Synoptic Analysis of a Period with Above-normal Precipitation during the Dry Season in Southeastern Brazil

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ABSTRACT: This study presents an analysis of a period with positive precipitation anomalies and anomalous severe weather activity in parts of the Southeastern Brazil during the dry season (austral winter). The objective of this work is to identify the synoptic pattern associated with the severe episodes on August 2018. The analysis was based on observational data and the CFSR (Climate Forecast System Reanalysis). Standardized anomalies of the main meteorological variables were used in the analysis. An anomalous trough in the mid and upper troposphere and the associated low-level flow from the Amazon Basin to Southeastern Brazil provided high amount of precipitable water, and were the main responsible for the rainfall markedly above the climatology along with severe hail and strong winds. The atmospheric environment was conditionally unstable due to a stationary front. These type of analyzes should be taken into consideration at this time of year to improve weather forecasts and minimize impacts in such circumstances.

KEY-WORDS: Brazil, Extreme Event, Precipitation, Synoptic.

1. INTRODUCTION

Brazil has a wide variety of climates (as equatorial, tropical and subtropical climates, with distinct precipitation and temperature regimes), especially due to its extensive territory (about 8.5 million km²), topography, vegetation and dynamics of air masses and sea currents (Mendonça and Danni-Oliveira, 2007; Zavattini and Boin, 2013). The Southeastern Brazil is the most economically developed region. The rapid population growth has been contributing to many environmental disasters occurring in the region, associated mainly with high rainfall volumes (Coelho Neto *et al.*, 2009; Ávila *et al.*, 2016), caused by phenomena such frontal systems, South

Atlantic Convergence Zones, troughs in the middle troposphere and mesoscale convective complexes.

The tropical climate predominates in most of Southeastern Brazil, which is characterized by rainy summers and dry winters (Torres and Machado, 2011; Alvares *et al*., 2013). This region presents high interannual variation of precipitation (Cavalcanti *et al*., 2009) and extreme weather events are common between October and March (austral spring and summer; Grimm, 2011). However, anomalous atmospheric configurations between April and September (austral autumn and winter) can also lead to severe weather episodes, although they are rarer in comparison to the warm season.

In the first half of August 2018, in the middle of the dry season in Southeastern Brazil, part of the region recorded above-average precipitation in several cities. Some cities of the States of São Paulo and Minas Gerais registered precipitation nearly three times the August monthly mean in just three consecutive days. Severe storms also occurred during this period, in particular between August 1st and 10th and were responsible for high winds and hail.

In this context, the objective of this study is to perform a synoptic analysis of the period and the causes of precipitation above average in the region during the peak of the dry season. The importance of this study lies in the fact that severe weather events during the dry period, when high atmospheric instability is unlikely, can cause greater impacts to the affected areas, especially to agriculture and general population. In addition, events like this may compromise climatic predictions for the period, since accumulated rainfall in the order of 40 mm to 80 mm, or even greater than 100 mm, can be recorded in only a few days or hours of the dry season. Thus, when the conditions favoring precipitation stall over a given region for a few days, several locations can easily surpass the monthly mean precipitation.

Therefore, the identification of atypical synoptic-scale patterns can be used to forecast such events and take preventive actions, minimizing impacts (Dolif and Nobre, 2012). Although these extreme events are not seen in a seasonal climate forecast, according to Coelho and Costa (2010), moving toward a more practical purpose of seasonal climate forecasts to uphold decision making depends on more valuable synergy among climate scientists and decision makers.

This work is structured as follows: Section 2 presents the study area, analyzed data and methods employed to investigate the precipitation anomalies; Section 3 exhibits the results that this research identified by examining observed and reanalysis data; and finally Section 4 shows the conclusions and final remarks of this paper.

2. STUDY AREA, DATA AND METHODS

2.1. Study Area

The analyzes of this study focus on the Southeastern Brazil (Figure 1), in particular the States of São Paulo and Minas Gerais. According to the Brazilian Institute of Geography and Statistics (IBGE), this area of the country has a population of approximately 70 million inhabitants, 42% of the entire Brazilian population. In addition, about 90% of the population of this portion of Brazil lives in urban areas. The Southeastern region concentrates important elements of the economy, such as agriculture, energy, livestock, petrochemical and steel industries and tourism. In this scenario, many people and sectors are vulnerable to natural disasters. The Southeastern Brazil has a considerable energy flux throughout the year, highly irregular distribution of precipitation in space and time, high evaporation in continental sectors and important participation of cyclonic and anticyclonic conditions (Cavalcanti *et al*., 2009).

Figure 1 – Brazil with the Southeastern region highlighted in red. The respective States are Espírito Santo (ES), Minas Gerais (MG), Rio de Janeiro (RJ) e São Paulo (SP).

2.2. Data

Rainfall data were extracted from the Center for Weather Forecasting and Climate Studies / National Institute for Space Research (CPTEC/INPE) website – http://clima1.cptec.inpe.br/monitoramentobrasil/pt (Figure 2). Data used include information from the National Institute of Meteorology (INMET – SYNOP and automatic meteorological stations), as well as the records of state meteorological centers. Data are interpolated in a grid of 1.0° x 1.0° resolution using the objective analysis method of Cressman (1959).

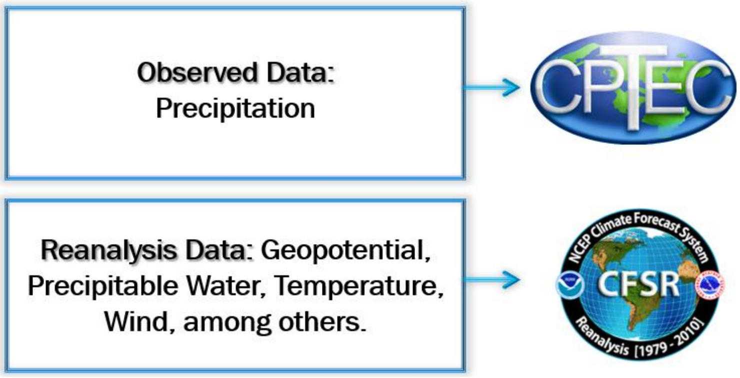


Figure 2 – Data sources used in this work.

The standardized anomalies of some atmospheric variables were calculated with the Climate Forecast System Reanalysis Version 2 (CFSR; Saha *et al*., 2014) data (Figure 2), from the National Center for Environmental Prediction (NCEP). The CFS is a model representing the global interaction between Earth's oceans, land and atmosphere. The CFS reanalysis is generated with a T382 model (~ 38 km horizontal resolution, interpolated to 0.5° x 0.5°), 27 vertical levels between 1000 and 100 hPa and available at the synoptic times (0000, 0600, 1200 and 1800 UTC). The atmospheric fields analyzed were geopotential, precipitable water, temperature, wind, among others. In order to investigate a particular case of a severe storm during the analyzed period, some variables, instability indices (Craven and Brooks, 2004) and satellite images were also examined in the Southeastern region of Brazil.

2.3. Methods

Using data from CPTEC/INPE and INMET, anomaly maps were built and they represent the point-to-point difference between the variable recorded in the selected month and year (in this research, precipitation) and the climatology (historical average of the period from 1979 to 1995). These maps are available on the CPTEC website (cptec.inpe.br). Severe weather reports were obtained from a database maintained by the third author of this research.

To produce the standardized anomalies from the CFSR data, a calculation is made using the mean and standard deviation from the CFSR of each variable on all days of the year during the 32-year reanalysis series (1979 – 2010). Then, the CFSR data for the studied period is transformed into an anomaly (the difference between the observed value and the climatological mean) that is proportional to the standard deviation of the variable at each location and at each time, as:

$$Standard\ Anomalie = \frac{Observed\ Value - Climatological\ Mean}{Standard\ Deviation}\ . \qquad (1)$$

Thereby, a standard deviation of +2, for instance, means the variable has a value that is 2 standard deviations above the mean for that time of the year in that region. These anomaly maps were made by the software GrADS®.

Thus, this work examines primarily the climate scale through INMET's precipitation climatological normals from 1981 to 2010 over Southeastern Brazil, comparing them with the anomaly observed by CPTEC/INPE on August 2018. Thereafter, the synoptic scale meteorological phenomenon is duly characterized by reanalysis data (CFSR's standardized anomalies), with detailed evaluation of the anomalous atmospheric patterns acting on that period.

3. RESULTS AND DISCUSSION

Figure 3 presents the average August precipitation for the period from 1981 to 2010 over Brazil, according to INMET. In Southeastern Brazil, the August average rainfall varies from just 10 mm in the north of the region to 50 mm in the south. This situation is characteristic of the peak of the dry season in this area, which extends from April to September. At this time of year, the South Atlantic Subtropical Anticyclone (SASA) reaches its westernmost position over the continent, greatly reducing the precipitation. Rainfall events mostly occur when frontal systems and subtropical and extratropical cyclones are strong enough to displace the SASA (Reboita *et al*., 2010).

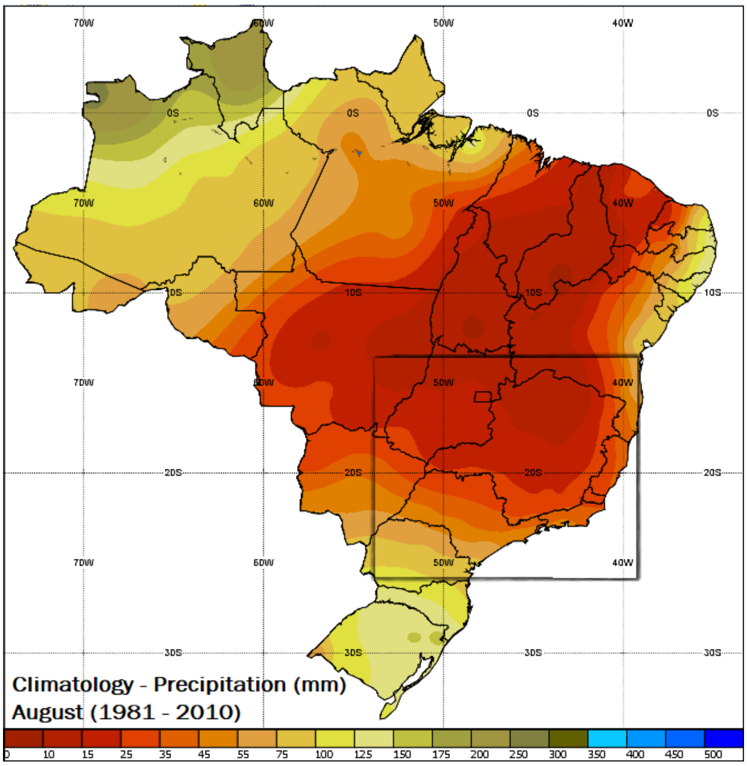


Figure 3 – Mean precipitation for August from 1981 to 2010 over Brazil. The gray box delimits the Southeastern region of the country (Source: INMET).

The rainfall anomalies for August 2018 (Figure 4) show positive precipitation anomalies appear especially in the State of Paraná (PR, Southern Brazil) and part of Southeastern Brazil with values up to 200 mm above the climatology (about four times the average). These rainfall volumes were associated with the most significant rain episodes that occurred in the first 10 days of the month. However, the common cold fronts that pass through this area at this time of year usually do not have enough moisture to cause such expressive precipitation (Siqueira and Machado, 2004).

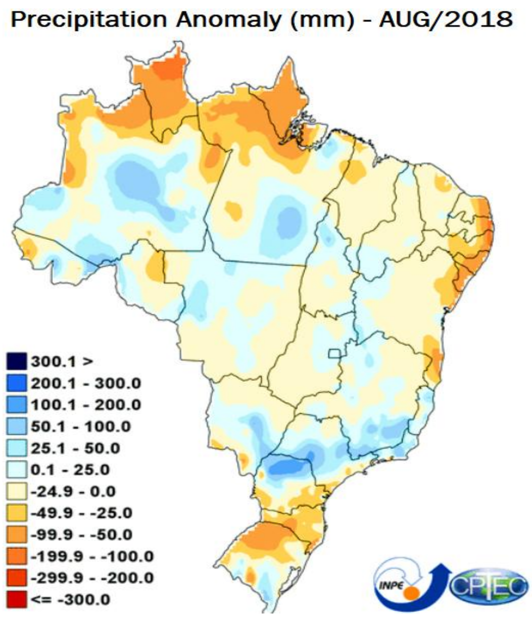


Figure 4 – Rainfall anomaly (mm) on August 2018 over Brazil (Source: CPTEC/INPE).

Figure 5 elucidates the differences between the first and second half of August, regarding the anomalies of the precipitation field, which leads us to focus our analysis in the period from August 1st to 10th, when most rainfall was concentrated.

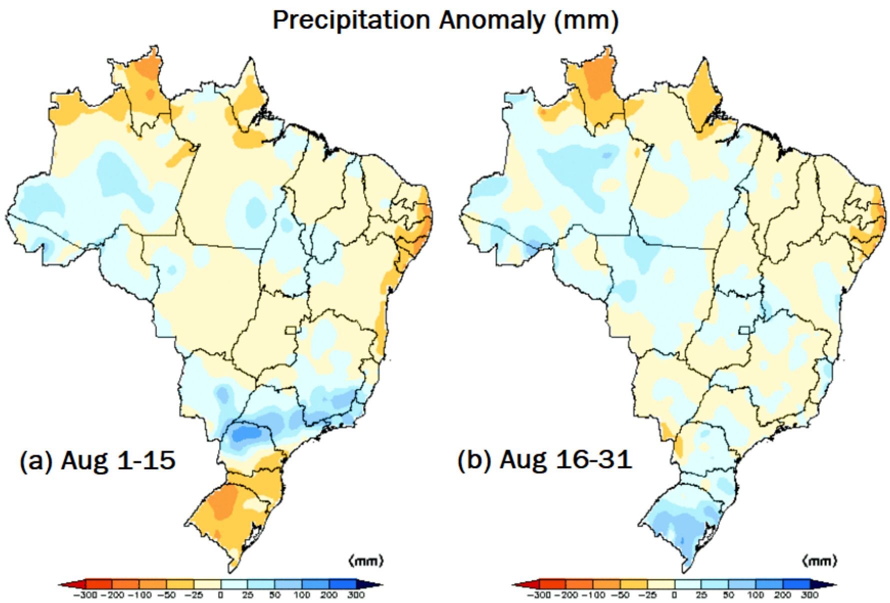


Figure 5 – Precipitation anomalies over Brazil in the (a) first half and (b) second half of August 2018 (Source: CPTEC/INPE).

The 850-hPa geopotential height anomalies (Figure 6) were in phase with cyclonic circulation at 250 hPa along the coast of Southeastern Brazil in August 2018, which relates to the passage of troughs and frontal systems over the region. Souza and Ambrizzi (2004) emphasize that zonal westerly flow occurs over most subtropical South America during this period. The inland penetration of the SASA is recurrent in winter and prevents the meridional displacement of frontal systems moving towards the tropical areas of South America (Ito, 1999). Also, this cyclonic upper-level circulation, in association with an anomalous 850-hPa anticyclone farther south, forms a dipole blocking system in the Atlantic Ocean. The typical winter configuration resumed after the advance of cold air over the region at the end of the first half of August.

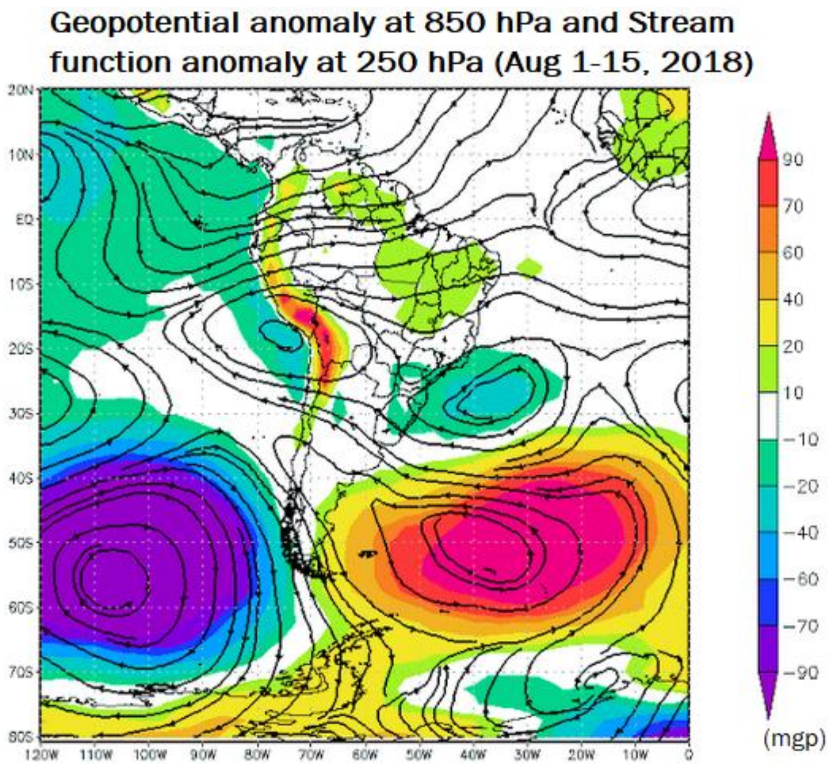
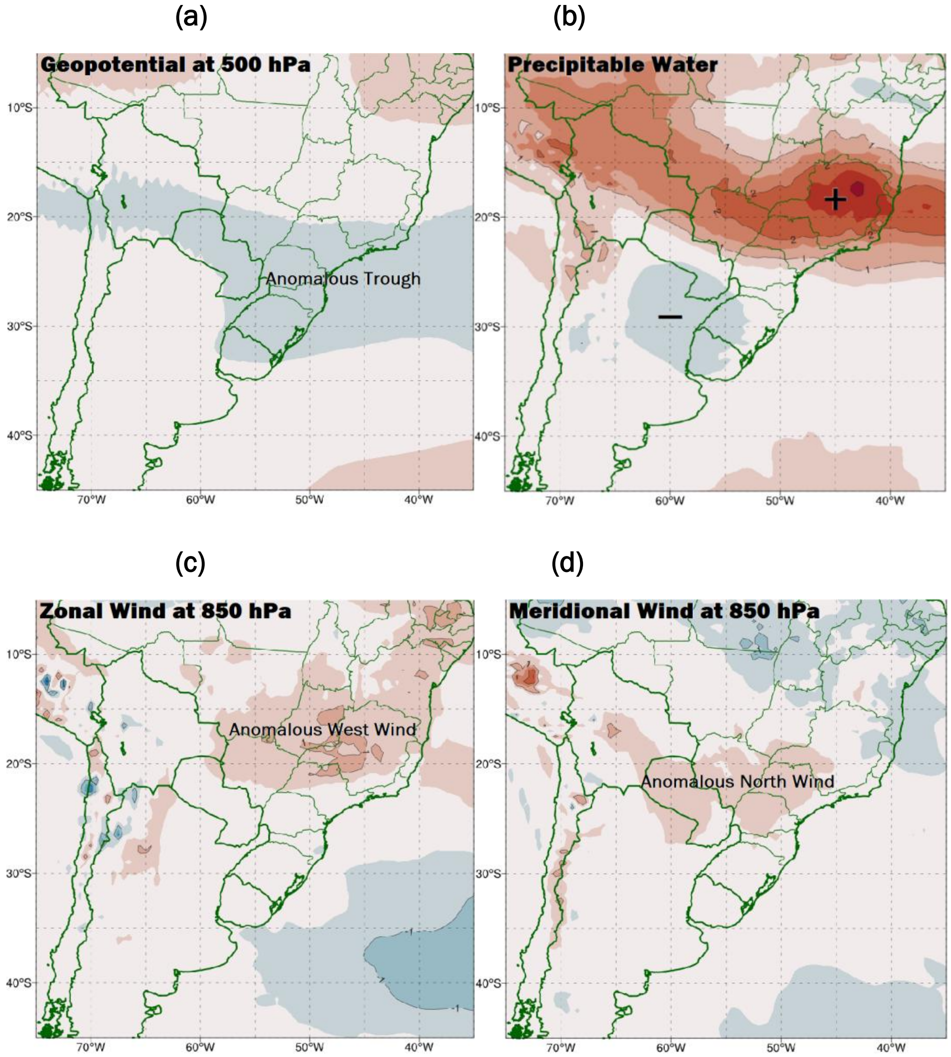


Figure 6 – 850-hPa geopotential height (shaded, mgp) and 250-hPa stream function anomalies during the first half of August 2018 (Source: CPTEC/INPE).

The standardized anomalies (Figure 7a) depict an anomalous 50-hPa trough over south-central Brazil, including part of the Southeastern region. Above-average precipitable water over the north-central São Paulo and the entire Minas Gerais

(Figure 7b) associated with the SASA's circulation and the constant transport of moisture from the Amazon Basin by the South American Low-Level Jet (SALLJ; Oliveira *et al*., 2018). According to flow patterns and moisture transport values in the lower atmosphere, the SALLJ transports atmospheric moisture from the trade winds flowing over the Amazon, which can obtain a greater amount of moisture due to evapotranspiration in the forest region. Then, this flux suffers a change of direction due to the topographical block and runs parallel to the Andes towards the Southern/Southeastern Brazil (Marengo *et al*, 2004). The anomalous northwesterly flow during this period is evidenced by the standardized anomalies of 850-hPa zonal (Figure 7c) and meridional (Figure 7d) wind, which respond to the anomalous low-pressure over the Atlantic Ocean (Figure 6).



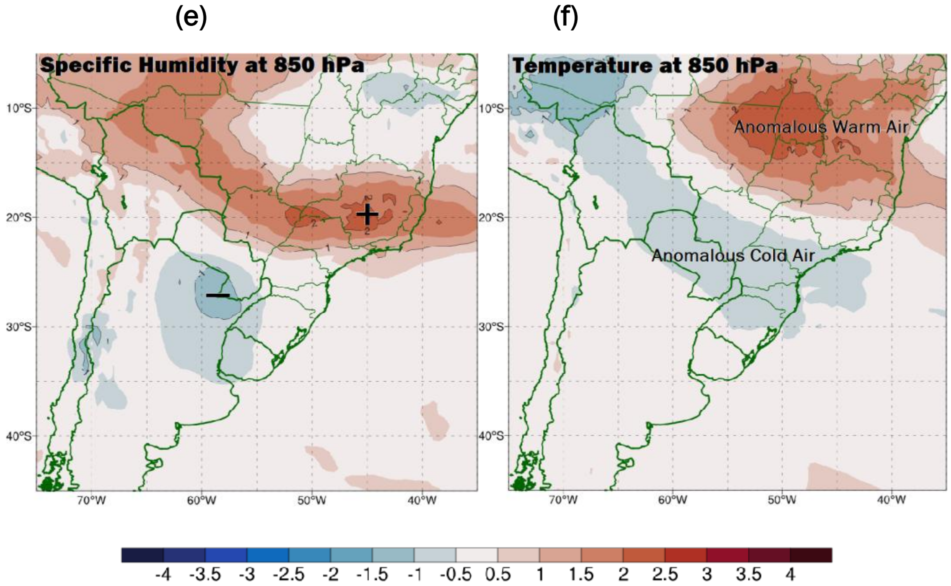


Figure 7 – Standardized anomalies of (a) geopotential at 500 hPa, (b) precipitable water, (c) specific humidity at 850 hPa, (d) temperature at 850 hPa, (e) zonal wind at 850 hPa and (f) meridional wind at 850 hPa between August 1-10, 2018 over center of South America.

The standardized anomalies of 850-hPa specific humidity (Figure 7e) follow the precipitable water anomalies and are positive from Northern Brazil to the Southeastern. Above-average 850-hPa temperatures are observed over the northern portion of Southeastern Brazil and below-average in the central-southern sector of the country (Figure 7f), with enhanced baroclinicity in the region where the anomalous precipitation occurred.

One way to analyze the intraseasonal variability of SALLJ is by the frequency of rainfall extremes and their connection to the jet events. Several researchers have shown that such intense precipitation episodes associated with the SALLJ are much more common during the austral summer (e.g., Liebmann *et al*., 2004; Weykamp and Ambrizzi, 2006), since there is sufficient warm and moist air for the development of severe storms, differently to what occurs in the austral winter.

The reports of severe hail and wind between August 1st and 10th, mainly in the south of the State of Minas Gerais, northeast of São Paulo and Paraíba Valley, are shown in Figure 8. According to the National Institute of Meteorology, the hail occurred in several cities of Minas Gerais on August 6, 2018, between afternoon and evening, was the only report in this month since 1910.

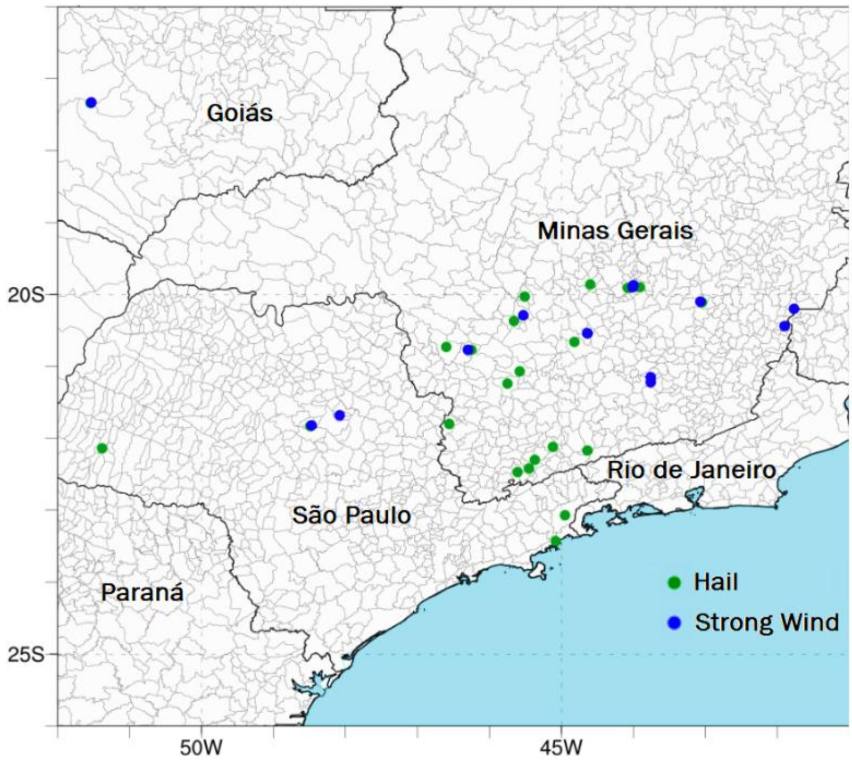


Figure 8 – Severe weather reports over Southeastern Brazil between August 1st and 10th (2018) with green dots representing hail and blue dots strong winds.

The severe weather event of August 6, 2018 in southern Minas Gerais is shown in the satellite image at 1900 UTC of Figure 9, where it is noted the presence of a stationary front in the Southeastern Brazil. The atmospheric environment was conditionally unstable in this region at 1800 UTC this day, especially due to the high 850-hPa θe (Figure 10a) associated with a warm and moist lower troposphere. The moisture convergence is noticed in the 850-hPa θe field between São Paulo and Minas Gerais states. The instability is further evidenced by the most-unstable convective available potential energy (MUCAPE) values greater than 2000 J/kg in this area (Figure 10b), which is very atypical for this time of the year. The 0-6-km wind shear is also high (more than 15 m/s) in association with the strong upper-level jet nearly parallel to the stationary front during the event. The northwestly flow from the SALLJ for several consecutive days contributed to the high MUCAPE values, thus allowing gradual warming and increased humidity of the air mass in the north of the frontal system.

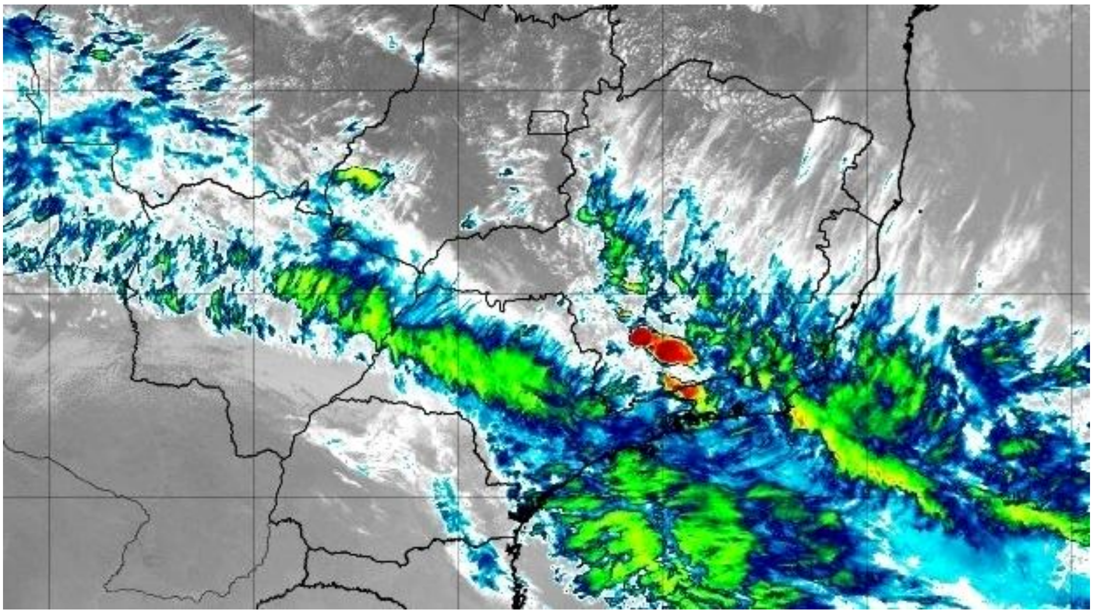


Figure 9 – Infrared channel enhanced image of the Geostationary Operational Environmental Satellite – GOES 16 over the Southeastern Brazil on August 6, 2018 at 1900 UTC (Source: CPTEC/INPE).

Convective events are strongly modulated by the total water vapor found at 700 hPa due to the thermodynamic instability, which is clear by the expressive precipitable water available between the States of Minas Gerais and São Paulo (Figure 10c). The 0-3-km storm-relative helicity (SRH) is greater than 200 m^2/s^2 along and north of the stationary front (Figure 10d), which is sufficient for the development of strong atmospheric instabilities. The stationary front in association with the anomalous baroclinicity between MG and SP was related to high wind shear in the region. This factor linked to the air mass with high MUCAPE generates a favorable environmental for severe storms.

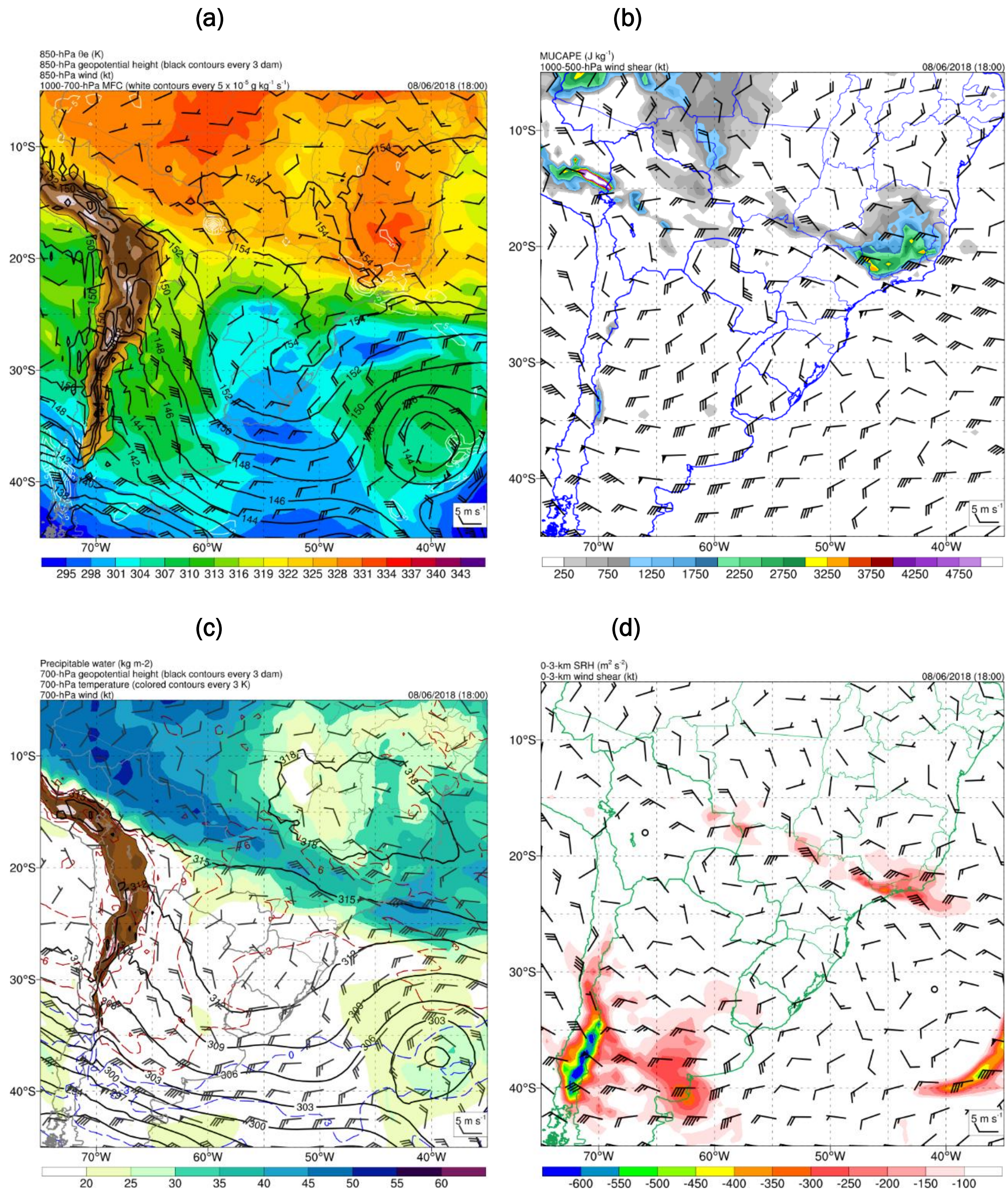


Figure 10 – (a) 850-hPa θe (shaded, K), geopotential heights (black contours, mgp) and winds, and MFC (white contours every $2x10^{-5}$ g kg^{-1} s^{-1}), (b) MUCAPE (shaded, J/kg) and wind shear between 1000 and 500 hPa, (c) PW (shaded, mm), 700-hPa geopotential height, temperature and wind, and (d) 0-3-km SRH and wind shear on August 6, 2018 at 1800 UTC.

4. CONCLUSIONS

An atypical atmospheric pattern occurred in the first half of August 2018 and culminated in above-normal precipitation and severe weather in areas of the Southeastern Brazil (middle of the dry season). In short, this event occurred specially as a function of an anomalous synoptic-scale stationary trough over south-central Brazil. Coupled with this, there was the displacement of troughs in the mid troposphere combined with an expressive positive precipitable water anomaly. Moreover, the flow at low-levels was favorable to the moisture transport and convergence directed to Southeastern Brazil. The SALLJ performance is more active in the austral summer months due to the predominant absence of SASA on the continent, thus allowing the jet to be established. In austral winter, this scenario is much more unusual, but still requires careful monitoring.

It should be noted that this kind of analysis permeates all the time scales that deserve attention in the management and operation environment of several sectors. In terms of climatology, it was observed that rainfall volumes were established above the climatology and also beyond what was predicted on the seasonal scale. In addition, this synoptic-scale atmospheric pattern can present its first evidence about 7 to 10 days in advance, thus alerting that a phenomenon with potential for anomalous severity has a high probability of occurrence. Finally, once the configuration is established, there is continuous monitoring of the meteorological variables and atmospheric instability indices, a process carried out with particular caution in nowcasting. In this sense, it is essential to emphasize the relevance that short-term meteorological phenomena can exert on the historical averages and seasonal forecasting.

From the synoptic point of view, this atmospheric configuration in the dry season has expressive intensity with respect to extreme weather episodes, despite the low frequency at this time of year (austral winter). This type of investigation has great importance, so that such severe events could be better identified in weather forecasting. Therefore, more detailed studies are needed to examine other possible dynamic and thermodynamic mechanisms involved in these meteorological situations. In this way, it will be also possible to investigate its climatology and trends over the last decades.

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