From:	Heffernan, Emily (AU)
To:	Justine Stansen
Cc:	Fox, Chris (AU)
Subject:	RE: Hazelwood Mine Fire Inquiry - KWM letter dated 15 October 2015 [KWM-Documents.FID1770821]
Date:	Friday, 16 October 2015 7:57:25 PM
Attachments:	image001.jpg Hazelwood Mine Fire Inquiry - KWM letter dated 6 October 2015 KWM-Documents.FID1770821.msg RE Hazelwood Mine Fire Inquiry - KWM letter dated 6 October 2015 KWM-Documents.FID1770821.msg FW Hazelwood Mine Fire Inquiry KWM-Documents.FID1770821.msg Hazelwood Mine Fire Inquiry #2 KWM-Documents.FID1770821.msg FW Hazelwood Mine Fire Inquiry KWM-Documents.FID1770821.msg Hazelwood Mine Fire Inquiry KWM-Documents.FID1770821.msg RE Hazelwood Mine Fire Inquiry KWM-Documents.FID1770821.msg FW Hazelwood Mine Fire Inquiry KWM-Documents.FID1770820.msg

---

Dear Justine,

Further to your email below, as requested please find attached copies of our correspondence to Dr Philip McCloud referred to in his letter dated 13 October 2015.

Regards,

Emily Heffernan | Senior Associate
King & Wood Mallesons
[redacted]

From: Justine Stansen [redacted]
Sent: Friday, 16 October 2015 1:32 PM
To: Heffernan, Emily (AU) <[redacted]
Cc: Fox, Chris (AU) [redacted]
Subject: RE: Hazelwood Mine Fire Inquiry - KWM letter dated 15 October 2015 [KWM-Documents.FID1770821]

Dear Emily

Please see **attached** letter. Can you please provide correspondence to Dr McCloud referred to in his letter dated 13 October 2015.

Kind regards

Justine Stansen
Principal Legal Advisor
Hazelwood Mine Fire Inquiry
[redacted]

cid:image001.jpg@01D0BF00.FDC13FB0

From: Heffernan, Emily (AU) [[redacted]]
Sent: Thursday, 15 October 2015 8:05 PM
To: Justine Stansen
Cc: Fox, Chris (AU)
Subject: Hazelwood Mine Fire Inquiry - KWM letter dated 15 October 2015 [KWM-Documents.FID1770821]

Dear Justine,

Please find attached our letter dated 15 October 2015, together with its enclosures.

Regards,

Emily Heffernan | Senior Associate
King & Wood Mallesons
[redacted]

From:	Heffernan, Emily (AU)
To:	Philip McCloud ([redacted]
Cc:	Fox, Chris (AU)
Subject:	Hazelwood Mine Fire Inquiry - KWM letter dated 6 October 2015 [KWM-Documents.FID1770821]
Attachments:	Materials referred to in KWM letter dated 6 October 2015.zip 4581_001.pdf

Dear Philip,

Please find attached:

1. Our letter dated 6 October 2015; and
2. A zip folder containing reports A1 – A7 and B1 – B3 referred to in the letter.

Please contact me should you wish to discuss.

Regards,

Emily Heffernan | Senior Associate
King & Wood Mallesons
[redacted]

Analysis of death data during the Morwell mine fire

Introduction

This document explains my analysis of the Morwell mine fire data. I have tried to give as much technical detail as possible whilst still making it understandable to the non-specialist reader.

I am happy for this document to be freely shared. I am also happy to answer further questions via e-mail: a.barnett@qut.edu.au.

Methods

Data

The data were monthly numbers of deaths from 2009 to 2014 for the months of January to June. The deaths were split by four postcodes (3840, 3842, 3825 and 3844) according to usual place of residence. The six years, six months and four postcodes gives 144 observations. In total there were 1,811 deaths.

Statistical model

I used a regression model to examine the key hypothesis of whether deaths rates were higher during the two months of the fire.

I give the model as an equation below and then explain each line of the equation.

$$
\begin{aligned}
d_{i,t} &\sim \text{Poisson}(\mu_{i,t}), \qquad i = 1, \ldots, 4,\ t = 1, \ldots, 36, \\
\log(\mu_{i,t}) &= \log(\text{pop}_t/10000) + \alpha_0 + \text{trend}_t + \text{season}_t + \text{postcode}_i + \text{fire}_t, \\
\text{trend}_t &= \alpha_1 t, \\
\text{season}_t &= \alpha_2 \cos\left(\frac{2\pi(\text{month}_t - 1)}{12}\right) + \alpha_3 \sin\left(\frac{2\pi(\text{month}_t - 1)}{12}\right), \\
\text{postcode}_i &\sim N(0, \sigma^2) \\
\text{fire}_t &= \begin{cases} \alpha_4, & \text{if year} = 2014 \text{ and month} = 2, 3, \\ 0, & \text{otherwise.} \end{cases}
\end{aligned}
$$

The first line says that the deaths from postcode i at time t are modelled as a Poisson distribution, which is the most appropriate distribution for count data. There are four postcodes and 36 times.

The second line is the regression model, it includes the population at time t (divided by 10,000) as an offset which is used to account for the region's growing population. This population data is for LaTrobe City Council which includes other postcodes outside the four in the death data. Ideally I would have had population data for each individual postcode, but I've assumed that the influx and outgoings of people in these four postcodes over time mirrors the patterns for the wider council area. In a sensitivity analysis I removed the population data and it had little impact on the results.

The regression equation uses a log-link which means the model is multiplicative and hence gives results as death rates rather than numbers. The overall mean death rate is modelled by α_0 (labelled as the intercept in the tables below). A linear trend in death rates is modelled by α_1 to control for the expected small reduction in death rates over 2009 to 2014.

Deaths in Australia are strongly seasonal with a winter peak. To model this I have include a annual sinusoidal model based on the month in time t.

To adjust for any differences in death rates between postcodes I included a random effect using a Normal distribution with a zero mean. This allows deaths rates to be higher or lower in some postcodes and constrains the differences to follow a Normal distribution.

The effect of the fire is modelled using a simple change in death rates during February and March 2014 compared with all other months.

The absolute number of deaths was estimated using: $\overline{d}[\exp(\alpha_4) - 1]$, which is the mean number of monthly deaths per postcode multiplied by the relative change in deaths.

In an alternative model I included a term for temperature: $\alpha_5\text{temperature}_t$, where temperature_t is the maximum monthly temperature from the Bureau of Meteorology. This adjustment is added because we know that high temperatures increase the risk of death. Ideally I would have used daily temperature data to give a finer adjustment, but this would also require daily death data.

The model was fitted using a Bayesian paradigm as this allowed me to easily estimate the probability that there was an increase in the death rate: $Pr(\alpha_4 > 0)$.

The plots and tables were created using the R software (`www.r-project.org`) and the Bayesian model was fitted using JAGS (`mcmc-jags.sourceforge.net`).

Results

Plots

Looking at the total figures, the deaths in 2014 in February and March do appear to be high. Another year with high deaths rates is 2009 and this may be due to bushfires and extreme heat that summer.

The differences in numbers on the y-axes between panels are because some suburbs are larger than others.

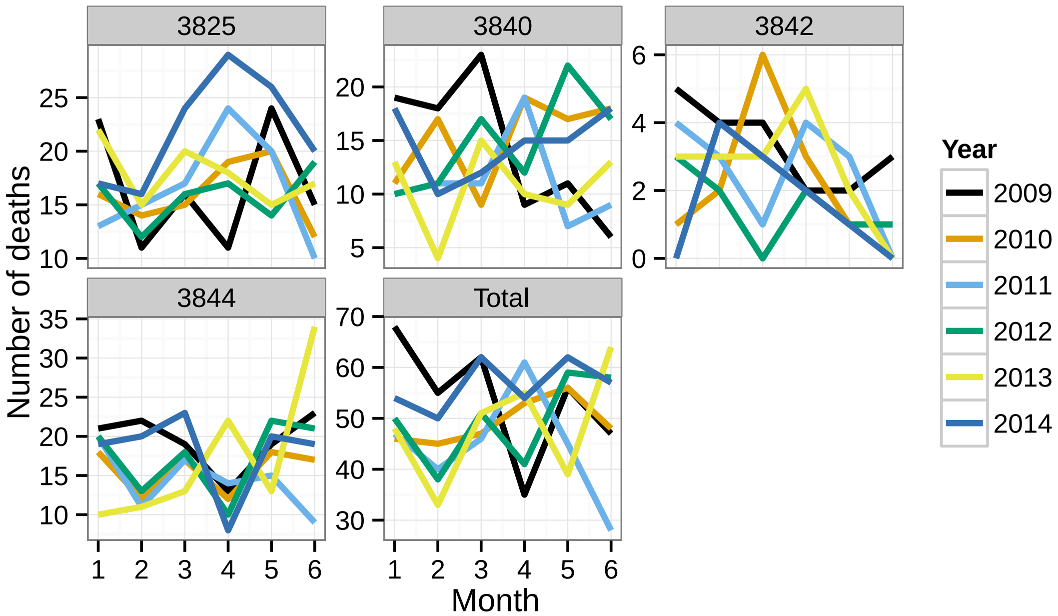

Figure 1: Deaths numbers by month and year in each postcode and the overall number of deaths. The scales on the y-axes differ between postcodes.

Statistical model results

Table 1: Estimates without adjusting for temperature. Statistics are the mean, standard deviation and lower and upper 95% credible interval. Estimates are on a log scale except for the relative risks and absolute number of deaths.

	mean	SD	lower	upper
Intercept	0.30	0.06	0.17	0.42
Trend	0.00	0.01	−0.03	0.03
Postcode 1	0.57	0.04	0.49	0.66
Postcode 2	0.31	0.05	0.22	0.40
Postcode 3	−1.43	0.08	−1.60	−1.27
Postcode 4	0.55	0.04	0.46	0.63
Season, cos	−0.04	0.04	−0.12	0.04
Season, sin	−0.02	0.08	−0.17	0.14
Fire	0.13	0.11	−0.08	0.34
Fire, relative risk	1.14	0.12	0.92	1.41
Absolute deaths	1.82	1.57	−1.02	5.10

The probability that the death rate was higher than the average during the fire is 0.89. This means that the probability that the death rate was not higher than the average during the fire is 0.11. The mean increase in deaths is as a relative risk is 1.14, or 14 as a percentage. The absolute number of deaths per postcode per month is 1.8, which over 4 postcodes and 2 months is 14.4.

Table 2: Estimates after adjusting for monthly temperatures. Statistics are the mean, standard deviation and lower and upper 95% credible interval. Estimates are on a log scale except for the relative risks and absolute number of deaths.

	mean	SD	lower	upper
Intercept	0.30	0.06	0.18	0.42
Trend	0.00	0.01	−0.03	0.03
Postcode 1	0.57	0.04	0.49	0.66
Postcode 2	0.31	0.05	0.22	0.40
Postcode 3	−1.43	0.08	−1.59	−1.27
Postcode 4	0.55	0.04	0.46	0.63
Season, cos	−0.16	0.15	−0.46	0.13
Season, sin	−0.01	0.08	−0.16	0.15
Fire	0.09	0.11	−0.13	0.32
Fire, relative risk	1.11	0.13	0.87	1.37
Absolute deaths	1.34	1.60	−1.58	4.71
Temperature	0.02	0.02	−0.02	0.06

The probability that the death rate was higher than the average during the fire is 0.80. The mean increase in deaths is as a relative risk is 1.11, or 11 as a percentage. The absolute number of deaths per postcode per month is 1.4, which over 4 postcodes and 2 months is 11.2.

The reduction in the risk of the fire and the death numbers after adjusting for temperature is plausible as we know that high temperatures can kill. High temperatures and high levels of air pollution can interact to produce greater combined risks than when only one exposure is present.

The figures in the first released analysis quoted 11 deaths rather than 14. This is because the request to present absolute deaths was made after the request to adjust for temperature.

Analysis of daily death data during the Morwell mine fire

Summary

This latest analyses gives a 99% probability of an increase in deaths during the 45 days of the fire, with an estimated 23 additional deaths. This is larger than the 79% to 89% probability and 10 to 14 additional deaths from my two previous analysis. This increase in probability and deaths occurred because this analysis used daily data whereas the previous analyses used monthly data. Using days instead of months reduces the measurement error between exposure and death, and an increased statistical significance and risk is entirely expected based on the theory of measurement error [1]. This analysis also had a better control for the potential confounder of temperature, as temperature was also modelled on a daily time scale.

Introduction

This document contains my third analysis of the Morwell mine fire data. This is an updated analysis using daily death data for four postcodes for the years 2009 to 2014.

Methods

Data

The death data were daily numbers from 1 January 2009 to 31 December 2014, which is 2191 days. The deaths were split by four postcodes (3840-Morwell, 3842-Churchill, 3825-Moe, 3844-Traralgon) according to usual place of residence. There were 3,414 deaths in total.

I used population data from the Australian Bureau of Statistics for each postcode over time. This is a further improvement on my previous analyses which used overall population data for the Latrobe Valley.

The temperature data came from the Bureau of Meteorology weather station at Morwell (station number: 85280), which provided daily maximum temperature. Two days were missing and I imputed the missing temperature using the mean temperature for the days either side of the missing day. I used maximum temperature rather than mean or minimum temperature because previous research found that most common temperature measures are highly correlated and perform equally well when predicting daily death rates [2].

Statistical methods

I used a regression model to examine the key hypothesis of whether deaths rates were higher during the 45 days of the fire.

I give the model as an equation below and then explain each line of the equation.

$$\begin{aligned}
d_{i,t} &\sim \text{Poisson}(\mu_{i,t}), \qquad i = 1,\dots,4,\ t = 1,\dots,2191,\\
\log(\mu_{i,t}) &= \log(\text{pop}_{i,t}/10000) + \alpha_0 + \text{postcode}_i + \text{trend}_t + \text{season}_t + \text{weekday}_t\\
&+ \text{temperature}_t + \text{fire}_t,\\
\text{postcode}_i &\sim N(0,\sigma^2)\\
\text{trend}_t &= \text{ns}(\alpha_{1:2}, t, 2),\\
\text{season}_t &= \alpha_3 \cos(2\pi f) + \alpha_4 \sin(2\pi f),\\
\text{weekday}_t &= \alpha_{5:10}\mathbf{D}_t,\\
\text{temperature}_t &= \text{ns}(\alpha_{11:19}, \text{maximum temperature}_t, 3\times 3),\\
\text{fire}_t &= \begin{cases}\alpha_{20}, & \text{if date} \in \{\text{9-Feb-2014}, \text{10-Feb-2014}, \dots, \text{26-Mar-2014}\},\\ 0, & \text{otherwise.}\end{cases}
\end{aligned}$$

The index i is for postcode and the index t is for time. I used a Poisson model as the data are daily counts of deaths. The trend was fitted as a natural spline (ns) with two degrees of freedom which allowed the underlying death rate to change slowly during 2009 to 2014 due to factors such as an ageing population. Season was fitted as an annual sinusoid and f is the fraction of the year from 0 (1 January) to 1 (31 December) [3]. I modelled the expected small difference in death rates by day of the week using an independent effect on each day with Sunday as a the reference day.

Temperature was modelled as a non-linear variable to allow for increased risks in low and high temperatures [4]. To allow for the known delay between exposure to temperature and death I also included a lag with a delay up to 21 days. Both temperature and lag were fitted using a natural spline with three degrees of freedom which is large enough to model a non-linear association.

To check the adequacy of the model I examined the residuals (difference between observed and predicted) using a histogram and autocorrelation plot.

Results

Simple table

Table 1 shows a higher mean number of daily deaths in all four postcodes during the period of the fire compared with all other times. These crude figures do not adjust for the seasonal pattern in deaths, and the regression model below should give a truer picture of any increase in death rates.

Table 1: Summary statistics on daily deaths by postcode and the time of the fire using data for 1 January 2009 to 31 December 2014

			Deaths			
Postcode	Fire	N	Mean	SD	Min	Max
Churchill	No	2145	0.075	0.27	0	2
	Yes	46	0.130	0.40	0	2
Moe	No	2145	0.558	0.74	0	5
	Yes	46	0.717	0.81	0	3
Morwell	No	2145	0.396	0.63	0	4
	Yes	46	0.413	0.62	0	2
Traralgon	No	2145	0.522	0.73	0	6
	Yes	46	0.652	0.87	0	3
All	No	8580	0.388	0.65	0	6
	Yes	184	0.478	0.73	0	3

Plots of daily deaths over time

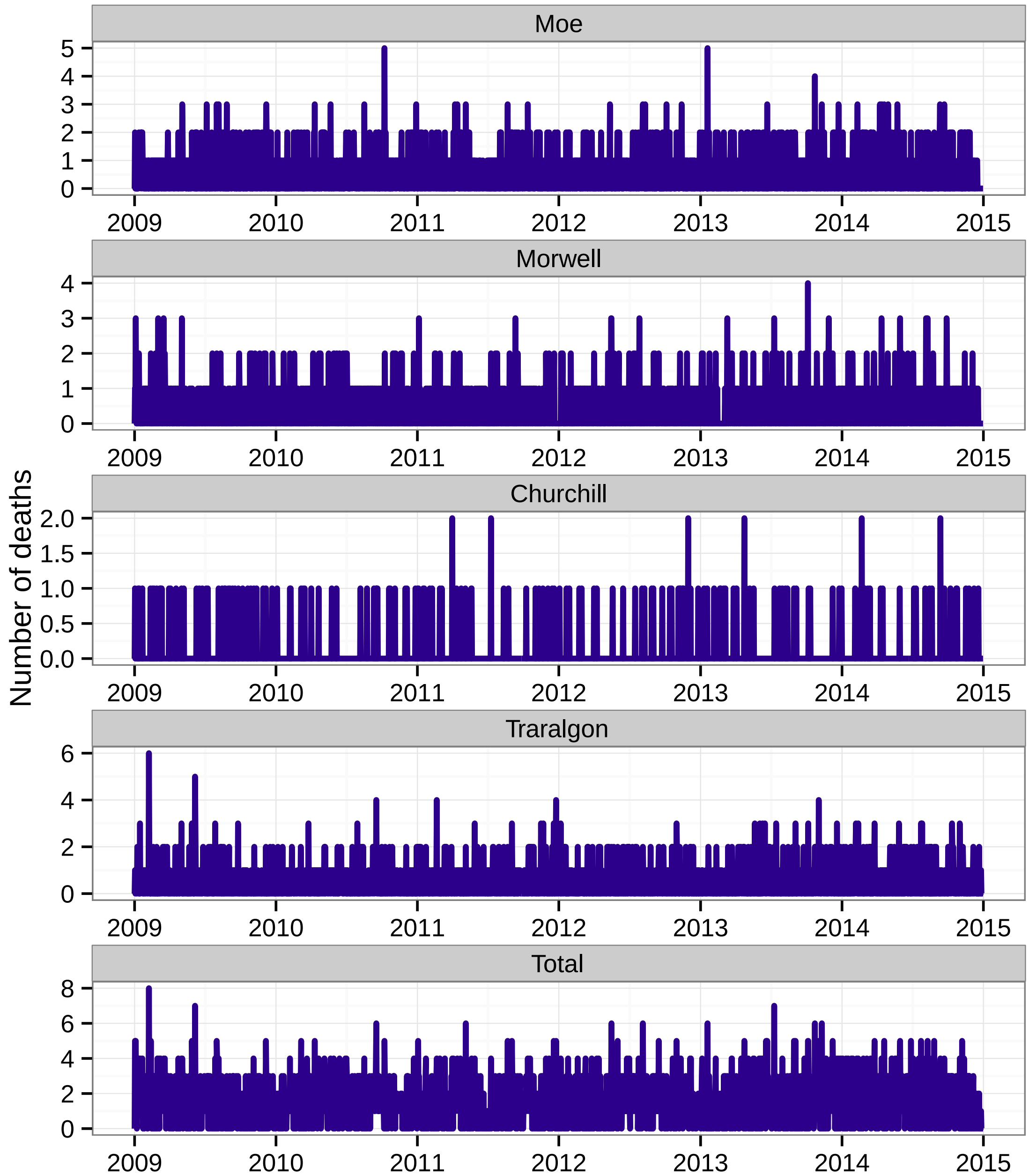

Figure 1: Daily death numbers in each postcode and the total number of deaths across the four postcodes for 1 January 2009 to 31 December 2014.

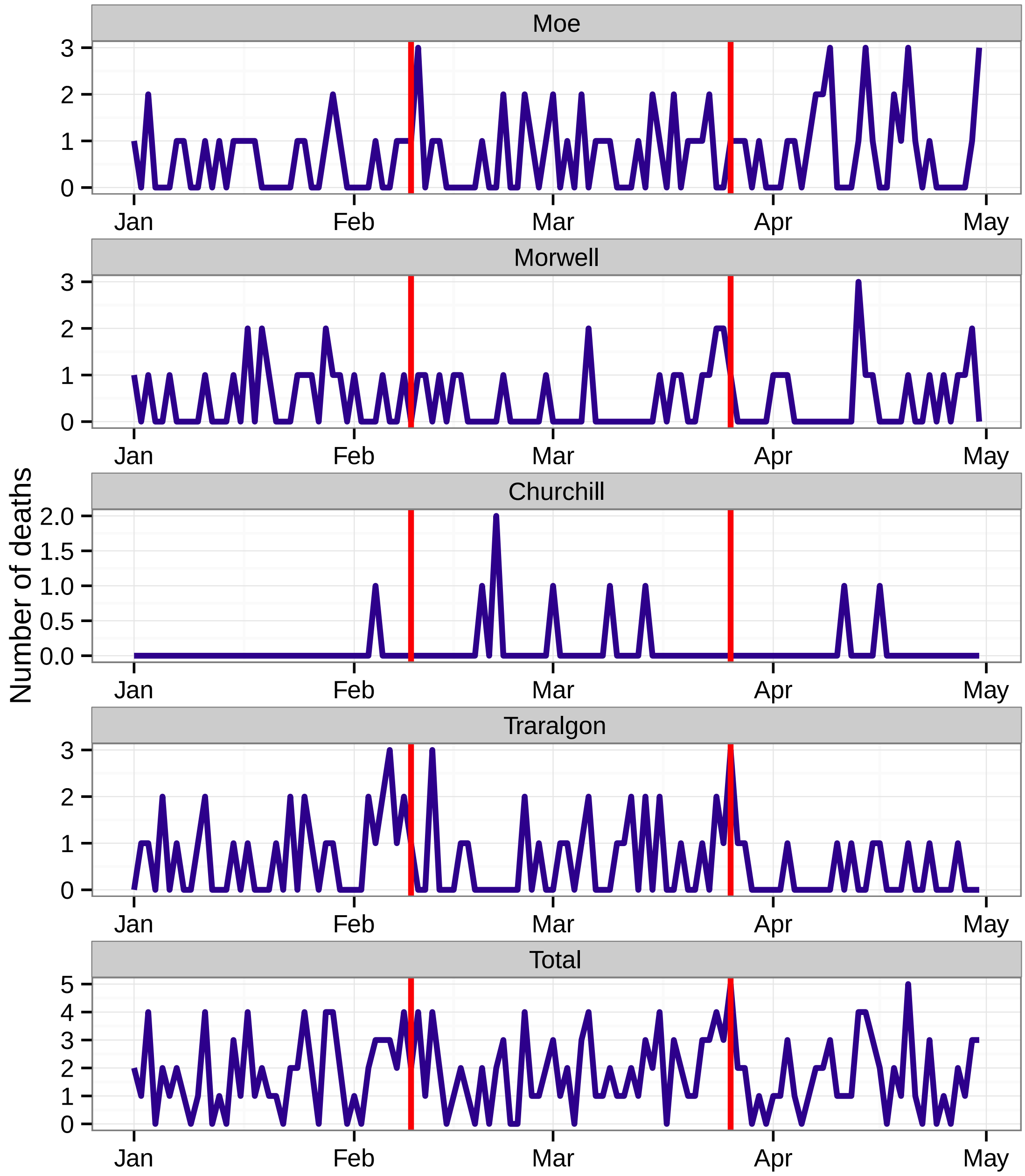

Figure 2: Daily death numbers in each postcode and the total number of deaths across the four postcodes for 1 January 2014 to 30 April 2014. The start and end of the fire are shown by vertical red lines.

Statistical model results

Table 2: Model of daily deaths. Statistics are the mean and lower and upper 95% credible interval. Estimates are on a log scale except for the relative risk and absolute number of deaths.

	Mean	Lower	Upper
Intercept	−1.601	−1.732	−1.475
Trend, 1	−0.125	−0.346	0.096
Trend, 2	0.137	0.016	0.258
Postcode, 3825	0.285	0.225	0.346
Postcode, 3840	0.129	0.062	0.194
Postcode, 3842	−0.310	−0.426	−0.196
Postcode, 3844	−0.104	−0.165	−0.042
Season, cos	0.105	−0.057	0.269
Season, sin	0.059	−0.033	0.153
Monday	−0.069	−0.196	0.056
Tuesday	−0.096	−0.223	0.031
Wednesday	−0.042	−0.165	0.083
Thursday	−0.060	−0.186	0.064
Friday	0.049	−0.074	0.172
Saturday	0.008	−0.114	0.131
Fire, relative risk	1.324	1.034	1.656
Additional deaths during fire, 3825	8.271	0.860	16.731
Additional deaths during fire, 3840	5.848	0.608	11.830
Additional deaths during fire, 3842	1.124	0.117	2.273
Additional deaths during fire, 3844	7.733	0.804	15.642
Additional deaths, all postcodes	22.976	2.388	46.476

The probability that the death rate was higher than the average during the fire is 0.99. This means that the probability that the death rate was not higher than the average during the fire is 0.01. The mean increase in deaths is 1.32 as a relative risk, or 32 as a percentage. The 95% credible interval for the relative risk does not include 1, indicating that the risk was higher than average during the fire. The mean estimated number of extra deaths during the fire over the four postcodes is 23.

Effect of temperature

The effect of temperature in Figure 3 is exactly as expected. It shows a steep rise in risk for high temperatures on the day of exposure, and smaller but longer lasting risk for low temperatures [4].

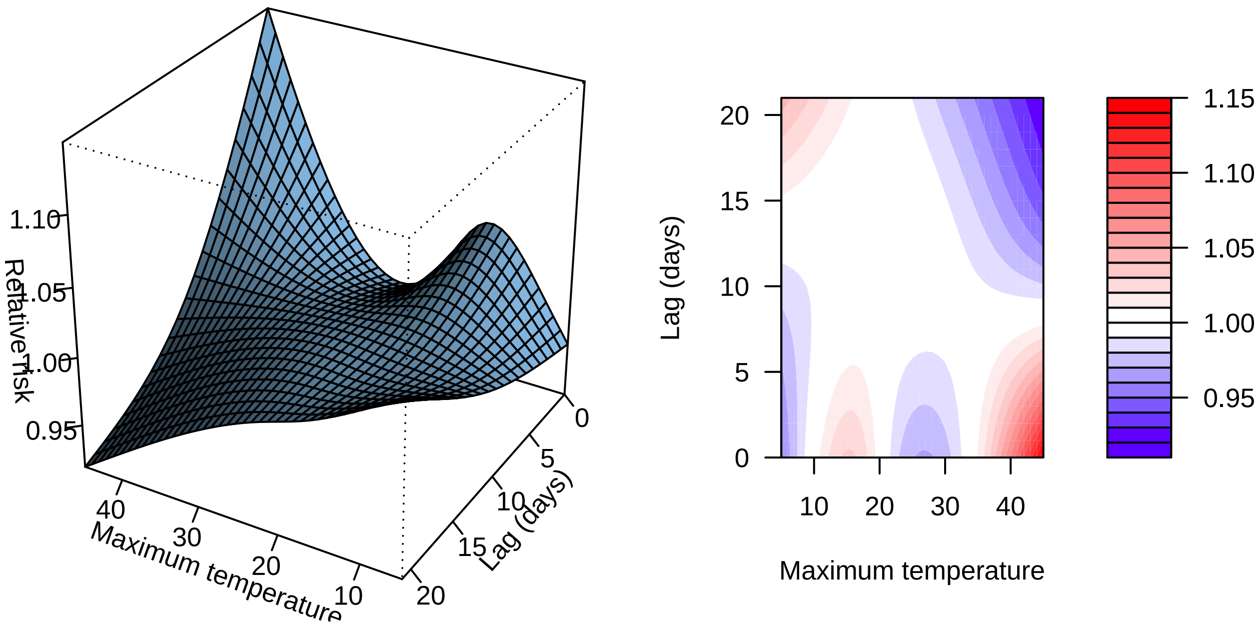

Figure 3: Estimated relative risk of maximum temperature (°C) by temperature and lag using a surface plot (left) and contour plot (right).

Residual plots

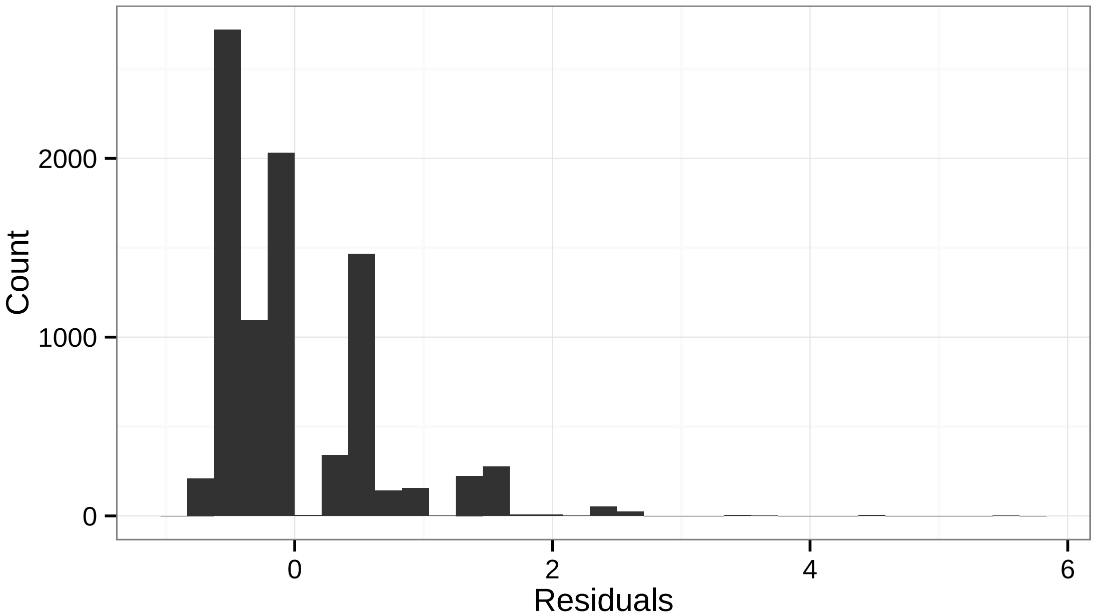

Figure 4: Residual histogram from the model of daily deaths.

The histogram of residuals are centred on zero but with a positive skew which is as expected when modelling small counts (Figure 4). There were four relatively large residuals over 4 as shown in Table 3. The large residual in Traralgon on 7/Feb/2009 may be the Black Saturday bushfires.

Table 3: Four large residuals where the model greatly under-predicted the number of deaths.

Date	Postcode	Deaths	Predicted	Residual	Pearson residual
08/Oct/2010	Moe	5	0.60	4.40	5.66
19/Jan/2013	Moe	5	0.51	4.49	6.27
07/Feb/2009	Traralgon	6	0.57	5.43	7.22
06/Jun/2009	Traralgon	5	0.58	4.42	5.78

The Pearson goodness of fit statistic is 8749 which is smaller than test limit of 8958, which is the 95th percentile of a chi-squared distribution [5]. This indicates that the model is an adequate fit to the data.

The autocorrelation plots of the residuals show no residual autocorrelation in any postcode as the correlations are small and close to zero (Figure 5). This means there is unlikely to be any residual confounding by other short-term environmental factors (e.g., humidity).

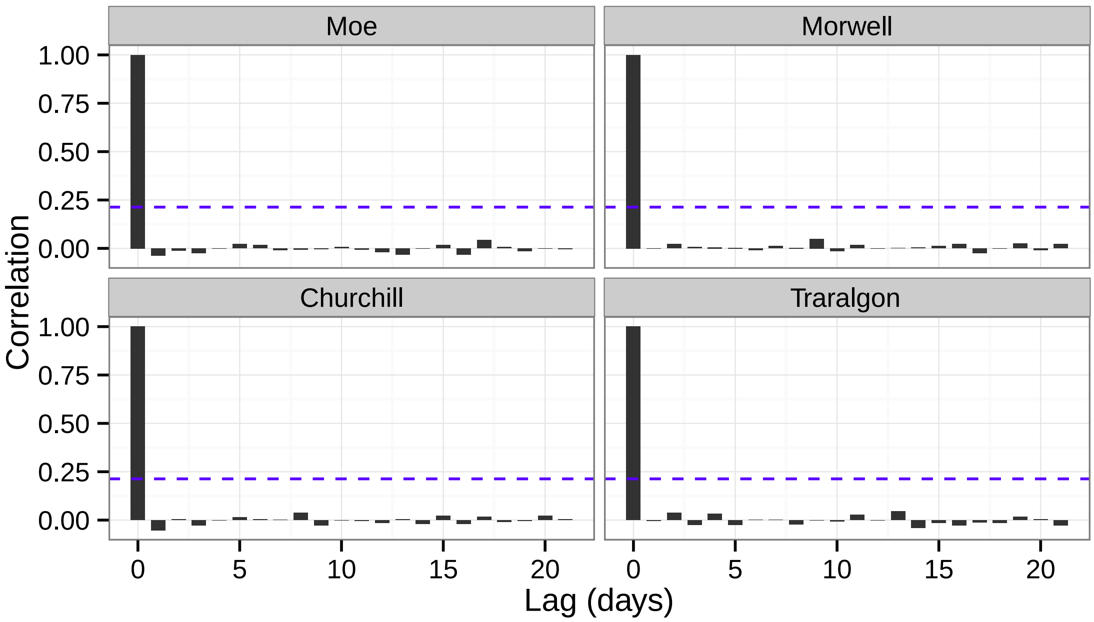

Figure 5: Autocorrelation of residuals from the model of daily deaths by postcode. The dotted horizontal blue line is the limit for assessing significant autocorrelation.

References

[1] Jennifer A Hutcheon, Arnaud Chiolero, and James A Hanley. Random measurement error and regression dilution bias. *BMJ*, 340, 2010.

[2] A. Barnett, S Tong, and ACA Clements. What measure of temperature is the best predictor of mortality? *Environmental Research*, 110(6):604–611, 2010.

[3] Adrian G Barnett and Annette J Dobson. *Analysing Seasonal Health Data*. Springer, Berlin, Heidelberg, 2010.

[4] Antonio Gasparrini and et al. Mortality risk attributable to high and low ambient temperature: a multicountry observational study. *The Lancet*, 386(9991):369–375, 2015.

[5] Annette J Dobson and A.G̃. Barnett. *An Introduction to Generalized Linear Models*. Texts in Statistical Science. Chapman & Hall/CRC, Boca Raton, FL, 3rd edition, 2008.

[6] Martyn Plummer. *rjags: Bayesian graphical models using MCMC*, 2013. R package version 3-11.

Appendix

JAGS Code

This is the code using the JAGS software that runs the Bayesian regression model of daily deaths [6].

```
model{
# likelihood
for (i in 1:N){
deaths[i] ~ dpois(mu[i]);
log(mu[i]) <- log.pop[i] + alpha + weekday[i] + trend[i] + gamma*fire[i]
+ delta.c[pcode[i]] + season[i] + temp[i];
weekday[i] <- inprod(dow[i,1:6], phi[1:6]);
trend[i] <- inprod(time[i,1:n.time], beta[1:n.time]);
season[i] <- theta[1]*cosw[i] + theta[2]*sinw[i];
temp[i] <- inprod(temperature[i,1:n.temp], zeta[1:n.temp]);
}
# priors
alpha ~ dnorm(0, 0.001) # intercept
for (k in 1:n.time){
beta[k] ~ dnorm(0, 0.001) # time trend
}
gamma ~ dnorm(0, 0.001) # fire
for (k in 1:6){
phi[k] ~ dnorm(0, 0.001) # week day
}
for (k in 1:n.temp){
zeta[k] ~ dnorm(0, 0.001) # temperature
}
for (k in 1:n.pcode){
delta[k] ~ dnorm(0, tau.delta); # random intercept for postcode
delta.c[k] <- delta[k] - mu.delta;
# absolute numbers
```

```
    absolute[k] <- mu.deaths[k]*(rr-1)
}
absolute[5] <- sum(absolute[1:4]) # total deaths
tau.delta ~ dgamma(1,1)
for (k in 1:2){
theta[k] ~ dnorm(0, 0.001); # season
}
## scalars
mu.delta <- mean(delta[1:n.pcode])
p.gamma <- step(gamma) # p-value for positive risk
rr <- exp(gamma) # relative risk
}
```

Analysis of daily death data during the Hazelwood mine fire

Summary

This latest analyses gives a 99% probability of an increase in deaths during the 45 days of the fire, with an estimated 23 additional deaths. This is larger than the 79% to 89% probability and 10 to 14 additional deaths from my two previous analysis. This increase in probability and deaths occurred because this analysis used daily data whereas the previous analyses used monthly data. Using days instead of months reduces the measurement error between exposure and death, and an increased statistical significance and risk is entirely expected based on the theory of measurement error [1]. This analysis also had a better control for the potential confounder of temperature, as temperature was also modelled on a daily time scale. Model checks show that there is unlikely to be any confounding with time and that there are no important influential observations. Overall the model is an adequate fit to the data.

Introduction

This document contains my third analysis of the Hazelwood mine fire data. This is an updated analysis using daily death data for four postcodes for the years 2009 to 2014.

Methods

Data

The death data were daily numbers from 1 January 2009 to 31 December 2014, which is 2191 days. The deaths were split by four postcodes (3840-Morwell, 3842-Churchill, 3825-Moe, 3844-Traralgon) according to usual place of residence. There were 3,414 deaths in total.

I used population data from the Australian Bureau of Statistics for each postcode over time. This is a further improvement on my previous analyses which used overall population data for the Latrobe Valley.

The temperature data came from the Bureau of Meteorology weather station at Morwell (station number 85280), which provided daily maximum temperature. Two days were missing and I imputed the missing temperature using the mean temperature for the days either side of the missing day. I used maximum temperature rather than mean or minimum temperature because previous research found that most common temperature measures are highly correlated and perform equally well when predicting daily death rates [2].

Statistical methods

I used a regression model to examine the key hypothesis of whether deaths rates were higher during the 45 days of the fire.

I give the model as an equation below and then explain each line of the equation.

$$\begin{aligned}
d_{i,t} &\sim \text{Poisson}(\mu_{i,t}), \qquad i = 1, \dots, 4,\ t = 1, \dots, 2191, \\
\log(\mu_{i,t}) &= \log(\text{pop}_{i,t}/10000) + \alpha_0 + \text{postcode}_i + \text{trend}_t + \text{season}_t + \text{weekday}_t \\
&+ \text{temperature}_t + \text{fire}_t, \\
\text{postcode}_i &\sim N(0, \sigma^2) \\
\text{trend}_t &= \text{ns}(\alpha_{1:2}, t, 2), \\
\text{season}_t &= \alpha_3 \cos[2\pi f(t)] + \alpha_4 \sin[2\pi f(t)], \\
\text{weekday}_t &= \alpha_{5:10}\mathbf{D}_t, \\
\text{temperature}_t &= \text{ns}(\alpha_{11:19}, \text{maximum temperature}_t, 3 \times 3), \\
\text{fire}_t &= \begin{cases} \alpha_{20}, & \text{if date}_t \in \{\text{9-Feb-2014}, \text{10-Feb-2014}, \dots, \text{26-Mar-2014}\}, \\ 0, & \text{otherwise.} \end{cases}
\end{aligned}$$

The index i is for postcode and the index t is for time. I used a Poisson model as the dependent variable is daily counts of deaths. The trend was fitted as a natural spline (ns) with two degrees of freedom which allowed the underlying death rate to change slowly during 2009 to 2014 due to factors such as an ageing population. Season was fitted as an annual sinusoid and $f(t)$ is the fraction of the year from 0 (1 January) to 1 (31 December) [3]. I modelled the expected small difference in death rates by day of the week using an independent effect on each day with Sunday as a the reference day.

Temperature was modelled as a non-linear variable to allow for increased risks in low and high temperatures [4]. To allow for the known delay between exposure to temperature and death I also included a lag with a delay up to 21 days. Both temperature and lag were fitted using a natural spline with three degrees of freedom which is large enough to model a non-linear association.

To check the adequacy of the model I examined the residuals (difference between observed and predicted) using a histogram and autocorrelation plot. To check for influential observations I used Cook's distance [5].

The estimated additional number of deaths due to the fire in each postcode were calculated using:

$$45 \times \overline{d}_i \times [\exp(\alpha_{20}) - 1],$$

where $\overline{d}_i$ is the mean number of daily deaths in postcode i and $\exp(\alpha_{20})$ is the relative risk of death during the fire. The daily estimate is multiplied by 45 to give an estimate for the period of the fire.

Results

Simple table

Table 1: Summary statistics on daily deaths by postcode and the time of the fire using data for 1 January 2009 to 31 December 2014

			Deaths			
Postcode	Fire	N	Mean	SD	Min	Max
Churchill	No	2145	0.075	0.27	0	2
	Yes	46	0.130	0.40	0	2
Moe	No	2145	0.558	0.74	0	5
	Yes	46	0.717	0.81	0	3
Morwell	No	2145	0.396	0.63	0	4
	Yes	46	0.413	0.62	0	2
Traralgon	No	2145	0.522	0.73	0	6
	Yes	46	0.652	0.87	0	3
All	No	8580	0.388	0.65	0	6
	Yes	184	0.478	0.73	0	3

Table 1 shows a higher mean number of daily deaths in all four postcodes during the period of the fire compared with all other times. These crude figures do not adjust for the seasonal pattern in deaths or changes over time in population size, and the regression model below should give a truer picture of any increase in death rates.

Plots of daily deaths over time

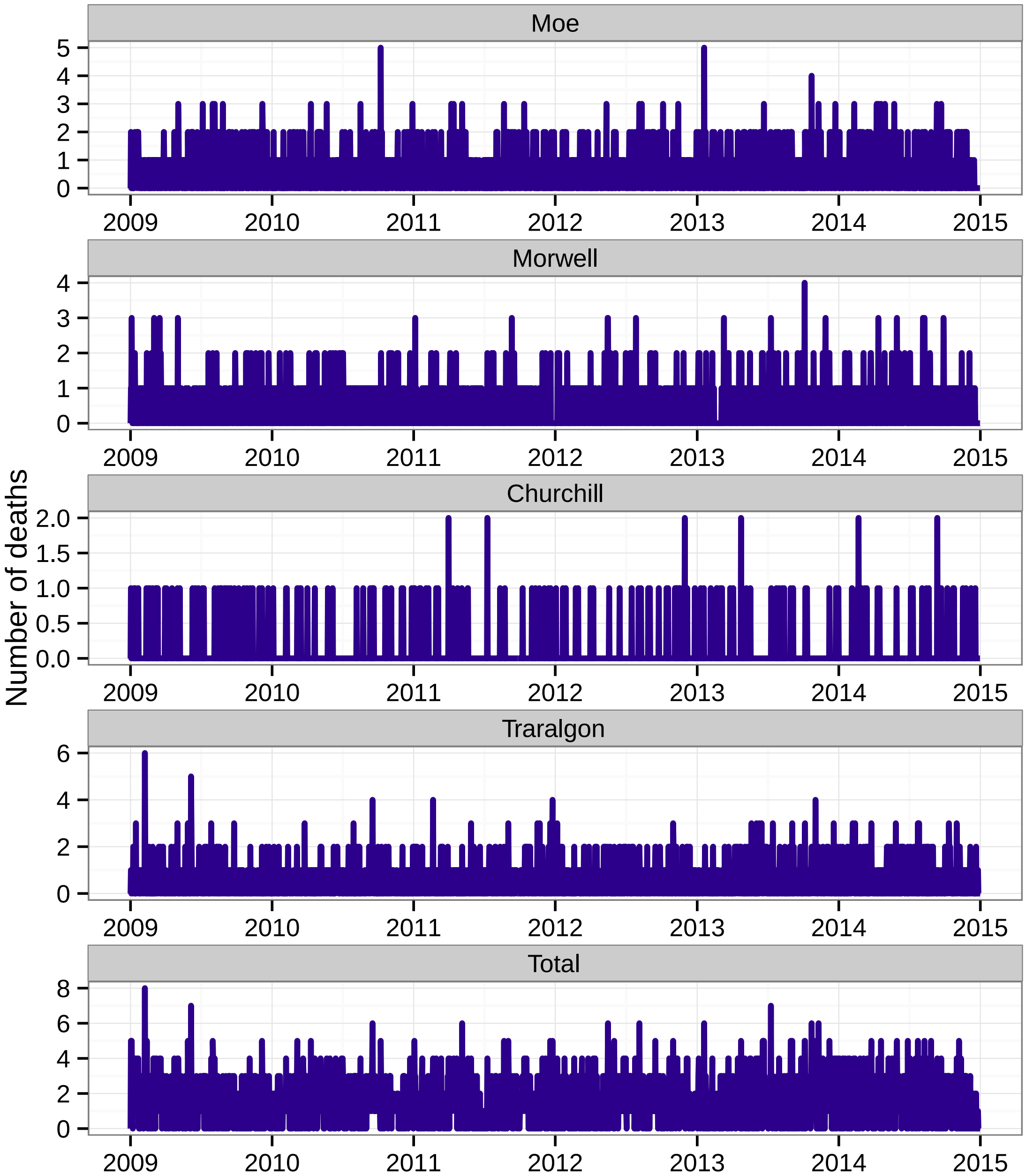

Figure 1: Daily death numbers in each postcode and the total number of deaths across the four postcodes for 1 January 2009 to 31 December 2014.

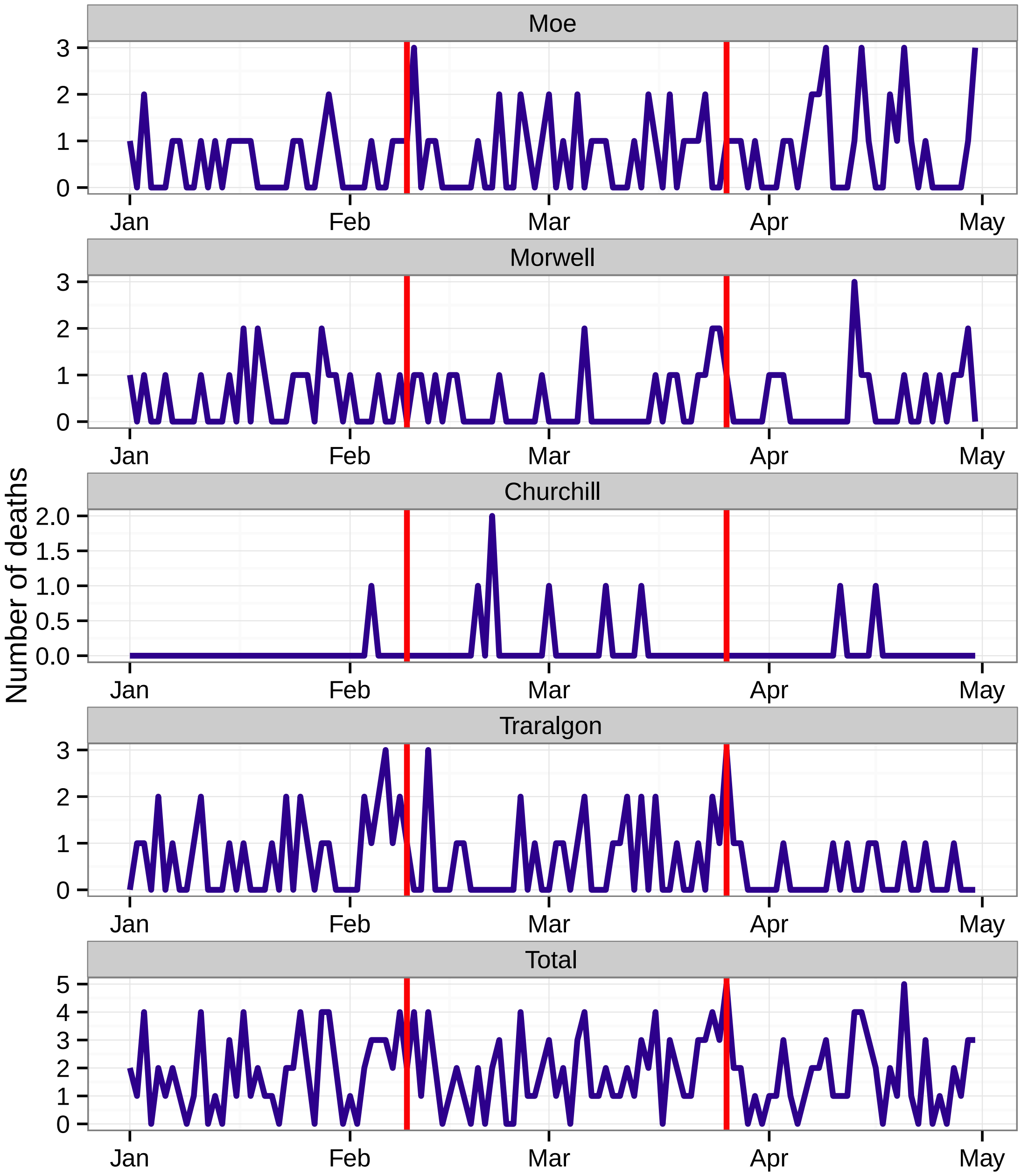

Figure 2: Daily death numbers in each postcode and the total number of deaths across the four postcodes for 1 January 2014 to 30 April 2014. The start and end of the fire are shown by vertical red lines.

Statistical model results

Table 2: Model of daily deaths. Statistics are the mean and lower and upper 95% credible interval. Estimates are on a log scale except for the relative risk and absolute number of deaths.

	Mean	Lower	Upper
Intercept	−1.601	−1.732	−1.475
Trend, 1	−0.125	−0.346	0.096
Trend, 2	0.137	0.016	0.258
Postcode, 3825	0.285	0.225	0.346
Postcode, 3840	0.129	0.062	0.194
Postcode, 3842	−0.310	−0.426	−0.196
Postcode, 3844	−0.104	−0.165	−0.042
Season, cos	0.105	−0.057	0.269
Season, sin	0.059	−0.033	0.153
Monday	−0.069	−0.196	0.056
Tuesday	−0.096	−0.223	0.031
Wednesday	−0.042	−0.165	0.083
Thursday	−0.060	−0.186	0.064
Friday	0.049	−0.074	0.172
Saturday	0.008	−0.114	0.131
Fire, relative risk	1.324	1.034	1.656
Additional deaths during fire, 3825	8.271	0.860	16.731
Additional deaths during fire, 3840	5.848	0.608	11.830
Additional deaths during fire, 3842	1.124	0.117	2.273
Additional deaths during fire, 3844	7.733	0.804	15.642
Additional deaths, all postcodes	22.976	2.388	46.476

The probability that the death rate was higher than the average during the fire is 0.99. This means that the probability that the death rate was not higher than the average during the fire is 0.01. The mean increase in deaths is 1.32 as a relative risk, or 32 as a percentage. The 95% credible interval for the relative risk does not include 1, indicating that the risk was higher than average during the fire. The mean estimated number of extra deaths during the fire over the four postcodes is 23 (95% credible interval: 2 to 46).

Effect of temperature

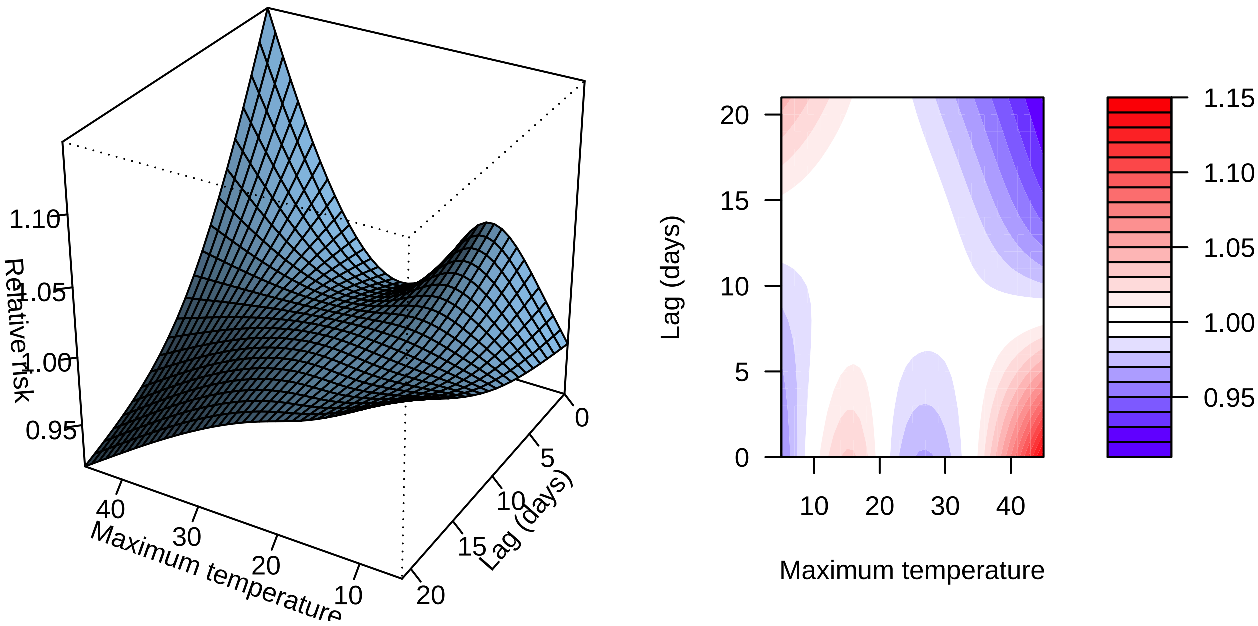

Figure 3: Estimated relative risk of maximum temperature (°C) by temperature and lag using a surface plot (left) and contour plot (right).

The effect of temperature in Figure 3 is exactly as expected. It shows a steep rise in risk for high temperatures on the day of exposure, and smaller but longer lasting risk for low temperatures [4].

Residual plots and model checking

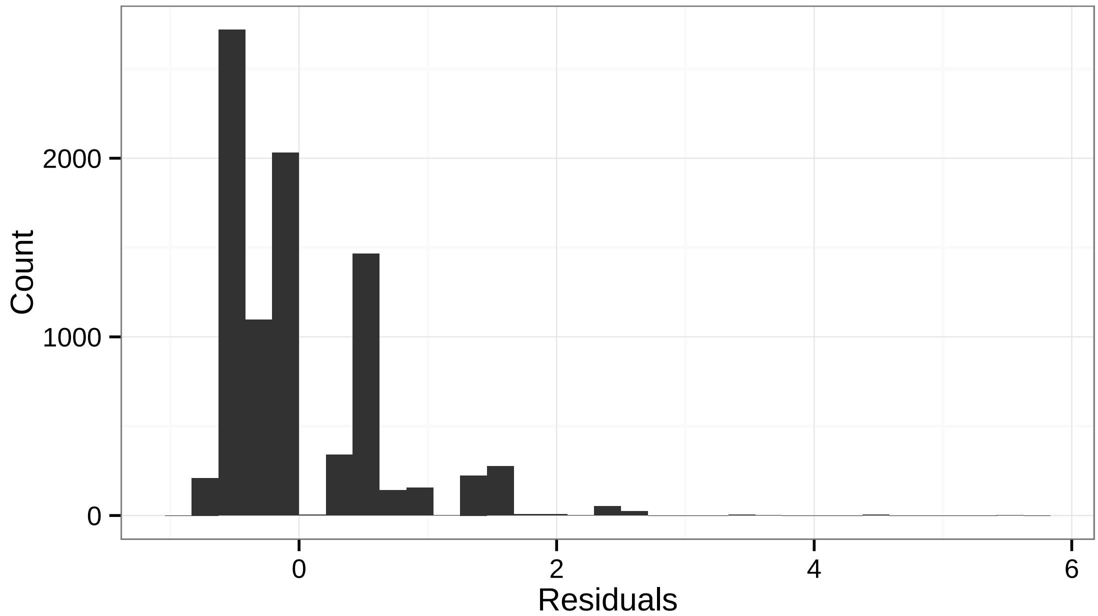

Figure 4: Residual histogram from the model of daily deaths.

The histogram of residuals are centred on zero but with a positive skew which is as expected when modelling small counts (Figure 4). There were four relatively large residuals over 4 as shown in Table 3. The large residual in Traralgon on 7th February 2009 may be the Black Saturday bushfires.

Table 3: Four large residuals where the model greatly under-predicted the number of deaths.

Date	Postcode	Deaths	Predicted	Residual	Pearson residual
08/Oct/2010	Moe	5	0.60	4.40	5.66
19/Jan/2013	Moe	5	0.51	4.49	6.27
07/Feb/2009	Traralgon	6	0.57	5.43	7.22
06/Jun/2009	Traralgon	5	0.58	4.42	5.78

The Pearson goodness of fit statistic is 8749 which is smaller than test limit of 8958, which is the 95th percentile of a chi-squared distribution [5]. This indicates that the model is an adequate fit to the data.

The autocorrelation plots of the residuals show no residual autocorrelation in any postcode as the correlations are small and close to zero (Figure 5). This means there is unlikely to be any residual confounding by other short-term environmental factors (e.g., humidity).

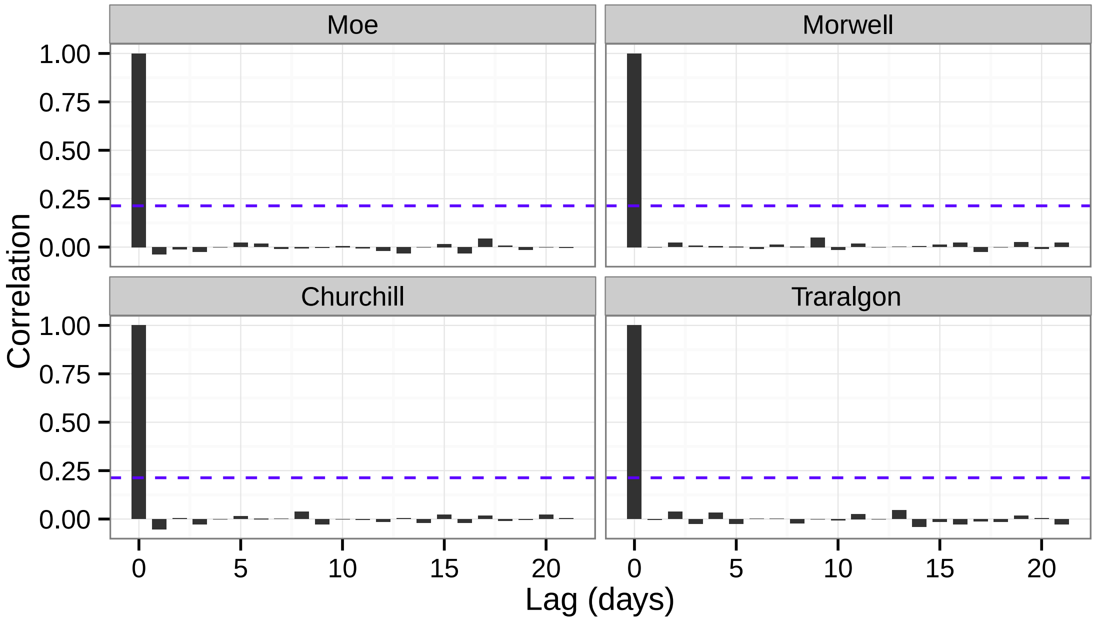

Figure 5: Autocorrelation of residuals from the model of daily deaths by postcode. The dotted horizontal blue line is the limit for assessing significant autocorrelation.

Cook's distance

There is one relatively large influential value in Figure 6, which was the six deaths in Traralgon on the 7th February 2009 possibly due to the Black Saturday bushfires. To check if this impacts on the results I removed this day and re-ran the model.

Table 4: Mean relative risk and 95% credible interval with and without influential day.

model	mean	lower	upper	p.value
Complete data	1.324	1.036	1.655	0.988
Influential observation excluded	1.344	1.048	1.681	0.990

The results in Table 4 show that excluding the influential day from Traralgon had little impact on the mean relative risk or probability that deaths increased during the period of the fire.

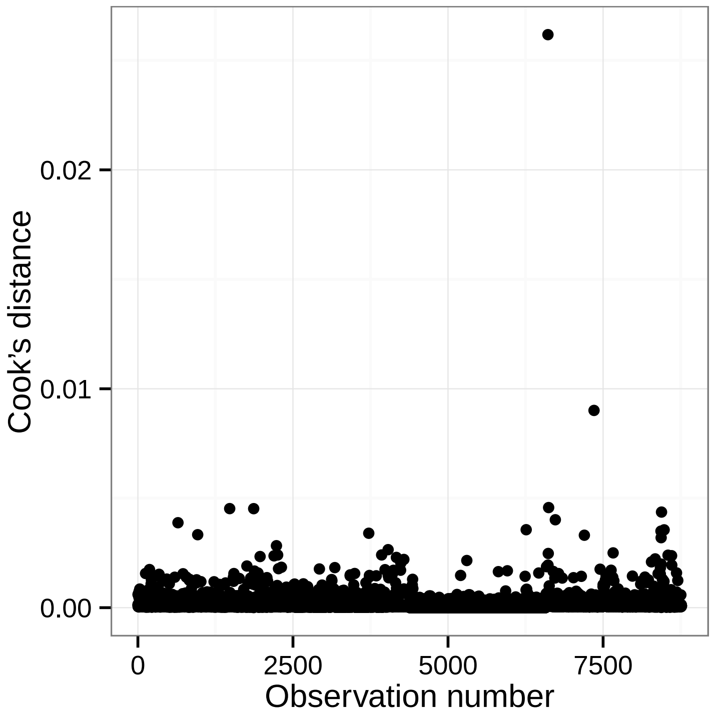

Figure 6: Cook's distance to identify influential observations.

Alternative models

In this section I examine the effect of three new variables from the previous monthly analysis: day of the week, daily temperature and daily trend. The models were as before except without each variable. I compared the relative risk of death, the probability that deaths were increased during the fire, and the model fit using the Pearson goodness of fit statistic. Smaller values for the Pearson goodness of fit statistic indicate a better fit of the model's predictions to the observed data.

Table 5: Estimates of the relative risk of death during the mine fire for alternative models without individual variables. Also shown are the 95% credible intervals and the probability that deaths were higher during the fire. The model fit column is the Pearson goodness of fit statistic.

model	mean	lower	upper	p.value	model.fit
Full model	1.324	1.036	1.655	0.988	8749.1
Without temperature	1.210	0.958	1.496	0.943	8749.7
Without time trend	1.385	1.091	1.719	0.996	8744.5
Without day of the week	1.322	1.033	1.653	0.987	8775.7

The results for the 'Full model' in Table 5 are the same as in Table 2 and are repeated here for ease of comparison.

Not adjusting for daily temperature has a relatively large effect on the mean relative risk as it decreases to 1.21. Temperature is a known confounder of air pollution [6] and has causal biological pathways linked to death that are independent of air pollution (e.g., heat exhaustion). The difference in model fit between a model with and without temperature is small. I prefer to adjust for temperature as this should give a better estimate of the number of deaths independently due to air pollution.

Removing the trend and day of the week had little impact on the relative risk estimates. Removing day of the week had a relatively large detrimental effect on model fit.

References

[1] Jennifer A Hutcheon, Arnaud Chiolero, and James A Hanley. Random measurement error and regression dilution bias. *BMJ*, 340, 2010.

[2] Adrian Barnett, Shilu Tong, and Archie CA Clements. What measure of temperature is the best predictor of mortality? *Environmental Research*, 110(6):604–611, 2010.

[3] Adrian G Barnett and Annette J Dobson. *Analysing Seasonal Health Data*. Springer, Berlin, Heidelberg, 2010.

[4] Antonio Gasparrini and et al. Mortality risk attributable to high and low ambient temperature: a multicountry observational study. *The Lancet*, 386(9991):369–375, 2015.

[5] Annette J Dobson and Adrian G Barnett. *An Introduction to Generalized Linear Models*. Texts in Statistical Science. Chapman & Hall/CRC, Boca Raton, FL, 3rd edition, 2008.

[6] Jessie P Buckley, Jonathan M Samet, and David B Richardson. Commentary: Does air pollution confound studies of temperature? *Epidemiology*, 25(2):242–245, 2014.

[7] Martyn Plummer. *rjags: Bayesian graphical models using MCMC*, 2013. R package version 3-11.

Appendix

JAGS Code

This is the code using the JAGS software that runs the Bayesian regression model of daily deaths [7].

```
model{
# likelihood
for (i in 1:N){
deaths[i] ~ dpois(mu[i]);
log(mu[i]) <- log.pop[i] + alpha + weekday[i] + trend[i] + gamma*fire[i]
+ delta.c[pcode[i]] + season[i] + temp[i];
weekday[i] <- inprod(dow[i,1:6], phi[1:6]);
trend[i] <- inprod(time[i,1:n.time], beta[1:n.time]);
season[i] <- theta[1]*cosw[i] + theta[2]*sinw[i];
temp[i] <- inprod(temperature[i,1:n.temp], zeta[1:n.temp]);
}
# priors
alpha ~ dnorm(0, 0.001) # intercept
for (k in 1:n.time){
beta[k] ~ dnorm(0, 0.001) # time trend
}
gamma ~ dnorm(0, 0.001) # fire
for (k in 1:6){
phi[k] ~ dnorm(0, 0.001) # week day
}
for (k in 1:n.temp){
zeta[k] ~ dnorm(0, 0.001) # temperature
}
```

```
for (k in 1:n.pcode){
delta[k] ~ dnorm(0, tau.delta); # random intercept for postcode
delta.c[k] <- delta[k] - mu.delta;
# absolute numbers
    absolute[k] <- mu.deaths[k]*(rr-1)
}
absolute[5] <- sum(absolute[1:4]) # total deaths
tau.delta ~ dgamma(1,1)
for (k in 1:2){
theta[k] ~ dnorm(0, 0.001); # season
}
## scalars
mu.delta <- mean(delta[1:n.pcode])
p.gamma <- step(gamma) # p-value for positive risk
rr <- exp(gamma) # relative risk
}
```

Expert assessment and advice regarding mortality information as it relates to the Hazelwood Mine Fire Inquiry Terms of Reference – Final report

Commissioned by the Board of Inquiry into the Hazelwood Coal Mine Fire 2015

Consultant:
Emeritus Professor Bruce Armstrong **MBBS(Hons), DPhil (Oxon), FRACP FAFPHM AM FAA**
Epidemiologist and Public Health Physician

August 2015

Contents

Introduction

This report was commissioned by the Board of Inquiry into the Hazelwood Coal Mine Fire, which was gazetted by the Victoria Government in May 2015 (Victoria Government Gazette No. S 123 Tuesday 26 May 2015). It relates to the Inquiry's term of reference that states: *Whether the Hazelwood Coal Mine Fire contributed to an increase in deaths, having regard to any relevant evidence for the period 2009 to 2014.*

In providing an expert assessment and advice to inform this term of reference, the consultant was required to:

(a) Consider the mortality information provided by the Registrar of Births, Deaths and Marriages;
(b) Review the mortality assessments undertaken by the Department of Health and other organisations commissioned by the Department;
(c) Review the mortality assessments undertaken by any third parties e.g. A/Prof Adrian Barnett;
(d) Consider any relevant public submissions, case reports.

On review of the assessments made by the Department of Health and Human Services (DHHS) and other organisations it commissioned, and other assessments DHSS made, and in consideration of the limited time for this assessment, I have not made a separate consideration of the mortality information provided by the Registrar of Births, Deaths and Marriages. Further, because of possible inconsistency between variation in emergency hospital admissions and variation in mortality in the Latrobe Valley during the period of the Hazelwood mine fire, I have given consideration to DHSS's assessment of emergency hospital admissions. I have also reviewed public submissions or case reports that may be relevant to my assessment.

I have sought primarily, through my assessments, to assemble evidence that would contribute to answering the question: Was there an increase in mortality in neighbouring populations during the course of the Hazelwood mine fire and, if so, what was the cause of the increase? This has been the main focus of the information provided to me. However, wherever possible, I have also assessed whether there are implications for later mortality from the information assessed for mortality during the mine fire.

Mortality assessments undertaken by the Department of Health and Human Services and other organisations commissioned by the Department

The Department of Health and Human Services undertook a number of mortality assessments and also commissioned the University of Melbourne's Centre for Epidemiology and Biostatistics to review Births, Deaths and Marriages Victoria's data on deaths in the Latrobe Valley in relation to the Hazelwood coal mine fire.

Mortality assessments undertaken by the Department of Health and Human Services

Context

DHHS made available the following assessments of mortality in the Latrobe Valley in relationship to the mine fire.

1. Publicly available, brief DHHS reports on mortality in the Latrobe Valley during the period of the mine fire:
    a. Reports of deaths in the Latrobe Valley related to the Hazelwood coal mine fire, 17 September 2014;
    b. Reports of deaths in the Latrobe Valley claimed to be related to the Hazelwood coal mine fire, September 2014[1];
    c. Reports of deaths in the Latrobe Valley related to the Hazelwood coal mine fire, 17 September 2014. Updated: 22 October 2014;
    d. Reports of deaths in the Latrobe Valley claimed to be related to the Hazelwood Coal Mine fire – Update. [Undated webpage, but after 22 October 2014].
2. Internal analyses of mortality that, in some cases, extend the publicly available reports. They were:
    a. September 2014. Latrobe Valley death data analysis. [R1-3.1 Latrobe Valley death analysis RL document September 2014.docx].
    b. November 2014. Latrobe Valley death data analysis. [R1-3.2Latrobe Valley death analysis RL document updated November 2014.docx[2]].
3. Detailed and, to my knowledge, unreported Excel spread sheet presentations and analysis of mortality data, hospital emergency admission data and relevant environmental and population exposure data. These were contained in two MS Excel documents:
    a. *R1-3.3 Morwell deaths enquiry 2015.xlsx[3].* Contains 12 work sheets with data, variously, on deaths, emergency admissions to hospital in the Latrobe Valley and population in the Latrobe Valley, and individual postcodes in the Valley in periods relevant to the mine fire (January to June 2014, 9 February to 25 March 2014 and 2013 for comparison with 2014).
    b. *R1-3.4 Morwell deaths enquiry 2.xlsx[4]*. Contains 13 work sheets with day by day data from 1 January 2014 to 30 June 2014 on deaths, PM2.5 and mean temperature for the Latrobe Valley and for four constituent postcodes, details of individual deaths from 9 February 2014 to 25 March 2014, a Postcode map and daily weather observations in the Latrobe Valley from January to June 2014. This is a confidential document because it contains detailed information on causes of death of non-identifiable individuals.

DHHS has consistently studied the population of four postcode areas – Churchill (3842), Moe (3825), (3840) and Traralgon (3844) – when considering possible health effects of the mine fire. In this cluster of areas, Morwell is central and immediately adjacent to the Hazelwood mine, and the population centres of the other three are those outside Morwell that are closest to the mine. The University of Melbourne also used this set of four postcode areas when it undertook analyses of mortality that DHHS commissioned. I have adopted the same approach, because I have generally used data that DHHS compiled, and, for simplicity, I refer to the four postcodes together as **Latrobe Valley** even though they are not the only postcode areas in the Latrobe Valley.

Consultant's analysis of the publicly available and internal DHHS assessments of mortality in the Latrobe Valley

The publicly available reports responded, it appears, to concerns raised in the Latrobe Valley community by press and other reports that the mine fire had contributed to a number of deaths in community members. The internal reports built on these public reports and contain a little additional information. The following analysis is based on *Reports of deaths in the Latrobe Valley claimed to be related to the Hazelwood coal mine fire. September 2014*[1] supplemented with yearly death information for February to June 2009 to 2013 in *November 2014. Latrobe Valley death data analysis*[2].

The analysis in *Reports of deaths in the Latrobe Valley claimed to be related to the Hazelwood coal mine fire. September 2014*[1] presented tables of numbers of deaths in each of the Churchill, Moe, Morwell and Traralgon postcode populations in each year from 2009 to 2014 and the average number per year for the period 2009-13 in three periods of each year: February-March, January-June and February-June. It presented also the per cent differences between the numbers of deaths in 2014 and the average numbers per year in 2009-13 and observed that Morwell is anomalous in having 19% fewer deaths in February-March 2014 than the average for February-March 2009-13. For each of Churchill, Moe and Traralgon the opposite was the case, 25% to 40% more deaths. The report notes: "If any effects were to be caused by the fire, then it [sic] would be expected to be seen primarily in Morwell, which was most directly affected by the smoke but there was a decrease in deaths in Morwell during February and March." Given the potential importance of this anomaly in explaining any increase in mortality in Latrobe Valley during the period of the mine fire, I have examined the DHHS data more closely and presented them more informatively by calculating rate ratios, their 95% confidence intervals and p-values for differences between rates in 2014 and rates in 2009-13 – see Table 1.

Table 1. Alternative analysis of data in DHHS documents "Reports of deaths in the Latrobe Valley claimed to be related to the Hazelwood coal mine fire. September 2014"[1] and "November 2014. Latrobe Valley death data analysis"[2].

Location and period	Rate ratio 2014 relative to 2009-13	95% CI	P-value
Morwell			
February-March	0.80	0.51-1.26	0.34
February-June	1.05	0.81-1.35	0.72
Churchill, Moe and Traralgon			
February-March	1.36	1.07-1.71	0.01
February-June	1.22	1.02-1.45	0.008

These results suggest that mortality rate ratios in Morwell in 2014 were different from those in Churchill, Moe and Traralgon. For each period, the ratio of the rate ratios (Morwell compared with Churchill, Moe and Traralgon) can be estimated, giving 0.80 (95% CI 0.35-0.98) for the February-March comparisons and 0.86 (95% CI 0.63-1.17) for the February-June comparisons[5]. That the upper bound of the 95% CI of the February-March comparison is very close to 1 and that the 95% CI of the February-June comparison includes 1 indicates that statistical evidence for this difference is quite weak. Notwithstanding these considerations, it remains the case that the February-March Morwell comparison is inconsistent, if not strongly so statistically, with an increase in mortality in February-March 2014 that was substantially due to the mine fire.

Conclusion

Crude mortality data suggest that mortality from all causes in Morwell in February and March and February to June 2014 was little if at all greater than that in the corresponding periods of 2009-13. In Churchill, Moe and Traralgon, however, crude mortality in these periods in 2014 was greater than in 2009-13. Since Morwell was the most exposed of these populations to emissions from the mine fire, the comparative lack of greater mortality in Morwell in 2014 than 2009-13 is inconsistent with the mine fire being the cause of greater mortality in Latrobe Valley.

DHHS commissioned mortality assessments

Consultant's analysis of University of Melbourne mortality assessments

I have introduced the University of Melbourne mortality assessments here because they appear to have been prompted by, and follow, from the DHHS analyses of mortality reviewed in the preceding section.

The Centre for Epidemiology and Biostatistics' first report[6] analysed monthly mortality data for 2009 to 2014 for Latrobe Valley (postcode areas 3825, 3840, 3842 and 3844) and for the Morwell postcode area (3840) separately. A Poisson regression analysis estimated that there were 37 more deaths in the Valley in 2014 than expected from the 2009-2013 mortality data. A further linear regression analysis estimated, for the whole Valley, that there were 7.4 additional deaths per month in 2014 compared with 2009-2013 and 9.2 additional deaths for February-March 2014 compared with February-March 2009-2013. A separate analysis was done for Morwell. The authors did not find the excess deaths in 2014 to provide conclusive evidence of "any particular effect", which, I have assumed, would include an increase in risk of death in 2014 that might have been caused by the mine fire. They noted that weather conditions had not been taken into account in the analysis, that they had not had access to age and sex distributions of the underlying populations or to information on the causes of the deaths.

The Centre's *second report*[7] (which I will subsequently refer to as Flander and others 2015) was based on an expanded data set of all deaths in 2009 to 2014, which included, for each death, information on date of death, age, 5-year age group, sex, cause of death and postcode. I have assumed that the authors also had access to information on the size and age and sex distribution of each of the Latrobe Valley postcodes included in the analysis (again 3825, 3840, 3842 and 3844), which they do not state. The centre piece of the analysis in this report is Poisson regression modelling of relative risk of death from 2009 to 2014. This analysis reports relative risk of death by year of death (2009, 2010, 2011, 2012 and 2013, with 2014 as the reference category, which is the category with which each other category is compared in the relative risk calculation and which is assigned a relative risk of 1), mean daily temperature ($\geq 30^{o}$C with $<30^{o}$C as reference category) and particulate air pollution (PM_{10} $\geq$50mg/m^3 with <50mg/m^3 as reference category), while taking account of year by year changes in the size and age and sex distribution of the population. Results were reported for deaths in both sexes and all ages together from all causes and, separately, deaths from respiratory conditions, cardiovascular conditions and the combination of these two. Results were similarly reported for deaths in people 65 years of age and older.

Briefly, and largely in the authors' own words, the *second report* found:

1. No statistical evidence that 2014 mortality rates differed from comparable rates for the same months in 2009, a season similar to 2014 with respect to high temperatures and high particulate matter from bushfire smoke;
2. A lack of statistical evidence for an overall higher mortality in 2014 than in 2009-2013.
3. Statistical evidence of effects of high PM_{10} concentrations on mortality throughout the period 2009-14.
4. It is possible that a proportion of deaths in 2014 could have been due to the mine fire because of this evidence for effects of high PM_{10} concentrations on mortality.
5. There is no statistical evidence for the association of daily average temperature at or over 30°C with mortality in the February-March period for 2009–2014.
6. There is moderate evidence that colder temperatures are associated with mortality in the February-June period for 2009–2014.

While these are generally justifiable conclusions, there are several issues that should be highlighted.

First, the authors' findings with respect to temperature and air pollution do not relate specifically to 2014, they relate to the whole period 2009 to 2014. The authors have analysed the day to day variation in these variables and in the occurrence of deaths and compared the average mortality rate across all days with high temperatures with the average rate across all days with lower temperatures and, correspondingly, compared the average mortality rate across all days with high air pollution with the average rate across all days with lower are pollution. Thus, there is no estimate of the extent to which very high temperatures or very high air pollution levels may have increased mortality in February and March or February to June 2014 specifically.

Second, it would have been preferable *a priori* if the authors had done, as their main analysis, an analysis in which mortality estimated over the period 2009-13 as a single unit was compared with mortality in 2014. An *a priori* decision could have been made in favour of such an analysis because it would be a more statistically powerful analysis than any of the individual year analyses and would almost certainly have provided in 2009-13 a more accurate historical baseline against which mortality in 2014 could be compared. Conveniently, the authors have presented their results in a way that permits construction of the results that would have been obtained if they had taken this approach. Table 2 shows these results, which are based on Tables 5 to 7 in Flander and others 2015[7]. The calculations required were not done for the results in Table 8 (cardiorespiratory causes) because it is clear from Tables 6 and 7 that the results for respiratory causes and cardiovascular causes are different, so it is uninformative to combine them.

Table 2. Latrobe Valley[a] mortality in 2009–2013 compared to 2014 for the months February to June and February to March.

Years	February-June			February-March		
	Rate ratio	95% CI	p-value	Rate ratio	95% CI	p-value
Deaths from all causes						
2014	1			1		
2009-2013[b]	0.90	0.80-1.00	0.04	0.83	0.68-1.02	0.08
Deaths from respiratory causes						
2014	1			1		
2009-2013[b]	1.20	0.88-1.66	0.25	1.31	0.77-2.23	0.31
Deaths from cardiovascular causes						
2014	1			1		
2009-2013[b]	0.80	0.61-1.04	0.10	0.64	0.42-0.97	0.04

[a]Latrobe Valley is defined as Moe (3825), Morwell (3840), Churchill (3842) and Traralgon (3844).

[b]Rate ratios, 95% confidence intervals (CIs) and p-values for 2009-2013 were calculated by fixed-effects meta-analysis of rate ratios for each year from 2009-2013. The variance of each rate ratio was inflated by a factor equal to the square root of 3 to account for the fact that each rate ratio from 2009 to 2013 had been calculated with reference to the same reference category, 2014.

Contrary to the Flander and others' 2015[7] conclusion that there is "a lack of statistical evidence for an overall higher mortality in 2014 than in 2009-2013", I consider, on the basis of Table 2, that there is moderate evidence for a higher mortality from all causes and from cardiovascular disease in 2014 than in 2009-13. There is also some evidence that the increases in mortality in February to March 2014 (the period of the mine fire) were greater than those in the wider period February to June 2014.

Third, notwithstanding my argument in favour of comparing mortality in 2014 with mortality in 2009-2013 as a whole, rather than just with mortality in 2009, 2010, 2011, 2012 and 2013 individually, a case can be made for a separate comparison between 2014 and 2009, because they were both periods of major bushfires in the Latrobe Valley area. (The 2009 fire began near Churchill on 10th February). For this reason, I have reproduced the comparison between 2014 and 2009 from Flander and others 2015[7] in Table 3 below and included for comparison estimates of the rate ratios for 2009-13 shown in Table 2.

Table 3. Latrobe Valley mortality in 2009 and in 2009-13 compared to 2014 for February to June and February to March (results reproduced or estimated from Flander and others 2015[7]).

Years	February-June			February-March		
	Rate ratio	95% CI	p-value	Rate ratio	95% CI	p-value
Deaths from all causes						
2014	1			1		
2009	0.93	0.81-1.06	0.30	1.01	0.79-1.28	0.91
2009-13	0.90	0.80-1.00	0.04	0.83	0.68-1.02	0.08
Deaths from respiratory causes						
2014	1			1		
2009	0.95	0.61-1.47	0.82	1.08	0.54-2.17	0.81
2009-2013	1.20	0.88-1.66	0.25	1.31	0.77-2.23	0.31
Deaths from cardiovascular causes						
2014	1			1		
2009	0.70	0.49-1.00	0.06	0.58	0.34-0.99	0.05
2009-2013	0.80	0.61-1.04	0.10	0.64	0.42-0.97	0.04

It can be seen in Table 3 that the rate ratios for deaths from all causes and for respiratory causes in 2009 were, in all cases, closer to 1, the 2014 reference value, than the rate ratios for 2009-13; which suggests that conditions causing death from all causes or respiratory causes in 2009 may have been more similar to those in 2014 than the average conditions in 2009-2013 were. This could mean that the bushfires in 2009 and in 2014 increased deaths from all causes and respiratory causes in both these years. However, for deaths from cardiovascular causes, the difference between 2009 and 2014 was greater than that between 2009-13 and 2014, which suggests something other than the bushfires and not present in 2009 may have increased deaths from cardiovascular causes in 2014.

Conclusions

Based on The University of Melbourne 2015 report entitled, *Age-standardised mortality and cause of death in the Latrobe Valley at the time of (and five years prior to) the Hazelwood coalmine fire in Morwell, Victoria*[7] and some additional analysis of it:

1. Across the whole period from 2009 to 2014, mortality in Latrobe Valley in February to June was greater on days when the temperature was <30°C than on days when it was higher than this. This difference was not evident in February and March of these years.
2. Across the whole period from 2009 to 2014, mortality in Latrobe Valley in both February and March and February to June was higher on days when particulate air pollution was ≥ 50ug/m^3 of PM_{10} than when it was lower.
3. There is moderate evidence for a higher mortality from all causes and from cardiovascular disease in Latrobe Valley in 2014 than in 2009-13.
4. There is weak evidence that the increases in mortality in February to March 2014 (the period of the mine fire) were greater than those in the longer period February to June 2014.
5. Mortality from all causes in February and March and February to June 2014 was closer to that in the corresponding periods of 2009 than in those of 2009-13. This observation may suggest that severe bushfires, which occurred in Latrobe Valley in February in both 2014 and 2009,

contributed to the probable increase in mortality from all causes in 2014. This was not evident for deaths from cardiovascular disease.

Consultant's analyses of detailed mortality data provided in MS Excel documents by the Department of Health and Human Services

These documents (*R1-3.3 Morwell deaths enquiry 2015.xlsx*[3] and *R1-3.4 Morwell deaths enquiry 2.xlsx*[4]) present high-level descriptions of the data with analysis limited to day by day graphical presentations of two or more variables of interest, for example superimposed graphs of daily numbers of deaths, mean temperature and $PM_{2.5}$ level for the Latrobe Valley and each constituent postcode for 1 January to 30 June 2014[4]. While this approach makes the data and their patterns of change highly accessible to readers, the comparatively large day to day fluctuations in the variables studied – due to natural conditions, the fluctuation of the mine fire and chance (as it affects daily numbers of deaths) – make consistent patterns in the data difficult to discern. Therefore, rather than describing the data as presented, I have done some simple graphical or analytical presentations of them with the aim of informing answers to this question: Did the number of deaths during the mine fire vary with concentration of $PM_{2.5}$ or CO, or with daily mean ambient temperature?

Variation in mortality by mean daily $PM_{2.5}$ concentration

There is strong evidence that environmental exposure to small particles in air, $PM_{2.5}$, increases risk of death[8].

In Figures 1, 2 and 3 below, I have plotted number of deaths per day during the period of the mine fire for which $PM_{2.5}$ measurements were available for three overlapping populations – Latrobe Valley, Morwell, and Churchill, Moe and Traralgon together (each defined in terms of their postcode areas, Latrobe Valley being the sum of Churchill, Moe, Morwell and Traralgon).

There were multiple stations measuring $PM_{2.5}$ during the period of the mine fire. I have obtained estimates of daily average exposure concentrations of $PM_{2.5}$ in air (in $\mu g/m^3$) in the following ways for each population specified above.

- Latrobe Valley: 14 to 20 February – the average of measurements from the Morwell East and Traralgon stations (the only stations from which data were available for this period); 21 to 28 February – the average of measurements from the Morwell East, Morwell South and Traralgon stations (the only stations for this period); 1 to 6 March – the same but with the addition of the Moe station; 7 to 25 March – the same but with the addition of the Churchill station.
- Morwell: As above for Latrobe Valley except that only measurements for Morwell East and Morwell South were used.
- Churchill, Moe and Traralgon: 9 to 28 February – measurements from the Traralgon Station; 1 to 6 March – the average of the Traralgon and Moe stations; 7 to 25 March – the average of the Traralgon, Moe and Churchill stations.

Figures 1, 2 and 3 follow.

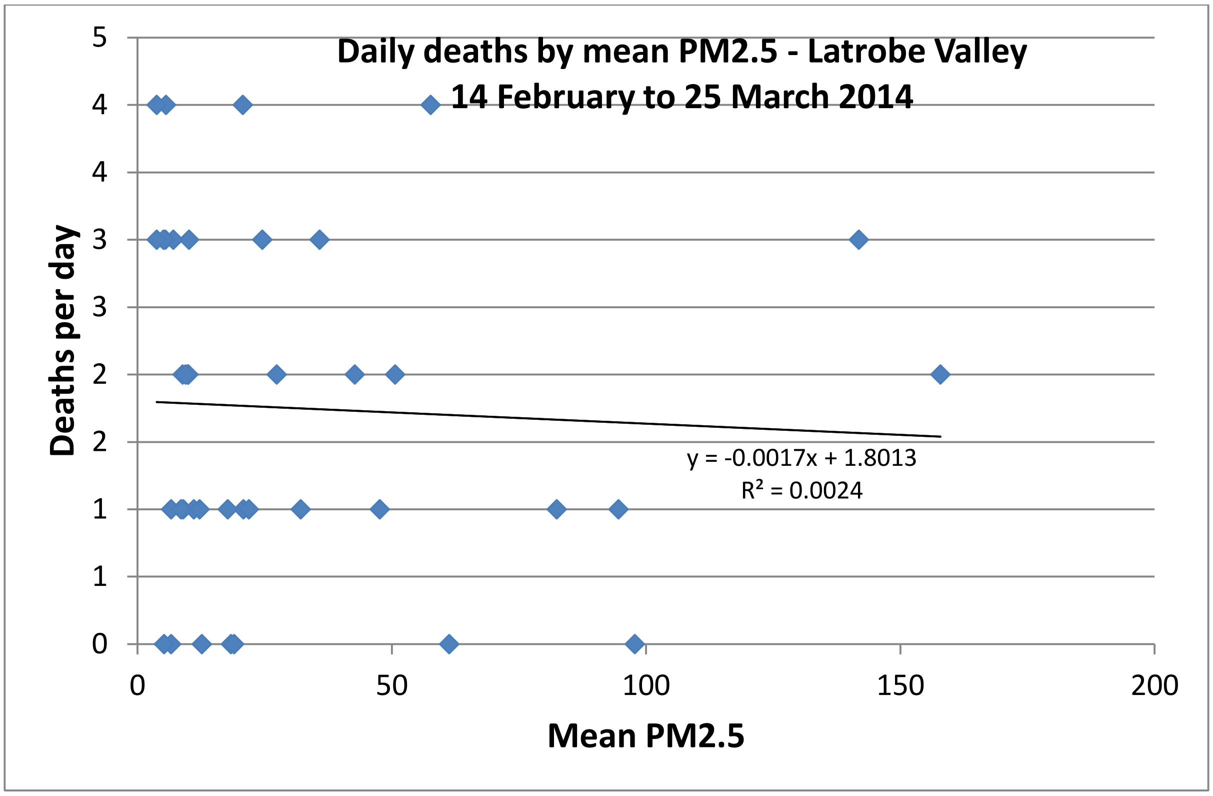

Figure 1 – Daily number of Latrobe Valley deaths by mean $PM_{2.5}$ level, 14 February to 25 March 2014.

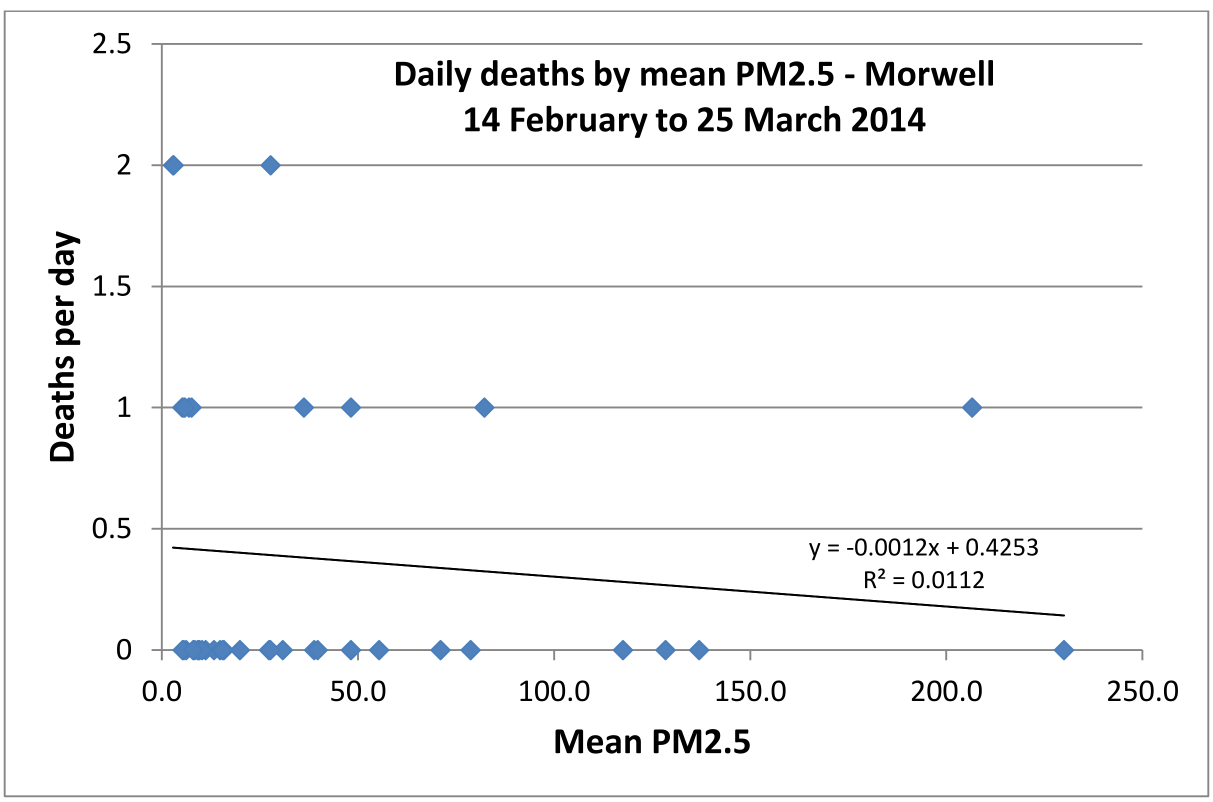

Figure 2 – Daily number of Morwell deaths by mean $PM_{2.5}$ level, 14 February to 25 March 2014.

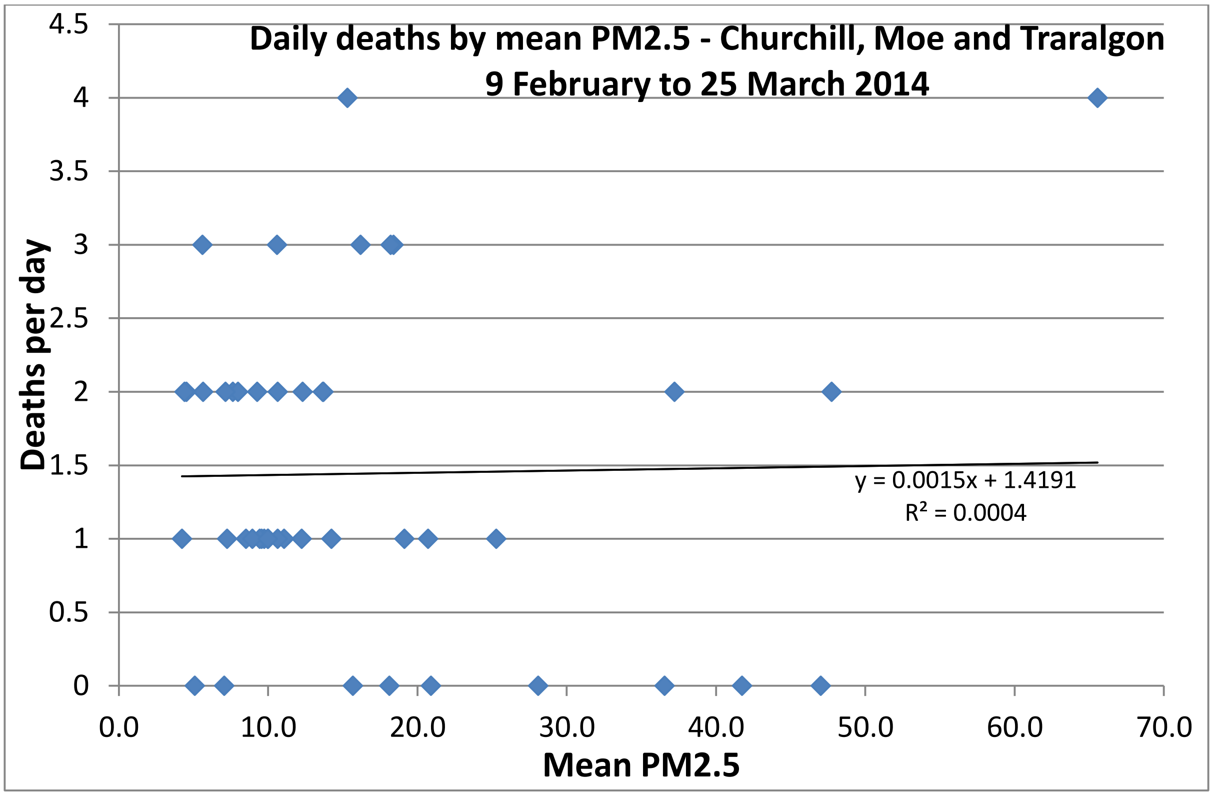

Figure 3 – Daily number of Churchill, Moe and Traralgon deaths by mean $PM_{2.5}$ level, 14 February to 25 March 2014.

There is little or nothing in Figures 1 to 3 to suggest that higher daily $PM_{2.5}$ concentrations were associated with higher numbers of deaths on the same day. If anything, fitted trend lines suggest that the trend was in the opposite direction and none of the trend lines explained more than 1.1% of the variance. The value R^2 is the decimal fraction of the day to day variation in mortality that is explained by the day to day variation in $PM_{2.5}$ assuming that any consistent increase in mortality with increasing $PM_{2.5}$ is a constant multiple of the $PM_{2.5}$ (e.g. 1 extra death per day for every 200 $\mu g/m^3$ increase in $PM_{2.5}$), that is that it is "linear". Thus in Figure 3 above an assumed linear relationship would explain 0.0004 of the variation or 0.04% of the variation (0.04 being obtained simply by moving the decimal point two digits to the right, that is multiplying by 100).

Deaths prompted by a sharp increase in $PM_{2.5}$ may happen after a period of delay; available evidence suggests that this period is from one to five days[9]. I therefore prepared Figure 4, which is similar to Figure 1 except that the concentration of $PM_{2.5}$ linked to any day's deaths was that from the day 3 days before the day of death (i.e. there was a lag period to death of 3 days). Figure 4 (below) shows no evidence of an increase in number of deaths lagged 3 days with increasing $PM_{2.5}$.

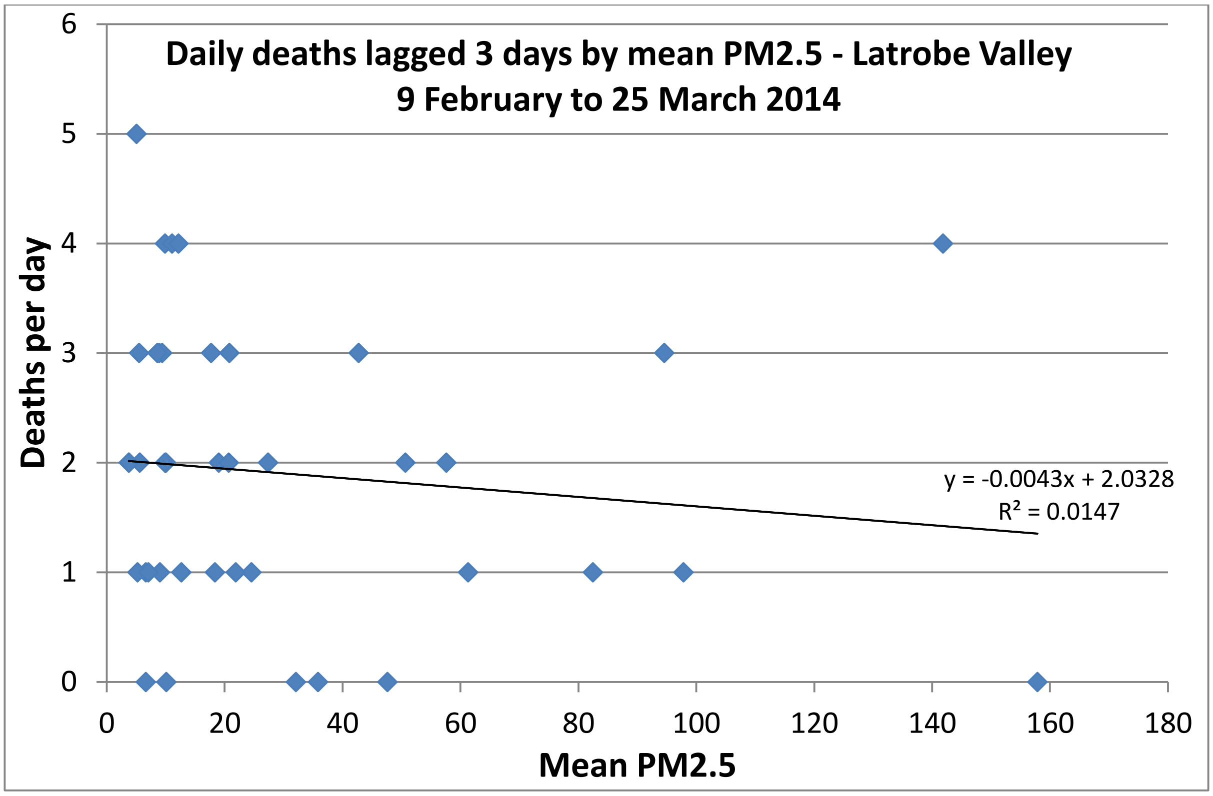

Figure 4 – Number of Latrobe Valley deaths lagged 3 days by mean $PM_{2.5}$ level, 14 February to 25 March 2014.

Given the relatively few deaths in Morwell and the much higher $PM_{2.5}$ levels there than elsewhere, I compared the mean $PM_{2.5}$ concentration in Morwell on days between 14 February and 25 March on which one or more deaths occurred with that on days when no deaths occurred. For days on which a death occurred the mean was 35.5 µg/m^3 averaged over 12 days, for days on which no death occurred it was 42.6 µg/m^3 over 28 days. The Student's T-test p-value for the difference between these two means was 0.76; that is there is about a 3 out of 4 probability that this difference (which was in the opposite direction to what it would have been if high $PM_{2.5}$ levels in this period had a measureable effect on mortality) was due to chance.

Given the relatively few deaths from cardiovascular disease, I made a similar comparison based on the Latrobe Valley cardiovascular disease deaths. The mean $PM_{2.5}$ on days with one or more cardiovascular disease deaths was 28.7 µg/m^3 over 23 days and on days with no cardiovascular disease deaths it was 33.8 µg/m^3, p-value 0.68 (a 2 in 3 probability of being a chance difference).

I also calculated these means with the deaths lagged by three days as in Figure 4. For all causes of death in Morwell, the mean $PM_{2.5}$ concentration on days with one or more deaths was 18.5 µg/m^3 averaged over 11 days and on days with no deaths it was 49.0 averaged over 29 days, p-value 0.32 (a 1 in 3 probability of being a chance difference). For deaths from cardiovascular disease in Latrobe Valley, the mean $PM_{2.5}$ concentration on days with one or more deaths was 24.1 µg/m^3 averaged over 22 days and on days with no deaths it was 46.0 averaged over 15 days, p-value 0.10 (a 1 in 10 probability of being a chance difference).

Overall, I have found no evidence in the data on the relationship between $PM_{2.5}$ concentration and deaths during the mine fire that $PM_{2.5}$ concentration increased mortality in Morwell, where the exposure was greatest, or in Latrobe Valley. This observation appears to be at variance with the work of Flander and others 2015[7], who found that mortality from all causes over the whole period 2009-14 was approximately two-fold higher in Latrobe Valley people exposed to PM_{10} at levels of 50 $\mu g/m^3$ or more on the day of death than in people not so exposed. It is more consistent with an estimate that less than one extra death would occur in Morwell within 6 weeks of onset of the mine fire as a result of the extra exposure to $PM_{2.5}$ due to the fire[8]. This estimate was based on measured exposures in Morwell and used a recently published evidence-based mathematical model of mortality from a range of relevant causes consequent on longer-term exposure to $PM_{2.5}$[10].

Variation in mortality by mean daily CO concentration

There is good evidence that environmental exposure to increased levels of carbon monoxide (CO) is associated with an increased risk of emergency department visits and hospitalisations for cardiovascular disease[11]. The evidence that it is also associated with an increased risk of death is less certain. It is also not completely certain that these effects of environmental exposure to CO are due to CO or due to other air pollutants with which it is usually correlated.

There was monitoring of CO in air at multiple sites during the period of the mine fire, all in Morwell until 28th February when monitoring in Traralgon began. I made estimates of daily maximum exposure concentrations of CO from 15 February to 25 March (each based on an 8 hour average and expressed in parts per million) by averaging data from a total of nine sites, with observations on any one day being available for averaging from between two and seven sites as summarised in Table 4 (note that the CFA measurements have not been calibrated by EPA Victoria). The data were extracted from a results table on page 9 of the EPA Victoria Information Bulletin, *Hazelwood Coal Mine Fire - Air Quality Monitoring Report*. There were only two CO measurements recorded before 15 February; they were measured at two different sites one day apart. Levels recorded were 0.6 ppm and 0 ppm; they have not been included in the analyses described below.

Table 4. Summary of CO monitoring sites contributing to estimates of daily maximum CO in Latrobe Valley during the period of the mine fire.

	EPA sites			CFA sites					
Date	**Morwell East**	**Morwell South**	**Traralgon–EPA**	**Kerrie St**	**Bowls Club**	**Keegan**	**Maryvale Childcare Centre**	**Morwell Police Station**	**Sacred Heart Primary**
15 Feb						X	X		
16 Feb				X	X	X	X	X	X
17 Feb					X			X	
18 Feb				X	X			X	X
19 Feb	X			X	X			X	
20 Feb	X	X		X	X				
21 Feb	X	X		X	X			X	X
22 Feb	X	X			X	X	X	X	X
23 Feb	X	X				X	X	X	X
24 Feb – 27 Feb	X	X				X	X	X	X
28 Feb - 3 Mar	X	X	X			X	X	X	X
4 Mar	X	X	X			X	X	X	
5 Mar	X	X	X			X	X	X	
5-25 Mar	X	X	X						

Given the lack of CO monitoring sites outside Morwell, I assessed the association of maximum CO concentration with mortality from all causes only in Morwell. However, given the possible importance of mortality from cardiovascular disease as an outcome and the few deaths from cardiovascular disease in Morwell during the period of the mine fire (six in all, one of them before CO monitoring began), I examined the association of deaths from cardiovascular disease in Latrobe Valley with the average CO levels. As with $PM_{2.5}$, I compared mean CO levels on days on which deaths occurred with mean CO levels on days on which there were no deaths.

For deaths from all causes in Morwell in the period 15 February to 25 March, the mean CO concentration was 4.4 ppm on 11 days with deaths and 2.2 ppm on 28 days without deaths. While consistent with an effect of CO on deaths in Morwell, the p-value for the difference between these two means was 0.33; that is a probability of 1 in 3 that these means were different simply by chance. For deaths from cardiovascular disease in Latrobe Valley in the period 15 February to 25 March, the mean CO concentration was 1.3 ppm on 23 days with deaths and 3.4 ppm on 16 days without deaths, p-value also 0.33 (1 in 3 chance probability).

A 2006 Australian study demonstrated increased hospital admission rates for cardiovascular disease in association with higher levels of environmental CO exposure with the measurement of exposure being the average of the level on the day of exposure and the day before[12]. I therefore also examined the association of CO with mortality with one day of lag. For deaths from all causes in Morwell in the period 15 February to 25 March, the mean CO concentration was 2.5 ppm on 12 days with deaths and 3.0 ppm on 27 days without deaths, p-value 0.73 (3 in 4 chance probability). Thus with one day of lag there is no longer the weak evidence for higher CO levels on days in which there was one or more deaths in Morwell that was observed without any lag. For deaths from cardiovascular disease in Latrobe Valley in the period 15 February to 25 March, the mean CO concentration was 1.9 ppm on 23 days with deaths and 4.2 ppm on 16 days without deaths, p-value 0.11 (1 in 9 chance probability).

Variation in mortality by mean daily temperature

Ambient temperature has powerful effects on the mortality of populations. Death rate is at a minimum in the low to mid 20^{o}C region and then increases as temperature falls or rises beyond this optimum[13]. Net effects globally of temperature on mortality are much greater at low temperatures (causes an estimated 7.29% of deaths) than at high temperatures (0.42% of deaths). Extremes of temperature (the top and bottom 2.5% of temperatures) contribute only a little (0.86%) to the total of these two. Since there were heatwave conditions in Victoria in early to mid-February 2014, it is important to consider temperature as a possible contributor to higher mortality in Latrobe Valley in February and March 2014.

In Figures 5 and 6 below, I have plotted numbers of deaths per day during the period of the mine fire (9 February to 25 March) against daily mean temperature for Latrobe Valley (Morwell, Churchill, Moe and Traralgon together, each defined in terms of their postcode areas) and for Morwell postcode area alone.

Daily mean temperature readings were as provided in DHHS data[3] and were almost certainly those from the Morwell Bureau of Meteorology Site 85280 at the Latrobe Valley Airport as used by Flander and others 2015[7] in their analysis.

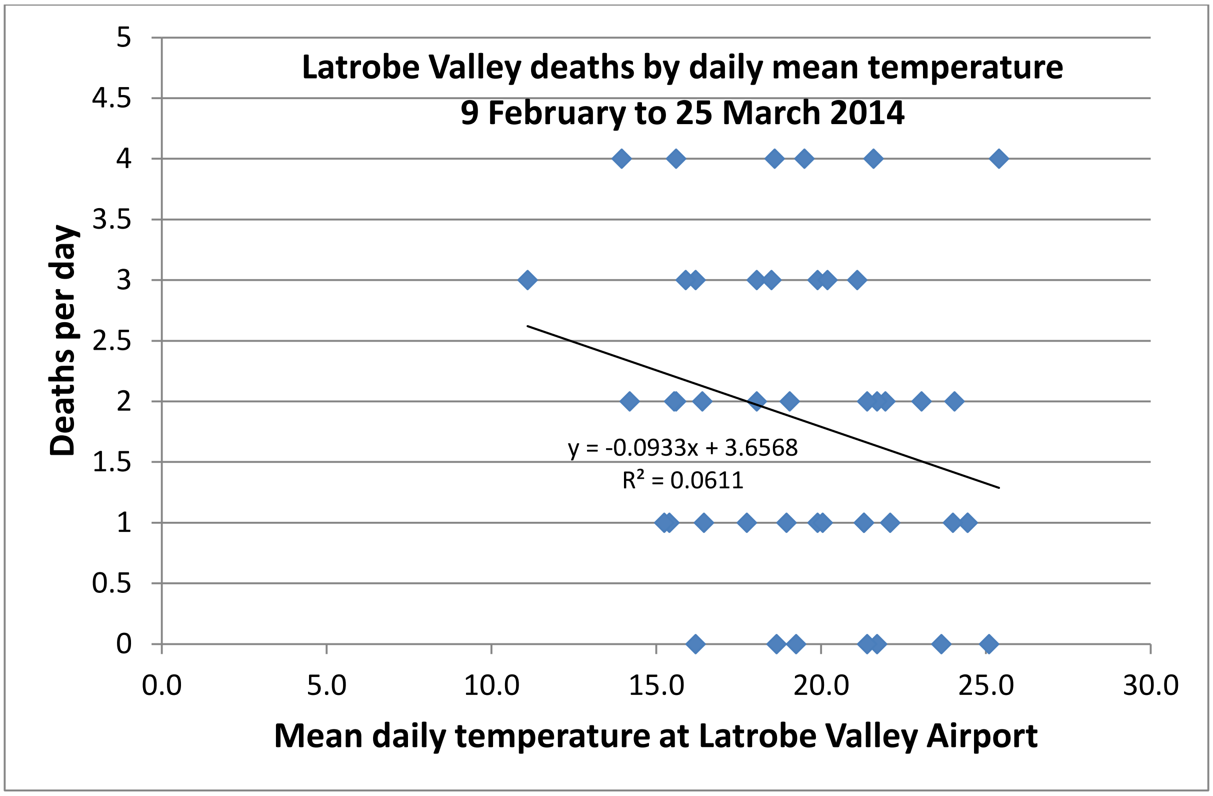

Figure 5 – Daily number of Latrobe Valley deaths by daily mean temperature from 9 February to 25 March 2014.

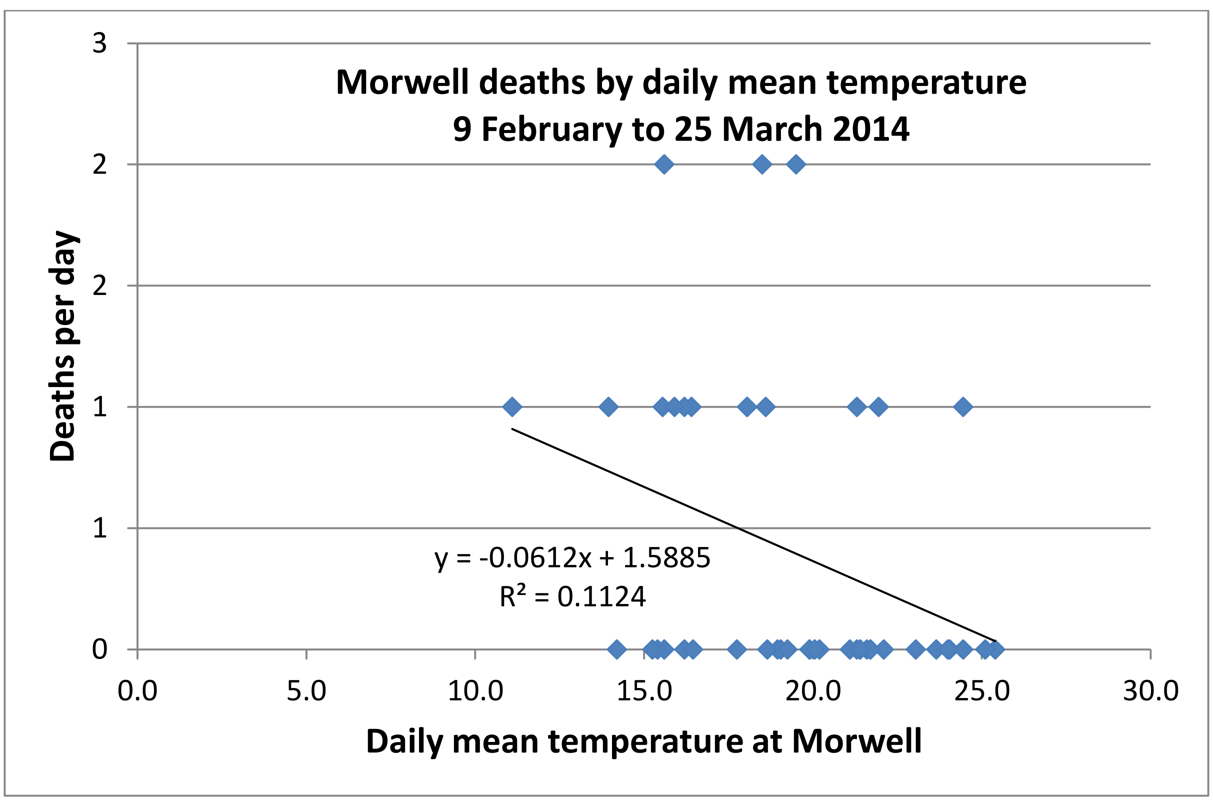

Figure 6 – Daily number of Morwell deaths by daily mean temperature from 9 February to 25 March 2014.

Visually Figures 5 and 6 suggest little trend in deaths with daily mean temperature (which varied from 11.1 to 25.4 during this period) in either Latrobe Valley generally or Morwell on its own. The trend lines suggest, however, that deaths were more frequent at lower temperatures than higher temperatures, with 6% and 10% respectively of the variance explicable by the trend lines. Importantly, they do not suggest that mortality was greater on days with higher temperatures during this period. Lack of higher mortality on high temperature days during the mine fire is quite consistent with a recent analysis of effects of high temperatures on mortality in Brisbane, Melbourne and Sydney, which showed small and uncertain increases in mortality at the *lower* temperature end of heat wave days. The temperature at the lower end of the heat wave spectrum was defined as a mean temperature over two consecutive days of 27.2°C in Brisbane, 25.3 in Melbourne and 26.1 in Sydney[14] The highest mean temperature over two consecutive days in Latrobe Valley between 9 February and 25 March was 24.4°C.

Deaths due to high ambient temperatures are subject to a small lag period, with an elevation in risk of death being evident on the day heatwave conditions are experienced (day 0) and persisting for the next two days (days 1 and 2) ; with the highest risk of death generally being on day 1 (Tong et al 2014). I therefore examined the relationship between Latrobe Valley and Morwell deaths and the temperature on the day before death occurred (1 day of lag) (Figures 7 and 8). These Figures show similar visual patterns to those observed in Figures 5 and 6, but the trend line for Latrobe Valley changes from downwards to slightly upwards; which is probably driven mainly by the 5 deaths on 26 March now linked to the temperature on 25 March and included in the Latrobe Valley chart.

There is, therefore, no evidence in these data that suggests that higher temperatures in Latrobe Valley during the period of the mine fire were associated with a higher risk of death.

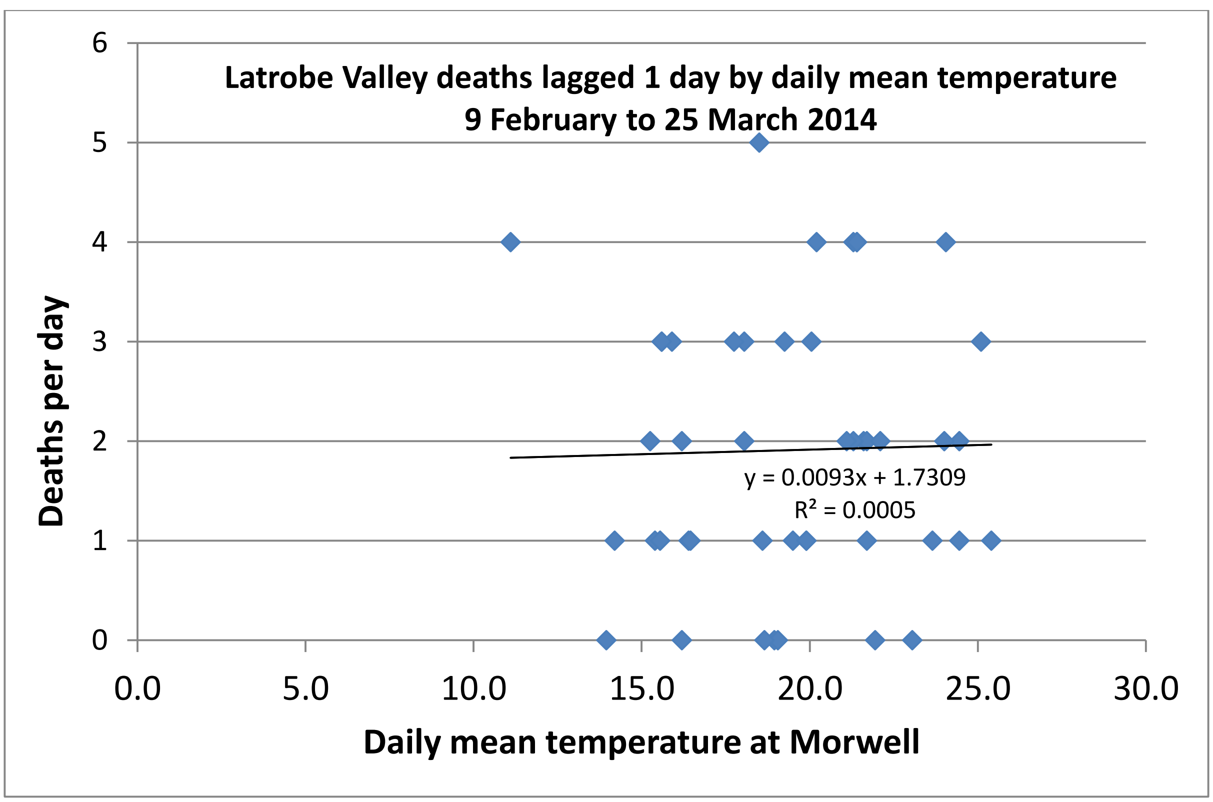

Figure 7 – Number of Latrobe Valley deaths lagged 1 day by daily mean temperature from 9 February to 25 March 2014.

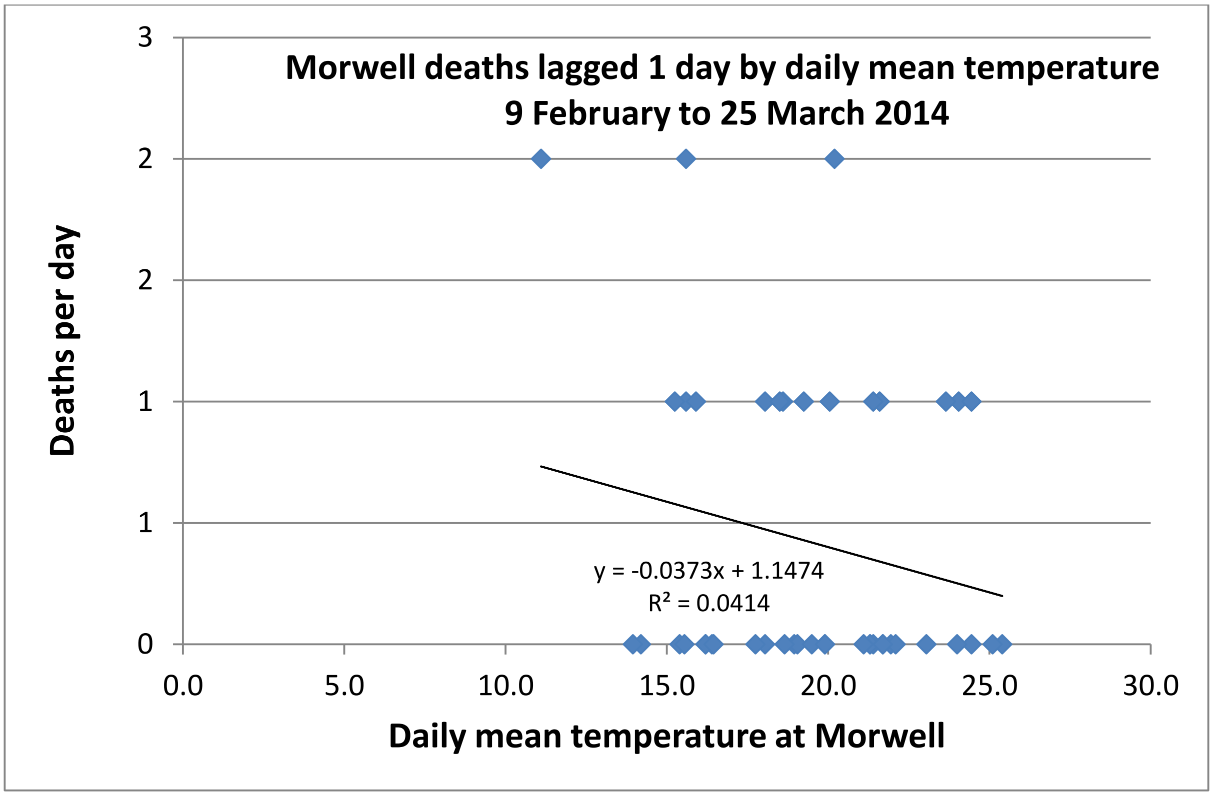

Figure 8 – Number of Morwell deaths lagged 1 day by daily mean temperature from 9 February to 25 March 2014.

As previously for $PM_{2.5}$ and CO exposure, I calculated also the mean of the daily mean temperatures in the period 9 February to 25 March for days with and without deaths in Morwell (for deaths from all causes) and for Latrobe Valley (for deaths from cardiovascular disease). For days on which there was one or more deaths in Morwell, the mean temperature was 17.7°C over 15 days; and on days when no deaths occurred the mean was 20.3°C over 30 days. The p-value for the difference between these two means was 0.02 (chance probability 1 in 50). For Latrobe Valley and deaths from cardiovascular disease, the means were 18.2 over 25 days with deaths and 20.9 over 20 days without deaths, p-value 0.006 (a chance probability of about 1 in 170).

These analyses were repeated with a one day lag. The mean temperature on days with a death from any cause in Morwell was 19.0 and it was 19.7 on days without any death (p-value for difference 0.55). The mean temperature on days with a cardiovascular death in Latrobe Valley was 19.3 and it was 19.6 on days without a cardiovascular death (p-value for difference 0.80).

These results suggest that mortality from all causes and from cardiovascular disease in Latrobe Valley was greater on cold days during the period of the mine fire than it was on other days.

Given this observation it was logical to ask: Was 9 February to 25 March 2014 colder than similar periods in 2009-13? No, it was not, at least on average. The mean daily temperature for 9 February to 25 March 2014 was 19.4°C; the mean for these days in 2009-13 was 19.1°C (p-value 0.51).

Conclusions

1. There was no evidence that deaths from all causes or from cardiovascular disease alone during the period of the mine fire were more frequent on days with higher $PM_{2.5}$ levels than on days with lower $PM_{2.5}$ levels. This observation appears not to be consistent with the work of Flander and others 2015[7], who found that mortality from all causes over the whole period 2009-14 was approximately two-fold higher in Latrobe Valley people exposed to PM_{10} at levels of 50 µg/m3 or more on the day of death than in people not so exposed. It is more consistent with an estimate, based on statistical modelling of international data, that less than one extra death would occur in Morwell within 6 weeks of onset of the mine fire as a result of the extra exposure to $PM_{2.5}$ due to the fire[8]. Either way, however, it is very likely that particulate air pollution during the mine fire caused an increase in mortality; realised, perhaps, more after the period of the fire than during it.
2. There was no consistent evidence that deaths from all causes or from cardiovascular disease alone during the period of the mine fire were more frequent on days with higher carbon monoxide levels than on days with lower carbon monoxide levels.
3. There is no evidence that higher temperatures in Latrobe Valley during the period of the mine fire were associated with a higher mortality, whereas there is strong evidence that higher mortality was associated with lower temperatures. Lower temperatures, however, do not appear to explain the higher mortality in February and March 2014 than in the same months in 2009-13 as the mean daily temperatures in these two periods were nearly identical.

Consultant's analyses of detailed hospital emergency admissions data provided in MS Excel documents by the Department of Health and Human Services

I have used DHHS data[3] to compare the frequency of emergency admissions to hospital in 2014 to that in 2013 and to see if there is any evidence of an association between numbers of emergency admissions to hospital and the coal mine fire. If there were no more emergency admissions in the period of the mine fire in 2014 than there were in the same period in 2013, this would suggest that the mine fire had not caused health effects and, therefore, that an increased mortality due to the mine fire was unlikely. On the other hand, if there were an increase in admissions, a parallel increase in mortality would be more plausible.

In Table 5, I compare, by way of rate ratio estimates, the rate of emergency hospital admissions in different categories of principal diagnosis (those used by DHHS) in Latrobe Valley from 9 February to 25 March 2014, with the corresponding rates in the same period in 2013 as the reference category. The population of Latrobe Valley was assumed to be the same in 2014 as in 2013 and was estimated at 69,477, the sum of the estimated populations of the four constituent postcodes at the 2011 Census[3].

Table 5. Rates of emergency admission to hospital in Latrobe Valley in 2014 compared to 2013 for the period 9 February to 25 March[3].

Principal diagnosis category	Numbers of hospital admissions		Rate ratio	95% Confidence interval	p-value
	2013	**2014**			
Cardiovascular conditions	116	134	1.16	0.90-1.48	0.26
Respiratory conditions	81	106	1.31	0.98-1.75	0.07
Cancers	19	16	0.84	0.43-1.64	0.61
All other conditions	658	761	1.16	1.04-1.28	0.006
All conditions	874	1017	1.16	1.06-1.27	0.001

Table 5 shows:

1. The rate of emergency hospital admissions for all conditions in the Latrobe Valley during the period of the mine fire in 2014 was 16% greater than it was for the same period in 2013; the probability that this difference was due simply to chance is estimated at 0.001 (1 in 1,000).
2. Of the four broad categories of conditions causing hospital admissions – cardiovascular conditions, respiratory conditions, cancers and all other conditions – the rate of all was greater in 2014 by between 16% and 31% except for cancer, for which it was less by 16% in 2014 but with great uncertainty.
3. The estimated rate of hospital admissions for cardiovascular conditions was 16% greater in 2014 than in 2013, but the probability that this difference was due simply to chance is 1 in 4.

The rate ratios in Table 5 could be inaccurate to the extent that the size, age or sex composition of the population of the Latrobe Valley was materially different in 2014 from what it was in 2013. I judge any important inaccuracy due to such differences to be unlikely.

Interpretation of the apparently greater rate of hospital admissions in 2014 than 2013 may be assisted by the examination of the way the rate ratio for admission for any condition varied by age, as shown in Table 6.

Table 6. Rates of emergency admissions to hospital of Latrobe Valley people by age for any condition from 9 February to 25 March 2014 compared to rates for the same period in 2013[3].

Age group	Numbers of hospital admissions		Rate ratio	95% Confidence interval	p-value
	2013	**2014**			
0-4 year	45	52	1.16	0.78-1.72	0.48
5-14 years	40	39	0.98	0.63-1.51	0.91
15-24 years	75	77	1.03	0.75-1.41	0.87
25-39 years	93	153	1.64	1.27-2.13	<0.001
40-64 years	283	292	1.03	0.88-1.21	0.71
65-74 years	112	154	1.38	1.08-1.75	0.009
75+ years	226	250	1.11	0.93-1.32	0.26

The estimated rates of admission in the period of the mine fire in 2014 were higher than those in the corresponding period in 2013 except in people 5-14 years of age. In only those 25-39 years of age, who had a 64% greater rate of admission in 2014 than 2013, and those 65-74 years, who had a 38% greater rate of admission in 2014, was chance an unlikely explanation for the higher rate (probabilities of occurring simply by chance of 1 in 1,000 and 1 in 110 respectively). These observations are broadly as expected from a conclusion of *Final report, Rapid health risk assessment (RHRA)* prepared for DHHS by the School of Public Health and Preventive Medicine at Monash University[8], which stated, with respect to the risk presented by exposure to smoke from a brown coal fire: "The most vulnerable subpopulations include children (<5 years old), the elderly (>65 years old) …".

The 64% increase in emergency admissions in people 25-39 years of age is large enough to be important but would not necessarily be associated with in an increase in mortality. It should be further investigated; initially by ascertaining the principal diagnosis categories that contributed most to it.

Conclusions

1. Emergency hospital admissions for all conditions in the Latrobe Valley during the period of the mine fire in 2014 were more frequent than they were for the same period in 2013. Hospital admission rates for respiratory and cardiovascular diseases, considered individually, were also greater in 2014 than in 2013, although the statistical evidence for these increases was weaker.
2. Emergency hospital admissions were greater in infants and children (0-4 years of age) in 2014 than in 2009-13, albeit with statistically weak evidence, and also greater in older people (65-74 years of age and, less so, 75+ years of age). These are recognised vulnerable groups for health impacts of air pollution.
3. There was strong evidence that emergency hospital admissions were greater in 2014 than 2009-13 in people 25-39 years of age. The causes of this increase should be investigated.

Mortality assessments undertaken by any third parties

The assessments prepared by Associate Professor Adrian Barnett of the Queensland University of Technology are the only substantial third-party assessments of mortality in relation to the Hazelwood mine fire that I know of. There are two reports of these assessments: *Analysis of death data during the Morwell mine fire,* first published in 2014[15] (available at http://eprints.qut.edu.au/76230/), and *An updated analysis of death data during the Morwell mine fire*[16], first published in 2015.

Consultant's analysis of Associate Professor Barnett's assessment

This analysis is based on the second of Barnett's reports[16]. This report is a brief and quite technical description of a Bayesian[1] biostatistical analysis of publicly available monthly numbers of deaths from January 2004 to November 2014 in six Latrobe Valley postcodes: the four I have previously

[1] Bayesian statistical methods differ from the more traditional statistical methods, which are usually called frequentist statistical methods. While they both have their place, frequentist methods are more commonly used to analyse the kind of issues discussed in this report, and were used in all other analyses.

referred to as "Latrobe Valley" (3825, 3840, 3842, 3844) and two more, 3869 and 3870, which share borders with the Morwell postcode (3840) (as do two more, 3824 and 3871). No explanation was given for the choice of these two additional postcodes; however it may have been to include most of the Latrobe Valley City Council area in the analysis since the population figures used were those for the City Council area. Like in Flander and others 2015[7] a Poisson regression model was used for the analysis. Any effect of the mine fire on mortality was inferred from a comparison of mortality in February and March 2014 with that in all other months in the model. Covariates also included in the model were postcode (each as a separate variable), season and maximum monthly temperature.

I have summarised the results from this model in rate ratio form, adjusted for temperature and season, in Table 7.

Table 7. Rate ratios and 95% confidence intervals[a] obtained for variables of interest included in Barnett's Poisson regression model and reported in Table 2 of Barnett 2015[16].

Variables	**Rate ratio**	**95% CI[a]**
Moe (3825)	4.59	4.30-4.90
Morwell (3840)	3.19	2.98-3.42
Churchill (3842)	0.60	0.54-0.67
Traralgon (3844)	4.18	3.92-4.47
Yinnar (3869)	0.18	0.15-0.21
Boolarra (3870)	0.15	0.13-0.18
Season (cosine)	1.01	0.89-1.15
Season (sine)	1.01	0.97-1.04
Fire (February-March 2014)	1.10	0.89-1.34[b]
Temperature (linear)	0.99	0.97-1.01
Temperature (quadratic)	1.00	1.00-1.00

[a]In Barnett's analysis CI means "credible interval" not "confidence interval". While the values of these two forms of interval estimate may be similar, they are probably not the same.

[b]P-value = 0.18. Barnett reported his p-value as a probability that the risk of death *was increased* of 0.82. I took 0.82 away from 1.00 to obtain the value 0.18. While taking 0.82 away from 1.0 to obtain a probability that the increase in the risk of death was due to chance (and thus that the risk of death *was not increased*) would not be expected to obtain the value of the p-value obtained by frequentist statistical methods, it would probably be similar.

In this analysis, the mine fire was estimated to have increased mortality by 10% during February-March 2014 over the six postcode areas. There is, however, statistical uncertainty in this estimate, which could credibly be as low as -11% (i.e. lower mortality during the mine fire) or as high as 34% (higher mortality). The 10% estimate is less than that obtained by Flander and others (2015)[7], who reported mortality in February-March of individual years from 2009 to 2013 to be between 31% less and 1% more than that in 2014, and less than my estimate of 20% based on a meta-analysis of data from Flander and others 2015[7] (Table 1). It was probably attenuated by inclusion of the two additional postcodes, both of which had rate ratios for mortality in 2014 with reference to that in 2004-13 that were less than one (0.61 and 0.64 Table 8), perhaps because of their greater distance from the fire.

The apparently large variation in mortality from 2004 to 2014 among the six postcode areas is notable. Differences in the age distributions of the populations in these postcodes over the period would be the most likely explanation. Health status would be unlikely to vary that much among postcodes in the Latrobe Valley, although this cannot be excluded, and effects of age could not be controlled in Barnett's analysis. This large variations bears some further investigation as it may have implications for other results in the analysis.

Barnett reported a further analysis of interest in Table 3 of Barnett 2015[16]. In it he estimated the effect of the period of the mine fire on mortality in each of the six postcodes. The results are shown in Table 8. As observed in the DHHS analysis (see Table 1), there was lower mortality in Morwell during this period and higher mortality in Churchill, Moe and Traralgon.

Table 8. Rate ratios and 95% confidence intervals[a] obtained by A/P Barnett for the estimated difference in mortality in February-March 2014, during the mine fire, relative to all other months in 2004 to 2014.

Variables	**Rate ratio**	**95% CI[a]**	**p-value[b]**
Fire on Moe (3825)	1.10	0.78-1.47	0.31
Fire on Morwell (3840)	0.87	0.55-1.28	0.76
Fire on Churchill (3842)	1.34	0.58-2.47	0.26
Fire on Traralgon (3844)	1.30	0.93-1.74	0.06
Fire on Yinnar (3869)	0.61	0.05-1.77	0.84
Fire on Boolarra (3870)	0.64	0.05-1.84	0.82

[a]See footnote a to Table 7.

[b]P-values were estimated as described in footnote b to Table 7.

Conclusions

1. Barnett (2015)[16] reported a 10% higher mortality in Latrobe Valley during February and March 2014 relative to that in these over the whole of 2004-14. This estimate is broadly consistent with other estimates in this report but probably attenuated and made statistically weaker by the inclusion of two additional Latrobe Valley postcodes in the analysis.
2. Barnett (2015)[16] also observed a lack of an increase in mortality in Morwell during February and March 2014 relative to that over the whole period 2004-14.

Conclusions

In this section I present again the conclusions stated at the end of each main section of this report but reordered and grouped so as to bring, as far as possible, conclusions addressing like issues together.

Was there an increase in mortality in Latrobe Valley during the coal mine fire in 2014?

1. There is moderate evidence for a higher mortality from all causes and from cardiovascular disease in Latrobe Valley in 2014 than in 2009-13.

2. There is weak evidence that the increases in mortality in February to March 2014 (the period of the mine fire) were greater than those in the longer period February to June 2014.
3. Barnett (2015)[16] reported a 10% higher mortality in Latrobe Valley during February and March 2014 relative to that in the same months in 2004-13. This estimate is broadly consistent with other estimates in this report but probably attenuated and made statistically weaker by the inclusion of two additional Latrobe Valley postcodes in the analysis.

What environmental exposures might have increased mortality in Latrobe Valley during the coal mine fire in 2014?

The associated bushfires?

1. Mortality from all causes in February and March and February to June 2014 was closer to that in the corresponding periods of 2009 than in those of 2009-13. This observation may suggest that severe bushfires, which occurred in Latrobe Valley in February in both 2014 and 2009, contributed to the probable increase in mortality from all causes in 2014. This was not evident for deaths from cardiovascular disease.

Fine particle (smoke) air pollution from the coal mine fire or the bushfires?

2. Across the whole period from 2009 to 2014, mortality in Latrobe Valley in both February and March and February to June was higher on days when particulate air pollution was ≥ 50μg/m^3 of PM_{10} than when it was lower.
3. There was no evidence that deaths from all causes or from cardiovascular disease alone during the period of the mine fire were more frequent on days with higher $PM_{2.5}$ levels than on days with lower $PM_{2.5}$ levels. This observation appears not to be consistent with the work of Flander and others (2015)[7], who found that mortality from all causes over the whole period 2009-14 was approximately two-fold higher in Latrobe Valley people exposed to PM_{10} at levels of 50 μG/m^3 or more on the day of death than in people not so exposed. It is more consistent with an estimate, based on statistical modelling of international data, that less than one extra death would occur in Morwell. within 6 weeks of onset of the mine fire as a result of the extra exposure to $PM_{2.5}$ due to the fire[8]. Either way, however, it is very likely that particulate air pollution during the mine fire caused an increase in mortality, realised, perhaps, more after the period of the fire than during it.
4. Crude mortality data suggest that mortality from all causes in Morwell in February and March and February to June 2014 was little if at all greater than that in the corresponding periods of 2009-13. In Churchill, Moe and Traralgon, however, crude mortality in these periods was greater than in 2009-13. Since Morwell was the most exposed of these populations to emissions from the mine fire, the comparative lack of greater mortality in Morwell in 2014 than 2009-13 is inconsistent with the mine fire being the cause of greater mortality in Latrobe Valley.
5. Barnett (2015)[16] also observed a lack of an increase in mortality in Latrobe Valley during February and March 2014 relative to that over the whole period 2004-14.

Carbon monoxide air pollution?

6. There was no consistent evidence that deaths from all causes or from cardiovascular disease alone during the period of the mine fire were more frequent on days with higher carbon monoxide levels than on days with lower carbon monoxide levels.

Very hot days?

7. Across the whole period from 2009 to 2014, mortality in Latrobe Valley in February to June was greater on days when the temperature was <30°C than on days when it was higher than this. This difference was not evident in February and March of these years.
8. There is no evidence that higher temperatures in Latrobe Valley during the period of the mine fire were associated with a higher mortality, whereas there is strong evidence that higher mortality was associated with lower temperatures. Lower temperatures, however, do not appear to explain the higher mortality in February and March 2014 than in the same months in 2009-13 as the mean daily temperatures in these two period were nearly identical.

Was there an increase in emergency admissions to hospital in Latrobe Valley during the coal mine fire in 2014?

9. Emergency hospital admissions for all conditions in the Latrobe Valley during the period of the mine fire in 2014 were more frequent than they were for the same period in 2013. Hospital admission rates for respiratory and cardiovascular diseases, considered individually, were also greater in 2014 than in 2013, though the statistical evidence for these increases was weaker.
10. There was strong evidence that emergency hospital admissions were greater in 2014 than 2009-13 in people 25-39 years of age. The causes of this increase should be investigated.

Why might emergency admissions have increased?

11. Emergency hospital admissions were greater in infants and children (0-4 years of age), albeit with statistically weak evidence in 2014 than in 2009-13, and greater in older people (65-74 years of age and, less so, 75+ years of age). These are recognised vulnerable groups for health impacts of air pollution.

References

1. Victoria Department of Health and Human Services. Reports of deaths in the LV claimed to be related to the Hazelwood Coal Mine fire. September 2014.
2. Victoria Department of Health and Human Services. R1-3.2Latrobe Valley death analysis RL document updated November 2014.docx.
3. Victoria Department of Health and Human Services. *R1-3.3 Morwell deaths enquiry 2015.xlsx*
4. Victoria Department of Health and Human Services. *R1-3.4 Morwell deaths enquiry 2.xlsx*
5. Altman DG and Bland JM. Interaction revisited: the difference between two estimates. BMJ 2003; 326: 219.
6. Flander L and English D. Review of Births, Deaths and Marriages Victoria (BDMV) mortality data for the Latrobe Valley and the time of the Hazelwood coal mine fire in Morwell. Centre for Epidemiology and Biostatistics, Melbourne School of Population and Global Health, University of Melbourne, 2014.
7. Flander L, Ouakrim DA, Dashti SG and Ugoni A. Age-standardised mortality and cause of death in the Latrobe Valley at the time of (and five years prior to) the Hazelwood coalmine fire in

Morwell, Victoria. Centre for Epidemiology and Biostatistics, Melbourne School of Population and Global Health, University of Melbourne, 2014.

8. Abramson M and others. Final Report Rapid Health Risk Assessment (RHRA). School of Public Health and Preventive Medicine, Monash University 12th March 2014,
9. Broook RD and others. Particulate Matter Air Pollution and Cardiovascular Disease An Update to the Scientific Statement From the American Heart Association. Circulation 2010; 2010: 2331-2378.
10. Burnett RT and others. An Integrated Risk Function for Estimating the Global Burden of Disease Attributable to Ambient Fine Particulate Matter Exposure. Environmental Health Perspectives 2014; 122: 397-403.
11. Agency for Toxic Substances and Disease Registry. Toxicological Profile for Carbon Monoxide. US Department of Health and Human Services June 2012
12. Barnett AG and others. The Effects of Air Pollution on Hospitalizations for Cardiovascular Disease in Elderly People in Australian and New Zealand Cities. Environmental Health Perspectives 2006; 114: 1018-23
13. Gasparrini A and others. Mortality risk attributable to high and low ambient temperature: a multicountry observational study. Lancet 2015; 386: 369-75.
14. Tong S and others. The impact of heatwaves on mortality in Australia: a multicity study. BMJ Open 2014; 4: e003579.
15. Barnett A. *Analysis of death data during the Morwell mine fire,* first published in 2014 (available at http://eprints.qut.edu.au/76230/).
16. Barnett A. *An updated analysis of death data during the Morwell mine fire* first published in 2015 (http://eprints.qut.edu.au/81685/).

Commentary on the Hazelwood mine fire and possible contribution to deaths

Professor Ian Gordon PhD, AStat, Director
Statistical Consulting Centre
The University of Melbourne

11 August 2015

Preliminaries

1. This report addresses instructions given to me by Ms Felicity Millner of Environmental Justice Australia. These instructions were contained in a letter dated 5 August 2015 (attached).

2. I was provided with the following documents to examine for the purposes of addressing these questions.

    1. Practice Direction No. 2, *Public Hearing for Terms of Reference 6.*
    2. Terms of Reference (refer to 6 and 7 only) dated 26 May 2015.
    3. Report prepared by VotV on the Births, Deaths and Marriages data, which includes the raw data received from BDM.
    4. Associate Professor Adrian Barnett's report.
    5. Department of Health analysis, *Reports of Deaths in the Latrobe Valley claimed to be related to the Hazelwood mine fire*, September 2014.
    6. Department of Health factsheet, *Reports of Deaths in the Latrobe Valley related to the Hazelwood mine fire*, 17 September 2014.
    7. Melbourne University, *Review of Birth Deaths & Marriages Victoria (BDMV) mortality data for the Latrobe Valley and the time of the Hazelwood coal mine fire in Morwell*, undated.
    8. Expert report of Professor Duncan Campbell.
    9. Email from Hazelwood Inquiry Board to VotV.
    10. Initial submission from VotV to Coroner dated 22 September 2014.
    11. Environmental Justice Australia submission to Coroner dated 29 October 2014.
    12. Extract from the 2014 Hazelwood Mine Fire Inquiry Report – Parts 4.1 to 4.3.

3. I am a Professor of Statistics and the Director of the Statistical Consulting Centre at The University of Melbourne. I have a PhD in Mathematical Statistics and am an Accredited Statistician of the Statistical Society of Australia Incorporated. I am a founding member of the Australasian Epidemiological Association. I have provided statistical consulting to several hundred clients from business, industry and government over the last 25 years. I am the author or co-author of about 70

papers in refereed journals. I have supervised or co-supervised four PhD students over the last ten years, and been Chief Investigator on ARC Discovery and Linkage Grants. I have appeared as an expert witness on statistical matters in numerous jurisdictions in Australia, including the Federal Court and the Australian Industrial Relations Commission. I was the President of the Victorian Branch of the Statistical Society of Australia in 2008-2009. I attach a brief CV to this report.

4. I assume that in general terms the readers of this report are familiar with the Hazelwood mine fire and the concerns raised about health. The essential details are described in my letter of instructions.

Data sources

5. The main data considered in the two reports I review here are deaths in four postcodes near the Hazelwood fire site, for the years 2009 to 2014 inclusive, and months January to June. This gives 4 × 6 × 6 = 144 observations. These numbers of deaths are in a table in the document "V.O.T.V. Birth Deaths & Marriages (BDM) Death Statistics Latrobe Valley". The four postcodes differ considerably in population size and area.

6. The report by Louisa Flander and Dallas English states that these are the only data considered by them; they did not take local weather conditions into account, and age and sex distributions, and population movements, were not available.

7. These data also defined the outcome variable in the models reported by Adrian Barnett in his report. However, he supplemented his analysis with other data: population data for the La Trobe City Council, and temperature data at a monthly level; specifically, the maximum monthly temperature. His report does not indicate the sources for these extra data. The location he used for the temperature data may have been the La Trobe Valley weather station (station ID: 085280), for example. Further, he included other adjustments in his modelling, for season and trend, which I discuss below. These do not entail more data, but are designed to account for known or supposed time-related phenomena.

Flander and English report

8. The approach taken to analysis in the Flander and English report is to aggregate the deaths across the four postcodes. This is a reasonable strategy, assuming the absence of a clear ranking of exposure across the postcodes. (If exposure could be measured and differentially assigned to the four postcodes, a more refined analysis could be conducted by keeping the postcodes separate.)

9. Flander and English carried out a Poisson regression. Underlying Poisson variation is appropriate and standard for counts of cases of disease or death, since such data record events arise in a process occurring at a rate. In a Poisson

regression model, the rate is allowed to depend on potential explanatory variables.

10. It is relevant and desirable to specify the explanatory variables considered or used in any model reported. In the Flander and English report, this is not made clear. They mention several plausible explanatory variables that were not used, such as weather conditions and population size. They state explicitly that their models did not take external factors into account. At face value, it seems that a single explanatory variables was used, namely, 'month' as a categorical variable. I attempted to replicate their results (shown in their Table 1) using such a model but was unable to do so. In fact, if their model did just have 'month' as an explanatory variable, and no other terms, the predicted numbers of deaths in the 2014 months would simply be the averages of the respective numbers in the years 2009 to 2013, but the 'Predicted' numbers in Table 1 are not these figures. I investigated whether some other terms may have been used in the model, such as an overall trend with time, but was not able to find a plausible model that gave the 'Predicted' numbers in Table 1. I do not conclude that Flander and English have made an error in their Poisson regression analysis, only that it is insufficiently reported for the purposes of proper review.

11. I now wish to comment on the interpretation of the Poisson modelling carried out in the Flander and English report. Their Table 1 compares the actual numbers of deaths in 2014 months, with the numbers predicted on the basis of the years 2009 to 2013. They note that there were 37 more deaths in 2014 than predicted by the model, and that 'the additional deaths occurred in March and May'. In fact, for every month of 2014, the observed number of deaths was greater than the predicted number shown in their Table 1, to a varying degree. The lowest excess was a difference of +2, in January (before the fire).

12. The 'Lower bounds' and 'Upper bounds' of Table 1 are not described. I believe they have been derived as confidence intervals, probably 95% confidence intervals. If intervals are to be used to assess how unusual the observed numbers of deaths are, the appropriate intervals are not confidence intervals but prediction intervals.

13. A more direct method to assess the statistical significance of the observed numbers of deaths in Table 1 is to obtain P-values. A P-value is a way of representing statistical inferences; they are used in Table 2 of the Flander and English report. Effectively, we may ask: if the predicted number of deaths in February 2014 was 43.38, how surprising is an observed number of 50 deaths?

14. Calculations along these lines are shown in Table 1 below. The focus of both reports (Flander and English, and Barnett) is on the months of February and March, due to the dates of the fire. I consider it is reasonable to believe that any effect of the fire on mortality may have continued for some time after the fire was declared safe on 25 March 2014. It is not hard to envisage scenarios for which this is a logical possibility. A frail elderly person with chronic obstructive

pulmonary disease, for example, could have their respiratory system stressed by the air pollution from the fire in such a way that their death is accelerated, without it necessarily occurring during the period of the fire. For this reason, in Table 1 I consider a variety of time periods in 2014, starting with the two fire months separately, and then considering groupings of months, successively including more months. All the relevant predicted numbers are based on Table 1 in the Flander and English report. It is a feature of the Poisson distribution that the sum of statistically independent Poisson counts has itself a Poisson distribution, with rate equal to the sum of the individual rates. This property is used in Table 1 below.

Table 1: Comparisons of observed and predicted numbers of deaths in 2014, based on Table 1 in the Flander and English report.

Period	Predicted	Observed	Ratio	P-value
February 2014	43.38	50	1.15	0.175
March 2014	52.98	62	1.17	0.122
Feb – Mar 2014	96.36	112	1.16	0.064
Feb – Apr 2014	146.26	166	1.13	0.058
Feb – May 2014	199.24	228	1.14	0.024
Feb – Jun 2014	249.64	285	1.14	0.015

The last four of these P-values are small, and the last two are less than the conventional threshold of statistical significance, which is 0.05. The interpretation of the P-value is the probability of the observed number of deaths, or more, given that the predicted number of deaths governs the rate at which deaths are occurring. The smaller the P-value, the stronger the evidence that the 2014 death rates were abnormally high. Thus, on the basis of the numbers in Table 1 of the Flander and English report, there is quite strong and statistically significant evidence that the death rates from February to June 2014 were abnormally high.

15. Flander and English do not report P-values for the excess deaths in their Table 1, although they do report them for the alternative analysis they carried out, which was based on assuming an underlying Normal distribution for the variation in the counts of deaths. A more complete approach would have been to report them for both analyses.

16. An inadequacy of the analysis in (my) Table 1 is that it treats the predicted numbers as fixed, whereas they have actually been estimated from the 2009 to 2013 data. This can be corrected by fitting a Poisson regression model. Table 2 below shows the result of this analysis, in which the potentially different risk due to the fire is allowed to be in the same variety of periods as in Table 1; the only difference is that February 2014 and March 2014 are not separately considered.

Table 2: Rate ratios for Poisson regression models, using various periods of potentially different risk.

Period	Rate ratio	95% conf. int.	P-value
Feb – Mar 2014	1.20	(0.97, 1.47)	0.088
Feb – Apr 2014	1.16	(0.98, 1.38)	0.078
Feb – May 2014	1.18	(1.02, 1.36)	0.026
Feb – Jun 2014	1.17	(1.03, 1.34)	0.014

The rate ratios in Table 2 are similar to those in Table 1; as expected, the P-values are also similar but slightly larger, since the Table 2 analysis takes account of the sampling variation in the 2009 to 2013 data.

17. Flander and English provide an alternative analysis, assuming a Normal distribution for the underlying variation in the numbers of deaths. In my view the Poisson assumptions are to be preferred, although the Normal distribution may be a reasonable approximation. In the results of this analysis, shown in their Table 2, one of the analyses they describe compares January to June 2014 with the January to June periods of 2009 to 2013. Since the fire did not start until 9 February 2014, it is inappropriate to include January 2014 in any proxy measure of exposure to the fire.

18. In that analysis (Table 2, Flander and English) they report a predicted number of additional deaths per month of 9.2, for February to March 2014. This is a total predicted excess of 18.4. Note that this is of similar magnitude, but slightly larger than, the excess for the same period implicit in their Table 1, which is 15.6, obtained as the total difference between observed and expected in Table 1, for February and March 2014.

19. In overall terms, the report of Flander and English has found that there was an excess of at least 15 deaths in February and March 2014, compared with 2009 to 2013, from the area as a whole. This excess was not statistically significant at conventional levels of significance.

20. There are a number of ways in which the analysis could be refined.

Barnett report

21. The analysis in the Barnett report has some similarities with one of the two Flander and English approaches. Most notably, Barnett uses an underlying Poisson model for the variation in the death rates. I agree with this approach.

22. His analysis has a number of differences with the Flander and English model however. The major one is that he uses a Bayesian paradigm, which leads to a fundamentally different way of representing the results, although the two approaches can be sensibly reconciled. I comment more on this later.

23. Barnett has also adjusted for other phenomena that could help to explain some of the variation in the numbers of deaths. He has adjusted for population using La Trobe City Council figures, but whether or not this was accounted for 'had little impact on the results'. He allowed for an overall trend in death rates. He incorporated a seasonal term in his model, which is equivalent to adjusting for month, but in a way that assumes a smoothly varying effect over the course of the year. This was an appropriate way to adjust for time of the year. His analysis was at the postcode level and he fitted a random term for postcode, to accommodate the varying sizes of the postcode. Finally, he attempted to allow for temperature, in a simple way, by using the maximum monthly temperature 'from the Bureau of Meteorology'. These investigations of other potentially relevant phenomena are appropriate, in the attempt to estimate any fire effect.

24. The term allowed for the fire in Barnett's approach implicitly assumed that the potentially different risk of death from the fire arose in the two fire months (only). Two estimates are provided, with and without adjustment for temperature. These are a rate ratio of 1.14 without temperature in the model (Table 1, Barnett) and a rate ratio of 1.11 after adjustment for temperature (Table 2). The 2014 months of February and March were among the hottest in the series, which is why adjustment for temperature reduces the estimate.

25. I have analysed the data using the aggregated deaths, but in other respects the same terms as Barnett, and have obtained essentially the same results as he did, although I did not use a Bayesian approach. His 'probability that the death rate was not higher than the average during the fire' was found to be 0.11 without adjustment for temperature, and 0.20 after adjustment for temperature. These correspond to the P-values in the non-Bayesian approach.

26. He also estimated the excess numbers of deaths during the two fire months, and obtained 14.4 without adjustment for temperature; this is similar to the figure of 15.6 obtained by Flander and English. After adjustment for temperature, his estimate of the same quantity was 11.2.

27. The analyses in both reports are broadly consistent, even though they adopt different analytic paradigms and use different terms in their models. There was an estimated excess of deaths in the two fire months, and also in the subsequent three months of 2014. The quantification of this excess number of deaths (for February and March 2014) depends on the model used, and varies between about 11 and 18.

28. In all of these analyses, the excess is not markedly unusual according to strict conventions of statistical significance, in that the P-values are not smaller than 0.05.

29. As I have noted, if the possibility of a lingering effect on the risk of death is entertained, the excess risk does become statistically significant at such levels, for the period February to May 2014 and February to June 2014.

Department of Health documents

30. In my instructions I was asked to focus on the two documents from the Victorian Department of Health, the Report dated September 2014 and the Fact sheet dated 17 September 2014. It is a good feature of the Report that the data, at least summarised across months and postcodes, are presented clearly. However, in my opinion both of these documents lack an appropriate level of objectivity, as they focus on particular elements of the data and appear to be arguing persuasively towards a particular conclusion, namely, that the mine fire did not cause any excess deaths. For example, in the Report, there is a paragraph on the VOTV estimate of a 40% increase in deaths, and an attempted rebuttal. The next paragraph begins "Looking at the two months in which the fire occurred (February-March) there was a decrease of 19%". From the context, it would appear that this is referring to all postcodes, but in fact, as is clear from the Table, the sentence is referring to Morwell.

31. The Report notes that for Jan-June in 2014 the number of deaths in Morwell was 88, 'very similar to deaths in the years 2012 (89), 2010 (91) and 2009 (86).' This is selective reporting; the rest of the picture is that the 2014 figure of 88 was markedly higher than the other two years, 2011 (67) and 2013 (64).

32. The Fact sheet dated 17 September has content that overlaps with the Report and to that extent is subject to the same criticisms. Further, in the postcodes where there were excesses of deaths in the February to March period of 2014, there is either little discussion, or a comment prefaced by the word 'but'. In the case of Moe, there was an excess of 32%. The Fact sheet indicates that the Department is obtaining additional data to better understand this excess. It would be helpful to know what these data are.

Other issues

33. In the V.O.T.V. document it is noted that in the black Saturday fires of 2009, '11 people died in their homes in February'. It is not clear to me whether these 11 deaths are included in the data analysed, but if they are, there is at least a question whether they should be. Deaths from a special cause, particularly one at a particular time-point, do not reflect the natural variation in death rates which is of interest as a background comparison to the possible mine fire effect. I do not suggest that this is a clear-cut matter: deaths due to a bushfire could, from an alternative perspective, be seen as part of the elevated risk of high temperatures.

34. I note that the Government received advice from Monash University researchers that "no additional deaths would be expected even if the level of exposure to the measured level of air quality continued for six weeks". Six weeks was the approximate duration of the fire. The Monash University report was a substantial document which I am not formally reviewing here. It is my

understanding and belief that this assertion is based on an integrated exposure-response analysis of many studies. If it is the case that in these studies the exposure recorded accumulated over a long period of time, gradually, this is a different kind of exposure than that of the air pollution arising from the mine fire. A short, sharply elevated exposure, which clearly occurred in the Hazelwood fire, is a different matter. The famous London Smog of 1952 lasted for only five days but has been estimated to have contributed to an excess of several thousands of deaths. I am not suggesting that the Hazelwood fire's levels of pollution were similar to that London event, only that it is possible for a short air pollution exposure to have lethal effects. Further, it is widely accepted that the London event had an adverse effect on mortality in the months following.

35. The outcome data analysed are "all-cause mortality" counts. It would be worth considering refining this to cause specific mortality, as there would be some causes that could be ruled out as possibly due to the air pollution.

36. The Hazelwood Inquiry report noted that a 65% of Morwell residents received a relocation or respite payment (page 370). I am not sure what effect that might have on the data analysed, since I have not investigated the precise way in which deaths are attributed to postcode. More broadly, movement of people, associated with the fire, would be worth understanding better.

37. The data are analysed by month. In principle, a more refined analysis by day could be considered, for two reasons. Firstly, the fire did not start until 9th February, so deaths in February before that date should not be considered as plausible outcomes of it. Secondly, the Environment Protection Authority measurements, reported in the Hazelwood Inquiry report, offer the potential to examine the association between exposure and outcome in a more fine-grained way, if the deaths were available by actual date.

Conclusion

38. There is no doubt that air pollution can contribute to death; this has been comprehensively studied. So this situation is different from other cases where a cluster of cases of disease, or deaths have been noted, and concern raised about a possible cause. Here the possible cause is manifestly unambiguous. The question is, do the data demonstrate a strong enough association between the mine fire and mortality, to conclude that, in this case, the fire did actually contribute to deaths in some cases?

39. In reviewing the two reports that analysed the data, I conclude that they arrive at broadly similar conclusions, which is that there was an excess of deaths in association with the fire, of between 11 and 18 deaths, approximately, on the basis of comparison with the previous five years, in the area of interest. For February and March (the actual fire months) this excess is not statistically significant at conventional levels. This means that the data are consistent with general background variation, and no special effect of the fire. The data are also

consistent with the fire causing some excess deaths. The Barnett report, and my own analysis, suggest that the apparent fire effect is partly, but not entirely, due to hot temperatures, in that after adjustment for temperature the rate ratio for the fire effect is reduced slightly.

40. Based on my own analysis, in which the period of potentially different risk is assumed to extend beyond the actual time of the fire, (for example, to May 2014), the excess of deaths is statistically significant at conventional levels.

41. I have outlined the limitations I see in the data, and possible further lines of inquiry, in the body of the report, and especially in the "Other issues" section.

Review of "Analysis of death data during the Morwell mine fire," A. Barnett, working paper, unpublished (2014, Queensland University of Technology) and

"An updated analysis of death data during the Morwell mine fire," A. Barnett, working paper, unpublished (2015, Queensland University of Technology)

Louisa Flander PhD
Antony Ugoni MSc
Centre for Epidemiology & Biostatistics
Melbourne School of Population & Global Health

Cindy Hauser PhD
School of Biosciences
University of Melbourne, VIC 3010

[redacted]

28 April 2015

Executive Summary

The working papers "Analysis of death data during the Morwell mine fire" by Adrian Barnett (2014, Queensland University of Technology, unpublished) and "An updated analysis of death data during the Morwell mine fire (2015, Queensland University of Technology, unpublished) are analyses of mortality data for the Latrobe Valley postcodes exposed to smoke from the Hazelwood coal mine fire, February-March 2014, compared to mortality up to ten years earlier.

The Barnett (2014) paper describes an analysis of the mortality data available at the time of the analysis, and includes temperature information to account for potential excess mortality in the four postcodes adjacent to the Hazelwood fire due to the summer heatwave during the weeks of the Hazelwood mine fire. The results show deaths in the months January to June 2009-14 in excess of the expected mortality for the 2009 and 2014 summers. The author concludes that there is an 80% probability that the excess mortality in the months of February-March 2014 was due to the fire, after adjusting for temperature. This assertion is not supported by the results reported in the paper.

The Barnett (2015) paper describes an expanded dataset for the analysis, including two additional postcodes further distant to the south and southeast of the fire, and additional mortality for the years 2004 to 2014, January to December. The author concludes that there is an 82% probability that the excess mortality in the months of February-March 2014 coincided with the dates of the fire, after adjusting for temperature. This assertion is not supported by the results reported in the paper.

These papers do not discuss the ambiguities in interpretation of estimates when such estimates are based on small datasets in the context of rare environmental events. There is no discussion of the decrease in deaths for the postcode (Morwell) where the Hazelwood mine is located and the fire occurred. Cause of death for these mortality data were not included in these analyses and strongly mitigate the author's assertions about the deaths at the time of the fire.

There is no statistical interpretation of evidence for any particular effect on the observed differences in reported mortality across the Latrobe Valley postcodes for the period of the Hazelwood coal mine fire. Although the fire's effect on mortality may be a supposition worthy of investigation, the data presented in these papers do not suggest strong evidence for the author's assertion of a significant effect of the period of the fire on mortality at that time. The mean increase in deaths (given as a relative risk with 95% credible intervals) for the February-March 2014 period with and without the seasonal temperature correction is not evidence of statistical significance.[1] The evidence given in these analyses of broad uncertainty around

[1] The 95% credible interval given with a point estimate in a Bayesian analysis is equivalent to the analyst's statement of a 95% degree of belief that the parameter in question is in fact contained within this interval. These intervals can be broader or narrower depending on several factors, including sample size and population variability. When the credible interval contains one (1), the evidence for an association/relationship is weak. We note that non-significant results in the case of small sample sizes

the estimated mortality shows that there were *no* additional deaths, rather than the 0.8 deaths per postcode per month and 9.6 deaths per postcode over two months reported by Barnett (2015).

Strengths of the analysis with regard to choice of analytic methods

There are several possible methods to model the variation in mortality across the Latrobe Valley postcodes for February-March 2014 compared to previous years. The methods used in these papers are appropriate to the problem, notwithstanding the failure to explain their use and the inconclusive results reached using these methods.

The Poisson regression model used in these papers is appropriate to this research question. The description of the statistical model used is clear. In addition to the regression model, the analysis is framed in the Bayesian paradigm, and used to estimate the probability of the observed mortality. This is a useful analytic tactic given the small numbers in the dataset, and the uncertainty surrounding the rare event of the mine fire.

There are considerations made in the model to allow for nuances in interpreting the regional excess mortality in February-March 2014. These include a consideration of regional population movements, although the specific source and assumptions for the use of Latrobe City Council population data (Barnett 2014) and the 'qualitative evidence of exposures and evacuations' (Barnett 2015) are not made clear in the papers. The lack of methodological context for these data sources does limit their use in the interpretation of the results.

These papers include a consideration of the usual and expected seasonal peak in mortality during the Australian winter months. Most importantly, a consideration of the maximum monthly regional temperature was included in the model to account for the possible effect of higher-than-average summer temperatures on mortality. However important it is to consider temperatures in explaining the mortality at the time of the fire, it is equally important to understand that it is *extreme* fluctuations in temperature and their duration, rather than monthly averages, that impact mortality. The lack of such data covering the entire 2009-14 period for the affected area limits the interpretation of models that include a gross temperature variable as a covariate.

In addition to the expanded dataset, Barnett (2015) includes a comparison of the complexity of the different models to account for temperature variation throughout the year and variable mortality across the different postcodes. Some postcodes reported fewer than expected deaths and some postcodes reported

---

are prone to misinterpretation, leading to the conclusion of an effect where there is none, or the conclusion of no effect where there is one (see Altman DG and Bland JM, 1995, Absence of evidence is not evidence of absence, *British Med J* 311:485).

greater than expected mortality; no postcodes in this analysis reported statistically significant excess mortality (by mean relative risk with 95% credible interval). Barnett (2015) contains a useful graphic comparison of the mean relative risks across the postcodes. This showed that all 95% credible intervals overlap with each other, and also contain the relative risk 1.0, meaning no significant increase or decrease (Figure 3).

In the comparison of the different explanatory models, the best model in this analysis showed no adjustment for seasonal temperature, and a fixed rather than variable effect of the fire on mortality across postcodes (Barnett 2015). Use of the deviance information criteria (DIC, Barnett 2015) is one of the better information criteria methods to use for Bayesian modelling. There were very minor differences in the DIC and these were explained correctly; that is, the temperature variable provided insufficient information to warrant its inclusion in the model.

Further, the use of residual plots is suited to identifying 'spikes' in the death rates, but only if we can assume that the question posed by the method is correct. Thus, the question is not whether this method is suitable for identifying 'spikes' in the death rates. It is rather whether this model is adequate to explain enough variance to conclude the coal fire's influence on death rates; we conclude from these results this is not the case.

Limitations of the analysis

There is not one single analytic method or combination of methods that can overcome the limitations in these mortality data. These limitations include the small numbers of deaths and the lack of identifying information for these deaths (age, sex, cause of death, underlying comparison population). A more thorough analysis of the cause of deaths for this period would be required to explore common risk factors.

There are limitations of this analysis that hinder the reader's understanding of the potential significance of the results. One is the lack of even a brief discussion of the analytic issues of uncertainty analysis when evaluating rare environmental events. This discussion could cover the limitations of interpreting broad credible intervals that contain one (1) in the context of small sample sizes. Some acknowledgment of the small numbers in this dataset, and the variation in mortality observations over the study period is warranted, such as the high mortality in the 2009 summer heatwave, and the lower mortality in the Morwell postcode (location of the fire) during the February-March 2014 period.

The inclusion of a Bayesian estimate of the probability of the February-March 2014 mortality may be problematic for the general reader, as it is difficult to link the relative risks reported to the estimated probabilities of the fire's effects on mortality. The Barnett (2014) paper shows this ambiguity in Tables 1 and 2 (1.14, 95% credible interval 0.92-1.41, and temperature corrected 1.11, 95% credible interval 0.87-1.37 respectively) with the probability that the deaths in these postcodes coincided with the dates of the fire (0.89 and temperature corrected 0.80 respectively).

The updated Barnett (2015) paper reports even more ambiguous results. The relative risk corrected for temperature is 1.103, with 95% credible interval 0.895-1.337. The 0.82 probability that the death rate increased at the time of the fire is the amount of the credible interval that falls above 1.0. Thus postcodes 3842 (Churchill) and 3844 (Tralralgon), show a relatively high probability that the relative risk increased, because most of the 95% credible interval around the mean falls above 1.0. However neither of these probabilities reaches 0.95, and that is why the credible intervals include 1.0, and overlap with each other.

These results show in fact that there were *no* additional deaths, rather than the 0.8 deaths per postcode per month and 9.6 deaths per postcode over two months reported by Barnett (2015). The interpretation of, and subsequent media reports of, increased mortality due to the fire appear to be based on this misinterpretation of an ambiguous result.

Barnett (2015) shows much uncertainty around the estimated likelihood that the dates of the fire are associated with excess mortality. These results do not evaluate the posited increase in mortality due to fire by considering the alternative explanations such as no effect at all or a decrease in mortality. Thus, for the Morwell postcode (location of the fire) along with the Jumbuk and Boolara postcodes, there is a greater than 0.76 probability that the dates of the fire are associated with *decreased* mortality (Table 3).

The scarce data underlying these reported likelihoods present a problem in interpretation that can be better understood by converting the mean absolute deaths per postcode into the 95% credible intervals (Table 3). Thus, we are 95% certain that for Moe (postcode 3825) the dates of the fire are associated with as many as many as 4 or fewer *prevented* deaths, or as many as 8 or fewer *caused* deaths. For Morwell (postcode 3840, location of the fire), we can be 95% certain that the dates of the fire are associated with as many as 5 or fewer *prevented* deaths, or as many as 3 or fewer *caused* deaths.

The scarce data underlying these analyses prevent the confident conclusion that the period of the fire is associated with statistically significant increased mortality in the Latrobe Valley postcodes. These analyses are framed by support for the argument of association between the excess mortality in some postcodes at the time of the fire. However, these analyses are limited by their neglect of a fuller explanation of results.

Age-standardised mortality and cause of death in the Latrobe Valley at the time of (and five years prior to) the Hazelwood coalmine fire in Morwell, Victoria

Louisa Flander PhD
Driss Ait Ouakrim PhD, MPH
Seyedeh Ghazaleh Dashti DDS, MPH
Antony Ugoni MSc

Centre for Epidemiology & Biostatistics
Melbourne School of Population & Global Health

[redacted]

4 June 2015

Executive Summary

This report examines mortality data from the Latrobe Valley postcodes during the period of the Hazelwood mine fire in February and March 2014. In this report, the mortality data for February and March 2014 are compared to the same summer months for the same postcodes in the previous five years. This comparison examines the epidemiological evidence for any excess number of deaths during this period, and the role of air quality and temperature on numbers of deaths. The mortality from the period February to June 2014 is included also in this report, and compared to the same period in the previous five years to examine whether there were associations of the Hazelwood fire on mortality beyond the summer months when the fire occurred.

Key findings in this report are to be interpreted cautiously, with the understanding that the finding of no statistical evidence of association cannot be interpreted as evidence for or against a particular cause of death.

The analyses examine these associations in terms of the statistical evidence linking the deaths with the occurrence of the mine fire. The findings reported are based on the small number of deaths in the affected postcodes, which limits the interpretation of the results.[1]

The analysis of these data shows no statistical evidence that 2014 mortality rates differ from comparable rates for the same months in 2009, a season similar to 2014 with respect to high temperatures and high particulate matter from bushfire smoke. Broad confidence intervals for each of the rate ratios for the years 2009–2013, which approach or overlap the confidence intervals of the 2014 rates, express the lack of statistical evidence for an overall higher rate of mortality in 2014.

There is statistical evidence that air quality exceedances are associated with mortality throughout the study period, not just during the period of the 2014 Hazelwood coalmine fire, or the 2009 bushfire.[2] Overall for the 2009–2014, February-June study period, most deaths that occurred on days with air quality over 50µg/m^3 for PM_{10} in the affected postcodes occurred outside of the February-March period and 85% of these occurred in 2012 and 2013. Mortality in all age groups was 2.13 times higher on

[1] The associations reported herein are given as point estimates of rates with associated 95% confidence intervals. The 95% confidence intervals given with a point estimate is equivalent to the statement that there is a 95% probability that the value of the point estimate lies within the stated range of values. These intervals can be broader or narrower depending on several factors, including sample size and population variability. When the confidence interval contains one (1), the evidence for an association is weak. We note that non-significant results in the case of small sample sizes such as those in this report are prone to misinterpretation, leading to the conclusion of an effect where there is none, or the conclusion of no effect where there is one (see Altman DG and Bland JM, 1995, Absence of evidence is not evidence of absence, British Med J 311:485).

[2] An exceedance is an instance or condition where the observed concentration of a pollutant goes beyond the permitted quality standard or threshold. The 'threshold' level used for the purposes of this analysis is the daily mean value of 50µg/m^3 although particulate matter is a non-threshold pollutant, and thus is not associated with a threshold level (http://www.epa.vic.gov.au/your-environment/air/bushfires-and-air-quality; see also Table 1, Standards and goals for pollutants other than particles as $PM_{2.5}$, National Environment Protection (Ambient Air Quality) Measure, http://www.comlaw.gov.au/Details/C2004H03935).

days with air quality over 50µg/ m^3 for PM_{10}, compared to days with lower levels for the entire period February-March, 2009–2014 ($p<0.01$). The mortality in the vulnerable age group 65 years and older was 2.0 times higher on days with air quality over 50µg/ m^3 for PM_{10} compared to days with lower levels for the same period ($p<0.01$). As mortality was associated with air quality over 50µg/ m^3 for PM_{10}, and the fire may have contributed to this measure of air quality, it is possible that a proportion of deaths in 2014 could have been due to the fire in February-March, 2014. However, as we do not know the individual circumstances of deaths on days with air quality over 50µg/m^3 for PM_{10} we cannot offer specific conclusions on this matter.

There is no statistical evidence for the association of daily average temperature at or over 30° C with mortality in the February-March period for 2009–2014. There is moderate evidence that colder temperatures are associated with mortality in the February-June period for 2009–2014.

Background

The Hazelwood mine fire occurred during a period of high temperatures with associated health risks in February 2014, during one of the hottest and driest Victorian summers on record. The most likely cause of the mine fire was found to be embers from one or both of two bushfires outside of the mine. (Hazelwood Mine Fire Report 2014, http://www.dpc.vic.gov.au/index.php/news-publications/hazelwood-mine-fire-inquiry-report).

Methods

Births, Deaths, and Marriages Victoria provided the mortality data for these analyses in the form of Stata files containing all Victorian deaths for the period 2009–2014. For each death, the dataset included variables for date of death, age, 5-year age group, sex, cause of death and postcode. Our analysis was restricted to the Latrobe Valley postcodes: 3840 Morwell; 3842 Churchill; 3844 Traralgon; and 3825 Moe.

There were 3414 deaths in the Latrobe Valley postcodes for the years 2009–2014. Our analysis is based on the 3398 deaths for which we have complete data. We excluded 13 deaths listed as 'unascertained'; of these, there were two unascertained deaths in 2014 (May and September). Three additional deaths were excluded from the final analysis due to missing data in other variables.

Cause of death categories and definitions

Cause of death was provided in the form of text description of the underlying cause of death. Using the *regular expressions* command in Stata 13.0, we generated variables for deaths that reasonably would be associated with exposure to fire, airborne particulate matter and/or pollutants. In this report we analysed the number of deaths from *all causes* and the number of deaths due to *respiratory*, *cardiovascular* or *cardiorespiratory* causes.

Deaths associated with exposure to fire, airborne particulate matter and/or pollutants: These categories are deaths by *respiratory* conditions, *cardiovascular* conditions, and deaths with *direct relationship to fire*.

Causes of death due to *respiratory* condition*s* included chronic obstructive pulmonary disease, asthma, pneumonia, bronchitis, bronchopneumonia, pulmonary embolism, pulmonary fibrosis, pulmonary oedema, and respiratory arrest.

Causes of death due to *cardiovascular* conditions included myocardial infarction, ischemic heart disease, congestive heart failure, coronary heart disease, cardiomyopathy, aortic dissection, aortic stenosis, arterial fibrillation, ventricular fibrillation, cardiac amyloidosis, cardiac arrhythmia and tachycardia, and cardiac arrest.

Due to the small number of deaths in the four postcodes of interest, the aggregated variable *cardiorespiratory* conditions for causes of death due to respiratory *and/or* cardiovascular conditions was generated by combining the two variables.

Causes of death from *direct relationship with fire* included carbon monoxide poisoning, inhalation of smoke and fire gases, complications of thermal burn injuries, and general effects of fire.

Temperature and air quality variables
The Morwell Bureau of Meteorology Site 85280 at the Latrobe Valley Airport, closely located to the four Latrobe Valley postcodes in this analysis, provided daily mean temperatures for 2009–2014. The threshold level for this analysis is daily mean temperature in excess of 30° Celsius, which is the threshold that triggers the state's Heat Health Alert System.

The Environmental Protection Agency Traralgon air quality monitoring site, closely located to the four Latrobe Valley postcodes in this analysis, provided daily mean measures of particulate matter in excess of 10 micrometers or less in diameter (PM_{10}) for 2009-2014. The threshold level used for the purposes of our analysis is 50µg/m^3, although particulate matter is a non-threshold pollutant and thus is not associated with a threshold level (http://www.epa.vic.gov.au/your-environment/air/bushfires-and-air-quality, see also Table 1, Standards and goals for pollutants other than particles as $PM_{2.5}$, National Environment Protection (Ambient Air Quality) Measure, http://www.comlaw.gov.au/Details/C2004H03935).

Age-standardisation
Age-standardisation allows for comparison of mortality rates over different years (2009–2014) and populations (the four postcodes of the region) that may have different age distributions. This is done by adjusting each year's deaths based on the age distribution of a single chosen 'standard' population, such as the national population. For example, in the case of the four Latrobe Valley postcodes, there is a five-fold difference in the population size of Churchill compared to Traralgon, and a nine-year difference in the median age of Churchill compared to Morwell (http://www.abs.gov.au/websitedbs/censushome.nsf/home/Census?opendocument#from-banner=GT).

Due to the small population size of the Latrobe Valley, the Morwell, Churchill, Moe and Traralgon postcodes' mortality data were aggregated for age standardisation into three age-categories: under age 50 years, 50-64 years and 65 years and over. For age-standardisation we used the direct method (Australian Institute of Health and Welfare 2011. Principles on the use of direct age-standardisation in administrative data collections: for measuring the gap between Indigenous and non-Indigenous Australians. Cat. No. CSI 12. Canberra: AIHW). We created age-specific population estimates from the Australian Bureau of Statistics using the age distribution of the 2011 Australian standard population (http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/3101.0Sep%202014?OpenDocument).

Statistical modelling
Poisson regression models adjusted for age and sex and for temperature and air quality were used to calculate mortality rate ratios and associated 95% confidence intervals. These rate ratios were used to compare the mortality observed for the periods February-June and February-March 2014 with the mortality observed during those periods for each year from 2009 to 2013. In this sense, the 2014 mortality rates were the reference rates (mortality rate ratio of 1.0) and the rate ratios for the other years indicate the proportional increase (rate ratios greater than 1.0) or proportional decrease (rate ratios less than 1.0) compared to 2014.

These analyses examined *all-cause* mortality and mortality due to *respiratory*, *cardiovascular* and the combined category of *cardiorespiratory* causes. Mortality rate ratios were calculated for all age groups combined and for the aggregated vulnerable age groups aged 65 years and older. There were insufficient deaths to analyse the vulnerable age groups aged 5 years and younger.