An Increase in the Number of Tornado Reports in Brazil

MARIA A. F. SILVA DIAS
Department of Atmospheric Sciences, University of São Paulo, São Paulo, Brazil

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ABSTRACT
This paper presents the development of tornado reports in Brazil since the middle of the twentieth century, both for the country as a whole and for the five regions of Brazil: the south, southeast, central-west, northeast, and north. No official tornado registry exists in Brazil so the reports come from various sources. Most of the tornadoes reported are from the south and southeast regions. The low number of reports for the central-west regions suggests, in view of the literature on intense storms and mesoscale convective complexes, that most tornadoes cases go unreported. The increase in tornado reports is compared to the evolution of population density and communications, with the latter represented by the evolution of local television stations and the popularization of the Internet. One particular event is a new Web site for volunteer tornado reports, which has completely changed the trends of tornado reports. Another possible cause for an increase in the number of tornado reports in the south and southern regions could be a shift in climate variability in this region in the 1970s, which has been reported by several authors. However, the increase in rainfall and extreme events reported by these studies point to an increase of as much as 40%, which is not compatible with the observed tenfold increase in tornado reports.

1. Introduction
One of the main threats of global warming as summarized by Solomon et al. (2007) is the possible increased frequency of weather extremes. This is a statement that has been frequently broadcast by the media and is understood by the general public, at least in Brazil, where every single occurrence of strong winds, hail, or floods immediately poses the question to climate scientists and to meteorologists: Is this phenomenon due to global warming? Balling and Cevenry (2003) commented that in the United States there appears to be a substantial mismatch between public perception and actual trends in severe storm activity. A recent opinion survey published by one of the leading newspapers in Brazil, O Estado de São Paulo, indicates that 88% of the 1000 people interviewed (from different regions and social backgrounds) know about global warming, and 80% said that they have noticed a climate change in recent years; 89% of those who think that they have perceived the climate change, classify it as “bad” (O Estado de São Paulo, 6 December 2009, p. A29).

Tornadoes are the most violent feature associated with severe storms, though they have a short lifetime (usually from a few minutes to 20 min), a short pathlength (usually less than 20 km), and small dimensions (a few hundred meters in diameter). Though they were practically unknown to most Brazilians just a few decades ago, tornadoes have been mentioned in the news more and more in recent years, and even more educated segments of society seem to believe they are a new weather phenomenon that Brazil had never experienced before.

Judging from the material in the international literature, tornadoes are practically absent in Brazil. Fujita (1973) was the first to attempt to map the geographical occurrence of tornadoes in the world. Goliger and Milford (1998) and Brooks and Doswell (2001a) updated Fujita’s world statistics on tornadoes, including more cases. In both studies, tornadoes in South America were detected only in Argentina, with very few cases in the southern region of Brazil.

According to Doswell et al. (1999), tornado reporting in the United States is a result of a combination of the public forecasting services and volunteer spotter programs. They state that in March 1952, the U.S. Weather Bureau started a Severe Local Storms Forecasting unit, which had the direct result of an increase in tornado reports from an average of less than 200 to 1200 yr⁻¹ by
the end of the 1990s (see also Verbout et al. 2006). Brooks and Doswell (2001b) attribute this increase to better observation and reporting procedures.

In Brazil, there is no official reporting system for tornadoes, but spontaneous volunteers have helped raise the awareness that tornadoes do occur and that they are a potential threat to life and property. This article addresses the increase in tornado reports found in the media, newspapers, television, and Internet in Brazil. Though this kind of reporting is irregular and unscientific, it is the only available source for this phenomenon, other than the very few cases that have reached the scientific literature.

The frequency of tornado reports in the various regions of Brazil is presented, and apparent trends over a few decades are discussed to attempt to explain the increased frequency, mostly based on the increase in media coverage and the advent of the Internet. Section 2 describes the data sources used, section 3 reports the geographical distribution and apparent trends, section 4 discusses other possibilities as causes for the observed trends based on climate variability and/or climate change, and section 5 presents the conclusions.

2. Data

There is no official compilation of tornado episodes by the Brazilian government weather service. The surface network of meteorological stations has improved considerably over recent years, mostly using automated weather stations that do not report severe weather–related phenomena. The weather stations that do have visual observations are restricted to larger cities.

Since the early twentieth century sporadic cases of tornadoes have been reported, with a few appearing in the international literature (De Sampaio Ferraz 1927; Dyer 1988, 1994; Silva Dias 1999), but most of those are in Portuguese, having been published in the proceedings of local meteorological meetings or local meteorological journals. Particularly relevant are the reports by Nechet (2002) and Marcelino (2003), which present the general conditions of tornado occurrence and the documentation of damage associated with tornadoes.

After the popularization of the Internet, in 2005 a group of meteorologists started to document tornado cases and publish their associated features on a Web site (http://www.temposeveronobrasil.com; see the acknowledgments section at the end of this paper). They also tried to compile past tornado events that were scattered over different publications and newspaper reports. With their permission, the data from their site, as of early 2009, will be used here. With the intention of confirming the occurrence of tornadoes, only cases with an associated newspaper article or television news report are used. The reason for choosing only documented cases is to ensure the reliability of the tornado cases.

To relate tornado observations with area and population of each of the five regions of Brazil (see Fig. 1), the information compiled by the Brazilian Federal Government (available online at http://www.ibge.gov.br) is used. Because most of the tornado occurrences are documented through local television stations, a possible indicator of media coverage is the number of affiliated local television stations of the largest network in Brazil, TV Globo, which today reaches 99% of the country. Their Web site (http://comercial.redeglobo.com.br/atlas2004) shows the present geographical distribution of affiliated local stations, and Munhoz Rosario (2008) describes the evolution of the TV Globo network since 1965.

3. Geographical distribution and trends of tornado reports

Brazil is a country with various regional climates, from very equatorial in the north to the subtropical climate in the south. The five political regions in Fig. 1 are also distinguished by well-defined regional climates. Satyamurti et al. (1999) describe the average climate of each region and emphasize the differences in annual rainfall regimes. With respect to intense storms that might generate damaging winds and eventually tornadoes, the work of Zipser
et al. (2006) indicates that the south region (see Fig. 1) is close to the maximum occurrence and intensity of heavy storms in South America, which is centered in northern Argentina. According to their work, intense storms can also be found in other regions—with lower frequency in the southeast, central-west, and north, and rarely in the northeast.

The list of tornadoes reported in Brazil from the various sources mentioned in the previous section, up to 2008, shows a total of 158 cases that can be separated into each of the five regions of Fig. 1. Figure 2 shows the cumulative number of tornado reports from 1960 to 2008. Three reports from before 1960 have been left out of the figure (1923, 1927, and 1957). Each report has an associated classification given by the source of the information. Table 1 shows the number of times each classification is used. The Fujita F scale (Fujita 1971) is used in some cases; in others, the authors of the report only mention a tornado, funnel cloud, or waterspout. It may be seen that the highest use of the Fujita scale is F3, which is seen in six cases. Waterspouts are tornadoes over water and are usually classified as F0 in Brazil. In Fig. 2 all of the cases that have been included in Table 1 are used. Figure 3 shows the geographical location and season of each report, excluding funnel clouds, which are not considered developed tornadoes.

Figures 2 and 3 show that most of the tornado reports are in the south region, followed by the southeast, north, northeast, and central-west, in this order. Referring again to Zipser et al. (2006), specifically to their Fig. 4, it can be seen that severe thunderstorms have been detected over most of Brazil, with the clear exception of the northeast region. The south region is in the usual track of most of the mesoscale convective complexes (MCCs) of subtropical South America, which are one of the important sources of tornadoes in northern Argentina, according to Velasco and Fritsch (1987). Durkee and Mote (2010) have a new climatology of MCC occurrence in South America and show that most of the south, southeast, and central-west regions are affected. As seen in Figs. 2 and 3, and the references above, it is possible that most tornadoes in the central-west region, especially in its southern half, are not reported.

Satyamurti et al. (1999) state that, in spite of the Amazon basin having the largest annual rainfall in the country, the frequency of thunderstorms is surprisingly low. There are tornado events, however, reported close to the northern coast, and along the Amazon River close

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**Table 1. Number and percent of tornado, waterspout, and funnel cloud classification by the various sources listed in text (but mainly from http://www.temposeveronobrasil.com).**

<table>
<thead>
<tr>
<th>Tornado classification</th>
<th>No.</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>F3</td>
<td>6</td>
<td>3.8</td>
</tr>
<tr>
<td>F2</td>
<td>5</td>
<td>3.2</td>
</tr>
<tr>
<td>F1/F2</td>
<td>4</td>
<td>2.5</td>
</tr>
<tr>
<td>F1</td>
<td>6</td>
<td>3.8</td>
</tr>
<tr>
<td>F0/F1</td>
<td>5</td>
<td>3.2</td>
</tr>
<tr>
<td>F0</td>
<td>9</td>
<td>5.7</td>
</tr>
<tr>
<td>Tornado</td>
<td>69</td>
<td>43.7</td>
</tr>
<tr>
<td>Funnel cloud</td>
<td>24</td>
<td>15.2</td>
</tr>
<tr>
<td>Waterspout</td>
<td>30</td>
<td>19.0</td>
</tr>
<tr>
<td>Total</td>
<td>158</td>
<td>100.0</td>
</tr>
</tbody>
</table>

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**Fig. 2. Cumulative number of tornado and waterspout reports in each of the five regions of Fig. 1.**

**Fig. 3. Location and season of tornadoes and waterspouts reports (funnel clouds have not been plotted). December–February (DJF) is summer, March–May (MAM) is fall, June–August (JJA) is winter, and September–November (SON) is spring.**
to the cities of Manaus (3°6′07″S, 60°1′30″W) and Santarem (2°26′35″S, 54°42′30″W). This is a region where intense squall lines are seen (Cohen et al. 1995; Rickenbach 2004). Interestingly, in the north region most of the cases have been reported close to the northern coast and documented by Nechet (2002), a professor of Meteorology at the Federal University of Para´ (located in Bele´ m, 1°27′21″S, 48°30′16″W), who has been collecting cases for the last 30 years. In the Amazon, basin blow downs associated with heavy rainfall events have been detected as forest disturbances by remote sensing, as reported by Nelson et al. (1994) and Espirito-Santo et al. (2010). These seem to be unidirectional wind events also called downbursts or microbursts (Fujita 1981), which are intrinsically different from tornadoes, although in some cases they are as destructive.

A possible relationship between tornado location and topography has not been sought here. Certainly the parent thunderstorms have a preferred location of initiation over the mountains but because of a lack of reliable data on tornado lifetime and trajectory, no attempt has been made to classify them according to altitude.

Several other features can be found in Fig. 2. Perhaps the most outstanding is the increasing number of tornado reports over the last three decades. Doswell et al. (1999) observed that in the United States tornado reports increased from 220 yr−1 in the 1950s to 1200 yr−1 in the late 1990s. The increase is related to the more effective observation of tornadoes resulting from several causes, including increasing public awareness. The Brazilian reports are just a small fraction of those in the U.S. case. However, we can still ask why the number of reports increased tenfold in three decades. From the personal experience of the author, the increase in the number of tornado reports has already resulted in revisions of nuclear power plant and power line specifications in the south and southeast regions of Brazil and risk assessment by insurance companies. In these cases the companies involved worked in the past from the premise that tornadoes did not happen in Brazil. To answer the question as to why the number of tornado reports has increased, the first reply is to relate it to population density, because tornado reports depend on direct observations made by people. The areas of the five regions may be seen in Table 2, where the evolving population of the five regions of Brazil from 1940 to 2000 is also included. The population density in 2000 is also shown in Fig. 4.

The southeast region shows the highest population density, followed by the south, northeast, central-west, and north regions. As seen in Table 2, the central-west and north regions are those where the population has increased by a factor of around 10 in 60 yr, though their population density is still the lowest. The north region includes the Amazon forest, which occupies most of the area. In the central-west region the original savannah has been mostly replaced by agriculture in the last 30 years with huge areas growing crops, such as soybeans, corn, and cotton, and also grass for pasture.

<table>
<thead>
<tr>
<th>Region</th>
<th>S</th>
<th>SE</th>
<th>CW</th>
<th>NE</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (km²)</td>
<td>575,316</td>
<td>927,286</td>
<td>1,604,852</td>
<td>1,556,001</td>
<td>3,851,560</td>
</tr>
<tr>
<td>1991</td>
<td>2000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.74</td>
<td>5.74</td>
<td>7.74</td>
<td>11.75</td>
<td>16.49</td>
<td>19.03</td>
</tr>
<tr>
<td>18.34</td>
<td>22.55</td>
<td>30.63</td>
<td>39.85</td>
<td>51.73</td>
<td>62.74</td>
</tr>
<tr>
<td>1.26</td>
<td>1.74</td>
<td>2.94</td>
<td>5.07</td>
<td>7.55</td>
<td>9.42</td>
</tr>
<tr>
<td>14.43</td>
<td>17.97</td>
<td>22.18</td>
<td>28.12</td>
<td>34.81</td>
<td>42.49</td>
</tr>
<tr>
<td>1.46</td>
<td>1.84</td>
<td>2.56</td>
<td>3.60</td>
<td>5.88</td>
<td>10.04</td>
</tr>
</tbody>
</table>

Fig. 4. Percentage of all tornado and waterspout reports (%), population density (number of inhabitants per square kilometer), and affiliated TV Globo stations (number per 0.5 million km²) for each of the five regions of Fig. 1. The vertical axis uses the units in parentheses. Population density and number of TV stations are for the years 2000 and 2008, respectively.
Another fact to consider in the report of tornado events is the evolution of the number of local television stations, which was helped by the advent of communication satellites, as reported by Munhoz Rosario (2008). Figure 5 shows the evolution of the number of TV Globo local stations, per 0.5 million km², from 1965 until 2008. The area of 0.5 million km² is approximately the area of the south region (Table 2), the smallest of the five regions.

The local stations provide a focal point for the dissemination of news and, in particular, tornado events. A simple phone call will trigger a local news crew to visit the reported area, and the occurrence will be in every home by the time of the national evening news. This is how a tornado report can easily be in the newspapers and be registered on a Web site. Figure 5 shows how the television coverage by local stations has increased in the various regions of Brazil in the last four decades. When comparing Figs. 2 and 6, we can see that the increasing trend of affiliated TV Globo stations in the south region precedes the increase in the number of tornado reports by a few years, but the rate of increase in tornado reports is higher after the mid-1990s, and it increases again in the 2000s. For the southeast region, particularly in its southern half, there is a frequency of intense storms similar to the south region, according to Zipser et al. (2006), and possibly more MCC than the south region according to Durkee and Mote (2010), so it is expected that a large number of tornadoes go unreported because of both a low population density and a low number of local television stations. In Fig. 4 the percentage of the total number of tornadoes reported in each region is compared with the population density and the number of television stations. Both the central-west and north regions are seen as places where severe weather can easily go undetected.

Table 4 shows the percentage of reports per region and season. The south and southeast regions are those with the highest number of reports, and consequently above, thunderstorms are seldom observed in the northeast region. However, in the central-west region, particularly in its southern half, there is a frequency of intense storms similar to the south region, according to Zipser et al. (2006), and possibly more MCC than the south region according to Durkee and Mote (2010), so it is expected that a large number of tornadoes go unreported because of both a low population density and a low number of local television stations. In Fig. 4 the percentage of the total number of tornadoes reported in each region is compared with the population density and the number of television stations. Both the central-west and north regions are seen as places where severe weather can easily go undetected.

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the seasonal variation is more reliable. For the other regions the seasonality may change if more reports are added in the future, so no attempts to discuss them will be made. It can be seen that the seasons with most tornado reports in the south region are spring and summer, while for the southeast region, fall has the majority of the reports. Even though the low number of reports does not provide reliable evidence, it is interesting to note that for the north region most of the cases are for June–August, which is the transition between the wet and the dry season in the northern part of the north region. At this time of the year, Alcântara et al. (2011) and Cohen et al. (1995) report the occurrence of Amazonian squall lines that propagate from the northern coast toward the southeast with lifetimes that may reach 24–48 h. These squall lines have been associated with damaging wind in the region, so they may also be associated with tornado occurrences.

A further examination of tornado intensity can be made by grouping the reports in Table 1 into the various categories of the F scale. Today in the United States, the original F scale has been replaced by the enhanced Fujita (EF) scale (McDonald and Metha 2006). However, the reports used in this study all make references to the original F scale, so no attempts will be made to relate to the new scale, although it is undoubtedly a more consistent form of registration. The new EF scale requires an examination of the vulnerability of the structures affected by the tornado, and this should be done just after the episode and not years after the fact as is the case here.

Because of the comparatively small numbers of tornado reports in Brazil, it is not meaningful to look into the trends of tornado intensity as measured by the F scale. However, it is still worthwhile to compare the number of cases in each category with those in other countries included in the work of Brooks and Doswell (2001a). For this comparison, the cases in Table 1 that are classified as F0/F1 and F1/F2 have been reassigned into the two neighboring categories in the following two ways: 1) by adding them into the lower-intensity category and 2) by adding them into the upper category. The resulting numbers have been labeled as Brazil 1 and Brazil 2, respectively, and used in Fig. 6. Cases that are classified in Table 1 as either a tornado or waterspout have all been added to the F0 category. Figure 6 shows the plot of the resulting numbers and compared them with the numbers in Fig. 4 of Brooks and Doswell (2001a) for various countries. For this comparison the Brazil cases have been scaled in the same way as in Brooks and Doswell (2001a), by attributing the number 100 to the F2 category and adjusting the other categories accordingly.

The two cases for Brazil stand out by having a relatively larger number of F0 cases when compared to other countries. There are at least two reasons for that—one is that the grouping of all cases labeled just “tornado” in Table 1 may include some cases with higher intensities, and the other reason is that, as a subtropical country, Brazil may have more weak tornadoes than the other countries that are used as comparison. The apparent lack of proper classification of the tornado reports points toward the need for an official registration of tornadoes with a program for training observers in their classification as is the case for the United States, reported by Doswell et al. (1999). In section 5 this will be mentioned again with respect to recommend actions to the weather service.

### 4. Global and regional changes in the circulation

The analysis of the observed changes in the number of tornado reports in Brazil would be incomplete if the question as to whether at least part of the increase could be a result of climate variability was not addressed.

Tornados are observed in association with deep convective clouds, cumulonimbi, which are also responsible for large amounts of rainfall. Rainfall has been extensively studied for all regions in Brazil, and, in particular, increasing trends over the last decades have been reported for the south and southeast regions of Brazil.

Of the five regions in Brazil only the south and perhaps the southeast have enough tornado reports to allow a more detailed interpretation of the causes of the observed trends. These regions of Brazil are part of the La Plata Basin (LPB), where a number of studies have indicated that a change in rainfall has occurred since the 1970s. Boulanger et al. (2005) show that there are upward trends in annual rainfall, with a maximum difference between 1976 and 2001, and from 1950 to 1974, centered in the south region of Brazil around 28°S latitude. Liebmann et al. (2004) show an increasing trend in annual rainfall of about 8 mm yr$^{-1}$ for the summer season and a 40% increase in this trend from 1976 to 1999. They also mention that the increase is due to more rainy days and more rain per event, and that the number of extreme rainfall events more than doubled over the same period. Penalba and Robledo (2010) showed that...
larger increases in rainfall in the LPB in the last 50 yr have occurred in the summer, spring, and fall, especially for extreme events of daily rainfall. Interestingly, the peak of tornado events in the south region is in spring and summer, when, according to Table 4, 74% of the cases were reported. In the southeast region 83% of the cases occur in summer and fall.

However, the events of extreme daily rainfall do not necessarily correspond to the systems associated with severe weather that trigger tornado events. As far back as Marwitz (1972), but also more recently in Doswell (2001), the low efficiency of rainfall has been associated with high values of wind shear and severe weather. Basically when a cumulonimbus cloud grows in an environment with strong shear, it will be subject to entrainment of environmental air, which is usually cooler and drier and will lead to the rapid evaporation of raindrops. The entrainment of dry air will lead to the formation of cloud-scale downdrafts and the potential formation of damaging winds (e.g., James and Markowski 2010). Wind shear is a feature that is more intense in midlatitudes than in the tropics (e.g., Cotton and Anthes 1989), thus partially explaining why the Midwest of the United States has so many severe storms with associated tornadoes while more tropical regions have fewer tornado events.

An investigation of the relationship between intense storms and wind shear has been attempted by certain authors. In the particular case of subtropical South America, a good indication of the increase in wind shear is the increase in speed of the upper-level jet and/or of the lower-level jet, which are dominant features in the MCC cases (Velasco and Fritsch 1987; Vera et al. 2006). Carvalho et al. (2005) show that Pacific sea surface temperature has an impact on the upper-level wind speed over the south region, and Barros et al. (2002) discuss the effect of this on both the upper- and lower-level jets. However, an evaluation of the past trends of the wind shear over the region appears to be lacking.

There is considerable discussion as to whether the observed changes in rainfall, and possibly circulation, over the south region of Brazil are due to natural climate variability associated with multidecadal cycles related to the Pacific and Indian Ocean sea surface temperature evolution (Kayano and Andreoli 2007), or whether they are already a manifestation of climate change. Anyway, recent work by Carvalho et al. (2010), among others, points to the early 1970s as a time when an abrupt change in rainfall patterns was observed in the south region, resulting in an enhancement of the moisture flux and a significant change in the flow of the Paraná River. The climatology of intense convective systems, such as those by Zipser et al. (2006) and Durkee and Mote (2010), do not cover a large enough time span to confirm the possible effect of an enhanced moisture flux on storm severity. However, according to Herdies et al. (2002), Nieto Ferreira et al. (2003), and Salio et al. (2007), it can be seen that when there is an enhancement of the moisture flux to the south and southeast regions through the low-level jet, this favors MCC formation and possibly tornadoes.

From the review of the literature, it may be concluded that there are in fact several changes in the climate conditions of the south and southeast regions that favor the occurrence of intense convective systems, as will be commented on further in the next section.

5. Discussion and conclusions

As mentioned in most studies on the observed changes in weather patterns, rainfall, or storm severity, the question arises as to whether they are due to natural climate variability or a climate change induced by global warming. Here we have shown the case of a tenfold increase in tornado reports in Brazil, mainly in the south and southeast regions, which is primarily due to the widespread use of communications to report these occurrences, a combination of an increase in number of local TV stations and the use of the Internet to communicate and register the cases. There is, however, a possibility that the actual number of tornadoes has actually increased in the south region after the 1970s as a result of a change in global circulation induced by warming of the Pacific and Indian Oceans. Whether such a change would actually support a tenfold increase of tornado occurrences is doubtful because in other parts of the world this has not been reported according to the literature survey. Del Genio et al. (2007) suggest that in a warmer climate in the central-eastern United States little change will be seen in severe storm occurrence with global warming, but they point out that severe storms will occur more often. This may also be the case for subtropical South America, where Zipser et al. (2006) mention that there have been record-breaking intense storms. However, because of the large climate variability of the region, the attribution of causes remains an unsolved problem.

From another point of view, it is plausible that a large number of tornadoes still go unreported, mainly in the north and central-west regions, where the population density is low and coverage by local television stations is not extensive enough to ensure detection of possible cases indicated by satellite based studies of intense storms.

The most obvious conclusion, and recommendation, in this study is that there should be an official registry of tornado reports in Brazil. The effect of a non-governmental initiative of volunteers that decided to
keep a documentation of tornado reports has clearly shown that tornadoes are more frequent in Brazil than one could judge from the literature. And, if this is the case, life and property are endangered, and these threats should be addressed by the authorities.

Acknowledgments. The data from the website http://www.temposeveronobrasil.com have been used with permission. (This site may be temporarily unreachable but contact information may be found at http://dawhois.com/siteinfo/?query=temposeveronobrasil.com.) This study has been supported by grants from FAPESP, CAPES, and CNPq. My thanks to B. Biazotto for help with the figures.

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