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Study of three days duration coupling between jets in South América

It can be understood by coupling between jets when Upper-Level Jet (ULJ) superimposes the Low-Level Jet (L LJ). The literature shows that such couplings tend to generate or intensify surface instabilities. Thus, the objective of this study was to analyze the synoptic configuration and the coupling between the jets associated with storms during the period of October 28-30, 2019, when instabilities hit southern Brazil causing intense precipitation and several damages. This work was carried out through the analysis of meteorological fields employing ERA5 reanalysis data and GOES-16 satellite imagery. The coupling between jets was verified in the three days of study. Upward vertical movements at 500 hPa was observed in the same area of occurrence of the upper level difluent flow, as well as an intense 850 hPa northerly flow, a large amount of moisture due to the action of the Northwestern Argentinean Low, and the presence of a frontal system between Uruguay and RS, except on the first day. Storms developed east (downstream) of the area where the coupling took place. The coupling was observed before and during the development of the mesoscale convective systems, and its dissipation occurred simultaneously with the storm. However, on the 30th, the peak of coupling did not occur together with the most intense phase of the system, it occurred before.

Keywords: Severe Weather; Low Level Jet; Jet Stream.

Estudo de acoplamento entre jatos com duração de três dias na América do Sul

Entende-se por acoplamento entre jatos quando o Jato de Altos Níveis (JAN) se sobrepõe ao Jato de Baixos Níveis (JBN). A literatura mostra que tais acoplamentos tendem a gerar ou intensificar instabilidades em superfície. Desta forma, o objetivo desse estudo foi analisar a configuração sinótica e o acoplamento entre os jatos associados a tempestades durante o período de 28 a 30 de outubro de 2019, quando ocorreram instabilidades que atingiram o sul do Brasil, causando precipitação intensa e diversos estragos. O trabalho realizou-se por meio da análise de campos meteorológicos usando dados de reanálise do modelo ERA5 e imagens do satélite GOES-16. Foi verificado acoplamento entre os jatos nos três dias de estudo. Foram observados movimentos verticais ascendentes em 500 hPa na mesma área de ocorrência do escoamento difluente em altos níveis, bem como um intenso escoamento de norte em 850 hPa, um grande aporte de umidade proveniente da atuação da Baixa do Noroeste Argentino, e a presença de um sistema frontal entre o Uruguai e o RS, exceto no primeiro dia. A leste (corrente abaixo) da área onde ocorreu o acoplamento houve desenvolvimento de tempestades. O acoplamento foi observado antes e durante o período de atuação dos sistemas convectivos de mesoescala, e a dissipação desse ocorreu simultaneamente com a tempestade. Contudo no dia 30, o pico de acoplamento não ocorreu junto a fase mais intensa do sistema, ocorreu antes.

Palavras-chave: Tempo Severo; Jato de Baixos Níveis; Corrente de jato.

Topic: **Meteorologia, Climatologia e Mudanças Climáticas**

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INTRODUCTION

Located in a subtropical climate zone, the Central-South region of South America (SA) is characterized by variability of meteorological systems that occur throughout the year, such as cold surges, squall lines, mesoscale convective systems (MCS), among others (GRIMM, 2009; REBOITA et al., 2012). This region presents well-defined seasons with little rainfall variation, the west of the southern Brazil is the location with the highest rainfall rates, ranging from 1050 to 1750mm annually (REBOITA et al., 2010).

In some regions of the globe, intense synoptic meridional flows are observed in the lower troposphere, around 1500 meters high. When such flow meet the criteria suggested by Bonner (1968) it is called Low Level Jet (LLJ). According to Paegle (1998) an LLJ appears east of an elevated topography, in SA it occurs east of Andes, presenting acceleration towards south (MARENGO et al., 2004). The SA-LLJ occurs throughout the year, however, it is an element of the monsoon system, transporting warm and moist air from the Amazon basin to the Paraná-Prata basin, favoring convective activity at the jet exit (MARENGO et al., 2002; NASCIMENTO, 2005). Salio et al. (2007) showed that during the warm seasons SA-LLJ contributes to the development of MCSs, mainly in northern Argentina, Paraguay and west of southern Brazil.

MCSs are cloud clusters, most of them convective with very cold tops, that is, with great vertical development. These systems are responsible for much of the rainfall occurring in the tropics and in many mid latitudes regions (HOUZE JUNIOR, 1993). The MCS convective cells can negatively impact society by causing floods, strong winds, thunderstorms and hail (WALLACE et al., 2006).

Synoptically, South American mid latitudes MCSs are generated by two continental low-pressure surface systems, Chaco Low (CL) and Northwestern Argentinean Low (NAL). CL is most easily observed at warm season, being generated by the release of latent heat due to the convection that occurs over the Chaco Plain, and generally develops to the north of the subtropical jet. The SA-LLJ's characteristic of transporting heat and humidity toward high latitudes tends to deepen CL and NAL (SALIO et al., 2002; SELUCHI et al., 2012). Unlike the origin of CL, NAL is usually located closer to the Andes, being influenced by transient systems and orography (ESCOBAR et al., 2012).

At mid latitudes, near the tropopause, an almost horizontal narrow band of intense wind is observed, called the Upper Level Jet (ULJ), or simply jet stream. This phenomenon is often related to events of intense convection, since it is directly associated with baroclinic systems such as extratropical cyclones and frontal systems (ESCOBAR, 2009; FEDOROVA et al., 2017). Diffluence conditions in the flow of ULJ lead to an increase in air evacuation, mass divergence at upper levels and convergence at lower levels, which tends to intensify surface instabilities (BLUESTEIN, 1993; SANDERS, 1993).

Cassol Machado et al. (2019) observed a diffluent flow at upper levels associated with a case of intense precipitation in Rio Grande do Sul State (RS), in which some cities recorded values above 100mm in a few hours. Lara et al. (2019), in a study on tornado cases in RS, also observed upper-level difluence associated with an event in Tapejara-RS, and in Canela-RS a coupling between jets was verified.

Uccelini et al. (1979) observed convective instabilities developing under situations of coupling between the jets, and that the orthogonality of the axes would result in greater conditions for the formation of storms due to cold advection from the jet stream superimposed on the heat transport from LLJ (NASCIMENTO, 2005). Through numerical simulations of a storm case, Brill et al. (1985) identified a transverse circulation at the jet stream exit due to the ageostrophic wind. Such circulation was directly associated with the LLJ. A similar behavior was observed by Sortais et al. (1993). The overlapping of the jet axes suggests an intense vertical wind shear, resulting in a strong convective instability crucial to the formation of MCS.

Thus, the objective of this work is to analyze the synoptic environment, with coupling between jets, related to the storms that hit southern Brazil causing several damages between October 28 and 30, 2019. The knowledge of this phenomena is an important additional tool to understand the behavior of convective systems in southeastern SA.

METHODOLOGY

The case was analyzed using reanalysis dataset from ERA5, the fifth generation of reanalysis from the European Center for Medium-Range Weather Forecasts (ECMWF)[1] (HERSBACH et al., 2019). ECMWF reanalysis data is widely used in meteorological studies. For example, according to Montini et al. (2019) the ERA-Interim reanalysis, a version prior to ERA5, showed the best results in LLJ estimate compared to other reanalyzes. The ERA5 data provides hourly variables on a 0.25° spatial resolution and 137 vertical levels.

Convective instabilities were identified in the thermal infrared channel imagery from GOES-16 (Geostationary Operational Environmental Satellite 16), obtained from the DSA/INPE (Division of Satellites and Environmental Systems/National Institute for Space Research) website[2]. Accumulated precipitation data was obtained from the INMET (National Institute of Meteorology) meteorological stations network, via web[3].

The LLJ was identified according to basic criteria from Bonner (1968), adapted by Salio et al. (2002), that is, the 850 hPa wind must exceed 12 m s^{-1} and the meridional (southward) component must be greater (in modulus) than the zonal. However, the vertical wind shear criterion (6 m s^{-1} between 850 and 700 hPa) was not considered, so that cases like the one presented in Oliveira et al. (2018) are not discarded. ULJ was identified when the mid latitudes 250 hPa wind is greater than or equal to 30 m s^{-1} (REITER et al., 2005).

The coupling field was obtained from the difference in degrees of the directions of the jets, calculated at the grid points where the UJL overlaps the LLJ, that is, when the coupling occurs. The difference in degrees between them is subtracted 90°, therefore the smaller the value of the coupling field, the more orthogonal (more intense).

RESULTS AND DISCUSSION

On 28 October 2019

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[1] https://cds.climate.copernicus.eu/#!/search?text=ERA5&type=dataset

[2] http://satelite.cptec.inpe.br/acervo/goes16.formulario.logic

[3] https://tempo.inmet.gov.br/PrecAcumulada

In the mean sea level pressure field at 09 UTC 28 October 2019 (Figure 1A) the NAL is observed over northern Argentina, extending an inverted trough over RS and Uruguay, contributing to the intensification of the LLJ, as indicated by Seluchi et al. (2012).

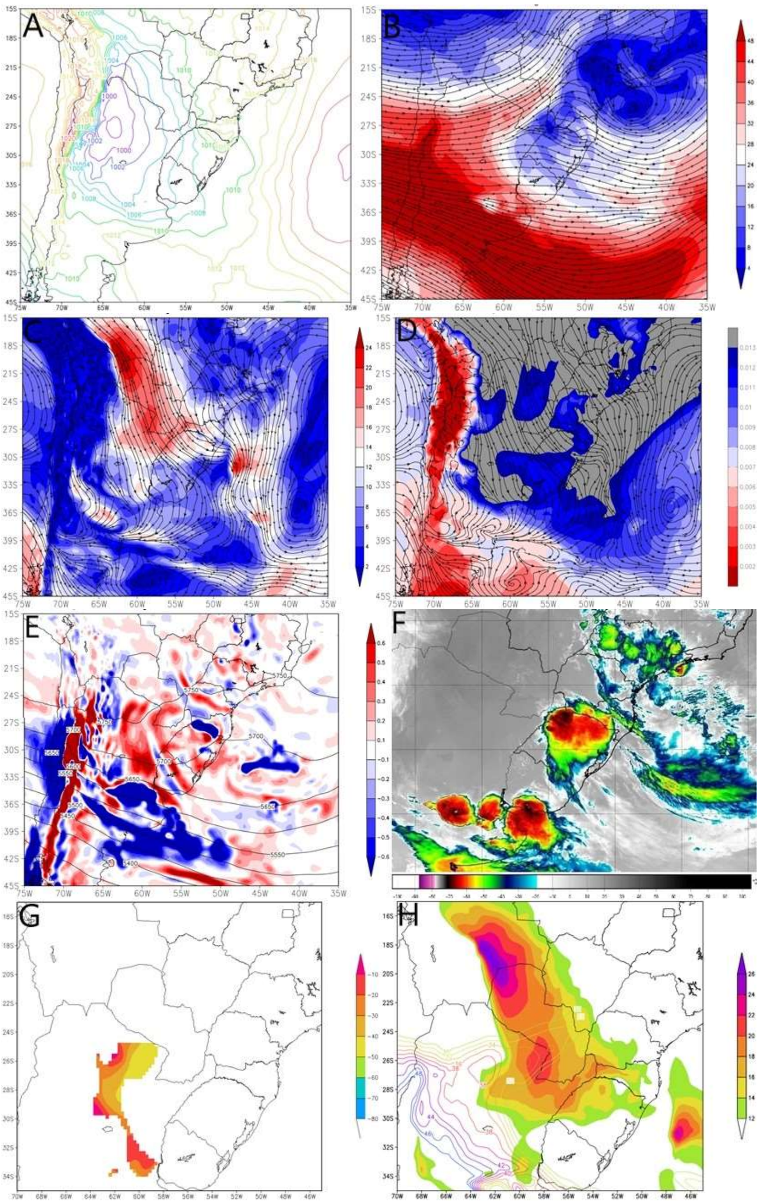

Figura 1: Fields for 10/28/2019 at 09 UTC. A) Mean Sea Level Pressure (hPa). B) 250 hPa streamlines (contour) and wind strength (shaded) (m s^{-1}). C) 850 hPa streamlines (contour) and wind strength (shaded) (m s^{-1}). D) 850 hPa streamlines (contour) and specific humidity (shaded) (g kg^{-1}). E) 500 hPa geopotential height (contour) (mgp) and omega vertical velocity (shaded) (Pa s^{-1}). F) GOES-16 infrared image. G) Coupling between jets (degrees). H) LLJ (shaded) and ULJ (contour) strength (m s-1).

A 250 hPa diffluent flow over the north of RS and west of SC was observed, from the moment of formation of MCS (not shown) until the moment of greater intensity of the system (Figure 1F).

Figure 1C shows an intense core (more than 20 m s^{-1}) of 850 hPa northerly wind over northern Paraguay, extending less sharply to the west and north of RS, indicating the occurrence of LLJ. This northern flow represents the transport of warm and humid air from the Amazon basin, providing support for the formation of storms. With part of this north flow converging on the north and west of RS, a large amount of humidity at low levels is observed over the region (Figure 1D), favoring the origin of surface instabilities.

Several works, such as Teixeira et al. (2007), Riquetti et al. (2018), Caballero et al. (2018) and Dorneles et al. (2020), indicate the association between LLJ-NAL (or LLJ-CL in the summer) with events of intense precipitation in the southern Brazil.

A small amplitude ridge extending onto RS (Figure 1E) is observed in 500 hPa, along with high thickness values (around 5750 mgp, not shown here), indicating a more unstable atmospheric layer due to warm air. The omega field (Figure 1E) shows localized intense upward vertical movement over the region at the same moment of greatest SCM intensity (Figure 1F).

The strength of the jets (Figure 1H) indicate great vertical shear (mainly within the coupling) before (not shown), during (Figure 1G) and after (not shown) system occurrence, presenting values closer to orthogonality (0º) during the most active phase of the MCS (Figure 1F), although the MCS was located downstream (east of) the coupling. According to 24-hour accumulated precipitation data maps from INMET, the northern half of RS showed several points above 50 mm on October 28, 2019, mainly in the west, with points above 80 mm.

On 29 October 2019

The following day, the inverted trough over the RS associated with NAL can still be seen. However, on the border with Uruguay there is a frontal system from an extratropical cyclone in Atlantic. The southern flow (Figure 2C) from the cold branch of frontal system and the northern flow from warm branch contributed to the instability growth. The difluence of upper levels flow persisted throughout the morning of the 29th. At low levels the continuous presence of LLJ is perceived, transporting warm and moist air to RS (Figure 2C), collaborating with the high specific humidity at 850 hPa over the entire border of RS with Uruguay and Argentina (Figure 2D).

There is a ridge at 500 hPa over southern Brazil associated with low levels warm air flow, indicating an unstable atmosphere, where intense upward movements (Figure 2E) led to the boost of the difluence already established at 250 hPa (Figure 2B). The enhancement of surface instabilities configured an SCM with greater intensity than the previous day (Figure 2F). These mesoscale systems caused significant precipitation in the southern half of RS, with values above 30 mm according to INMET precipitation maps.

There were small coupling cores between 03 and 12 UTC, since at 03 UTC there was the formation of a first MCS, intense, but which reached an area smaller than the second one. However, here the 09 UTC image is shown because it is the moment with the greatest coupling (Figure 2G) and the greatest system intensity (Figure 2F).

As in the previous day, the coupling occurred between the exit of LLJ and the tropical sector of ULJ, and upstream the MCS (Figures 2 F-H). The high strength of the jets indicate a strong vertical wind shear, which implies intense convective activity, an important factor for the formation of the two convective systems (not shown) observed on the 29th.

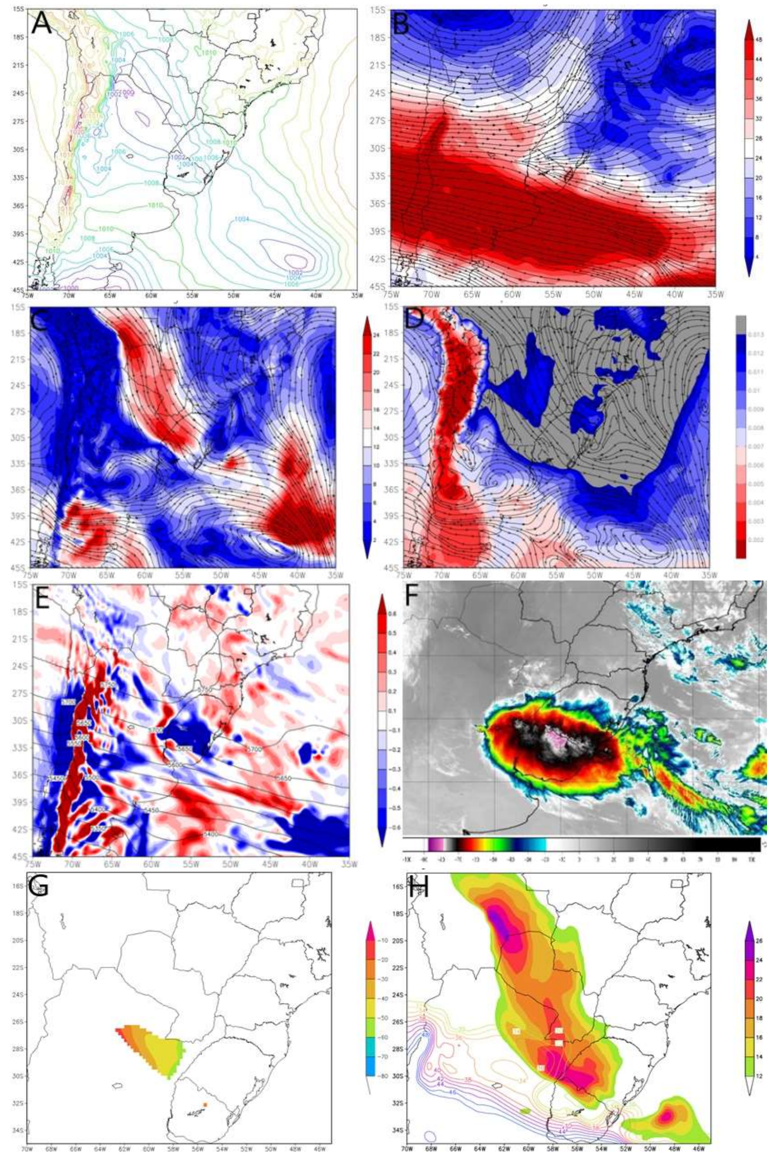

Figura 2: Fields for 10/29/2019 at 09 UTC. A) Mean Sea Level Pressure (hPa). B) 250 hPa streamlines (contour) and wind strength (shaded) (m s^{-1}). C) 850 hPa streamlines (contour) and wind strength (shaded) (m s^{-1}). D) 850 hPa streamlines (contour) and specific humidity (shaded) (g kg^{-1}). E) 500 hPa geopotential height (contour) (mgp) and omega vertical velocity (shaded) (Pa s^{-1}). F) GOES-16 infrared image. G) Coupling between jets (degrees). H) LLJ (shaded) and ULJ (contour) strength (m s-1).

On 30 October 2019

On October 30 the synoptic environment remains with little change, with the inverted trough associated with NAL over RS and the cold front moving away from the continent (Figure 3A).

On this third day of analysis, upper-level difluence was observed until the morning (Figure 3B), intensifying at the exact moment of greatest surface instability (Figure 3F). At low levels, the LLJ continues to influence the high values of specific humidity in the region (Figures 3C-D).

Such difluence is a consequence of intense upward movements, which in turn are associated with a warm layer, as indicated by the persistent ridge at 500 hPa (Figure 3E). Figure 3F shows the formation of a new MCS, elongated type, similar to the one on the 29th, which lasted for several hours in southern Brazil. This system caused heavy rain in the southern half of RS, with values above 50 mm, especially in the Campanha region (80 mm).

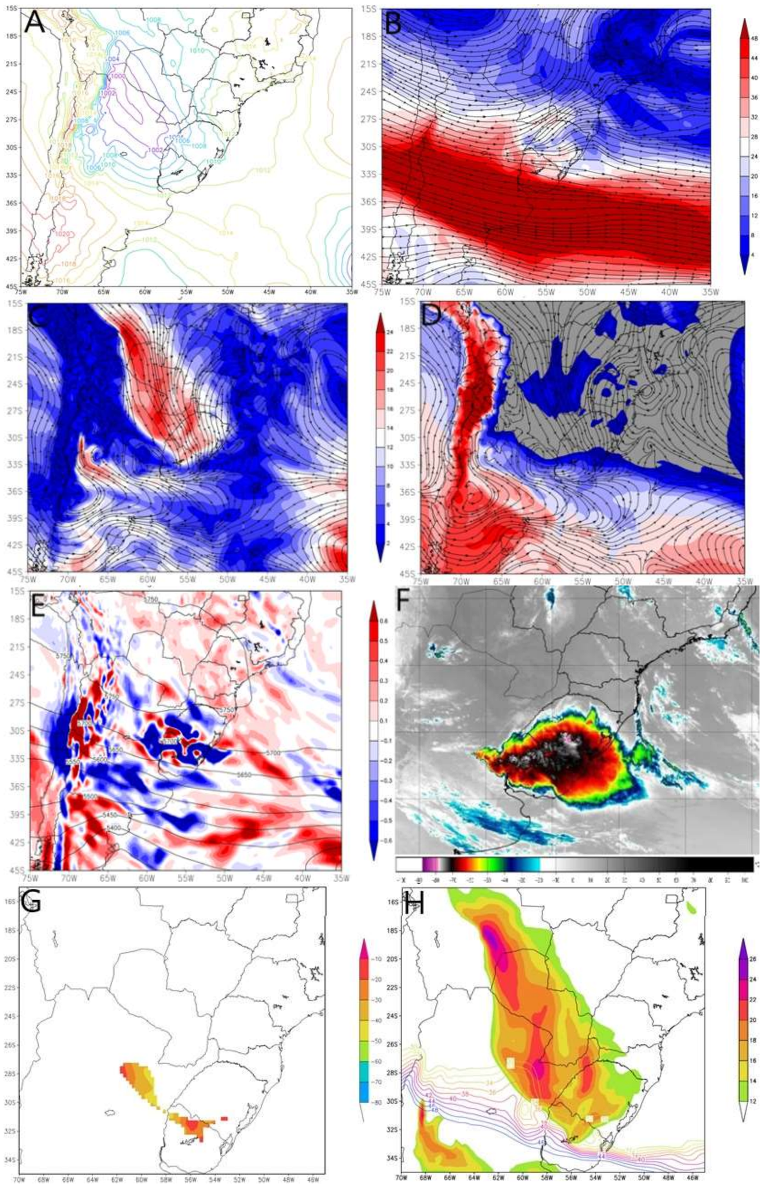

Figura 3: Fields for 10/30/2019 at 09 UTC. A) Mean Sea Level Pressure (hPa). B) 250 hPa streamlines (contour) and wind strength (shaded) ($m\ s^{-1}$). C) 850 hPa streamlines (contour) and wind strength (shaded) ($m\ s^{-1}$). D) 850 hPa streamlines (contour) and specific humidity (shaded) ($g\ kg^{-1}$). E) 500 hPa geopotential height (contour) (mgp) and omega vertical velocity (shaded) ($Pa\ s^{-1}$). F) GOES-16 infrared image. G) Coupling between jets (degrees). H) LLJ (shaded) and ULJ (contour) strength (m s-1).

There were intense cores of jet coupling before (not shown) and during (figure 3G) the storm. The most intense coupling time occurred at 06Z (not shown), that is, the coupling closest to the orthogonal occurred before the instabilities, but here the 09 UTC fields are shown (figure 3G-H), when the cloudiness was more intense (figure 3F). As in previous days, the convective system occurred downstream the coupling. In the dissipation stage of the system, not shown here, there was also no coupling.

CONCLUSIONS

A coupling between LLJ and ULJ was identified in South America on October 28, 29 and 30, 2019. The development of storms, which caused intense precipitation and several damages in southern Brazil, was observed downstream the coupling. The coupling was observed before and during the life span of the MCSs, and its dissipation occurred along with that of the storm. It should be noted that on the 30th the most intense coupling (close to the orthogonal) did not occur simultaneously with the most intense phase of the system, it occurred before. It is understood here, according to previous studies, that coupling must have contributed to the development of the convective instabilities observed in this work.

In the three days under analysis, in addition to the coupling, a synoptic environment composed by the ULJ was observed, which intensified the trough associated with NAL and carried heat and humidity from the north, heating the layer as indicated by geopotential height field. The warm and moist atmospheric layer supported upward movements and diffluent flow at upper levels over RS. Except on the first day studied, a frontal system was observed between Uruguay and RS.

Future work will be carried out in order to check whether in most cases the coupling occurs before and during the lifetime of the storms. In addition, the relationship between coupling and transverse indirect circulation of the ageostrophic wind should be studied.

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