Assessing risk from meteorological phenomena using limited and biased databases

Alan Sharp discusses a number of meteorological databases and briefly evaluates their usefulness in risk assessment.

Abstract

The assessment of risk attributable to many phenomena relies on the analysis of past history. In the ideal situation, statistics derived from these data should reveal probabilities and trends in the occurrence of significant events. For more dangerous meteorological events like Tropical Cyclones and Severe Thunderstorms, the number of recorded events is somewhat limited. Changes in the nature of information gathering, and technology have biased these limited observations. We need to consider these factors when using the data to assess future risk

Introduction

The estimation of the risk of adverse impact from weather-related disasters relies heavily on hindsight. The assumption is that the frequency of major events in the past will follow on to a similar frequency in the future. There are two main questions that need to be asked:

- Is the recorded history representative of long term climate? and
- Is there any change occurring in climate?

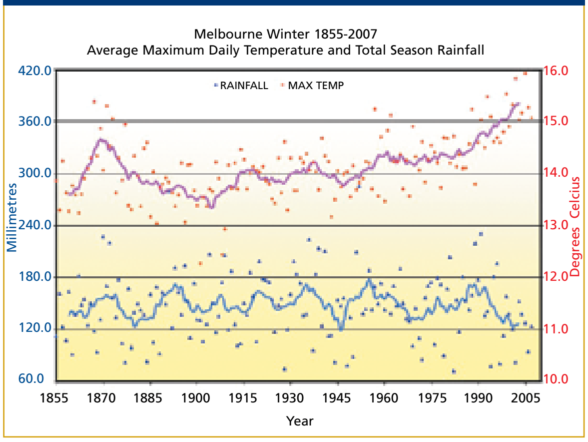
To answer each of these questions, we need to examine the available meteorological databases to assess their accuracy and limitations. The quality of the data is important. Errors and omissions will introduce biases into the dataset that will skew risk assessments. These will not necessarily be the consequence of negligence as many scientific and technical advances have improved weather observing techniques over the years. Where data is more limited, statistical theory shows the probability of the dataset being representative of population is reduced. Also, the extent of the database back into the past has to be great enough to capture longer-term fluctuations in climate.

In this paper we will discuss a number of meteorological databases and briefly evaluate their usefulness in risk assessment in the light of the above mentioned potential limitations.

Assessment of risk

Estimating the risk to the community posed by meteorological phenomena relies on an assessment of the probability of occurrence of the particular hazard phenomenon in the light of the impact that it would be expected to have on the community. Both the weather, and the impact it can have on communities are complex issues that cannot be accurately assessed in any analytical manner. We must use estimations which will often rely heavily on past experience.

Figure 1: Melbourne meteorological observation statistics with 9-point centred moving averages.

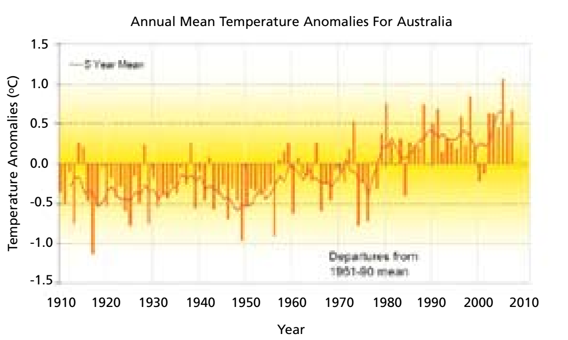


Meteorological probabilities can be evaluated from the analysis of past data. The reliability of these probability estimates relies on the size and quality of the meteorological dataset used. Extreme events that pose the greatest hazard are also less common, so the statistical datasets are relatively small, hence conclusions derived from them are less reliable. Overlying real trends also need to be considered—particularly those caused by global warming. The limited number of significant events also limits the assessment of impact—which is also hampered by a changing landscape and technological infrastructure. The impact assessment is beyond the scope of this paper.

Robust databases

Many of the Bureau of Meteorology's databases are comprehensive, extending over many years. For example, to examine the winter climate of Melbourne we can look at observations from the official Melbourne observation sites. These are the current site near the corner of Latrobe and Spring Streets (since 1908), and Flagstaff gardens in most of the preceding period. This produces a database of over 14,000 daily observations dutifully made at 9am each morning since 1855. Figure 1 shows mean maximum daily temperature and total rainfall for each winter in Melbourne since reliable records commenced in 1855. Before this time there is doubt about the quality of the instrumentation and measurement techniques used.

Figure 2: Mean temperature anomalies derived from observations across the whole country.



Assessments of weather over a region can be further supported by examining multiple stations. As well as increasing the size of the statistical dataset, the individual site problems should be averaged out across the many stations. The national average maximum temperature trends are illustrated in Figure 2. It is possible that some of the variations in the mean Melbourne winter temperature are due to site problems, particularly in the early days, however the national figures are most certainly more robust—supporting the argument that the recent upward trend is in fact due to global warming.

Probabilities & trends

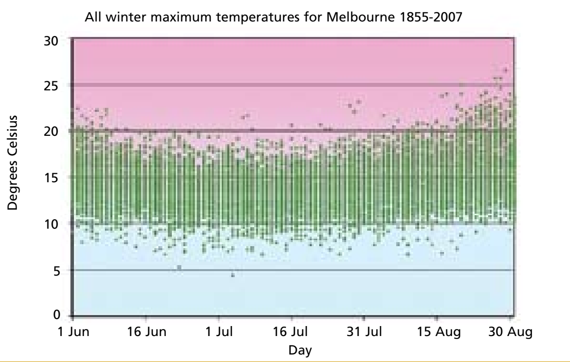
In assessing the probability of certain meteorological conditions occurring, the most obvious methodology is to look at the historical data. The information should be a reasonable indicator of patterns that may occur in the future. The statistical distribution of the data has to be considered in tandem with underlying temporal trends. The trends exhibited in the database can be caused by natural climatic variations, anthropological (human induced) climate change and biases introduced by changing methodologies in data gathering. The Melbourne and Australian maximum temperature illustrates some of these factors.

The annual mean winter maximum temperatures recorded at Melbourne show a considerable level of scatter over the past 150 years—making the raw data quite messy to interpret (Figure 1). Using running means does iron out much of the scatter, but there is still evidence of long term fluctuations in the data. Some of these seem to be the consequence of the relocation of the observation site. Other trends may be due to the general change in environment from the semi-rural environment of the 1850's to the inner metropolitan site that exists now. The examination of data from multiple sites can illustrate real trends (Figure 2). Of note are the brief cooling trend around the time of World War Two and the more recent increase in temperatures.

Limitations of extreme weather databases

Most community and infrastructure planning is based on the type of weather that can be expected to occur in the region, for example, the stormwater drains in Darwin are much bigger than those in Hobart. There is a limit to which systems are engineered to manage rarer events—the cost of implementation needs to be weighed up against the probability of the event. The questions that are therefore asked are, how extreme can the weather get, and how often?

Figure 3: Winter maximum temperatures for Melbourne. Each point is a recorded daily minimum temperature, the colours representing the different years.



In general, the more extreme events will occur less often, hence the number of occurrences in the historical databases will be lower. The fewer occurrences mean that the statistics are less robust and hence less reliable. Figure 3 shows all winter maximum temperatures for Melbourne in the period 1855 to 2007. The large number of observations shows the obvious trend with the coolest expected period being in early July and an obvious warming trend by the end of August. This agrees with the expected trend as the days get longer. If you look at the extremes, that are the days with a maximum less than 7°C, the dataset is much more limited. Viewed in isolation, the warmer trend is not so obvious.

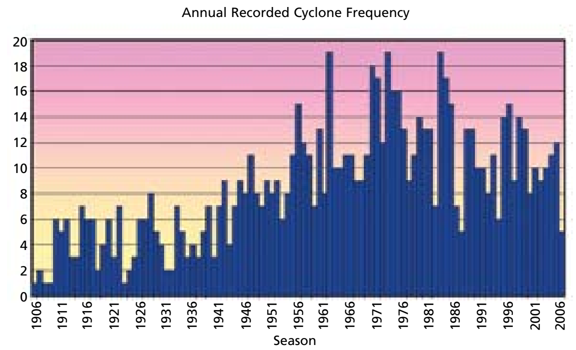
In the case of extreme temperatures, we can view this in the light of the non-extreme data, and common sense. For unusual extreme weather phenomena, like Tropical Cyclones or Severe Thunderstorms—there is not an option of viewing the data in light of "less extreme cases". While some conclusions can be drawn from meteorological reasoning, the issues are complex—particularly when considering the possible influences of global warming.

Tropical Cyclone database

The Australian tropical cyclone database has been maintained by the Bureau of Meteorology since its inception in 1908. Despite this being a relatively long period of 100 years, the total number of cyclones in the database amounts to less than 1000. The annual frequency shown in Figure 4 illustrates the improvement in cyclone detection efficiency rather than any real trends. In the first half of the twentieth century, most cyclones passed unnoticed. Cyclones that did not impact the coast near populated areas were mostly not recorded. Very few systems were detected at sea—and often if a ship did come across a cyclone, it never returned to tell the tale. Through the middle part of the century, improved technology and radio communications improved the detection efficiency, but it was not until the introduction of satellite technology in the 60's that most storms could be detected. It was 1978 when routine geostationary satellite imagery became available, allowing for effective monitoring of cyclones throughout their lifetimes.

In the past thirty to forty years, satellite imagery has permitted the detection of almost all tropical cyclones around the world. Very few cyclones actually pass over a barometer or anemometer and in earlier times most instruments were destroyed by the stronger cyclones. The estimation of intensity of many cyclones relies on satellite image interpretation. The assessment of cyclone intensity over this period has not been consistent as technology and knowledge has evolved. In recent years there has been much debate about the recent trends in cyclone frequency and intensity. The existing database suggests that the frequency of cyclones is mostly unchanged, but that the mean intensity is increasing. The question being asked is: Is the trend in intensity real—possibly a consequence of global warming—or is it a result of improved analysis techniques?

Figure 4: Tropical Cyclones Recorded in Bureau of Meteorology Database.



The answer to this question cannot be discovered without a detailed reanalysis of older data—at least to the start of the satellite era. This can be done by the Bureau, but will require significant resources currently not available.

Whatever the nature of the trend observed in the current database, it still must be considered when assessing risk. If it is real, then we must consider the possibility of the trend continuing into the future if global warming continues. Even if it is not real, the implications to existing risk profiles is serious. The most recent data is more reliable, but many decisions on coastal defences and building codes have been based risks assessments that were developed some time ago using just the less reliable data that was then available. It is likely that these risks may be understated in the light of more recent information. An example is the frequency of Severe Cyclones (those with hurricane-force winds defined as category 3 or above[1]) impacting the coast between Gove and Kalumburu. Figure 5 shows the recorded coastal impacts up until 2002. There have been three category five impacts in the zone in the ensuing three years. Cyclone Monica (2006) was particularly savage as it crossed the Top End coast, however the impact on populated centres was limited. It was only post-event aerial photography that revealed the serious damage to vegetation (Figure 6). Had this cyclone occurred 50 years earlier it is likely to have been recorded as Category 2-3 crossing "somewhere west of Maningrida".

Severe thunderstorm database

Like the cyclone database, the severe thunderstorm database is biased by the limitations in the ability to detect the events. Thunderstorms can be detected nationwide using satellite imagery and, more recently, lightning sensor networks. These observations cannot distinguish between severe and non-severe thunderstorms. Even radar is not reliable beyond a range of about 70km, and the Bureau radar network contains many gaps in spatial coverage.

[1] See table 1.

The verification of severe thunderstorms relies mainly on eye-witness accounts and damage assessment.

In recent years, the Bureau of Meteorology has implemented measures to better detect and verify severe thunderstorms. This includes the implementation of a storm-spotter network of about 3000 volunteers, Severe Weather Sections in each capital city Bureau office that are better equipped to follow up suspected events, and increased and improved weather radar. Not surprisingly, the frequency of severe thunderstorms recorded has increased in recent years. Severe thunderstorms are more frequent than tropical cyclones, so a lesser time period is required to build up valid statistics. Longer term trends will be more difficult to detect. At present the database is fragmented between states, a project is planned to consolidate these data and make them available to the public.

Figure 5: Recorded tropical cyclone coastal impacts: 1906-2002 (severe impacts in red).

Figure 6: Impact of Cyclone Monica (2006) on tropical trees at landfall 35 km west of Maningrida. Notice the trees have been striped of foliage and small branches.

Solutions

For some extreme weather conditions, the data available will provide good guidance on threat and trends in threat posed. For example, extreme fire weather situations relate to temperature and wind for which much data exists. Even though extreme events are uncommon, these represent the tail of a much bigger and robust statistical database. This benefit can be enhanced by reanalysis where possible. Better understanding of risk relies on the collection of supporting information from some less conventional sources.

For isolated phenomena like tropical cyclones, the assessment of risk is more difficult.

The removal of errors and complete reanalysis of the cyclone database using current scientific knowledge will improve the utility of the database. Despite this, the period of reliable data still will be limited as little information exists before the satellite era. To assess risk, there needs to be research done beyond the scope of detection of cyclones by meteorological systems. Some information exists on significant cyclone impacts in living history—like Cyclone Mahina that impacted Bathurst Bay north of Cooktown in 1899 causing the most recorded deaths for a single event in Australia.

To better understand the risks posed in the longer term we need to find data that may reveal fluctuations in frequency that may occur over periods of greater than

Figure 7: Correlation of 20th century tropical cyclone events with stalagmite isotope ratios in caves at Chillagoe, west of Cairns. (Nott, et al, 2007). The graph shows the deviation of ^{18}O:^{16}O isotope ratio.

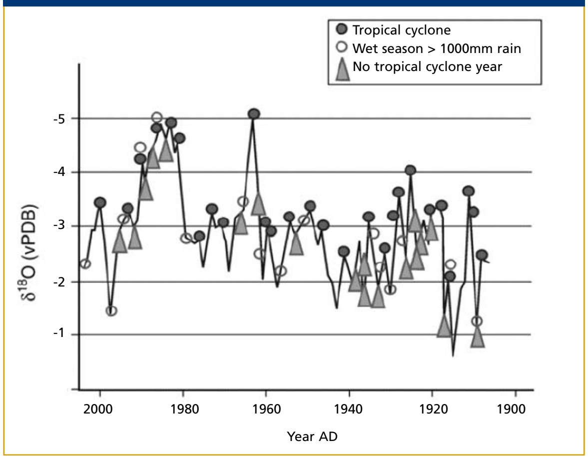


Figure 8: Stalagmite isotope ratios from caves at Chillagoe, west of Cairns. (Nott, et al, 2007). The graph shows the size of the variation from maximum to minimum between years.

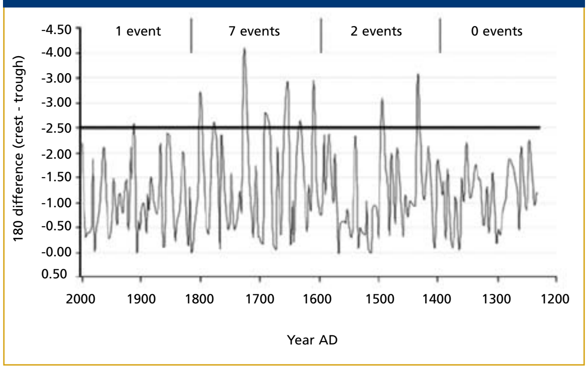


Table 1: Australian Tropical Cyclone Category Scale

Category	Strongest gust (km/h)	Typical effects
1	Less than 125 km/h Gales	Minimal house damage. Damage to some crops, trees and caravans. Boats may drag moorings.
2	125 - 164 km/h Destructive winds	Minor house damage. Significant damage to signs, trees and caravans. Heavy damage to some crops. Risk of power failure. Small boats may break moorings.
3	165 - 224 km/h Very destructive winds	Some roof and structural damage. Some caravans destroyed. Power failure likely.
4	225 - 279 km/h Very destructive winds	Significant roofing and structural damage. Many caravans destroyed and blown away. Dangerous airborne debris. Widespread power failures.
5	More than 280 km/h Extremely destructive winds	Extremely dangerous with widespread destruction.

a few decades. This includes the collation of historic disaster reports, and the examination of physical evidence using paleoclimatology. More obvious examples of these techniques involve the detection of past ice-ages. More subtle analysis of specific information can reveal trends over the past millennium. Research into oxygen atom isotope ratios (^{16}O:^{18}O) in stalagmites in caves at Chillagoe, 130 km inland from Cairns, suggests evidence of markers that can identify floods caused by past cyclones. Work by Nott, et al (2007) illustrates this (figures 7 & 8). The correlation is established in the twentieth century, but the longer time series suggest that the 20th century records may represent a relatively quiet period. The period 1600-1800 shows a much higher frequency of large peaks that have been shown to be correlated to major cyclone/flood events.

The importance of sourcing alternative pre-historic data is also presented in a paper by Nott (2003) that examines past impact evidence to evaluate the threat based on a longer-term period—particularly in the Cairns Region. This includes the examination of debris deposits from past storm surges, and tsunamis; landslides; past floods etc. While these data do show that historical records may underestimate the variability in severe weather phenomena over time, there is also scope for much more detailed research in this area. It should be noted that long-term climate variations have also been observed in the northern hemisphere where history extends much further into the past. This includes a cool period between 1550 and 1850 referred to as "The Little Ice Age" (Grove, 1988) which illustrates that significant climatic variation can occur century to century. The cause of the cooling is unknown, although theories include reduced solar radiation, volcanic activity and/or disruption to ocean currents.

Conclusions

The existing meteorological databases for the occurrences of extreme weather conditions do show some limitations. These limitations can affect the usefulness and accuracy of risk assessments that are derived from the data. However, knowledge of these limitations is important in that it can be factored into any future risk estimates in a sensible way. This appropriate evaluation and use of the data allows it to play an important role in the disaster mitigation assessment process, and reduces the possibility of false definitive conclusions being reached by planners.

There is a need to continue extending and improving the meteorological databases. This will not only improve the statistical robustness of the database, but also help to measure climatic variations that may be occurring at this time—particularly man-made global warming. A main consequence of global warming is likely to be a change in frequency and severity of significant weather events. The sooner we can assess the nature of these changes the sooner we can update the estimate of risk to the community.

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