure 7). The whole region was constantly producing non-fire Cbs, but it also seems to have produced a tropical pyroCb with lightning. The key aspect of this is that, prior to this, there had never been a confirmed pyroCb in the tropics. Anywhere. In either hemisphere. Confirming tropical pyroCbs requires a high level of confidence, to allow them to be distinguished from Cbs. If tropical pyroCbs are now possible, then a lot more tropical vegetation is coming under threat.

Unfortunately, in July and August 2019 the international group confirmed four tropical pyroCbs in tropical savanna in Bolivia. Smoke from one of these passed over Canberra.

Tasmania, as I mentioned earlier, had serious wildfires in the 2018-2019 summer. A lot of effort was expended keeping fire out of pristine Gondwana-relict forests around the Walls of Jerusalem, and critical impacts were closely avoided.

The Victorian high country saw a tightly clustered group of pyroCbs. While this was not unprecedented, the repeated burning of these areas may have long-term ecological and hydrological impacts.

The ACT has seen major dust storms over the years. This year we saw a lot of them. This reflects the severity of the inland drought and the impacts on rangeland ecosystems. We gained skill in alerting our community to the potential for more dust events, and "Dust Event" went from a novelty to an entry on the standard hazard list, along with bushfires, floods, storms and so on.

The most interesting aspect of this summer that reflects climate change was the grass curing. The usual rule book was thrown out - for the first time since I started looking, three decades ago, the curing value basically flat-lined. It sat within 10% points of 70% for nine months, between July and March (Figure 8). Typically in Canberra curing is high at the end of winter, due to frost, then it plummets for the spring growing season, and rises steeply after the onset of summer heat. None of these happened.

This reflects the change in the balance between heat and moisture. The impacts of hot air on grasslands are fairly clear, but hot air has the capacity to carry more water and the potential to produce more thunderstorms. The convergence of inland and coastal air masses produced regular storms over the ACT. The grass was able to hang on “a bit green”, but never built-up high fuel loads. All the while grazing pressure was intense.

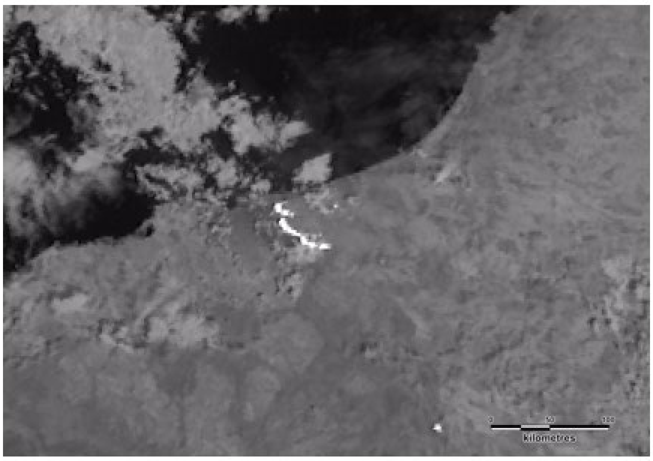

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Figure 7: Infrared view of flames 120 km east of Port Hedland, WA, and other fires on 15th November, 2018. Fire shows as white [Himawari-8 Imagery: SSEC].

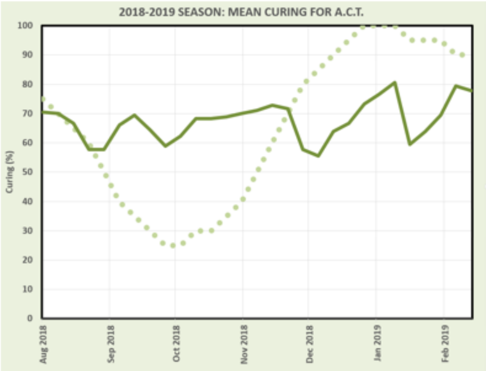

Figure 8: Canberra curing trend, 2018-2019 (solid line), compared to typical season pattern (dotted line) [Data: LandGate, WA, Plot: McRae].

In February 2018 we had a 100 year Average Return Interval flash flood event in North Canberra. This was a salient event, driven by the Dew Point Temperature exceeding 21°C (an extreme value for Canberra). This is still within inter-annual variability, but may become more likely in the future (AdaptNSW).

So, what are my “take home messages”?

Firstly, for me, as an active FBAN, climate change is no longer just the elephant in the room, it is the big angry grizzly bear threatening to tear our limbs off. Secondly, it has changed what fire services have done in Australia for the last 18 years, and we have barely acknowledged this. Thirdly, other allied services are increasingly having to deal with the impacts of climate change – for example town planning, health services, ambulance services – and we cannot tackle this in isolation. Fourthly, understanding the problem requires broad-scale collaboration. I am routinely liaising with researchers in numerous countries, and by working together a more comprehensive picture is developed. Fifthly, do as I have often done, and change your foundation concept set completely. We are all learning rapidly, and this will only accelerate. Finally, it is only by being prepared to observe what goes on around us that we will learn. Build observational capabilities that can be deployed at major incidents, and also develop the tools to create intelligence from the resulting data. Observe, share, prepare and adapt.

References

ACT Government 2019, *ACT Extreme Heat Plan*. https://esa.act.gov.au/cbr-be-emergency-ready/emergency-arrangements Retrieved 1/10/2019.

AdaptNSW, https://climatechange.environment.nsw.gov.au/Impacts-of-climate-change/Floods-and-storms. Retrieved 1/10/2019.

Berkeley Earth, http://berkeleyearth.org/; http://berkeleyearth.lbl.gov/locations/36.17S-149.17E. Retrieved 1/10/2019.

Bureau of Meteorology 2019*, Widespread heatwaves during December 2018 and January 2019*. Special Climate Statement 68

Di Virgilio G, Evans JP, Blake SA, Armstrong M, Dowdy AJ, Sharples J & McRae R 2019, Climate Change Increases the Potential for Extreme Wildfires, *Geophysical Research Letters*, vol. 46. Available from: https://doi.org/10.1029/2019GL083699

Dowdy AJ, Fromm MD & McCarthy N 2017, Pyrocumulonimbus lightning and fire ignition on Black Saturday in southeast Australia, *Journal of Geophysical Research: Atmospheres*, vol. 122. Available from: https://doi.org/10.1002/2017JD026577

Earth Observatory 2017, *Fire and Ice in Greenland*. Available from: https://earthobservatory.nasa.gov/images/90709/fire-and-ice-in-greenland. Retrieved 1/10/2019.

Fromm M, Tupper A, Rosenfeld D, Servranckx R, McRae R 2006, Violent pyro-convective storm devastates Australia’s capital and pollutes the stratosphere, *Geophysical Research Letters*, vol. 33, L05815.

Fromm M, Lindsey DT, Servranckx R, Yue G, Trickl T, Sica R, Doucet P & Godin-Beekmann S 2010, The Untold Story of Pyrocumulonimbus, *Bulletin American Meteorological Society*, vol. 91, pp. 1193–1209.

Fromm MD, McRae RHD, Sharples JJ & Kablick GP 2012, Pyrocumulonimbus pair in Wollemi and Blue Mountains National Parks, *Australian Meteorological and Oceanographic Journal*, vol. 62, pp. 117–126.

Holland WN, Benson DH & McRae RHD 1992, Spatial and Temporal Variation in a Perched Headwater Valley in the Blue Mountains: Geology, *Geomorphology, Vegetation, Soils and Hydrology,* proceedings Linnaean Society of NSW., vol. 113, no. 4, pp. 271-295.

Holland WN, Benson DH & McRae RHD 1992, Spatial and Temporal Variation in a Perched Headwater Valley in the *Blue Mountains: Solar Radiation and Temperature*, proceedings Linnaean Society of NSW., vol. 113, no. 4, pp. 297-309.

Hope G, Nanson R & Jones P 2017, *Peat forming bogs and mires of the Snowy Mountains of NSW*, technical report, Office of Environment and Heritage, Sydney.

Hsu NC, Herman JR, Gleason JF, Torres O & Seftor CJ 1999, Satellite Detection of Smoke Aerosols Over A Snow/Ice Surface By TOMS. *Geophysical Research Letters*, vol. 26, pp. 1165-1168.

Luke RH & McArthur AG 1978, *Bushfires in Australia*, Australian Government Publishing Service, Canberra.

Mann ME, Bradley RS & Hughes MK 1999, Northern hemisphere temperatures during the past millennium: Inferences, uncertainties, and limitations, *Geophysical Research Letters*, vol 26, pp. 759-762

McRae R 2019, "An error of definition - and a need to make valid science key to our best practices." In “Response to the IAWF Issue - Dialog Paper: Extreme Fires”. Wildfire Magazine, Issue 3, 2019 https://www.iawfonline.org/article/dialogue-issue-paper-extreme-fires/

McRae RHD, Sharples JJ, Wilkes SR & Walker A 2013, An Australian pyro-tornadogenesis event, *Natural Hazards*, vol. 65, pp. 1801-1811.

McRae RHD, Sharples JJ & Fromm M 2015, Linking local wildfire dynamics to pyroCb development, *Natural Hazards and Earth System Sciences*, vol. 15, pp. 417–428.

Mitchell RM, O'Brien DM & Campbell SK 2006, Characteristics and radiative impact of the aerosol generated by the Canberra firestorm of January 2003, *Journal of Geophysical Research*, vol. 111.
Nairn J & Fawcett R 2013, *Defining heatwaves: heatwave defined a sheet impact event servicing all community and business sectors in Australia*, CAWCR technical report, no. 60.

Peterson D, Campbell JR, Hyer EJ, Fromm MD, Kablick GP, Crossuth J & DeLand MT 2018, *Wildfire-Driven Thunderstorms Cause a Volcano-Like Stratospheric Injection of Smoke*, proceedings, AGU Fall Meeting 2018, Washington DC.

Sharples JJ, McRae RHD, Weber RO, Wilkes SR 2012, Wind-terrain effects on the propagation of wildfires in rugged terrain: fire channeling, *International Journal of Wildland Fire*, vol. 21, pp. 282–296.

Sharples J, Cary G, Fox-Hughes P, Mooney S, Evans JP, Fletcher M-S, Fromm M, Baker P, Grierson P & McRae R 2016, Natural hazards in Australia: extreme bushfire, *Climatic Change*.

Struzik E 2019*, Fire-Induced Storms: A New Danger from the rise of Wildfires*. YaleEnvironment360, Yale School of Forestry & Environmental Studies. Available from:
https://e360.yale.edu/features/fire-induced-storms-a-new-danger-from-the-rise-in-wildfires Retrieved 1/10/2019.

Thomas JL, Polashenski CM, Soja AJ, Marelle L, Casey KA, Choi HD, Raut J-C, Wiedinmyer C, Emmons LK, Fast JD, Pelon J, Law KS, Flanner MG & Dibb JE 2017, Quantifying black carbon deposition over the Greenland ice sheet from forest fires in Canada, *Geophysical Research Letters*.