Thundersnow in Brazil: a case study of 22 July 2013

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Abstract

On 23 July 2013, a snowstorm hit southern Brazil causing material damage and two deaths. Radar reflectivity and lightning data revealed a rare thundersnow occurrence. This study revealed that a Rossby wave propagation followed a typical pattern of cold incursions in South America, but some fundamental differences can be pointed out: (1) further northward Rossby wave amplification; (2) strong upward vertical motion within a deep nearly saturated layer and (3) a conditional symmetric instability layer, in response to strong vertical shear, beneath a layer of weak conditional instability, and above a significant near-surface vertical depth where temperatures hover around 0 °C.

Keywords: thundersnow; cold surge; southern Brazil; lightning; radar; symmetric instability

1. Introduction

Cold Surges (CSs) can have a devastating impact on the economy in many countries of South America, with Brazil’s multimillion dollar Arabic coffee market being traditionally (in the past) one of the most severely affected (DaMatta and Ramalho, 2006; Camargo, 2010). The most documented impact of CSs in South America is indeed economic damage to the agriculture sector (Marengo et al., 1997). Livestock loss, transportation disruptions and increased energy demands are commonly associated with CSs.

In these early studies, frost has been the most relevant motivating factor, as frost has had a sustained impact on the Brazilian agriculture over the years. On the other hand, snow events have been very rare and largely unreported in Brazil, although they have been known for causing significant damage in the past (Pezza and Ambrizzi, 2005b). The reporting of thundersnow, however, has only one known published study, Dolif Neto et al. (2009).

The July 2013 CS event broke a large number of records including temperature, first time snow occurrence (Figures S1 and S2) and thundersnow. The city of São Paulo had the coldest maximum temperature on record with only 8.7 °C, and Curitiba measured snow for the first time since 1975. In Guaraípava city, media news reported damage to buildings and traffic accidents resulting in two deaths (G1. News Portal, 2014). Guaraípava is a small city (180 000 inhabitants) located in the central portion of the Brazilian Parana State at 1120 m above sea level (25.3 S and 51.4 W – denoted by black filled star in Figure 2).

Previous studies of CSs revealed that the primary mechanism behind CSs is a surface anticyclone/cyclone couplet over the affected region, which results from a significant meridional amplification of a Rossby wave (Pezza and Ambrizzi, 2005a; Müller and Berri 2007; Müller and Berri, 2012; Sprenger et al., 2013). Cold air reaches low latitudes, channeled also by the north–south orientation of the Andes (Garreaud, 2000; Vera and Vigliarolo, 2000; Pezza and Ambrizzi, 2005a; Escobar, 2007). As a result of the interaction with the Andes, the baroclinic Rossby wave is amplified, acquiring a north/south elongated shape (Gan and Rao, 1994; Seluchi et al., 1998), which is also observed in parts of North America (Schultz et al., 1998) and Asia (Lau and Chang, 1987) where the topography is sufficiently pronounced.

In Brazil, Dolif Neto et al. (2009) studied a rare event comparing low-latitude thundersnow events in Brazil and in the United States. Although their results revealed the importance of the synoptic-scale driver, the smaller-scale influences such as orographic lifting and increased instability were also highlighted. This late 2005 winter episode in southern Brazil produced a significant frequency of cloud-to-ground flashes,
without appreciable snow accumulation. Some broad features were highlighted as being consistent with the literature for the Northern Hemisphere: (1) significant and well-defined synoptic-scale weather systems at low latitudes, (2) a strong baroclinic zone with a well-defined (>60 m s\(^{-1}\)) jet structure aloft, (3) cold air with appreciable depth and areal extent reaching regions very far to the north and (4) a moist neutral to conditionally unstable layer above the frontal zone. A recent study (Bech et al., 2013) of a low-latitude thundersnow event in Spain also revealed important synoptic and mesoscale features, namely upper level cold trough and gravity wave dynamics.

In this study, the broad features of the 22–23 July 2013 thundersnow episode are investigated in comparison to previous studies. In Section 2, data and methodology are detailed. Results are addressed in Section 3. Discussion and concluding remarks will be offered in Section 4.

2. Data and methodology

Radar and lightning data were employed in order to reveal evidences of thundersnow occurrence in Southern Brazil on 22–23 July 2013. Radar reflectivity (Z) measurements from Meteorological Service of Parana State (SIMEPAR) S-band weather Doppler radar have been used to diagnose the main precipitation characteristics. The radar is located at Teixeixa Soares and makes continuous volume scans with 14 elevations and 250-m gate resolution every 10 min. Lightning discharges are from RINDAT (Beneti et al., 2000) and STARNET (Morales et al., 2011). Those two networks measure mainly cloud-to-ground lightning strikes by measuring both the magnetic and electric field emitted by the atmospherics discharge in the low frequency (LF) and very low frequency (VLF) spectrum, respectively. The lightning strikes detected within a radius of 50 km centered in Guarapuava city were considered. Supporting Information also presents lightning and radar data for Candói city, neighboring Guarapuava city (Figure S3).

For synoptic and frontal zone cross-section analyses, output from the US National Weather Service’s Global Forecasting System – GFS (n.d.) was employed. This approach helps promote a more uniform, larger-scale comparison to other meteorological episodes with similar characteristics. Horizontal model resolution is 0.5° × 0.5° and there are 64 unequally spaced vertical sigma levels. The horizontal grid spacing works out to be ~50 km at the latitude of Santa Catarina, suitable for resolving waves at the low meso-α scale. For a surface pressure of 1000 hPa, 15 levels are below 800 hPa, and 24 levels are above 1000 hPa with the top level at 3 hPa.

3. Results

Thundersnow occurrence was evidenced through ground measurements at Guarapuava city, in the central portion of Parana State. The time evolution of the reflectivity and cloud-to-ground strikes between 22 July 2013 2136 UTC and 23 July 2013 0224 UTC is shown in Figure 1. The cooccurrence of high (Z ~ 40 dBZ) radar reflectivities and cloud-to-ground strikes, defining the thundersnow, is evident twice: on Julian day 22.99 (22 July 2013 2355 UTC and 23 July 2013 0224 UTC). The same evidence of thundersnow was found for Candói city, neighboring Guarapuava city (Figure S3).

Figure 2 shows surface atmospheric pressure fields associated with the CS that resulted in the thundersnow occurrence. The region marked as a star denotes the approximate location of Guarapuava, within the high terrain, steep plateau which climatologically receives cold outbreaks from Argentina. The four maps (day 1 to day 1) show a very strong blocking anticyclone in the south-eastern Pacific Ocean. This high pressure is very vigorous (stronger than 1040 hPa), and projects a ridge well into the Atlantic Ocean on day −2. As a result of this intrusion, the Atlantic sector receives a continuous influx of very cold air coupled with cyclonic circulation over the Southern Atlantic Ocean getting more organized on day −2, increasing the pressure gradient with the high pressure over the South American continent. On day 0, the affected area is under the domain of anticyclonic conditions, with strong continental advection of cold air forced by the projection of the Pacific blocking high inland. This evolution of the synoptic pressure fields suggests a large equatorward amplification of a Rossby wave.

Besides this, the evolution of the 1000–500-hPa thickness from day −3 to day 0 is shown in Figure 3, where the jet stream is shown in shading (wind velocity over 40 m s\(^{-1}\)). The black thick line represents the 5400-gpm layer, which has been traditionally associated with the occurrence of snow in southern Brazil based on the experience of authors. It becomes obvious...
that the event was characterized by the overlap of very low thickness as well as a very strong upper level jet from day −1. The position of Guarapuava, marked on the map (black filled star), approximately coincides with the equatorward side of the jet entrance, where the cold front is positioned and which dynamically would offer the ideal conditions for deep convection (Shapiro and Keyser, 1990; Moore and Vanknowe, 1992). This configuration suggests that the environment was highly conducive for the outburst of convective systems embedded in a very cold layer of mid-level air.

An environment conducive to convection, besides the presence of a mesoscale cyclonic curvature of 1020 hPa isobar northeast of Guarapuava (Figure 1), reinforces the importance of mesoscale processes. The mesoscale environment is then analyzed. A cross section of equivalent potential temperature ($\theta_e$), omega ($\omega$), moist potential vorticity (MPV), and relative humidity (Figure 4) reveals the well-developed baroclinic structure of a frontal zone. We note a deep nearly saturated layer (with respect to water) over the area of interest, with upward vertical motions in excess of $-8 \mu \text{b s}^{-1}$ and regions of elevated instability with appreciable vertical shear. The cross section also shows a shallow moist neutral region atop a region of conditional symmetric instability (CSI), diagnosed with negative MPV (Moore and Lambert, 1993; Schultz and Schumacher, 1999). This CSI layer exists in response to large changes in vertical winds and thus in the vertical gradient of geostrophic pseudo-angular momentum. However, this layer also exists above a significant near-surface vertical depth where temperatures hover around 0°C. Further aloft, there is a small, weak area of conditional instability very high in the profile. The GFS skew-T profile for that location (25.3°S, 51.4°W; Figure 5) corroborates the shallow moist nearly neutral region beginning at 500 hPa, which is a quite high lifting parcel level (LPL) compared with what has typically been observed at higher latitudes (Market et al., 2006). Yet, the temperature of the LPL is $-10°C$, which suggests the presence of sufficient super cooled liquid water to supply any weak updraft that might form. Also, no convective available potential energy (CAPE) was found for a parcel lifted from that level. These model solutions suggest a region of significant frontogenesis (not shown) collocated with an area of weak CSI beneath a layer of weak CI.
4. Discussion and conclusions

On the 22 and 23 July 2013, a CS resulted in a very rare snowfall accompanied by thundersnow in southern Brazil. In Curitiba, one of the most important southern metropolises of Brazil, the phenomenon had not been observed since 1975. In Guarapuava, state of Parana, the accumulated snow caused damage to roofs and disrupted roads, resulting in two deaths in a traffic accident.

Radar precipitation analysis revealed radar reflectivity (Z) values between 10 and 30 dBZ over Guarapuava in most of the period when snowfall was observed. STARNET and RINDAT detected 9 and 5 cloud-to-ground strokes, respectively, close to 23 July 2013 0000 UTC as shown in Figure 1. Reflectivity (Z) values around 40 dBZ were found prior to the first strokes and in the exact moment of the last discharges.

The most important feature on the synoptic scale was the large amplification of the Rossby wave from the Pacific Ocean which is typical of South American CSs (e.g. Pezza and Ambrizzi, 2005a). In association with the particular case here discussed, however, the inclination of the mid-tropospheric level trough component of the wave was such (to the west) as to favor the displacement of the largest anomalies within the southern part of Brazil. The stationarity of such pattern was then a pivotal component in allowing the cold advection to last sufficiently long so as to trigger the event, while the upper level jet gave the right conditions for the convective nature of the air mass, with fairly cold air in the mid-troposphere.

Dolif Neto et al. (2009) found a similar synoptic setup associated with the 2005 thundersnow case in Santa Catarina state, without significant accumulation in that case. Our results suggest that the greater wave amplification in 2013, in synergy with a more northward displacement of the upper level jet was responsible for the more unusual conditions. In both cases, the slow propagation of the upper level trough was crucial to provide the necessary persistence for the cold air to unfold.

This situation is one of the classic modes of cold air incursion leading to frosts in South America (Escobar et al., 2004; Pezza and Ambrizzi, 2005a; Escobar, 2007; Pezza et al., 2010), but is unusual in a sense that convective snow would primarily be associated with cyclonic conditions (Market et al., 2002). However, Figure 2 also shows an evident shortwave trough projecting around...
Figure 4. Cross section from the GFS initial condition fields for South America valid at 23 July 2013 0000 UTC over Guarapuava along from 27.8°S, 53.8°W to 23.2°S, 48.6°W). In upper corner the black filled star denotes Guarapuava city, and the arrow indicates the horizontal location of the cross section from Foz do Iguazu to Sao Paulo. Winds are plotted in station model format (in m s⁻¹), with relative humidity greater than 90% (with respect to slanted lines fill), equivalent potential temperature (dashed red lines, every 2 K), pressure vertical velocity (dotted fill, < -8 μb s⁻¹; zig-zag lines fill, > 4 μb s⁻¹), freezing isotherm (cyan line), moist potential vorticity (black bold lines; negative values, every 0.5 x 10⁻⁶ m K s⁻³ Pa⁻¹).

the location of Guarapuava (day zero), suggesting the presence of a mesoscale upper level disturbance within the anticyclonic region.

Mesoscale analysis using a cross section over Guarapuava revealed a well-developed baroclinic structure of a frontal zone. The cross section also shows a shallow moist nearly neutral region atop a region of CSI. The CSI exists in response to large vertical shear what is caused by the structure of the upper level jet stream. This highlights the importance of the synoptic-scale Rossby wave amplification and interaction to the surrounding atmosphere in order to produce such a jet stream.

Equatorward Rossby wave breaking (RWB) over South America is typically associated with intense CSs causing frosts in southern and southeastern Brazil (Sprenger et al., 2013). Comparing our studied case to other CSs in South America or other thundersnow events in Brazil and in the United States (Dolif Neto et al., 2009) or in Spain (Bech et al., 2013), the convective structures and synoptic pattern observed are more intense and more amplified. The marked Rossby wave amplification, resulted from RWB, was crucial to enable snowfall reaching subtropical latitudes in Parana State. Furthermore, the vigorous convective regime favored the occurrence of thundersnow, with a significant snow accumulation. In comparison to classical thundersnow cases in the United States (Market et al., 2002), the present event occurred much further from the cyclone’s center (at least 500 km further), what highlights the importance of mesoscale processes.

In summary, the CS accompanied by thundersnow and heavy snow appears to be a combination of: (1) further northward Rossby wave amplification; (2) strong upward vertical motion within a deep nearly saturated layer and (3) a CSI layer, in response to strong vertical shear, beneath a layer of weak conditional instability, and above a significant near-surface vertical depth where temperatures hover around 0°C.

Finally, we conclude that a typical atmospheric pattern of CSs in South America presented some particular features that permitted the rare occurrence of a thundersnow event and heavy snow in southern Brazil on 22 and 23 July 2013. Indeed, further studies will be necessary to better establish the underlying microphysical properties and atmospheric electricity that were also pivotal within this development. Future improvements in the Brazilian network of in situ remote sensing would be a desirable outcome in order to study and predict future thundersnow cases.

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Figure 5. Skew-T log p profile from the GFS initial condition fields for South America, at 25.3°S and 51.4°W valid at 23 July 2013 0000 UTC.

Supporting information

The following supporting information is available:

Figure S1. Diário Catarinense newspaper front page from 24 July 2013 showing an unforgettable (in Portuguese: ‘Inesquecível’) view of the Serra do Tabuleiro mountains covered by a deep layer of snow. The picture was taken from Florianópolis city, which is at sea level.

Figure S2. Remote sensing image from TERRA/Modis on 23 July 2013 1320UTC, and Aerial photograph (upper left corner – Picture taken by Eliana Panty Schwarz) over the same area and within the same day.
Figure S3. Vertical radar reflectivity profiles over Candói city in Brazilian Parana State, neighboring Guarapuava city, from 22 July 2013 21:36 UTC until 23 July 2013 02:24 UTC. Vertical black bars indicate the number of cloud to ground strokes detected by STARNET within a radius of 10 km.

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