Normalised Australian Bushfire Building Damage and Fatalities: 1925–2009

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ABSTRACT

This study re-evaluates the history of building damage and loss of life due to bushfire (wildfire) in Australia since 1925 and does so in light of the 2009 Black Saturday fires in Victoria in which 173 people lost their lives and 2,039 homes were destroyed along with many other structures. Historical records are normalised in order to estimate the building damage and fatalities had events occurred under year 2008/09 societal conditions. The average annual normalised fatalities and building damage is 14 deaths and 296 house equivalents (HE) respectively (HE include non-residential buildings by conversion to equivalent houses using relative floor areas and construction costs). There are relationships between normalised building damage and the El Niño-Southern Oscillation and Indian Ocean Dipole phenomena, but, to this point in time, there is no discernable evidence that the normalised data is being influenced by climate change due to the emission of greenhouse gases. The 2009 Black Saturday fires rank second (fourth) in terms of normalised fatalities (building damage). The public safety concern is that of the 10 most damaging years the 2008/09 bushfire season ranks second, only to the 1925/26 season, in terms of the ratio of normalised fatalities to building damage. A feature of the building damage in the 2009 Black Saturday fires in some of the most affected towns – Marysville and Kinglake – is the large proportion destroyed either within bushland or at very small distances from it (< 10 m). Land use planning policies in bushfire-prone parts of this country that allow such development increase the risk bushfires pose to the public and built environment.

1. Introduction

Widely heralded in the media as Australia's worst natural disaster (http://www.theage.com.au/national/our-darkest-day-20090208-810q.html; http://news.ninemsn.com.au/national/744864/at-least-93-dead-in-victorian-bushfires; http://www.abc.net.au/news/btn/story/s2488554.htm), the 7 February 2009 Black Saturday bushfires (wildfires) in Victoria were but the most recent reminder of the potential for natural hazards to impact Australian communities (Crompton and McAneney 2008). Fuelled by record high temperatures and high winds in the midst of a protracted drought, the Black Saturday fires claimed 173 lives, 2,039 houses, as well as numerous other structures including schools and a police station (Victorian Bushfire Royal Commission 2009). This paper attempts to place these most recent bushfires into an historical context.

Following a methodology analogous to Crompton and McAneney (2008) and other recent work, it asks: What would have been the impact of past bushfires if they were to recur under current societal conditions? Without accounting for the known influence societal factors have on disaster records, it is impossible to know whether the devastation inflicted by the Black Saturday fires was truly anomalous, whether this provides a glimpse of the future under expected changes in climate, and what policy changes might prove effective in reducing the impact of future disasters. In examining such questions, we shall also re-evaluate work undertaken before the Black Saturday fires (e.g., McAneney et al. 2009) and present some patterns of building destruction in these particular bushfires.

Despite claims that the loss of life and property damage in the Black Saturday fires was unprecedented in Australia, several previous natural disasters have been more destructive, even before the societal influence has been accounted for: in 1974, Cyclone Tracy laid waste the city of Darwin, demolishing about 3,700 dwellings and damaging another 3,300 to the point that only 4% of the building stock was left habitable (Walker 1975); in 1899, Cyclone Mahina, a Category 5 tropical cyclone, claimed about 410 lives, and the heatwave that preceded the 1939 Black Friday bushfires in Victoria is blamed for 438 excess deaths (*PerilAUS,* Risk Frontiers' natural disaster database: Blong 2004; McAneney et al. 2009). Of the more extreme bushfires, over 2,000 houses and other buildings were lost in the 1983 Ash Wednesday fires in Victoria and South Australia and, although we have been unable to verify this independently, several sources (e.g., Ellis et al. 2004) report some 2,000 buildings destroyed in the 1898 Red Tuesday fires in Victoria. Regardless of its ranking in terms of numbers of fatalities and property damage, the extreme impacts in the Black Saturday fires warrant critical examination. This same sentiment led the Victorian State government to form a Royal Commission with wide executive powers to scrutinise all aspects of bushfire management leading up to and during the bushfires (Victorian Bushfire Royal Commission 2009).

The process of adjusting time series of disaster losses for changes in population, wealth and inflation, and, in some cases, improved construction standards, is known as normalisation and has been applied in a wide range of locales for a range of phenomena (e.g., Pielke and Landsea 1998; Pielke et al. 2008; Crompton and McAneney 2008; Zhang et al. 2009; Barredo 2009, 2010; Bouwer 2009, manuscript submitted to *Environ. Res. Lett.*; Vranes and Pielke 2009). Accounting for inflation/deflation is necessary because the value of a currency changes over time while increases in population and wealth means more people and property located in exposed areas.

In respect to Australian bushfire, McAneney et al. (2009) argued that the stability over the last century of exceedance loss statistics for building damage suggested that it was premature to conclude that a signal of greenhouse emissions was present. The authors contend that given these loss statistics had proved so stable in the face of the vast societal changes that took place over the 20th century, then any greenhouse gas signal cannot be large or significant. This study revisits this question using a different approach by explicitly accounting for these societal changes.

Whereas a greenhouse gas driven climate change signal has thus far not been detected in normalised disaster loss records for a wide range of phenomena in locations around the world (see review by Bouwer (2009, manuscript submitted to *Environ. Res. Lett.*) and references therein), and is unlikely to be detected in at least storm and flood losses in the near future (Höppe and Pielke 2006), patterns of behaviour characteristic of meteorologic cycles such as El Niño-Southern Oscillation (ENSO) have been identified in normalised Atlantic hurricane damages (Pielke and Landsea 1999). ENSO and another coupled ocean-atmosphere oscillation, the Indian Ocean Dipole (IOD), are also known to influence the weather and climate of eastern Australia (McBride and Nicholls 1983; Power et al. 2006; Ashok et al. 2003; Cai et al. 2009a); the former oscillation is in the equatorial Pacific Ocean and the latter in the Indian Ocean.

An El Niño (La Niña) phase of the ENSO cycle refers to the situation when sea surface temperatures (SSTs) in the central to eastern Pacific Ocean are significantly warmer (cooler) than the long-term average whereas a positive IOD (pIOD) event is when the eastern Indian Ocean is cooler than normal and the western Indian Ocean is anomalously warmer (Saji et al. 1999). El Niño events increase the chance of drought along eastern Australia (Kiem and

Franks 2004) and bushfire (Williams and Karoly 1999), while La Niña events often presage wide-spread increases in rainfall (Power et al. 2006) and chance of flooding (Kiem et al. 2003). Ummenhofer et al. (2009) showed that a lack of negative IOD (nIOD) events was strongly related to drought in southeast Australia and Cai et al. (2009b) report a link between pIOD events and enhanced bushfire risk over Victoria. Moreover, Cai et al. (2009b) found that pIOD events were more effective than El Niño events in preconditioning Victorian bushfires, a robust result that was not conditional on the definitions adopted for each. This paper will examine the relationships between ENSO and the IOD and normalised bushfire building damage in Australia.

The remainder of this paper is structured as follows: we begin with a description of Risk Frontiers' *PerilAUS* inventory of Australian bushfire building damage and the bushfire fatality database of Haynes et al. (2009, manuscript submitted to *Environ. Sci. & Policy*). The normalisation methodologies, ENSO and IOD definitions and the methodology used to examine patterns of building damage in the Black Saturday fires for two of the most severely impacted towns – Marysville and Kinglake, are then detailed. We then present key results, including those from two historic case studies (the 1967 Hobart fires and the 1983 Ash Wednesday fires) used to 'ground truth' the normalisation methodology. The paper concludes with a discussion of results and some implications for public policy *a propos* bushfire in Australia.

2. Data and methodologies

a. Bushfire building damage and fatality data

The current study draws upon Risk Frontiers' databases of natural disasters in Australia (hereafter referred to as *PerilAUS*). Data entries were derived mainly from archival searches of the *Sydney Gazette* and *Sydney Morning Herald* (dating from 1803 and 1831, respectively) (Coates 1996; Blong 2004). In the case of bushfire and except for some years prior to 1926 where data are incomplete, it provides the best available national record of Australia's loss events. Although the two newspapers are New South Wales (Sydney) based, bushfires in other States or Territories are also well captured from local newspapers and official records. While it is expected that any bushfire that resulted in significant building damage and numbers of fatalities has been already catalogued, the database is constantly being improved. In the course of this study, further events, including a bushfire that destroyed over 450 houses in Victoria in 1962, were identified and added to the record. These additional events and those from more recent bushfire seasons were not included in the McAneney et al. (2009) analysis.

For almost 1,200 events listed in *PerilAUS*, it is possible to estimate the number of buildings destroyed with damaged buildings (residential, public, commercial and industrial, etc.) converted to house equivalents (HE) using relative building costs and floor areas for different types of buildings (Blong 2003). One HE can correspond to the complete destruction of one median-sized house, two such houses each 50% destroyed or, for example, a suburban police station experiencing damage amounting to 47% of its replacement value. McAneney et al. (2009) note that most outcomes from bushfires tend to be binary in nature with buildings either being completely destroyed or surviving relatively unscathed. Damage to building contents, cars, machinery, aircraft, crops, etc. is not included in the HE estimates.

In addition to building damage information, *PerilAUS* also contains details of bushfire-related fatalities including names of the deceased. This information was used by Haynes et al. (2009, manuscript submitted to *Environ. Sci. & Policy*) as the entry point to forensic, witness and police statements contained in coronial inquest reports for each known death from 1901 to 2007/8. An outcome of that study was a database of civilian bushfire fatalities; our study will analyse those entries over a common time horizon with building damage for bushfire years 1925-2008. The definition of 'bushfire years', where 1925 represents the 12-month period beginning July 1 1925, reflects the southern hemisphere bushfire season.

b. Normalising house equivalents (HE)

Normalising bushfire building damage (HE) records to current societal conditions is straight-forward. We simply convert the HE in bushfire year i (HE_i) to bushfire year 2008 numbers (HE_{08}) as follows:

$$HE_{08} = HE_i \times N_{i,j} \tag{1}$$

where j is the State or Territory impacted by the event and $N_{i,j}$ is the dwelling number factor defined as the ratio of the number of dwellings in bushfire year 2008 in State or Territory j to those present in bushfire year i. The number of dwellings in each State or Territory is reported in the Census of Population and Housing and/or Year Books (Australian Bureau of Statistics (ABS) - http://www.abs.gov.au). A dwelling is defined as a structure intended for human habitation, normally a house, flat, caravan, etc., but also includes hotels, prisons, hospitals, etc. that were occupied on Census night. National Censuses were undertaken irregularly until 1961 and at five yearly intervals since. Linear interpolation was used to determine the number of dwellings for years between Census years and the 2007 and 2008 bushfire year numbers were estimated by extrapolating from the 2001 and 2006 figures. Growth in the number of dwellings is assumed as a proxy for growth in HE.

Equation (1) ignores any explicit correction for inflation and wealth as measured in economic terms. The HE representation avoids the need for an inflation adjustment; whether an adjustment for increasing economic wealth is required is less obvious. An argument for its inclusion stems from the manifest increase in the average size of Australian dwellings over time: for example, the average increase in the average number of bedrooms per dwelling between 1976 and 2006 was 0.3% per year (ABS - http://www.abs.gov.au). If this rate of increase held constant over the entire analysis period, then the average dwelling size would have increased by 28% between 1925 and 2008. On the other hand, we expect most of that increase has been implicitly accounted for in the manner by which the HE data was derived: if, by way of example, we imagine a hypothetical bushfire event in which 100 houses were destroyed, then we assume that this equates to 100 HE whether the event occurred in 1930 or 1990. Although Blong (2003) differentiates between small, median and large houses based on floor areas, this level of detail is not often included in the source documents and so, for most building types, numbers of HE were based on a single (median) size of each building type. This being the case, we have chosen not to further adjust the HE data for changes in wealth, however any adjustment of economic losses would also require both an inflation and economic wealth adjustment.

c. Normalising fatalities

Bushfire-related fatalities (F) are normalised in a similar manner to HE under the assumption that fatalities change in proportion to population (Pielke et al. 2003; Vranes and Pielke 2009):

$$F_{08} = F_i \times P_{i,j} \qquad (2)$$

where $P_{i,j}$ is the population factor defined as the ratio of the population in bushfire year 2008 in State or Territory j to the population in bushfire year i. The population in each State or Territory is reported annually in the Australian Historical Population Statistics (ABS - http://www.abs.gov.au). The 2008 bushfire year State and Territory populations were extrapolated from 2007 values using the average population growth rate over the previous five years. Where a bushfire event impacted more than one State or Territory, the database provides a geographical breakdown of fatalities so that the data can be normalised separately and added together to determine the F_{08} numbers. This was similarly the case for the HE data and normalisation of it.

d. Validation of normalisation methodologies

Equations (1) and (2) assume that growth in the exposure – number of bushfire-prone dwellings and population in the areas impacted – occurred at the same rate as the growth in total number of dwellings and population for each State or Territory. Except for a few particular bushfires, data is not available to allow a more precise estimate of growth in exposed areas over time.

We can get some sense of the relative accuracy of this assumption by comparing State/Territory based dwelling number and population event factors with those derived by weighting equivalent local level factors by each local area's proportional contribution to event building damage and fatalities. Urban Centre/Locality (UCL) based factors were calculated for two of the most damaging historical bushfires: 1967 Hobart fires and 1983 Ash Wednesday fires. Although local level growth may not necessarily mirror bushfire-prone dwelling and population growth, this is the best available proxy.

The UCL structure is one of the seven interrelated classification structures of the Australian Standard Geographical Classification that groups Census Collection Districts together to form areas defined according to population size (ABS - http://www.abs.gov.au). In broad terms, an Urban Centre is a population cluster of 1,000 or more people while a Locality comprises a cluster of between 200 and 999 people. The number of dwellings and population in each UCL is reported in Census years in the Census of Population and Housing (ABS - http://www.abs.gov.au).

e. El Niño-Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD)

There exist multiple definitions for the El Niño and La Niña phases of ENSO, based upon either the Southern Oscillation Index (SOI) or various SST-based metrics but these generally concur for the major El Niño and La Niña events. Here we adopt the Japan Meteorological Agency (JMA) index of five-month running mean of spatially-averaged SST anomalies over a region of the tropical Pacific (4°S-4°N, 150°W-90°W). An ENSO year of October through to the following September is then categorised as El Niño (La Niña) if JMA index values are 0.5^{o}C (-0.5^{o}C) or greater (less) for at least six consecutive months (including October, November, December). All other years are classified as Neutral. The JMA index for the post-

1949 period is based on observed data and for the years 1925-1948 upon reconstructed monthly mean SST fields (Meyers et al. 1999).

Similarly IOD events are definition-dependent and we adopt that of Cai et al. (2009b). They define an event using an index of the IOD called the Dipole Mode Index (DMI) (Saji et al. 1999) in spring (September, October, November), referenced to the climatological mean over the period 1880-2008. A pIOD (nIOD) event occurs when the index is greater (less) than 0.75 of its long-term standard deviation. Cai et al. (2009b) focused on the spring season as this is when pIOD events peak and they relate the classification to the following summer season (December, January, February). All other years are classified as Neutral.

The above ENSO and IOD definitions correspond for the worst months for Australian bushfire impacts – December, January and February – with bushfire years defined earlier as 12-month periods starting July 1. Classifications according to the above definitions are given in Table 1 (http://coaps.fsu.edu/jma.shtml). Cai et al. (2009c) noted the recent high frequency of pIOD events with five occurring during 2002-2008.

Insert Table 1 approximately here

f. Post-Black Saturday observations

Risk Frontiers undertook an aerial reconnaissance following the Black Saturday fires for the Kinglake area and Melbourne's north-eastern suburbs that are interfaced with extensive bushland. On-the-ground surveys were not possible at the time (11 February 2009) with access to many of the impacted areas prohibited while police conducted crime scene investigations. Quantitative damage analysis focused on Marysville and Kinglake, the two towns most severely damaged. The main aim was to reveal the spatial pattern of destroyed properties in relation to distance from surrounding bushland boundaries.

A Melbourne-based company, Airtech (http://www.airtechaust.com/), provided 15cm-resolution, geo-referenced post-fire imagery captured on 22 and 24 March 2009. These images were manually interpreted and locations of a total of 1,156 destroyed buildings and other surviving structures digitised. For the distribution and extent of pre-fire bushland, we performed various supervised image classifications with the 2.5m-resolution, ortho-rectified imagery – 2009 SPOTMaps series (http://access.spot.com/). It was possible to reliably evaluate the best classification results given the fine-resolution of imagery employed and the relative small size of the study area. Once the location of buildings and bushland boundaries were known, we then calculated distance-based statistics relevant to land use planning and insurance pricing.

3. Results

a. Case studies

We first test the legitimacy of our assumptions that HE and fatalities have increased in proportion to the State/Territory level increase in the total numbers of dwellings and population. Table 2 shows State based dwelling and population factors (as defined previously) for the 1967 Hobart and 1983 Ash Wednesday bushfires as well as UCL-weighted event factors, calculated by weighting UCL dwelling and population factors by their relative contribution to the total event HE and fatality numbers.

Insert Table 2 approximately here

For the Hobart fires, State dwelling and population factors closely mimic their UCL-weighted equivalents (Table 2). Seven UCLs were used to calculate the weighted dwelling factor with a 60% weight given to the Hobart UCL factor. Only the Hobart UCL was used for the weighted population factor as all 64 fatalities occurred there. The closeness of the State and UCL-weighted factors is not surprising given the size of Hobart compared with the rest of Tasmania – in 2008 the population in the Hobart UCL stood at approximately one quarter of the total for the entire State (ABS - http://www.abs.gov.au). In other words, the State based figures are also highly weighted towards Hobart.

In contrast to the Hobart fires, 12 UCLs were used to calculate the weighted dwelling factor for the Ash Wednesday fires with no one contributing more than 22% of the total building damage. Similarly for the weighted population factor where nine UCLs were used with a weighting of not more than 19% applied to each of the contributing UCL factors. All of the UCLs impacted by this event were small relative to the State in which they're located and the differences are greater than was the case for Hobart with both State level factors underestimating growth in dwellings and population at the local level (Table 2).

Table 3 compares the Hobart and Ash Wednesday UCL-weighted normalised HE and fatalities with the data recorded for these events together with those experienced on Black Saturday. The key observation is that the Black Saturday death toll appears aberrant: after normalising the data, the ratio of fatalities to building damage in the Black Saturday fires is roughly three times that for Hobart and Ash Wednesday. We remind the reader that the normalisation factors are different for HE and fatalities and so the values shown in the final column in Table 3 are not just a simple arithmetic ratio of the recorded data.

The vast majority of event level building damage and fatalities recorded for the Hobart and Ash Wednesday fires were able to be used in the calculation of the UCL-weighted factors. Those locations listed in *PerilAUS* that either were missing data or did not have a corresponding UCL were excluded. Table 2 gives some confidence that while it is possible for State and local level normalisation factors to diverge, the variation does not appear systematic and, if anything, it provides some indication that our assumption may be conservative as State level data may underestimate dwelling growth in exposed areas. It was not possible to derive UCL-weighted factors for the entire analysis period as the UCL structure did not exist prior to the 1966 Census (ABS - http://www.abs.gov.au).

Insert Table 3 approximately here

b. Time series of building damage and fatalities

Figures 1(a) and 2(a) show time series of the annual aggregated bushfire HE and fatalities recorded in *PerilAUS* and the Haynes et al. (2009, manuscript submitted to *Environ. Sci. & Policy*) database for bushfire years 1925-2008; Figures 1(b) and 2(b) present the corresponding normalised values. Regression analysis on the recorded data reveals very slight increasing trends (Figures 1(a) and 2(a)), albeit marginal in the case of Figure 2(a), trends that are reversed in the normalised data (Figures 1(b) and 2(b)). None of these trends are statistically significant at the 10% level and the overriding impression is of a time series dominated by occasional extreme excursions from the mean.

The average annual normalised HE over all years is 296 (Table 4), while the equivalent figure for fatalities is 14. The former is some 3.5 times that determined by McAneney et al. (2009), a difference that arises primarily from normalising the data. Other factors to influence this difference are: (1) the inclusion of other events that had not been previously identified; (2) extending the analysis period to include Black Saturday and (3) beginning the analysis in 1925 rather than in 1900 – the years between 1900 and 1926 for which data exists being characterised by low levels of building damage, although we remind the reader of the very destructive event (~ 2000 buildings) thought to have occurred in 1898 (Ellis et al. 2004).

The seemingly anomalous loss of life in the Black Saturday fires and 2008 bushfire year is subject to further scrutiny in Figure 3, which shows the ratio of annual aggregate normalised fatalities (Equation (2)) to normalised HE (Equation (1)) for those bushfire years when the normalised HE is greater than 600. Adoption of a 600 HE threshold, which conveniently reduces the data to the 10 most damaging years, is simply to eliminate those years where there was little or no building damage and/or few or no fatalities. The generally decreasing pattern in Figure 3 over time is broadly insensitive to the threshold of building damage adopted: a very similar pattern is revealed if a threshold of 100 HE is applied. Of the 10 most damaging years, not since the beginning of the analysis period, the 1925 bushfire year, has there been a higher ratio of normalised fatalities to building damage (Figure 3) than in the 2008 bushfire year. The ratio of total normalised fatalities to HE over the entire analysis period is 4.7%.

Insert Figures 1, 2 and 3 approximately here

c. ENSO and IOD relationship with normalised bushfire building damage

Table 4 shows the median, average and standard deviation (of normalised HE) over the 84-year study period for ENSO and IOD classified years. There are distinct differences in the median annual and average annual normalised HE for El Niño and La Niña years as there is for pIOD and nIOD years. As expected, the average building damage is highest in El Niño and pIOD years and the median damage in La Niña and nIOD years is zero. The distribution of damage over all years is highly skewed.

The relationship between ENSO and bushfire building damage is reasonably robust though the strength of the relationship is weakened if an alternative SOI based definition is applied (Table 4). Under the SOI definition, an El Niño (La Niña) year occurs when the average of June to December monthly SOI values is less (greater) than -5 (5) (S. Power 2009, personal communication). The difference between the average building damage in El Niño and La Niña years is reduced under the SOI definition but the median in La Niña years is still zero.

It is important to note the statistics in Tables 4 and 5 are sensitive to building damage in the most destructive of bushfire years. The 10 most damaging years in terms of normalised HE account for almost 80% of total normalised damage and the ENSO classification of only one of these bushfire years (2008 – the fourth largest) differs between the two ENSO definitions: using the SST definition, the 2008 bushfire year is classified as Neutral (Table 1) whereas under the SOI definition, it is categorised as La Niña.

Insert Table 4 approximately here

Tables 4 and 5 suggest that the IOD is more discriminating than ENSO in relation to normalised bushfire building damage in Australia (the SST definition of ENSO was used in Table 5). The two most damaging combined phases are pIOD/El Niño and pIOD/Neutral, which together comprise17 of the 84 bushfire years in the study period (Table 5). The 1938 bushfire year (La Niña year, Neutral IOD year) is the only example where extreme building damage (normalised HE > 1000) occurred in either a La Niña or nIOD year.

Insert Table 5 approximately here

As pointed out earlier, bushfire years (beginning 1 July), ENSO years (beginning 1 October) and IOD years (relating to the summer season) do not completely overlap. The effect of this difference is negligible as less than 0.2% of the total normalised HE 'occurred' in the months July 1 to September 30 inclusive and almost 95% of the total normalised building damage 'occurred' during summer (December, January, February).

d. Post-Black Saturday analysis – Kinglake and Marysville

Destroyed buildings in Kinglake and Marysville were categorised as a function of distance from bushland boundaries; this data is presented in Figure 4 along with other comparable data from Chen and McAneney (2004). The patterns of damage vary widely between bushfires but a key feature of the Kinglake and Marysville experience is that about 25% of destroyed buildings were located physically within the bushland boundary, and 60% and 90% within 10m and 100m of bushland (Figure 4). Most buildings in Marysville lay within 200m of the bushland boundary and, given the wind change that occurred early evening on 7 February 2009, would have been subject to ember attack from multiple directions (Victorian Bushfire Royal Commission 2009).

Insert Figure 4 approximately here

4. Discussion

In assuming bushfire-related building damage and fatalities change in proportion to dwelling numbers and population, Equations (1) and (2) estimate the number of HE and fatalities in a given event had it occurred under 2008 bushfire year societal conditions. There are other factors not accounted for in the normalisation methodologies, though we expect their influence, particularly on the building damage record, to be minimal relative to societal change. For example, it is likely that some historical bushfires occurred in what were formerly unpopulated areas and thus would have registered no building damage, whereas in these same areas large losses may now be possible. The opposite is also true where original bushlands have been converted to suburbs so that some historical bushfire impacts may now be physically impossible.

Haynes et al. (2009, manuscript submitted to *Environ. Sci. & Policy*) suggest a reduction, over time, in the number of people living and working in isolated rural locations influenced the fatality data. The effect of this shift was evident in the decreased number of fatalities due to late evacuation, the most common activity at time of death (Haynes et al. 2009, manuscript submitted to *Environ. Sci. & Policy*). More specifically, Haynes et al. (2009, manuscript submitted to *Environ. Sci. & Policy*) found a marked decline in those who died while evacuating from working outside and they concluded that this in part explained the absence of a trend in the fatality data (prior to the Black Saturday fires) despite there being considerable population growth. Notwithstanding these and other qualifications, Figures 1(b) and 2(b) show our best estimates of normalised bushfire building damage and fatalities.

Is the normalised building damage realistic? The average nominal value of a new house (excluding land) in Australia in the 2008 bushfire year was approximately AUD$260,000 (ABS - http://www.abs.gov.au) so that in dollar loss terms, the average annual building damage of 296 HE (Table 4) equates to AUD$77 million. As noted earlier this amount excludes building contents and cars, etc. so will underestimate the property loss, but it does include both insured and uninsured building damage. From an independent data set, but using a conceptually similar normalisation methodology, Crompton and McAneney (2008) found the average annual insured property loss from weather-related natural disasters between 1967 and 2006 to be around AUD$820 million (in 2006 dollars) of which about 12% or AUD$98 million can be attributed to bushfire. Despite the stated differences the closeness of these two independent estimates provides some confidence in the methodology and results. The relationship between normalised building damage and ENSO and the IOD provides additional confidence.

Similar to the result of Cai et al. (2009b) we found normalised Australian bushfire building damage to be more strongly related to the IOD than to ENSO. This is unsurprising as Cai et al. (2009b) follow the Ellis et al. (2004) definition of a significant bushfire and this incorporates historical impacts (fatalities, property and livestock losses) rather than meteorological variables or indices. The significant Victorian summer bushfire seasons that the Cai et al. (2009b) study is based on are therefore correlated with years of high normalised Australian building damage at least over the common time period, since 1950.

The Black Saturday fires rank fourth in terms of normalised building damage. There were 173 fatalities, more than double the recorded number in any other bushfire event over the analysis period. After normalisation, the Black Saturday death toll ranks second to the 1939 Black Friday fires with 214 normalised ‘fatalities’. In other words, history suggests that larger impacts are possible even under the climate of past decades. However, this should not detract from the extreme impacts and high ratio of normalised fatalities to building damage in the Black Saturday fires and the need for changes to address this. The 2008 bushfire year is especially abnormal in the context of recent years.

One unequivocal result from our analyses is the absence of any significant trend in normalised HE over time (Figure 1(b)). This being the case, a reasonable conclusion at this time, consistent with similar studies summarised by Bouwer (2009, manuscript submitted to *Environ. Res. Lett.*), is that it is not possible to detect a greenhouse gas climate change signal in Australian bushfire building damage once it has been normalised. While such an influence is not ruled out by our analysis, if it exists, it is clearly dwarfed by the magnitude of the societal change and the large year-to-year variation in impacts. Moreover it seems highly implausible that the net effect of other factors such as changes in bushfire risk management is being exactly balanced by a greenhouse gas driven climate change influence.

5. Policy implications

This study has shown that increasing building damage due to bushfire in Australia is largely being driven by increasing dwelling numbers. With this in mind, to reduce the impact of future bushfire events, investments to reduce societal vulnerability through more sensible land use planning policies, especially in relation to the distance of buildings from bushland, need to be made and are likely to bring immediate benefit. Adaptation should be undertaken concurrently with mitigation so that success in addressing bushfire risk in Australia in the short-term at least is not misunderstood in terms of obtaining global agreement on reduction of greenhouse gas emissions.

The Black Saturday tragedy occurred in the face of significant investments (Ashe et al. 2009) and improvements in bushfire risk management and suppression. We take the view that the extreme impacts are in part related to the close proximity of many dwellings to bushland and a misinterpretation of policy if people in those dwellings believed their homes were defendable under the extreme conditions. Chen and McAneney (2004) showed that although distance to bushland is not the only variable determining bushfire vulnerability it is demonstrably the most important with the probability of home destruction decreasing strongly as a function of this distance, a result interpreted as being indicative of ember density and flammability. In the towns of Kinglake and Marysville that experienced the majority of building damage in the Black Saturday fires, we have shown that 25% of destroyed buildings were literally located within bushland and 60% within 10m of the bushland boundary.

The “prepare, stay and defend, or go early” Australian bushfire policy arose on the basis of concerns about the likelihood of large losses of life occasioned by late evacuation (Handmer and Tibbits 2005; Haynes et al. 2009, manuscript submitted to *Environ. Sci. & Policy*) and the impracticability of evacuating large numbers of people every time severe bushfire conditions exist, circumstances that might arise in some years and some parts of the country for much of the summer. The policy puts the actions of residents as central in the protection of lives and property and has the commendable attribute of discouraging an unwarranted dependence upon emergency services. On the other hand, an incorrect interpretation of this policy during Black Saturday may have contributed to the large death toll if this encouraged people in the belief that their homes, in many cases constructed within the bushland itself, could be successfully defended against the bushfires.

Under the extreme conditions prevailing on Black Saturday, it is difficult to imagine that homes in the flame zone could have been successfully defended against the combined threats of flames, radiant (and perhaps convective) heating and embers. This raises serious questions about land use planning in this country in relation to bushfire risk. The comparison of State and UCL level normalisation factors (Table 2) is cause for further concern as it suggests dwelling growth in areas of high bushfire risk may be occurring faster than State averages. We echo the sentiments of McAneney et al. (2009) that without changes in policy, particularly in land use planning, further bushfire catastrophes are inevitable.

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FIGURES

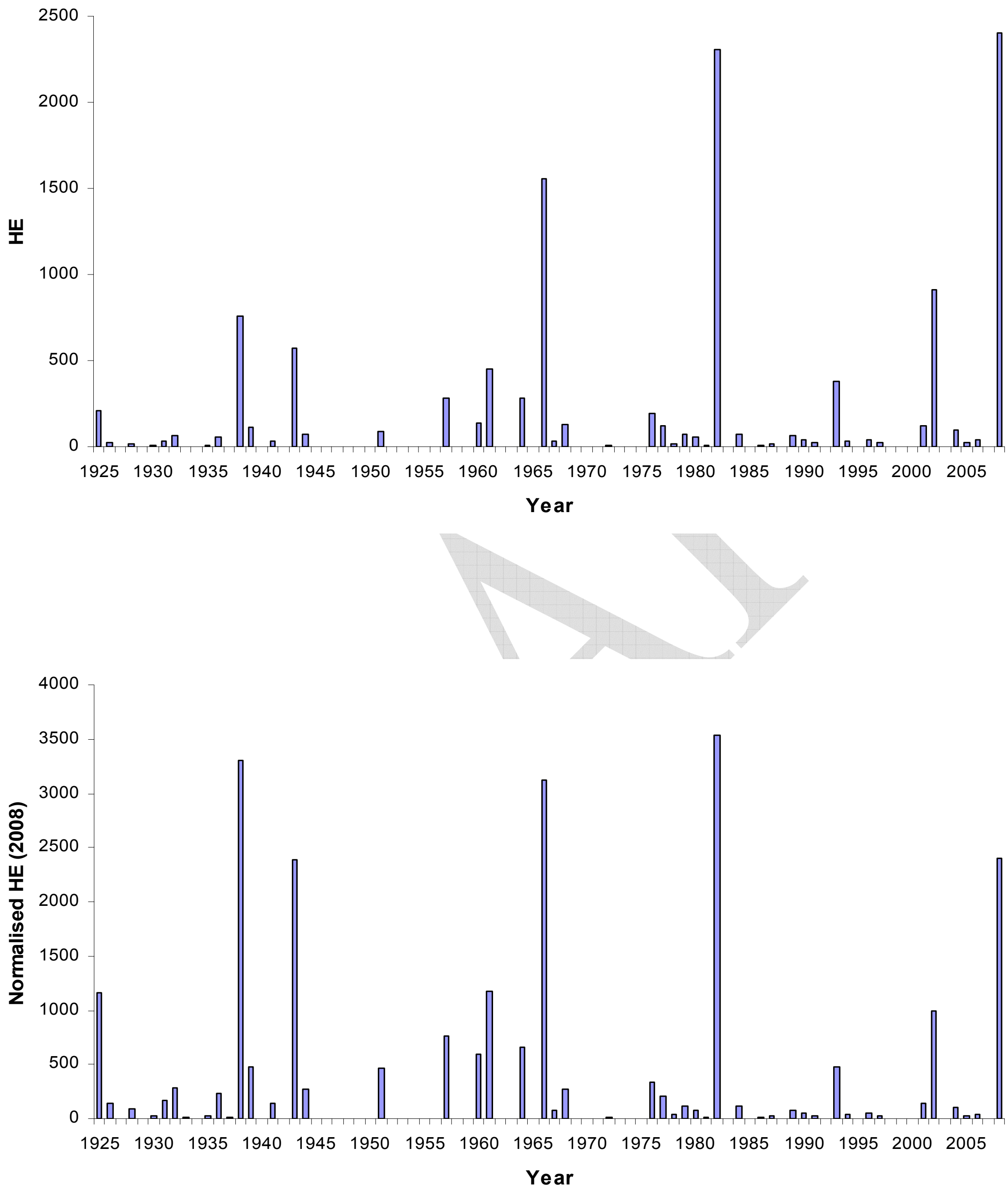
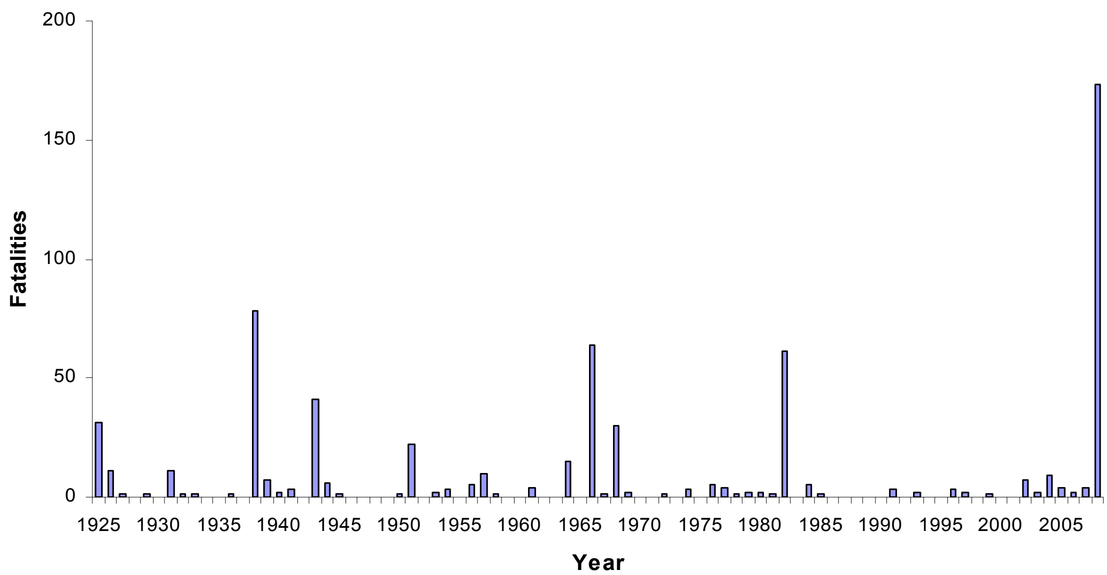


Figure 1: (a) Annual aggregate HE for bushfire events in *PerilAUS* for years beginning 1 July, and; (b) as for (a) but with HE normalised to 2008 bushfire year values.



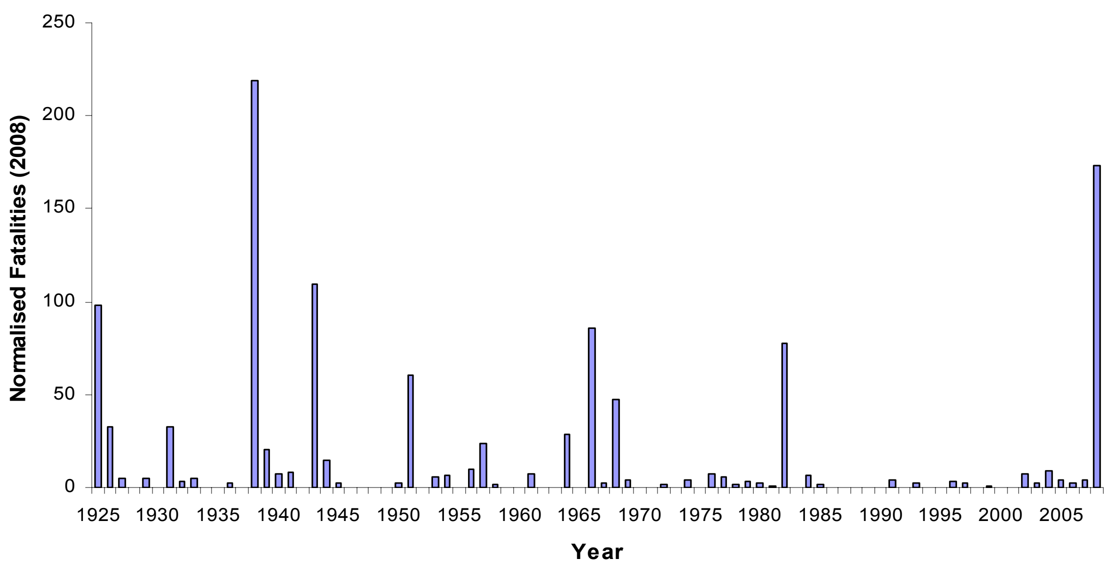


Figure 2: (a) Annual aggregate fatalities for bushfire events in the Haynes et al. (2009, manuscript submitted to *Environ. Sci. & Policy*) database for years beginning 1 July, and; (b) as for (a) but with fatalities normalised to 2008 bushfire year values.

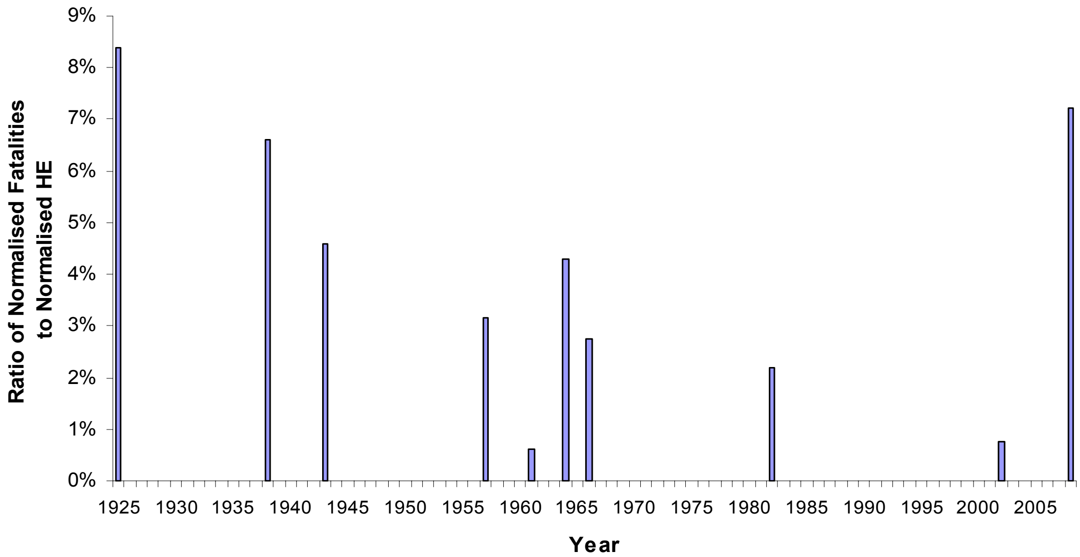


Figure 3: Ratio of annual aggregate normalised fatalities (Equation 2) to HE (Equation 1) for years (beginning 1 July) when normalised building damage exceeded 600 HE.

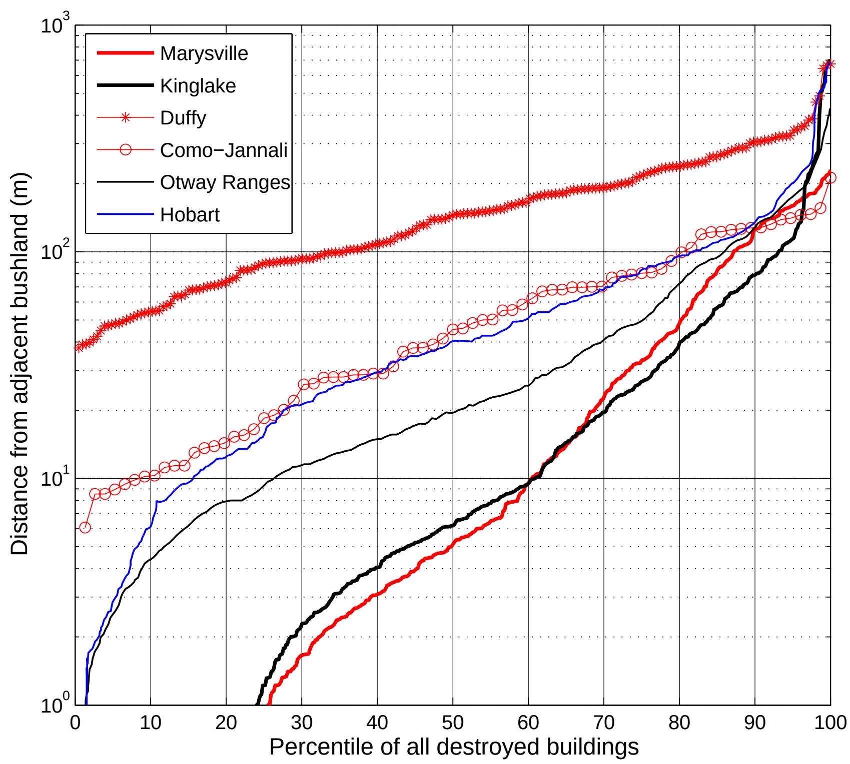


Figure 4: Cumulative distribution of buildings destroyed in major bushfires in Australia in relation to distance from nearby bushland. The number of samples for Marysville, Kinglake, Duffy and Como-Jannali is 540, 616, 206 and 76, respectively. The Otway Ranges curve (648 samples) from the 1983 Ash Wednesday fires and the Hobart curve (370 samples) from the 1967 Hobart fires reported by Ahern and Chladil (1999) are also shown.

TABLES

Table 1: Bushfire years (1925-2008) identified as either: El Niño or La Niña (ENSO), and pIOD or nIOD (IOD). Other years are classified as Neutral for each oscillation.

		Years
ENSO	El Niño	1925, 1929, 1930, 1940, 1951, 1957, 1963, 1965, 1969, 1972, 1976, 1982, 1986, 1987, 1991, 1997, 2002, 2006
	La Niña	1938, 1942, 1944, 1949, 1954, 1955, 1956, 1964, 1967, 1970, 1971, 1973, 1974, 1975, 1988, 1998, 1999, 2007
IOD	pIOD	1925, 1941, 1946, 1951, 1961, 1963, 1967, 1972, 1977, 1982, 1987, 1991, 1994, 1997, 2002, 2004, 2006, 2007, 2008
	nIOD	1933, 1942, 1947, 1954, 1956, 1958, 1959, 1960, 1964, 1974, 1975, 1996

Table 2: State and UCL-weighted dwelling and population normalisation factors for the 2008 bushfire year.

Bushfire	State Dwelling Factor	UCL-Weighted Dwelling Factor	State Population Factor	UCL-Weighted Population Factor
Hobart 1967	2.0	2.1	1.3	1.1
Ash Wednesday 1983	1.5	1.8	1.3	1.9

Table 3: Recorded and UCL-weighted normalised HE and fatalities in the 1967 Hobart, 1983 Ash Wednesday and 2009 Black Saturday fires.

Bushfire	HE	Fatalities	Normalised HE	Normalised Fatalities	Ratio of Normalised Fatalities to Normalised HE
Hobart 1967	1557	64	3196	70	2.2%
Ash Wednesday 1983	2253	58	3958	110	2.8%
Black Saturday 2009	2400	173	2400	173	7.2%

Table 4: Summary statistics by ENSO and IOD phase for annual aggregate normalised building damage for bushfire years 1925-2008. Numbers in brackets were derived using the SOI definition of ENSO.

		Median Annual Normalised HE	Average Annual Normalised HE	Standard Deviation of Annual Normalised HE
ENSO	El Niño	29 (37)	414 (378)	864 (823)
	Neutral	38 (33)	272 (252)	657 (606)
	La Niña	0 (0)	240 (306)	783 (871)
IOD	pIOD	77	550	959
	Neutral	10	247	690
	nIOD	0	110	244
All Years		20	296	726

Table 5: Average annual normalised HE by ENSO (SST definition) and IOD phase for bushfire years 1925-2008. Numbers in brackets are the number of years the average is based on.

		IOD		
		pIOD	Neutral	nIOD
ENSO	El Niño	631 (10)	142 (8)	N/A (0)
	Neutral	581 (7)	239 (35)	110 (6)
	La Niña	39 (2)	358 (10)	110 (6)