Dear Air Chief Marshal Mark Binskin, The Honourable Dr Annabelle Bennett and Professor Andrew Macintosh,

We wish to submit this response to the Commissioners' request for further submissions from the air quality / atmospheric chemistry sector and hope that it will still be useful. We are happy to expand on any points should this be of interest.

Yours sincerely,
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Cite as: Schofield, R., Silver, J., Ryan, R., Walter, C., Rayner, P., Murphy (Paton-Walsh), C., Deutscher, N., Fisher, J., Forehead, H., Heyworth J., Ristovski, Z., Morwaska, L., Miljevic, B., submission in Response to Issues Paper: Health arrangements in natural disasters of the Natural Disaster Royal Commission, June 2020

Response to Issues Paper: Health arrangements in natural disasters of the Natural Disaster Royal Commission

We repeat some of the response made as a submission to Royal Commission Inquiry on Australia's preparedness for, and response to, natural disasters [1] here as it is relevant also to our response to this Issues paper.

Question 1: Are the current national health coordination arrangements appropriate to respond to natural disasters in Australia? If not, how should they be improved?

Currently, national health coordination with respect to air hazard disasters is insufficient to respond to natural disasters in Australia.

- **Air quality categories**, **action plans** and **information dissemination** for air should be nationally coordinated, with state and expert health and air quality representation. This national coordination effort should be responsible for:

[1] Schofield, R., Silver, J., Ryan, R., submission to Royal Commission Inquiry on Australia's preparedness for, and response to, natural disasters, June 2020 – reference number NND.600.00397

- Determination of indoor and outdoor criteria air pollutants requiring regulatory health based monitoring, reporting and forecasting. These criteria pollutants should be based on World Health Organization recommendations and international treaties to protect the human environment against air pollution (i.e. the Convention on Long-Range Transboundary Air Pollution, Stockholm Convention Persistent Organic Pollutants, Minamata Convention on Mercury, Paris Climate Agreement)
- National Environmental Protection Measures (NEPM) air quality standard revisions for criteria pollutants to take into account national and international health advisories and updates with regularity not exceeding 5 years.
- Establish a network of all Australian air composition monitoring, modelling and prediction to collate, validate, publish and report internationally our air monitoring data and to build forecasting/planning tools.
- Establishing national air hazard forecasting capability to build resilience to volcanic, dust, fire and bio-aerosol and toxic gas threats
- Development of a nationally consistent AQI system, emergency action plan advisories and public health information to be disseminated via a national emergency response website, social media platforms, phone app and alerts to health carers and emergency response teams
- Identifying 'at risk' groups and providing additional support i.e. with targeted community clean air shelters and public housing upgrades
- Developing air hazard health fact sheets for health practitioners to enhance continuing education between threat advisory providers and emergency response networks

Question 2: Should primary care providers and primary health networks be better integrated in natural disaster preparedness, response and recovery? If so, how should this be done?

Magnitude and temporal patterns of natural disaster wildfire smoke health impacts can differ depending on exposure duration, age, sex and presence of underlying disease (Walter, Schneider-Futschik, Knibbs, & Irving, 2020). Improved awareness of air hazards through targeted education programs to primary care providers and emergency response providers can improve health outcomes and ameliorate emergency system burden. Poor air quality in Australian cities is shown to be strongly associated with groups and locations that already suffer socioeconomic status inequalities (Cooper, 2015). Populations with higher residential NO_2 exposure have been shown to place higher burdens on the healthcare system due to thunderstorm asthma events (Lai et al., 2018). A cross-sectional survey showed that a 1 μgm^{-3} increase in residual population exposure in $PM_{2.5}$ was associated with 8% higher COVID19-death rates (Wu, Nethery, Sabath, Braun, & Dominici, 2020). Two Australian cohort studies showed an increased risk of mortality associated with $PM_{2.5}$ residual population exposures: Hanigan et al., (2019) found a 5% increase in all-cause mortality per 1 μgm^{-3} $PM_{2.5}$ (albeit non significant) and Dirgawati et al., (2019) found that a unit increase in $PM_{2.5}$ absorbance (black carbon) significantly increased the risk of mortality by 12% in a cohort of older men. It is clear that increasing health care provider education and improving regulatory controls leading to indoor and outdoor air quality improvements experienced by our population will provide natural disaster air hazard resilience.

We recommend:

- Identify vulnerable groups within spatial locations susceptible to hazardous/extreme air quality with a reduced capacity to shelter in place and less recourse for action, i.e. can't move or adapt housing ventilation/filtration, etc. => provide community clean air shelters / invest in housing upgrade programs.

- Provide a national, validated air quality prediction system to deliver location-relevant, forecasted poor air quality status reports to health care and emergency service providers to enable resource and personnel planning.

- Develop health fact sheets and action response plans for health care and emergency service provider planning.

As an example, fact sheets would include:
For smoke events (Walter et al., 2020):

- Immediate exposure: expect increases of out of hospital cardiac arrests for men
- 2-3 day post-event exposure: expect cardiac issues to become more prevalent in women with increases in Ischemic Heart Disease (IHD) hospital admissions
- Asthma: unlike ambient pollution smoke expect greater respiratory impacts in women
- Expect supra-additive impacts with heat and also cool changes (Claeys, Rajagopalan, Nawrot, & Brook, 2017)

For dust storms it has been shown that adverse health effects are due to triggering of oxidative stress mechanisms including COPD, asthma, sarcoidosis and pulmonary fibrosis. Fine and ultrafine dust particles can potentially impact the circulation system (Schweitzer et al., 2018).

- Expect a 3 day post-event increase in all-cause hospitalisation / mortality (Zhang et al., 2016)
- Expect an increase in asthma severity, presentations and hospital admissions (Merrifield, Schindeler, Jalaludin, & Smith, 2013; Rutherford, Clark, McTainsh, Simpson, & Mitchell, 1999)

A heightened awareness of these previously observed patterns would aid identification and preparedness of services. This is best approached through coordination with existing health networks and bodies such as Royal Australasian College of Physicians, Royal Australian College of General Practitioners, Royal College of Emergency Medicine Australia, The Thoracic Society of Australia and New Zealand, Lung Foundation Australia, Asthma Australia, and The Heart Foundation. Embedding education programs within the continuing education provided by these health organisations will ensure that air hazard health response is well coordinated with the prediction of air threats and hazards.

Question 3: What approaches could be adopted to better support primary care providers to provide health services in the response and recovery phases of a natural disaster?

Provision of evidence-based and timely advice on how patients, in particular vulnerable groups can reduce their exposure under acute and chronic exposure conditions. This information would be disseminated through:

- Education and development of air hazard health resources
- Coordinated nationally consistent air quality advisories
- Fact sheets for the public, practitioners and for identified ‘at risk’ groups
- National emergency response website, social media and phone app providing air quality real-time and prediction information

Question 4 Should a standard approach to reporting and categorising air quality across Australia be implemented, and if so, how?

The issues paper cites an Australian Academy of Health and Medical Sciences review[2] that describes the NEPM regulated and monitored criteria pollutants of carbon monoxide, sulfur dioxide[3], nitrogen dioxide, ozone, lead and particulates (PM_{10} and $PM_{2.5}$). Air quality health impacts of bushfire smoke result from many more compounds, in addition to these criteria pollutants, that are either currently unregulated or only monitored irregularly or with very limited geographical representation. Bushfire smoke contains several additional toxins, and carcinogens such as formaldehyde, acrolein, hydrogen cyanide and mercury (Desservettaz et al., 2019; Guérette et al., 2018; Howard et al., 2019).

These additional airborne toxins are not measured at air quality monitoring stations (as they would usually be below the detection limits of available instruments – with the exception of formaldehyde and mercury), but nevertheless will impact on the health of those breathing the smoke. These gases fall into the toxicological classes of upper and lower respiratory tract disorders, eye irritation, disruption of oxygen transport and carcinogens (MacSween et al., 2019). The combined effect of breathing in these gases and the particles is likely to put further stress on the body.

AQIs are only as useful as the NEPM standards to which they refer. The NEPM standards for sulfur dioxide, nitrogen dioxide, ozone from which AQIs are generated have not been revised since 1998 (they are still under review in 2020). Therefore, all Australian NEPM derived AQIs reported currently are not the health protecting relevant metrics they seek to be. For AQI to protect public health the NEPM standards need to be revised at a regular interval according to the latest World Health Organization (WHO) recommendations (i.e. every 3 or 5 years). In particular, the ozone standard is inconsistent with WHO recommendations of an 8-hour 100 mgm^{-3} standard which is equivalent to ~50 ppb (ppb = parts per billion; the recently proposed 8-hour standard of 65 ppb will not provide a health based reference standard). It is also noted that the WHO Air quality guidelines are currently under revision with an expected publication date in 2020.

In Table 1 we provide an example of how the current ozone NEPM air quality standards both provide confusion for the Australian public and lag behind WHO recommendations by considering the number of ozone standards exceedances over the recent Black Summer. The number of days on which a 4-hour (80 ppb) NEPM ozone standard exceedance occurred is less than half of the number of days registering a WHO exceedance across the available urban air quality monitoring sites in New South Wales, Queensland and Victoria. The NEPM 1-hour (100 ppb) standard was exceeded only 11-20% of the days where WHO exceedances were found. This suggests that during such severe bushfire conditions as the recent Black Summer, Australia's current NEPM standards give exceedance results which are both internally inconsistent and under-representative of the true public health exposure risk.

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[2] Australian Academy of Health and Medical Sciences, The Australian Bushfires: Impacts on Health – The Evidence (2020), The Australian Academy of Health and Medical Sciences referenced by the Issues paper contains errors in their presented World Health Organization 24-hour standard for $PM_{2.5}$ – this should be 25 μgm^{-3} (not 35 μgm^{-3}) https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health.

[3] The internationally accepted spelling for the chemical sulfur is with an f. This was determined in 1990 by the International Union of Pure and Applied Chemistry (IUPAC) https://www.nature.com/articles/nchem.301

Table 1 – Number of days on which an ozone standard exceedance was recorded at any site in the survey region between 1st October 2019 and 29th February 2020. WHO indicates the air quality standard recommended by the World Health Organization. NEPM specifies the Australian National Environment Protection Measure standards for Australia.

	Sydney, Wollongong, Newcastle	Melbourne, Geelong, LaTrobe Valley	Brisbane, Gold Coast, Sunshine Coast
Number of sites	23	13	7
WHO (8-hour, 50 ppb standard)	62	21	28
NEPM (4-hour, 80 ppb standard)	26	6	5
NEPM (1-hour, 100 ppb standard)	13	4	3

Cumulative Firefighter Exposure to Multiple Toxins Emitted During Prescribed Burns in…

Table 2 Toxicological classes of bushfire smoke components, from MIXIE and Work safe Australia exposure standards (Safe Work Australia, 2013) for airborne toxics commonly emitted during a bushfire

Air toxic	Exposure Limit (TWA)	STEL	Emission ratio (to CO)	Toxicological class										
	ppm	ppm		1	2	3	4	9	11	13	19	27	30	32
1,3-Butadiene	10		0.00052											x
Acetaldehyde	20	50	0.0034		x		x	x						
Acetic acid	10	15	0.015	x	x									
Acetone	500	1000	0.0019	x	x						x			
Acetonitrile	40	60	0.0005[b]				x							
Acetylene	1000		0.0034[f]				x							
Acrolein	0.1	0.3	0.0011[a]	x	x	x						x		x
Ammonia	25	35	0.021[b]	x	x									
Benzene	1	–	0.001											x
Carbon dioxide	5000	30000	8.74[b]				x							
Carbon monoxide	30	200	–				x							
Elemental Mercury	0.003	–	2.3×10^{-7} [c]	x		x				x	x	x	x	
Ethane	1000		0.0037[b]				x							
Ethyl benzene	100	125	0.00012[a]	x	x				x	x	x			x
Ethylene	1000		0.011[b]				x							
Formaldehyde	1	2	0.013[b]	x	x	x						x		x
Formic acid	5	10	0.0021[b]	x	x							x		
Furfural	2	–	0.0013[a]	x	x				x					x
Hydrogen cyanide	4.69	–	0.0042[f]		x		x	x						
Methane	1000		0.052[b]				x							
Methanol	200		0.017[b]	x							x			
Methyl ethyl ketone	150	300	0.00045	x	x									
n-Hexane	20	–	0.00014[a]									x		
Nitrogen dioxide	3	5	0.004[d]	x	x	x								
Nitrous oxide	25	–	0.00081[b]								x		x	
Phenol	1	–	0.000014[a]	x	x	x			x	x	x	x		
Sulphur dioxide	2	5	0.0041[a]	x	x									
Toluene	50	150	0.0022	x	x						x		x	
Trimethylbenzene	25	–	0.00028	x	x	x					x			
Xylene	80	150	0.0011	x	x						x			
Respirableparticles	3		0.068[e]	x	x	x						x		x

[a]Andreae and Merlet (2001)

[b]Paton-Walsh et al. (2014)

[c] Howard et al. (2019)

[d]Young and Paton-Walsh (2010)

[e]De Vos et al. (2009)

[f]Paton-Walsh et al. (2005)

Table 2 from MacSween et al., (2019) where STEL = Worksafe Australia's short term exposure limits and the toxicological classes 1:Eye disorders, 2: Upper respiratory tract irritation, 3: Lower respiratory tract disorder, 4: Disruption of oxygen transport, 9: Antithyroid effect, 11: Liver disorder, 13: Kidney disorder, 19: Central nervous system disorder, 27: Skin disorder (irritation/sensitisation), 30: Embryonic or foetal disorder, 32: Cancer

While ozone and $PM_{2.5}$ are the most widely cited air quality metrics of interest – accounting for ~4880 excess premature deaths annually in Australia[4] (outside of the Black Summer impacts), we also suffer dust and pollen air quality risks. The thunderstorm asthma event in Melbourne in November 2016 and the dust storms (with iron toxicology), need also be observed and reported upon. As these fall outside of regulatory frameworks, but within natural disaster responses, the preparedness of response is lacking. For example, we have few/no observations of the population exposure to iron due to the dust storms experienced concurrently with the bushfire smoke during the Black Summer. Observing aerosol composition is key for linking to natural disaster air hazard health impacts beyond smoke.

As is clear from Figure 1, and widely appreciated, health impacts occur in bushfire smoke well below the 24-hour threshold for $PM_{2.5}$ of 25 μgm^{-3} and even the annual NEPM reporting standard for $PM_{2.5}$ of 8 μgm^{-3}.

We believe a task force should be established to discuss AQI and categories for bushfire smoke. The categories could be established by $PM_{2.5}$ alone (as we suggest below) and as reported for many state based AQ stations currently anyway. Additionally, this would provide a means of extending the AQ monitoring network by, for example, augmenting BoM meteorological monitoring with $PM_{2.5}$ monitors.

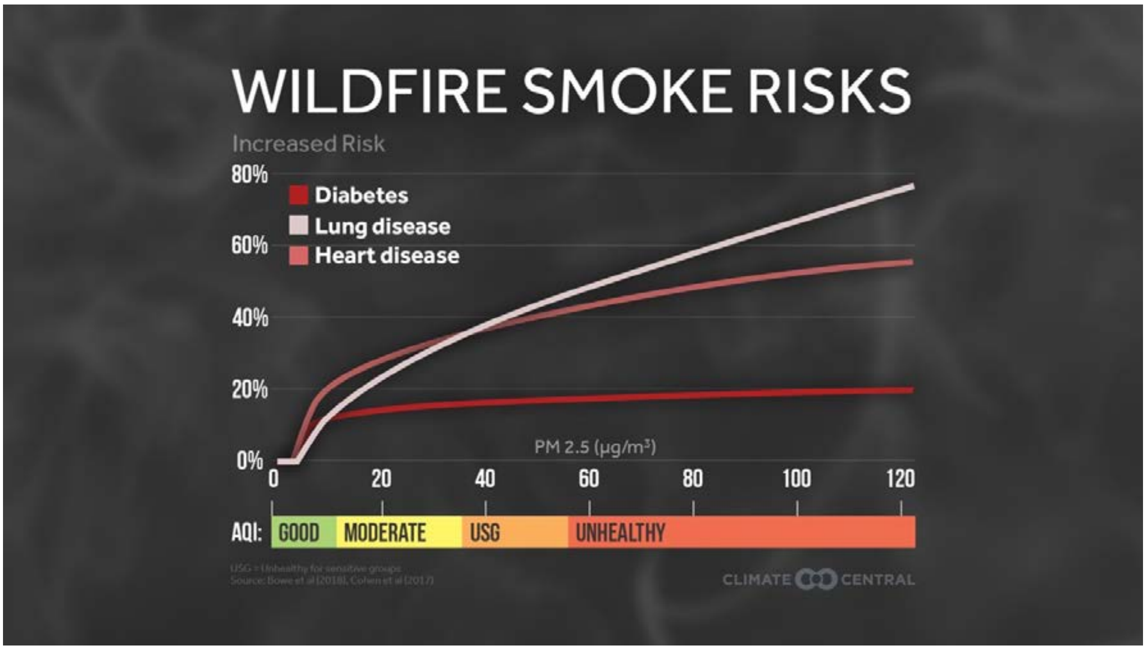

Figure 1: Clear messaging about health associated risks from 24-hour average exposures to $PM_{2.5}$ to smoke. Accessed from https://medialibrary.climatecentral.org/resources/wildfire-smoke-waves-2018 on the 4th June 2020.

As the issues paper notes, there is a confusing number of categories across the States and Territories, and in the public realm for air quality. Figure 2 presents the hourly and 24-hourly

[4] https://www.stateofglobalair.org/data/#/health/plot screenshot of plot for air pollution deaths for Australia provided at end of document.

$PM_{2.5}$ data (rolling average to last hour) for the single station of the Melbourne CBD for January 2020.

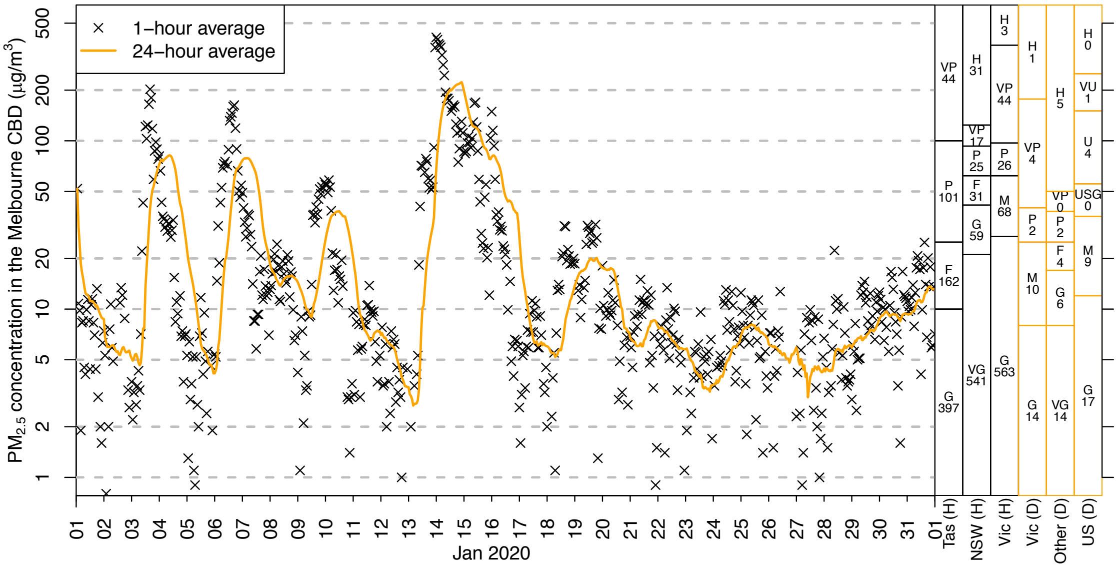

Figure 2: PM2.5 hourly data (black crosses), 24-hour rolling average to the last hour (orange) for the Melbourne CBD from 1st January to 1st February 2020. The right hand panel translates this in Air Quality Index advisories based on NEPM for each hour (H) given as black categories: for Tasmania, New South Wales and Victoria. The 24-hour average (D) in orange provided by Victoria and Other (combining the states NSW, ACT, NT, WA(Extreme replaces Hazardous) and SA & QLD (who don't have a Hazardous category with Very Poor being their worst category)) and the World Health Organization categories. G=Good, F=Fair, P=Poor, VP=Very Poor, H=Hazardous, M=Moderate, USG=Unhealthy for Sensitive Groups, U=Unhealthy, VU=Very Unhealthy are all the terminology used across the states and world for these AQ categories. The numbers in the right hand panel represent the total number of Hours or Days within each category (i.e where VIC would have reported just 3 hours of hazardous conditions, NSWs would have reported 31 hours for the same dataset).

Clearly, streamlining of the states' AQI category systems is required, and this should be done considering appropriate public health protection. We think this should be achieved through the establishment of a national research infrastructure strategy for Air. AQI categories should be discussed and determined via an expert panel and updated with the NEPM standards to reflect new knowledge at a regularly required set interval of not more than 5 years.

The categories and how they are calculated, and used for advisories could follow US, China or European AQI categories. Or Australia could recognize that our NEPM $PM_{2.5}$ standard reflects our Southern Hemispheric background conditions which Northern Hemispheric categories do not. It should be noted that the associations between $PM_{2.5}$ exposure and health are not linear but supralinear at lower concentrations – see for example heart disease in figure 1. That is, relative effects at lower concentrations, as we see in Australia, are greater than at higher concentration.

We suggest (see Table 3 also in response to Question 5):

Good air is <8 µgm^{-3} / AQI <33

Moderate air is 8 – 24 µgm^{-3} / AQI: 34-99 as there will be health impacts at this level, especially if sustained (see figure 1: 25 µgm^{-3} represents NEPM 24-hour standard);

Poor 25 - 49 µgm^{-3}/ AQI: 100-199 (this is up to twice the 24-hour standard);

Hazardous 50-249 µgm^{-3}/ AQI: 200-999 (this is up to 2 to 10 times the 24-hour standard);

and a new **Extreme** level where $PM_{2.5}$ > 250 μgm^{-3}/ AQI: >1000 (this is greater than 10 times the 24-hour standard).

As AQIs are used by the public to determine current and future actions, categories should be applied as a rolling 24-hour average (12 hours observed historically and 12 hours forecast) – and updated every 10 minutes. Basing future smoke risk assessment and public health advisories on the previous 24-hour of observations, as was done this Black Summer in some states, is therefore inadequate (just as the fire risk tomorrow is not based on today's weather). Therefore, an air hazard prediction system (forecasting) is required. Forecasting of air hazards, similar to weather hazards, has the most skill when assimilation of air quality observations, both from surface monitoring as well as satellite-derived remote sensing, are incorporated. **Skilled forecasting is required for planning and action advisories to be effective for better health outcomes.**

Question 5 How should public health information about bushfire smoke be improved?

In order to provide useful advisories on future actions to be taken, a forecast system for $PM_{2.5}$ needs to be developed at a national level (provided as 3 or 6 hourly meteorology forecasts). Current state advisories from the regulators are based on historical 1 hour or 24-hour rolling mean observations, therefore they are only useful and valid for the past 24 hours, and are too late to afford public health protection. Inherently, advisories deal with the future and without a forecast system there is no way to ensure that advisories are publicly relevant or useful.

Nationally consistent, multi-day air quality forecasts (such as are already produced internally at the Bureau of Meteorology and locally by some state EPAs) should be disseminated. The emissions inventories used to drive air quality models are not currently nationally coordinated or consistent. The total $PM_{2.5}$ burden experienced during air disasters will depend on the combined contributions from (1) direct local emissions from the bushfires, (2) $PM_{2.5}$ from other sources including ongoing anthropogenic emissions, and (3) $PM_{2.5}$ transported from sources upwind or formed from chemical precursors transported from sources upwind (including in bushfire smoke plumes). As a result, it is critical that updated, nationally consistent emissions encompassing all sources (including anthropogenic sources) are available for forecasts. These emission inventories should be published and updated regularly as open-access datasets. Research and establishment of observational aerosol and atmospheric composition supersites for health-relevant inventory calibration and satellite validation, as well as real-time data assimilation into forecast models are required. Current observational data availability is not nationally coordinated to facilitate assimilation. Many required observations (i.e. Aerosol Optical Depth, aerosol composition and formaldehyde) are not conducted in our capital cities, to validate either satellite products or forecast models.

A network of all Australian air composition monitoring, modelling and prediction needs to be established to collate, validate, publish and report internationally our air monitoring data and to provide planning tools. This would go beyond current criteria pollutants (i.e. to include toluene, formaldehyde, mercury) and be capable of providing ground-based satellite validation contributing to the generation of satellite-based air pollution information. This could be achieved through validation of existing satellite air quality products and may also present opportunities for linkage with the recently established Australian Space Agency. This could be funded in a similar way and magnitude (i.e., through NCRIS funding) to the ocean observation network IMOS, carbon flux TERN, geoscience AUSCOPE, AURIN, NCI networks that provide ongoing maintenance and technical support for research infrastructure, data collation, national connectivity and visibility of data by delivering international research standard, quality controlled and high traceability observations quickly to the public. This would coordinate the currently very disparate monitoring and data delivery performed by private industry, state government, state EPAs, CSIRO, ANSTO, BoM and Universities. By streamlining best observational practice, creating a pool of instruments and building a research community (creating atmospheric monitoring test-beds in our states) our resilience and ability quickly address the many air and smart city sensor challenges will be met. AIRBOX http://airbox.earthsci.unimelb.edu.au/ is an example of an air quality platform coordinated across university and governmental institutions. While AIRBOX demonstrates expertise and interest amongst the air quality research community, it lacks dedicated technical support, scale and long-term funding to provide data delivery that a national program could provide. A dedicated national program is the necessary foundation to deliver air quality satellite products and forecasts for all Australians – not just those living near monitoring stations.

For a nationally consistent, health relevant actions to be provided to the public using an Australia relevant category system (Table 3), we suggest combining of the Good/Very Good to Good ($PM_{2.5}$ levels are below NEPM annual average reporting standard); Good/Fair to Moderate ($PM_{2.5}$ levels are below NEPM 24-hour average reporting standard); Poor/Very Poor to Poor ($PM_{2.5}$ levels are above NEPM 24-hour average reporting standard); Severe/Hazardous to Hazardous ($PM_{2.5}$ levels over twice the NEPM 24-hour average reporting standard); and creating an Extreme category ($PM_{2.5}$ levels are over ten times the NEPM 24-hour average reporting standard). This is a suggestion only, and establishment of a national expert body for air management and coordination is recommended to create the categories, methodology and advisories/actions like Table 3 provides.

Table 3: Our suggestion for $PM_{2.5}$ AQI categories. These categories should be provided as rolling 24 hourly averages (12 hours historically observed and 12 hours forecast) – updated every ten minutes.

Category	**$PM_{2.5}$** μgm^{-3}	**AQI**	**Actions**
Good	< 8	0-33	➢ Enjoy normal activities
Moderate	8 - 24	34-99	➢ Most people: enjoy normal activities ➢ At risk populations: should reduce / reschedule outdoor activities
Poor	25 - 49	100-199	➢ Issue advisories on how to reduce exposure in place (stay indoors, reduce / reschedule outside activities) ➢ Issue mask wearing advisory ➢ **If forecast to remain for >24 hours:** ➢ Notify public of clean air shelter locations and prepare to invoke smoke action plans
Hazardous	50 – 249	200-999	**Immediate action:** ➢ Issue advisories on how to reduce exposure in place (filtration/ air conditioning) ➢ Cancel/postpone outdoor sport events (children's play and all competitive sport) ➢ Postpone non-essential outside work ➢ Issue mask wearing advisory **If forecast to remain for >24 hours:** ➢ Prepare to cancel public events, school and work - dependent on travel requirements and preparedness ➢ Open clean air shelters
Extreme	>250	>1000	**Immediate action:** ➢ Issue: 'seek clean air shelter / evacuate to clean air' recommendation ➢ Cancel all outdoor activities ➢ Advise: wear masks outside **If forecast to remain for >24 hours:** ➢ Cancel school where clean air shelters not provided ➢ Cancel work where clean air shelters not provided

Regulatory / legislative recommendations

Hazard reduction burning is most effective when the bush is burned around the areas closest to the assets that are to be protected. The weather conditions that are most suitable for such controlled burns (cool and still) are exactly the same as those most likely to trap the pollution close to the ground and result in significant air pollution impacts. There are models being developed that can allow for the prediction of the air quality impacts of a decision to light a hazard reduction burn (Cope et al., 2019); however, current legislation excludes pollution events that occur as a result of hazard reduction burning from the exceedances count, thereby deterring the investment in the development of these tools.

Current legislation excluding both wildfires and hazard reduction events from official AQI exceedance counts suggests that the legislation does not provide health protection that the public expects from air quality monitoring and forecasting. Air quality standards should capture all exceedances as health impacts will be experienced and avoidance actions need to be taken. Some exceedances could be avoided through investment in air management tools, such as is the case for hazard reduction burns, as recommended in the Clean Air Plan for Sydney (Paton-Walsh et al., 2019). The categories and actions provided in Table 3 should be designed to provide the public with real-time and forecast information on their pollutant health exposure risk, and as a metric by which to assess long-term change of population weighted pollutant exposure risk. Considering AQIs as an essential public health tool, there should be no distinction between air quality standard exceedances from fuel reduction burns, wildfires or any other source. Source attribution and $PM_{2.5}$ composition will be important to determine the toxicological link with emergency presentations, hospital admission and mortality. Additionally, the premise of distinguishing anthropogenic from natural wildfires (and therefore beyond air management abatement strategies) is flawed due to the fact that anthropogenic climate change is believed to have significantly enhanced wildfire risk in Australia (e.g. Clarke & Evans, 2019; Di Virgilio et al., 2019).

Question 6 What should be the priority areas of research concerning the physical and mental health impacts of natural disasters?

Research into physical health impacts of air disasters

- We recommend that further research into the health impacts from the bushfire smoke exposure includes recognition of the potential impact of the gas phase toxins, rather than consider solely the impact of $PM_{2.5}$ alone.
- As wildfire smoke ages and interacts with background or urban pollution we expect the toxicological human health response to change, yet this hasn't been evaluated to date. In order to translate this into public health advisories Australia needs to routinely monitor the composition of $PM_{2.5}$ to link pollution sources to toxicological responses and subsequent hospital presentations, admissions and mortality.
- As bushfires become more intense and bushfire seasons become more prolonged, we need to investigate the impacts of medium to long term exposure to bushfire smoke on cardiopulmonary health. In addition, pregnant women/foetuses were a particularly at risk group during the 2019/2020 bushfires and further investigation on birth outcomes is needed.
- There should be research into the effectiveness of filtration, air purifiers, and air conditioning systems for clean air shelters. Similarly, research on the effectiveness of different masks for personal protection of the public, fire-fighters and outside workers in polluted/smoky/dusty environments is required.
- There is preliminary evidence to suggest that some types of Australian homes do not perform well as shelters from severe smoke events. We recommend investigations into features of Australian architecture and strategies that could improve the effectiveness of buildings as clean air shelters.
- Health impacts of fire mitigation (control burning and indigenous land management practices), climate change abatement and air quality management strategies be carefully evaluated.

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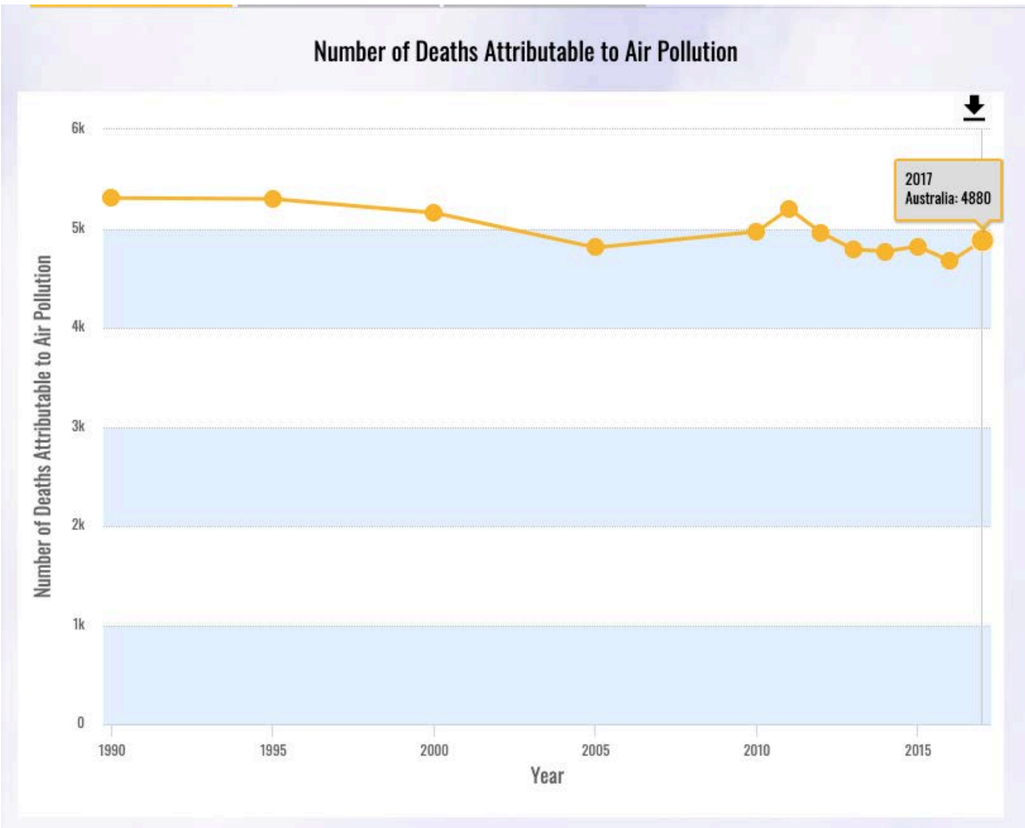

Figure A1: from https://www.stateofglobalair.org/data/#/health/plot from Global Burden of Disease data, accessed June 2020.