3A.3 IDENTIFYING SEVERE THUNDERSTORM ENVIRONMENTS IN SOUTHERN BRAZIL: ANALYSIS OF SEVERE WEATHER PARAMETERS.

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1. INTRODUCTION

The mid-latitude and subtropical sectors of South America (SA), east of the Andes mountain range, have been recognized as prone to the occurrence of severe convective storms for a long time (Fujita 1973, Schwarzkopf 1982, Guedes and Silva Dias 1984, Velasco and Fritsch 1987, among others). In agreement with those early studies, the more recent work by Brooks *et al* (2003) identified the area enclosing Paraguay, Uruguay, northeastern Argentina and southern Brazil as one of the regions in the world where atmospheric conditions potentially favorable for severe thunderstorms and tornadoes are occasionally found.

One reason for that is the frequent establishment of a northerly low-level jet (LLJ), east of the Andes, during the South American warm season (e.g., Marengo *et al* 2002). This circulation is responsible for the transport of moisture from the Amazon Basin to the higher latitudes of continental SA (e.g., Berri and Inzunza 1993), and occasionally becomes dynamically coupled with the westerly upper-level jet stream. The latter is often associated with migrating baroclinic systems. Figure 1 shows a schematic diagram summarizing a synoptic condition associated with severe thunderstorms in SA, and how it compares with the general conditions found in North America during severe weather season in that continent.

Given these points, there is an increasing need for the assessment of operational strategies aiming at the identification of atmospheric environments conducive to severe weather in SA. This article represents a preliminary initiative in this context, where severe weather parameters, originally conceived for the mid-latitudes of North America, are evaluated for severe thunderstorm forecasting in southern Brazil. For at least a few episodes during the short period studied, the severe weather indices did capture atmospheric conditions associated with the actual occurrence of strong to severe convective storms in the region being considered. However, our analysis also suggests a relatively high false alarm ratio for the parameters examined. Despite the somewhat mixed (and not fully conclusive) results discussed in this work, our findings strongly encourage further study in this topic.

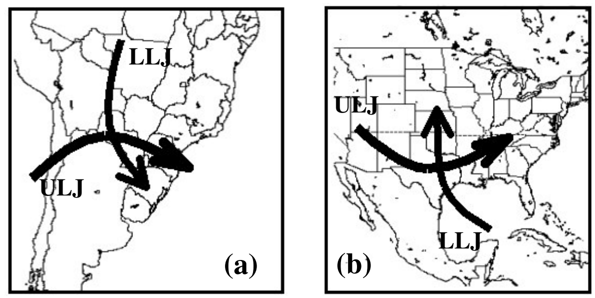

Figure 1: Diagram of the dynamic coupling between the low-level (LLJ) and upper-level (ULJ) jets during conditions favorable for severe weather in (a) South America and (b) North America.

2. DATA AND METHODOLOGY

The data examined include daily 00Z and 12Z atmospheric soundings (radiosondes) from Foz do Iguaçu (SBFI), in western Paraná state, southern Brazil (Fig. 2), covering the warm seasons (September to April) of 2002/2003 and 2003/2004. (The corresponding local standard times for 00Z and 12Z are, respectively, 9pm and 9am). Table 1 indicates the number of soundings effectively examined in this study for each season.

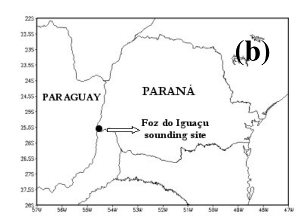

Figure 2: (a) geographical location of the SBFI sounding site (indicated by a dot). Panel (b) provides a close up view of the site location.

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Table1: Foz do Iguaçu (SBFI) soundings examined.

PERIOD	NUMBER OF SOUNDINGS
Sep/2002 to Dec/2002 (spring 2002)	00Z: none available 12Z: 108 soundings
Jan/2003 to Apr/2003 (summer / early fall 2003)	00Z: 93 soundings 12Z: 104 soundings
Sep/2003 to Dec/2003 (spring 2003)	00Z: 99 soundings 12Z: 104 soundings
Jan/2004 to Apr/2004 (summer / early fall 2004)	00Z: 44 soundings 12Z: 39 soundings

From the observed thermodynamic and kinematic profiles, the following severe weather parameters are computed: surface-based CAPE (SBCAPE), lifted index (LI), bulk Richardson number shear (BRNSHR), storm--relative helicity in the first 3km (SRH), energy-helicity index (EHI), and the supercell composite parameter (SUP) (as this study continues, other parameters will be tested; e.g., CAPE for a PBL-mixed air parcel). Definitions of these indices can be found, for example, in Galway (1956), Rasmussen and Blanchard (1998), and Thompson *et al* (2003) (henceforth, TEHEM03). Keeping in mind an operational concern, **the main goal of this initiative is to start an assessment on how these parameters perform in detecting atmospheric conditions conducive to severe convective weather in southern Brazil.**

Instead of identifying proximity soundings for severe weather events followed by the calculation of the indices for these soundings (as usually done in similar studies for North America; e.g., Evans and Doswell 2001), we choose to compute the indices for the entire data set. For the days in which the parameters indicate favorable conditions for severe thunderstorms we verify if storms were actually reported in western Paraná state. This different approach is motivated by the fact that in Brazil no official data bank of severe storms (similar to *Storm Data* in the USA) exists. Potential implications of this approach for the analysis of forecast verification for the convective parameters are briefly discussed.

3. RESULTS

Before presenting the results, we need to stress some important points. First, one must recall that, in contrast with the Northern Hemisphere, **negative** values of SRH are (or tend to be) observed in atmospheric environments favorable for mid-latitude severe storms in the Southern Hemisphere, leading to negative values of EHI and SUP under such conditions. Second, we note that, in this first study, we use as reference the same severe weather thresholds for EHI, SUP, SRH (with inverted signs) and BRNSHR identified in investigations for North America (e.g., Kerr and Darkow 1996, Stensrud *et al* 1997, Rasmussen and Blanchard 1998, Thompson 1998, Evans and Doswell 2001, TEHEM03). This is because, so far, no climatology of severe weather indices including such parameters exists for SA. Therefore, all of our results associated with "severe weather thresholds" must be interpreted in a qualitative sense, rather than quantitative. Finally, we do not conduct an assessment of the performance of the parameters in discriminating different types of severe weather. Future work will address this important issue.

Figure 3 displays time series of severe weather parameters for the 12Z SBFI soundings for spring 2002 — no 00Z sounding from SBFI was available for this period (Table 1). Values of EHI **and** SUP less than –1

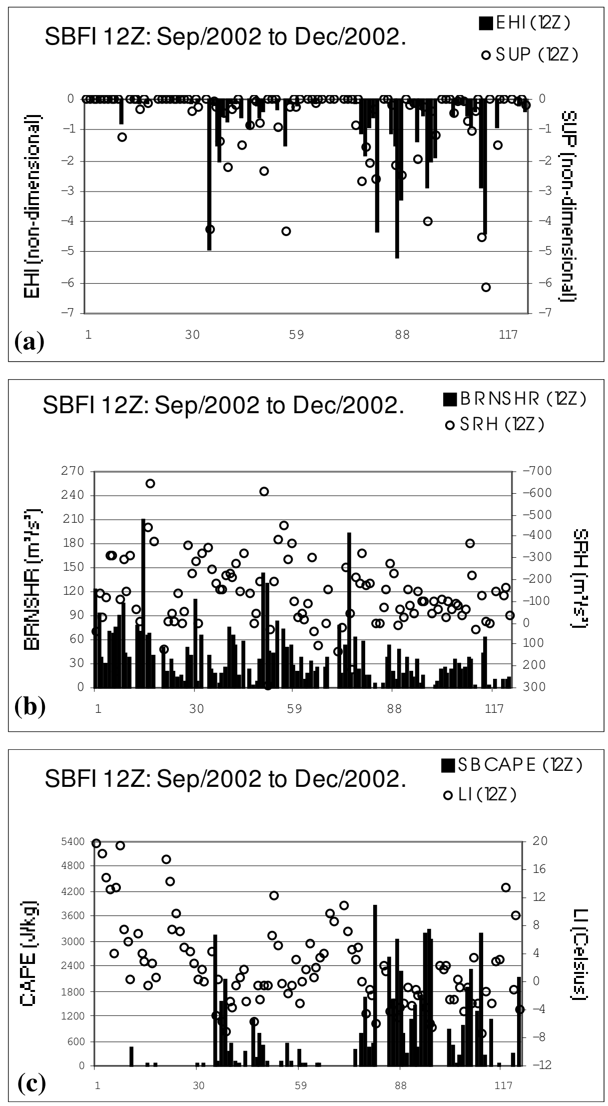

Figure 3: Time series of (a) EHI and SUP, (b) BRNSHR and SRH, and (c) SBCAPE and LI for daily Foz do Iguaçu 12Z soundings from Sep/2002 to Dec/2002. In all panels the abscissa represents consecutive days within the period. Only negative values of EHI are shown in (a). Note that in (b) the ordinate for SRH is reversed.

were found in 14 of the 12Z soundings (Fig. 3a). On the other hand, for the 2003 summer and early fall season (not shown), the number of soundings with EHI **and** SUP less than -1 reduced to 6 for the 00Z soundings, and to 5 for the 12Z soundings. This result seems consistent with the fact that stronger baroclinic systems are more often observed in southern Brazil during the spring season, rather than during summer, when a more tropical atmospheric regime takes place.

This becomes more evident if we compare the parameters associated with the vertical wind shear, since larger shear values accompany the stronger baroclinic systems. Based on investigations for North America (mentioned above), in our analysis we will consider the values of 50 $m^2\ s^{-2}$ and –150 $m^2\ s^{-2}$ for BRNSHR and SRH, respectively, as being (first-guess for) thresholds for supercell environments. During spring 2002, 32 [41] 12Z soundings displayed BRNSHR [SRH] equal to or larger [equal to or less] than 50 $m^2\ s^{-2}$ [–150 $m^2\ s^{-2}$] (Fig. 3b). In contrast, during summer 2003, only 2 [5] 12Z soundings reached the same thresholds (not shown).

The relatively high number of days with SRH less than –150 $m^2\ s^{-2}$ during spring 2002 requires some comments. The Davies and Johns (1993) method (adapted for the Southern Hemisphere, and hereafter referred to as DJ93mod method) was used to estimate the storm motion (STRM) when calculating SRH. It has been shown that this is not necessarily the best method to estimate STRMs (e.g., Bunkers *et al* 2000), which may be particularly true for Brazil. Thus, it is possible that SRH values discussed here could be overestimated. As a first analysis, we assess the estimation of STRM for the 9 October 2003 case — which refers to an event that is examined with more details later in this text. The 00Z sounding for that day displayed the lowest values of EHI and SUP for the entire period analyzed. For this sounding, the DJ93mod method predicted a STRM from 287^o at 9.4 m s^{-1}, leading to a SRH of –431 $m^2\ s^{-2}$. Figure 4 shows the western sections of the reflectivity display (PPIs) from SIMEPAR´s radar for the morning of 9 October 2003. Isolated storm I (Fig.4a) developed ahead of an advancing cold front, and underwent a splitting process between 7:20Z and 7:30Z (Figs. 4b, 4c). By keeping track of the centroid of the left-moving storm L until 8:40Z (not shown) we estimated the true STRM as being from 270^o at 11.0 m s^{-1}, which leads to a SRH of –500 $m^2\ s^{-2}$. Hence, it appears that the DJ93mod method did not lead to an overestimation of SRH for this case, and, perhaps surprisingly, provided a fairly good estimate of the observed STRM for the left moving cell. However, this cannot be considered a conclusive assessment of DJ93mod method for southern Brazil. As this work continues, the sensitivity of SRH to distinct STRM estimators for Brazil will be addressed. For now, our

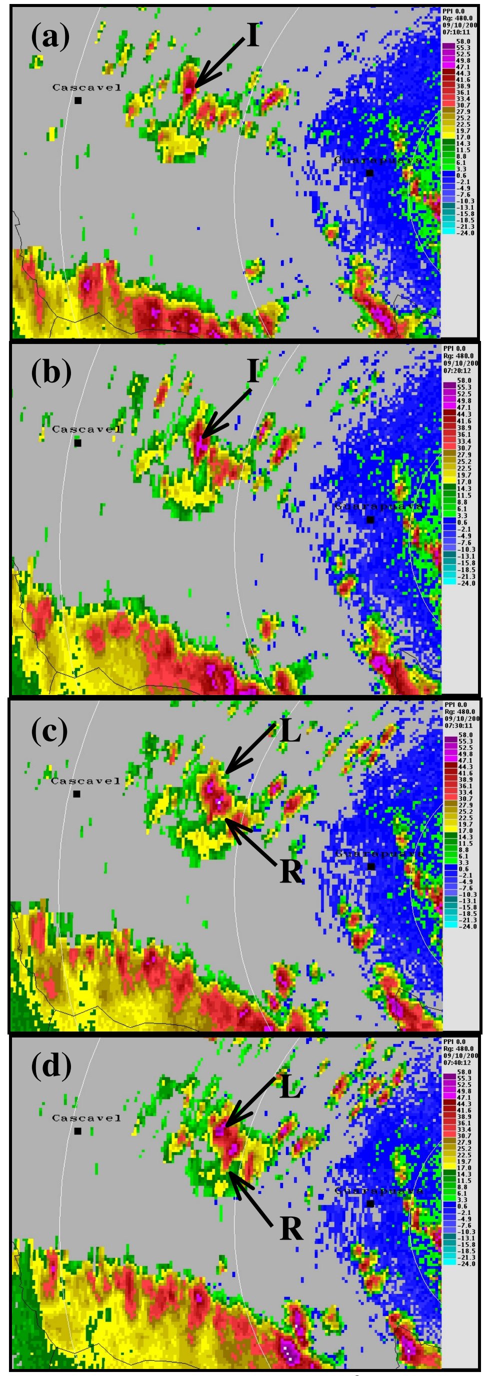

Figure 4: PPI reflectivity displays (0^o elevation) from SIMEPAR´s radar for the western portion of Paraná state for 9 October 2003. From top to bottom, the panels refer to 7:10Z, 7:20Z, 7:30Z and 7:40Z. Concentric white lines indicate distances of 200km and 400km from the radar location. The SBFI sounding site is located around 120 km southwest of the city of Cascavel indicated in the panels.

analysis on SRH and derived parameters will be mostly qualitative.

Regarding SBCAPE and LI, Fig. 3c shows that the most significant values in spring 2002 were reported during October and from late November into December. There is a reasonably good correspondence between the distributions of SBCAPE (Fig. 3c) and EHI/SUP (Fig. 3a). Thus, while large values of BRNSHR and SRH were more homogeneously distributed during the 2002 spring season, SBCAPE was the parameter that effectively modulated EHI and SUP, highligting the presence of both thermodynamic and kinematic forcing for severe storms. For the 12Z soundings, the average SBCAPE increased from 561 J kg^{-1} during spring to 792 J kg^{-1} during summer 2003 (not shown). The average SBCAPE for 00Z soundings during summer was particularly high, reaching 1410 J kg^{-1}. However, high values of SBCAPE during summer did not translate into more days with significant EHI/SUP, given that shear profiles favorable for severe weather were less frequent during this season, as mentioned before.

Figures 5 and 6 show, for spring 2003, time series of severe weather indices computed from SBFI 00Z and 12Z soundings, respectively. A discernible difference between spring 2002 (Fig. 3a) and spring 2003 (Figs. 5a and 6a) is the occurrence of fewer days with low values of EHI and SUP in the latter period. For the 00Z soundings (Fig. 5a), values of EHI and SUP below –1 were found for 7 days, while for the 12Z soundings (Fig. 6a) the total number of days with EHI and SUP less than -1 was 8.

This result is associated with less frequent occurrence of significant values of BRNSHR and SRH during spring of 2003 (in comparison with the previous spring season). For the 2003 season, BRNSHR [SRH] with magnitudes equal to or larger [equal to or less] than 50 $m^2 s^{-2}$ [–150 $m^2 s^{-2}$] were found in 18 [12] days for the 00Z soundings (Fig. 4b), and in 12 [21] days for the 12Z soundings (Fig. 6b). Despite fewer days with low EHI and SUP during spring 2003, the overall *lowest* values of EHI and SUP parameters for the entire data set examined were found in this season (as discussed below).

The analysis of summer 2004 was jeopardized by the large data gaps during this particular season — especially for the months of February and March 2004, for which a total of only 8 soundings were available. In addition, the 2004 summer was characterized by a significant drought in the western portions of southern Brazil, with below-average convective activity, reducing the representativeness of the results for this season, which are not discussed here.

To gain some insight into the parameters´ performance in detecting conditions conducive to severe weather in Paraná state, we select a few cases to analyze. Table 2 indicates SIMEPAR´ s automatic surface stations

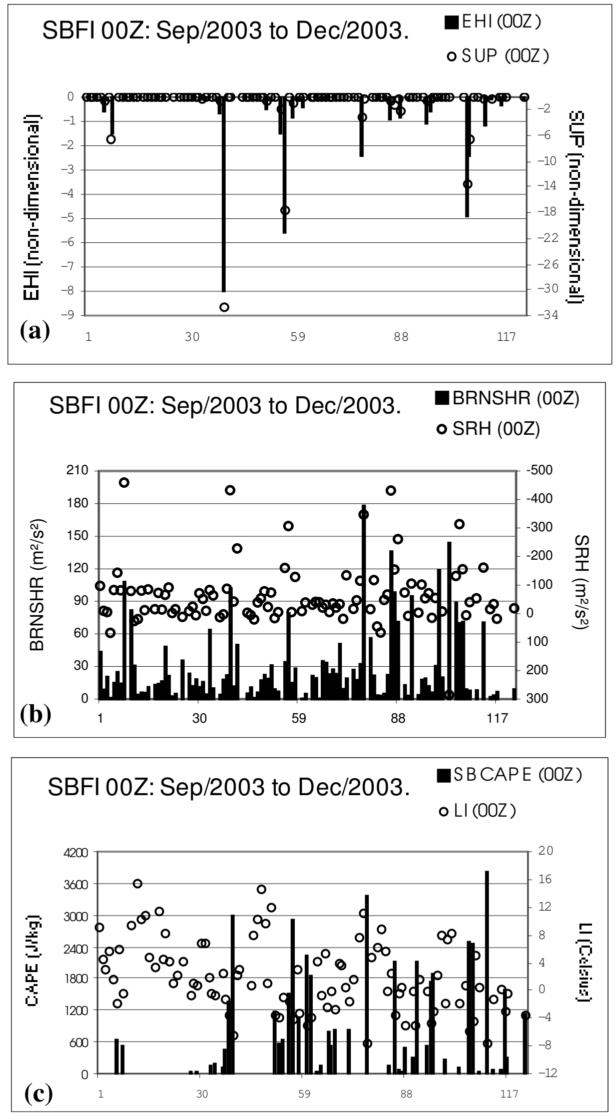

Figure 5: As in Fig. 3, but for 00Z soundings from Sep/2003 to Dec/2003.

located on southwestern Paraná state and their distance from Foz do Iguaçu. Figure 7 depicts their geographic distribution. Wind reports from these stations are used in our analysis.

Table 3 lists seven SBFI soundings that displayed significantly low values of EHI and SUP within the period studied. In five of these selected cases, strong to severe thunderstorms were reported in SW Paraná within the 18h period following the release time of the sounding balloon. On the other hand, in none of these cases could we confirm the occurrence of a severe weather episode in the SBFI area within 2h from the release time of the balloon. (We cannot **affirm** that **no** severe convective event occurred within this time frame either, because we do not have detailed weather reports

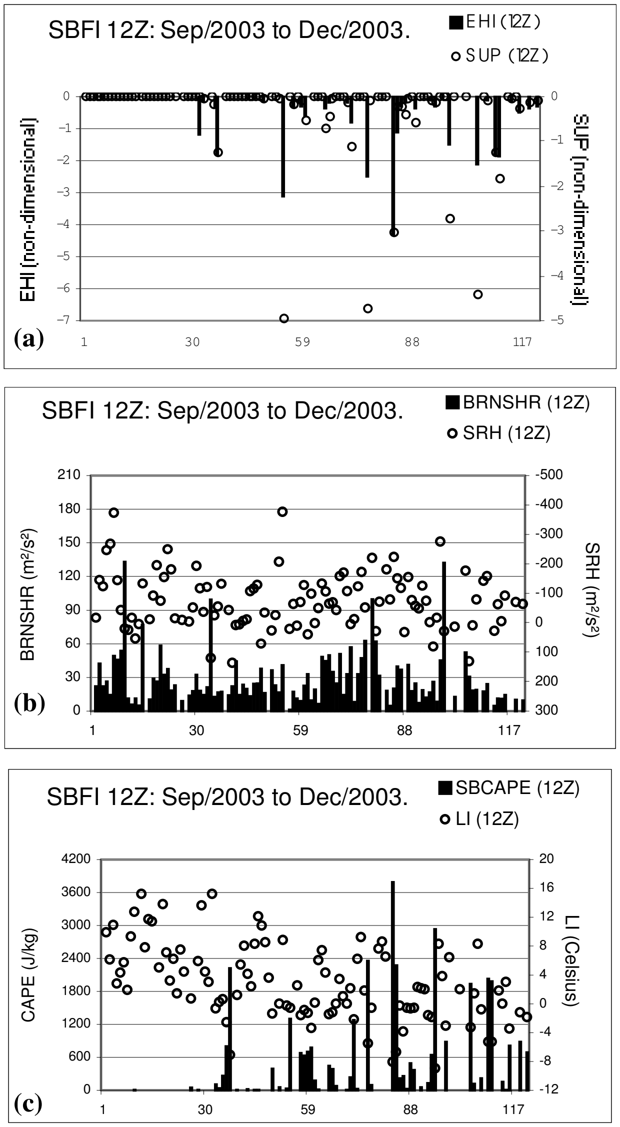

Figure 6: As in Fig. 5, but for 12Z soundings.

upstream from the sounding location, i.e., west from the border with Paraguay).

Thus, we could not characterize the selected SBFI soundings of Table 3 as true proximity soundings (Brooks *et al* 1994, Evans and Doswell 2001), even for those days when strong convective storms were reported in western Paraná. Nevertheless, except for the 26 November 2002 and 23 November 2003 cases, we consider that the parameters computed for the SBFI soundings of Table 3 did detect the **general** background environment within which the thunderstorms developed. In these cases, a well trained meteorologist in South America could, at least, have his/her attention drawn to atmospheric conditions favorable for severe weather in the hours following the release time of the weather balloon. This was the case for the 9 October 2003 event. The 00Z sounding of that day displayed EHI and SUP reaching the extremely low values of –8 and –33, respectively (Table 3). This happened because of the rare combination of very high values of BRNSHR, SBCAPE and SRH (see Figs. 5b and 5c). (Thompson *et al* (2004) indicate that extreme values of SUP are possible when employing the formulation used here, which follows TEHEM03. Thompson *et al* (2004) propose the use of the effective SRH in SUP to avoid the generation of such excessively large/low values).

The skew-T diagram and hodograph for that particular sounding are indicated in Figure 8.

Table 2: SIMEPAR´ s surface stations in southwestern Paraná state and their distance from Foz do Iguaçu. (See also Figure 7).

STATION	ACRONYM	DISTANCE
Assis Chateaubriand	ACH	156 km
Cascavel	CAS	122 km
Foz do Iguaçu	FOZ	0 km
Foz do Areia	FOA	307 km
Guaíra	GUA	152 km
Guarapuava	GPV	313 km
Nova Prata do Iguaçu	NPI	111 km
Palmas	PAL	290 km
Palmital	PMI	247 km
Palotina	PTN	141 km
Pato Branco	PTO	210 km
Pinhão	PIN	268 km
Salto Osório	SOS	143 km
Santa Helena	SHE	70 km
São Miguel do Iguaçu	SMI	55 km

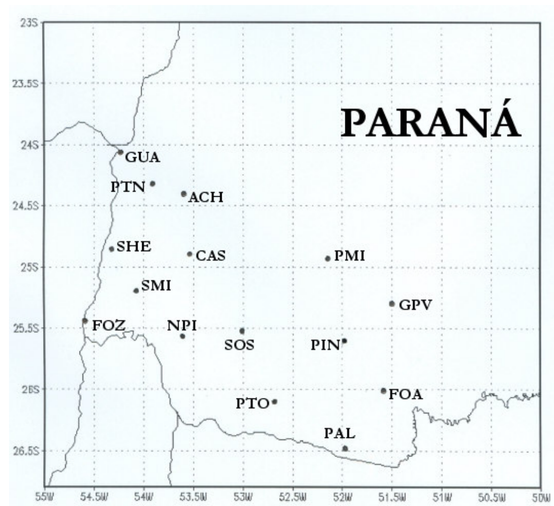

Figure 7: Geographical distribution of SIMEPAR´ s surface stations in the southwestern sector of Paraná.

Table 3: SBFI soundings with significant values of EHI and SUP for the period studied. The convective event that followed in the same day (in the SW Paraná area) and the strongest wind gust reported by a SIMEPAR´ s station are also indicated. Acronyms in the 5th colmun indicate the station that reported the wind gust (refer to Table 2 and Fig. 7 for station location).

SBFI SOUNDING	EHI	SUP	OBSERVED EVENT	WIND GUST (STATION)
05 October 2002 (12Z)	-5.0	-4.3	Strong storms (late afternoon)	21.3 m/s (NPI)
26 November 2002 (12Z)	-5.2	-10.8	Weak storms (mid-afternoon)	12.8 m/s (ACH)
20 December 2002 (12Z)	-4.4	-6.1	Strong storms (morning)	18.4 m/s (FOA)
09 October 2003 (00Z)	-8.0	-32.7	Severe storms (morning)	25.5 m/s (PIN)
26 October 2003 (00Z)	-5.6	-17.7	Strong storms (morning)	16.9 m/s (NPI)
			Severe storms (early afternoon)	28.7 m/s (PTN)
23 November 2003 (12Z)	-4.3	-3.0	No convection in SW Paraná	-
15 December 2003 (00Z)	-4.9	-13.6	Strong storms (early afternoon)	18.9 m/s (PAL)

The diagram displays a *loaded-gun* sounding (Fig. 8a), with mid-level lapse-rates reaching 8.9° C km^{-1}. The environmental hodograph (Fig. 8b) shows a strong low-level curvature associated with a northerly LLJ, which contributes to the enhancement of SRH (e.g., Doswell 1991). Based on the DJ93mod method to estimate the STRM, the SRH is just below -430 m^2 s^{-2} in this hodograph (for a left-moving storm), and BRNSHR is slightly above 100 m^2 s^{-2}. SBCAPE for this sounding is 2978 J kg^{-1}, with a LI of –6.4°C. Thus, thermodynamic and kinematic profiles were favorable for the development of severe storms, including possible supercells.

During the early morning hours of 10/09/2003, damaging winds were reported in western Paraná, associated with strong convective storms developing along and ahead of an advancing surface cold front, including **at least** one splitting storm (see Fig. 4), which seems consistent with a supercell-prone environment. Table 4 indicates the highest gusts reported in SIMEPAR´ s surface stations in southwestern Paraná. A 25.5 m s^{-1} gust was clocked within 6am and 7am, local time, at Pinhão station. Other nine stations in the same region reported wind gusts of at least 15 m s^{-1} that morning. Although the reported gusts were only marginally severe (based on the 26 m s^{-1} threshold for severe storm winds; e.g., Moller 2001), the damage associated with this event was widespread over the western sections of Paraná, characterizing a severe weather event. Around 500 houses and buildings suffered considerable damage (no F-scale damage assessment available, though), and more than 270 thousand residences experienced power outages statewide, due to downed power lines in western Paraná. State of emergency was declared for the city of Cascavel, located around 120 km northwest of Foz do Iguaçu, because of the large number of damaged homes (around 230).

The widespread damage reported suggests that surface winds stronger than those indicated in Table 4 might have struck some locals while remaining undetected by the surface stations. Moreover, depending on the building standards of the structures, winds below

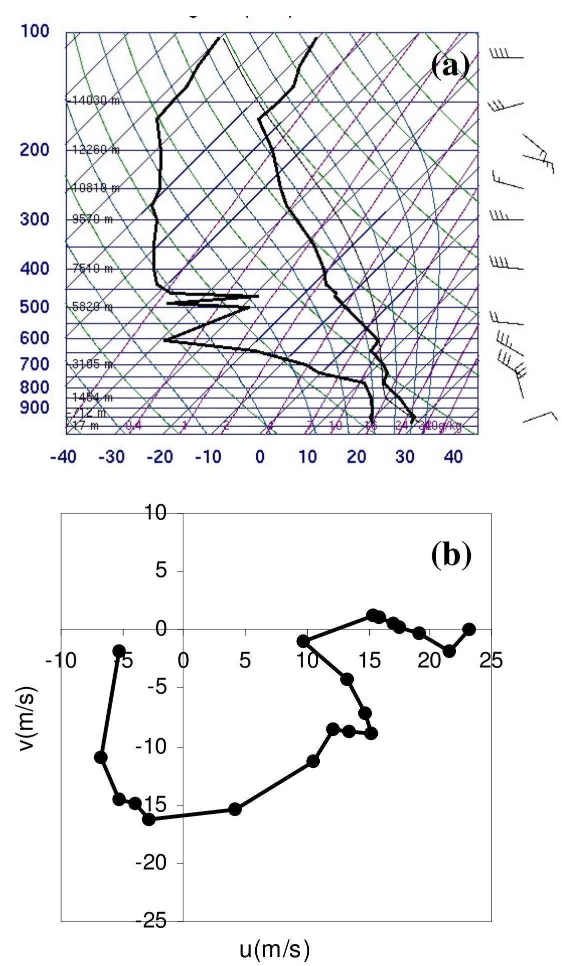

Figure 8: (a) Skew-T diagram (T in Celsius, p in hPa), and (b) surface-to-8km hodograph for the SBFI 00Z sounding of 10/09/2003. Wind barbs are in kt in the skew-T diagram. Dots along the hodograph are height indicators at levels 180, 479, 574, 712, 904, 1454, 2215, 2547, 2742, 3105, 3566, 3781, 4291, 5019, 5820, 5851, 6024, 6314, 6462, 6867, 7510, and 7713m. (Skew-T adapted from weather.uwyo.edu/upperair/sounding.html).

Table 4: Wind gusts reported in southwestern Paraná in the morning of 10/09/2003. The third column indicates the hour within which the gust was reported.

STATION	WIND GUST	LOCAL TIME
ACH	15.4 m/s	9:00 – 10:00 AM
CAS	16.9 m/s	7:00 – 8:00 AM
FOZ	13.4 m/s	6:00 – 7:00 AM
FOA	22.1 m/s	6:00 – 7:00 AM
GUA	11.8 m/s	10:00 – 11:00 AM
GPV	18.0 m/s	7:00 – 8:00 AM
NPI	18.6 m/s	5:00 – 6:00 AM
PAL	23.5 m/s	5:00 – 6:00 AM
PMI	16.5 m/s	7:00 – 8:00 AM
PTN	11.5 m/s	9:00 – 10:00 AM
PTO	17.0 m/s	5:00 – 6:00 AM
PIN	25.5 m/s	6:00 – 7:00 AM
SOS	11.7 m/s	5:00 – 6:00 AM
SHE	19.1 m/s	6:00 – 7:00 AM
SMI	14.7 m/s	5:00 – 6:00 AM

26 m s^{-1} may still cause considerable damage, which is particularly true for the poorer disctricts of some of our cities.

We again stress that the computation of severe weather parameters showed that the 00Z SBFI sounding from 9 October 2003 did contain enough information to draw the attention of a well trained meteorologist to the presence of an environment potentially favorable to severe weather development — even though it could not be classified as a proximity sounding in a strict sense. This was the case also for the episodes selected in Table 3 where the occurrence of strong convective storms was verified.

As an important counterpoint, however, during the spring of 2002, strong to severe thunderstorms were reported in western Paraná in only 6 of the 14 days when EHI **and** SUP (computed from SBFI soundings) were below –1. The sampling period is extremely short, but this result points to a possibly large false alarm ratio for the parameters studied. It also raises the question of whether or not the DJ93mod method to estimate STRM is leading to a sistematic overstimation of SRH. We showed that this was not the case for the 9 October 2003 event, but this is one of the important issues being investigated as this initiative continues. Other relevant issues that can potentially influence the analysis conducted here are discussed below.

4. CONCLUSIONS AND FUTURE WORK

Based on a preliminary analysis of 591 soundings from Foz do Iguaçu (SBFI) in southern Brazil covering the spring and summer seasons of 2002/2003 and 2003/2004, our study has found rather mixed results regarding the performance of some weather indices (SBCAPE, BRNSHR, SRH and their combinations) in capturing severe thunderstorm environments in southern Brazil. Strong to severe storms were actually verified around the SBFI balloon release site in some of the days when the indices detected conditions favorable for severe convection — especially when the parameters reached extreme magnitudes.

On the other hand, in several ocasions, no strong storm was observed in the region when those indices pointed to conditions conducive to severe weather. Because of the short period analyzed, we cannot yet draw a solid conclusion about the statistics of "hits" and "misses" for such parameters. However, our results suggest a possibly high false alarm ratio for them.

We still need to compute the indices based on better methods for estimating STRM (e.g., Bunkers *et al* 2000) and evaluate the sensitivity of our results to distinct CAPE formulations (e.g., CAPE for a PBL-mixed air parcel, and the most unstable CAPE). Regarding STRM, a "climatological" analysis of the typical storm motion observed in southern Brazil for distinct atmospheric conditions is needed. Data from a few weather radars located in this region will be useful for that matter. In addition, because we could not characterize here any proximity sounding in a strict sense, we ought to interpret our results with caution. (The analysis of storm episodes for the days when the indices highlighted favorable situations for severe weather is still under way). Mesoscale and stormscale numerical simulations will be conducted for some cases analyzed here in order to assess the degree of variability (in space and time) of the atmospheric profiles for both successful and null cases. This could help in the characterization of proximity soundings.

Despite the limitations described above, we did examine an interesting case of a severe weather event in western Paraná state that occurred several hours after the SBFI sounding displayed a classic mid-latitude *loaded gun* structure, with a hodograph showing strong curvature from surface to mid-levels. In that episode, at least one splitting storm was detected by radar, damaging winds were reported in a wide area, and the estimated STRM using the DJ93mod method was fairly good. This result should encorage further sutdies on the topic addressed in this short paper.

Ongoing work is addressing the performance of the severe weather parameters using larger data sets. Any initiative in this context must include the analysis of the winter season as well, when severe weather is also reported in southern Brazil (see for example **www.lemma.ufpr.br/ernani/torbraz.html**).

Our results also indicate that the time series analysis of severe weather indices during entire seasons can provide important climatological information regarding atmospheric patterns conducive to severe convective storms in Brazil. Finally, future investigations will assess the performance of severe weather indices computed from operational mesoscale model outputs in Brazil (Nascimento 2004).

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