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A review of worldwide occurrence of tornadoes

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Abstract

The objective of the present study was to re-visit and up-date data on tornado occurrences throughout the world. This was carried out by accessing the relevant literature, analysing, re-analysing and comparing the data on tornado occurrence from various sources. The investigation was aimed at those countries/regions for which no or little information is available. In addition to the literature survey, nearly 30 Weather Monitoring Authorities in various countries throughout the world were contacted. For some countries/regions a more detailed description of tornado occurrences than that found in the literature, was obtained. Several discrepancies between various sources of information were also identified. In addition to South Africa, contour maps of the mean rate of occurrence for France, Austria and Australia were developed.

Keywords: Tornado occurrence in the world; Probability of a tornado strike

1. Introduction

Tornado loads become critical in the design of certain structures such as transmission lines and nuclear power stations located in regions prone to severe thunderstorms. In fact the vast majority of transmission line failures due to wind loading have been due to extreme winds arising from severe local wind storms including tornadoes and downbursts [1].

Tornado events have been recorded on all continents except Antarctica. While there is a large amount of data available on North American tornadoes, for many other countries the information is fragmented and in some cases contradictory. For example a large number of tornadoes has been predicted by Fujita [2] for Europe but in contrast with this, and despite its high population density, the information is scarce

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and in many cases disputable. On the other hand Fujita's estimate for South Africa compares well with recent results [3].

The current research has been based on large number of data sources but in view of the space limitations of the current paper it is not possible to include all the relevant references. A comprehensive list of references is given in Ref. [4].

2. World overview

A summary review of the world tornado occurrences is presented in Ref. [2]. This includes a map of expected events in a 4-year period which is reproduced in Fig. 1. It can be seen that tornadoes occur on both hemispheres between the latitude 20° and 60° but predominantly over the territory of the USA. In the following sections selected data on the occurrence of tornadoes in various parts of the world is summarised.

3. North America

More events occur in the central USA than anywhere else in the world and their occurrence has been researched and documented in several publications. An average of 800 tornadoes per year is given in Ref. [5]. Contour lines of mean rate of occurrence due to Fujita are given in several publications. The most tornado prone region is the mid-west with an occurrence rate of about 5×10^{-4}/yr/km^2.

Tornadoes have also been reported in Canada, and more than 600 were identified during the 30 year period from 1950 to 1979 [6].

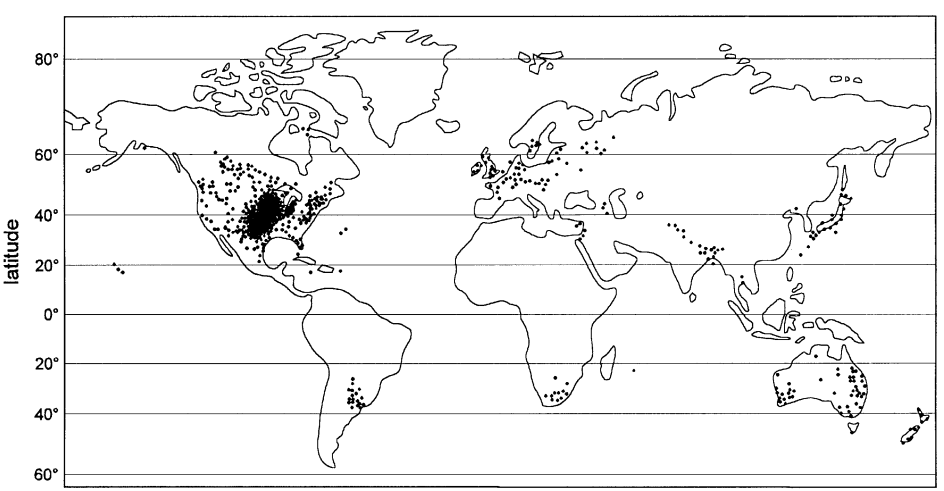

Fig. 1. Tornadoes around the world expected to occur in about a 4-year period [2].

4. South America

Tornadoes have been reported in Argentina and its neighbouring countries of Brazil, Chile and Uruguay. The occurrence of Argentinean tornadoes for the period 1930–1987 has been investigated in [7] and a probable number of 10 events per year was suggested. Contours of the mean annual relative rate of occurrence corrected for population density, are shown in Fig. 2 (re-drawn from Ref. [7]). In this figure the occurrence in region B is half that of region A, and double the rate of occurrence in region C. The approximate value of the rate of occurrence in region A is 2×10^{-4}/yr/km^2. The shaded area in Fig. 2 refers to the regions where the high-intensity winds (including tornadoes) occur.

5. Europe

Although tornadoes have been reported in most of the European countries (typically in summer), data on their occurrence is fragmented and in many aspects contradictory. In the following subsections a brief overview of tornadic occurrences in various countries will be discussed.

5.1. United Kingdom

A distribution of destructive tornadoes which occurred in Britain between 1868 and 1950 [8] suggests a maximum frequency of 8 events per 1 200 sq. miles for this period

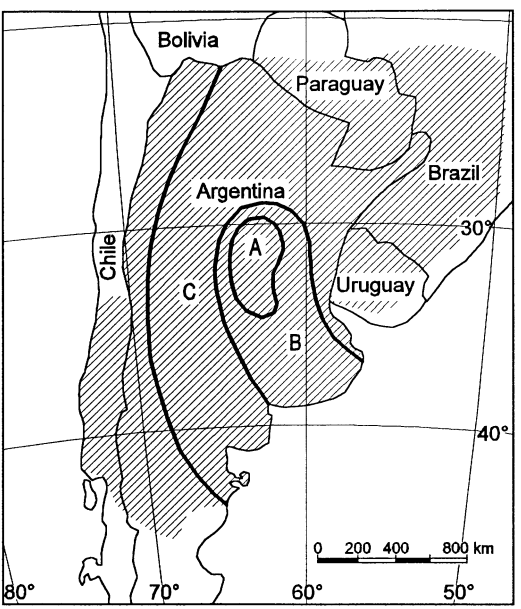

Fig. 2. Relative rate of occurrence of tornadoes over Argentina [7].

of time, which corresponds to an occurrence rate of 3.1×10^{-5}/yr/km^2. The analysis reported in Ref. [9] refers to 36 tornadic days, with a total of 78 tornadoes over a period of four years (1963–1966). (This suggests an average of nearly 20 tornadoes per year.) The largest number of tornadoes reported on one day was 15. Most of the tornadoes occurred in southeastern UK. Interestingly, more tornadoes occurred in winter than in summer. Ref. [10] indicates an average of about 12 tornadoes per year for the period 1950 to 1970. (This corresponds to a mean annual occurrence rate of about 5×10^{-5}/yr/km^2.) At least four tornadoes in this century have been of intensity F3 (1913, 1931, 1950 and 1954).

5.2. *France*

The occurrence of tornadoes in France was analysed in Ref. [11]. The analysis considered only significant events (referred to by the authors as 'grand') which were classified as Fujita F2 to F5. For the period 1680–1988, 107 tornadoes were reported, 58 of which occurred in the period of 1960–1988. The number of later events implies an average of about two significant tornadoes per year. The geographical distribution of tornadoes shows that they occur throughout France but mostly in the north and along the south coast.

On the basis of the geographical distribution of tornadoes presented in Ref. [11], the development of contour lines of the mean rate of occurrence was undertaken in the present project. Only recent events (reported between 1960 and 1988) were considered on the assumption that for this period the data would be fairly comprehensive and representative. No consideration was given to the F-scale classification (i.e. the relative strength of events). The resultant, most realistic, contour lines are presented in Fig. 3. (Also included in this map are the locations of events recorded between 1960 and 1988.) It can be seen that the highest rate of occurrence of 1×10^{-5}/yr/km^2 was obtained.

An extrapolation of the number of tornadic events was attempted to include the hypothetical number of F1 tornadoes which were ignored in Ref. [11]. This was done on the basis of the intensity distribution in the USA and South Africa. (Both distributions show similar patterns with between 55% and 60% of all tornadoes being F1.) The extrapolation based on these values would suggest the total number of tornadoes (i.e. F1–F5) in France being about 135 for the period 1960–1988. Considering the entire area of the country, such a number of tornadoes corresponds to an average occurrence rate of about 1×10^{-5}/yr/km^2.

5.3. *Austria, Czech Republic, Hungary*

Analysis of Austrian tornadoes was reported in Ref. [12]. On the basis of the geographical distribution given in this reference, a development process of contour lines of mean rate of occurrence was undertaken. For this process only 62 events which occurred between 1947 and 1971 (i.e. more than two tornadoes per year) were considered.

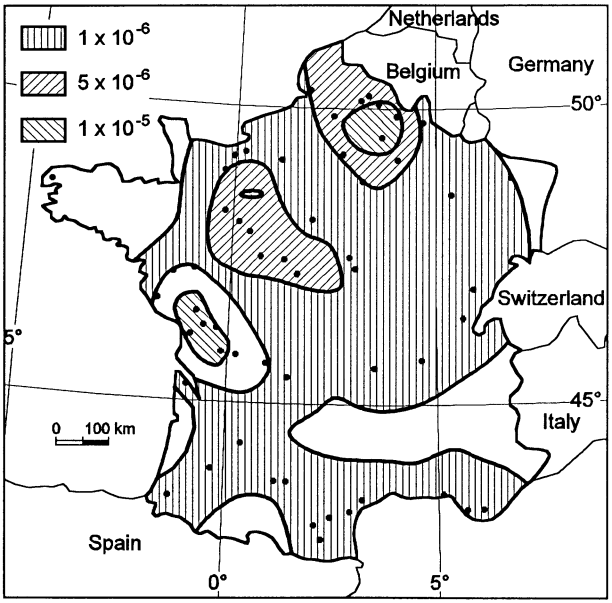

Fig. 3. Map of mean rate of occurrence of significant tornadoes in France.

The resultant map of mean rate of occurrence is presented in Fig. 4. It can be seen that the tornado-prone zone extends over the planes of the eastern portion of the country where highest rate of occurrence is about 7×10^{-5}/yr/km^2.

In contrast with the Austrian data, no tornado events were recorded in the neighbouring Czech Republic. In Hungary 17 events were recorded between 1889 and 1972 with the largest one being 140 km long and between 150 m and 3 km wide. Nine of the events which occurred between 1941 and 1972 produce an occurrence rate of 3×10^{-6}/yr/km^2.

5.4. *Italy*

The annual distribution of Italian tornadoes between 1948 and 1970 was presented in Ref. [13]. A total of 192 events (i.e. an average of about 9 events per year) was given, with a maximum of 25 events in 1964.

A comprehensive study of tornado occurrence was presented in Ref. [14]. The study included a total of 280 verified events over a period of 27 yr (1946–1973) (i.e. about 10 events per year). (This further implies an average rate of occurrence of about 3.5×10^{-5}/yr/km^2.) Nearly, 70% of events occurred in six regions namely: Lazio (59), Lombardy (38), Veneta (26), Tuscany (25), Piedmont (23) and Liguria (21). Considering these individual regions, occurrence rates of between 4×10^{-5} and 1.5×10^{-4}/yr/km^2 can be inferred.

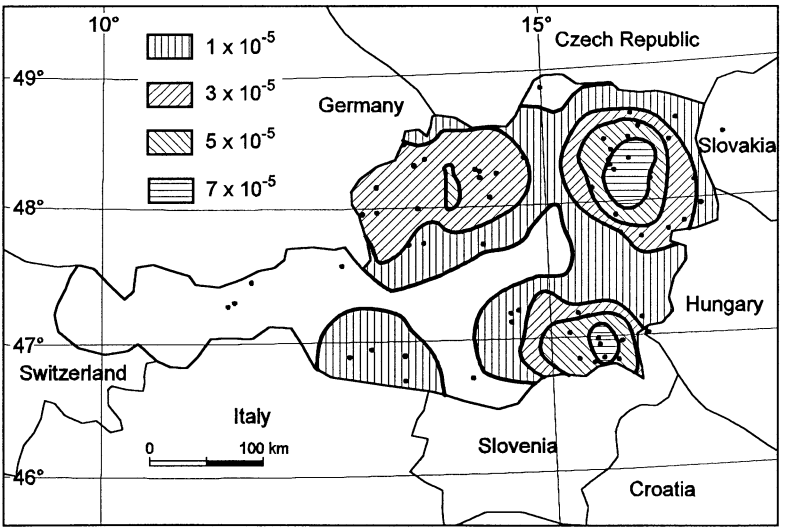

Fig. 4. Map of mean rate of occurrence of Austrian tornadoes.

In contrast with the above, recent contacts with the Italian Meteorological Service imply that tornado events in Italy are rare, with no statistics currently being kept.

5.5. *Germany*

The present investigation revealed conflicting information with respect of the occurrence of German tornadoes. Historical analysis by Wegener (presented in Ref. [13]) suggests that Germany is the most 'tornado-prone' country in Europe with five times more events in Germany than in Italy. In light of the information included above this would in turn indicate an average of about 50 tornadoes per year!

Ref. [15] estimates this number to be less than 10. Furthermore, recent contacts with the German Weather Bureau revealed that tornado events in Germany are very unusual and apart from Wegener (who quoted 46 events for the period of 1456 to 1913) there is very little information available on recent tornadoes. (Five reports on specific summer events in 1947, 1948, 1952, 1968 and 1983 have, however, been published.)

5.6. *Republics of the former USSR*

The interest and research on tornadic events in the former USSR was sparked by a devastating tornado in 1984 which was characterised by wind speeds exceeding 100 m/s. Following this event [16] analysed and summarised 248 tornadoes which occurred in between 1844 and 1986. In more recent years it includes about 10 events per year.

The majority of tornadoes occurred in the European part of the former USSR (Baltic Republics, Ukraine, White Russia and part of the Russian Republic). As the information on the geographical distribution given in Ref. [16] is very limited, only an approximate analysis of the mean rates of occurrence for various republics was possible. This analysis revealed rates of occurrence of between 2 and 4×10^{-6}/yr/km^2 for Ukraine, White Russia and Moldavia.

5.7. Other countries

Tornadoes have been reported in Scandinavia and several Swedish events have been documented. Although an estimate of the frequency of occurrence is very difficult due to the sparse population of the country, less than 10 events per year are suggested [17]. This would correspond to an occurrence rate in the order of 1×10^{-5}/yr/km^2.

A tornado-prone belt extending over Estonia has been referred to in several references [18]. The estimate of the annual rate of occurrence of tornadoes can be made on the basis of one which refers to 30 events occurring between 1960 and 1984. This implies a mean rate of occurrence of about 3×10^{-5}/yr/km^2.

Tornado events were also reported in Holland, Spain, Switzerland and Malta.

6. Africa

Tornado events have been recorded in several Southern African countries (Botswana, Swaziland and Namibia) and possibly over Liberia, Ivory Coast and Ghana. No tornadoes have been reported in Northern Africa although they do occur across the Mediterranean Sea in Italy and Spain.

Tornado activity in South Africa for the period 1905–1991 has been investigated in Ref. [3]. An average of about 3 tornadoes per year has been reported. The map of the mean annual rate of tornado occurrence per unit area for the period 1948 to 1991 is shown in Fig. 5. This map has been developed using a Kriging geostatistical analysis [19] which allows the weighting of not only the geographical distribution of tornadoes but also the correlation between their relative strength (i.e. F-scale indicator). Tornadoes F0 have been excluded from this analysis as many of these events have gone unreported or have been reported as strong local winds.

7. Asia and Pacific Rim

The occurrence of tornadoes in China and the Asian portion of the former USSR has been mentioned in Refs. [13,15]. Reference [15] refers to China having between 10 and 100 tornadoes per year, whereas the map presented in Fig. 1 does not indicate any events. Ref. [16] lists a relatively small number of events in Siberia and the southern Asian regions of former USSR.

The climatology of tornadoes in India and Bangladesh was reported in Ref. [20]. Fifty-one events occurred, since 1835, mostly on the northeastern fringes of India and

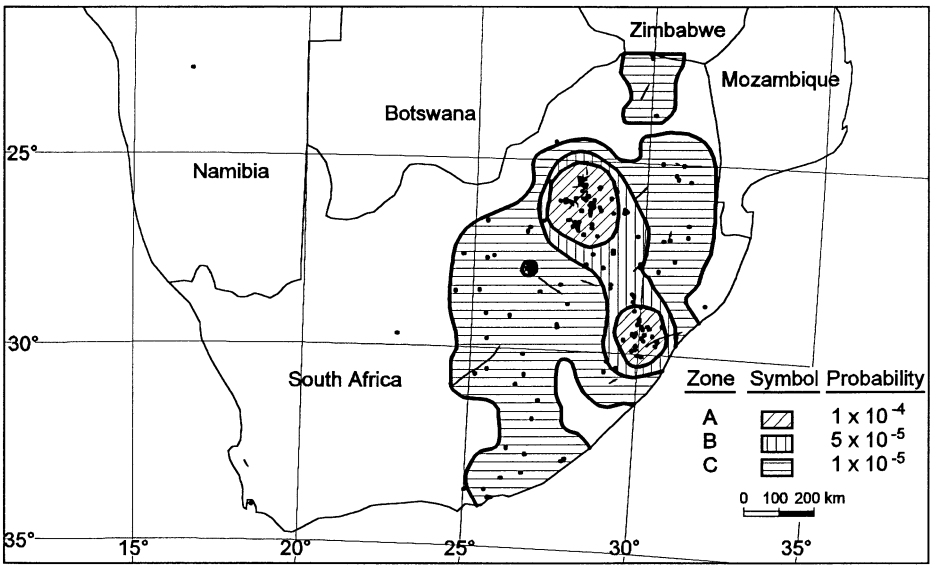

Fig. 5. Map of mean rate of occurrence of South African tornadoes [3].

in Bangladesh. In between 1972 and 1978, 13 tornado events occurred in the area approximately coinciding with Bangladesh. Considering the entire area of the country, this gives a frequency rate of occurrence of about 1×10^{-5}/yr/km^2.

The available information from the Pacific Rim is limited to Japan. In Ref. [21] a reference is made to over 200 tornadoes and waterspouts in Japan. An average of about three events per year can be inferred from Ref. [21] and seven is quoted in Ref. [22].

8. Australia and New Zealand

Publications on tornado occurrence in Australia reveal some contradictions.

Clarke [23] comes to the tentative conclusion that tornado-like storms in Australia are 'on the whole about as frequent as, but much less intense than, North American tornadoes'.

An investigation reported in Ref. [24] suggests an average of 15 tornadoes per year in New South Wales and that 36% of severe local wind storm days contain tornadoes. Ref. [2] reports the average number of tornadoes per year for Australia as 14.6. It is apparent that the occurrence rate of tornadoes given in Ref. [24] is higher than that given in Ref. [2] (as tornadoes occur not only in NSW but also in Queensland and on the west coast). Furthermore, the figure given in Ref. [2] is also higher than that which could be inferred from Ref. [23].

Analysis of Australian tornado climatology [25] revealed the highest mean rate of occurrence in the Sydney area to be more than 8×10^{-5}/yr/km^2. More recently,

Ref. [26] re-analysed the available information on Australian tornadoes and mapped 348 events which occurred between 1960 and 1992 (on average 29 tornadoes per year). In the Sydney metropolitan area, an average of 6 tornadoes per year is reported over 26 000 km^2 (i.e. probability of 2.3×10^{-4}/yr/km^2).

The issue of low population density affecting the detection of events was considered in Refs. [26,27]. Contradictory conclusions were reached: the latter implies that low population density inland affects the detection of tornadoes, whereas the first reference suggests that only the coastal areas, and not inland Australia, are in fact prone to severe thunderstorms and tornadoes. Ref. [27] also concludes that the occurrence rates of tornado-like storms, normalised according to population density suggest that certain parts of Australia experience a similar frequency of tornadoes to parts of the USA.

Contacts with the Australian Bureau of Meteorology [28] provided access to the Severe Thunderstorm Data-Base which includes nearly 700 tornadoes which occurred between 1795 and 1996, and are recorded on a $1^\circ \times 1^\circ$ geographical grid. On the basis of this information the development of contour lines of the mean rate of tornado occurrence was undertaken. For this analysis only the events which occurred between 1985 and 1995 were considered. As the F-scale rating is not available for all of these events, the rating was ignored and the development of the contour lines was based on a similar method as for France and Austria. The resulting map of the mean rate of occurrence is presented in Fig. 6. It can be seen that two tornado-prone zones are apparent and that the highest rate of occurrence of 1×10^{-5}/yr/km^2 is obtained.

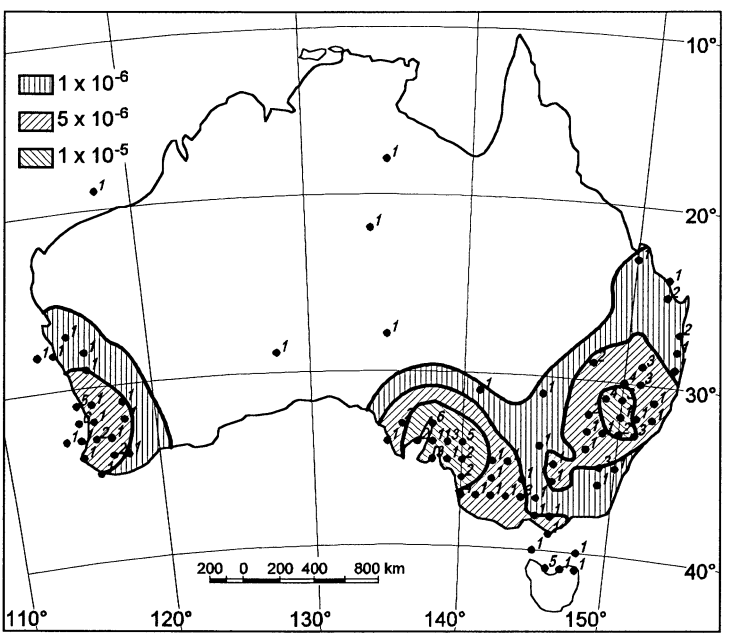

Fig. 6. Map of mean rate of occurrence of Australian tornadoes.

Although this finding does not contradict the higher rates of occurrences for very localised areas obtained in Ref. [26] it contradicts the estimates presented in Ref. [27]. On the other hand this finding supports the statement by Fujita [2] in which frequency of Australian tornadoes is at least one order of magnitude smaller than in the USA.

The most recent analysis of New Zealand tornadoes has been reported in Ref. [29], which considers more than 230 events and implies an average of 17 tornadoes per year.

9. Conclusions

A summary review of the tornado occurrences throughout the world has been presented. Maps of the mean rate of tornado occurrence for France, Austria and Australia have been developed. The existing discrepancies between various sources of information and countries have been highlighted. More cooperative efforts in this respect, especially in Europe, are necessary. In fact, as one of the outcomes of the present research, a joint initiative between Hungarian and Austrian Weather Monitoring Authorities will be undertaken.

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