P1.18 THE NEED FOR AN IMPROVED DOCUMENTATION OF SEVERE THUNDERSTORMS AND TORNADOES IN SOUTH AMERICA.

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1. INTRODUCTION

The subtropics and mid-latitudes of South America, east of the Andes Mountain Range, have been recognized as prone to severe convective weather for quite some time (Fujita 1973; Velasco and Fritsch 1987; Silva Dias 2000; Brooks *et al* 2003; Nascimento 2004, 2005), including the occasional occurrence of tornadoes (Schwarzkopf 1982; Antonio *et al* 2005; Nascimento and Marcelino 2005a,b; Held *et al* 2005a,b; among others).

Despite that, there is no institutionalized procedure for a systematic documentation of severe thunderstorms in that part of the world, and the few efforts for documenting severe weather episodes are conducted by individual initiatives with little or no formal support (Schwarzkopf 1982, Nechet 2002, Torena 2003, Antonio *et al* 2005, Nascimento and Marcelino 2005a). The availability of a reliable and standardized archive of severe weather reports is fundamental for any quantitative investigation of severe storms. This is particularly crucial in South America, where mesoscale observing systems — including weather radars — are far from adequate, being confined to localized regions in the continent (e.g., Nascimento 2004).

Building on the North American experience in documenting severe weather reports, we discuss the relevance of maintaining such archives to the study of severe thunderstorms in South America, including the development and testing of techniques to predict severe weather in that continent. We also describe possible ways to start addressing the generation of a severe weather data bank based upon the infra-structure already existent in at least a few countries, such as Brazil.

2. SEVERE THUNDERSTORMS IN SOUTH AMERICA

Severe deep convection has been observed in the entire South American continent, except perhaps over the Andes Mountains and the far southern Patagonia. However, a number of studies (Velasco and Fritsch 1987; Silva Dias 2000; Brooks *et al* 2003; Zipser *et al* 2004; Held *et al* 2005a) suggest that the most significant severe weather episodes — associated with large hail, damaging winds and tornadoes — are concentrated within the 20-40°S latitude range, east of the Andes (Figure 1).

Figure 1: Map of the approximate geographical region in South America where severe convective weather is most frequent (inside the red curve). Several important metropolitan areas are located in this sector, including Buenos Aires (Argentina), Montevideo (Uruguay), Asunción (Paraguay), Curitiba, Porto Alegre and São Paulo (Brazil).

The combination of ingredients for severe convection: low-level moisture, convective instability and vertical wind shear, necessary for severe storms, is occasionally found in that region, especially from late September to May (a more detailed discussion and additional references can be found in Silva Dias 2000, Barnes 2001, and Nascimento 2004, 2005a).

The threat that severe weather episodes pose to the society is evident in subtropical South America. Figure 2 displays a rather simple ten-year statistics (from 1990 to 1999) of the main natural disasters that occurred in Paraná state, in southern Brazil, based on the archive of reports from the Civil Defense (CD) System of that state. Considering only hail events and thunderstorm-induced damaging winds (phenomena more clearly related to severe storms), nearly 50% of the natural disasters

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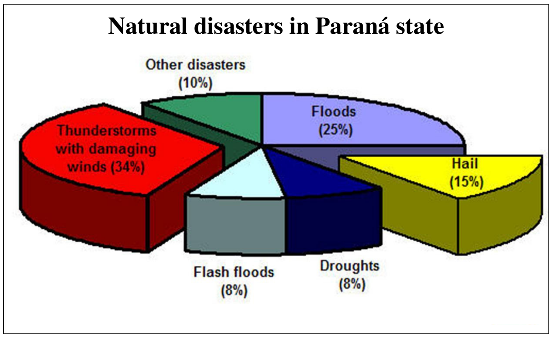


Figure 2: Statistics of the main natural disasters reported in Paraná state (southern Brazil) from January 1990 to December 1999. (Adapted from www.pr.gov.br/defesacivil/calamidades.html)

reported by the CD were associated with severe convective weather. Hence, noting that they are relatively rare compared to other atmospheric systems, severe storms are responsible for a disproportionally large number of high-impact episodes for the society, as recognized for other parts of the world as well (e.g., Doswell 2005).

In an annual basis, electric power utilities in South America also report important operational losses associated with severe weather (Assuncão 2002). Frequent outages associated with power lines downed by severe thunderstorms have become an issue of particular interest for the electric power sector in countries like Brazil (e.g., Lima and Menezes 2004). Such developing awareness motivated a recent workshop addressing the impact of severe convective storms on the operation of power utilities in that country (www.furnas.gov.br/rindat/workshop2005.htm).

As in other areas of the globe, a small — but still to be determined — percentage of the severe weather episodes in subtropical South America can reach significant proportions. A recent example was the large F3 tornado that struck the town of Indaiatuba, interior of São Paulo state (around 23°S) in Brazil, on 24 May 2005 (Held *et al* 2005b, Nascimento and Marcelino 2005b, Amorim *et al* 2005). Figure 3a, obtained from a video, shows a broad view of the Indaiatuba tornado and its parent low-level mesocyclone; the thick arrow indicates the sense of rotation. A close-up view of some of the sub-vortices produced is provided by Figure 3b, from the same video.

Other tornadoes of F3 intensity (and even stronger) have been also identified in other regions of South America (Argentina: Schwarzkopf 1982; southern Brazil: Marcelino *et al* 2005). A non-comprehensive list of severe weather episodes in southern and southeastern Brazil can be found at www.lemma.ufpr.br/ernani/torbraz.html, and brief case studies of tornadoes in Uruguay are found in Torena (2003).

Figure 3: Still frames from the 24 May 2005 Indaiatuba tornado video (Brazil). Thick arrow in (a) indicates the clockwise rotation of the tornado and of the parent low-level mesocyclone. Local standard time is shown on the top of each frame. The camera faces the north-northeast in (a), and northeast in (b). Courtesy of Rodovias das Colinas S.A.. (Adapted from Nascimento and Marcelino 2005b).

The points above refute the perception that South American severe local storms are too rare to justify a serious public awareness to the problem and a systematic research in that area. There ***is*** a strong demand for the assessment of operational strategies aiming at the identification and prediction of atmospheric conditions conducive to severe weather in that continent. One of the issues that make this task particularly challenging is the lack of a data bank of severe weather events. In the next section, we discuss the relevance of a standardized severe weather data archive to the development of research on the prediction of severe convective storms, based on the long and successful North American experience on that area.

3. SEVERE WEATHER ARCHIVES AND RESEARCH ON SEVERE STORMS FORECASTING: A NORTH AMERICAN EXPERIENCE.

The United States (US) has the greatest number of severe thunderstorms and tornadoes worldwide. A long history of significant episodes of destructive and deadly severe convective weather has raised an important public awareness around the threat posed by these weather systems. Beginning around 1925, the scientific interest in understanding and predicting severe storms combined with public awareness, developed a "culture" of preparedness for severe weather in the US, where accurate and timely warnings, and spotting and reporting severe storms as they occur, became important activities that are commonplace today (Doswell *et al* 1999).

The influence of the increasing number of individuals and initiatives interested in ***reporting*** severe storms upon the number of tornadoes detected each year in the US during the second half of the twentieth-century is discernible, as shown in Fig. 4 (from Doswell *et al* 1999). The first spotter networks were set during the 1940's and

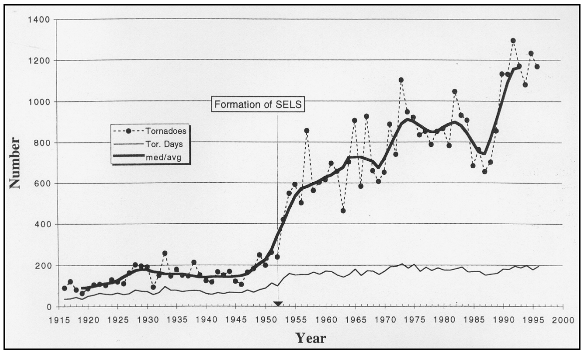


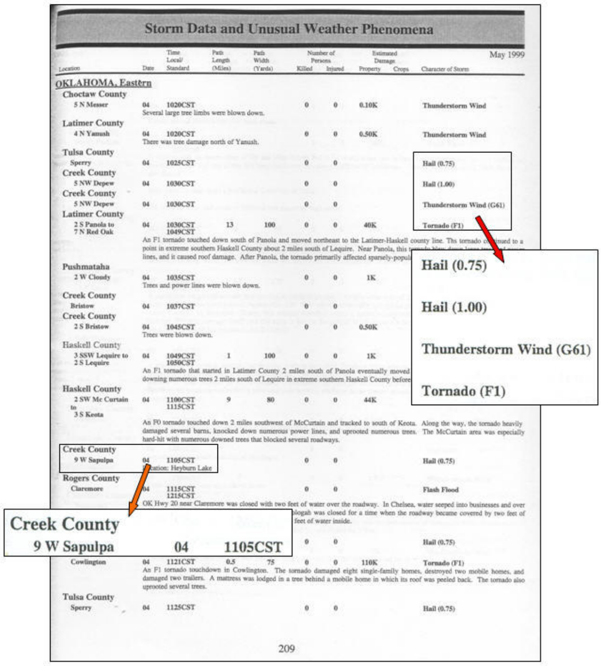
Figure 4: Number of tornadoes recorded annually in the US from 1916 to 1995 (solid circles: raw data; thick solid line: smoothed data; thin solid line: number of tornado days. From Doswell *et al* 1999).

1950's, after which the number of reported tornadoes increased considerably.

To a given extent, there exists a synergetic relationship between the (good-quality) reporting of storm events and severe storms research/forecasting which is not always recognized, but which is crucial. Storm spotting, conducted by meteorologists, NWS-trained volunteers, emergency management and law enforcement officials, in addition to information from NWS damage surveys, newspaper clipping services and the insurance industry, have contributed to the creation of a remarkable archive of severe weather reports in the US that dates back to 1950, known as *Storm Data.* (*Storm Data* contains reports from all types of storm hazards, not only from severe convection).

An example of the standardized information contained in *Storm Data* is shown in Figure 5. The information is compiled by the US NWS every month (from the sources mentioned above), and published by the US National Climate Data Center. The information provided by *Storm Data* has played some role on convective storms research (López *et al* 1995), particularly for climatological studies addressing the characterization of severe storms environments (e.g., Davies and Johns 1993, Thompson 1998, Evans and Doswell 2001).

For example, the classic study by Johns and Hirt (1987) on the definition and identification of derechos did use *Storm Data* as one of the main sources of information. Other severe weather archives and documentations are kept by operational centers such as the Storm Prediction Center, and by research groups. One quite evident usage of severe weather archives in research applied to convective forecasting is regarding the identification of the so-called "proximity soundings".



Storm Data and Unusual Weather Phenomena

May 1999

Location	Date	Time Local/ Standard	Path Length (Miles)	Path Width (Yards)	Number of Persons Killed	Number of Persons Injured	Estimated Damage Property	Estimated Damage Crops	Character of Storm
OKLAHOMA, Eastern									
Choctaw County									
5 N Messer	04	1020CST			0	0	0.10K		Thunderstorm Wind
	Several large tree limbs were blown down.								
Latimer County									
4 N Yanush	04	1020CST			0	0	0.50K		Thunderstorm Wind
	There was tree damage north of Yanush.								
Tulsa County									
Sperry	04	1025CST			0	0			Hail (0.75)
Creek County									
5 NW Depew	04	1030CST			0	0			Hail (1.00)
Creek County									
5 NW Depew	04	1030CST			0	0			Thunderstorm Wind (G61)
Latimer County									
2 S Panola to 7 N Red Oak	04	1030CST 1049CST	13	100	0	0	40K		Tornado (F1)
	An F1 tornado touched down south of Panola and moved northeast to the Latimer-Haskell county line. The tornado co inued to a point in extreme southern Haskell County about 2 miles south of Lequire. Near Panola, this lines, and it caused roof damage. After Panola, the tornado primarily affected sparsely-popul								
Pushmataha									
2 W Cloudy	04	1035CST			0	0	1K		
	Trees and power lines were blown down.								
Creek County									
Bristow	04	1037CST			0	0			
Creek County									
2 S Bristow	04	1045CST			0	0	0.50K		
	Trees were blown down.								
Haskell County									
3 SSW Lequire to 2 S Lequire	04	1049CST 1050CST	1	100	0	0	1K		
	An F1 tornado that started in Latimer County 2 miles south of Panola eventually moved downing numerous trees 2 miles south of Lequire in extreme southern Haskell County before								
Haskell County									
2 SW Mc Curtain to 3 S Keota	04	1100CST 1115CST	9	80	0	0	44K		
	An F0 tornado touched down 2 miles southwest of McCurtain and tracked to south of Keota. Along the way, the tornado heavily damaged several barns, knocked down numerous power lines, and uprooted numerous trees. The McCurtain area was especially hard-hit with numerous downed trees that blocked several roadways.								
Creek County									
9 W Sapulpa	04	1105CST			0	0			Hail (0.75)
	cation: Heyburn Lake								
Rogers County									
Claremore	04	1115CST 1215CST			0	0			Flash Flood
	OK Hwy 20 near Claremore was closed with two feet of water over the roadway. In Chelsea, water seeped into businesses and over ologah was closed for a time when the roadway became covered by two feet of feet of water inside.								
					0	0			Hail (0.75)
Cowlington	04	1121CST	0.5	75	0	0	110K		Tornado (F1)
	An F1 tornado touchdown in Cowlington. The tornado damaged eight single-family homes, destroyed two mobile homes, and damaged two trailers. A mattress was lodged in a tree behind a mobile home in which its roof was peeled back. The tornado also uprooted several trees.								
Tulsa County									
Sperry	04	1125CST			0	0			Hail (0.75)

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Hail (0.75)
Hail (1.00)
Thunderstorm Wind (G61)
Tornado (F1)

Creek County
9 W Sapulpa 04 1105CST

Figure 5: Sample page from the May 1999 issue of Storm Data (NCDC 1999), highlighting some key information such as: location, date and time of a given event (left box) and the character of the severe weather events (right box).

Proximity soundings (PSs) are loosely defined as atmospheric profiles, obtained from rawinsondes, that are representative of the large-scale atmospheric environment in which severe thunderstorms develop (at least, this is what PSs are intended to represent; Brooks *et al* 1994, 2003). Hence, before characterizing a sounding as a PS, one needs to identify where and when the severe weather event happened, which, in turn, ***depends on the available documentation*** (and on its accuracy).

Many studies have addressed the problem of forecasting severe convection utilizing the PS approach, by either using observed soundings or model-derived "soundings" — see Brooks *et al* (2003) and Nascimento (2005) for a long list of such studies. Despite some serious limitations of this approach (Brooks *et al* 1994; Markowski and Richardson 2004), several findings from climatological analysis of PSs in the US have been successfully translated into operational tools for forecasting, such as the determination of sets of convective indices for the characterization of severe weather potential (Thompson 2005).

Moreover, the accurate documentation of different types of severe events (as depicted in Fig. 5) is needed to meet the goal of developing forecast methodologies that not only identify environments conducive to severe weather in general, but that are capable also of discriminating distinct forms of severe weather (e.g., Brooks *et al* 2003).

The importance of severe storms archives is also substantial when assessing the accuracy and/or skill of a given convective forecast methodology: that is, the forecast verification issue. Accuracy measures (such as the false alarm ratio) applied to severe storms forecasting can only be assessed in the presence of sufficiently large data sets of severe weather events that allow statistically significant analysis.

In summary, the long North American experience with severe convective storms highlights the relevance of keeping good-quality severe weather archives. As with Europe (Doswell 2003), we do not simply propose that the North American severe storms archiving system be blindly "copied" by the South American severe weather community, but to be used as inspiration for similar initiatives. This is considered in the next section.

4. THE CHALLENGE IN DOCUMENTING SEVERE WEATHER AND POSSIBLE WAYS OF ADDRESSING THE ISSUE IN SOUTH AMERICA

It is important to stress that severe weather is associated with sub-cloud phenomena that typically cover small areas and last few minutes, and ***cannot*** be detected by remote sensed observing systems, except in highly particular situations — e.g., by literally chasing storms with weather radars adapted to vehicles; Wurman (2002); Bluestein *et al* (2003) — which are not available in a operational basis anywhere in the world.

Thus, in contrast with the perception that is often valid for large- and mesoscale meteorology, improved satellite and radar coverage of the large data void areas of South America does not solve the specific problem addressed here: the documentation of severe thunderstorms. This demands confirmation of what happens at ground level. More recently, it has been proposed the use in Brazil of high resolution satellite imagery to document destruction paths left by tornadoes (M. A. Antonio, personal communication). Previously, Dyer (1988, 1994) identified tornado paths over forest terrain in northeastern Argentina, Paraguay and southern Brazil using similar approach. This represents a promising alternative for documenting tornado tracks, particularly over low-populated areas. However, such capability, still in research mode (Yuan *et al* 2002), can not replace a detailed *in situ* documentation of severe weather events.

Lightning detection networks such as the ones implemented in Brazil (Beneti *et al* 2000, Silveira 2005) play a very important role in tracking convective activity in real time, but, again, cannot provide unequivocal confirmation of the occurrence of large hail, damaging winds or tornadoes.

Another argument in favor of an improved system for documenting severe storms in South America is that, most often, media coverage is the main information source for meteorologists regarding the confirmation of a severe weather event. In many situations, meteorologists are only aware of the event after the news coverage on TV, internet, or newspaper, several hours after the severe weather occurrence. (These statements are based on the first author's experience in Brazil, but we believe that they are also valid in other South American countries affected by severe weather). Creating a severe weather data set from media coverage (e.g., Nechet 2002) can be highly laborious because such reports usually lack reliability and quantitative information concerning the meteorological component of the event. It is not rare to find episodes related to storm-induced damage being reported as a tornado by the media, when in fact thunderstorms with damaging straight-line winds were responsible for the destruction. Another problem is that any given event of severe weather that does not reach a certain (unknown) threshold of "importance" to justify a journalistic coverage will remain unreported by the media. Thus, while media coverage does contribute to the documentation of severe storms, we believe that it should not be considered the primary source of information for severe weather episodes.

Other sources of information associated with infrastructures already existent in most South American countries seem more reliable, namely: damage reports from emergency management teams and from the electric power companies, and direct severe weather reports from airports.

In Brazil (as in other countries), CD teams are responsible for providing disaster relief to populations affected by all sorts of hazards, including severe weather (SEDEC 1999). Usually, these emergency management teams represent the first technical personnel to arrive at places affected by severe weather phenomena. By the time a CD team arrives, the "destruction signature" left by the weather event is still very clear, as confirmed by some damage survey photographs taken by CD officials (Figure 6) — it is part of CD's responsibility to conduct damage surveys caused by disasters in Brazil (SEDEC 1999). Hence, an opportunity exists to use the information collected *in situ* by the emergency management personnel as a support for severe weather documentation.

One example of such potential was the study conducted by Marcelino *et al* (2005), who utilized the archive of weather-related damage reports from the CD System of Santa Catarina State (southern Brazil) as the main source of information to identify tornadic events in that state from 1976 to 2000.

Figure 6: Destruction likely caused by a tornado in Muitos Capões, in Rio Grande do Sul State (southern Brazil) on 29 August 2005. Picture taken by a state CD official during the damage survey. (Courtesy of CD System of Rio Grande do Sul State.)

After careful scrutiny of the damage surveys (and journalistic records), Marcelino *et al* (2005) were able to confirm the occurrence of ten tornadoes and to identify other eight potentially tornadic events. For fifteen events, the available information allowed a damage assessment following the Fujita scale. (Five waterspouts, identified by means other than the destruction reports, are part also of Marcelino *et al*'s documentation). Figure 7 shows the geographical distribution of the weather events.

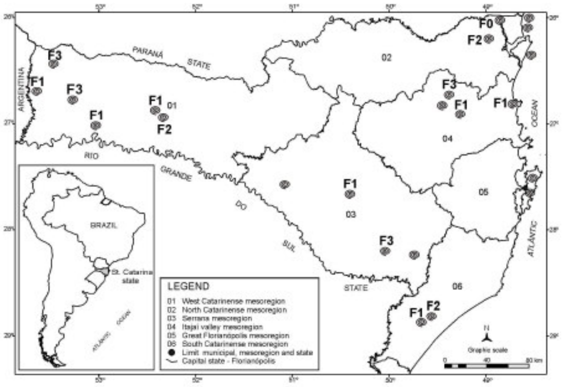

Figure 7: Tornadoes and waterspouts in Santa Catarina state (southern Brazil) from 1976 to 2000. The Fujita damage scale is assigned to some cases (From Marcelino *et al* 2005).

As stated by Marcelino *et al* (2005), the true number of tornadoes in Santa Catarina during that period was, most probably, substantially higher, because events that did not strike populated areas remained unreported. Similar studies for Santa Catarina have been conducted for hail, flash floods and non-tornadic wind events (e.g., Marcelino *et al* 2004).

Damage reports kept by power utilities can also contribute to the creation of a severe weather archive, with the caveat that such information is usually considered confidential by the electric power companies. These reports often contain detailed information about the destruction inflicted by the weather event to the engineering structures (mostly powerlines), including occasional aerial photography. Meteorology teams working for power utilities can use the archives to identify days and times of severe weather episodes. Furthermore, a closer cooperation with power utility engineers responsible for damage surveys should be sought. The possibility of training them in specific techniques which extract information that is particularly relevant for the characterization of type and intensity of the weather event (e.g., NWS 2003) should be considered.

Figure 8 shows significant damage inflicted to powerline structures in the state of São Paulo (southeastern Brazil) on the evening of 22 July 2002. This damage was caused by wind gusts from an isolated severe thunderstorm, as studied by Lima and Menezes (2004). Ongoing work in Brazil is seeking to build a data base of severe convective weather events based on damage reports from an important electric power company (Daniele O. Lima, personal communication).

Figure 8: Damage caused by convectively-induced winds to powerline structures in São Paulo State (southeastern Brazil) on 22 July 2002. (From Lima and Menezes 2004).

Convective weather reports from airports are another important (and quite obvious) source of weather information that can play a role on the creation of severe weather archives. For example, Fogaccia (2001) used a sort of PS approach to characterize the atmospheric environments associated with a number of cases of strong turbulence and windshear reported by pilots during landing and take-off procedures around São Paulo International Airport from 1994 to 1999. Although the events were not necessary related to severe convection (ordinary "pulse-type" storms produced most of the episodes), their effect over airport operations were relevant. Documentation of such events contribute to an important convective weather archive to research seeking the identification and prediction of atmospheric conditions favorable to potentially hazardous aviation weather (Fogaccia 2001).

5. CLOSING DISCUSSION

Severe weather phenomena are inherently difficult to observe and to predict, but they represent a tangible threat to many human activities. The lack of good-quality severe weather archives hinders research on the climatological and synoptic aspects of severe thunderstorms that are fundamental for improving convective weather prediction. As severe thunderstorm archives with meteorologically relevant information become more readily available, more research initiatives can work concomitantly, addressing various topics of severe storms: from thunderstorm dynamics to severe weather climatology (including the important interannual variability issue) and short range forecasting.

In this context, we emphasize that subtropical South America is among some of most evident hot spots for severe convective weather in the world (Brooks *et al* 2003), and strong demand for predicting such events does exist (e.g., Lima and Menezes 2004). Furthermore, any study addressing the impact of climate changes upon the frequency of severe thunderstorms (e.g., identification of possible trends and downscaling of extremes; Brooks 2004) for any part of the globe requires background knowledge on the "current climatology" of severe weather events and of the large-scale atmospheric environments in which they develop (Brooks *et al* 2003). These can only be accurately determined after extensive work on the topic, where the systematic documentation of severe thunderstorms can play an important role.

We have discussed some possible ways of addressing the issue of the creation of severe weather data banks in South America utilizing infra-structures that ***already exist*** in the continent. Nevertheless, we do recognize some limitations on the alternatives presented, which would have to be addressed by the South American severe weather community. (Moreover, we did not intend to present an exhaustive list of alternative forms of creating severe weather data sets). First, emergency management officials have an overwhelming set of responsibilities to be met during disaster relief campaigns, and it is not their job to conduct weather-related damage surveys from a meteorological standpoint. Thus, it is obvious that only after a thorough discussion concerning needs and capabilities between meteorologists and CD systems that a reasonable common-ground can be reached on that matter.

Second, CD teams are deployed to ***populated*** areas affected by severe storms. Hence, severe weather occurring away from urban areas (which typically represents most of the cases; Doswell 2003), will not be part of a severe weather archive that is based on damage reports kept by CD systems, leading to underreports (Marcelino *et al* 2005). Similarly, damage surveys conducted by maintenance teams of electric power utilities are confined to small areas around damaged structures, while aviation reports of severe weather are confined to areas surrounding airports. Analysis of high resolution satellite imagery of surface features affected by severe weather phenomena seems a promising alternative for the documentation of severe events over broader areas (regardless of the level of human occupation), but with some caveats briefly described in this article.

The large number of good-quality severe thunderstorm reports in the US is due, in part, to the existence of a relatively large body of trained storm spotters (Doswell *et al* 1999). Such volunteer groups do not exist in South America, at least not officially. While we do not recommend untrained individuals to chase severe storms for the seek of reporting weather phenomena (a dangerous activity), the severe weather research community in South America could consider training volunteers to spot severe thunderstorms from their own homes and report the events in a standardized form.

South America's atmospheric sciences community can contribute to the effort in understanding severe convection, as already shown from studies addressing tropical and subtropical convection, like the remarkable field campaigns in the Amazon (Large-scale Biosphere-Atmosphere Experiment, LBA) and subtropics (the South American Low-Level Jet Experiment, SALLJEX; and the Tropical Convection and Cirrus Experiment in Brazil; TrocciBras). A coordinated effort for an improved documentation of severe thunderstorms is needed, though. For now, we do not have a reasonable estimate of how many severe thunderstorms and tornadoes occur each year in South America; we still do not have a solid knowledge on the seasonal and interannual variabilities of severe convection in that continent; and there still is a long way to go in transferring the knowledge acquired from severe weather research to forecasting products in support of operational meteorologists (Nascimento 2005).

ACKNOWLEDGEMENTS

The first author's work was partially supported by Brazil's Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), under grant number 476904/2004-8, and by Instituto Tecnológico SIMEPAR. We acknowledge Rodovia das Colinas S.A., FURNAS Centrais Elétricas S.A., and the CD from Rio Grande do Sul State, in Brazil, for providing photographs and video still frames utilized in this article. We wish to thank researchers Isabela Marcelino and Daniele O. Lima for enlightening discussion on some of the issues addressed in this paper.

6. REFERENCES

Amorim, W. C. M., C. A. R. Morales, R. I. Albrecht, and R. M. Rosa, 2005: Yes, we do have tornadoes in São Paulo, Brazil. From the mesoscale models to the radar reflectivity point of view. *Preprints, 32nd Conference on Radar Meteorology*, Albuquerque,NM. (http://ams.confex.com/ams/32Rad11Meso/techprogram/paper_97176.htm)

Antonio, M. A., C. A. A. Antonio, and J. C. Figueiredo, 2005: Tornadoes of the 2004 autumn season in the countryside of São Paulo. *Preprints, 12th Brazilian Symposium on Remote Sensing*, Goiânia/GO, Brazil, 2819-2826. (In Portuguese).

Assunção, L. A. R., 2002: Powerline structures downed by winds. *Preprints, International Seminar on Wind Effects on Powerlines*, Belo Horizonte/MG, Brazil. (In Portuguese).

Barnes, G., 2001: Severe local storms in the Tropics. *Severe Convective Storms*, C. A. Doswell III (Ed.), Meteorological Monograph, **28 (50)**, Amer. Meteor. Soc., 359-432.

Beneti, C. A., E. A. Leite, S. A. M. Garcia, L. A. R. Assunção, A. Cazetta, F°, and R. J. Reis, 2000: RIDAT – Rede integrada de detecção de descargas atmosféricas <Integrated network for detection of lightning discharges>: perspectives and future. *Preprints, 11th Brazilian Congress on Meterology*, Rio de Janeiro/RJ, Brazil,

Bluestein, H. B., C. Weiss, and A. L. Pazmany, 2003: Mobile Doppler radar observations of a tornado in a supercell near Bassett, Nebraska, on 5 June 1999. Part I: tornadogenesis. *Mon. Wea. Rev.*, **131**, 2954-2967.

Brooks, H. E., 2004: *Downscaling of Severe Thunderstorms from Reanalysis Data.* Project abstract, University Corporation for Atmospheric Research, 3pp. (www.assessment.ucar.edu/2004review/brooks.pdf)

Brooks, H. E., C. A. Doswell, III, and J. Cooper, 1994: On the environments of tornadic and nontornadic mesocyclones. *Wea. Forecasting*, **9**, 606-618.

Brooks, H. E., J. W. Lee, and J. P. Craven, 2003: The spatial distribution of severe thunderstorm and tornado environments from global reanalysis data. *Atmos. Res.,* **67-68**, 73-94.

Davies, J. M., and R. H. Johns, 1993: Some wind and instability parameters associated with strong and violent tornadoes. 1. Wind shear and helicity. *The Tornado: its Structure, Dynamics, Prediction, and Hazards*, C. Church, D. Burgess, C. Doswell III, R. Davies-Jones (Eds.), AGU Geophysical Monograph 79, 573-582.

Doswell, C. A., III, 2003: Societal impacts of severe thunderstorms and tornadoes: lessons learned and implications for Europe. *Atmos. Res.*, **67-68**, 135-152.

Doswell, C. A., III, 2005: Progress toward developing a practical societal response to severe convection. *Submitted to Natural Hazards and Earth System Science*.

Doswell , C. A., III, A. R. Moller, and H. E. Brooks, 1999: Storm spotting and public awareness since the first tornado forecasts of 1948. *Wea. Forecasting*, **14**, 544-557.

Dyer, R. C., 1988: Remote sensing identification of tornado tracks in Argentina, Brazil, and Paraguay. *Photogramm. Eng. Remote Sens.*, **54**, 1429-1435.

Dyer, R. C., 1994: A review of tornado activity in Brazil. *Proceedings, Int. Soc. Photogramm. Remote Sens.*, INPE, São José dos Campos, Brazil, Vol. 30, Part 7a, 203-213.

Evans, J. S., and C. A. Doswell, III, 2001: Examination of derecho environments using proximity soundings. *Wea. Forecasting*, **16**, 329-342.

Fogaccia, A. J. P., 2001: Analysis of turbulence and windshear events in the vicinity of São Paulo's International Airport. *Master's Thesis*, Department of Atmospheric Sciences, University of São Paulo, 131pp.

Fujita, T. T., 1973: Tornadoes around the world. *Weatherwise*, **26**, 56-62.

Held, G., A. M. Gomes, E. L. Nascimento, O. Pinto Jr., K. P. Naccarato, C. A. Antonio, and A. B. P. da Silva, 2005a: Tornado signatures for nowcasting using radar and lightning observations in Brazil. *Geophys. Res. Abstracts*, **7**, 10221, 2005 General Assembly of the European Geosciences Union, Vienna, Austria.

Held, G., A. M. Gomes, K. P. Naccarato, O. Pinto Jr., E. L. Nascimento, A. A. Correia, and I. P. V. O. Marcelino, 2005b: Analysis of tornado characteristics in the State of São Paulo for the improvement of an automatic alert system. *Preprints, 32nd Conference on Radar Meteorology*, Albuquerque, NM. (http://ams.confex.com/ams/32Rad11Meso/techprogram/paper_96729.htm)

Johns, R. H., and W. D. Hirt, 1987: Derechos: widespread convectively induced windstorms. *Wea. Forecasting*, **2**, 32-49.

Lima, D. R. O., and W. F. Menezes, 2004: Downed powerline structures in Cachoeira Paulista (SP) and the occurrence of severe thunderstorms. *Preprints, 13th Brazilian Congress on Meteorology*, Fortaleza/CE, Brazil. CD-ROM. (In Portuguese).

López, R. E., R. L. Holle, and T. A. Heitkamp, 1995: Lightning casualties and property damage in Colorado from 1950 to 1991 based on Storm Data. *Wea. Forecasting*, **10**, 114-126.

Marcelino, I. P. V. O., M. Mendonça, and F. M. Rudorff, 2004: On the occurrence of hailstorms in Santa Catarina State. *Preprints, 1st Brazilian Symposium on Natural Disasters*, Florianópolis, Brazil, in CD-ROM. (In Portuguese).

Marcelino, I. P. V. O., M. L. P. Herrmann, and N. J. Ferreira, 2005: The occurrence of tornadoes in Santa Catarina State, Brazil. *Submitted to Austr. Meteor. Mag.*

Markowski, P. M., and Y. Richardson, 2004: Multiple-Doppler radar observations of vertical wind profile heterogeneity in convective boundary layers. *Preprints, 22nd Conf. on Severe Local Storms*, Amer. Meteor. Society, Hyannis/MA. (http://ams.confex.com/ams/11aram22sls/ techprogram/paper_81183.htm).

Nascimento, E. L., 2004: Identifying severe thunderstorm environments in southern Brazil: analysis of severe weather parameters. *Preprints, 22nd Conf. on Severe Local Storms*, Amer. Meteor. Society, Hyannis/MA. (http://ams.confex.com/ ams/11aram22sls/ techprogram/paper_81745.htm).

Nascimento, E. L., 2005: Severe storms forecasting utilizing convective parameters and mesoscale models: an operational strategy adoptable in Brazil? *Braz. Meteor. Magazine*, **20**, 121-140. (In Portuguese).

Nascimento, E. L., and I. P. V. O. Marcelino, 2005a: Preliminary analysis of the 3 January 2005 tornadoes in Criciúma/SC. *Bull. Brazilian Meteor. Soc.*, **29**, 33-44. (In Portuguese).

Nascimento, E. L., and I. P. V. O. Marcelino, 2005b: A multiple-vortex tornado in Brazil. *To be submitted to Monthly Weather Review.*

NCDC, 1999: *Storm Data*. Vol. 41, No. 5, 372 pp. (www5.ncdc.noaa.gov/pubs/publications. html)

Nechet, D., 2002: The occurrence of tornadoes in Brazil. *Bull. Brazilian Meteor. Soc.*, **26**, 29-39. (In Portuguese).

NWS, 2003: *A Guide to F-Scale Damage Assessment*. National Oceanic and Atmospheric Administration, U. S. Dept. of Commerce, 94 pp. (http://meted.ucar.edu/resource/wcm/ftp/Final NWSF-scaleAssessmentGuide.pdf)

Schwarzkopf, M. L., 1982: Severe storms and tornadoes in Argentina. *Preprints, 12th Conf. on Severe Local Storms*, Amer. Meteor. Soc., San Antonio/TX, 59-62.

SEDEC, 1999: *Manual for Civil Defense Planning*. National Secretariat of Civil Defense (SEDEC), Vol. I, Brasília, Brazil, 70 pp. (In Portuguese).

Silva Dias, M. A. F., 2000: Storms in Brazil. In: *Storms*, *Volume II*, R. Pielke Jr. and R. Pielke Sr. (Eds.), Routledge Press, p. 207-219.

Silveira, R., 2005: Report on the operational use of lightning detection methods in Brazil. *WMO Commission for Instruments and Methods of Observation*, Expert Team on Remote Sensing Upper-Air Technology and Techniques, Geneva, Switzerland, Doc.5.1(1) Rev. 1, 9pp.

Thompson, R. L., 1998: Eta model storm-relative winds associated with tornadic and nontornadic supercells. *Wea. Forecasting*, **13**, 125-137.

Thompson, R. L., 2005: *Explanation of SPC Severe Weather Parameters.* Storm Prediction Center (web page), Norman/OK, www.spc.noaa.gov/sfctest/help/ sfcoa.html.

Torena, F., 2003: Tornadoes in Uruguay. Unpublished technical note. (http://ar.geocities.com/lapaginaderio negroyneuquen/temas/uruguay. doc). (In Spanish).

Velasco, I., and J. M. Fritsch, 1987: Mesoscale convective complexes in the Americas. *J. Geophys. Res.*, **92 (D8)**, 9561-9613.

Wurman, J., 2002: The multiple-vortex structure of a tornado. *Wea. Forecasting*, **17**, 473-505.

Yuan, M., M. Dickens-Micozzi, and M. A. Magsig, 2002: Analysis of tornado damage track from the 3 May tornado outbreak using multispectral satellite imagery. *Wea. Forecasting*, **17**, 382-398.

Zipser, E. J., P. Salio, and M. Nicolini: Mesoscale convective systems activity during SALLJEX and the relationship with SALLJ events. *Clivar Exchanges*, **9 (1)**, 14-19.