The Impact of Observational Technology on Climate Database Quality: Tropical Cyclones in the Tasman Sea

BRUCE W. BUCKLEY

Bureau of Meteorology, West Perth, Australia

LANCE M. LESLIE

School of Meteorology, University of Oklahoma, Norman, Oklahoma

MILTON S. SPEER

Bureau of Meteorology, Sydney, Australia

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ABSTRACT

The recorded climatology of tropical cyclones that affect the Tasman Sea spans the period from 1911 to the present. This climatology is a subset of the much larger Australian Tropical Cyclone database, which is the official record of all tropical cyclones in the Australian area of responsibility. Such a long, detailed record should provide an excellent dataset for regional climate research. However, a detailed analysis of the database has revealed that it must be used with caution over the Tasman Sea, where statistically significant discontinuities are present, greatly reducing its quality and length for climate and climate change studies. Problems with the complete Australian Tropical Cyclone database have been identified and discussed earlier by a number of authors. This study is concerned with two statistically significant discontinuities that occurred in the Tasman Sea portion of the database in the mid-1950s and in 1977. The first discontinuity almost trebled the recorded frequency of tropical cyclones, whereas the second discontinuity exhibited an opposite trend, decreasing the recorded frequency of tropical cyclones by a factor of 8 from the previous period. Some possible explanations for the abrupt changes in this subset of one particular database are discussed. It is suggested here that the most likely explanation is the improved observing technology and the associated changes in interpretation of the new data. Finally, it is likely that other climate databases have been affected by similar problems and should be treated with the same degree of caution.

1. Introduction

The understanding and prediction of regional climate change and interseasonal variability, particularly for extreme events that affect highly populated weather-sensitive coastlines, is growing rapidly in importance. Many of these predictions are based upon the identification and extrapolation of trends from official databases. It is vital that such datasets are homogeneous and have been subject to rigorous quality control as secular changes contained within the databases can limit the success of such predictive techniques (e.g., Nicholls 1992). A careful analysis has been performed of a subset of one such database, the Australian Bureau of Meteorology's Australian Tropical Cyclone database, following an extreme weather event that affected the northern coastline of New South Wales (NSW), Australia, in March 2001. Because of its importance this database has been subject to significant scrutiny in the past. Holland (1981) identified the impact of the enhanced observational technology on the detection of intense tropical storms. However, his study was too early to describe the impact of observations from the geostationary satellite program. Nicholls (1992), in a follow-up to a series of studies linking Australian region tropical cyclone seasonal frequencies to the Southern Oscillation index (SOI), also suggested that the availability of enhanced satellite imagery was a likely reason for the increase in tropical cyclone frequency between 1959 and the mid-1980s. However, he left open the possibility that the increase might be the result of a real increase in tropical

Corresponding author address: Dr. B. W. Buckley, Bureau of Meteorology, P.O. Box 1370, West Perth, Western Australia 6872, Australia.
E-mail: b.buckley@bom.gov.au

cyclone activity. In a later study, Nicholls et al. (1998) carried out a more detailed study of trends in Australian region tropical cyclone frequency. They sought explanations for the increase in tropical cyclone numbers in the period 1959 to the mid-1980s and the subsequent drop in numbers after 1986. Again, improvements afforded by evolving observational technology, particularly satellite imagery, were suggested as a possible cause. However, they offered a number of alternative explanations. The alternative possibilities included genuine trends in the SOI; an improved understanding of tropical cyclone characteristics, enabling better discrimination from other systems; changes in official directives, with corresponding changes in the definition of tropical cyclones; and climate change, for example, global warming. The importance of improved observations is confirmed by earlier work on tropical cyclone databases outside the Australian region. For example, changes in measurement technology for tropical cyclone activity were suggested by Landsea (1993) as probable causes of inconsistencies he found in the Atlantic climate record for intense storms.

In this study we restrict ourselves to only one part of the Australian Tropical Cyclone database, namely the Tasman Sea region. Like Nicholls et al. (1998), we find that the dataset contains three distinct tropical cyclone populations that are abruptly separated from each other by two discontinuities. These discontinuities between the populations occur in the mid-1950s and in 1977. As will be seen in section 3, these dates suggest that an explanation for the sudden changes lies in improved observational technology, combined with an altered interpretation of these new data. At the same time, as will also be discussed later, we cannot rule out the other possibilities raised by Holland (1981), Nicholls (1992), and Nicholls et al. (1998).

Our interest in the nonhomogeneity of the database was stimulated by a recent case of an intense tropical low that crossed the east coast of Australia. The tropical low had an eye that was clearly discernable on infrared satellite imagery from the Japanese Meteorological Agency geostationary satellite *GMS-5* during the final 18 h leading up to and including landfall. Sustained 10-min-average winds of 54 kt (28 m s^{-1}) were measured at Evans Head automatic weather station (AWS), with the highest gusts measured at 75 kt (39 m s^{-1}). This would have made it a category-2 tropical cyclone according to the current Australian Bureau of Meteorology's cyclone severity category (Bureau of Meteorology 2002), which differs from the U.S. Saffir–Simpson scale (Simpson 1974; Simpson and Riehl 1981). The eye was also well depicted on the base scan of an S-band weather watch radar, several hours before landfall. However, because of its baroclinic origins, the tropical low was not named a tropical cyclone and hence is not recorded in the Australian Tropical Cyclone database. There is still ongoing debate about the status of this storm (see, e.g., McCrone 2002), but at present it remains classified as a subtropical low with some tropical cyclone characteristics. That is, it is regarded as a ''hybrid'' system, as defined in a number of studies, most recently by Reale and Atlas (2001). Reale and Atlas (2001) identified hybrid cyclones in the Mediterranean Sea that were midlatitude systems, but had many features in common with tropical cyclones. In their mature stages the surface characteristics and impact on affected communities of these weather systems closely resemble that of tropical cyclones. Satellite imagery reveals that they can vary substantially during their life cycles, moving from tropical or subtropical lows at genesis to tropical cyclones at other stages. The tropical low of 8 March 2001 encountered atmospheric and ocean conditions that were highly favorable for transition to tropical cyclone status.

The inconsistencies found in the Australian Tropical Cyclone database for the entire database and for the Tasman Sea region subset have far-reaching implications. A major objective of regional climate analyses and prediction initiatives is to provide information on the future occurrence of weather systems likely to affect particular communities. Predictions of future climatic states should only be undertaken by utilizing datasets that are adequate. A major outcome of this work is to confirm and extend inconsistencies in this particular database, identified by Holland (1981), Nicholls (1992), and Nicholls et al. (1998). Similar inconsistencies are highly likely to be present in many other climate databases resulting from the massive improvement in observational coverage following the routine use of satellite and radar data.

2. Climatology of tropical cyclones in the Tasman Sea

Tropical cyclones and other lows of both tropical and subtropical origin are an ongoing threat to the entire eastern Australia coastline including the Tasman Sea coastal region, which is the most populous area in Australia. The most comprehensive record of their occurrence is contained in the Australian Bureau of Meteorology's Tropical Cyclone database. A total of 63 tropical cyclone events in the Tasman Sea region have been documented in the first 92-yr history of records contained in this database, from 1911 to 2002. Although they do not make landfall frequently, cyclones of tropical origin have a severe to devastating impact when they near or make landfall. Given their impact, it is of vital importance to carry out research programs that might lead to an increased knowledge of possible trends in frequency and intensity.

a. The Australian Tropical Cyclone database

The Australian Tropical Cyclone database was developed as a joint initiative of the Bureau of Meteorology Program Office and the three Australian Tropical Cyclone Warning Centres (Brisbane, Darwin, and Perth,

TABLE 1. Climatological summary of tropical cyclone occurrence in the Australian Tasman Sea region. Note the three distinct frequency regimes.

Time interval	No. of tropical cyclones	Recurrence interval	Correlation coefficient
1911–54	29	1.6 yr	0.98
1955–76	29	0.6 yr	0.99
1977–2001	5	4.8 yr	0.94

Australia). The aim was to include all historical events that had a tropical cyclone signature impact in the Australian region of responsibility (Bureau of Meteorology 2001). This database is the official climatological database of tropical cyclone activity for this part of the globe. It contains details of all known tropical cyclones (including some early entries for unnamed systems that were believed to be tropical cyclones). The database is comprised largely of 6-hourly position and intensity fixes. It has been used extensively over many decades and continues to be heavily used.

In this study the focus is on the frequency of occurrence of that subset of tropical cyclones that affected the Australian Tasman Sea region, defined as the area south of 28°S and stretching from the east Australian coastline to 160°E.

b. *Historical tropical cyclone frequencies*

Analysis of the Tasman Sea subset of the full tropical cyclone database has revealed two step changes in tropical cyclone annual numbers. The observed annual frequency of tropical cyclones from 1911 to 2001 exhibits a step change commencing in the summer of 1955–56, with an even larger discontinuity in 1977. Table 1 summarizes a number of our results. Between 1911 and 1976 a total of 58 tropical cyclones, representing an average of one tropical cyclone every 1.1 yr, were recorded. In the 25-yr period from 1977 to 2001, inclusive, only five tropical cyclones were recorded, equating to a frequency of one tropical cyclone every 4.8 yr. Further refining of the database by separating the frequency of occurrence into pre- and post-1955 periods showed an average of one tropical cyclone recorded every 1.6 yr prior to 1955. For the 22-yr period from 1955 to 1976, inclusive, this frequency jumps to one tropical cyclone every 0.6 yr. The correlation coefficients for the linear regression lines that provide the best fit for these three periods are all very high. During the first period ending in 1954, the correlation coefficient was 0.98, a measure of how consistently tropical cyclones were recorded as occurring over these waters. A correlation coefficient of 0.99 was calculated for the line of best fit for the interval from 1955 to 1976, inclusive, indicating a new, but different, population of documented tropical cyclones in these waters was being entered into the database. The correlation coefficient for the post-1977 period remains very high at 0.94. These correlations support the hypothesis that a different population of tropical cyclones is now being documented when compared with those from the two earlier periods. Further analysis of the data was undertaken using the Kruskal–Wallis nonparametric test (Kruskal and Wallis 1952) to determine whether the tropical cyclones in each of these eras were from the same or independent populations. All three tropical cyclone subsets were found to be from different populations with different annual frequencies of occurrence, at greater than the 99% confidence level.

c. *Time series representation of Tasman Sea cyclone numbers*

Additional analysis of the Tasman Sea subset of the Australian Tropical Cyclone database was carried out by plotting time series of 5-yr mean numbers of observed tropical cyclones. To obtain a useful time series, given the small annual numbers of tropical cyclones observed in the Tasman Sea, it was decided to use 5-yr means. The complete time series is shown in Fig. 1a, together with trend lines for the three different populations: 1913–53, 1954–76, and 1977–2000. The mean values for each of the three populations are clearly very different and are shown, together with the extreme values and standard deviations for the distributions, in Table 2. They show a marked rise in numbers commencing in the mid-1950s and extending to the late 1970s, followed by an even more marked decrease in numbers from the late 1970s to the present. The time series support the statistical analysis of section 2b but also have a common characteristic. In each of the three populations the trend exhibits a decrease in recorded numbers over the period. At this stage we have no explanation for this feature and simply present them. Turning to each of the individual times series, we note from Fig. 1b that over the first period (1913–53) the observed 5-yr mean tropical cyclone frequency drops slowly from 4.3 at the start of the period to 2.8 at the end. The second period is somewhat shorter, but still covers more than 20 yr, from 1954 to 1976. The mean values, shown in Fig. 1c are significantly larger than for the first period, with the trend line starting at almost 8 at the beginning of the period in 1954, but dropping to 5.2 at the end of the period in 1976. The third and final period from 1977 to 2000 is shown in Fig. 1d and again covers a period of over 20 yr. It is this period that we expected, and indeed see, the largest change of the three. The trend line of 5-yr mean frequency is well below that of the previous two periods and exhibits a further decrease of 2.0 at the beginning of the period to about 0.4 at the end of the period. We expected the largest change in this period because most of the advances in the observational network have occurred in this period.

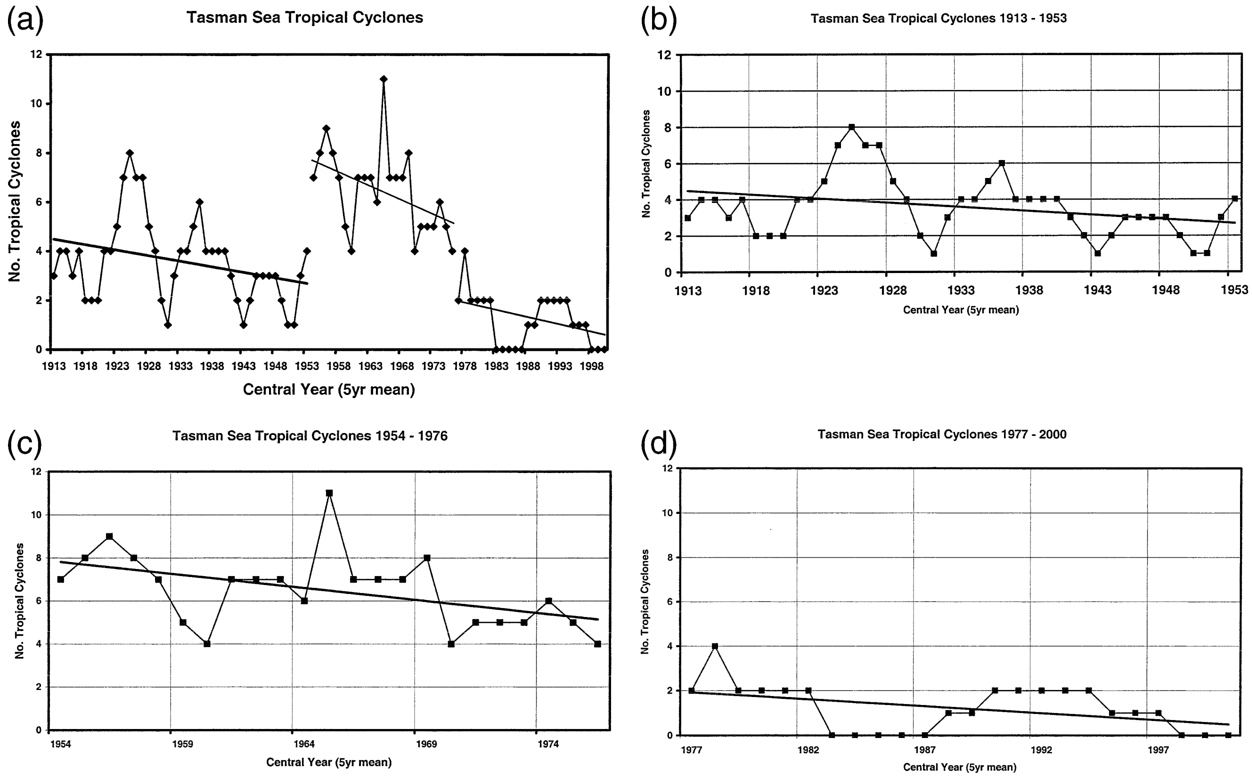

FIG. 1. (a) Time series of 5-yr mean Tasman Sea tropical cyclone frequencies plotted against the central year of the mean. The period covered is from 1911 to 2002. The three distinct populations identified in Table 1 are separated and trend lines for each are shown. (b) Same as in (a), except for the first period, 1913–53. (c) Same as in (a), except for the second period, 1954–76. (d) Same as in (a), except for the third period, 1977–2000.

3. Possible causes of the step function frequency changes in the database

The results of the analysis of the Tasman Sea tropical cyclone frequencies would seem to leave little doubt that there have been three distinct periods demarcated by two sudden changes in numbers in the mid-1950s and the late 1970s. It is tempting to suggest that the main causes of these changes are almost entirely observational and observation related, rather than climatic. By observation related we mean that the changes in the data were accompanied by changes in interpretation of the data. Such a conclusion is supported by Holland (1981) and Nicholls (1992). A later study by Nicholls et al. (1998), listed a comprehensive set of plausible alternative explanations, including real changes in the tropical cyclone numbers, changes in the tropical atmosphere, and increased understanding of tropical cyclone structure and climate change. While we do not disagree that a component of any change in recorded frequencies of tropical cyclones could well be the result of one or more of these factors, we suggest that the coincidence of changes in the database with the beginning of very significant advances in the observing system remains the most appealing explanation. The first abrupt change in the climatological frequency of tropical cyclones in this region appears soon after a change in observational practice. A concerted international effort was made to boost the temporal and spatial frequency of observations of the global environment for the International Geophysical Year (IGY). The IGY ran from July 1957 to December 1958 (Gibbs 1999) and was substantially implemented in the Australian region during the lead up to this experiment, notably in 1955 and 1956. Improving the near-real-time collection of weather observations from ships at sea was a major component of this experiment. The program of collecting oceanic observations was enhanced immediately prior to the commencement of IGY with the appointment of three Port Meteorological Agents, one each in Perth, Sydney, and Melbourne, Australia (Gibbs 1999), to enhance

TABLE 2. Climatological summary of 5-yr running means for the three periods of interest for tropical cyclone occurrence in the Australian Tasman Sea region.

Period (5-yr mean)	1913–53	1954–76	1977–2000
Average TCs per 5 yr	3.6	6.5	1.2
Max	8	11	4
Min	1	4	0
Std dev	1.7	1.7	1.1

availability of real-time oceanic weather data to the international meteorological community. During the period 1955–60, seven dual-purpose wind find–weather watch radar were installed in coastal locations bordering the Tasman and Coral Seas (Holland 1981). With increased observations came much higher detection rates of intense lows that remained over the oceans throughout their entire life cycles. The intensity of many of these lows was probably significantly underestimated in years prior to the IGY initiative, through the lack of observations over the oceans. The impact of these lows would have been very similar to that of tropical cyclones. As a consequence, many systems that were not tropical cyclones nevertheless would have been recorded as tropical cyclones during this period.

Turning to the second discontinuity in the tropical cyclone database, prior to 1977 a tropical cyclone present in the Tasman Sea was identified primarily from surface observations. After July 1977, when the first Japanese Meteorological Agency geostationary satellite (*GMS-1*) was launched, satellite-based identification of tropical cyclones became the principal observational tool over the data-sparse oceans surrounding Australia. It is postulated that the cause of the massive decrease in the recorded frequency of tropical cyclones shown in Table 1 and Fig. 1 is related to two factors: the modernization of observing technology that commenced with the launch of *GMS-1* in July 1977; and directives within the Australian Bureau of Meteorology following the increased ability to discriminate between tropical cyclones and other tropical and subtropical systems, following access to data from polar-orbiting and geostationary satellites. Many intense low pressure systems that would have been included in the database as named tropical cyclones before the era of polar-orbiting and geostationary satellites are now excluded, owing to their nonclassic genesis, structure, and/or life cycles. The limited coverage, lack of rectification, and digital enhancements afforded by the first-generation polar-orbiting satellites were almost certainly insufficient to exclude these hybrid systems in the pre-1977 satellite era. The tropical low that made landfall on 8 March 2001 is a prime example of this type of event. As mentioned in the introduction, the *GMS-5* satellite imagery revealed an intense tropical low at 0600 UTC 8 March 2001. This system displayed many features of a tropical cyclone, but was not named because of its baroclinic origins. The low possessed a distinct eyelike feature, anticyclonically curved upper-level outflow, and strong low-level spiral cloud bands typical of a tropical cyclone, but was embedded initially in a broader low pressure system of baroclinic origin and hence was not named. The lowest mean sea level pressure for this system also was higher than usual for a tropical cyclone with a similar appearance on satellite and radar. However, there remains a very high probability this system would have been a named tropical cyclone in a presatellite environment as its impact upon the coastal community was that of a category-2 tropical cyclone. Discussion of this aspect is continuing, as mentioned in the introduction.

4. Conclusions

The Australian Tropical Cyclone database is a valuable resource that has been, and continues to be, widely used for meteorological research. Prior studies, including those of Holland (1981), Nicholls (1992), and Nicholls et al. (1998) detected problems with the variable quality of the database. In the present study, which focuses on the Tasman Sea region of eastern Australia, it is confirmed that the database is not homogeneous. We find instead that it is composed of three statistically distinct frequency regimes (populations). This finding is consistent with that of Nicholls et al. (1998) for the complete database and has significant implications for the east-central Australian coastal region, which is the most populous part of the country and would be severely affected by any increase in the severity or frequency of tropical cyclones nearing or making landfall.

The intense tropical low event of 8 March 2001 alerted us to the fact that climate databases suitable for regional climate and climate change impact research must be checked rigorously for completeness and consistency in the identification and classification of the weather phenomenon being studied. Such quality control often can reduce the length of climatic records that are intended for use in climate modeling and climate change applications. This is especially true for climate databases that are sensitive to the massive advances that have occurred in the observational network over the past several decades.

The significance of these step changes in the database studied is that they can render highly suspect conclusions concerning the frequency of occurrence of tropical cyclones associated with, for example, future climate change. We note that although care should be taken in using datasets of this type, it still is possible to use them effectively. Nicholls (1992) derived a new relationship from the post-1979 years of the dataset, this time between the Southern Oscillation index and yearly changes in seasonal numbers, rather than the seasonal numbers themselves.

It is possible that other oceanic and data-sparse areas have experienced similar inconsistencies in recorded frequency of tropical cyclone activity that can be attributed to changes in the observational practices or classification scheme. The databases of these regions should also first be examined in detail to determine whether they suffer from problems similar to those present in the Australian Tropical Cyclone database.

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