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Environment

Seasonal climatology of cold fronts in south-central South America from an automated detection system

Climatologia sazonal de frentes frias no centro-sul da América do Sul a partir de um sistema de detecção automatizado

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ABSTRACT

The cold fronts (CF) operating in south and south-central South America are the main ones responsible for heavy rain, thunderstorms with strong winds, and accentuated temperature drops. This study aimed to perform a seasonal climatology of CF's displacement and intensity in the region above mentioned. A computational algorithm was developed called the Normalized Cold Front Detection Index (NCFI) for detecting and characterizing CFs through the CFSR and CFSv2 reanalysis data, using the meridional component of the wind at 10 meters and the air temperature at 2 meters. Ten areas were delimited: five coastal and five continentals. Seasonal climatology showed a higher frequency in winter, when these systems are more intense, averaging 20 per year. The patterns of displacement and intensity exhibited a decrease in CFs as they advanced toward lower latitudes. The synoptic analysis and the accumulated precipitation composites revealed that the CFs that act in the spring concentrated the accumulated precipitation in Santa Catarina's western portion. In the summer, convection cells are responsible for storms and poorly distributed rain. In the autumn, rainfall is associated with CFs and maritime circulations, impacting Rio Grande do Sul and the west and north of Santa Catarina. In the winter, CFs dominate the precipitation pattern. According to the NCFI, spring, autumn, and winter cases are categorized as intense, while summer cases are moderate.

Keywords: Detection algorithm; Climatology; Frontal systems; Frontogenesis

RESUMO

As Frentes Frias (FFs) atuantes no sul e centro-sul da América do Sul (AS) se caracterizam como causadores de eventos como chuvas intensas, temporais com ventos fortes e queda acentuada da temperatura. Este trabalho teve como objetivo realizar uma climatologia sazonal do deslocamento e da intensidade das FFs na região mencionada acima. Na metodologia desenvolveu-se um algoritmo computacional, denominado de Índice de Detecção de Frentes Frias Normalizado (IFFN), para detecção e caracterização das FFs por meio dos dados da reanálise do CFSR e CFSRv2, da componente meridional do vento a 10 m e da temperatura do ar a 2 m. Dez áreas foram delimitadas: sendo cinco litorâneas e cinco continentais. A climatologia sazonal de FFs apresentou uma maior frequência no inverno, onde esses sistemas são mais intensos, com uma média de 20 FFs por ano. Os padrões de deslocamento e intensidade mostram a diminuição de FFs conforme estas avançam em direção à latitudes menores. A análise sinótica e a composição da precipitação acumulada mostrou que as FFs que atuam na primavera, por vezes associadas aos CCMs e SCMs, favorecem os acumulados de precipitação na porção Oeste do estado. No verão, as células de convecção são responsáveis pela chuva mal distribuída e temporais. No outono, a chuva está associada às FFS e à circulação marítima e influenciam o Rio Grande do Sul (RS) e as regiões Oeste e Norte de Santa Catarina (SC). No inverno, as FFs são responsáveis pelo padrão de precipitação. Segundo o IFFN de cada caso, tem-se que os casos da primavera, outono e inverno são categorizados como intensos, já o de verão como moderado.

Palavras-chave: Algoritmo de detecção; Climatologia; Sistemas frontais; Frontogênese

1 INTRODUCTION

The south-central region of South America (SA) is favorable to the formation and intensification of a cold front (CF) (Satyamurty & Mattos, 1989; Reboita *et al*., 2010; Simmonds *et al.*, 2012). The CFs are defined as the transition zone between two air masses - with different densities and temperatures - capable of influencing other meteorological variables (Bjerknes, 1919). This is one of the main meteorological systems that cause significant changes in weather and climate, resulting in heavy rainfall, strong winds, and accentuated temperature drops, impacting socioeconomic sectors.

Several studies about CFs applied detection methods to try to improve the predictability of these systems around the globe (Renard & Clarke, 1965; Clarke & Renard, 1966; Hewson, 1998; Berry, *et al.*, 2011; Simmonds *et al.*, 2012). In SA and Brazil, besides detecting CFs, many authors seek to determine their climatology. Kousky (1979) analyzed the occurrence of cold fronts that reached the northeast of Brazil in 10 years (from 1961 to 1970). The author identified a higher frequency in the winter and spring, relating this recurrence to the highest rainfall totals over the region.

Furthermore, using satellite images, Oliveira (1986) made a climatology intending to evaluate the interaction of cold fronts with the Amazon. As a result, it was observed that they decreased toward lower latitudes.

Justi da Silva and Silva Dias (2002) determined a climatology of CFs based on grid points delimited by 10ºS and 60ºS, 30ºW and 90ºW, from 1981 to 1999, using NCEP reanalysis. They defined the occurrence of a CF when the reversal in the signal of the meridional component of the wind, from north to south, was detected. Subsequently, they showed a higher frequency of frontal systems on the coast than on the continent, around 35ºS.

Rodrigues *et al.* (2004) used a numerical algorithm and reanalysis data from NCEP to produce a climatology about the CFs frequency at Santa Catarina's coast. The authors identified 429 systems over 10 years and showed that they hit the region 3 to 4 times the coast during the year; the highest frequency occurs in the spring. The criteria used by the authors occurred as follows: wind rotation from north to south (negative to positive); the permanence of the southern wind for at least a day; temperature drop at the wind turn moment, or up to two days later, at least 0,5º degrees Celsius.

Andrade (2005) studied the frontal systems during 1980-2002 over the south of South America. The criteria utilized to detect the CFs were: the temperature drop at 925 hPa, the increase in the mean sea level pressure, and the change of the southern component of the wind at 925 hPa from one day to another. The study revealed that there is a decrease in the occurrence of frontal systems from Argentina toward lower latitudes. Also, near south and southeast Brazil, spring is the most recurrent season for CFs. The author noted that CFs could not penetrate the continent's interior in the summer, decreasing the frequency in all studied areas.

Cavalcanti and Kousky (2009) analyzed the passage of CFs from 1979 to 2005 using the following parameters: the presence of southern winds with at least 2 m/s, a temperature drop of at least 2ºC, and an increase in mean sea level pressure of at least 2 hPa. They obtained 45 CFs on the east coast of extreme southern South America and

30 CFs on the east coast of southeastern Brazil. In addition, the highest occurrences throughout the year take place between 25ºS and 30ºS.

Morais *et al.* (2010) investigated the climatology of CFs and the wind regime induced by these phenomena over the Metropolitan Region of São Paulo (MRSP) from 1987 to 2007. The central methodology was similar to Rodrigues *et al.* (2004). Wind data from the IAG/USP weather station in the Água Funda neighborhood (São Paulo) were used. The results showed that three fronts, on average, arrive at the MRSP monthly; their frequency is higher from March to May and August to December. Regarding the wind, it was more intense a few days before the CFs passage, reached the lowest value on the arriving day, and gradually increased in the following days. The correlations between cold fronts and the reservoir dynamics revealed that the response time from one event to another was 2 to 3 days in the Guarapiranga Reservoir and 3 to 4 days in the Billings Reservoir. The physical-chemical parameters measured in the reservoirs were temperature (ºC), pH, and Turbidity (NTU).

Silva *et al.* (2014) quantified the passage of CFs through the Southern Region of Minas Gerais (SRMG) from 2004 to 2010. To detect the CFs, they used the 2-meter air temperature, mean sea level pressure, and 10-meter meridional wind from ERA-Interim reanalysis and an objective identification scheme. In the annual average, they found that 27 CFs pass through the SRMG; winter and spring are the most regular seasons.

Cardozo *et al.* (2015) evaluated the occurrence of CFs in eight locations on the east coast of SA. This work applied an automatic method similar to Rodrigues *et al.* (2004) and Morais *et al.* (2010). The objective was to quantify the CF occurrence, showing the need for specific studies to define thresholds when using automated algorithms, and relate them with the different Southern Annular Modes (SAM) phases. In Argentina, the CFs presented little seasonal variability, while in Brazil, all studied cities showed higher frequency in the winter and lower in the summer. The relationship between the CFs occurrences and the SAM phases revealed a preference for CFs in the positive phase in the summer and negative in the winter and spring for most cities.

Escobar *et al.* (2016) identified the main synoptic patterns associated with extreme rainfall in the Itajaí Valley/Santa Catarina region. The methodology used was the Principal Component Analysis technique, applied to the Climate Forecast System Reanalysis (CFSR) series from 1979 to 2010 for the east of Santa Catarina. Separately, to select the frontal systems associated with extreme rainfall events, the authors used the precipitation data from MERGE products (a combination of observational and satellite data). They used a method similar to Andrade (2005) to identify the frontal systems. The results showed a higher frequency of CFs associated with extreme rainfall in the Itajaí Valley during spring.

Moreover, the analysis provided five main synoptic patterns representing 83,4% of the cases. The most frequent synoptic pattern showed an intense flow from the southeast quadrant, determined by a robust post-frontal anticyclone observed over southern Buenos Aires state, whose CF associated was in the extreme northeastern part of Santa Catarina. Finally, two typical summer synoptic patterns related to extreme rainfall in the Itajaí Valley were found: one related to the South Atlantic Convergence Zone (SACZ) and the other to the Chaco Low.

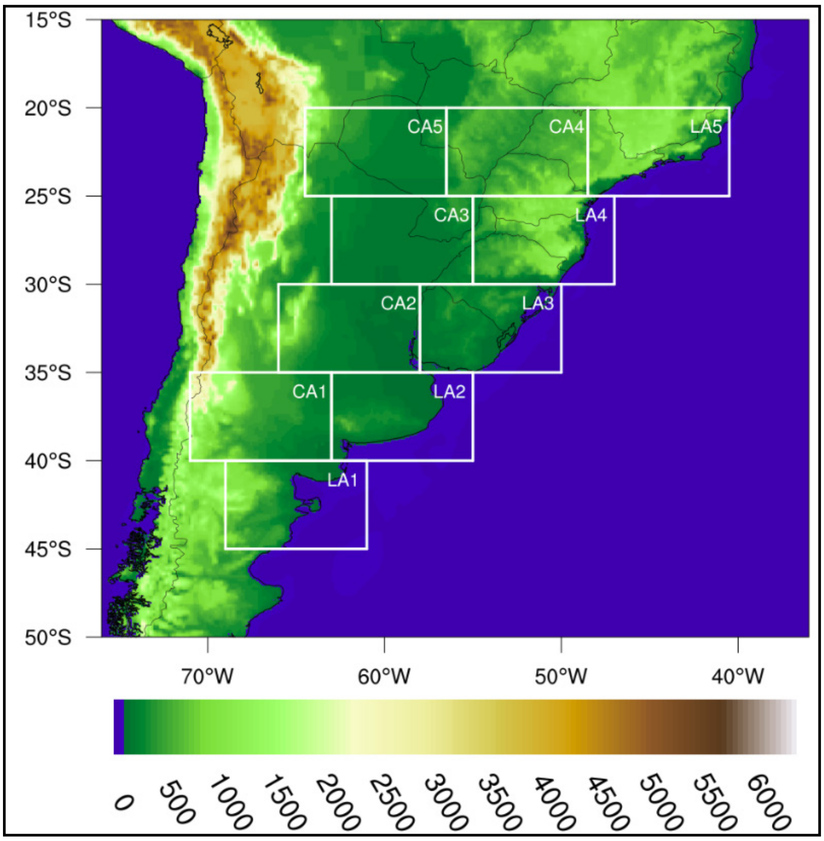
Therefore, the principal results found by all these authors were: i) the CFs frequency decreases toward lower latitudes and ii) CFs are more regular in the winter and spring seasons. However, these studies did not quantify CFs concerning intensity over the studied regions. Based on this context, this work aimed to evaluate, climatologically, the CF’s displacement and intensity through the south and south-central SA using an objective detection method.

2 DATA AND METHODS

2.1 Study Area

The study area covers most of South America. This region has a diverse relief and is influenced by the Andes Cordillera, Pacific and Atlantic Oceans, and various meteorological systems. In the study region, there were ten areas, five coastal (LA) and five continental (CA) (Figure 1).

Figure 1 – The white rectangles delimit five coastal areas (LA) and five continental areas (CA). The shaded information reveals the topography of SA. The scale ranges from the sea level (0 meters) to the Andes Cordillera on the western side of SA (approximately 6000 meters)



Source: The Authors (2023)

Notably, these subdivisions were made to evaluate the formation (cyclogenesis followed by frontogenesis) and displacement of the frontal systems over the southern cone of SA (Satyamurty and Mattos, 1989).

2.2 Data

We used the 10-meter meridional wind component (m/s) and 2-meter air temperature (ºC) from CFSR reanalysis (Saha *et al.*, 2010; Decker *et al*., 2012), available from 1979 to March 2011, and CFSv2 (Saha *et al.*, 2014), available from April 2011 to the present (https://rda.ucar.edu/datasets/ds093.0/). Both versions were used in grib2 format, with a 0,50º x 0,50º spatial resolution and a 6-hour temporal resolution, for 30 years (1991 to 2020).

2.3 Methodology

To detect the CFs, an automated algorithm was developed based on the methodology used by Rodrigues *et al.* (2004), Silva *et al.* (2014), and Cardozo *et al.* (2015). The software GrADS (Grid Analysis and Display System) provided by the Center for Ocean-Land-Atmosphere Studies (COLA) was used.

Initially, a CF was detected when the algorithm signaled the following conditions: i) northern wind at time t-1 (6 hours before); ii) southern wind from time t to t+3, indicating the rotation from the north wind (negative values) to the south wind (positive values), and persistence for 24 hours; and iii) decrease of the 2-meter air temperature up to 24 hours after the CF passage, considering the times t-1 and t+3.

The above mentioned conditions resulted in the Cold Front Detection Index (CFI). To make CFI dimensionless, it was normalized, relying on the domain's maximum value. Thus, the normalized CFI (NCFI) was obtained on a scale ranging from 0 to 10, which shows the intensity of the CF. From the NCFI, the events of CFs detected were categorized as follows: Weak Event ($0.1 \leq$ IFFN > 4.0), Moderate Event ($4.0 \leq$ IFFN > 7.0), and Strong Event ($7.0 \leq$ IFFN ≥ 10.0).

The daily precipitation product MERGE (Rozante *et al.*, 2010) was used to evaluate the seasonal composites of the accumulated precipitation, from 2015 to 2020, on the dates of the 51 cases discovered. There were 13 episodes in the spring, 8 in the summer, 6 in the autumn, and 10 in the winter.

The mean sea level pressure allied with u and v wind components, air temperature, and specific humidity at multiple vertical levels were analyzed synoptically using CFSR and CFSv2 reanalysis data. These fields are essential for examining the performance of the low-level jet, prefrontal condition, the atmosphere's vertical profile, and temperature and humidity behavior during CF development.

3 RESULTS AND DISCUSSIONS

3.1 Seasonal Climatology of CFs Detected by the Algorithm

The climatology of CFs was defined as the study of their patterns through a statistical description over 30 years. The following presents the CFs seasonal variability (grey bars) and NCFI (green bars) for each delimited area (Figure 2).

The analysis of coastal areas (LAs) shows that winter and spring have higher CFs occurrence. Also, there is a decrease in the number of cold fronts from the highest latitudes (LA1) to the lowest (LA5). This result corroborates studies by Justi da Silva and Silva Dias (2002), Andrade (2005), and Reboita et al. (2009). They showed that, on average, the CFs that travel along the South American coast and reach lower latitudes begin their dissipation process (frontolysis) next to 20ºS. The highest frequency of CFs was presented in the summer, around 45ºS. CA exhibited slight seasonal variation and lower CFs numbers related to LA.

In LA1, there is a more significant number of detected systems and higher values of NCFI compared to the other areas. The systems are intense in summer, autumn, and spring, while in winter, they are moderate. There is a seasonal variation, with 18 CFs in the summer and 21 in the winter. In this area, even though it is influenced by

South Pacific Subtropical High (SPSH), studies show that some meteorological systems (troughs and low pressures) migrate from the Pacific and manage to pass through the Andes Cordillera. Some go to the Atlantic, and others are deflected toward the equator (Muller & Berri, 2007; Muller & Ambrizzi, 2007). However, most of these systems favor or strengthen the acting frontal systems throughout the seasons.

Other studies denominate LA1 and its surroundings as a frontogenetic region. It becomes more active in the summer and shifts to lower latitudes in the winter (Satyamurty and Mattos, 1989; Reboita *et al.*, 2010; Simmonds et al., 2012). Still, where AL1 is located, there is a higher frequency of CFs, although many asymmetries exist in the ocean (Simmonds *et al.*, 2012).

In CA1, the CF's seasonal variability presented a lower number related to LA1, ranging from 11 CFs in the autumn to 13 in the winter. SPSH also influences this region, and by being localized within the continent, most CFs cannot reach it. The mean intensity in CA1 also decreased related to LA1; during all seasons, the mean intensity of CFs is moderate.

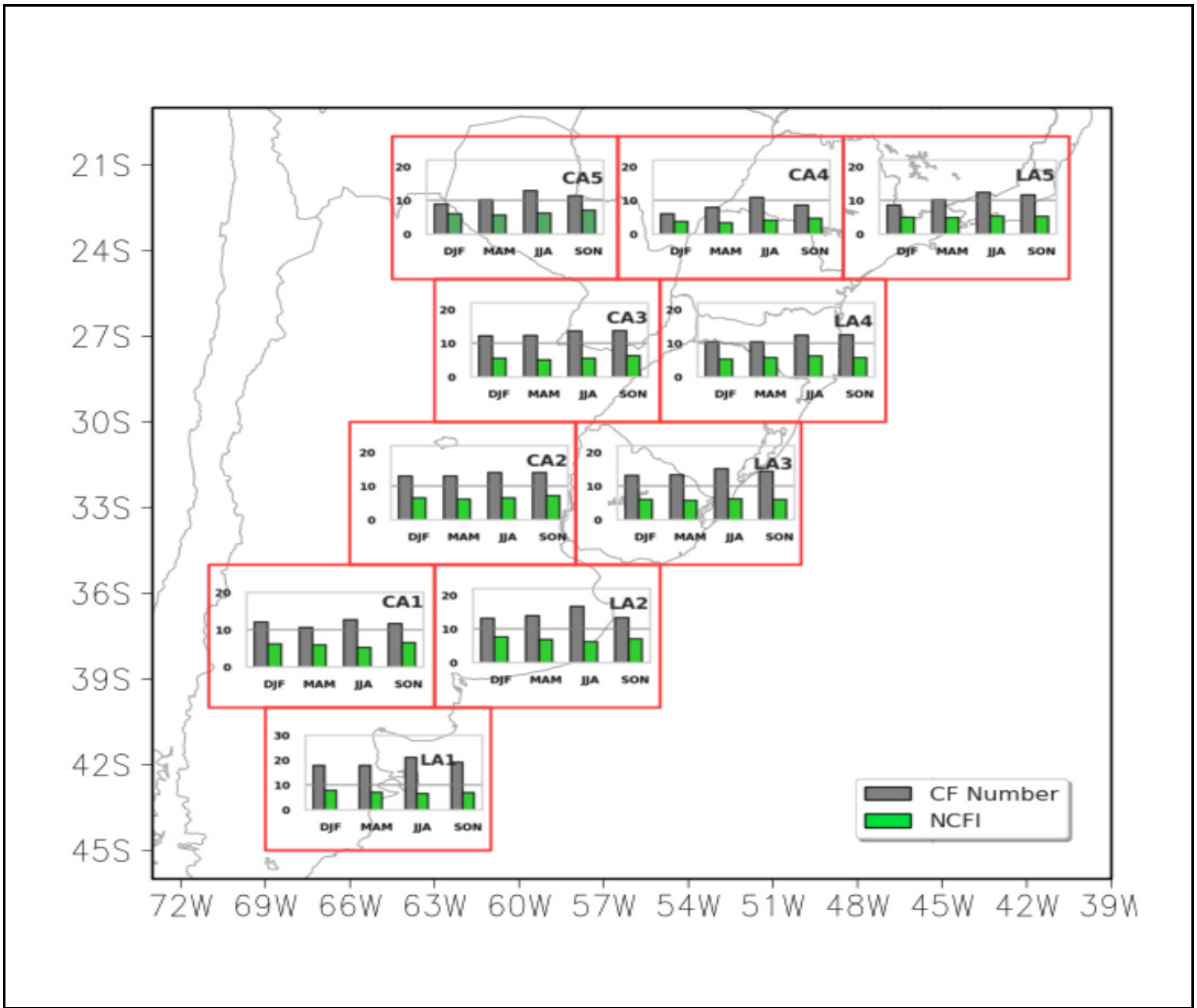
Concerning NCFI in CA2, CFs are intense in the spring and moderate in the other seasons, while in CA3, all seasons are moderate. In CA2 and CA3, winter and spring are the most affected seasons, with approximately 14 cases.

In LA2, CFs were more frequent in winter, averaging 17 systems, and their intensity was lower than in other seasons. In LA3, the CFs varied between 13 and 15, with winter being the most frequent season, followed by spring. In LA4, the highest frequency occurred in the spring with 13 systems, followed by winter with 12, and the other seasons with 10 CFs on average. Both LA3 and LA4 presented moderate intensity during all seasons.

In LA5, CA4, and CA5, the winter stands out as the most recurrent season, with an average number of 12, 11, and 13, respectively. Summer is presented in the three areas mentioned with fewer systems. The NCFI analysis showed that LA5 CFs were moderate. In CA5, they were intense in spring and moderate in the other seasons.

Finally, in CA4, the CFs were moderate in winter and spring and weak in summer and autumn.

Figure 2 – Average seasonal number of cold fronts and the Normalized Cold Front Index average monthly value in Coastal and Continental Areas (1991-2020)



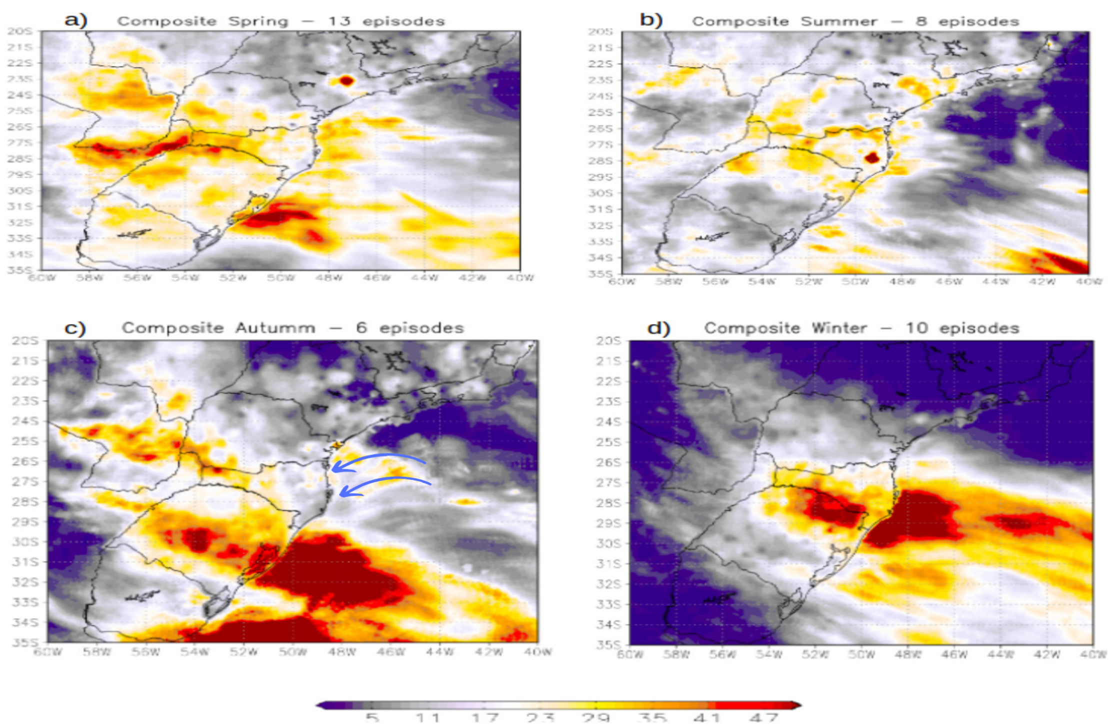
Source: The Authors (2023)

3.2 Seasonal Analysis of four CF episodes detected by the NCFI

Figure 3 illustrates the accumulated precipitation composites, from 2015 to 2020, distributed according to the seasons on the dates encompassing the cases. It was observed that the CF cases, which acted in the spring (Figure 3a), concentrated the accumulated precipitation in the state's western portion. It is noteworthy that spring is the second season in which CFs most act in Santa Catarina, while winter is the most common. However, when a CF is associated with other meteorological systems, such as Mesoscale Convective Complexes and Mesoscale Convective Systems, they can cause a massive socioeconomic impact.

Due to substantial warming, convection cells form disorganized during the summer, causing storms responsible for flash floods and flooding, among others. The CFs in this season are more coastal than the others (Figure 3b), presenting greater accumulated around Santa Catarina's eastern part.

Figure 3 – MERGE's accumulated precipitation (mm/day) concerning CF cases dates for all seasons: a) Spring; b) Summer; c) Autumn; d) Winter



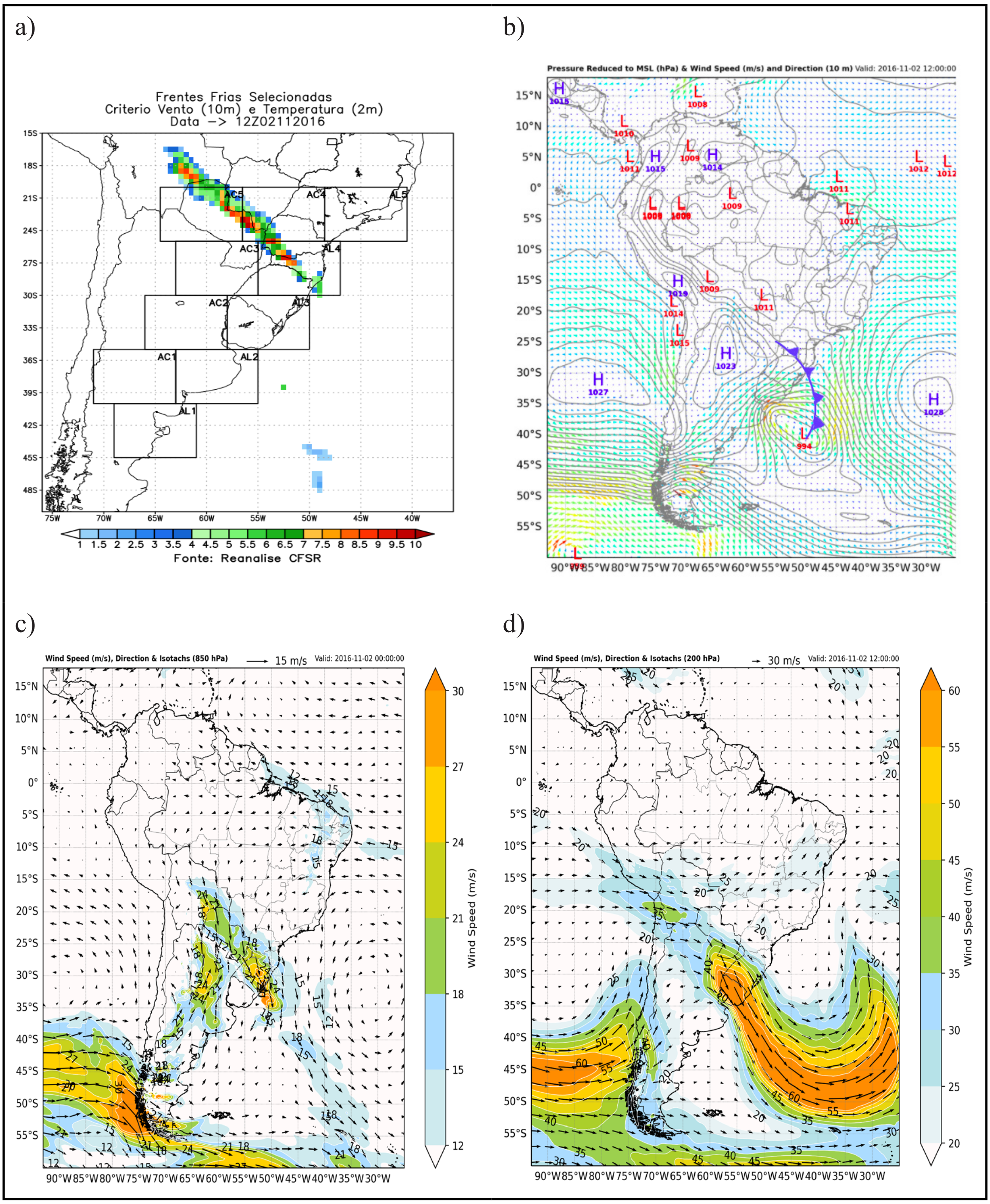
Source: The Authors (2023)

CF's frequency through the south of Brazil increases in the autumn compared to the spring and summer. Figure 3c displays the largest accumulated over the Rio Grande do Sul state. The fronts that can advance to lower latitudes cause rains in the western and northern regions of Santa Catarina. On the coast, rain is often related to post-frontal circulation, where a transient anticyclone causes weak to moderate intensity stratiform precipitation, called maritime circulation rain (Dereczynski *et al.*, 2009). During these synoptic events - also known as "*lestadas*" - winds over the ocean blow toward the continent, carrying moisture (Haas, 2002; Oliveira, 2022).

In winter (Figure 3d), a typical precipitation pattern is observed. Air masses can reach lower latitudes, and CFs become more regular over Santa Catarina, dominating the precipitation totals.

Figures 4, 5, 6, and 7 display four CF cases detected by the algorithm that impacted Santa Catarina in each season (spring, summer, autumn, and winter). Figure 4 exemplifies a CF that influenced the West, Southern Plateau, and North Plateau regions in the spring from November 01 to 04, 2016. According to the NCFI values, this system was considered intense (Figure 4a). The CF formed over CA1 and LA1 at 00Z on 11/01 (figure not shown) and reached LA4 at 12Z on 11/02 (Figure 4b). During its passage through Santa Catarina, thunderstorms were recorded accompanied by heavy rain. INMET stations in the west and plateau of the state registered up to 69 mm, with 27 mm in a single day. The highest accumulated were registered on Rio Grande do Sul (105 mm - Alegrete).

Figure 4 – Meteorological fields used in the spring case between 11/01/2016 and 11/04/2016: a) NCFI detected by the algorithm at 12Z11/02/2016; b) Mean sea level pressure (hPa) and magnitude and direction of the 10-meter wind at 12Z11/02/2016; c) 850 hPa magnitude and direction of the wind at 12Z11/02/2016; d) 200 hPa magnitude and direction of the wind at 12Z11/02/2016

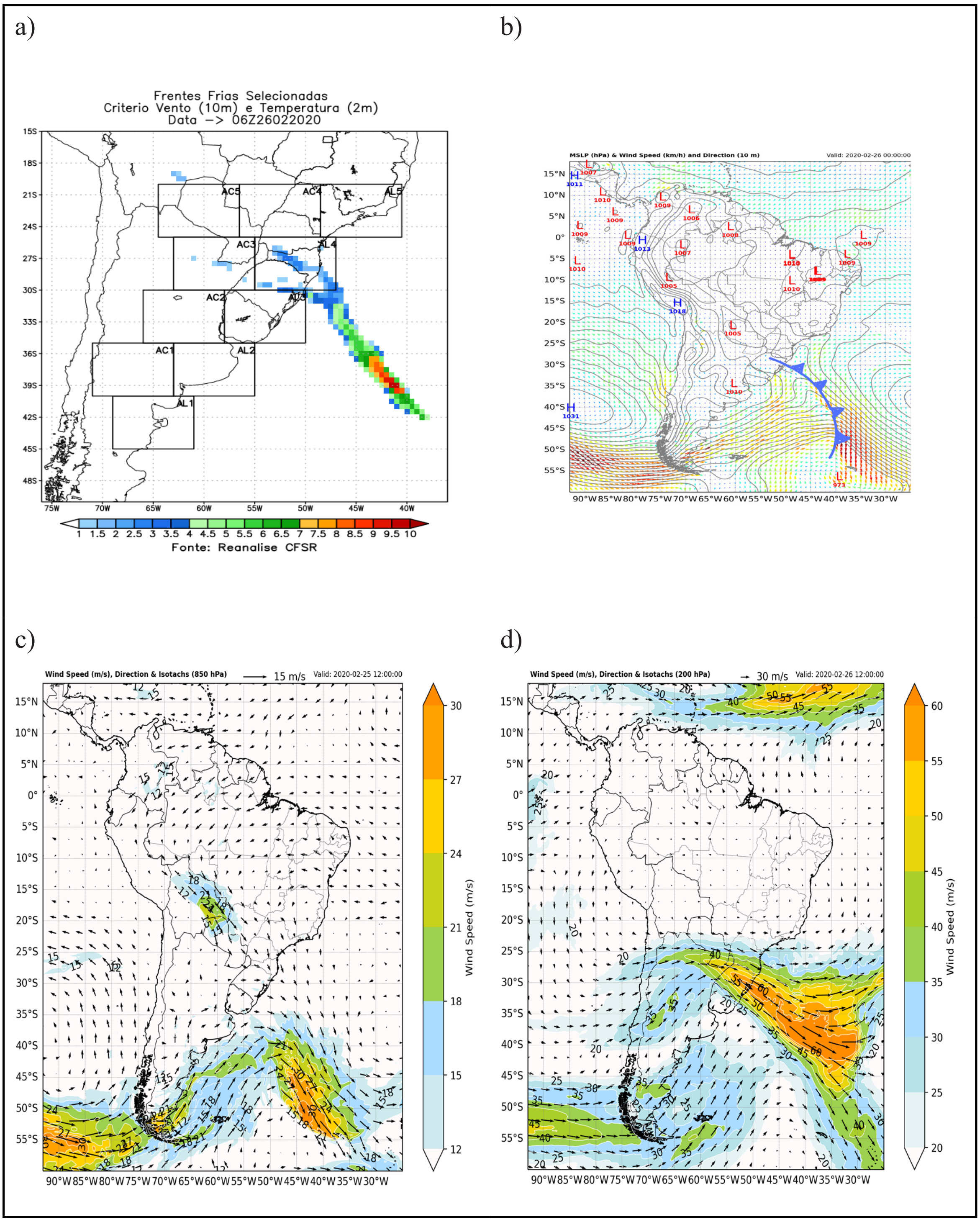


Source: The Authors (2023)

The synoptic analysis of this episode indicates the presence of an amplified trough at 200 hPa (Figure 4d) with a positive horizontal tilt. It highlights the temperature contrast between the air masses over the regions of interest and offers dynamic support. At 850 hPa (Figure 4c), the union of the low-level jet and the high-level trough, associated with the frontal system, favored the instabilities over the North of Argentina, Paraguay, Rio Grande do Sul, and Santa Catarina. Besides, the parallel coupling of the low-level jet and the surface cold front supports the lifting air in this border region. This configuration occurred especially over the hardest-hit area of the state. However, even though the NCFI indicated an intense system, the thunderstorms and heavy rains did not provoke significant changes in the standard conditions of municipalities.

Figure 5 shows a CF case during the summer, between February 25 and 28, 2020, that resulted in heavy and voluminous rain in all states of Southern Brazil. This system was formed over LA2 on 02/25/2020, and its advance over LA4 occurred at 06Z on 02/26 (Figure 5a). In Santa Catarina, 138 mm was recorded by INMET. According to the NCFI detected, this system was categorized as moderate (not shown in Figure 5a). The synoptic analysis of this event showed the CF intensifying (Figure 5b) due to the effects of subtropical jet and difluent flow at high levels over Santa Catarina (Figure 5d). This case was the only one where the low-level jet flow did not actively favor the synoptic configuration (Figure 5c).

Figure 5 – Meteorological fields used in the spring case between 02/25/2020 and 02/28/2020: a) NCFI detected by the algorithm at 06Z02/26/2020; b) Mean sea level pressure (hPa) and magnitude and direction of the 10-meter wind at 06Z02/26/2020; c) 850 hPa magnitude and direction of the wind at 06Z02/26/2020; d) 200 hPa magnitude and direction of the wind at 06Z02/26/2020

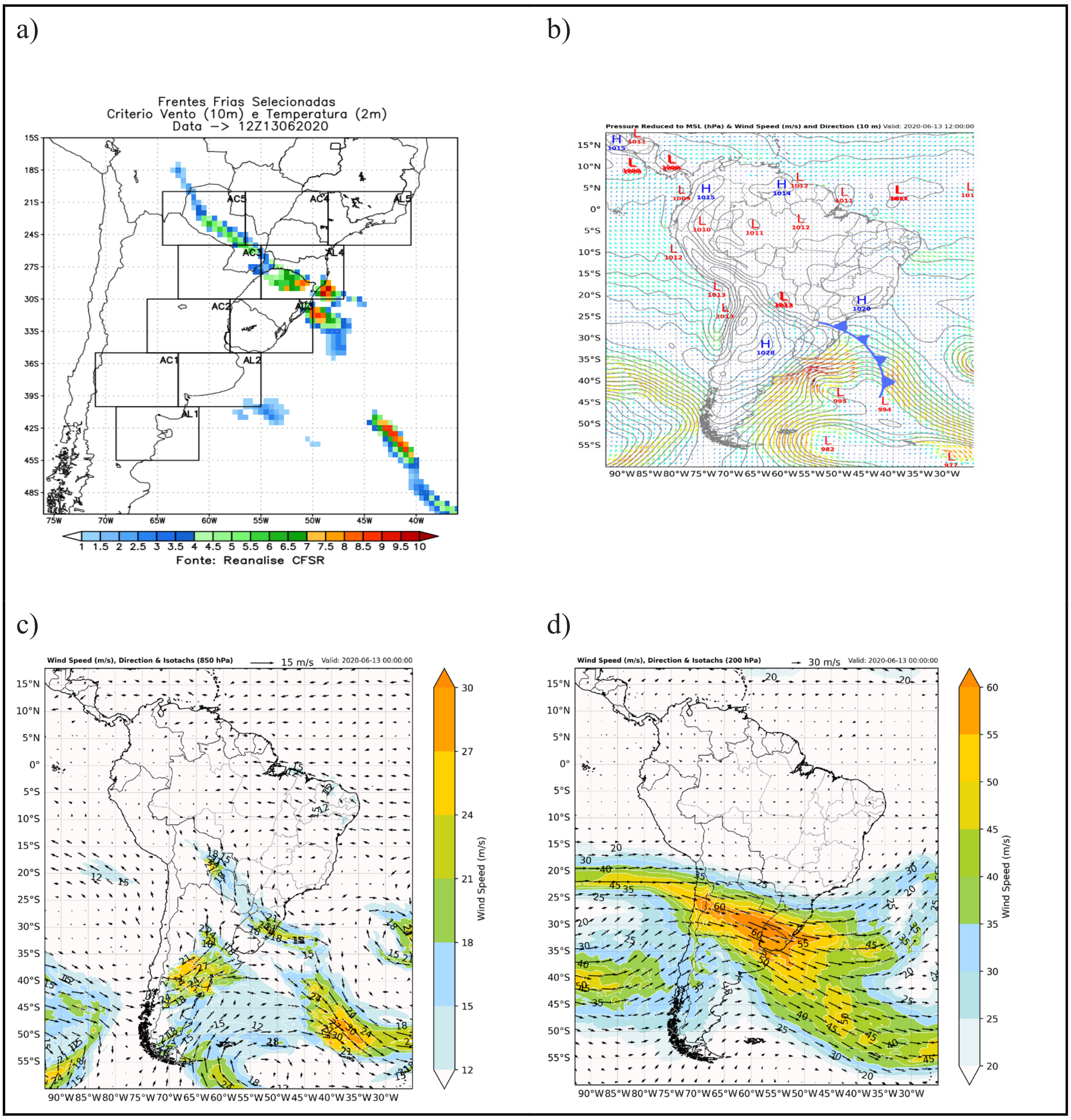


Source: The Authors (2023)

Figure 6 illustrates a CF formed at 12Z on 06/12 over LA1, CA1, LA2, and CA2 with a northwest/southeast orientation. It exemplifies a system from the autumn, between June 10 and 13, 2020. This system presented displacement from southwest to northwest, advancing to LA3, LA4, CA3, and CA5 the other day, mainly influencing Santa Catarina. It affected weather conditions, especially in the southern plateau, north, and west. The NCFI detected was maximum, indicating an intense CF. According to the Civil Defense/Santa Catarina information, Lages recorded 40 occurrences in 22 neighborhoods, with 25 flooding points. In Canoinhas, four communities were affected by flooded streets and houses. In the western region, the most significant losses were in Saudades, registering flooding points, submerged roads, and bridge falling. Other municipalities, such as Xanxerê, Nova Erechim, Águas Frias, and Cunha Porã, also reported problems with flooding.

The synoptic analysis showed that the subtropical jet at high levels (Figure 6d) presented the jet streak over the southern region of Brazil, indicating higher temperature gradients. In addition, a difluence pattern was observed at the exit of the jet streak, contributing to divergence at high levels and the intensification of surface systems. An intense low-level jet was noted at 850 hPa (Figure 6c), transporting moisture and heat to the system. At the surface, CF acted mainly over the frontier between Rio Grande do Sul and Santa Catarina (Figure 6b).

Figure 6 – Meteorological fields used in the spring case between 06/10/2020 and 06/13/2020: a) NCFI detected by the algorithm at 12Z06/13/2020; b) Mean sea level pressure (hPa) and magnitude and direction of the 10-meter wind at 12Z06/13/2020; c) 850 hPa magnitude and direction of the wind at 12Z06/13/2020; d) 200 hPa magnitude and direction of the wind at 12Z06/13/2020

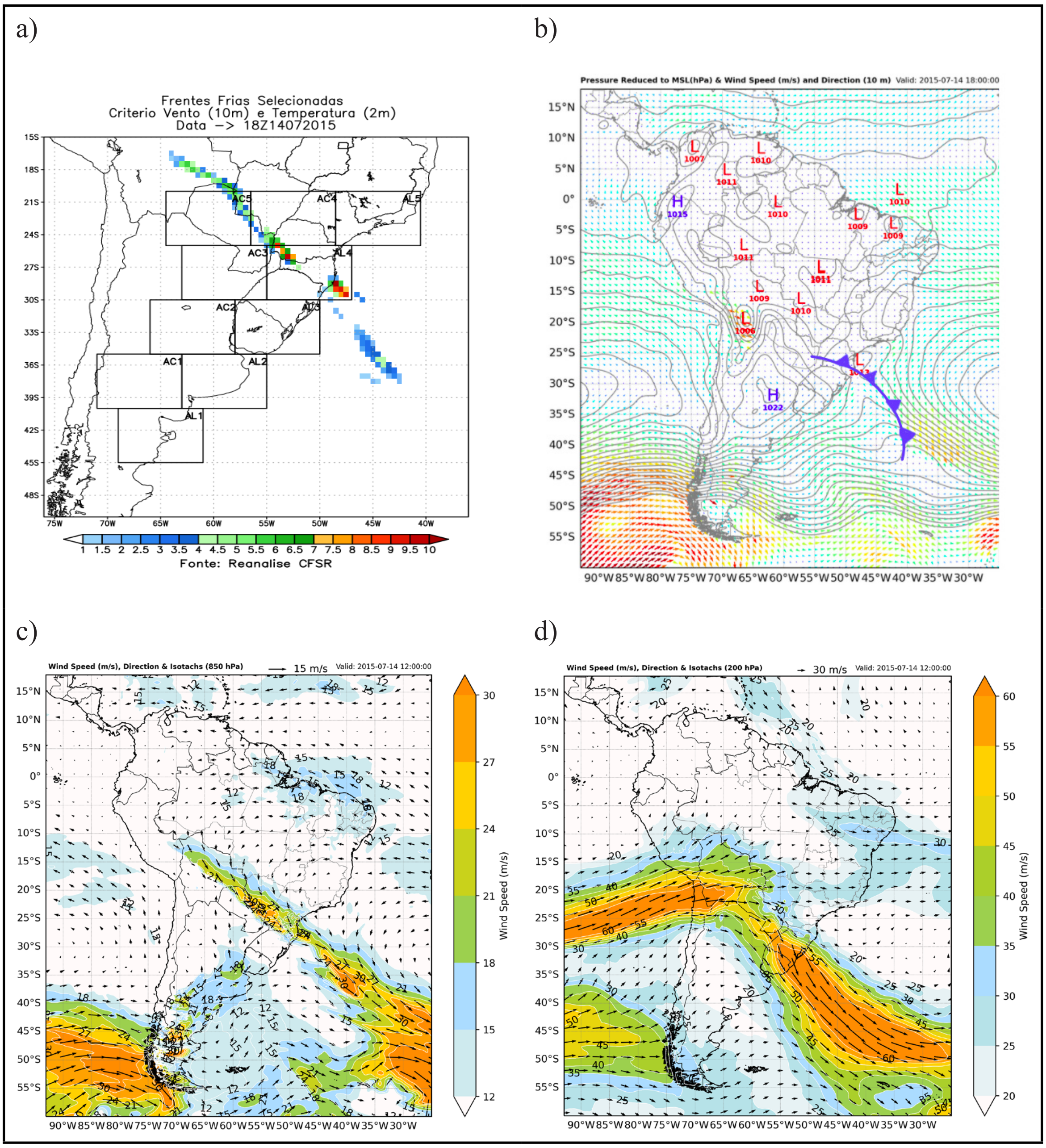


Source: The Authors (2023)

Figure 7 exhibits a CF case, in the winter, between July 13 and 16, 2015. This system was detected by the NCFI as intense, with 167 mm accumulated. This case formed at 00Z on 07/13 in LA2 and CA2. It hit LA4 at 00Z on 07/14 and remained stationary until 00Z on

07/15. On July 14th, the CF influenced the West, Midwest, South Plateau, and South Coast of Santa Catarina, causing thunderstorms accompanied by heavy rain, hail, and strong winds.

Figure 7 – Meteorological fields used in the spring case between 07/13/2020 and 07/16/2020: a) NCFI detected by the algorithm at 18Z07/14/2015; b) Mean sea level pressure (hPa) and magnitude and direction of the 10-meter wind at 18Z07/14/2015; c) 850 hPa magnitude and direction of the wind at 18Z07/14/2015; d) 200 hPa magnitude and direction of the wind at 18Z07/14/2015



Source: The Authors (2023)

The synoptic analysis is similar to the three cases already described. The high-level diffluent flow (Figure 7d) is noteworthy, especially over the West of Santa Catarina. In addition, the intense low-level jet (Figure 7c) with a well-defined flow over the same region favored the accumulated precipitation observed.

4 CONCLUSIONS

The research indicated that the highest seasonal frequency of CFs occurred in the winter, agreeing with Andrade (2005), Reboita *et al.* (2009), and Silva *et al.* (2014). They state that frontal systems can advance to lower latitudes and further longitudes during the winter compared to the other seasons. This is due to a more prominent thermal contrast separating the air masses; such gradient drives these masses to the central region of Brazil.

Regarding the mean seasonal NCFI of each area, it was observed that in LA1, the systems were intense, except in the winter. In CA1, LA3, LA4, CA3, and LA5, the CFs had moderate intensity in all seasons. In CA2 and CA5, the CFs were intense in the spring, while in the other seasons, the systems were moderate. In CA4, the CFs were moderate in winter and spring and weak in summer and autumn. Notably, in CA2, CA3, LA3, and LA4, spring also registered a high CF number, besides winter.

In addition to the precipitation pattern, a synoptic analysis and an evaluation of NCFI were made with one case per season that impacted Santa Catarina. The synoptic analysis showed that the accumulated precipitation was concentrated in the state's western portion in the spring. Also, this season, the Mesoscale Convective Complexes and the Mesoscale Convective Systems commonly appear. When associated with CFs, both can cause massive impacts related to heavy rain.

In the summer, convection cells poorly distributed formed over Santa Catarina, causing heavy rain. In the autumn, CFs caused precipitation at Rio Grande do Sul along with the west and north of Santa Catarina. In this season, the influence of maritime circulation - also known popularly as "lestada" - was quite significant. In the winter, a rainfall pattern associated with CFs was observed. During this last season, these air mass movements mainly dominated precipitation over Santa Catarina. According to the NCFI of each case, spring, autumn, and winter were categorized as intense, while summer was moderate.

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