COSTS AND BENEFITS OF TROPICAL CYCLONES, SEVERE THUNDERSTORMS AND BUSHFIRES IN AUSTRALIA

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Abstract. The historical frequency, distribution and impact of tropical cyclones, severe thunderstorms and bushfires in Australia are discussed. Although the climatological record of frequency and distribution is incomplete for some hazards, this information is more reliable than that available on the impacts of the hazards. Insurance payout costs form the best quantitative measure of negative impacts, but such figures represent only a fraction of the true costs of damage from severe weather. For tropical cyclones the insurance payout since 1967 has been $1715 million, for severe thunderstorms $1808 million and for bushfires $488 million. Tropical cyclones and storms each result in the loss of 4 to 6 lives each year, while bushfires have an average annual death toll of about 10. Although significant benefits arising from severe weather events can also be identified, quantitative estimates of their alue are not available.

1. Introduction

This paper discusses the historical frequency, distribution and impact of some severe weather hazards in Australia. Any discussion of climate change, as it affects severe weather and its impact, must start from such knowledge of the past climate and its effects. However, even given this information, the extrapolation to a changed severe weather frequency or intensity and consequent impact is not straightforward. This is because existing knowledge about severe weather climatology and about the nexus between weather and its impacts are, for most phenomena, inadequate. The discussion here concentrates on climatology and known impacts, without exploring the relationship between the two, and is limited to the phenomena which are grouped together in the Bureau of Meteorology's (BoM) Severe Weather Warning Services Program, namely:

- tropical cyclones;
- bushfires; and
- severe thunderstorms.

The effects of global climate change on the distributions, frequencies and intensities of these three phenomena are not known. Although most climate models now agree on increased average global air and sea surface temperatures as a result of doubling the atmospheric concentration of CO_2, the corresponding impacts on extreme weather events pose an even more complex prediction problem. Under the double CO_2 scenario Australia could expect average temperatures to increase, with the change being greatest in the south. This scenario also suggests that rainfall would increase in the summer rain areas, but decrease in the southwest (CSIRO,

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1990). Some international models (Emanuel, 1987) have suggested increased hurricane intensities as a result of higher sea surface temperatures. In the Australian region, however, interannual variations in tropical cyclone activity are dominated by Southern Oscillation (SO) effects (Holland *et al.*, 1988). Uncertainty of SO predictions under climate change scenarios means that no meaningful predictions of cyclone behaviour are possible in the region. Nevertheless, one possible impact stems from the expected rise in sea level due to global warming: given a one metre rise in sea level, the possibility of major storm surges from tropical cyclones rises by a factor of 4 at Darwin and a factor of 13 at other locations along the northern Australian coast. Combined with the possibility of more intense and frequent cyclones, rising sea level could mean that the return periods for major storm surges at some locations along the Western Australian coast fall from tens of thousands to hundreds of years (Love, 1988).

Increased surface temperatures should allow the air to hold greater absolute volumes of water vapour, intensifying global rainfall, but an increase in average rainfall does not necessarily mean a greater frequency of high intensity events, such as flash floods from thunderstorms. Yu and Neil (1991) have shown that high rainfall intensities have occurred in southeastern Australia during a period of low to average rainfall and low temperature, and they point out that it is likely that the prerequisites for extreme events are not controlled by average climatic conditions. Beer *et al.* (1988) have investigated the effect of increased summer temperatures, rainfall and wind speeds on forest fire danger, and found an overall increase. However, relative humidity (RH), which strongly influences the fire danger index used, was assumed to be constant because of the lack of reliable estimates of RH change.

As part of an on-going upgrading of warning services, the BoM is improving its procedures for archiving information about severe weather events. In the past, emphasis has been given to recording meteorological data about the state of the atmosphere, but information on the impact of severe weather is patchy and unreliable. In some cases even climatological statistics such as the frequency and distribution of severe weather phenomena are not reliably known, making analysis of their impacts even more difficult.

The information needed to detect severe weather events and assess their impact comes from many varied sources. The conventional archive of meteorological data which is maintained by the BoM is very reliable, but does not include information on weather-caused damage or injury and often does not even include the severe weather event as such (until recently severe thunderstorms were not recorded in any nationally consistent way and bushfire events are not recorded at all by the BoM). Newspapers and insurance companies are the most important sources of event and impact information, but the available compilations are incomplete and have not been exhaustively checked. Organisations such as the State and Territory Emergency Services, Police and bushfire authorities also maintain some records which have been utilised here.

In the following discussion the frequency and distribution of each of the three hazards are presented (as far as they are known) and some measures of the costs of each are described. Our knowledge of the costs of severe weather is far from complete, but the benefits which result from these events have undergone even less analysis and so cannot be quantified here. The discussion of benefits is therefore brief and purely descriptive.

2. Historical Costs of Severe Weather

2.1. *Tropical Cyclones*

The tropical cyclone is defined in Australia as a non-frontal cyclone of synoptic scale (200 to 2000 km) developing over tropical waters and having a definite organised circulation with average wind of 63 km/h (gale force) or more surrounding the centre. The weakest tropical cyclones thus do not reach hurricane force (118 km/h). Of the three weather phenomena discussed here, tropical cyclones enjoy the most reliable archive, at least since the advent of weather satellites. Although a considerable effort (Lourensz, 1981) has gone into verifying records of cyclones from about 1909 onwards, it is only since the 1959–60 cyclone season, when satellite pictures first became available, that we can be reasonably sure that all cyclones are detected and tracked.

The Australian region is defined for the purposes of tropical cyclone records as that area from longitude 105 East to 165 East, southward from latitude 5 South to 32 South on the east coast and to 36 South in the west. The region is broken into western, northern and eastern areas, each of which is served by a Tropical Cyclone Warning Centre: at Perth, Darwin and Brisbane, respectively. Figure 1 shows a map

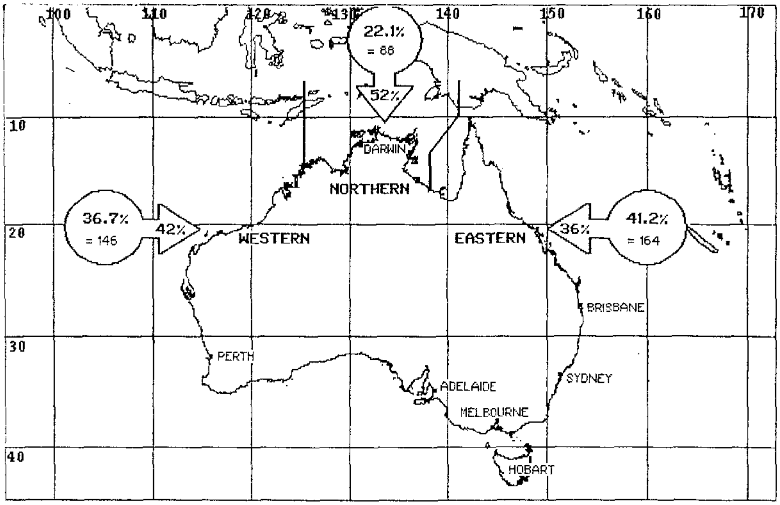


Fig. 1. Tropical cyclone occurrences in the Australian region from 1959–90, broken up by warning area (the percentage within each circle). The percentage of landfalling cyclones within each area is shown inside the point of each arrow.

of the region and the percentage of all cyclones during 1959–89 which have occurred in each of the warning areas. The figure also shows within each area the fraction of cyclones which made landfall on the Australian continent.

The tropical coast is, naturally, most affected by cyclones and this climatological fact is reflected in building codes and engineering design. However, as Figure 2 shows, individual cyclones do follow tracks which are farther south than the norm and which bring them into contact with the more populous southern parts of the continent. Figure 3 gives a more quantitative view of the cyclone climatology, showing that the maxima in cyclone occurrence are off the northwest coast of the continent and in the Coral Sea. Growth in population and industry along the tropical coast is already increasing Australia's vulnerability to cyclones. If one of the results of global warming were to be an increase in cyclone frequency, or a southward shift of the frequency maxima the risk would obviously increase much further, although the southern part of the east coast would still be protected to some extent by the normal westerly steering flow which directs cyclones away from the coast.

Cyclone frequency in the region has shown considerable variability over the short period of reliable record, from a minimum of 5 cyclones in 1988–89 to a maximum of 19 in 1963–4, as Figure 4 shows. No trend is apparent in the annual frequency. It should be noted that some doubt exists about the record of the 1963–4 season, which may overestimate the number of cyclones in that year (Solow and Nicholls, 1990). It is interesting to compare the variations in cyclone frequency displayed

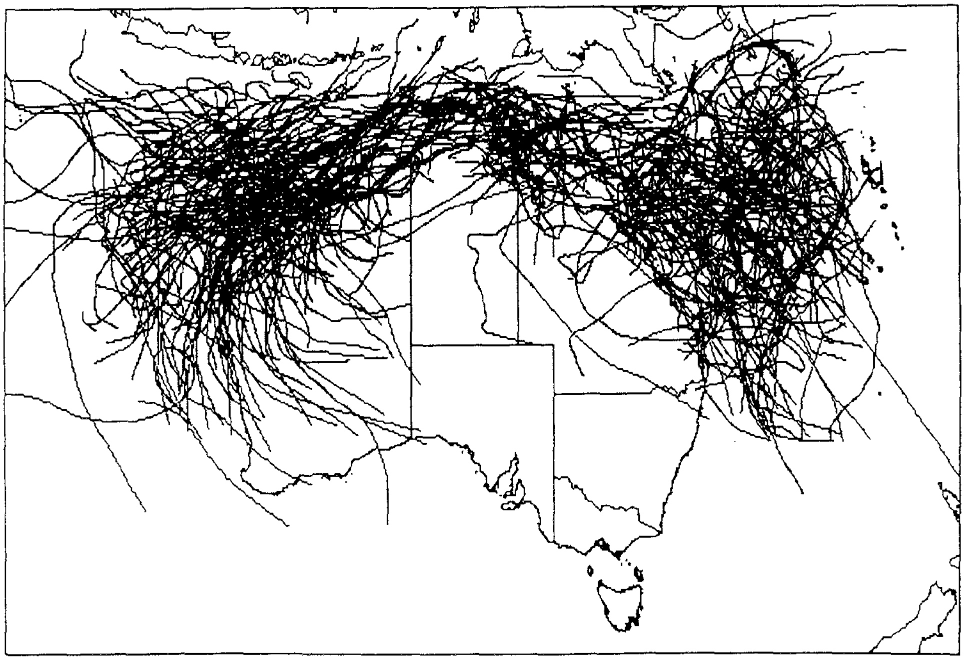


Fig. 2. Tracks of all tropical cyclones detected in the australian region from 1959 to 1989.

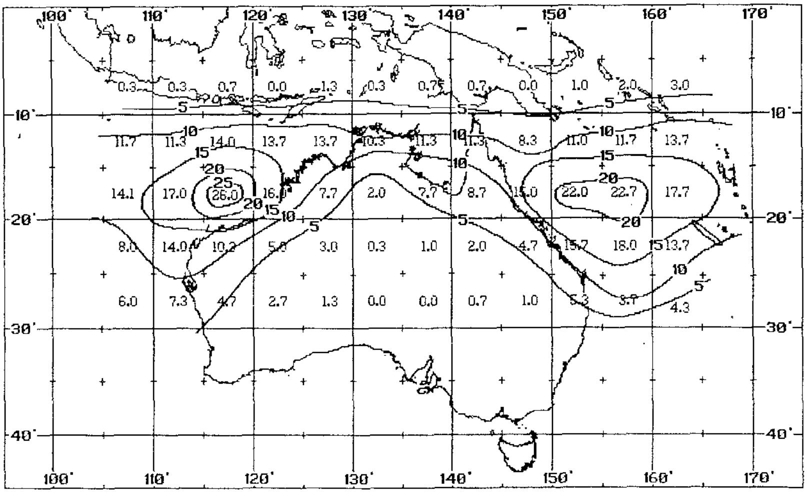


Fig. 3. Average decadal incidence of tropical cyclones in 5 degree latitude/longitude squares from July 1959 to June 1989.

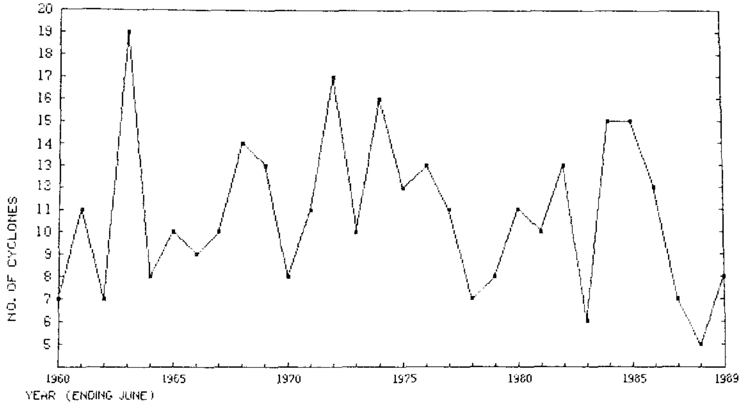


Fig. 4. Yearly occurrences of tropical cyclones from July 1959 to June 1989 for the Australian region.

in Figure 4 with the record of the costs of cyclones over the same period. In Figure 5 the insurance costs of tropical cyclones in Australia since 1967, as compiled by the Insurance Council of Australia (ICA) are shown. It should be noted that this compilation includes only those events defined by the ICA as 'major disasters' (insurance payout of $2 million or more) and that the allocation of costs to particular hazards is open to subjective judgement, e.g. 'flood' or 'tropical cyclone'. Further, the compilation ignores costs other than insurance payouts, and its completeness is dependent upon the reporting to the ICA by individual insurance companies. Bearing these caveats in mind, it can be seen that a single cyclone (Tracy) dominates the damage record, not because it was a uniquely intense system, but because it happened to strike a city. It is obvious that the relationship between

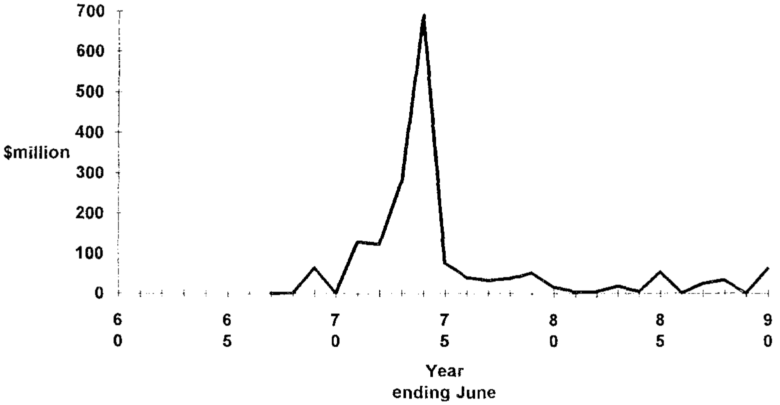


Fig. 5. Yearly insurance costs (1991 Australian dollars) of tropical cyclones from July 1967 to March 1991 (from Insurance Council of Australia figures).

cyclone frequency and damage cost is far from being linear or simple, so that predictions of the impact of climate change would be extremely difficult even if the degree of change were known precisely in terms of cyclone frequency.

Of course, deaths and injuries are also part of the costs of tropical cyclones. The number of people who die because of cyclone winds and floods has been decreasing unsteadily since the beginning of the century as warning systems become more efficient. Table I shows the number of deaths which have been recorded in each decade since the beginning of records. It is possible that this trend could cease or even be reversed as the population of the tropical coasts increases rapidly. Similarly, an increase in cyclone frequency or intensity would almost certainly result in more frequent deaths.

Tropical cyclones bring benefits as well as costs, mainly in the form of essential rain for inland parts of northern Australia. In Western Australia, for example, it has been calculated (Milton, 1978) that from the coast to about 300 kilometres inland, northwards from latitude 25 South, between 30 and 50% of the total rainfall comes from tropical cyclones. Unfortunately, the value of such benefits is virtually impossible to estimate. Suffice it to say that the continuation of agriculture of all types in the inland of the northern half of Australia depends on rainfall produced by decaying tropical cyclones.

2.2. *Bushfires*

The term bushfire is used in Australia to refer to any rural fire burning out of control in the open. Bushfires have perhaps the most complex climatology of the three phenomena discussed here, mainly because of the influence of human activities. The complexity also arises because the frequency and distribution of bushfires are functions of the interactions between plant growth, seasonal-scale weather trends (droughts, etc.) and short-term small-scale weather phenomena such as cold fronts

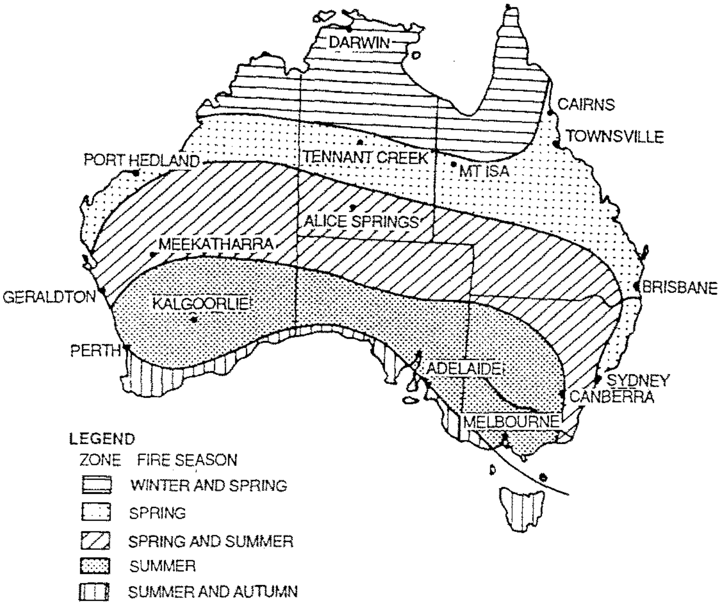
TABLE I: Deaths from tropical cyclones in Australia from 1830 to 1989

Decade	Number of Deaths
1830–39	12
1840–49	0
1850–59	0
1860–69	0
1870–79	59
1880–89	140
1890–99	446
1900–09	68
1910–19	395
1920–29	20
1930–39	256
1940–49	26
1950–59	47
1960–69	6
1970–79	109
1980–89	0
Total	1593
Annual average since 1960	4.1

and thunderstorms. It should not be surprising that bushfire climatology exhibits more variability across the continent than do cyclones or severe storms. Figure 6 illustrates this point by showing the pattern of seasonal fire occurrence.

Human society affects bushfire frequency, distribution and intensity through a number of different activities, including fire suppression, fuel reduction burning, deliberate and accidental ignition and cultivation of different plant species. Separation of the natural factors from human ones is necessary to assess the impact of any climate change, but is an extremely difficult task. Considering just one important aspect of bushfire climatology, source of ignition, the relative frequency of natural and human sources can be seen in Figure 7 to vary enormously amongst the States. Nationally, the average number of wildfires annually is not precisely known, but has been estimated (Bureau of Meteorology, 1986) at about 1800, with the total area burnt being in excess of 750,000 ha each year.

Uncertainties abond, again, in measuring the impact of bushfires. Although the number of lives lost to fires in Victoria (Table II) is unambiguous, the national toll is less certain and has been estimated (Bureau of Meteorology, 1986) to average between 8 and 10 deaths annually. Estimates of economic cost are confused by widely varying land and crop values. The Bureau of Meteorology (1986) presents average annual costs of bushfires in New South Wales for the period 1980–83. Extrapolating these figures to the whole country and converting to 1991 dollars allows an approximate cost to be allocated to fires ignited by various sources (Figure 8).



MONTH OF THE FIRE SEASON

	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
▤	N	N	N	N	O	O	O	–	–	–	O	O
⬚	–	O	N	N	N	N	O	O	–	–	–	–
▨	–	–	O	N	N	N	N	O	O	–	–	–
▩	–	–	–	–	O	N	N	N	O	O	–	–
▥	–	–	–	–	–	O	N	N	N	O	O	–

N = Normal months when serious fires are likely to occur
– = Months when fire occurrence is unlikely.
O = Occasional months when serious fires are likely to occur.

Fig. 6. The pattern of seasonal fire occurrence in Australia, from Luke and McArthur (1978).

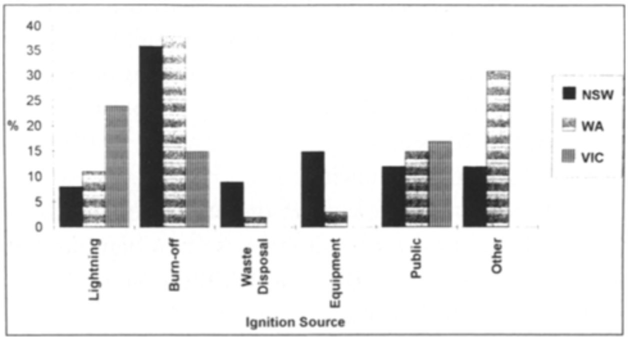


Fig. 7. Percentage of all wildfires in New South Wales, Western Australia and Victoria ignited by various sources. 'Burn-off' includes escaped prescribed burns and re-ignition of controlled fires; 'Public' includes fires started by escaped campfires, dropped cigarettes and arson.

TABLE II: Lives lost in Victorian bushfires 1938–1983, from Bureau of Meteorology (1986)

Year	Lives Lost
1938–39	71
1943–44	51
1951–52	7
1953–54	1
1954–55	1
1956–57	4
1957–58	1
1958–59	1
1961–62	12
1964–65	12
1968–69	23
1975–76	3
1976–77	5
1979–80	1
1981–82	4
1982–83	49
Total	246
Annual average since 1960	4.5

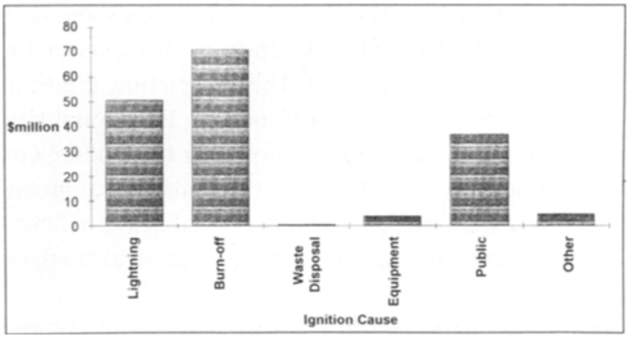


Fig. 8. Estimated national annual cost of fires ignited by various sources (1991 Australian dollars). Ignition categories are as Figure 7.

A comparison of this estimate with the ICA figures for 1967 to 1991 reflects the fact that much of the land burnt by bushfires is uninsured. The annual average insurance cost due to fires for this period is $19.5 million, which is only 12% of the total cost represented by Figure 8.

As is the case with tropical cyclones, bushfires are known to have beneficial effects, but their value is unknown. Many native plant species have evolved in the presence of regular fires, so that seeds will not germinate unless heated by a fire of the appropriate intensity. Regular low-intensity fires have the effect of clearing out undergrowth and debris which would otherwise build up over years and then act as fuel for a disastrous high-intensity fire.

2.3. *Severe Thunderstorms*

In 1990 the BoM adopted, for the first time, a definition of severe thunderstorms, as part of a plan for upgrading its warning service. The definition is similar to that used in the U.S.A. and states that a severe thunderstorm is one which produces:

- tornado(es);
- wind gusts of 90 km/h or greater at the ground;
- hail of 2 cm diameter or greater at the ground; or
- flash floods.

Flash floods were defined as resulting from rainfalls exceeding the 1 in 10 year 1 hour fall.

As part of the upgrading, existing records of severe thunderstorms were collected into a database and tested against the new definition. Because most events had been recorded in terms of damage and injury, rather than in terms of meteorological parameters, it was not possible to confirm objectively the severity of most of the archived storms. Over the last 2 years, officers of the BoM in each of the States have attempted to improve the quality of the database, by checking existing records and by seeking out evidence of other events. The database has grown considerably in the process, but the statistics presented here form a preliminary analysis only. There can still be no doubt that only a fraction of the severe storms which have occurred in Australia have been recorded. The most telling hindrance to the storm archive has been the low population density outside the capital cities, so that conclusions about storm frequency and distribution over most of the continent must be treated with great caution. Bearing the imperfections of the archive in mind, the most reliable analysis is that confined to the capital cities, where the population density is, and has been, great enough to ensure that all storms are observed, even if not officially recorded.

The recent frequency of severe thunderstorms in each of the capital cities is summarised in Figure 9, which shows the number of storms recorded in the 32 year period 1960 to 1991. The breakup of storms into the different severe phenomena is also shown. It should be noted that the local characteristics of buildings, roads, drainage, etc. in the cities can affect the recorded frequency of storms, because it is the level of damage which generally decides the classification of a storm. For example, in Darwin where most buildings are relatively new and are built to withstand tropical cyclones, there would almost certainly be fewer instances of damage than in Brisbane for the same storm intensity, and so possibly a different assessment of storm severity. Because the recent development of the severe storm archive has been carried out in the various Regional Offices of the BoM and is not complete, the record for some cities is better than for others. Thus Figure 9 is dominated by the Melbourne database which has benefitted from an intensive newspaper search and is probably the closest to being a complete record. For this reason comparisons between cities could be misleading.

A change in the relative frequencies of severe and non-severe thunderstorms is a climatological factor which would have an obvious impact should it change. A sample of 10 years was used to derive Figure 10, which shows the relative frequencies for the capital cities. Again, the differences between cities are quite large, suggesting that any assessment of the impact of climate change should avoid using national averages.

The cost of these recorded storms is portrayed, imperfectly of course, in Figures 11 and 12. The numbers of deaths due to the storms of the 1960 to 1991 period are shown, together with the total insurance payout. Deaths from lightning are not included in this summary, but the annual average death toll from this source is around 5 (R. Blong, personal communication). The total average annual number of

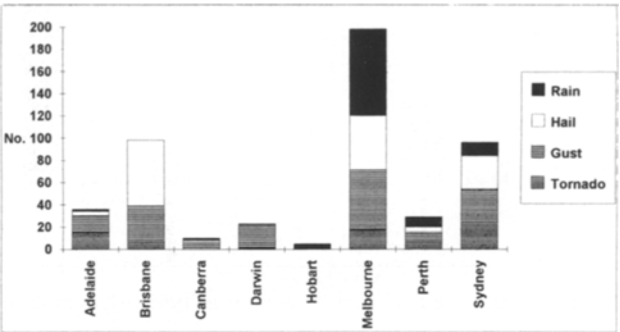


Fig. 9. Preliminary comparison of the number of severe thunderstorms recorded in each of the capital cities over the period 1960 to 1991. Note that for Brisbane the numbers have been extrapolated from the period 1977–90, which has the most reliable record. The Melbourne database is currently the best developed so appears to suggest that severe storms are most frequent there. Further extraction of historical records remains to be done for most of the other cities, so comparisons between cities could be misleading.

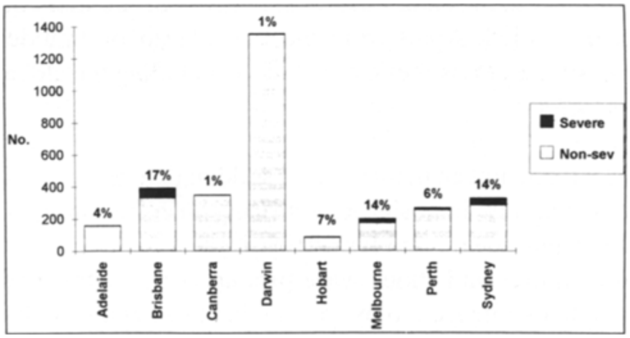


Fig. 10. The relative frequencies of severe and non-severe thunderstorms at each capital city during the decade 1978 to 1987. The figures at the top of each column represent the percentage of thunderstorms which were classified as severe.

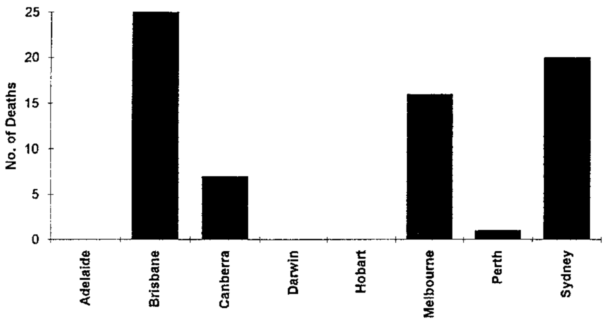


Fig. 11. The number of deaths from severe thunderstorms from 1960 to 1991. Note that the Brisbane figure is extrapolated from the period 1977–90.

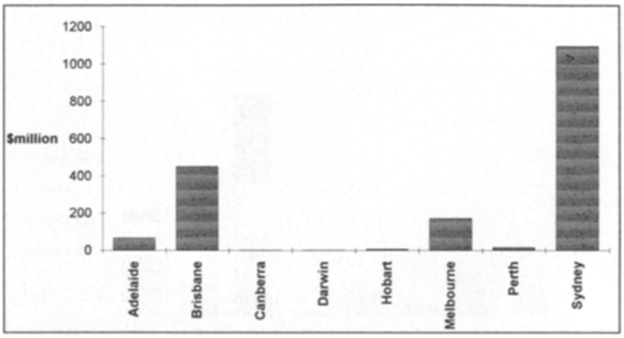


Fig. 12. Insurance costs from severe storms 1967–91, from ICA.

deaths from thunderstorms is therefore about 6. Because of their small size and short lifespan most severe thunderstorm damage bills are smaller than those from tropical cyclones, but because of the frequency of storms a very large cost accumulates (Figure 12). In every storm the insurance payout is much lower than the total cost, but the actual ratio is not known.

As in the case for cyclones and bushfires, benefits of thunderstorms can be described but not quantified. Apart from the role played by thunderstorms in the complex balances of the atmospheric circulation, including the global electrical circuit, the benefits include:

- rainfall;
- scouring of stream and channel beds by sudden deluges;
- ignition of regular low-intensity, fuel-clearing bushfires by lightning; and
- fixing of atmospheric nitrogen for use by plants.

The high temperatures and shock wave produced by lightning cause a reaction which fixes atmospheric nitrogen to oxygen molecules, usually as NO, which is then converted to nitric acid in rainwater. It is estimated (Kessler and White, 1983) that lightning is responsible for about 2% of all the fixed nitrogen supplied to the biosphere.

3. Summary

Available statistics on the costs and benefits of the 3 weather hazards discussed here are far from perfect. This is a field of knowledge which obviously requires more attention. Much of the argument presented here relies heavily on figures provided by the Insurance Council of Australia, and those figures are an invaluable aid. However, they do not represent a complete inventory, and the method of classification used is not ideal for all purposes. The relationship between insurance payout and total damage cost is also the subject of uncertainty.

Existing records suggest that the average annual cost of tropical cyclones and severe thunderstorms in human lives is about 4 to 6 for each. Bushfires are estimated to take an average of 8 to 10 lives each year. For each of the hazards the number of injuries is considerably greater but reliable records are not available. The insurance costs of the 3 phenomena, using ICA summaries of insurance payouts since 1967 are:

- tropical cyclones, $1,715 million;
- severe storms $1,808 million; and
- bushfires $488 million.

Another $112 million in insurance costs can be attributed to thunderstorms because of hail damage to crops. These storms might not have reached the strict threshold for classification as severe (2 cm diameter hail), but obviously did have a major impact. Similarly, the deaths due to lightning are not strictly attributable to severe thunderstorms according to the meteorological definition of severity. Another complication which arises when analysing the ICA severe storm statistics is the inclusion of severe windstorms which might not have been associated with thunderstorms at all.

The distribution of severe weather in terms of insurance costs is skewed towards the smaller, less damaging events, particularly for severe storms, as Figure 13 shows. However, the catastrophic nature of the damage caused by unusually intense events means that the total damge bill is dominated by those relatively rare events.

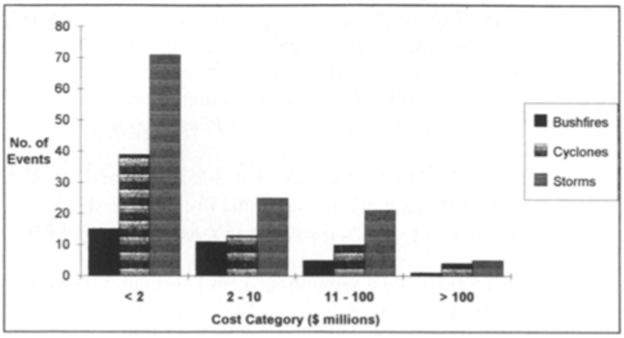


Fig. 13. Distribution of insurance costs from severe weather 1967–91 from ICA figures.

When this distribution, together with the large differences in climatology and vulnerability amongst the States and territories is considered it becomes obvious that prediction of the impact of climate change is complex and difficult. Even if the nature and degree of changes in climate were to be accurately forecast, any resulting changes in the costs and benefits of severe weather hazards could not be reliably extrapolated from currently available data. Those involved in planning for or predicting the future in the multitude of disciplines affected by severe weather must therefore be prepared to be flexible.

Incomplete though the information is on the costs of severe weather hazards, it is much better developed than our knowledge of their benefits. Each of the hazards here forms an integral part of the climate and environment of Australia, and in the cases of cyclones and thunderstorms also play a role in global atmospheric processes. From that point of view the benefits of these 'hazards' are probably much greater than their costs. More specific benefits such as rainfall, natural fertiliser and native plant germination are obviously extremely significant, but quantification is beyond the scope of this paper.

Acknowledgements

The summary of insurance costs provided by the Insurance Council of Australia was an essential part of this analysis. Colin Pierrehumbert and Russell Blong provided many useful comments and suggestions, and the officers of the Regional Severe Weather Sections of the Bureau of Meteorology supplied many of the statistics on severe weather frequency. The diagrams relating to tropical cyclones were prepared by Liz Ritchie and Ingrid Schipperheyn, and Helen Tseros assisted in the analysis of insurance data.

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