Servicio Meteorológico Nacional Argentina

Destructive wind events over central Argentina during December 16 and 17, 2023

Nota Técnica SMN 2024-191

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Abstract

Between December 16 and 17, 2023, a series of convective events occurred over the central region of Argentina, predominantly in the province of Buenos Aires. The most severe impacts occurred in the city of Bahia Blanca and the metropolitan area of Buenos Aires, leaving numerous fatalities, injuries and extensive damage. This Technical Note describes the event in its different stages, from its prediction, through its monitoring by means of conventional observations and remote sensing, to damage assessment. Emphasis is placed on the study of the predictability of the event and a description of the use of numerical models by forecasters. This study, with its attempt to analyze the event from many different perspectives, is an opportunity to capture the challenges faced by forecasters during extreme events.

Key words: Case study, convective storm, wind, high impact

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1. INTRODUCTION

On December 16 and 17, 2023, the central area of Argentina was affected by a large convective system that caused significant damage and human losses. The intensity of the event and its social impact stimulated the production of different internal reports within the National Meteorological Service of Argentina (SMN) which were used for communication to the public and with national authorities (see for example *report*).

The coincidence of this event with the start of a pilot project[1] on model verification by the European Centre for Medium-Range Forecasting (ECMWF) in the region, stimulated the choice of this destructive event as the object of study. This led to several months of detailed analysis of various aspects associated with its development. During these activities, SMN representatives in the project became familiar with the ECMWF Severe Events catalogue, which proposes an approach focused on the predictability of events and the performance of models (Magnusson 2019, see *catalogue*). At the same time as this analysis was being carried out, the World Meteorological Organization (WMO) *High Impact Weather* (HIWeather) initiative was promoting the study of cases extended to the entire value chain (see *Warning Value Chain Project*). Given the importance of this proposal and the positive impact it can have on an institution such as the SMN, it was decided that this Technical Note should take advantage of both the lessons of the pilot project and the recommendations of HIWeather.

This Technical Note is the result of the work of many people and the collaboration of many others from both the SMN and the academic sector. Due to its ambitious objective and the multiplicity of topics involved, this document is unusually long, which makes it difficult not only to read but also to write, finish and polish. However, given the interest in compiling this information in a single document, it was agreed that its virtues outweighed its obvious disadvantages.

An important antecedent to this study is Torres Brizuela et al. (2010), who studied a very intense convective event in October 2008 that also took place in the province of Buenos Aires. The article focused mainly on synoptic aspects, also taking advantage of the information available from satellites and from the Pergamino and Ezeiza radars.

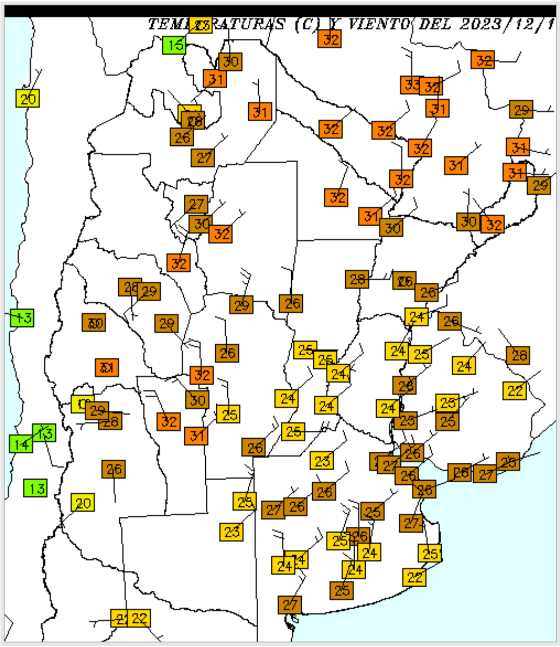
2. EVENT DESCRIPTION

2.1 General meteorological situation

The meteorological situation associated with the event was characterized by the presence of a warm, very humid and unstable air mass located over the center and north of the country. A frontal zone was located over the north of the Patagonian region (Fig. 1), which began to move towards the center of the country. To the north of this system in the afternoon hours of Saturday, December 16, temperatures were between 29 and 35°C (Fig. 1a) with dew points between 19 and 25°C (Fig. 1b).

[1] The *South American Regional Model Verification Pilot project* led by WGNE and JWGFVR of the WMO started in January 2024 and this Technical Note is one of its outcomes (see https://wgne.net/activities/on-going-activities/**).**

(a) (b)



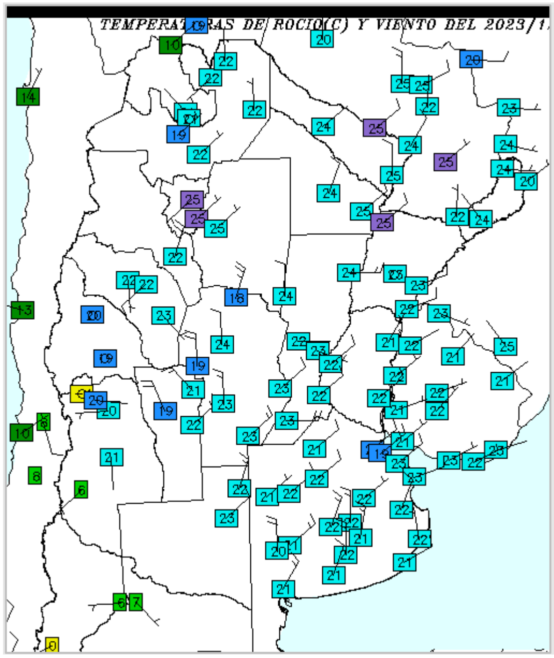


Figure 1: *Wind and temperature (a) and dew point (b) observed at 09 HOA on Saturday, December 16, 2023.*

This very humid air mass was also observed at the 850 hPa level on the morning of Saturday, December 16, with dew points above 12°C from the north of Río Negro towards the north of the country, thanks to a flow coming from the north (Fig. 2a). At medium and high levels of the troposphere, an important trough or axis of minimum pressure was located over the Pacific Ocean (Fig. 2b, 2c and 2d), which advanced towards the east, giving rise to the formation of rain and storms over the provinces of Mendoza, Río Negro, La Pampa and San Luis. This system also caused zonda (foehn) wind conditions in the afternoon and evening of Saturday 16 in the provinces of Mendoza and San Juan, with maximum temperatures reaching 45°C.

Radiosonde information from the morning of Saturday 16th showed the instability of the air mass over the center and north of the country as seen in Resistencia (Fig. 3a), Córdoba (Fig. 3b), Aeroparque (Fig. 3c), Mendoza (Fig. 3d) and Santa Rosa (Fig. 3e). To give an idea of the instability of the air mass, these soundings showed MUCAPE values above 2000 J/kg since the morning of the 16th, with peaks in the afternoon between 3000 and 4500 J/kg, together with precipitable water values of the order of 40 to 50 mm. Likewise, the evening Santa Rosa sounding shows a northeasterly flow of 20 knots at 500 meters high, turning north at 30 knots at 1000 meters (Fig. 4a), which denotes a strong vertical wind shear at the lower levels. Consequently, the risk of severe storms was very high in the region, and the possible occurrence of tornadoes in this area was even expected. It should be noted that the evening and night Aeroparque soundings show a northerly wind flow in the first 500 meters with an intensity of around 40 knots, giving a very intense wind shear. This could generate favorable conditions for the occurrence of very violent instability lines and arcs (Fig. 4b and 4c), which would occur in the early hours of Sunday 17th. Finally, in the Neuquén sounding it can be seen that the air mass was much drier compared to the provinces in the center of the country (Fig. 3f). However, there was instability in the region, with MUCAPE values of around 1000 J/ kg. Another aspect to highlight in this sounding is the strong northwesterly flow at medium and high levels that accounted for the proximity of the intense trough located to the west.

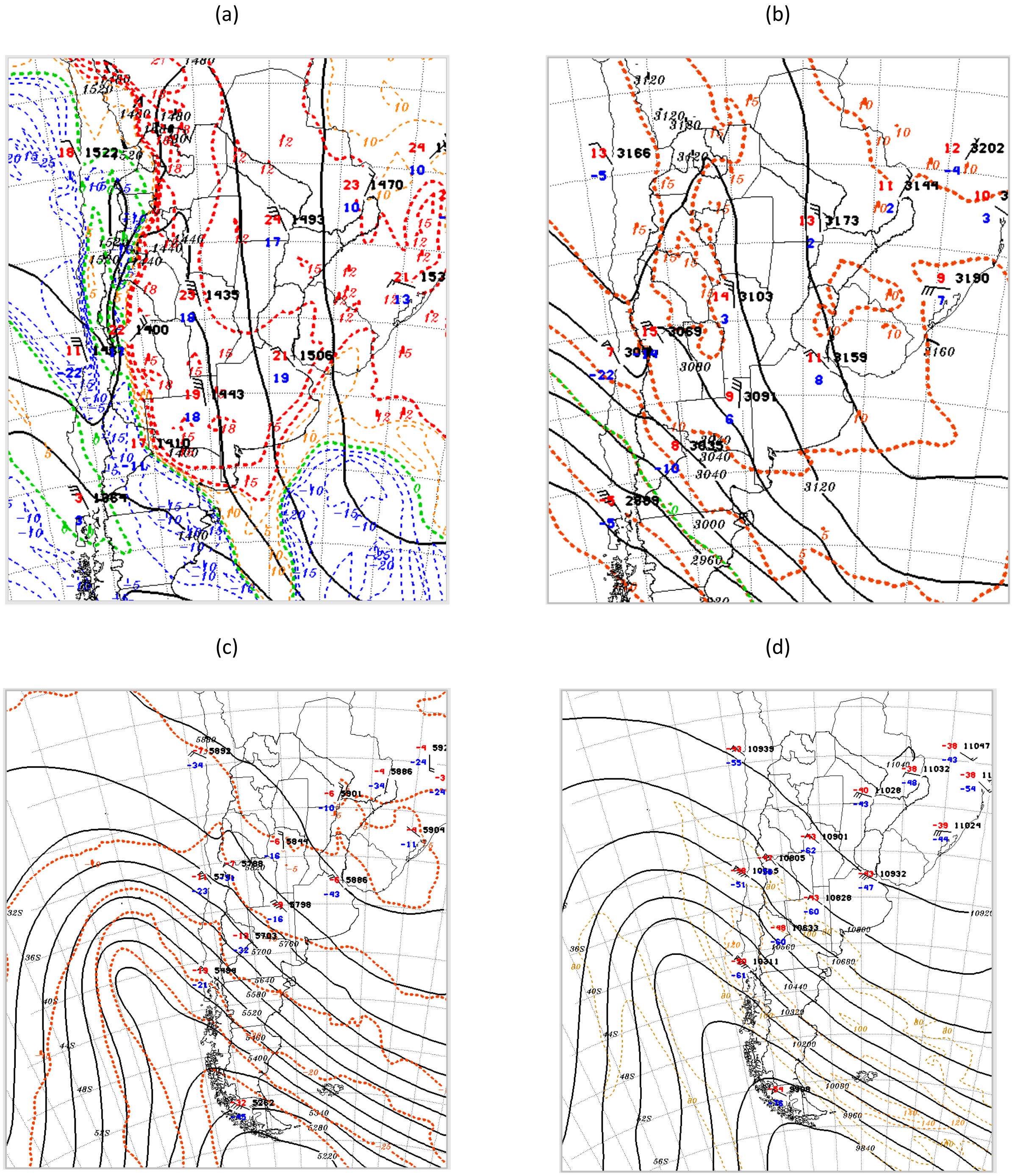
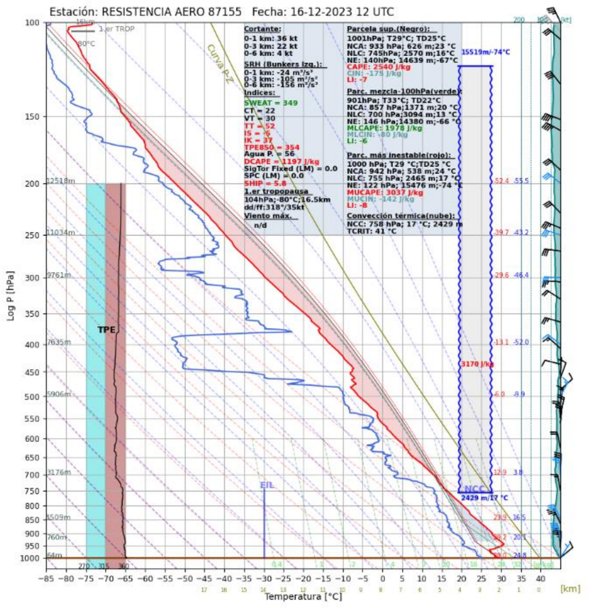
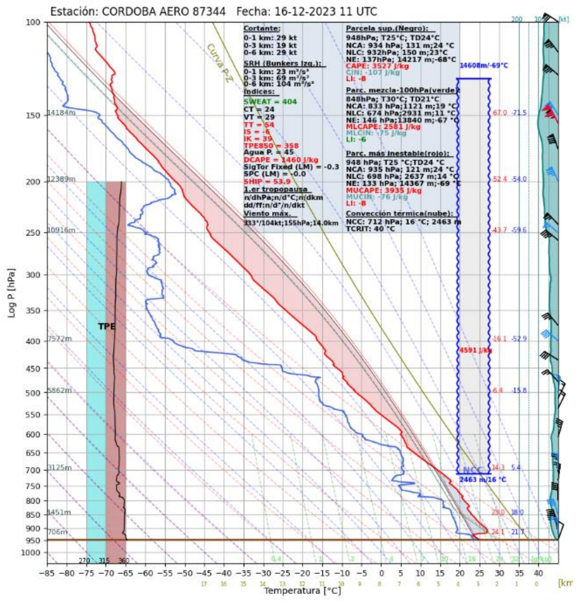


Figure 2: *Geopotential (solid black lines) and isodrosotherms (dashed lines) at 850 hPa (a), geopotential and isotherms (dashed lines) at 700 hPa (b) and 500 hPa (c), and geopotential and isotachs (dashed lines) at 250 hPa (d) corresponding to 12 UTC on 16 December 2023 from the Global Forecasting System (GFS) model analysis, together with plotted radiosonde data.*

(a)


Estación: RESISTENCIA AERO 87155 Fecha: 16-12-2023 12 UTC
Log P [hPa]
Temperatura [°C]

(b)


Estación: CORDOBA AERO 87344 Fecha: 16-12-2023 11 UTC
Log P [hPa]
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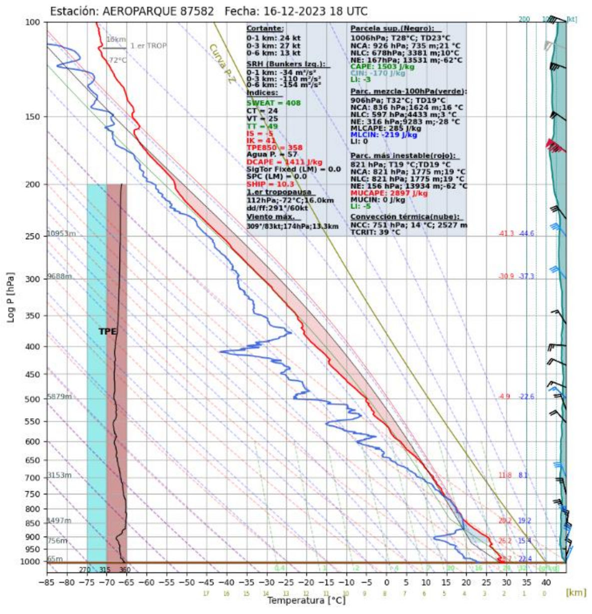
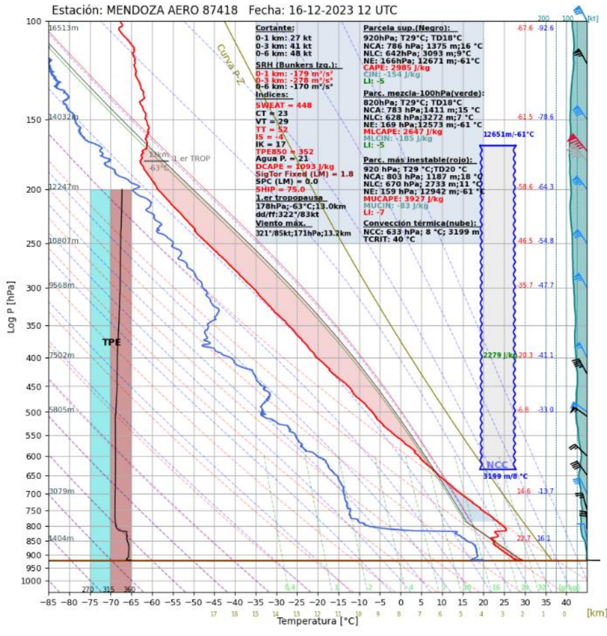
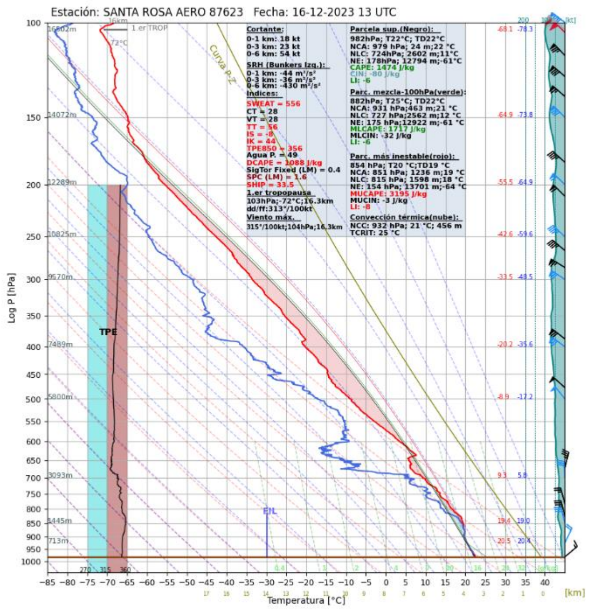
(c)


Estación: AEROPARQUE 87582 Fecha: 16-12-2023 18 UTC
Log P [hPa]
Temperatura [°C]

(d)


Estación: MENDOZA AERO 87418 Fecha: 16-12-2023 12 UTC
Log P [hPa]
Temperatura [°C]

(e)



(f)

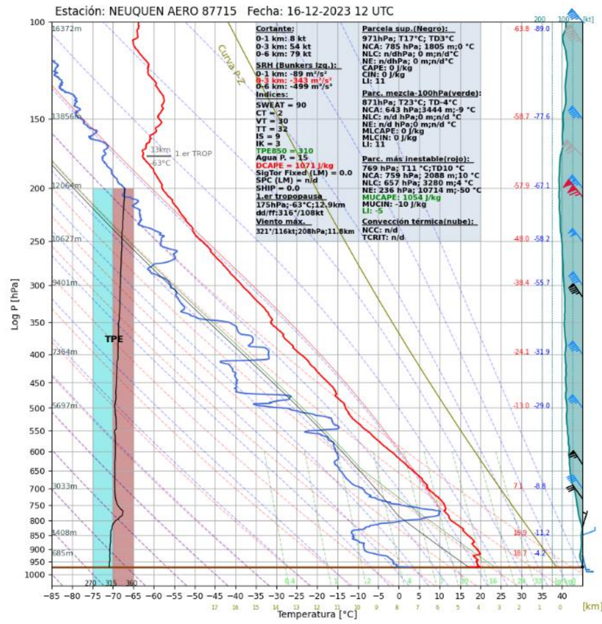
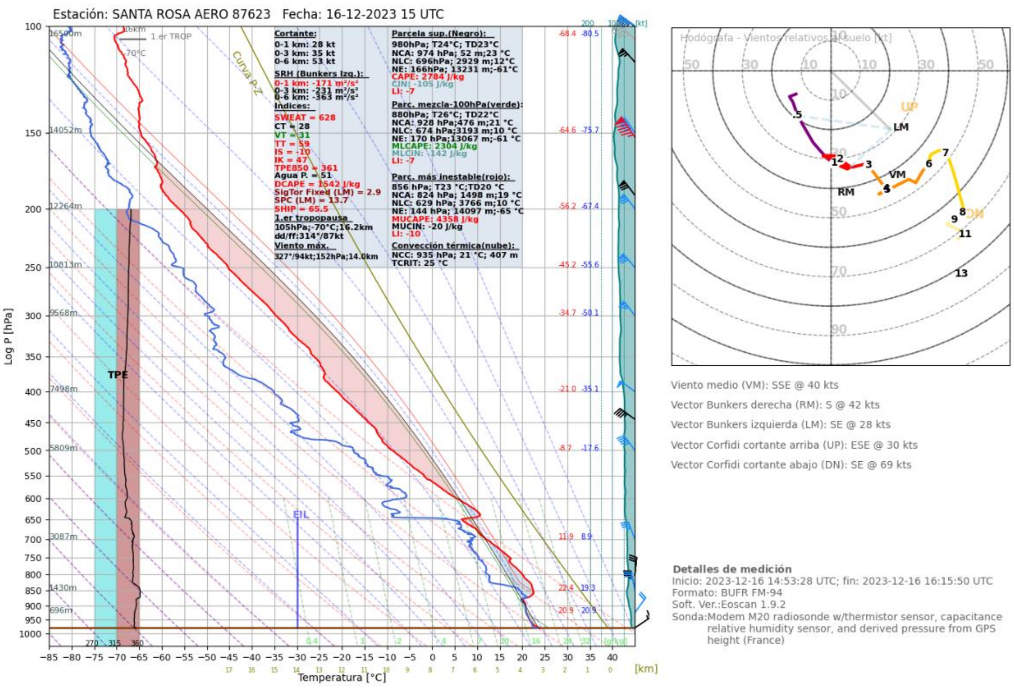


***Figure 3:** Radiosondes corresponding to 1200 UTC on Saturday, December 16, from (a) Resistencia, (b) Córdoba, (c) Aeroparque, (d) Mendoza, (e) Santa Rosa and (f) Neuquén.*

(a)



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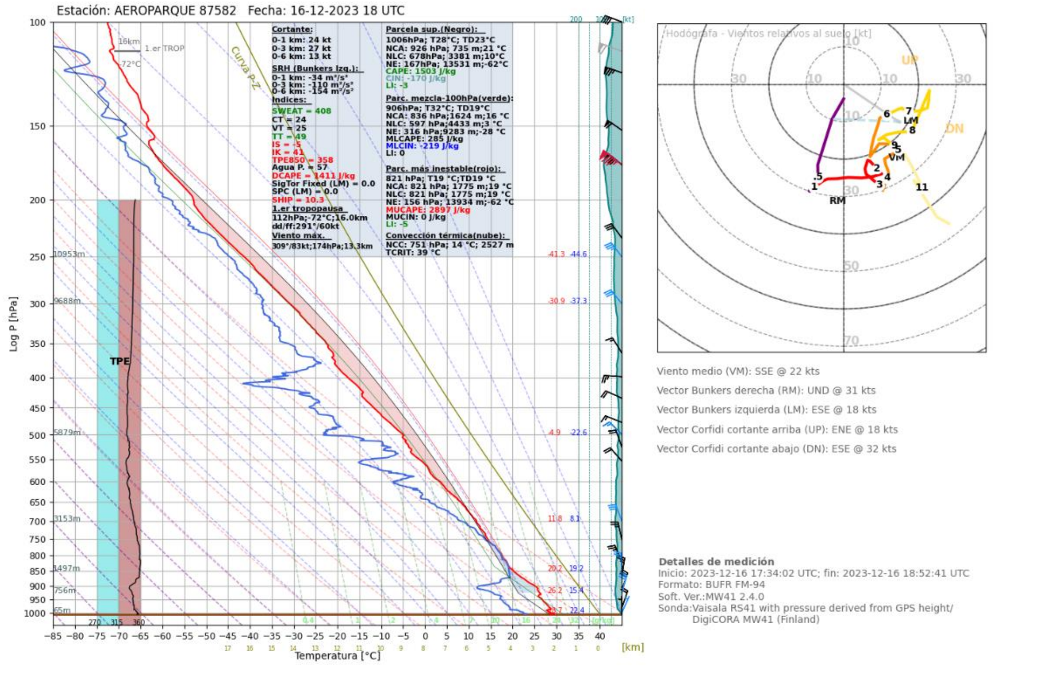

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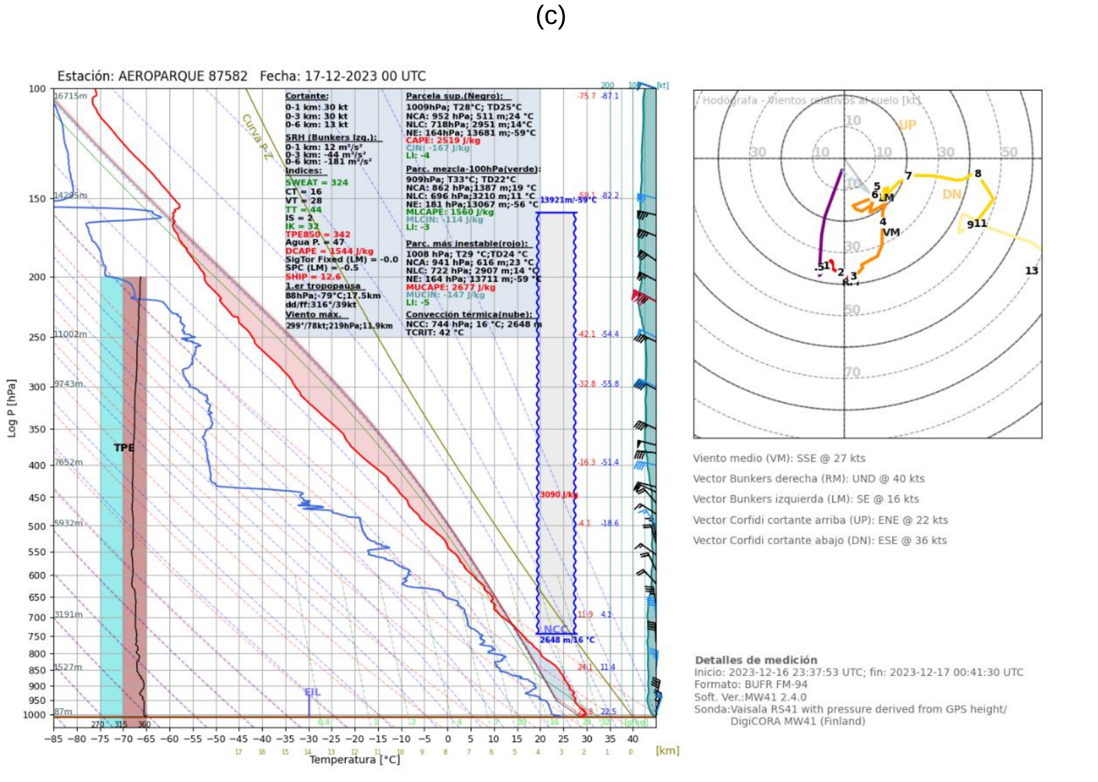


Figure 4: *Radiosondes corresponding to 1800 UTC on Saturday, December 16 from (a) Aeroparque and (b) Santa Rosa, and to 0000 UTC on December 17 from (c) Aeroparque.*

The situation described above could explain the formation of storms of varying intensity from the early hours of Saturday, December 16 over La Pampa, Río Negro, eastern Mendoza and San Luis. In the afternoon, a convective system began to take shape over the provinces of San Luis, La Pampa and eastern Río Negro, which spread eastwards between late afternoon and the night of Saturday, December 16 (Fig. 5b and 5c) and during the early hours of Sunday, December 17 (Fig. 5d, 5e and 5f).

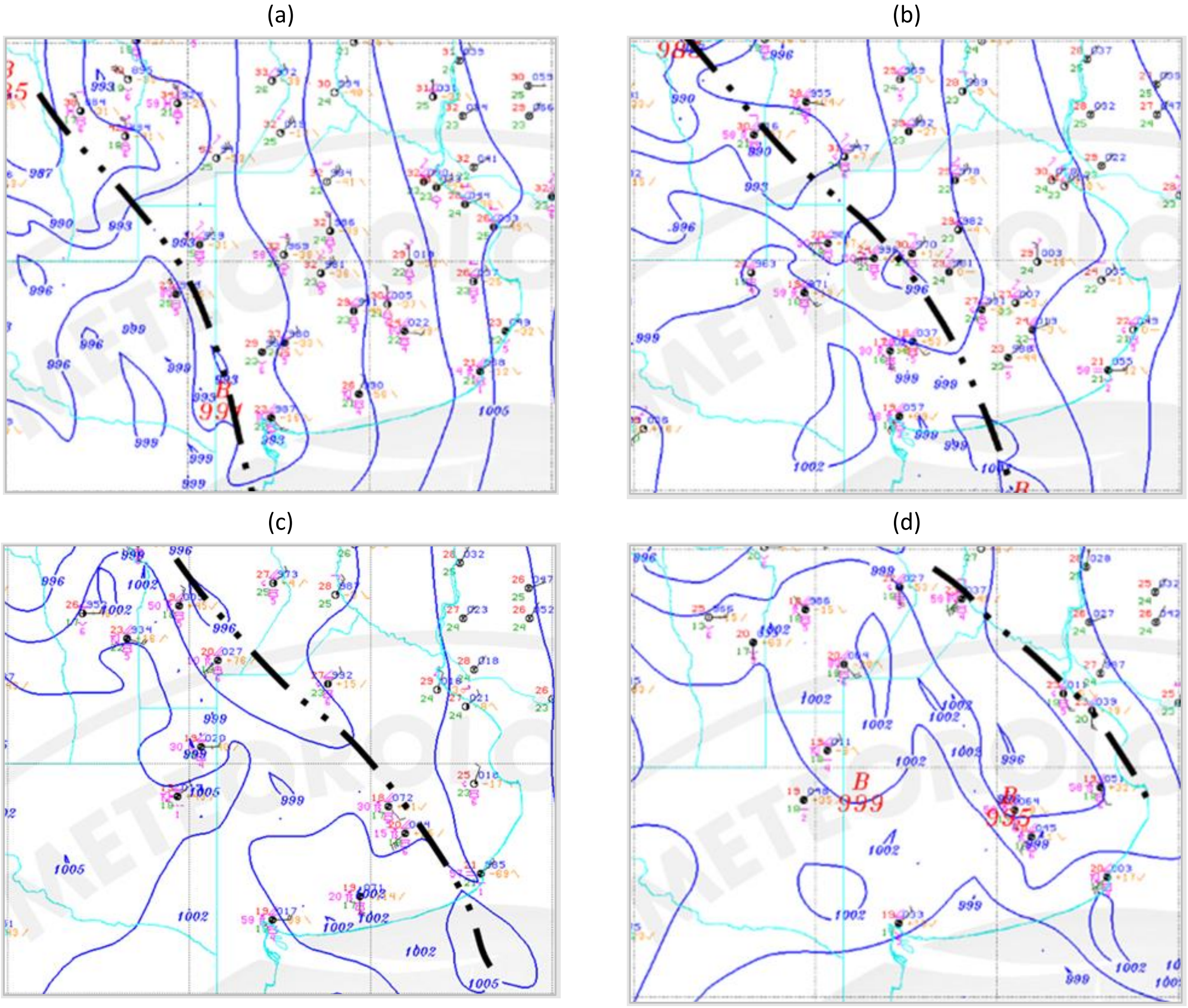


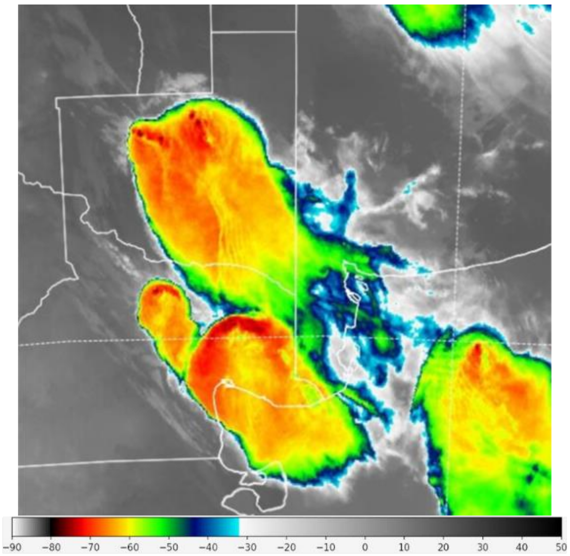
Figure 5: *Surface pressure field with the estimated position of the instability line at 21:00 UTC on 16 (a), 00:00 (b), 03:00 (c) and 06:00 (d) on 17 December 2023.*

Although the phenomena associated with this event leave their mark on conventional observations, it is in the information from remote sensors where its nature can be appreciated in more detail.

2.2 Remote sensing monitoring

On Saturday, December 16, storms of varying intensity began to develop over the northeast of the province of Río Negro and central La Pampa (Fig. 6). Specifically, these storms already showed signs of severity, at least distinguishable in the very well-defined emerging "*overshooting tops"* that are an indicator of the severe potential of this type of storm, along with intense electrical activity (Fig. 6b) and significant reflectivity values (>55 dBZ) (Fig. 6c). Other sources of information show that these storms extended vertically above 10 kilometers.

(a)



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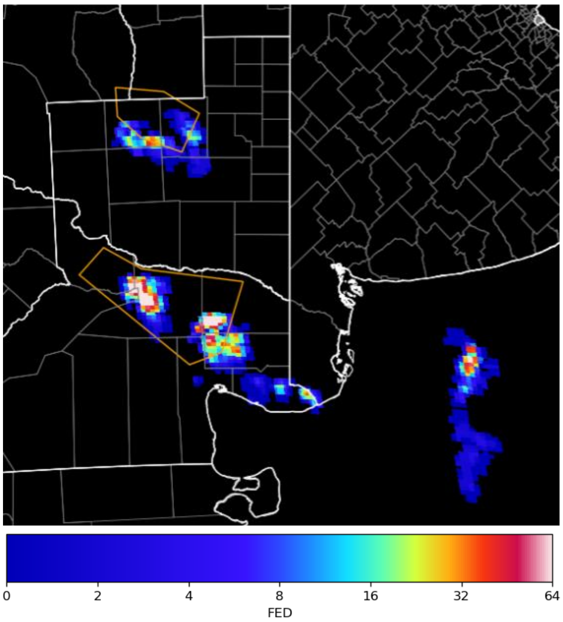

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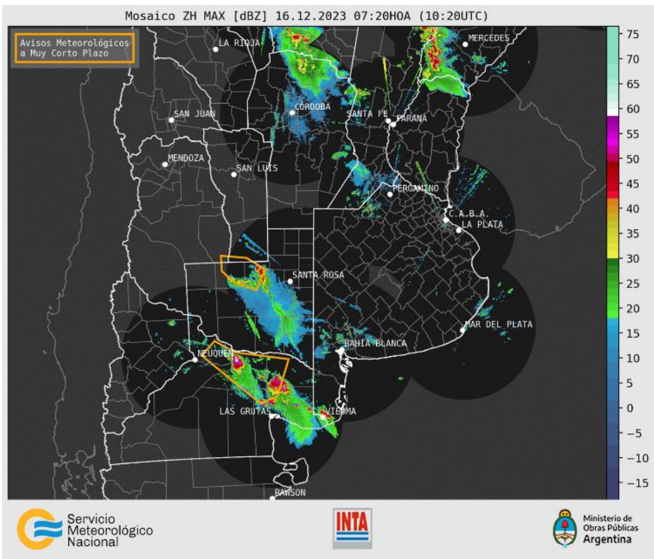


Figure 6: *(a) Cloud top temperature image from GOES-16 satellite for 16/12/2023 at 7:20 local time (10:20 UTC). (b) Electrical activity observed with the GLM sensor onboard GOES-16 satellite for the same day and time. (c) Composite of maximum reflectivity in the column from SINARAME radar network. The polygons corresponding to the Very Short-Term Weather Warnings (ACPs) in effect at that time are shown in orange. For more information on ACPs, see Ishikame et al. (2022).*

(a) (b)

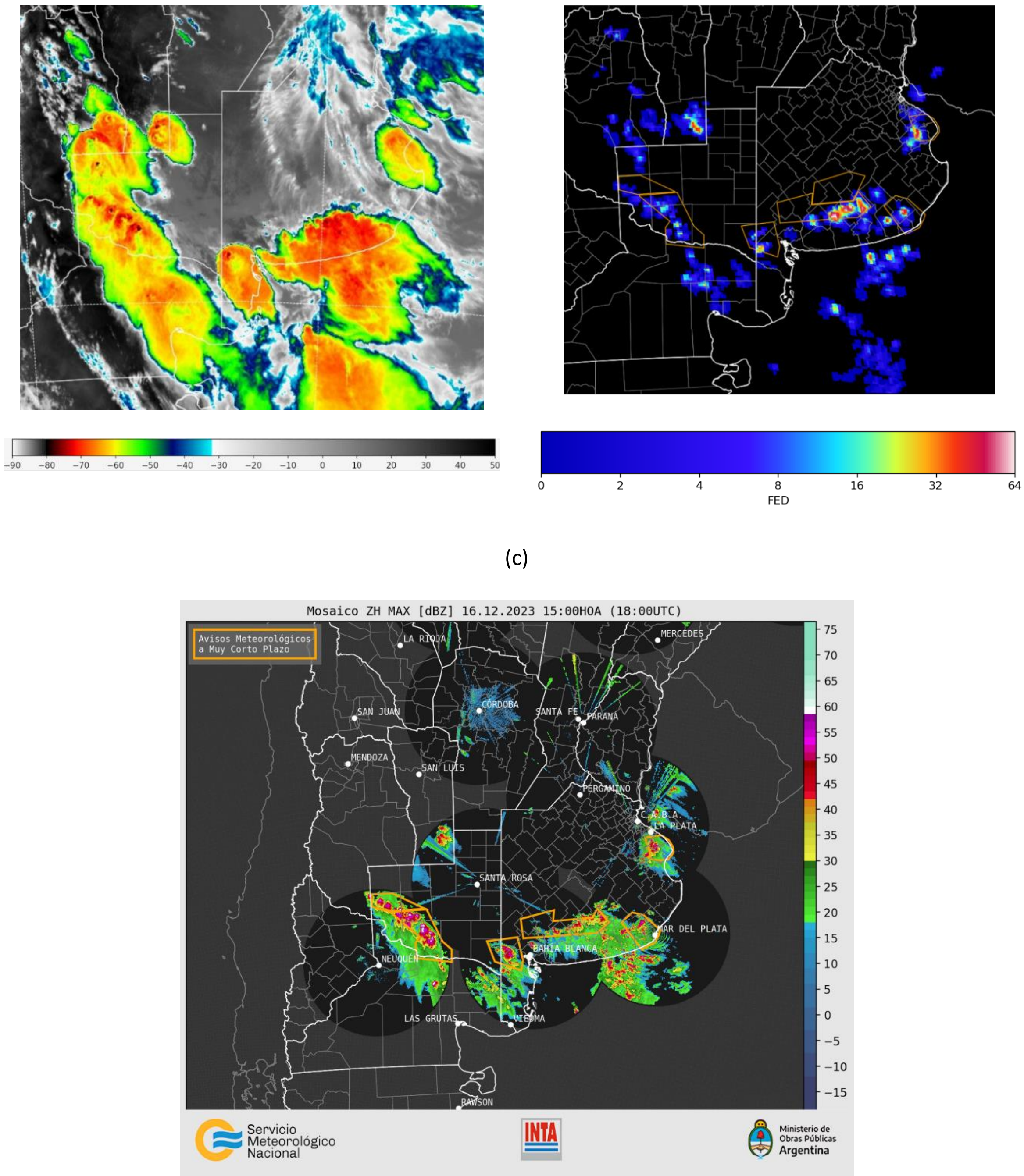


Figure 7: *(a) Cloud top temperature image from the GOES-16 satellite for 16/12/2023 at 15:00 local time (18:00 UTC). (b) Electrical activity observed with the GLM sensor on board the GOES-16 satellite for the same day and time. (c) Composite of maximum reflectivity in the column from SINARAME radar network. The polygons corresponding to the ACPs in force at that time are shown in orange.*

As the hours passed, convective activity moved east and southeast, and in the afternoon new storm centers began to activate from southern Mendoza to eastern Río Negro, as can be seen in the satellite images (both cloud tops and electrical activity (Fig. 7a and b), and in the reflectivity composite (Fig. 7c). Again, these storms showed signs of severity (overshooting tops, lightning jumps, among others) and in the following hours they were organized into an extensive mesoscale convective system with severe characteristics.

At the beginning of the situation and associated with supercell convective modes, many reports of large and/or giant hail and severe gusts were observed. Of note were the damages to cherry crops in localities of the Middle Valley of Río Negro (reports of hail up to 4 cm). In addition, giant-sized hail (estimated at 12 cm) was observed associated with the supercell that passed through Fortuna, south of San Luis.

By 18:30 local time, this system showed an organization similar to an instability line (Fig. 8 b and c). In the segment located over the southwest of the Province of Buenos Aires, an arc structure began to be observed in the radar images, indicating the presence of “bow echo” type storms (Fig. 8d) that would affect the city of Bahía Blanca around 19 hours local time. The system generated strong winds that reached 150 km/h with the particularity of the persistence of gusts above 100 km/h for at least 20 to 30 minutes, according to the record of meteorological instruments located at the Airport (Fig. 12a). This part of the system continued its movement towards the east and southeast, towards the sea, showing a weakening.

On the other hand, the rest of the line continued its displacement towards the northeast to show an intensification over the northeast of the province of Buenos Aires at 03:00 HOA on Sunday, December 17, which ended up affecting the Metropolitan Area of Buenos Aires between 03:30 and 04:00, with gusts of wind exceeding 140 km/h according to records at the Jorge Newbery Airport of the Autonomous City of Buenos Aires and the San Fernando International Airport (see Fig. 9). The storm system again showed characteristics of a bow echo line, systems that produce strong and destructive gusts of wind as their main severe phenomenon, in addition in some specific sectors rotation systems could lead to the development of a tornado. However, to determine the latter, it is necessary to carry out more exhaustive analyses of both the observed data and the field surveys.

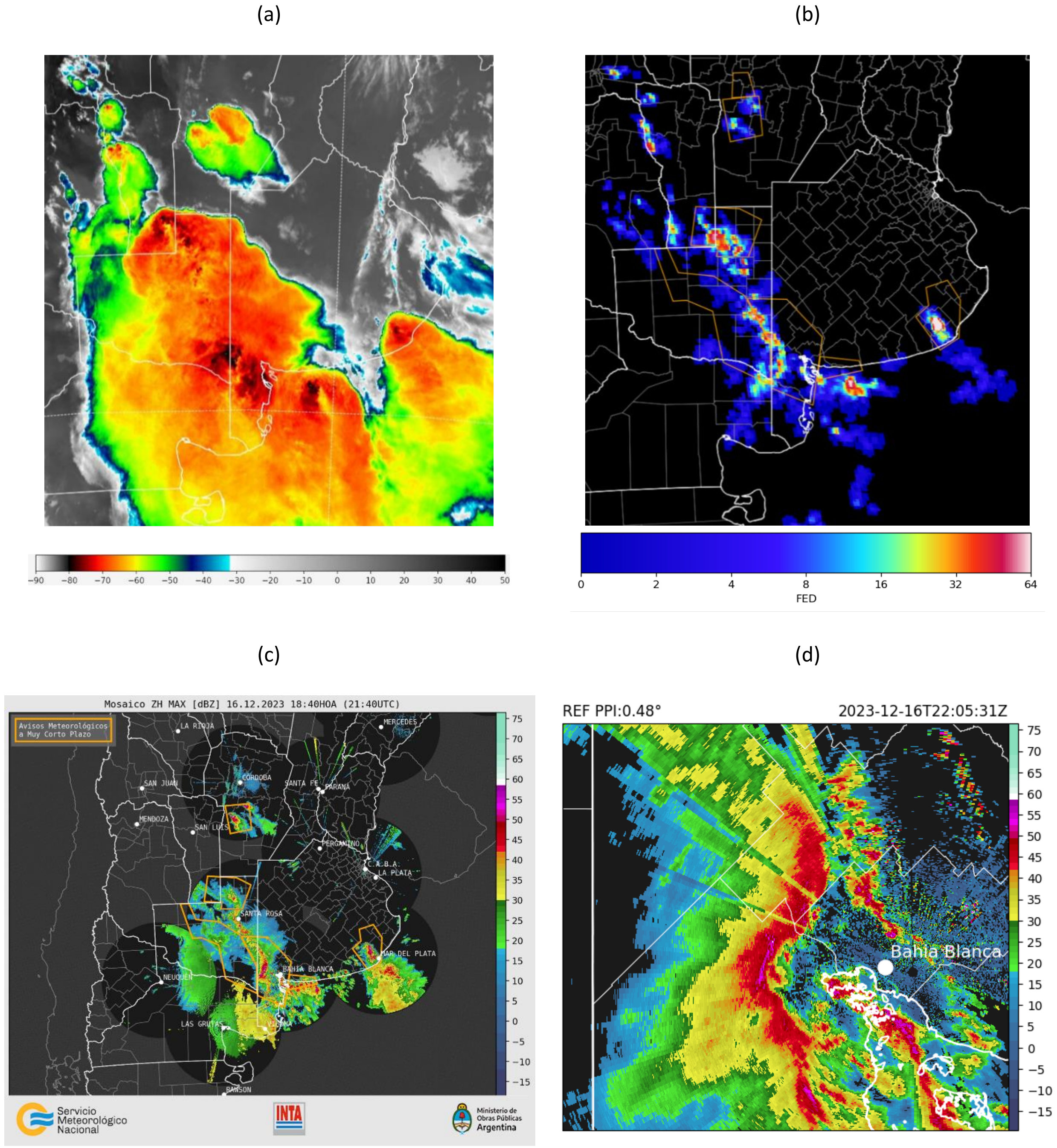
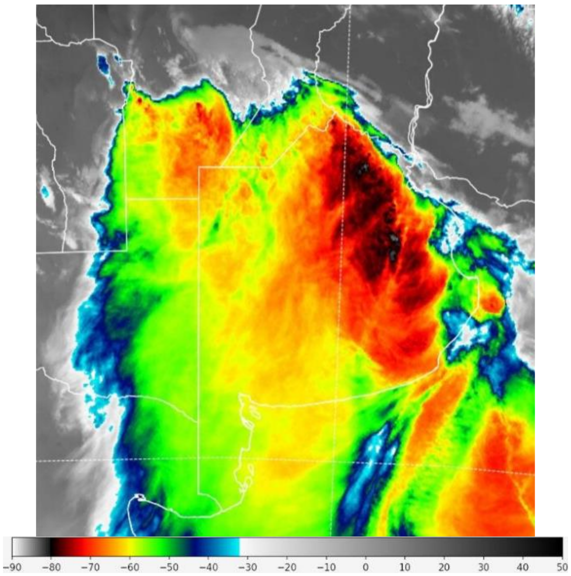
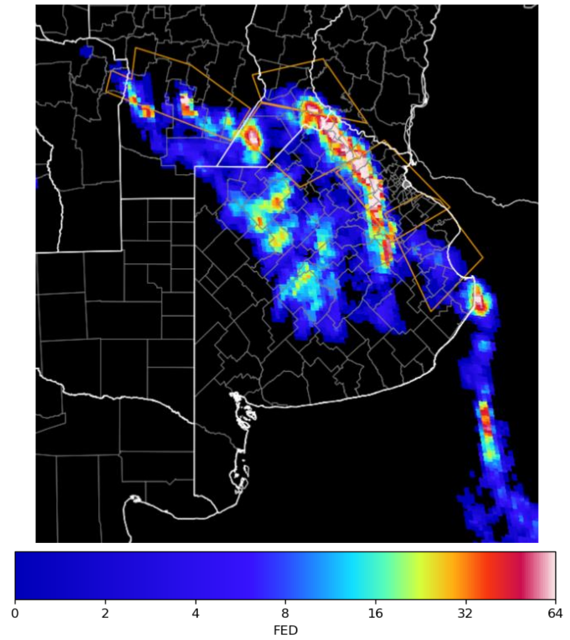


Figure 8: *(a) Cloud top temperature image from the GOES-16 satellite for 16/12/2023 at 18:40 local time (21:40 UTC). (b) Electrical activity observed with the GLM sensor on board the GOES-16 satellite for the same day and time. (c) Composite of maximum reflectivity in the column from SINARAME network. The polygons corresponding to the ACPs in force at that time are shown in orange. (d) Scan of the lowest reflectivity elevation of the SINARAME RMA10-Bahía Blanca radar at 19:05 local time (22:05 UTC).*

(a)



(b)



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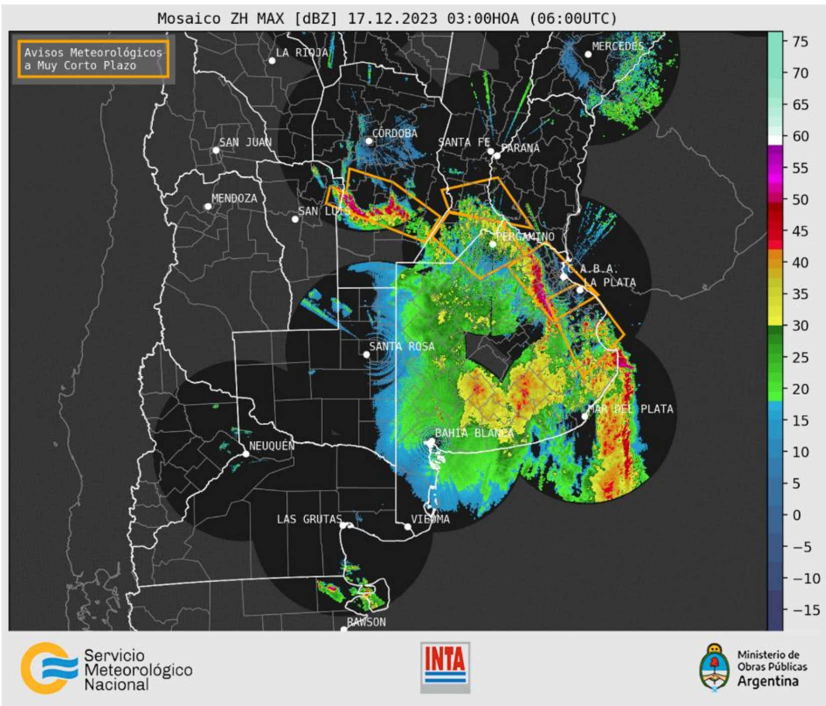


Figure 9: *(a) Cloud top temperature image from the GOES-16 satellite for 17/12/2023 at 03:00 local time (06:00 UTC). (b) Electrical activity observed with the GLM sensor on board the GOES-16 satellite for the same day and time. (c) Composite of maximum reflectivity in the column for SINARAME radar network. The polygons corresponding to the ACPs in force at that time are shown in orange.*

Figure 10 illustrates the evolution of electrical activity over successive days in the Buenos Aires province region. Each panel shows the number of hours with activity according to the color bar. It is interesting to note that the areas with the most destructive events studied here have been found to be little affected by electrical activity, although they are close to areas of high activity (see the case of Bahía Blanca in panel b and Buenos Aires City in panel c). It should be noted that convective systems that move at high speeds naturally reside for a relatively short time in the area through which they evolve.

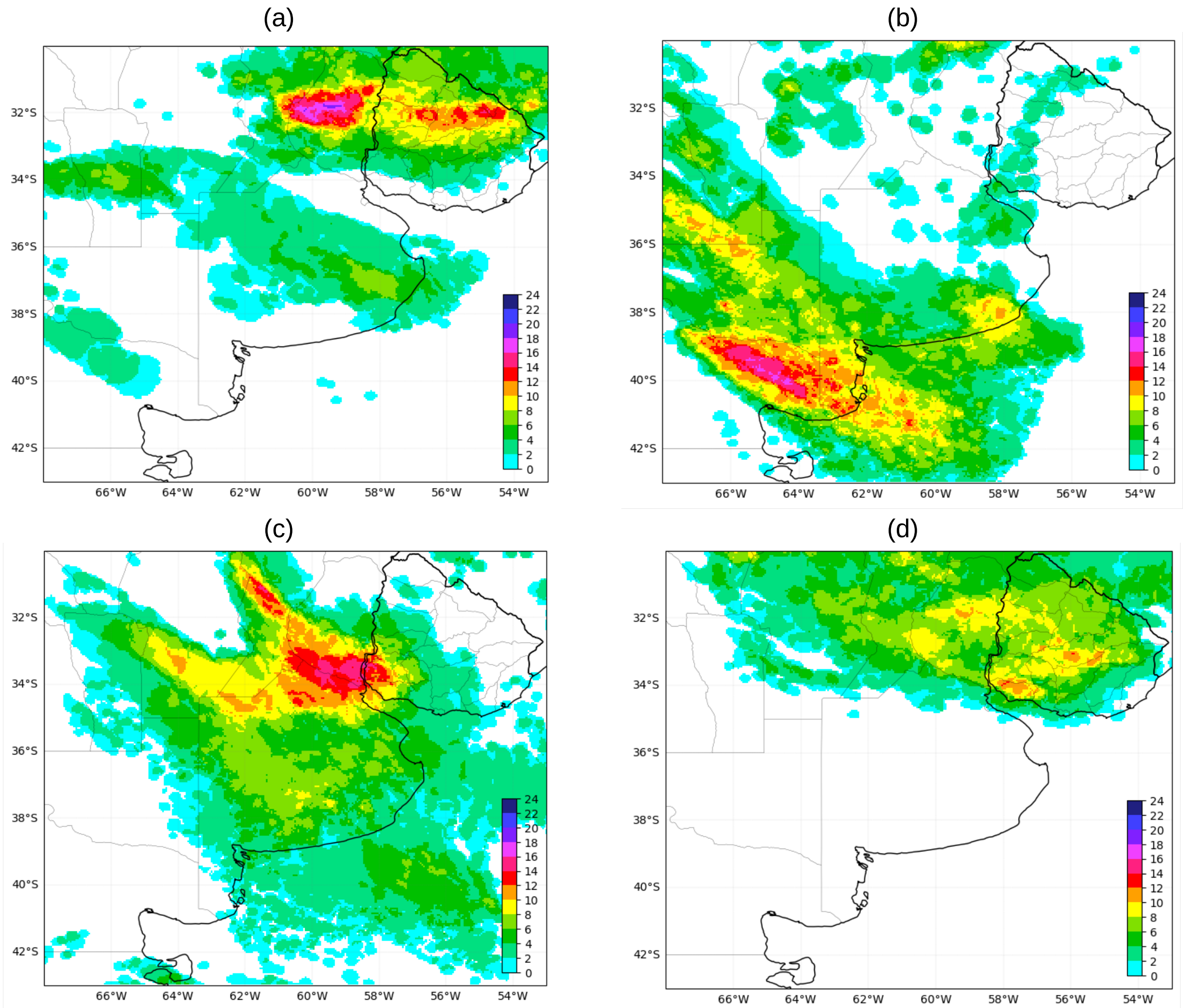
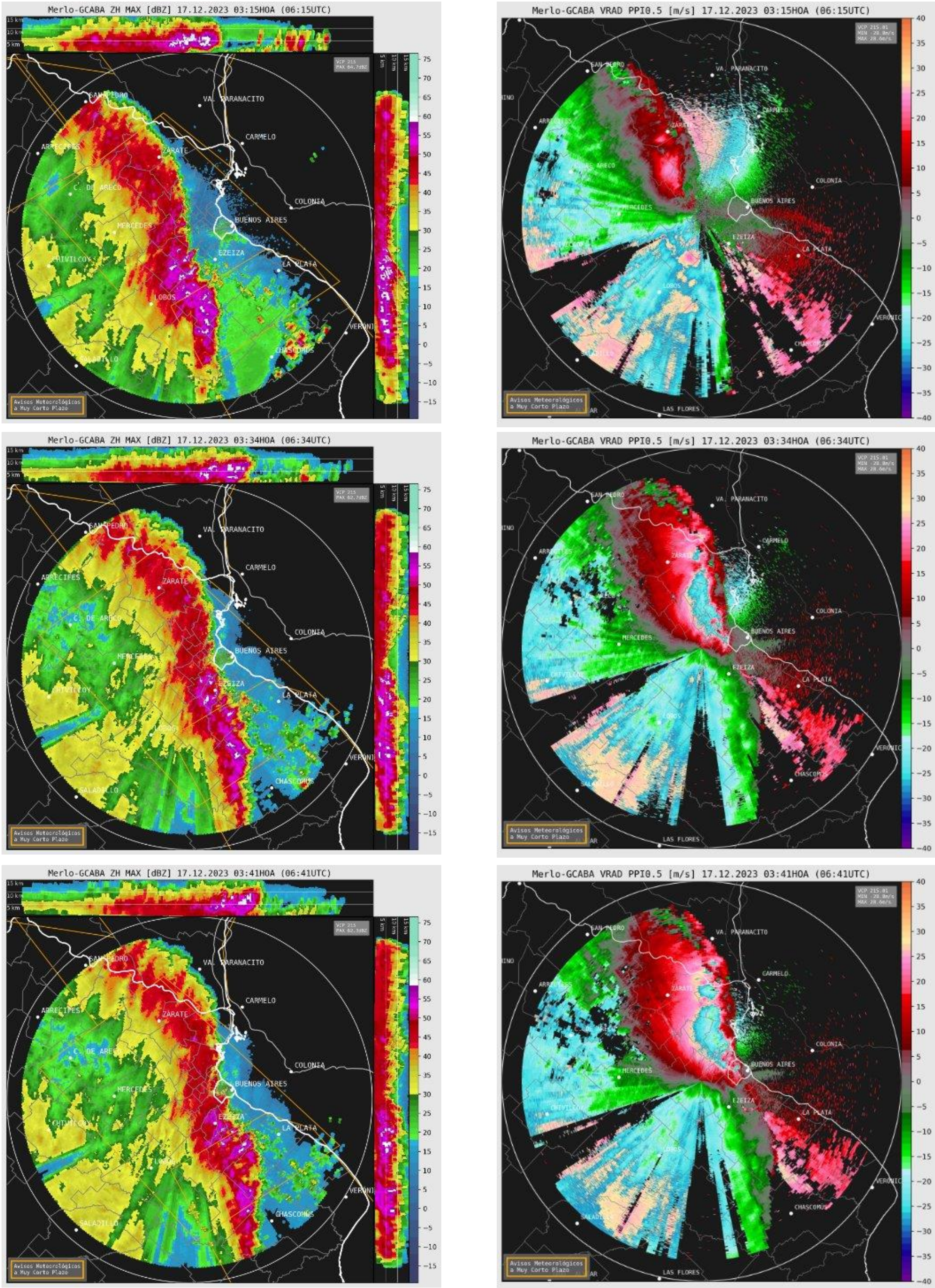


***Figure 10**: Number of hours with electrical activity per day for (a) 15/12/2023, (b) 16/12/2023, (c) 17/12/2023, and (d) 18/12/2023. Data from the ENTLN Global Lightning Network (DiGangi et al. 2022).*

The AMBA and its surroundings are monitored by two meteorological radars, one located in Ezeiza (Buenos Aires Province) belonging to the National Meteorological Radar System (SINARAME, Undersecretariat of Water Resources) and another belonging to the City of Buenos Aires located in Merlo, Buenos Aires Province. This second radar, which operates in S band, has the possibility of offering a more complete view of an event of this nature with high reflectivities and very strong winds. Figure 11 shows the time series of the maximum reflectivity in the column (left) and Doppler at low levels (right) during the arrival of the line to the AMBA area. The progress of reflectivity reflects the most intense part to the south of the City, while the Doppler variable, which informs us of the radial component of the velocity, has its maximum towards the north.


Merlo-GCABA ZH MAX [dBZ] 17.12.2023 03:15HOA (06:15UTC)
Merlo-GCABA VRAD PPI0.5 [m/s] 17.12.2023 03:15HOA (06:15UTC)
Merlo-GCABA ZH MAX [dBZ] 17.12.2023 03:34HOA (06:34UTC)
Merlo-GCABA VRAD PPI0.5 [m/s] 17.12.2023 03:34HOA (06:34UTC)
Merlo-GCABA ZH MAX [dBZ] 17.12.2023 03:41HOA (06:41UTC)
Merlo-GCABA VRAD PPI0.5 [m/s] 17.12.2023 03:41HOA (06:41UTC)

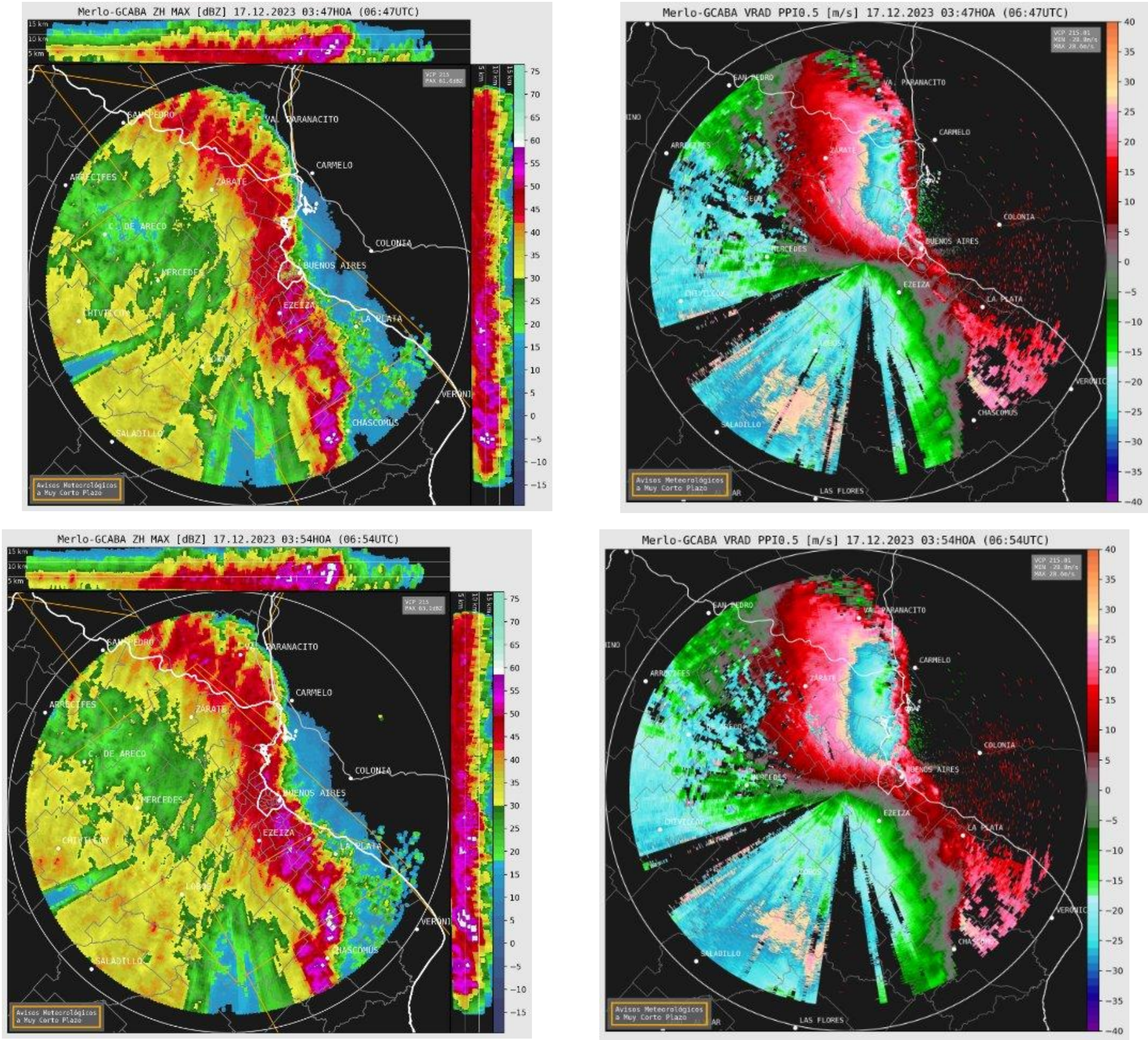


***Figure 11**: Time series of reflectivity (COLMAX, left) and 0.5° elevation Doppler (right) from the radar located in Merlo, belonging to the City of Buenos Aires. The images illustrate the progress of the system between 3:15 and 3:54 Argentine time on December 17, 2023.*

A simple estimate of the speed of the convective system between successive scans indicates an average reflectivity displacement speed of approximately 70 km/h. The Doppler velocity at the surface indicates a component behind the instability line in the southern sector of approximately 90 km/h in a sustained manner. The maximum radial speed measured by the radar corresponds to a local maximum in the Paraná Delta southwest of Carmelo with values of 170 km/h after correcting for aliasing (28.7 m/s). This wind corresponds to an approximate height of 500 m. This maximum occurs near the center of the jet located over the delta, and whose wind component is parallel to the front in the area north of the City of Buenos Aires. The curved structure of the zero-value line in the Doppler variable indicates that the wind turns rapidly with height until it becomes westerly in the first 1000 meters.

2.3 Winds recorded on the surface

The evolution of the system was accompanied by intense gusts in several points of the province of Buenos Aires, with the maximum values recorded at the SMN stations described in Table I. Note that all the maximums come from the southwest quadrant.

Table I: *Maximum gust intensity (in knots) recorded at SMN stations between the afternoon of Saturday 16 and the early morning of Sunday 1,7 December 2023.*

Season	***Date and Time (HOA)***	***Direction and maximum gust speed***
Bahia Blanca	16/12/23 19:48	250/84 kt (155 km/h)
San Fernando	17/12/23 03:42	240/73 kt (135 km/h)
OCBA	17/12/23 3:42 AM	230/54 kt (100 km/h)
Airpark	17/12/23 3:54 AM	210/56 kt (104 km/h)
El Palomar	17/12/23 3:42 AM	230/67 kt (124 km/h)
Moron	17/12/23 3:30 AM	200/60 kt (111 km/h)
Ezeiza	17/12/23 3:30 AM	200/47 kt (87 km/h)
The Silver	17/12/23 4:06 AM	230/51 kt (94 km/h)

The severity of the wind gusts associated with the systems that affected both Bahía Blanca on the afternoon of Saturday, December 16 and AMBA in the early hours of Sunday, December 17 was recorded by the anemometers of the AWOS automatic observation systems (Fig. 12). In the case of the AWOS located at the Comandante Espora Airport in the city of Bahía Blanca, the maximum records were 138 and 154 km/h (points approximately 3 kilometers apart), with a period of approximately 30 minutes (between 22:40 and 23:10 UTC) where the gusts remained above 120 km/h (Fig. 12a). In AMBA, the maximum speeds were 105 km/h (runway 13), 120 km/h (runway 31) and 142 km/h (center of the runway) at Jorge Newbery Airport, and 132 km/h (runway 05) and 135 km/h (runway 23) at San Fernando International Airport. Note the interruption of the anemometer measurement at the center of the runway at Aeroparque, damaged by an object carried by the wind.

In Figure 13, three anemometers from the Rio de la Plata Administrative Commission (CARP) also indicate wind peaks in areas surrounding the Rio de la Plata (Conchillas and Colonia in Uruguay, and the Norden pile, located between La Plata and Colonia, see here).

2.4 Rain and hail events

The analysis of the precipitation that occurred during this event was carried out considering the satellite precipitation estimates and the rainfall observations available at the SMN. Thus, several satellite precipitation monitoring products at higher temporal resolution were used, such as the Hydroestimator (Hobouchian 2017), IMERG (Huffman et al. 2020) and GSMaP (Mega et al. 2018), as well as the satellite precipitation estimate adjusted with rainfall observations (SQPE-OBS). The experimental SQPE-OBS product (Fig. 14) is obtained on a daily scale by performing a rainfall adjustment to the IMERG Early Run satellite estimate (Huffman et al., 2020). For more information on this product, see Hobouchian et al. (2021).

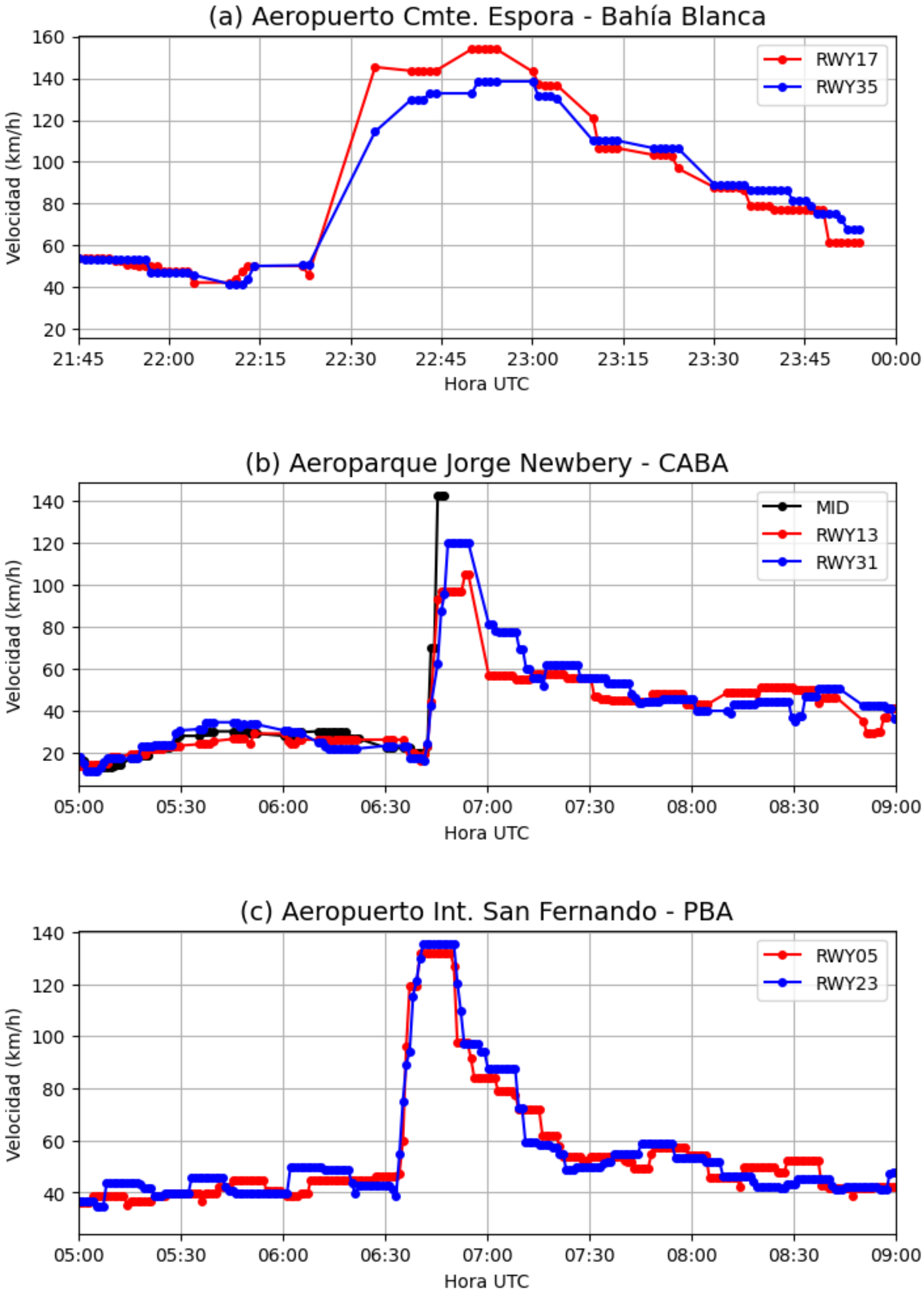


Figure 12: *Temporal evolution of the maximum 10-minute gusts recorded on 16/12/2023 (Bahía Blanca) and 17/12/2023 (Aeroparque and San Fernando) by the AWOS automatic systems located at the airports of Bahía Blanca (PBA), Aeroparque (CABA) and San Fernando (PBA). The different colors correspond to the anemometers located at the different runway heads of each airport. The time indicated is in UTC (HOA+3). Information provided by the Argentine Air Navigation Company (EANA).*

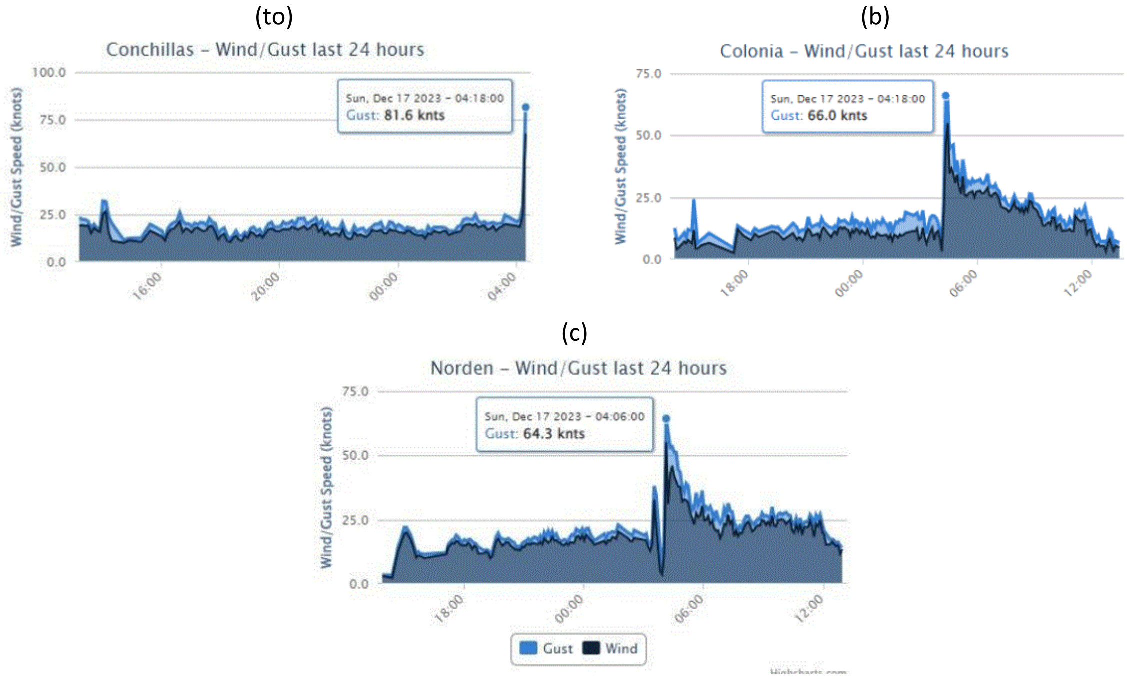


***Figure 13**: Wind measurements on the Rio de la Plata, in Conchillas (northwest of Colonia), Colonia and between Colonia and La Plata (Pilote Norden). Data from the Rio de la Plata Administrative Commission (CARP).*

Figure 14 and 6-hourly precipitation monitoring (not shown) coincide with an area of continuous and widespread precipitation moving from northern Patagonia into northeastern Argentina. This continuous rainfall pattern is seen mainly between 09:00 HOA on 16 December until 21:00 HOA on 17 December lasting more than 24 hours, which is consistent with mesoscale convective systems (see Markowski et al. 2010).

The maximum precipitation values in Bahía Blanca and the AMBA occur on the rainfall day 16 December 2023 (between 09:00 HOA on the day in question and 09:00 HOA the following day) in line with the previous description of the event (Fig. 14b). This maximum turns out to be higher in the southwest of the province of Buenos Aires compared to the AMBA area. The estimated precipitation values for Bahía Blanca range from 50 mm to over 75 mm in the surrounding area, while for the AMBA area they exceed 30 mm to values above 50 mm in some points. Table II, with surface measurements, helps to complement this information.

As for the following days, it is observed how the area of precipitation moves towards the northeast with similar maximum values (Fig. 14 c and d). In turn, the occurrence of rain is observed in San Luis, Córdoba and northern Buenos Aires with estimated values between 10 and 20 mm.

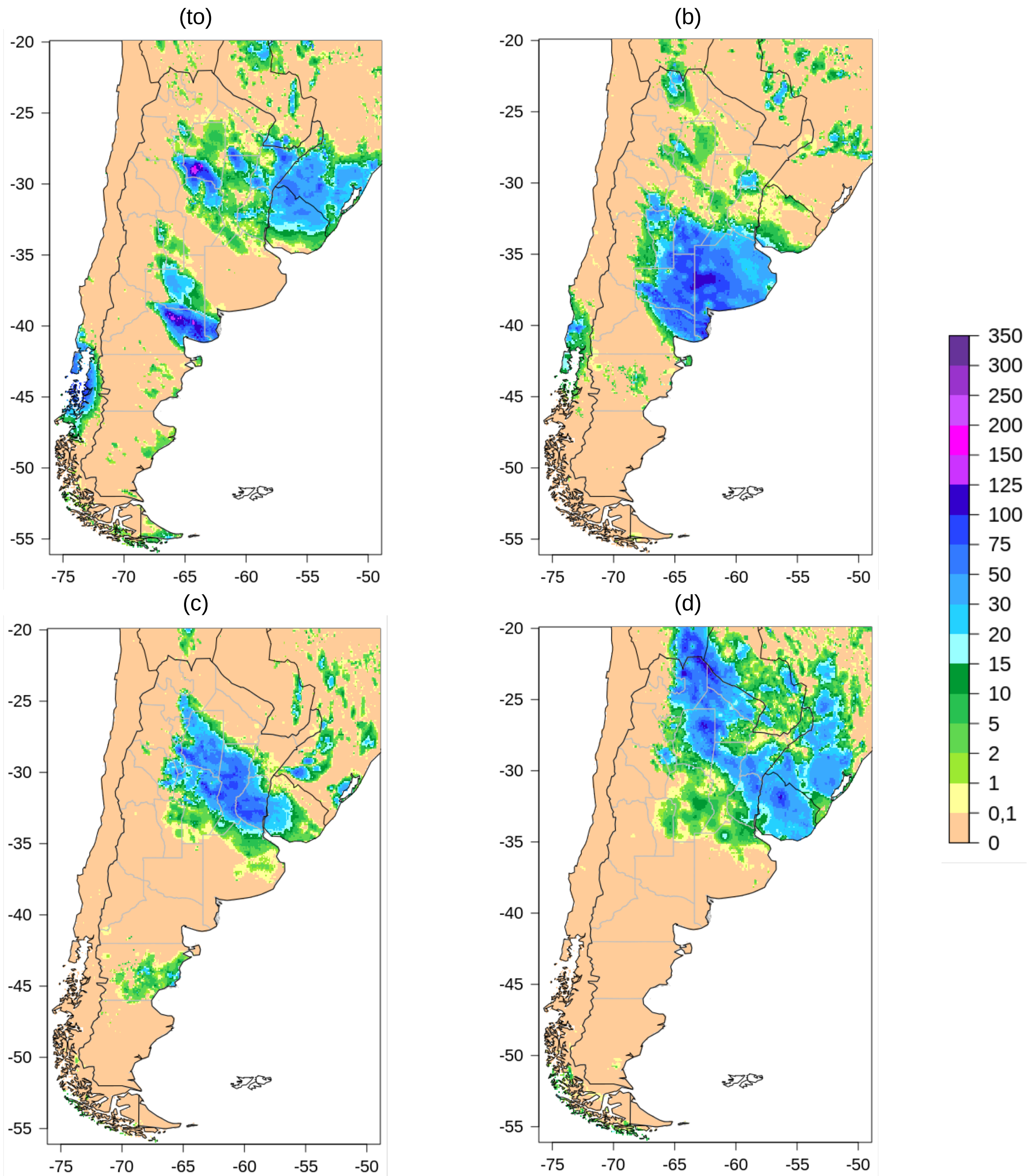


Figure 14: *Estimated daily accumulated precipitation [mm/day] from the SQPE-OBS experimental product for the rainfall days (09:00 on the initial day to 09:00 HOA on the following day) (a) 15/12/2023, (b) 16/12/2023, (c) 17/12/2023 and (d) 18/12/2023. In these figures, the ocean is masked due to lack of data to properly apply the methodology.*

***Table II**: Precipitation totals recorded at SMN stations between 9:00 a.m. on December 16 and 9:00 a.m. on December 17, 2023. The stations are arranged in decreasing order of accumulated precipitation.*

Estación Meteorológica	Precipitación (mm)
NUEVE DE JULIO	74
BENITO JUAREZ AERO	71
BAHIA BLANCA AERO	60
RIO CUARTO AERO	59
EZEIZA AERO	57
AZUL AERO	55
GENERAL PICO AERO	54
OLAVARRIA AERO	54
PIGUE AERO	53
CORONEL SUAREZ AERO	52
LA PLATA AERO	52
LAS FLORES	48
JUNIN AERO	46
BOLIVAR AERO	45
TANDIL AERO	45
PEHUAJO AERO	44
VENADO TUERTO AERO	44
MERLO AERO	43
MORON AERO	42
SANTA ROSA AERO	42
TRES ARROYOS	41
MAR DEL PLATA AERO	40
BUENOS AIRES OBSERVATORIO	39
DOLORES AERO	37
LABOULAYE AERO	36
SAN FERNANDO AERO	34
EL PALOMAR AERO	33
GUALEGUAYCHU AERO	30
TRENQUE LAUQUEN	30
PUNTA INDIO B.A.	24

* sólo se muestran los valores superiores a 15mm

2.5 Description of events from a mesoscale perspective

Given the extent of damage generated by severe gusts and the appearance of convective systems on radar imagery, there is a high probability that two *derechos* were recorded during this event (Bruno Ribeiro, personal communication). A derecho is defined as a mesoscale convective system that produces damaging straight-line gusts that occur continuously or intermittently over a swath of at least 650 km with a minimum width of approximately 100 km (American Meteorological Society glossary, https://glossary.ametsoc.org/wiki/Derecho). Derechos typically contain bow-echo structures, with the most severe gusts observed in association with the appearance of rear-inflow jet (RIJ) structures or book-end vortices. Depending on the structure of the convective system and the forcing associated with its occurrence, derechos are usually classified as either “serial” or progressive. Serial derechos are composed of multiple bow-echoes embedded in a long line of instability, under conditions of strong synoptic forcing. They differ from progressive derechos in that the latter are generally somewhat smaller in extent and their propagation is dominated by the internal dynamics of the mesoscale convective system.

Examples of the latter were those recorded in the north of the province of Buenos Aires and which also affected the AMBA during the early morning of October 21, 2008 (Torres Brizuela et al., 2010). Although these classifications are regularly used in the literature, there is an open debate regarding the precise definition of these systems, as discussed in Corifidi et al. (2016). In turn, these systems may be accompanied by the formation of cyclonic circulations (mesovortices) and possible tornadogenesis if there is sufficient forcing, instability and wind shear. Weisman (1993) carried out idealized studies of the so-called “book-end vortices” reaching the conclusion that their origin lay in the vertical inclination of the horizontal vorticity of the system (in the area of the leading edge of the RIJ). A complete review of this last topic can be found in Schenkman and Xue (2016). This work shows a conceptual model (their Figure 6) that is very similar to that observed in Figure 11 and that could justify the specific damages observed in the area of the Palermo forests and the Jorge Newbery Airport in the City of Buenos Aires. There, a very narrow strip of severe damage was observed, mainly in the trees. Video records were also found taken on the airport platform where the passage of a mesovortex that rotates several planes that were being prepared for their corresponding flights is observed (see https://www.instagram.com/reel/C08iJmdsBxJ/?igsh=QkFLZFQ1NVhkdA%3D%3D).

As mentioned, the analysis of the radar images shows two well-defined lines of instability, linked by a region of weaker convection between them (Fig. 9). The line of instability moving across the north of Buenos Aires Province produced reports of damage from severe gusts in a strip from the northeast of La Pampa to localities in southern Uruguay (see Fig. 15), so it meets the definition of a derecho. This derecho developed in an environment of strong synoptic forcing, and it was organized ahead of/over the advance of a cold front, following the evolution of the large-scale synoptic system, so it could be classified as a “serial” derecho.

On the other hand, the line of instability that developed further south, affecting the city of Bahía Blanca and moving east over the Argentine sea, shows similar characteristics in terms of the extent of damage. It is highly probable that this system was also a derecho with the development of at least one tornado or mesovortex (Meteorological Information Center of the SMN, personal communication), although the movement towards the ocean interrupted the collection of reports of severe gusts, so it cannot be determined with certainty whether the extension criteria were actually met to consider it as such.

Advances in the operational radar network, as well as the availability of severe event reports provided by the SAMHI database, are beginning to make it possible to adequately characterize this type of event in the country. Given the spatial extent and severity of damage to this type of system, it is essential to continue advancing in the development of forecasting and communication tools for these events, in order to minimize the impact on the population.

3. DESCRIPTION OF IMPACTS

Although impacts have been mentioned in previous sections, this section describes them in more detail. As with any impact study, obtaining robust data on a large scale is a great challenge and partly haphazard due to the immense field work that this requires.

3.1 Overview

Figure 15 shows a map of the important meteorological events that affected the region in terms of wind, rain and hail. Intensity peaks can be seen in particular over areas surrounding the city of Bahía Blanca and the Metropolitan Area of Buenos Aires. Since obtaining these observations depends on the presence of stations and/or human presence, the accumulation near urban areas does not necessarily reflect the real distribution of the phenomena.

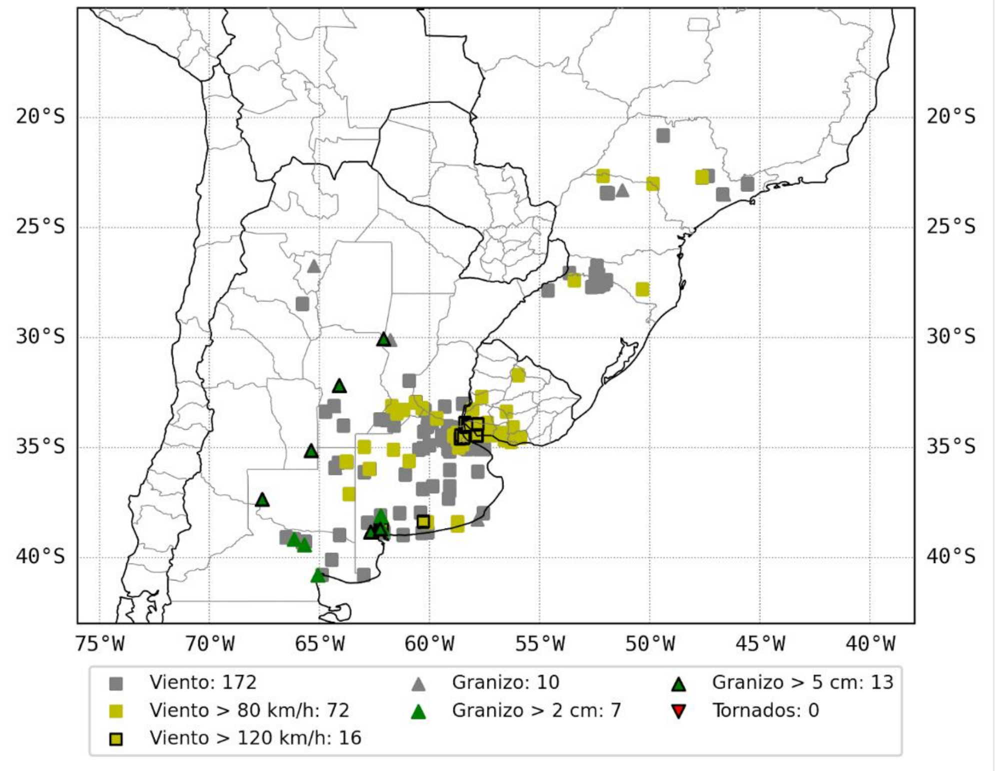


***Figure 15**: Map of meteorological phenomena extracted from the SAMHI database for December 16, 17 and 18, 2023. Note the predominance of wind, the presence of some hail and zonda events in Mendoza and San Juan. Most of this data comes from social media posts and, in the case of wind, from measurements by unofficial meteorological stations. Source: SAMHI database .*

This storm system generated numerous impacts that affected both the lives and property of the population across several provinces. The most important source of information is the *South American Meteorological Hazards and Impacts Database* (SAMHI; see Salio et al., 2024). This tool, maintained by the Center for Marine and Atmospheric Research (CIMA) and the Department of Atmospheric and Ocean Sciences (DCAO) of the University of Buenos Aires (UBA), in which the SMN also participates, aims to carry out the systematic cataloguing of significant meteorological events and their associated socio-environmental impacts. The information is categorized into seven thematic units linked to different types of impacts: to the population and their livelihoods, to housing, to transportation infrastructure, to urban infrastructure and essential services, to trees and to the vehicle fleet.

Figure 16 shows a compilation of all records associated with the impacts that took place in the period considered for the December event.

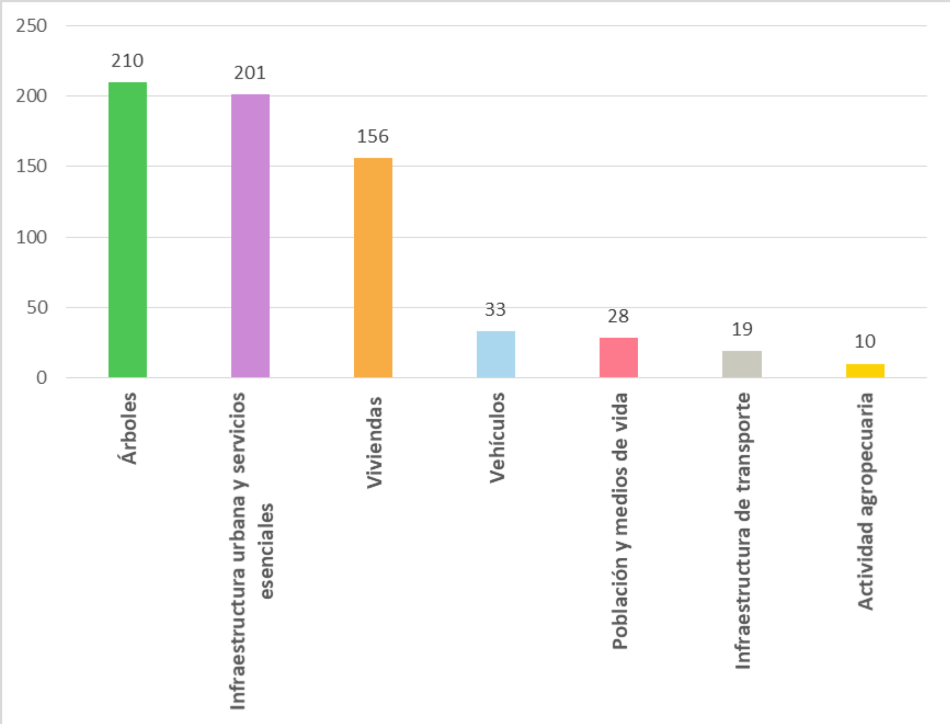


***Figure 16**: Impact records as characterized in the SAMHI database during the severe weather event of December 16-17, 2023. Source: SAMHI database*.

Analysis of the records reveals that the damage was concentrated in the family of trees, with a total of 210 reports divided between broken trees and large broken branches. The next most affected category was urban infrastructure and essential services, with just over 200 reports of damage, mostly affecting low and medium voltage poles with power outages and also causing damage to telecommunications lines. There are 156 reports of impacts on homes, mostly with blown roofs and general damage to building structures, associated with strong gusts of wind. Damage to vehicles continues to be high, mainly concentrated in dents and broken windshields due to hail. Subsequently, there are impacts on the population and their livelihoods, with the largest number of records of deceased people in the city of Bahía Blanca and in the Buenos Aires municipality of Moreno, as well as injuries, evacuations after the meteorological event and suspension of commercial, economic and general activities, which generated losses in the economy. For its part, the impacts on the transportation infrastructure are those that continue in the number of reports in the SAMHI database, mainly associated with the closure of traffic routes due to falling trees and flooding, as well as the suspension of flights, closure of airports and damage to the airport structure. Finally, impacts on agricultural activities were also recorded, with crops and livestock affected.

Following the analysis, Figure 17 breaks down the information in each affected province to analyze how the impacts were distributed throughout the national territory, as shown in the following graph.

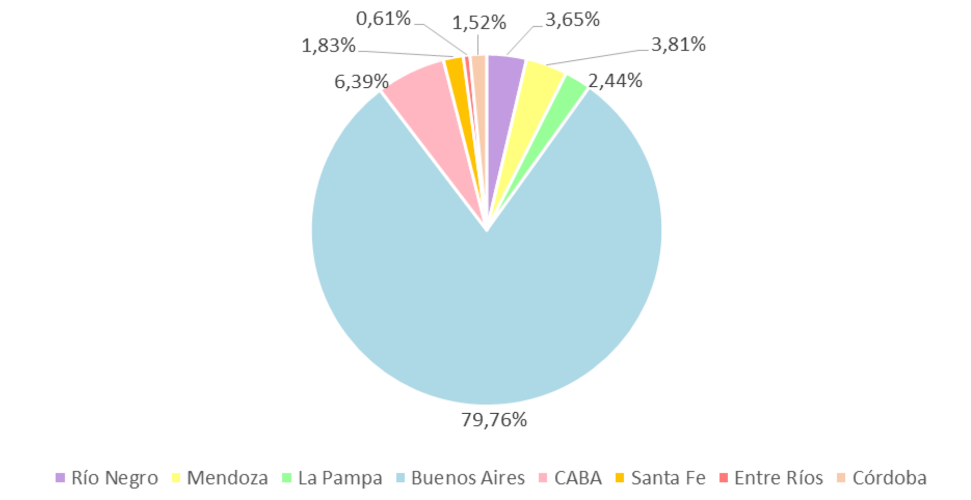


Figure 17*: Impact records by province in the SAMHI database during the severe weather event of December 16-17, 2023. Source: SAMHI database.*

When looking at the number of records by province, a notable disparity in the impacts can be observed in the province of Buenos Aires, which accounts for almost 80% of the total reports. Secondly, the Autonomous City of Buenos Aires represents 6.39% of the damage entries collected in the SAMHI database for the event in question.

In parallel, the temporal dimension can also be incorporated into the analysis. To this end, the following map shows the time at which each impact recorded occurred and their location based on the georeferenced information extracted from the SAMHI database.

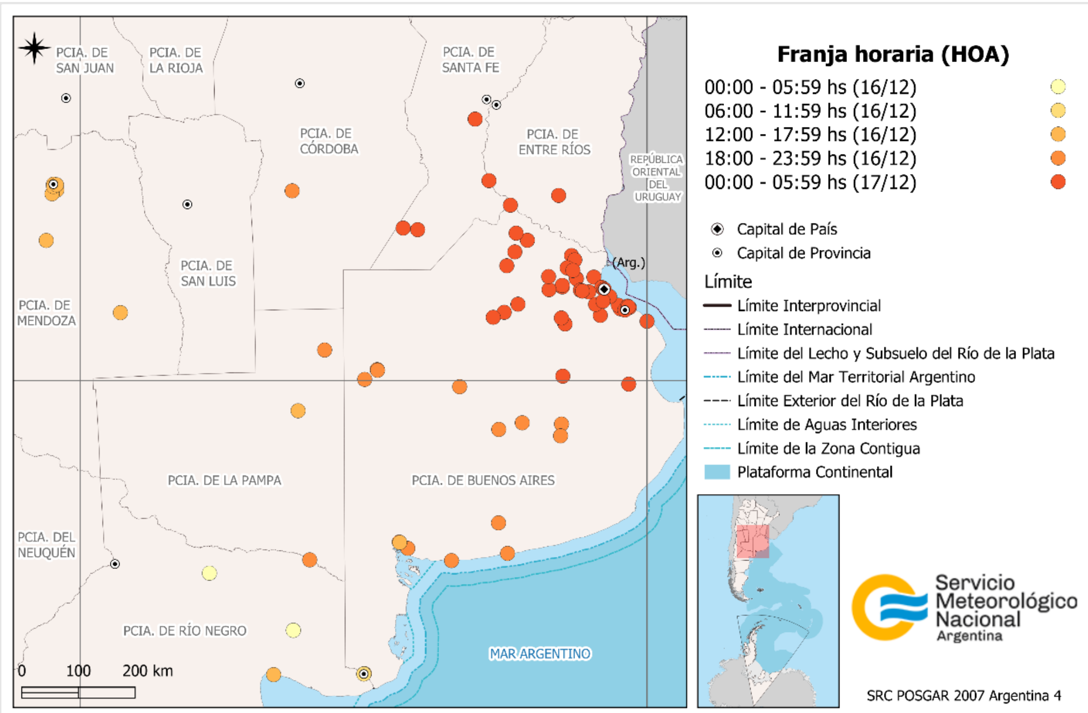


Figure 18: *Impact record from the point of view of its temporal evolution. SAMHI database.*

It can be determined that from the early hours of Saturday, December 16, the consequences of the advance of the storm in the northeast of the province of Río Negro were recorded. Later, the effects extended to the provinces of La Pampa and Mendoza, reaching the southwest of the province of Buenos Aires in the last hours of that day. Towards the beginning of Sunday, December 17, the storm continued its path through most of the province in Buenos Aires, impacting from the southwest until reaching, in the early hours of that same day, the Metropolitan Area of Buenos Aires. Later, the effects were felt in the south of Entre Ríos and Santa Fe in the morning hours.

3.2 City of Bahia Blanca

Bahía Blanca was the first urban centre affected and where human losses were recorded. Figure 19 shows the state of the covered stadium where the tragic episode took place, which left 13 dead. The event was not restricted to a local incident, but impacted a wide area around the city (see Fig. 20).

***Figure 19**: State of the Bahiense del Norte Club after the damage on December 16, 2023. That night, an end-of-year figure skating event took place (Source: X).*

The city of Bahía Blanca and its surroundings were among the areas most affected by this event due to the intense winds and rainfall in the late hours of December 16 (see Fig. 21). The strong gusts caused the collapse of the structure of the Bahiense del Norte club, resulting in the death of 13 people and leaving numerous injured. The vast majority of buildings for community use suffered serious material damage. Sports institutions such as Olimpo, El Nacional, Tiro Federal and Puerto Comercial White saw their walls, changing rooms, stands, covered courts, event halls, metal roofs, sheds and buffets destroyed. For its part, the educational infrastructure was no exception: a total of 157 schools were affected, of which 47 were classified as having considerable damage and 15 suffered very serious damage.

(a)

(b)

(c)

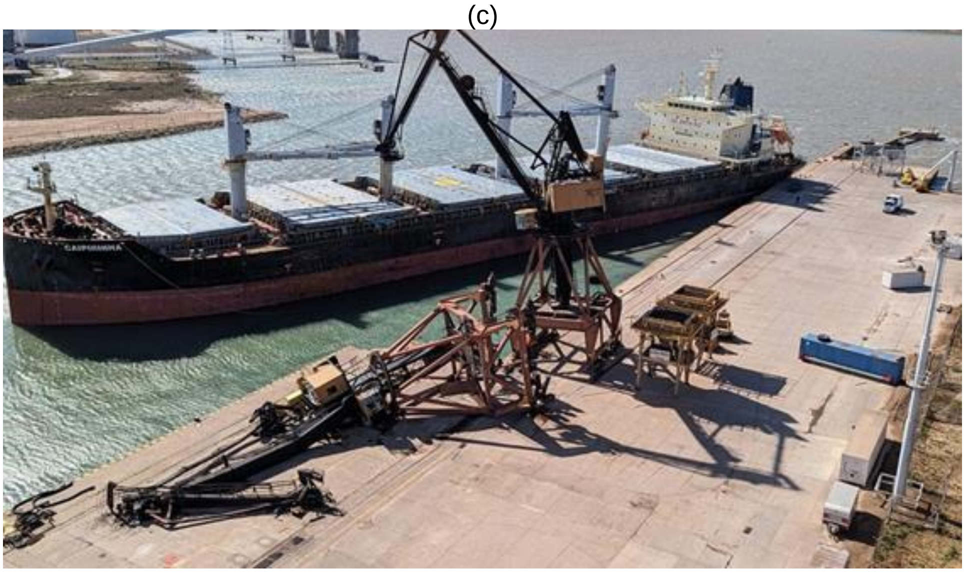


Figure 20*: Impact of the December 16, 2023 event near Bahía Blanca. (a) Note the final state of the Radio Nacional antenna (Source: X), (b) the destruction of a forest due to falling trees (Credit Pablo Argirroffi) and (c) the damage to facilities at the port (Source: CaféxMedio).*

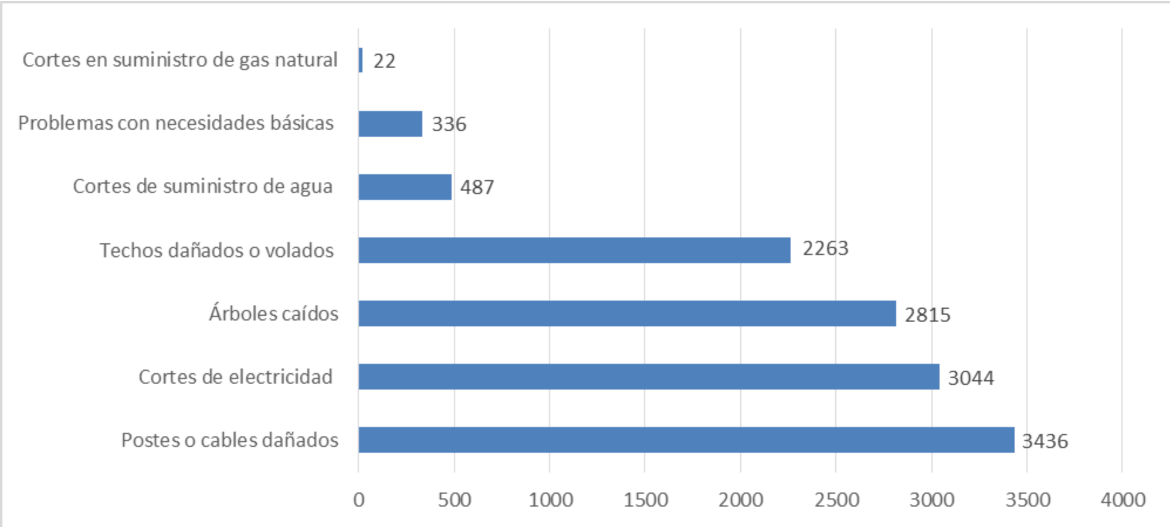


***Figure 21**: Impact records in the city of Bahía Blanca. Source: Emergency Operations Center – Municipality of Bahía Blanca.*

Information provided by the Bahía Blanca Emergency Operations Centre reveals that the situation also generated problems related to the basic needs of the population. Not only were there obstacles to guaranteeing food security, due to the interruption in the supply of food and drinking water, but also problems linked to the loss of mattresses, furniture and clothing.

In terms of energy infrastructure, significant impacts were recorded, such as the collapse of thirteen high-tension towers, damage to main lines and individual connections in buildings, and more than 3,000 records of fallen electric poles due to the action of the wind. According to the National Energy Secretariat, the company EDES (Empresa Distribuidora de Energía Sur) reported that approximately 112,000 users in the urban area were affected by power outages. In addition, more than 14,000 trees fell throughout the city, mostly concentrated in the central area. Green spaces such as Parque de Mayo, El Pinar, Parque Independencia, Plaza Almirante Brown and Parque Noroeste were also affected.

The damage also extended to the water network, with supply cuts attributable to broken pipes caused by falling trees. ABSA (Aguas Bonaerenses SA) also reported that the Patagonia and Grünbein water treatment plants, as well as the sewage pumping system in Ingeniero White, were affected by power cuts. Likewise, the domestic gas network in various parts of the city was affected due to damage to pipes and cabins caused by the strong winds.

In the residential area, 300 homes were reported to have completely collapsed and more than 12,000 with roof damage. Subsequent reports indicate that the strong gusts also damaged walls and windows, causing significant damage to many properties. In the face of such an emergency situation, local authorities implemented various measures, including the evacuation of the most affected areas and the opening of shelters, which provided shelter to more than 350 people.

Finally, the port of Bahía Blanca suffered severe damage that paralyzed its operations, leaving the grain terminals without electricity or connectivity. The strong winds also caused landslides and significantly affected the port facilities, making it impossible to receive trucks and load ships. In addition, two cranes fell and production was interrupted at the region's petrochemical plants. Table III presents a list of the press articles that reported on this matter.

__Table III:__ Press articles that reported information on impacts in the city of Bahía Blanca.

Title of the article	Reference	Access link
Update on the status of electrical power disruption	Official Portal of the Argentine State	Link
Storm in Bahia: power outage affects water and sewage services	BVC News	Link
Assistance continues in Bahía Blanca after the storm	Government of the Province of Buenos Aires	Link
The storm caused serious damage and paralyzed the port of Bahía Blanca	DataPortuaria	Link
Strengthening ties to rebuild Bahía Blanca	Pagina 12	Link
The effects of the storm in the region	Bahia Blanca Cereal and Products Exchange	Link
The drama caused by the massive loss of trees	La Brújula 24	Link

3.3 Metropolitan Area of Buenos Aires

During the early hours of Sunday 17, the storm also impacted the Metropolitan Area of Buenos Aires (AMBA), affecting both the vast majority of the municipalities in the province of Buenos Aires that comprise it and the Autonomous City of Buenos Aires itself. According to the categories of the SAMHI database (Salio and others, 2024), one fatality was recorded in the town of La Reja, in the Moreno district, where a woman lost her life due to the fall of a large branch. In addition, injured people were reported in towns such as General Rodríguez and Tigre, and evacuations were carried out in areas near Zárate.

In the Autonomous City of Buenos Aires, strong gusts of wind caused the partial collapse of the stage and furniture of an electronic music party held at the Gimnasia y Esgrima Club (see Fig. 22), leaving 15 people injured. The time at which the incident occurred, at 3:45 am, was probably a determining factor in avoiding fatalities. In addition, another event that occurred at the Palermo Hippodrome resulted in three people injured.

One of the elements most affected by the storm were the trees. In the city of La Plata, 800 fallen trees were recorded, while in Tigre the figure reached 1,200. According to the Ministry of Security of the Autonomous City of Buenos Aires, on Sunday, 3,112 fallen trees and 74 fallen branches were. On Monday, the 18th, the number of fallen trees was 601, with 77 fallen branches, and on Tuesday, the 19th, 350 trees and 64 fallen branches were counted.

The damage to urban trees also caused other impacts throughout the AMBA, such as road closures, damage to signs and vehicles with dents, broken windshields and shattered glass.

The storm also left more than 400,000 users without electricity throughout the metropolitan area due to fallen poles and damage to power lines. There were 337,905 Edesur users without service and 72,743 Edenor users. In turn, according to the Government of the City of Buenos Aires, 195 fallen poles and 171 affected lines were recorded. The most affected Edesur areas were the districts of Almirante Brown, Avellaneda, Esteban Echeverría, Cañuelas, Berazategui, Ezeiza, Florencio Varela, Lanús, Lomas de Zamora, Presidente Perón, Quilmes and San Vicente, while, in CABA, the most affected neighborhoods were Recoleta and San Telmo. In the Edenor area, the most impacted localities included Tres de Febrero, General Las Heras, General Rodriguez, General San Martin, Hurlingham, La Matanza, Escobar, Ituzaingo, Malvinas Argentinas, Marcos Paz, Merlo, Moreno, Moron, Pilar, San Fernando, San Isidro, San Miguel and Tigre.

As for damage to homes, the gusts of wind mainly caused damage to roofs and walls in various towns in the Buenos Aires metropolitan area. According to the SAMHI database, damage was reported in the southern area, including La Plata, San Francisco Solano, Ensenada, Quilmes and Berisso; in the western area, affecting towns such as El Palomar, Hurlingham, Ituzaingó and Moreno; and in the northern area, in Tigre, Campana, Maquinista Savio, Pilar and Zárate.

Finally, urban transport services were also severely affected by the interruption of train services on the Mitre, Sarmiento, San Martín, Belgrano Norte and Urquiza lines. Table IV presents a list of press articles that reported on this matter.

Table IV: *Press articles that reported information on impacts in the Metropolitan Area of Buenos Aires (AMBA).*

Title of the article	Reference	Access link
Floods, destruction and fallen trees: what was left behind by the storm that hit AMBA	INFORAMA	Link
One death, destruction and power cuts: what the brutal storm left behind in the AMBA	El Cronista	Link
Storm in Buenos Aires and provinces: power cuts, alerts and when there will be rain	Página 12	Link
Storm devastates AMBA: flooded streets, fallen trees and power outages	Arriba Lanús	Link
Storm in AMBA: a woman died in Moreno and 18 people were injured in CABA	Nexofin	Link
The damage caused by the storm led to evacuations and damage to vehicles and homes	La posta! News General Rodriguez	Link
After the storm in AMBA, delays and cancellations on trains: which lines are affected	C5N	Link

Servicio Meteorológico Nacional Argentina

(a) (b)

Figure 22: *(a) Stage destroyed during the La Bresh festival held at GEBA (Source X). (b) Fallen trees caused damage (Credit Alejandro Pagni/AFP).*

3.4 Impacts on the aeronautical sector

In the aeronautical sector, the event also produced significant impacts associated with the passage of storms through the AMBA area. Especially at the Jorge Newbery Airport in the City of Buenos Aires, where planes parked on the platform moved due to the passage of these storms, and it also caused movement of light elements (stairs, luggage transport carts, etc.) that were not secured and impacted on some planes (see Fig. 23b). On the other hand, at the San Fernando International Airport, located in the city of the same name, taking into account that smaller aircraft operate from there, they all moved, concentrating on a particular sector and in some cases, they were flipped upside down. (see Fig. 23c).

In particular, the aerodrome meteorological office and the aerodrome meteorological station, both located at Jorge Newbery Airport, issued the corresponding regular aeronautical meteorological messages (TAF, METAR) and special ones (Aerodrome Warning, SPECI) in accordance with the meteorological situation. In this regard, it is relevant to mention that meteorological instruments located at the midpoint of the Aeroparque runway were hit by a metal structure that broke off from the roof of a hangar, putting it out of service (see Fig. 12).

According to the information provided by the Air Traffic Flow Management Service, dependent on the Argentine Air Navigation Company (EANA), the post-operations report corresponding to December 17, 2023 for the Baires terminal control area, which showed the comparison between the expected air traffic demand and actual operations, showed that between approximately 02:30 hours and 08:00 hours there were fewer actual movements than expected, especially between 3:00 hours and 06:00 hours where they were almost zero.

(to) (b) (c)

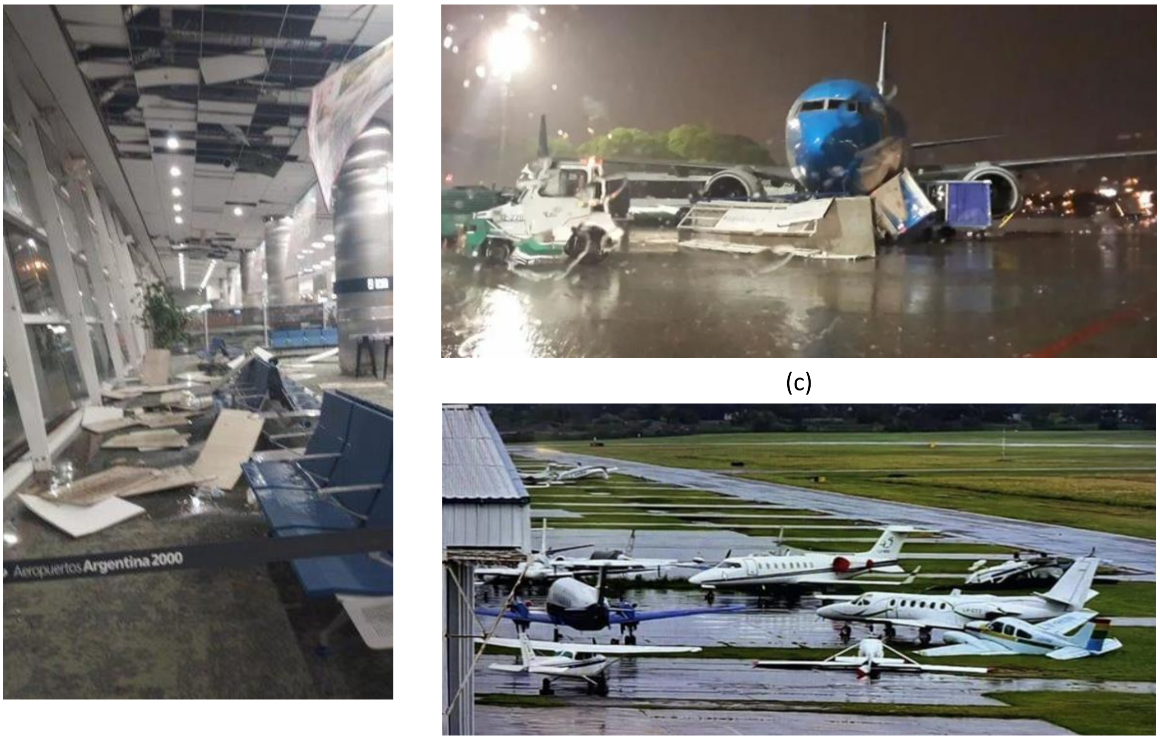


Figure 23: (a) Interior of *Jorge Newbery Airport (Source X), (b) Image of a staircase impacting with a luggage cart and on a parked aircraft due to the strong winds at Jorge Newbery Airport (Source X), (c) Image of a section of the platform at San Fernando International Airport (Source X).*

4. ANALYSIS OF NUMERICAL FORECASTS

This section aims to analyze a set of products derived from numerical modeling generated with different models, as well as to carry out a predictability study. Among the models considered are: 1) WRF (deterministic and ensemble) (Skamarock et al. 2019) of the SMN Assimilation and Forecast System (SAP.SMN) (Maldonado et al., 2024), 2) GFS (deterministic and ensemble) of the National Centers for Environmental Prediction (NCEP) (Zhou et al., 2017) and 3) Integrated Forecast System (IFS HRES and ENS) of the European Center for Medium Range Weather Forecasts (ECMWF). The main characteristics of the models considered are presented in Table V.

***Table V**: Models used in these studies. Spatial resolution refers to the information available.*

Model	***Domain***	***Spatial resolution***	***Temporary resolution***	***Convection***	***Forecast horizon***
WRF DET/ENS (SAP.SMN)	Regional	4 km	1 h	Explicit	72/48 hours
IFS HRES/ENS (ECMWF)	Global	0.125°	1 h	Parameterized	10/15 days
GFS DET/ENS (NCEP)	Global	0.25°	1 h	Parameterized	15 days

The SAP.SMN has the advantage, compared to the IFS and GFS, of providing higher resolution forecasts, which allows representing the processes associated with convection in a more realistic way. It should be noted that the SAP.SMN version uses the analyses and forecasts of the GFS DET/ENS as initial and boundary conditions. For this work, in addition to the traditional variables, information from the Extreme Forecast Index (EFI) and Shift Of Tails (SOT) indices from the IFS ensemble was used, which account for the magnitude - in terms of historical extremes - of the event considered (see definitions in Tsonevsky (2015).

For this study, forecasts initialized at 00 UTC on December 16, 2023 were selected, which corresponds to approximately 24 hours before the occurrence of the events in Bahía Blanca and Buenos Aires.

4.1 The SMN WRF model

4.1.1 City of Bahia Blanca

Figure 24 presents the SAP.SMN-DET forecasts for 23 UTC on December 16, the approximate time of the event in Bahía Blanca. Panel (a) shows the precipitation field together with the mean sea level pressure and the wind at 10 m. A region of maximum precipitation is observed in the vicinity of Bahía Blanca, which moved from the NW to the SE (not shown). Likewise, it can be seen that the area of maximum precipitation is also accompanied by gusts exceeding 45 kt, although displaced to the east of Bahía Blanca (Fig. 24b). The latter could indicate that the occurrence of the event in the city (maximum gusts observed at 23 UTC) is predicted a few hours before it actually occurred.

(a) (b)

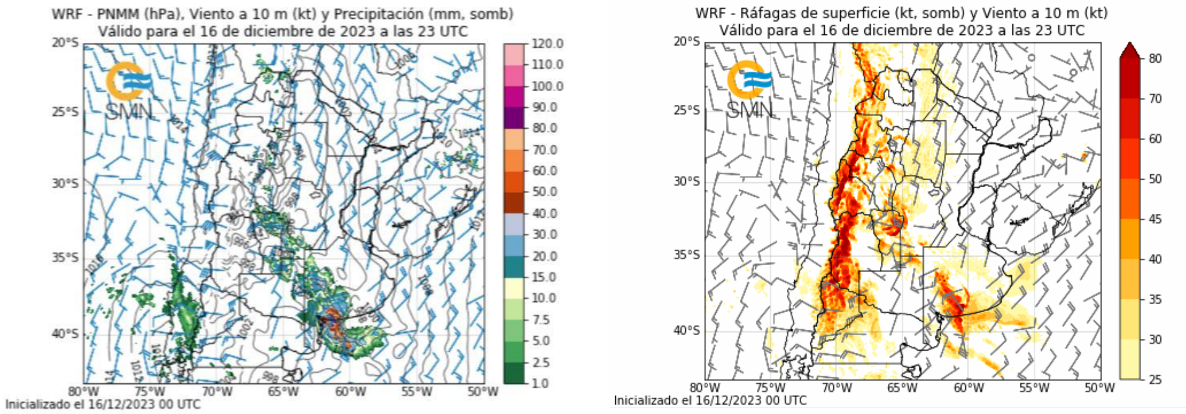


Figure 24*: SAP.SMN-DET forecasts of precipitation, sea level pressure and 10 m wind (left) and surface gusts and 10 m wind (right), valid for 16 December 2023 at 23 UTC and initialized on 16 December 2023 at 00 UTC.*

Figure 25 shows the wind magnitude at 10 m forecast by each member of SAP.SMN-ENS at 23 UTC (20 HOA). In particular, it can be seen that member 12 presents a zone of maximum wind, greater than 45 kt, over the Bahía Blanca area. On the other hand, there are members, such as 2, 3, 10 and 11, that show the maximum wind in advance and others such as 4, 16 or 20 that practically do not present wind forecasts in the province of Buenos Aires. This uncertainty in the forecasts could be given by the physical configuration of each of the members, as well as by the dispersion coming from the initial conditions. It is important to highlight that these values refer to the 20 HOA, which does not imply that similar events were not forecast before or after.

Figure 26 shows the forecast probability of surface gusts greater than certain thresholds, valid for 23 UTC. For the thresholds of 30 and 45 kts, probabilities greater than 20% are forecast, while for the threshold of 60 kts, a signal of between 0 and 10% is seen, covering a large part of the south of the province of Buenos Aires.

Figure 27 shows the time series for Bahía Blanca of different variables of the deterministic forecast (left) and ensemble (right). The passage of the system is clearly visible in the pressure variable and in the associated precipitation (third panel, left) for 21 UTC, in agreement with the drop in surface temperature and the high dew point (second panel, left). The wind intensity and gusts do not show very intense values (first panel, left). On the other hand, the right panel shows how the wind intensity reaches maximums in some members of the ensemble between 19 UTC on the 16th and 00 UTC on the 17th (third panel, right).

4.1.2 Metropolitan Area of Buenos Aires

Figure 28 presents SAP.SMN-DET run fields for 7 UTC on December 17 (approximate time of the event occurrence in the AMBA). Panel (a) illustrates the precipitation field along with mean sea level pressure and wind at 10 m. A zone of maximum precipitation is observed located north of the province of Buenos Aires and to the east of this maximum there is a zone of strong gusts over the AMBA (Fig. 28a).

Figure 29 shows the wind magnitude at 10 m forecast by each member of the SAP.SMN-ENS at 07 UTC (04 HOA). Several members of the ensemble - panels 3, 6, 12, 18 and 20 - show an intense gust over the AMBA area, while in the rest of the members less intense or null events are observed. As in the analysis of Figure 25, it is important to highlight that these values refer to hour 04 HOA, which does not imply that before or after notable events were not forecast in the other members.

Figure 30 shows the forecast probability of surface gusts greater than certain thresholds valid for 07 UTC (04 HOA). For the different thresholds, the probabilities reach their maximum in the AMBA, with an indication of probabilities of gusts greater than 80 knots.

Figure 31 shows the time series for Ezeiza for different variables of the deterministic forecast (left) and ensemble (right). The passage of the system is clearly visible in the pressure variable at 06 UTC on the 17th and in the associated precipitation (third panel, left), as well as in the drop in surface temperature and the high dew point (second panel, left). The gusts show a maximum of more than 40 knots (first panel, left). On the other hand, the third panel on the right shows how some member of the ensemble predicted a maximum of 55 knots in wind intensity for 04 UTC on the 17th.

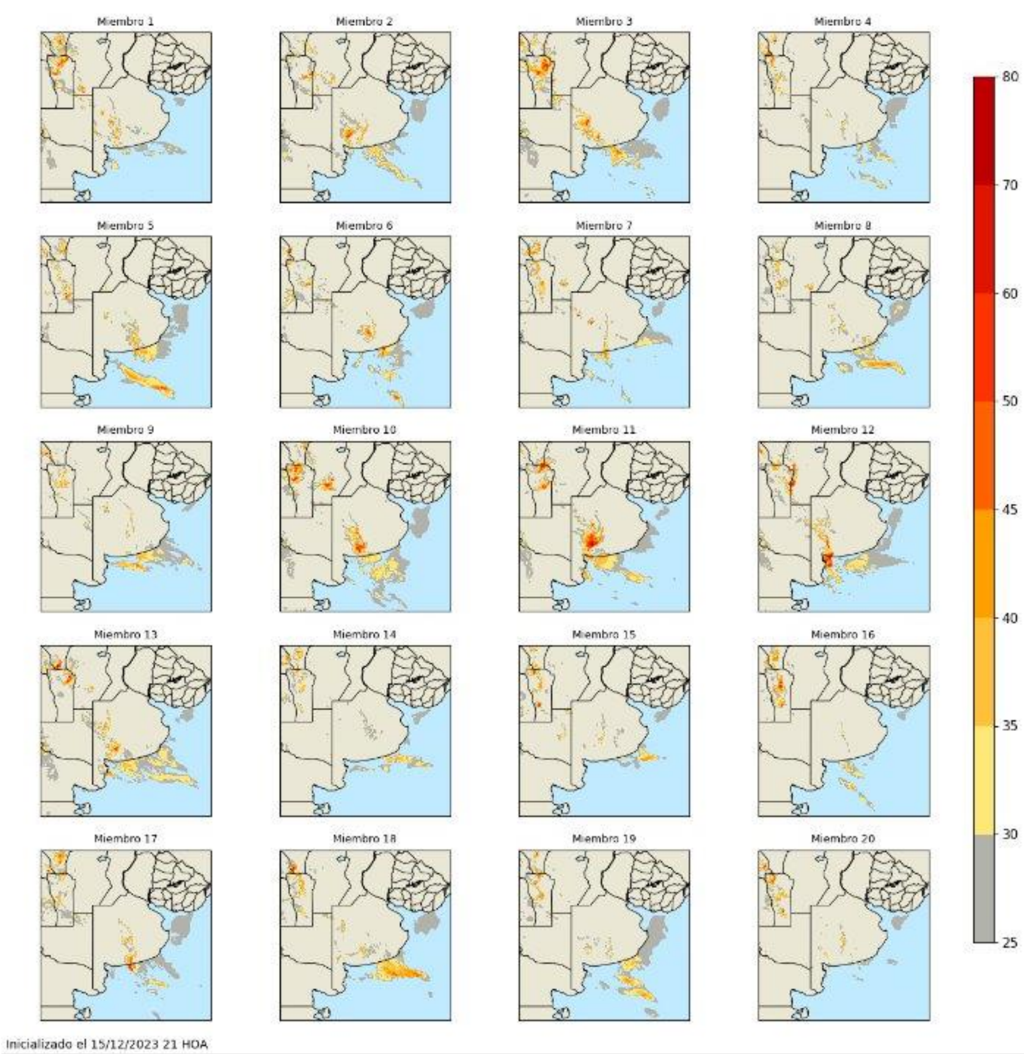


***Figure 25**: SAP.SMN-ENS 10 m wind magnitude forecasts valid for 16 December 2023 at 23 UTC and initialized on 16 December 2023 at 00 UTC.*

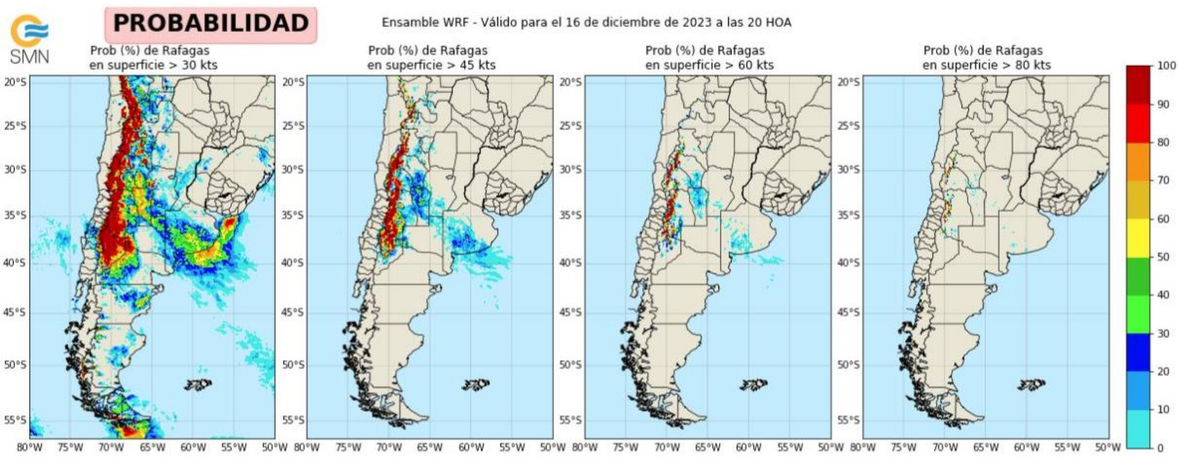


***Figure 26**: SAP.SMN-ENS forecasts of probability of surface gusts greater than 30, 45, 60 and 80 kts, valid for December 16, 2023 at 23 UTC and initialized on December 16, 2023 at 00 UTC.*

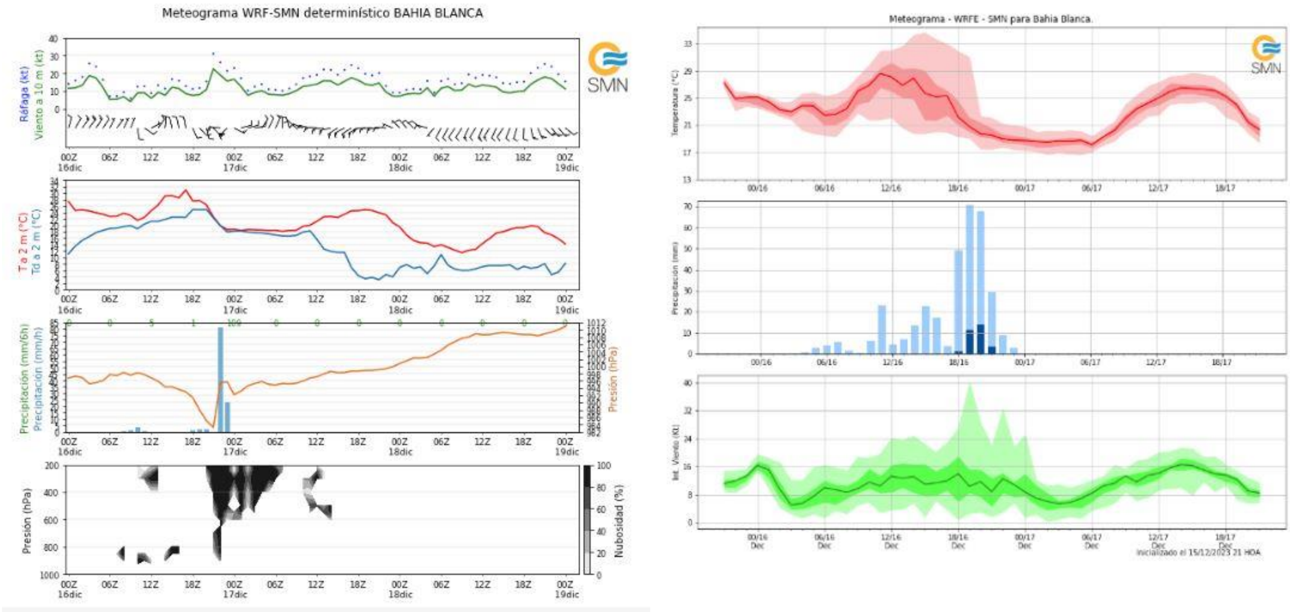


__Figure 27__: Time series for Bahía Blanca produced by SAP.SMN of different variables of the deterministic forecast (left) and ensemble (right). Both initialized on December 16 at 00 UTC.

(a) (b)

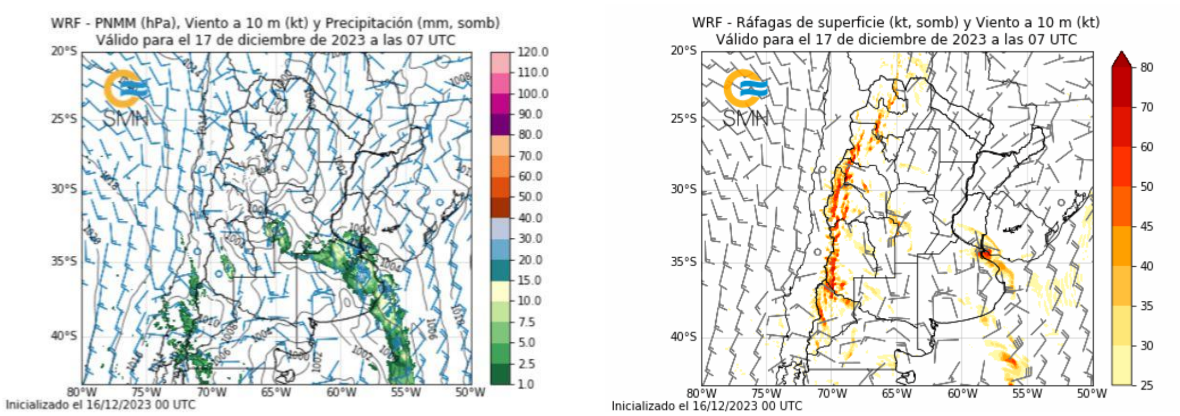


__Figure 28__: SAP.SMN-DET forecasts of precipitation, sea level pressure and 10 m wind (left) and surface gusts and 10 m wind (right), valid for December 17, 2023 at 07 UTC and initialized on December 16, 2023 at 00 UTC.

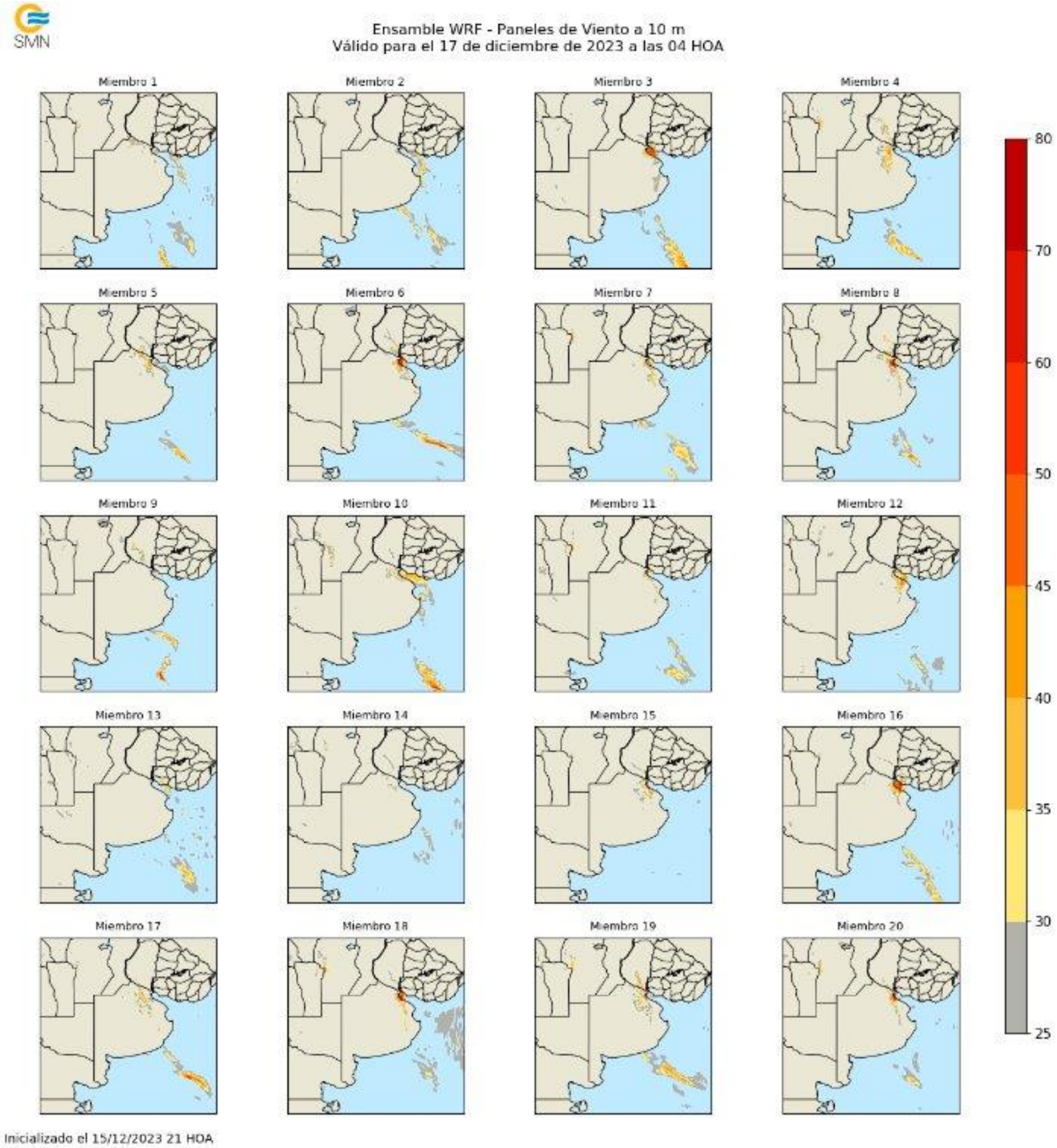


***Figure 29**: SAP.SMN-ENS forecasts of 10 m wind magnitude valid for 17 December 2023 at 07 UTC and initialized on 16 December 2023 at 00 UTC.*

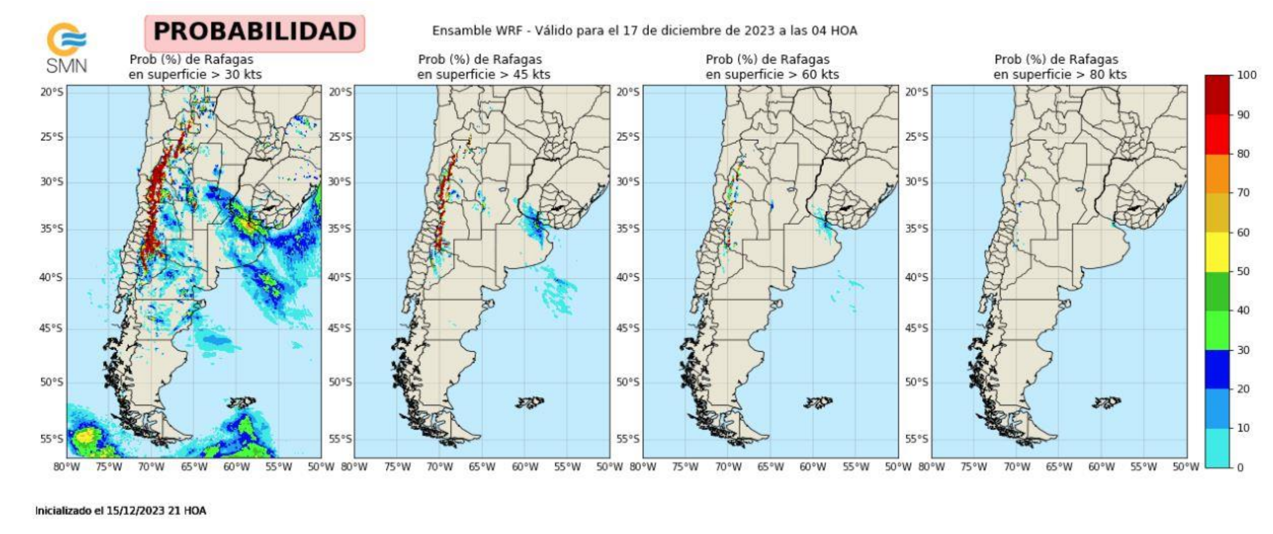


Figure 30*: SAP.SMN-ENS forecasts of probability of surface gusts greater than 30, 45, 60 and 80 kts, valid for December 17, 2023 at 07 UTC and initialized on December 16, 2023 at 00 UTC.*

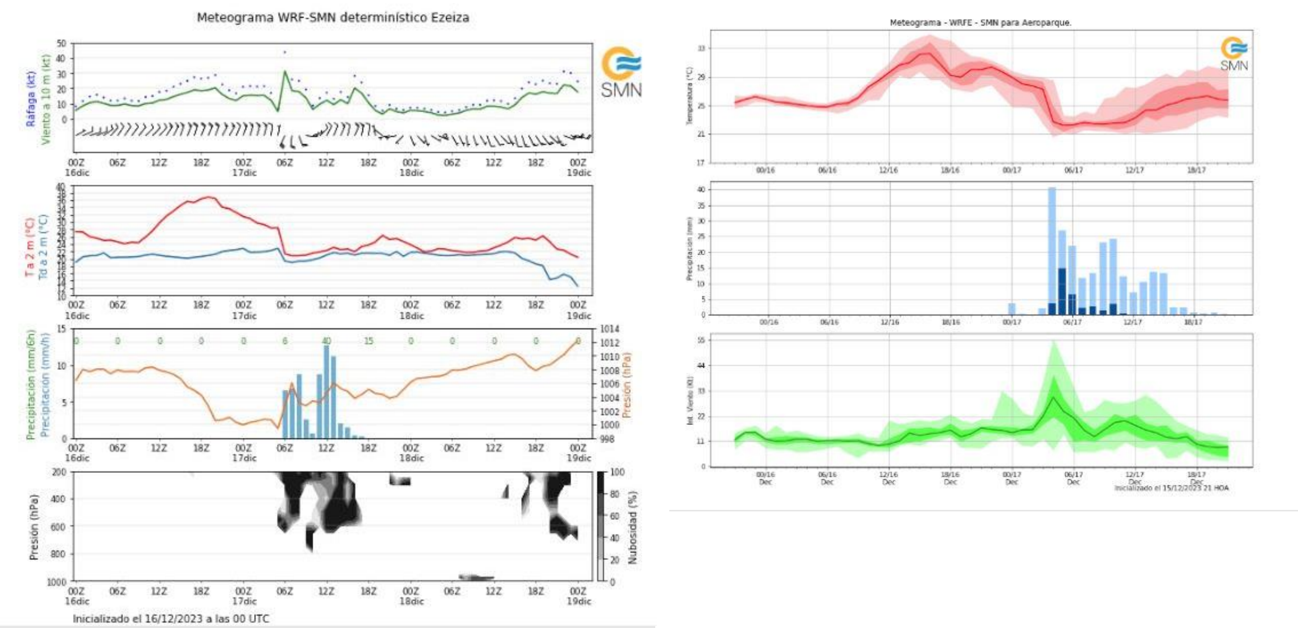


Figure 31*: Time series for Ezeiza produced by SAP.SMN of different variables of the deterministic forecast (left) and ensemble (right). Both initialized on December 16 at 00 UTC.*

4.2 The GFS model

4.2.1 City of Bahia Blanca

Figure 32 presents the deterministic GFS forecast fields at the approximate time of the event occurrence in Bahía Blanca. Panel (a) illustrates the forecast precipitation at 23 UTC. The convection zone is directed towards the southeast of the province of Buenos Aires accompanied by gusts greater than 45 knots (Fig. 32b). Note the difference between these spatial structures of gusts and those produced by deterministic WRF (Fig. 24b). Also, note that, in this case, both the precipitation and gust patterns are delayed.

(a) (b)

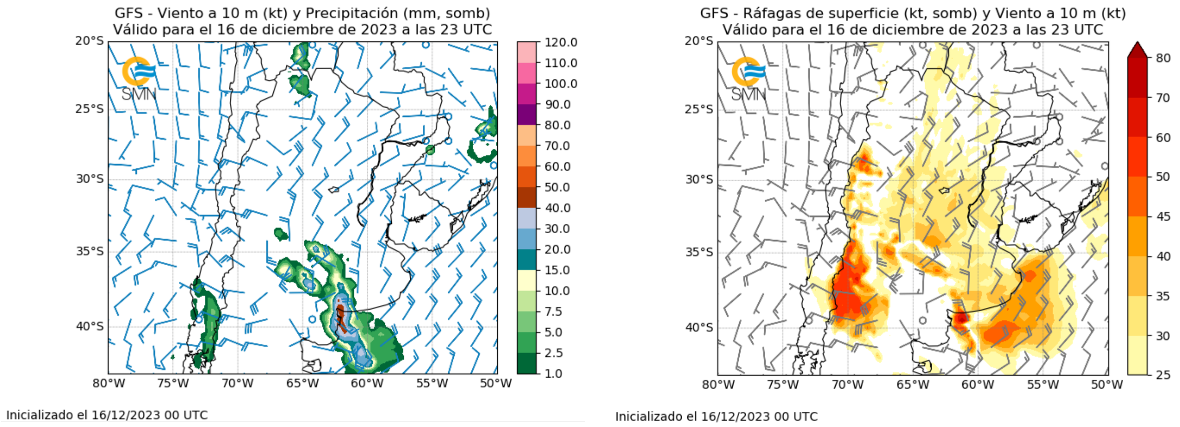


***Figure 32**: GFS forecasts of (a) precipitation, sea level pressure, and 10 m wind and (b) surface gusts and 10 m wind, valid for 16 December 2023 at 23 UTC and initialized at 16 December 2023 at 00 UTC.*

Figure 33 shows the wind magnitude at 10 m predicted by the 20 members of the GFS ensemble. It should be noted that they were used as initial and boundary conditions for the 20 members of the SAP.SMN-ENS illustrated in Fig. 25. In particular, the absence of gusts in the Bahía Blanca area can be seen in panel 9, while members 5, 6, and 7 show similar patterns. Member 12 shows the most intense case in the SAP.SMN-ENS version illustrated in Fig. 25, here it produces a milder wind intensity, which may be due to the lower spatial resolution of the model. It is important to note that these values refer to the 21 HOA, which does not imply that similar events were not predicted before or after.

Figure 34 shows the forecast probability of surface gusts greater than certain thresholds valid for 00 UTC on December 17. The area with a forecast probability of gusts greater than 45 knots is located east of Bahía Blanca, reaching values between 10-15% and zero probability of exceeding the upper thresholds.

Figure 33*: GEFS 10 m wind magnitude forecasts valid for 17 December 2023 at 00 UTC and initialized on 16 December 2023 at 00 UTC.*

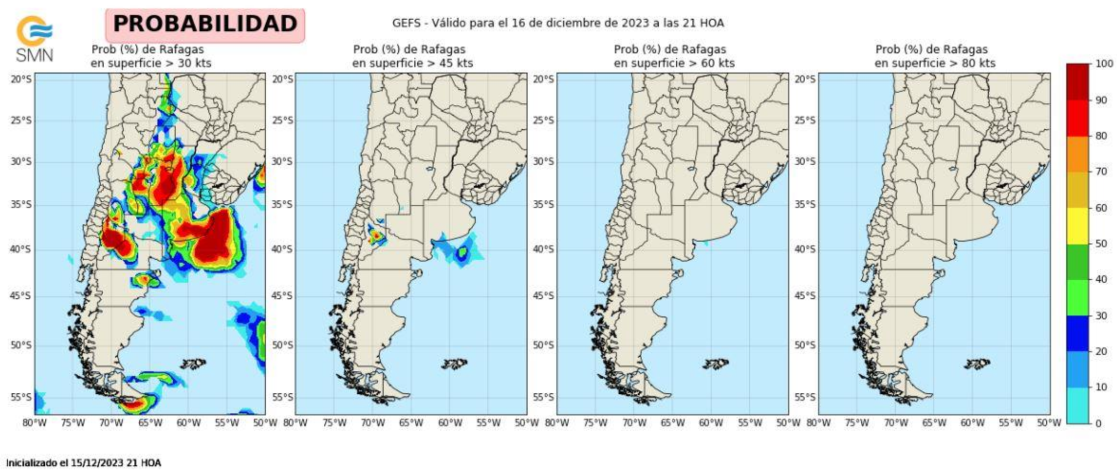


Figure 34*: GEFS forecasts of probability of surface gusts greater than 30, 45, 60, and 80 kts, valid for December 17, 2023 at 00 UTC and initialized on December 16, 2023 at 00 UTC.*

4.2.2 Metropolitan Area of Buenos Aires

Figure 35 presents the deterministic GFS forecast fields at the approximate time of the event occurrence in AMBA. Panel (a) illustrates the precipitation field together with the mean sea level pressure and the wind at 10 m, the latter being further behind in its displacement than that produced by the deterministic WRF (see Fig. 28a). The area of maximum precipitation is located over the center of the province of Buenos Aires and heads north of the province accompanied by strong gusts exceeding 40 knots (Fig. 35b). Note the difference between these spatial structures of gusts and those produced by the deterministic SAP.SMN, which are much more concentrated in the AMBA area (see Fig. 28b).

(to) (b)

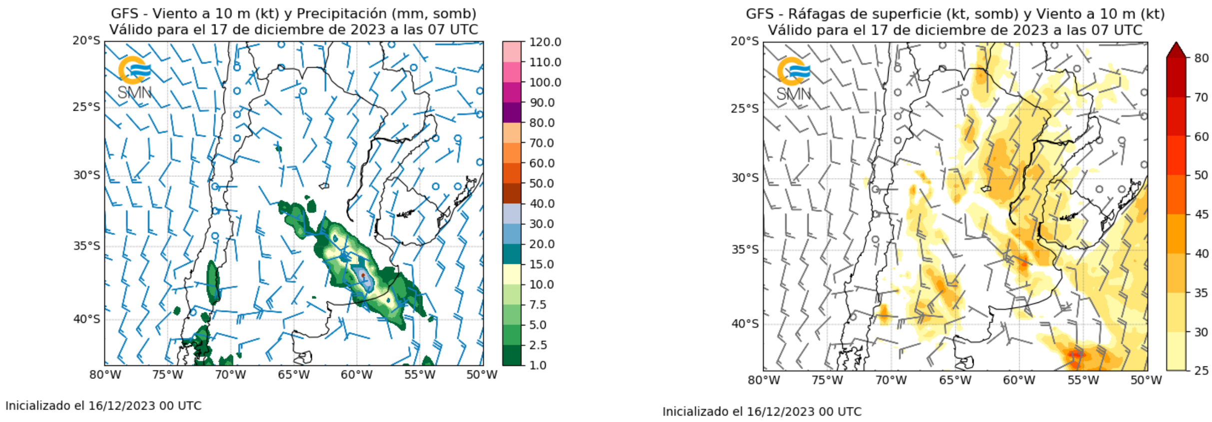


Figure 35: *(a) GFS forecasts of precipitation, sea level pressure, and 10 m wind and (b) surface gusts and 10 m wind, valid for 17 December 2023 at 07 UTC and initialized on 16 December 2023 at 00 UTC.*

Analyzing the wind magnitude at 10 m predicted by the GFS ensemble (Fig. 36) it can be seen that no member of the global model manages to predict strong winds over the AMBA area or its surroundings, unlike those shown by the SAP.SMN-ENS (Fig. 29). It should be noted that the forecasts of the GFS ensemble are available every 3 hours, so in this case the fields valid at 03 HOA are analyzed instead of 04 HOA as in the case of the SAP.SMN-ENS.

Figure 37 shows the forecasts for surface gusts in terms of probability. It can be seen that the probability of having gusts of more than 45 knots in the AMBA area is zero.

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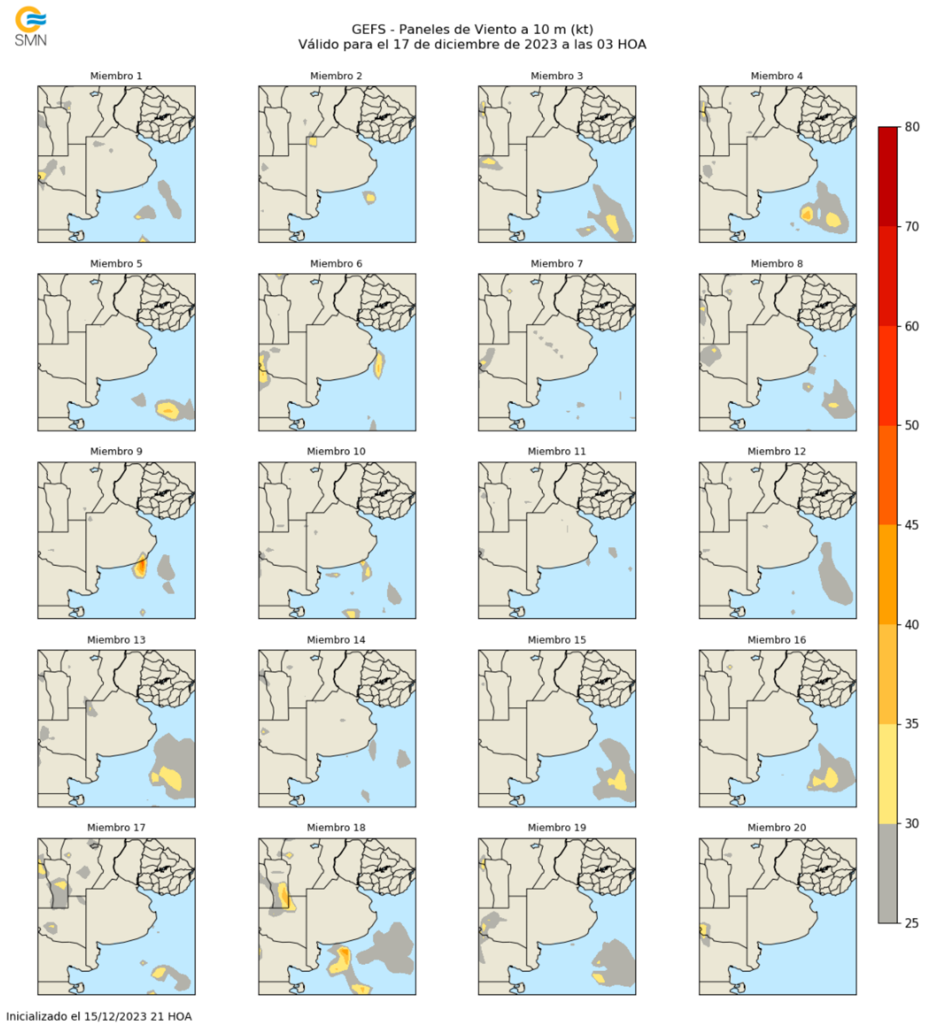

Figure 36: *GEFS 10 m wind magnitude forecasts valid for 17 December 2023 at 06 UTC and initialized on 16 December 2023 at 00 UTC.*

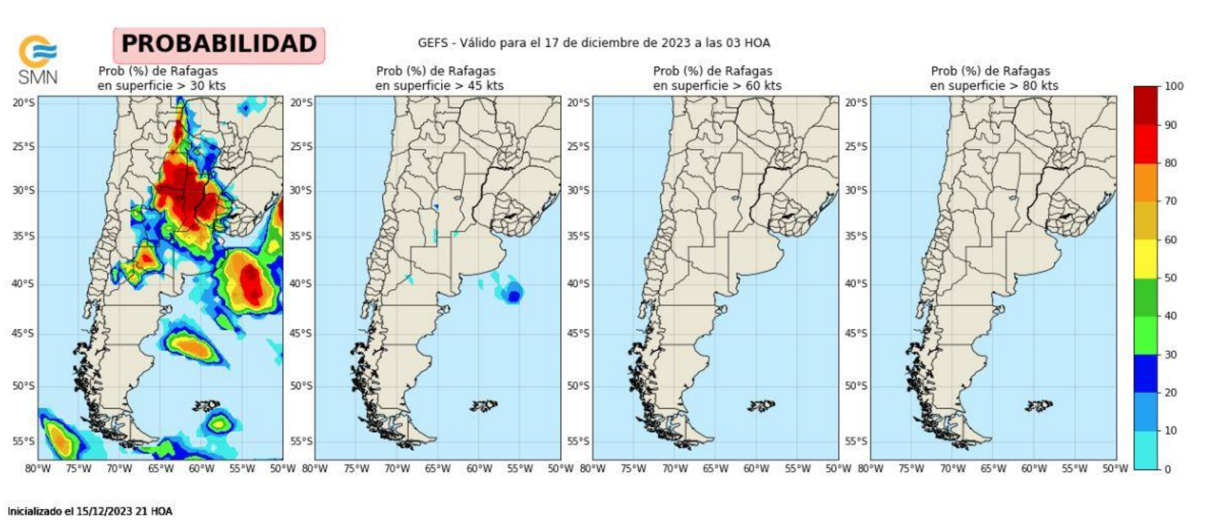

Figure 37: *GEFS forecasts of surface gust probability greater than 30, 45, 60, and 80 kt, valid for December 17, 2023 at 06 UTC and initialized on December 16, 2023 at 00 UTC.*

4.3 The IFS model

All ECMWF operational forecasts are derived from the Integrated Forecast System version 48r1 (IFS). It includes the global atmospheric and oceanic dynamical models and the data assimilation system. In particular, forecasts from the following components of the IFS were used for this work: the High Resolution Deterministic 10-day Forecast (HRES) and the Operational Ensemble (ENS). Information from the Extreme Forecast Index (EFI) and Shift Of Tails (SOT) indices, which account for the magnitude of the forecast extremes relative to the model climate, was also used. More information on the calculation of these indices can be found here.

4.3.1 City of Bahia Blanca

Figure 38 presents the accumulated precipitation (left) and instantaneous gust (right) fields valid for 23 UTC (20 HOA) on day 16. In the precipitation field it can be seen that the maximum of around 15 mm is located over Bahía Blanca with a more zonal spatial pattern and lower intensity than in the case of WRF (Fig. 24). On the other hand, the model fails to forecast gusts for the region of interest.

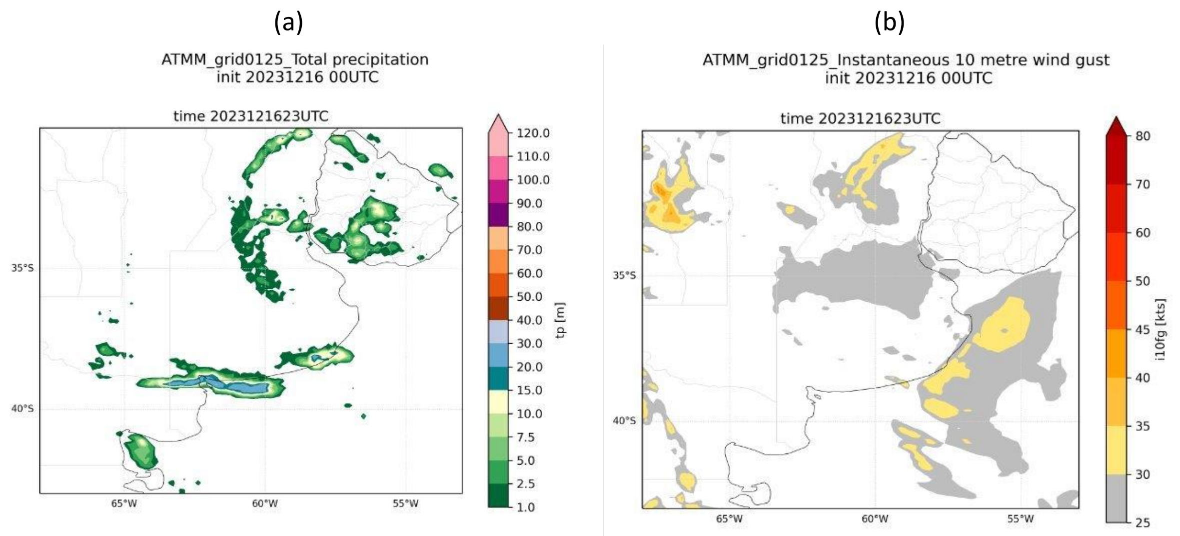

***Figure 38**: HRES forecasts of (a) precipitation and (b) surface gusts valid for 16 December 2023 at 23 UTC and initialized at 16 December 2023 at 00 UTC.*

4.3.2 Metropolitan Area of Buenos Aires

As for Bahía Blanca, Figure 39 presents the accumulated precipitation fields (left) and instantaneous gusts (right) valid for 07 UTC (20 HOA) on the 17th. In the precipitation field, the delay of the system in its approach to the AMBA can be seen, something also observable in the GFS (Fig. 35). The gust forecasts are not particularly observed over Buenos Aires, but are forecast towards the southeast with an intensity of 25 knots.

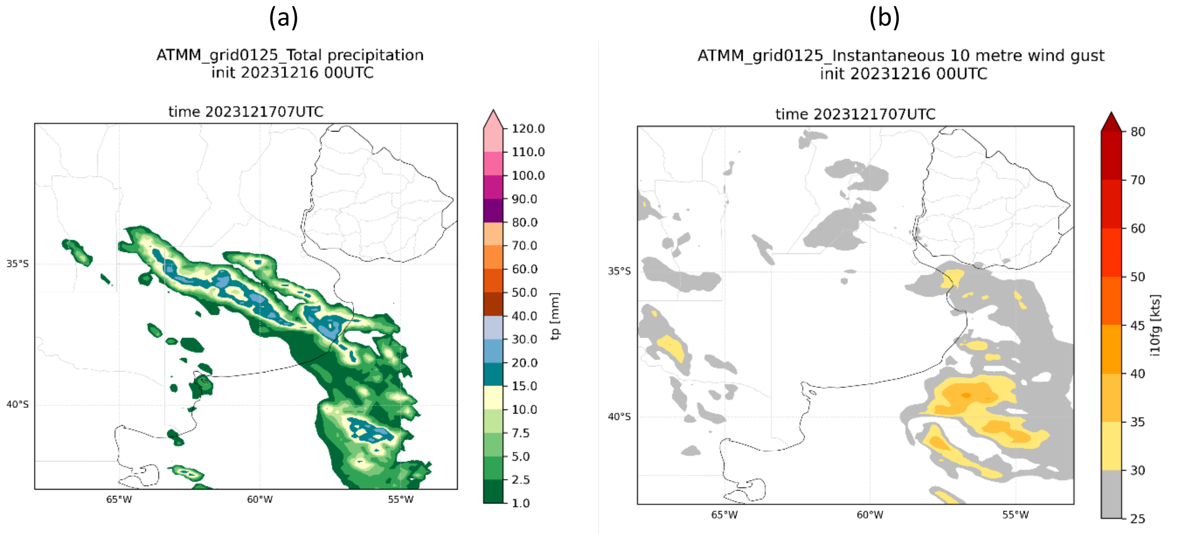

Figure 39: *HRES forecasts of (a) precipitation and (b) surface gusts, valid for 17 December 2023 at 07 UTC and initialized on 16 December 2023 at 00 UTC.*

4.3.3 Forecast overview

An analysis of the EFIs of different variables helps us to have an overview of the evolution of the forecast. This index, which takes values between -1 and 1, provides a measure of how extreme the forecast event would be with respect to the climatology of the model. The evolution of the fields of EFIs forecast for four successive days can be seen in Figure 40. The forecast is initialized on December 13 at 00 UTC and the EFIs of gusts, total precipitation, CAPE and CAPE-shear are shown, the latter being an indicator that combines both the available CAPE and the existing low-level vertical shear (see definition in Tsonevsky 2015). It also maintains a close relationship with the probability of hail and thunderstorm activity (see for example Battaglioli et al. 2023). It is important to note that EFI values correspond to extreme values for the day mentioned, for example, an EFI forecast of wind gusts valid for the 16th means that extreme gusts are forecast between the 16th and 17th.

It can be seen that by day 14, high CAPE and CAPE-shear EFI values were forecast, indicating convection over La Pampa, Córdoba and Entre Ríos, which was recorded during the days prior to the events in Bahía Blanca and Buenos Aires. Three days in advance, the CAPE EFI showed values greater than 0.9, covering almost the entire province of Buenos Aires, while the CAPE-shear EFI was restricted to the south, and in particular over Bahía Blanca. Likewise, the CAPE for precipitation also shows values greater than 0.8 over the Bahía Blanca region, although the CAPE for gusts shows a more advanced signal towards the north, which may be associated with the occurrence of a larger-scale northerly wind prior to convection. On the other hand, for day 17, maximum CAPE and precipitation EFIs are seen, but the CAPE-shear EFI reaches moderate values, such as the gust EFI.

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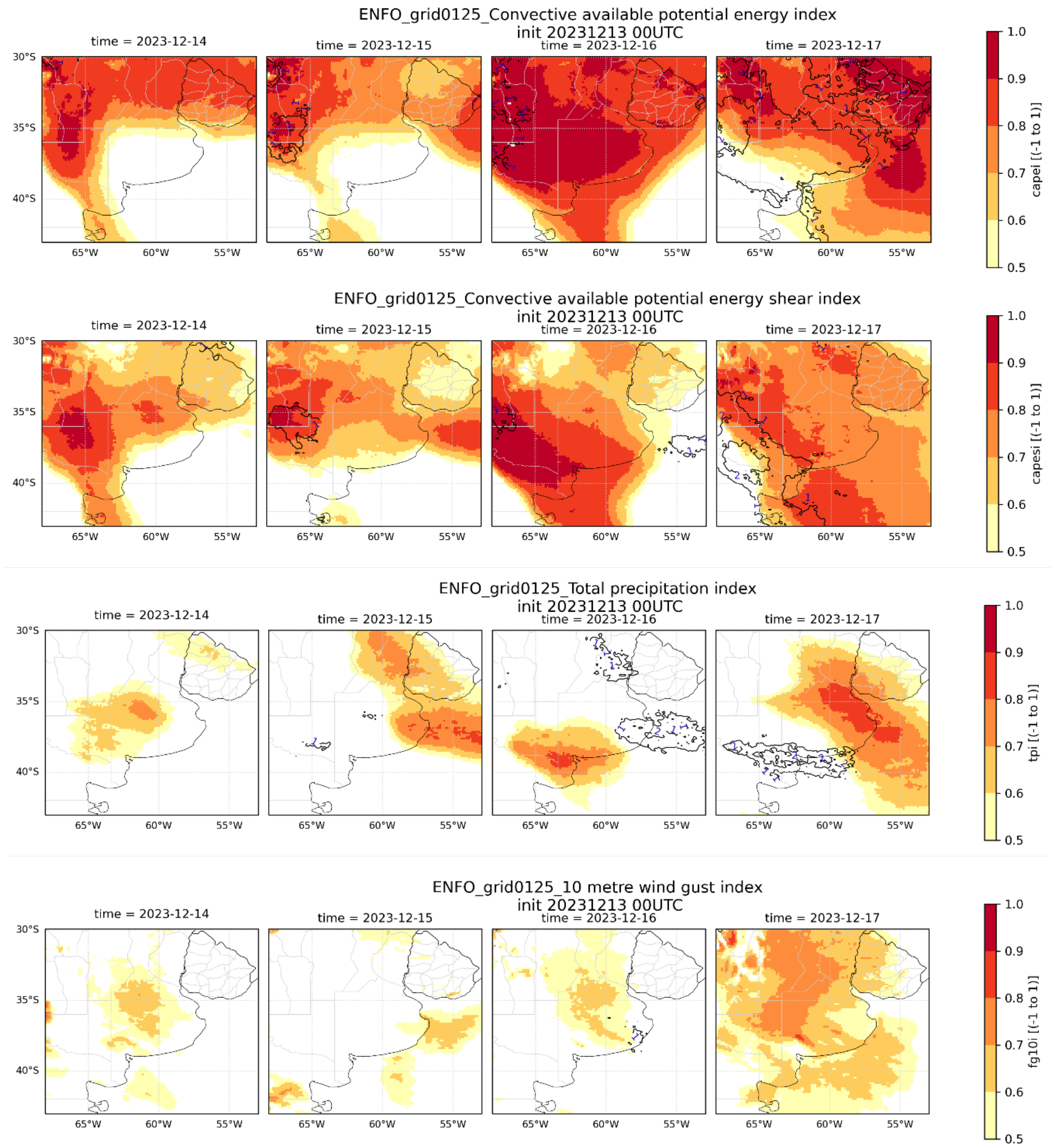


Figure 40*: EFIs of the CAPE, CAPE-shear, precipitation and gust variables (from top to bottom), from forecasts initialized on December 13, 2023 at 00UTC valid for four consecutive days December 14, 15, 16 and 17.*

4.4 Predictability analysis

Figure 41 shows the evolution of the EFI forecast based on different initialization dates. Since the EFI values are integrated over 24 hours and computed with an initialization at 00 UTC, in the case of Bahía Blanca the series is shown up to December 16th according to the time when the maximum wind and surface gusts were recorded. In contrast, for Ezeiza, a validity for December 17th at 00 UTC was considered since the greatest impacts were recorded during that early morning.

In the case of Bahía Blanca, it can be seen that the CAPE and CAPE-shear EFIs take values higher than 0.8 --and sometimes above 0.9-- indicating the possibility of occurrence of unusual extreme events forecast at least 6 days in advance. The precipitation signal is not as strong while the wind magnitude and gusts do not show a signal in any of the days prior to the event. In the case of Ezeiza, the CAPE and CAPE-shear EFIs and even precipitation are around 0.8 and the gust EFI, although lower, indicates a forecast of unusual gusts valid between December 17 and 18. It should be noted that these gusts do not necessarily refer to convective events, but were probably associated with the strong northerly wind prior to the passage of the front.

(to) (b)

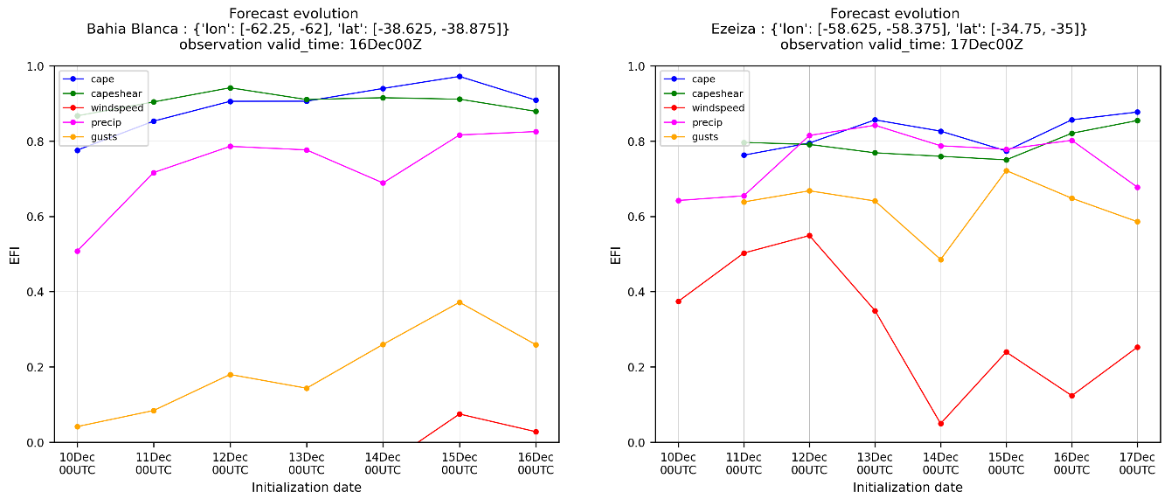


***Figure 41**: Evolution of the EFI forecast for different variables for (a) Bahía Blanca and (b) Ezeiza. The abscissa indicates the start day of the forecast, all of which are valid for the day of the event in the respective cities.*

Figure 42 shows the evolution of the CAPE-shear forecast over a week for December 16, when the events in the Bahía Blanca area were observed. It can be seen that a zone of maximum EFI was present since a week earlier in the same region without much variation, mainly in La Pampa and the south of the province of Buenos Aires. The general situation shows high predictability and the occurrence of important impacts in the area can be confirmed by comparing it with Figure 15.

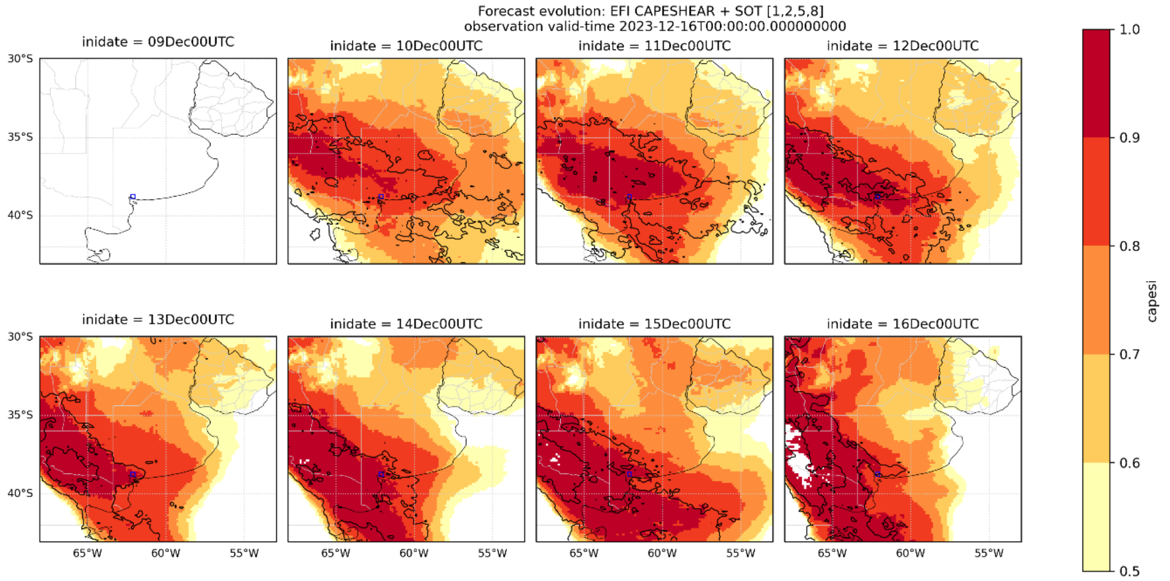


Figure 42*: Evolution of the forecast of EFIs and SOT (contours) valid for December 16 for CAPE-shear. Each field corresponds to a different initialization date.*

5. OFFICIAL FORECASTS OF THE SMN AND ITS GENESIS

5.1 Evolution of warnings

Below are the warnings issued for the town of Bahía Blanca and the AMBA for the meteorological event in question.

<u>Update Thursday 12/14 at 8:09 AM</u>

The area will be affected by rain and storms, some of which will be locally strong or severe. These are expected to be accompanied by intense gusts, hail of various sizes, electrical activity and, mainly, abundant rainfall. Accumulated precipitation values between 60 and 100 mm are expected, which may be exceeded at certain times.

Timeline for Bahia Blanca Saturday 16th

Tormentas	2023-12-14 08:09:15	Tranquilidad	Tranquilidad	Informate	Tranquilidad

Update Friday 15th at 07:02 AM

The area will be affected by rain and storms, some of which will be locally strong or severe. These are expected to be accompanied by intense gusts, hail of various sizes, electrical activity and, mainly, abundant rainfall. Accumulated precipitation values between 60 and 100 mm are expected, which may be exceeded at certain times.

Timeline for Bahia Blanca Saturday 16th

Tormentas	2023-12-15 07:02:37	Informate	Tranquilidad	Informate	Preparate

Timeline for CABA Sunday 17th

Tormentas	2023-12-15 07:02:37	Tranquilidad	Informate	Tranquilidad	Tranquilidad

Update Friday 15th at 19:05

Fecha de emisión: 15/12/2023 19:05h

Fecha de emisión: 15/12/2023 19:05h

The area will be affected by rain and storms, some of which will be locally strong or severe. These are expected to be accompanied by intense gusts, hail of various sizes, electrical activity and, mainly, abundant rainfall. Accumulated precipitation values between 60 and 100 mm are expected, which may be exceeded at certain times.

Timeline for Bahia Blanca Saturday 16th

Tormentas	2023-12-15 19:05:35	Informate	Informate	Preparate	Preparate

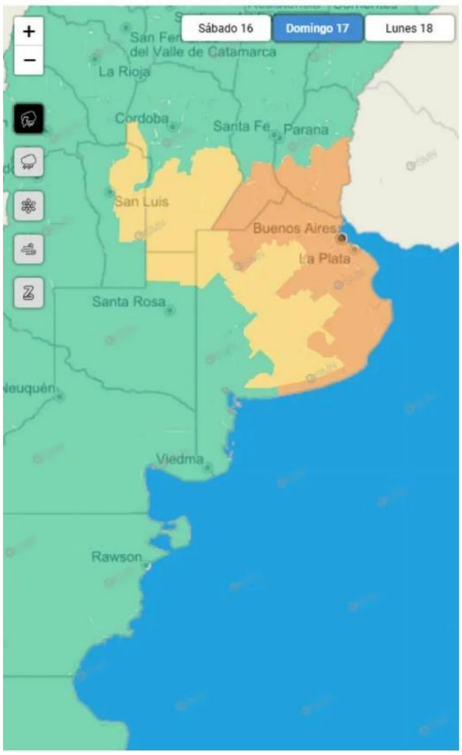
Timeline for CABA Sunday 17

Tormentas	2023-12-15 19:05:35	Informate	Informate	Tranquilidad	Tranquilidad

Update Saturday 16th at 07:03 AM

Fecha de emisión: 16/12/2023 07:03h

Fecha de emisión: 16/12/2023 07:03h



The area will be affected by rain and storms, some of which will be locally strong or severe. These are expected to be accompanied by intense gusts, hail of various sizes, electrical activity, and mainly abundant rainfall. Accumulated precipitation values between 40 and 100 mm are expected, which may be exceeded at certain times.

Timeline for Bahia Blanca Saturday 16th

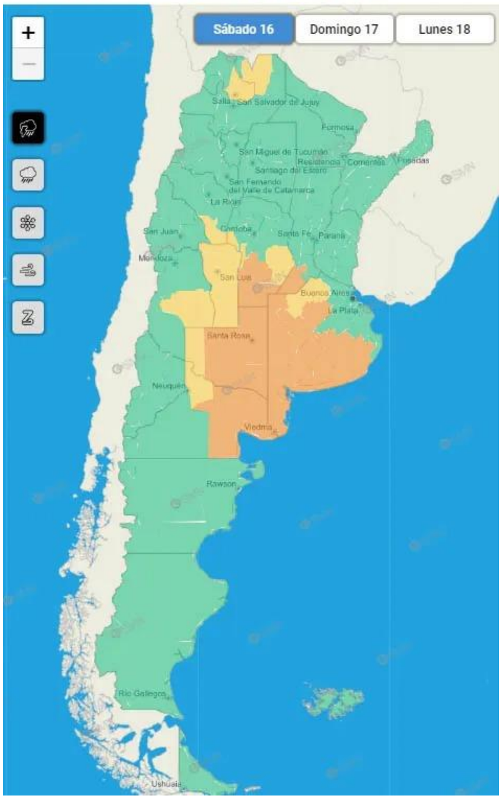
Tormentas	2023-12-16 07:03:35		Informate	Preparate	Preparate

Timeline for CABA Sunday 17

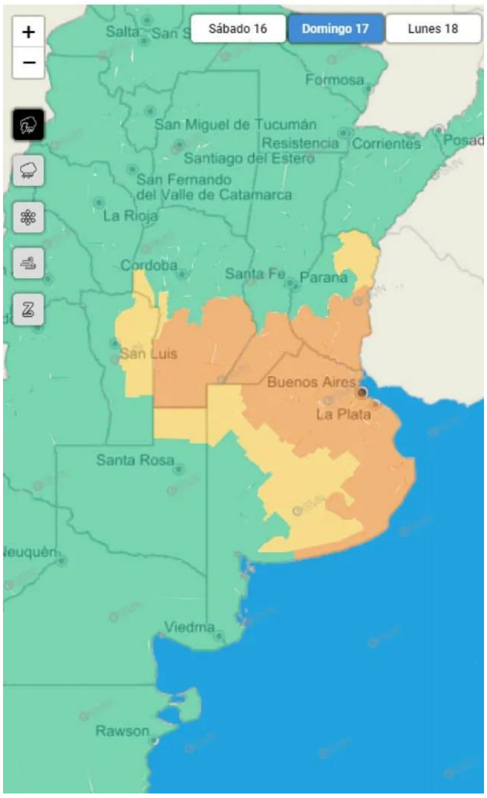
Tormentas	2023-12-16 07:03:35	Preparate	Preparate	Tranquilidad	Tranquilidad

<u>Update Saturday 16th at 17:44 HOA</u>

Fecha de emisión: 16/12/2023 17:44h



Fecha de emisión: 16/12/2023 17:44h



The area will be affected by storms, some of which will be locally strong or severe. These are expected to be accompanied by very intense gusts with speeds <u>that may exceed 100 km/h</u>, hail that could be locally very large, very strong electrical activity and abundant rainfall in short periods. Accumulated precipitation values between 70 and 130 mm are expected, which may be exceeded at certain times.

CABA timeline Sunday 17

5.2 From numerical forecasts to warnings

In order to gain an overview of the forecasters' experiences during the event, a dialogue was held six months after the event occurred. In general, post-event analyses are carried out immediately after the event and conclude with the production of a report. In this case, the idea behind this dialogue was to make explicit opinions that are taken for granted in discussions between forecasters, so that those involved in the case study have a clearer view of how the protagonists experienced the event and how they acted during the decision-making process.

—The situation that day was quite unusual for the month of December. There was a blocking in the northeastern part of the country and a trough was visible with a zone of maximum wind forecast for Saturday. We had already started to see this on Thursday. The situation was quite clear on Friday, and it was expected that some important event would happen in the province of Buenos Aires. We had already been issuing yellow alerts. Even the orange alert in Bahía Blanca came out well in advance, from Thursday to Saturday.

— *It would be interesting to know how you come to the conclusion that something was going to happen, and what kind of phenomena was going to take place*.

—We have several tools to be able to see if an event may be out of the ordinary, and one of them is the EFI[2]...

—We also look at routine charts, the ones we always use to get a general overview, which are the surface charts, 500 and 200 hPa. Regarding the EFI, we look at the EFI for precipitation, wind and snowfall.

—*Don't you look at CAPE's EFI?*

— Yes, but that is for something more specific, what I mentioned is more like giving a first overview. Even in the presentations we make every day, we look at the EFI; but not just for the next day, but we look at the EFI for 5 or 6 days. So, we are already forming an idea of where to look in the next few days. For example, if the EFI for four days is marking something, for us that is already a traffic light that turns on. So, for this event, that first signal was the EFI. Especially in December, because for that month it was a rather strange situation. The EFI signal suggested that there was going to be something, some abnormal precipitation phenomenon, but of course, we did not know how much. First there was a very strong signal from the EFI, even the north winds already had an EFI close to 1, that is, a strong advection of humidity. In fact, the 850 hPa charts showed a fairly marked tongue of humidity, reaching as far as central Buenos Aires, south of Córdoba, although not so far south as to touch Bahía Blanca. And then the EFIs also reflected the southerly winds after the event. Also a very intense signal; and of course we also saw very high precipitation EFIs from the south of Córdoba to Bahía Blanca and its surroundings.

—Yes, I think that in general terms the maps we saw showed something strong. Of course, defining what was going to happen specifically in Bahía Blanca was impossible. We knew that it was the area of the southwest of the province of Buenos Aires, including Bahía Blanca. Then the system swept north. The size of the affected area was a problem because we had to have the entire province either on orange or red alert.

—A positive element for this situation was that all the models we looked at - the GFS, the HRES, and the WRF - saw the situation quite well[3]. Perhaps they did not predict the maximum values at some places, but they saw everything quite well, the rapid advance, even the times at which they would occur. The forecast for CABA was quite good with the timing. It was a system that was advancing very quickly and yet all the models were following it quite well.

— *We have been studying the event, especially the passage on AMBA, and the HRES does not look so good. So, maybe you were paying more attention to the WRF, right?*

—We make the final decision with the WRF. We look at it in the roundtable we do every day for a horizon of 3 days, 2 days, 1 day; we even wait for the 12Z run, we don't stick to the 6Z run for the final decision.

[2]EFI is the acronym for the Extreme Forecast Index developed by ECMWF, see https://charts.ecmwf.int/?query=efi .

[3] It is interesting to note that in places like the Met Office there is personnel that provides feedback to forecasters on the quality of the models being used, allowing forecasters to give different weights to different scenarios proposed by the models. This capability is still under development at the Met Office, where forecasters use subjective criteria in decision making (see Brown and Buchanan, 2018).

— The GFS divergence chart showed, the huge divergence expected in height south of Córdoba and northwest of Buenos Aires, that is, further north than what happened in Bahía Blanca, but it was incredible how it showed divergence in height from the previous days. It is not useful for a specific forecast because it is a rather crude graph, but it gives you a signal, a very quick idea of where there will be events with very important convection.

— Regarding WRF, what exactly do you look at? Do you look at environmental variables, let's say the "ingredients", or do you look at variables that have a direct impact, such as gusts and reflectivity for example?

— We look at everything, but obviously we pay particular attention to both the gusts and the COLMAX (simulated reflectivity maxima). In particular when there is a chance that an instability line will form. What we have to be careful about, and it even happened in this situation that we are discussing, is that sometimes the pattern changes from one run to another...

— But in this case it was not surprising, since even the members of the ensemble were very different from each other. I understand that, for reasons of time, you tend to look mainly at the deterministic, but the panorama that the vision of the 20 members gave you is one of great heterogeneity, of great uncertainty in the location of the events. In some you had a line of instability in one area, in others isolated sectors of convection here and there.

—Yes, for example, the night before Friday to Saturday, the WRF at one point gave a convective system over the south of the province of Buenos Aires, which ultimately never appeared. And in the following run it was no longer there. Generally what I do is to check whether the global model supports it in that idea or not, because sometimes the WRF decouples, and if the global does not do that, I give it less confidence,

— Once you are confident that something is going to happen, that there is strong divergence in the upper levels, that everything is prepared for some strong convection to take place, what is the next step, to begin to describe what is going to happen during that alert? In this case, for example, it is said that there will be storms with winds of more than 100 km/h. How do you get to this point?

—First, once you have evaluated the event and you consider that it will be strong, you have to look at the thresholds that we have in order to decide what type of alert it is[4]. For an orange alert we are thinking of storms where there are gusts that are greater than 90 km/h. The case of storms and gusts is complex, because one thing is the expected post-frontal gusts, which are easier to predict, and another is the one associated with convection. It is more difficult there, one has to be looking at the sounding, the shear, etc. You are looking at the sounding of the previous day and the one of the day of the storm, but unfortunately in Bahía Blanca there are no soundings (although there are in Santa Rosa). And a special sounding was requested for 18Z in Santa Rosa and Aeroparque and then we asked for another one for 0Z in Aeroparque. When one foresees such important events, extra soundings are requested, which for budget or logistical reasons are not always available, but this time they were.

— Once you see the whole picture, the issue of the alert color appears. How do you resolve this point?

—When the situation is so clear and can be seen so far in advance, the first thing we do is paint it yellow three days in advance. This way, users will already have an idea that something serious could happen. Then comes the most delicate part of raising the alert to orange or red, which is a rather elaborate process

[4]See Saucedo et al. (2021), in particular their Fig. 4 and 5.

between those of us at SAT and the OVM corresponding to the region in question. In this particular case, the day before (December 16) I had spoken with Córdoba, because our doubt was whether we should put any red and where. At that time, the south of Córdoba and the northwest of Buenos Aires were where more water was accumulating in less time. I remember that they said "with orange we will be fine; in this area we will not reach the precipitation thresholds of red."

—Among the forecasters, when we make the shift, we check, so that you are not surprised by the presence of an orange storm, but, as we said before, we had been following it for four or five days. The one in Bahía Blanca was quite difficult. The WRF gave a fairly important signal there in the southwest of Buenos Aires and then it moved north,

—You decided that it should be orange. In other words, there is an orange alert covering an area larger than the province of Buenos Aires[5] for Saturday 16th in the evening and Sunday 17th in the morning. We talked about this with some of you and you mentioned the doubt at that time about whether it should be orange or red. Now, since there is no procedure that contemplates all the options, you cannot know after the fact if the choice of colors was the most appropriate or not. The area was so large that, if you make it red, there are many chances that there will be places where nothing or almost nothing happens. So, do you think that orange is the appropriate color when you have areas that would be red mixed with other green or yellow ones?

— It is very difficult to define the color because with which of all the parameters that define the storm could you define the color in the best way? With the storm winds, with the descending winds, with the existence of a *bow echo,* of an instability line, by the size of the hail, by the presence of electrical activity? These are all things that are very difficult to quantify on a simple map, in a field[6]. We use the accumulated precipitation as a proxy, *roughly speaking*, but then it is very difficult for an accumulated precipitation to reach those values in half an hour, which is about how long the storm lasted. I think that makes it very difficult to perfectly standardize the red in storms. In other phenomena everything is much more tangible, -- accumulated precipitation, synoptic wind, sustained winds, centimeters of snow -- everything is much clearer. But with storms it can be affected by the size of the hail, the electrical activity or the gusts after the storm. So it is very difficult.

—We also don't want to be exaggerated with the use of red, because that's how the public ends up losing confidence in the alerts. The red alert is very delicate. What's more, the procedure is different when it comes to communication with civil defense[7].

[5] Almost double that of the province of Buenos Aires, see section 5.1, update Saturday 16th in the afternoon, combining Saturday and Sunday.

[6] This coincides with comments in Brown and Buchanan, (2018): "There are multiple ways to infer thunderstorm risk from numerous parameters and so it is not appropriate to define events based on stringent thresholds. "

[7] It is important to note that the tendency to avoid red alerts is quite common in meteorological services. In some cases this position is explicit, such as Météo-France which has a “zero false alarm” policy for red alerts (see Gillet-Chaulet 2020). This position coincides with the general suggestions of the WMO (WMO 2018) on the need to minimize false alarms in warning systems.

5.3 Continuous monitoring by ACPs

Meteorological alerts are not the final instance of communication between SMN and users, but rather Very Short Term Meteorological Warnings (ACPs) are used for this purpose. These are issued in the form of polygons enclosing the area at risk, when phenomena such as strong or severe storms, winds or intense rains have been detected by instruments or eyewitnesses (for a detailed discussion of ACPs see San Martino et al. 2019, Ishikame et al. 2022, Saucedo et al. 2023, Lohigorry et al. 2024).

Figure 43 illustrates the evolution over time of the ACPs (polygons) and their color indicates the moment of their emission. Beyond their role as "last warning to the population" it is interesting to note that together they serve to confirm the area where phenomena judged significant by the forecasters of the *Coordination of Immediate Forecasts* were actually found. It is also interesting to compare the area covered by the ACPs in this figure with the evolution of alerts discussed in Section 5, in particular with the temporal evolution of impacts presented in Figure 18. In general, a good coincidence is seen except in the region of southern Córdoba, northern La Pampa and northwest of the Province of Buenos Aires where there were no ACPs. It should be noted, however, that southern Córdoba has poor radar coverage, which limits the emission of ACPs.

Although Figure 43 shows the ACPs as if they were identical, in practice the ACPs have their own identity depending on the most relevant meteorological factors that are warned about. Figure 44 shows the distribution of ACPs according to the threats that are warning about. The most important difference to note is between strong and severe storms, the latter being the highest level in terms of severity. In addition, it can also be seen that the most frequent ACP was *Strong storms, with intense rain, gusts and occasional hail* (perhaps the most standard of the warnings to describe convective events), but at the same time other more specific ones can be seen that, for example, do not contain warnings for hail, or for gusts or intense rain.

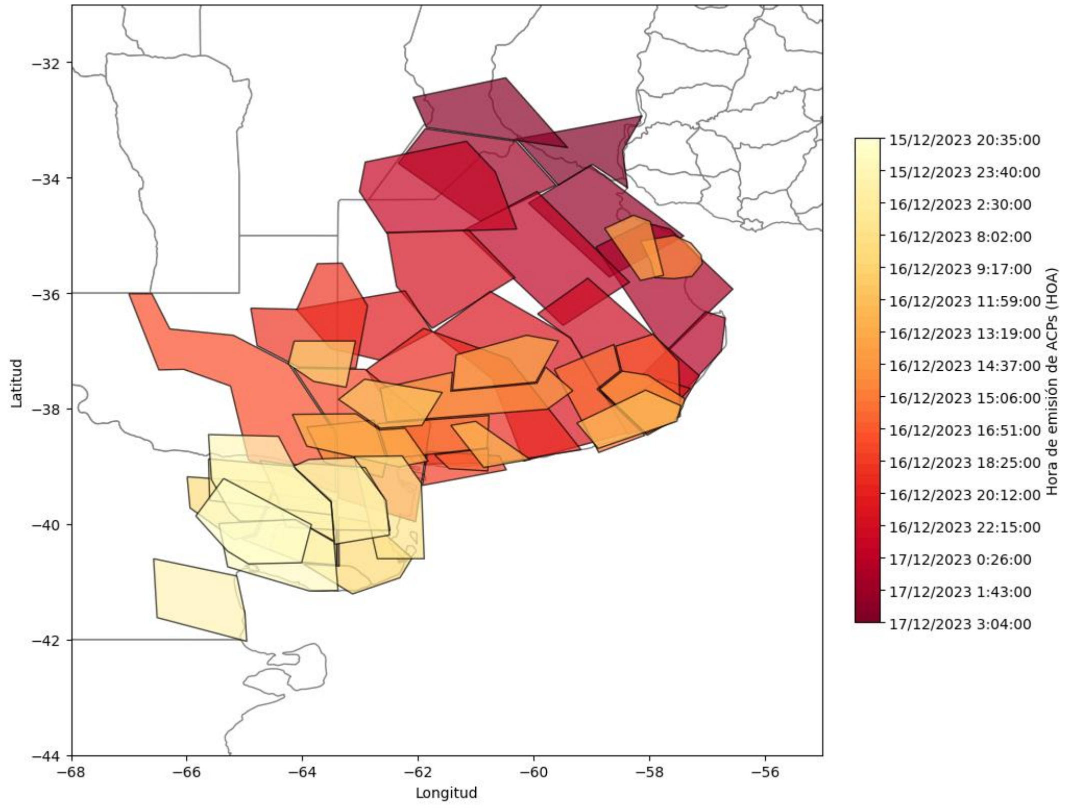


***Figure 43**: Evolution of Very Short-Term Weather Warnings (colored polygons) throughout the event. The color corresponds to the time at which they were issued (colored legend on the right).*

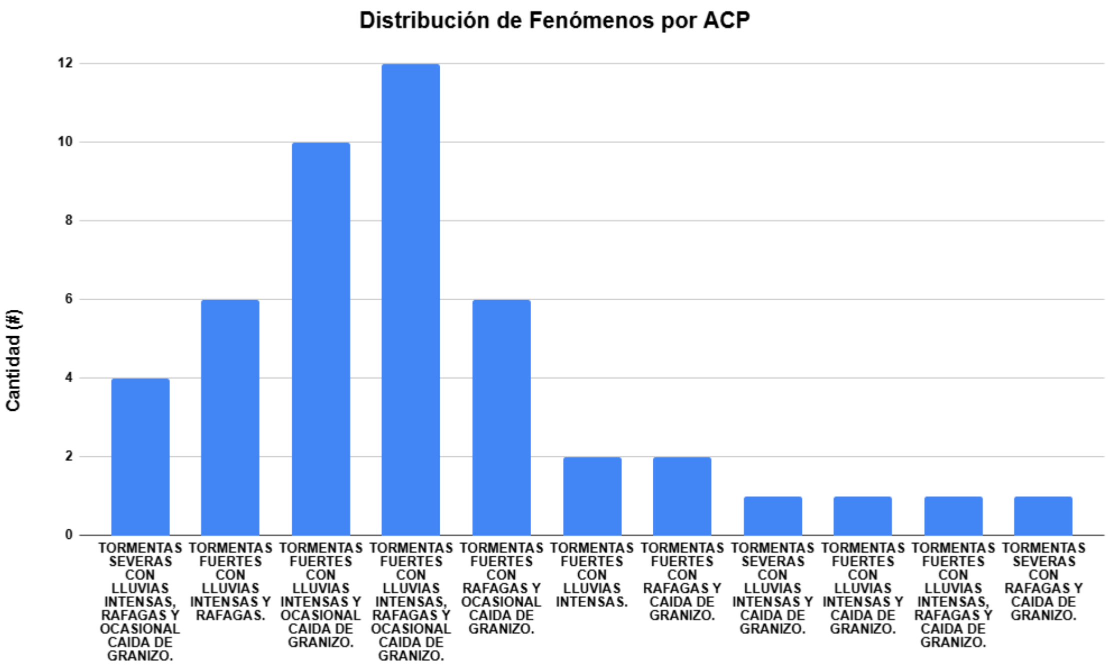


***Figure 44**: Distribution of ACPs according to the threats that the forecaster considers most important for each case.*

6. CONCLUSION

This Technical Note provides an integrated view of the multiplicity of elements that involve the SMN during the development of an extreme event. As can be seen, the mission of forecasting obliges the institution to provide as much information as possible regarding an event of this nature, monitor its progress, evaluate its impact and analyse the institutional performance at all stages a posteriori. This last stage is generally carried out without further in-depth analysis because the institution is already subject to new meteorological events that require its maximum attention.

The objective here was to use the extreme event to look deeper than usual and reveal elements that normally go unnoticed. The first thing to note is that, since many of the participants do not share activities on a daily basis, some of the topics discussed were new to several of them. For this reason we believe that this Technical Note can be a key text to understand the functioning of the institution, not only outside, but also for existing or new staff. The length of this work prevents it from being taken as a model for future event reports, however, it should serve to design an event report that is more automatic and complete than it is at present.

As can be seen, for the SMN an event exceeds the meteorological event itself. That is, the threat of a possible meteorological event - based on a variety of numerical forecasts - is already a "fact", in the sense that it sets in motion a number of measures. The threat studied here materialized in reality, but it could have been othewise, giving rise to a false alarm. For example, the storm over Bahía Blanca could have occurred outside the city, or over the sea, having a much smaller impact or having been weaker than expected.

Just as the appearance of a threatening numerical forecast is a "fact" in the SMN, it is also a "fact" in society when the SMN transmits this threat to the population. This fact ends when the meteorological event finally does not occur, or when the impact of this event is no longer discussed in the media. What is mentioned in this Technical Note has to do with different pieces of information that define an event in the SMN, from the prediction of a meteorological event to its consequences, if any.

In all the sections presented here, it was necessary to process information that is not normally used, for example, by using observations that do not belong to the SMN, by carrying out calculations with forecast data to which the SMN does not have access on a regular basis, and by obtaining impact information from other agencies or from the press. It would be of interest to the institution to analyse the need to have this type of information in a more fluid manner when making "conventional" reports to the public or the authorities, while it would also be important for the SMN to define in a more thoughtful way the structure that these reports should have and what discourse they should favor. For example, in the original report that followed the occurrence of this event, its evolution through observations and the relationship between these and the characteristics of the alerts were exclusively discussed.

This way of describing the event ignores the essential role played by numerical models in supporting decision-making regarding alerts, and the limitations of these models that can result in errors that partly explain the mistakes of forecasters when they occur. This perspective - which this Technical Note tries to avoid - carries significant risks for the institution because it makes it bear problems that do not belong to it. For example, the "low predictability" of an event - a problem intrinsic to its nature - can be read as "low expertise of forecasters" by society. In other words, the lack of reference to numerical forecasts naturally causes the forecaster to "appropriate" the events of low predictability and the uncertainty of the models.

To avoid this type of stance, this Technical Note presents an overview of the evolution of the forecast that serves as a basis for forecasters to support and explain the decision process on which they based their decisions. This would require a change in future reports on events that take place. For example, a pre-designed report "template" could be available. A key element of such a template would be to establish the position of the institution, which implies a structured speech that should mention the predictability of the event, in its general situation ("ingredients"), intensity, timing, macro, meso, and micro spatiotemporal location. In this sense, phrases such as those mentioned in Table VI could be used.

Table VI: *Examples of expressions that could be used in case study reports to facilitate the reader's understanding of the forecasting process and challenges.*

Role	***Text type***
Informing about the role of numerical models as source	"The models began to have a signal of the severe event from ..."
Illustrate that some predictions are accompanied by uncertainty	"The recorded event was of very low probability according to what the numerical models showed days before"
Issues of scale and their influence when forecasting	"The models gave an idea of the area where the events could occur, but not a precise location that would have allowed..."

The SMN has made an effort in recent years to make the issuance of alerts objective. As in many other institutions around the world, however, there is room for the subjective perspective of the forecaster on duty. This is the type of challenge seen in Section 5.2 where forecasters explain the decision-making process for issuing the alert. This process, complex and with high stress due to the implications of the decisions [8], is usually carried out behind closed doors, so this Technical Note offers a window into the type of discussion that takes place. Some elements of decision-making that could be improved can also be extracted from this interview. For example, regarding the type of alert that implies an event that would apparently bring severe weather corresponding to red alerts while in others it would correspond to yellow. Is red privileged as a measure of protection for the population or orange to avoid such conspicuous false alarms? The institution should define this type of eventuality more clearly so as not to unnecessarily transfer the inconsistency of the forecasts to the forecaster.

One clear element in regard to numerical forecasts is that, despite the great progress made by global models, regional modelling (WRF-SMN in this case) continues to have a key value when it comes to knowing the details of the forecast event. Global models, however, do a unique job of forecasting in advance the general situation (the "ingredients" needed for a particular phenomenon). This information on the general situation to come is already key information to warn the forecaster of the risks that this situation may entail. Then, closer to the event, the forecast of the regional model gives more precision on the possibly associated eventualities.

Despite the large amount of information compiled in this text, several points of interest were left out. Among the points that would be interesting to study in more depth is the use of the information provided by the SMN (alerts and ACPs) for decision-making, both by the population and by specific users and civil defenses.

[8]It is important to know that making weather forecasts in times of severe events is not a job for everyone and that few can withstand the stress, commitment and responsibility that it entails.

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Instructions for publishing Technical Notes

In the SMN there were and are a significant number of periodical publications dedicated to informing users about different aspects of the service's activities, generally associated with meteorological observations or forecasts.

There is, however, abundant written material of a technical nature that does not have an adequate communication vehicle since it does not fit into the publications mentioned above nor is it appropriate for scientific journals. This material, however, is essential to capture the activities and developments of the institution and for it to account for its technical production. It is important that the activities of the institution can be understood by simply looking at its different publications and the length of the documents should not be a limitation.

Those interested in transforming their work into Technical Notes can contact Ramón de Elía (rdelia@smn.gov.ar), Luciano Vidal (lvidal@smn.gov.ar) or Martin Rugna (mrugna@smn.gov.ar) of the, to obtain the WORD template that serves as a model for writing the Technical Note. Once the document is prepared, it must be sent in PDF format to the aforementioned emails. Before final submission, authors must find out the serial number that corresponds to their work and include it on the cover page.

The digital version of the Technical Note will be published in the Digital Repository of the National Meteorological Service. For any questions or queries, please contact Melisa Acevedo (macevedo@smn.gov.ar).