INVERTED COMMA CLOUD IN A CONVEYOR BELT FRAMEWORK: CASE STUDY OF 22 AUGUST 1989

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ABSTRACT

Apresenta-se um estudo de caso de vórtice de ar frio associado à presença do padrão de nuvem vírgula (invertida no Hemisfério Sul), ocorrido sobre o leste do Paraguai e porções do oeste dos Estados de São Paulo e Paraná, em 22 de agosto de 1989. São utilizadas as re-análises do ECMWF com resolução horizontal de 1.125º. As análises diagnósticas são realizadas sobre os campos obtidos em coordenadas isobáricas e, posteriormente, isentrópicas. Dentre os resultados alcançados destacam-se o papel exercido pelas "esteiras transportadoras fria e quente" no desenvolvimento do vórtice a partir do distúrbio inicial e a constatação de altos valores absolutos de vorticidade potencial isentrópica, associados ao movimento descendente de massas de ar oriundas da média e alta troposfera sobre a porção leste do vórtice de ar frio. Por fim, apresenta-se um esboço de modelo conceitual para a formação deste vórtice, considerando-se os resultados obtidos nas análises isobáricas e isentrópicas.

1. INTRODUCTION

The cold air vortices, also called comma-shaped clouds (inverted comma-shaped clouds in the Southern Hemisphere), are mesoscale convective systems that are usually observed in the rear of cold fronts, embedded in the polar air mass. They are observed between latitudes of 20º and 35º S in South America. Generally, these systems reach maturity in the time scale of 6 to 12 hours and represent a problem for the short-range forecast because the surface and upper air network in South America does not have the necessary time and space high resolution information (Silva Dias, 1988). The cold air vortices are sometimes called polar lows and are a special case of cyclogenesis, more frequent in winter and over the ocean.

Case studies of inverted comma-shaped clouds in South America are rare. Bonatti and Rao (1987) used a baroclinic model to study a convective system observed in April 1979 in Uruguay. The evolution of this system lead to a frontal system of small dimensions. Bonatti and Rao pointed out the role of latent heat release in the modification of the baroclinic instability associated with the phenomenon. D'All Antonia (1991) studied the formation of an inverted comma-shaped cloud system in Paraguay and north of Argentina in August of 1989. Dereczynski (1995) studied a case whose formation resulted in severe precipitation events in the north coast of São Paulo and strong gusty winds in the Campos Basin (Rio de Janeiro) in June 1989.

Some comma cloud systems evolve to large-scale cyclogenesis. Satyamurty et al. (1990) and Gan and Rao (1991) presented climatologies of cyclogenesis for South America based on infrared satellite images and global model gridded analyses. However, a comma cloud system may be very short lived as opposed to a case of cyclone formation.

Browning (1986) introduced the concept of warm and cold conveyor belts to explain the precipitation associated to mid latitude frontal systems and the comma cloud formation. The warm (and moist) conveyor belt is seen as an isentropic flow initiating in low latitudes and low levels and moving upwards towards higher latitudes, almost parallel to the surface front. The cold (and dry) conveyor belt is found in the polar air mass in middle levels with a trajectory that may be quite variable, sometimes leading to upper levels other times descending to near surface levels. Conservation of potential vorticity indicates that a subsiding cold conveyor belt, reaching a layer of reduced thermodynamic stability, has to acquire cyclonic vorticity. As such, the presence of a cold conveyor belt is one of the indicators of a possible formation of a cold air vortex embedded in the polar air mass, whose predominant descending motion in the rear of the frontal system produces a local drying and heating of the atmosphere. The north and east sectors of the vortex in the Southern Hemisphere become cloudy due to moisture convergence and define the inverted comma-shaped cloud identified in infrared images (Reed, 1977).

The main objectives of this work are:

- to diagnose the physical features of a cold air cyclonic vortex observed over Paraguay and Southeastern Brazil in August 21-22, 1989;
- to present a conceptual model with the purpose of providing a framework of the structure of a cold air mass vortex in South America identifiable from a larger scale viewpoint in global model gridded analysis.

2. DATA AND ANALYSIS PROCEDURE

The case study will focus on the precursors of the cold air vortices, making use of surface charts, satellite images and the ECMWF (European Centre for Medium-Range Weather Forecasts) global re-analyses in isobaric coordinates. From the global analysis, an isentropic coordinate analysis is derived following the methodology described in Bernardet and Silva Dias (1989).

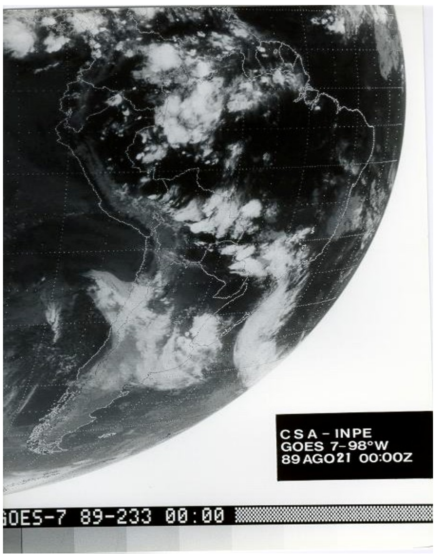
The ECMWF re-analyses contain fields of geopotential, temperature, relative humidity, horizontal and vertical wind components in 17 isobaric levels between 1000 and 10 hPa, for 00, 06, and 12 UTC, with 1,125 degrees resolution. With these fields, some derived diagnostic fields, e.g., moisture divergence, potential vorticity (Holton, 1992) and temperature advection are calculated in isobaric and isentropic coordinates.

The main sets of lines drawn in an isentropic chart are those associated with the geopotential, streamlines and water vapor mixing ratio. The first one shows essentially the isentropic surface heights and inclination. The streamlines basically give the paths followed by air parcels in an adiabatic motion. The information of mixing ratio together with the streamlines allows the identification of moist and dry tongues in isentropic surfaces, which are associated with warm and cold conveyor belts (Browning, 1986).

3. RESULTS

Among the observational precursors of comma clouds in the Northern Hemisphere, Carlson (1991) identified regions of strong surface temperature gradients with moisture supply in the rear of the cold front, inside of the polar air mass, as well as the presence of a low-level airflow with ascending slantwise motion. At the surface, Carlson indicates that pressure falls and that regions of warm and cold air advection may be found ahead and behind the polar vortex, respectively. According to Carlson, this horizontal differential temperature advection pattern seems to be a prominent mechanism for development of the disturbance.

Figure 1 shows a sequence of the GOES-7 infrared images between 00:00 UTC 21 August 1989 and 00:00 UTC 23 August 1989. Fig. 1a shows two cold front systems located over southern Brazil and Argentina. The first one is decaying in the Atlantic Ocean and the second one is intensifying over central Argentina. Behind the last one, a cold air mass crosses the Andes while the first signals of convection appear at 12:00 UTC 21 August (Fig. 1b) over Paraguay. Fig. 1c (00:00 UTC 22 August) shows the frontal system well developed over East Argentina and South Brazil, organizing convection. By 12:00 UTC 22 August (Fig. 1d), a cold air vortex is fully developed in Paraguay, northeast of Argentina and south of Brazil with the inverted comma-shaped cloud pattern. Fig. 1e and 1f show the decaying stages of the cold air vortex between 18:00 UTC 22 August and 00:00 UTC 23 August. From these images, the vortex is seen reach its maximum intensity at 12:00 UTC 22 August.



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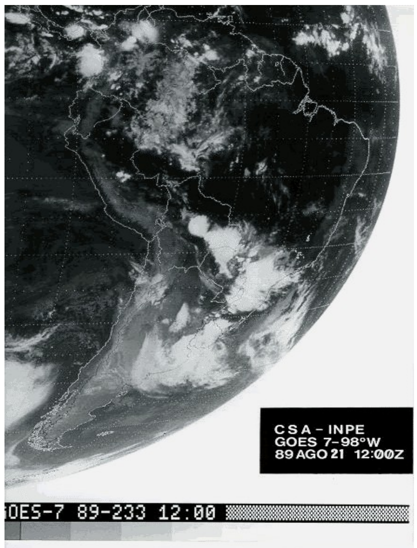

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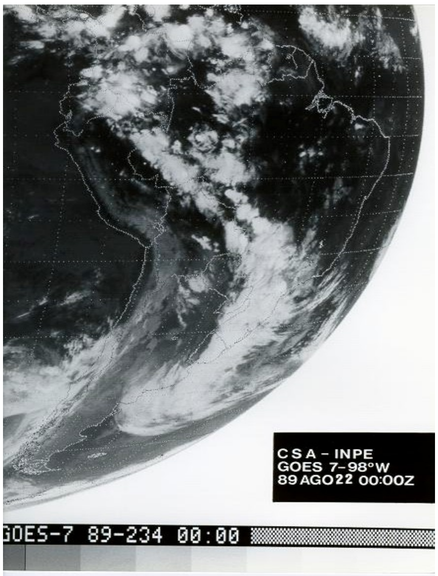
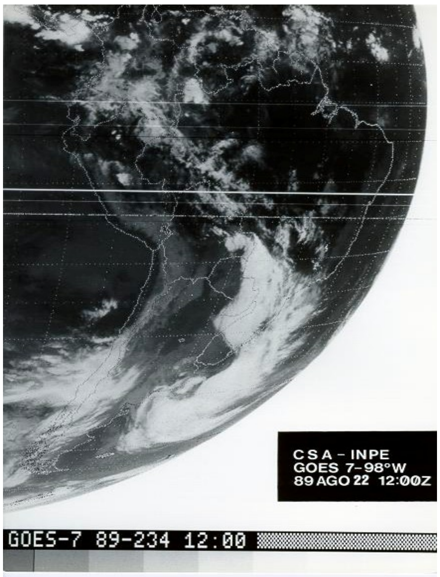
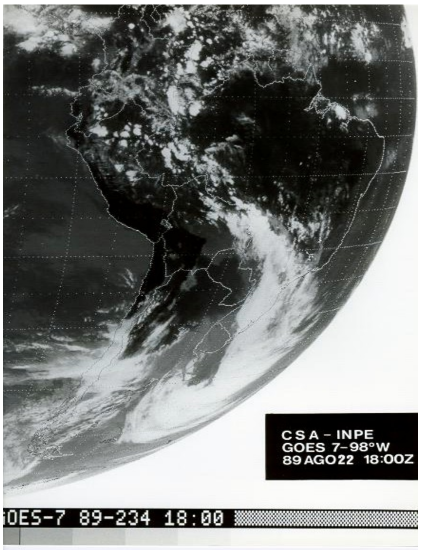


(c)



(d)

Figure 1 - Sequence of GOES-7 infrared images for 21-23 August 1989.



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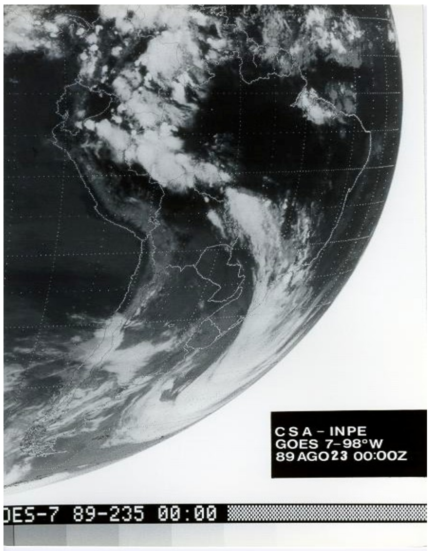


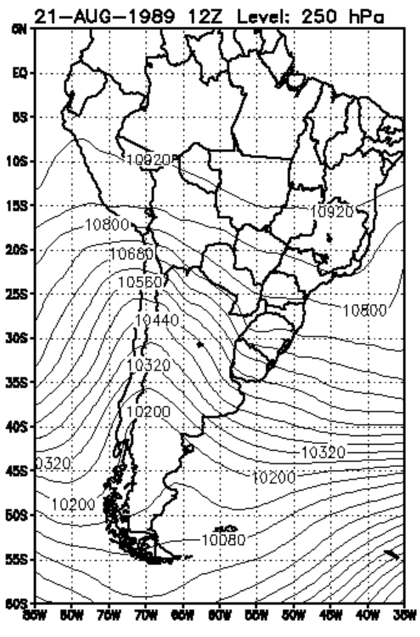
(f)

Figure 1 - Continued.

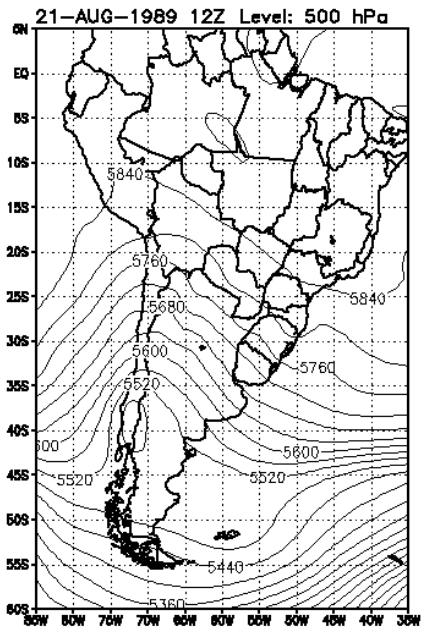
(I) ISOBARIC ANALYSIS

The surface pressure charts of the Brazilian Navy Meteorological Service (figures not shown), present a double low-pressure center on Paraguay and central region of Argentina for 12:00 UTC 21 August. The low center of 1006 hPa over Argentina is associated with the cold front, while the low center of lesser extension over Paraguay, also of 1006 hPa, is associated with the initial formation stage of the cold air vortex seen in the satellite images in Fig.1.

Fig. 2 shows the geopotential height in the isobaric surfaces of 250, 500, 700 and 850 hPa for 12:00 UTC 21 August. The inclination to the southwest of the trough axis with height denotes a baroclinic situation of the front and the availability of potential energy for the system as a whole.

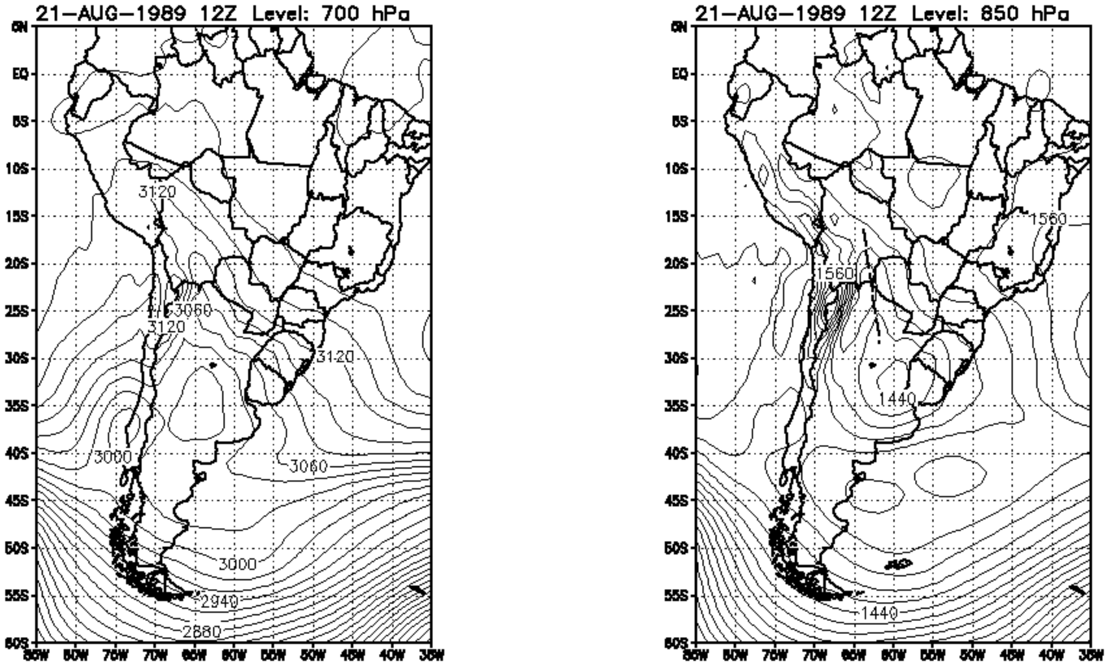


(a)



(b)

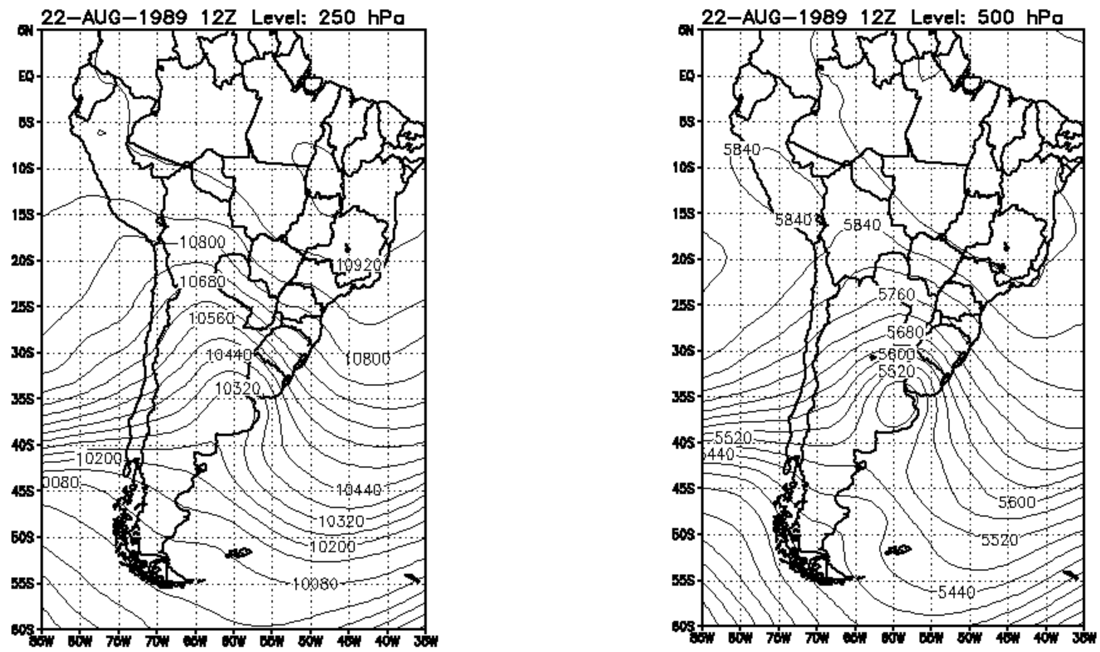
Figure 2 - Geopotential height analysis for 12Z 21 August 1989 for (a) 250 hPa, (b) 500 hPa, (c) 700 hPa and (d) 850 hPa. The dashed line in (d) indicates short wave trough. Contours are drawn at intervals of 60 m in (a), 40 m in (b) and 20 m in (c) and (d).



(c) (d)

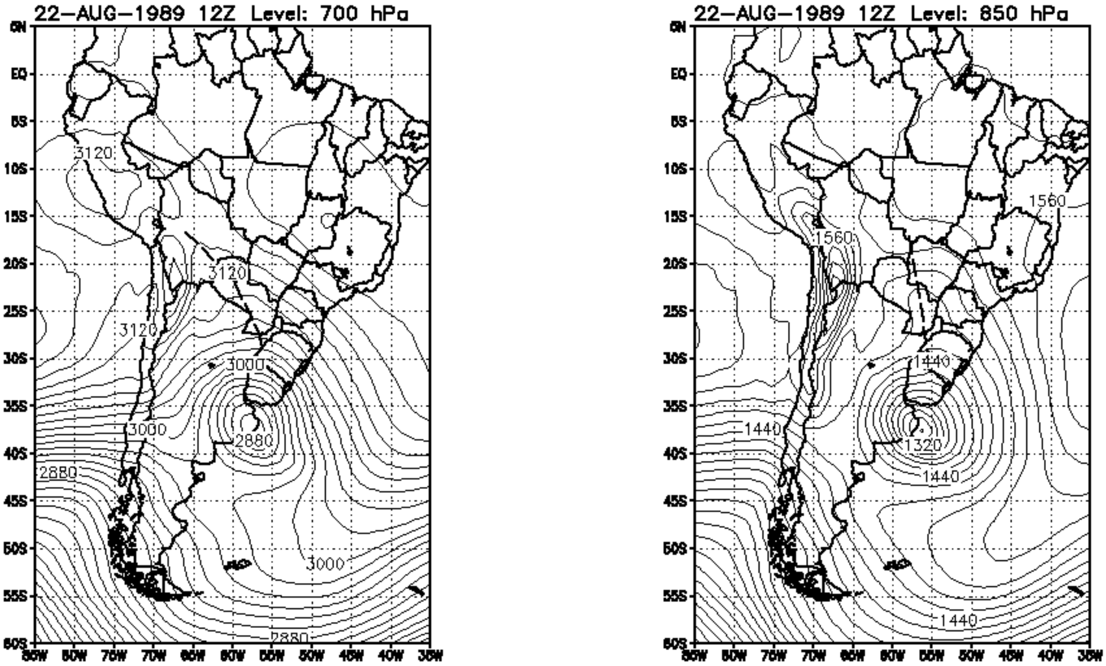
Figure 2 - Continued.

A short wave trough on the synoptic-scale trough of 700 and 850 hPa can be observed on the border between north of Argentina and west of Paraguay, where convection started giving origin to the comma cloud. By 12:00 UTC 22 August (Fig. 3), the closed centers of low geopotential height on the vortex associated with the surface cold front (see Fig. 5) appear vertically superimposed denoting its occlusion. The signals of short wave on the troughs of 700 and 850 hPa still remain, being more visible on this last one.



(a) (b)

Figure 3 - Geopotential height analysis for 12Z 22 August 1989 for (a) 250 hPa, (b) 500 hPa, (c) 700 hPa and (d) 850 hPa. The dashed line in (c) and (d) indicate short wave trough. Contours are drawn at intervals of 60 m in (a), 40 m in (b) and 20 m in (c) and (d).



(c) (d)

Figure 3 - Continued.

Despite the 250 and 500 hPa geopotential height fields do not clearly show the signals of a short wave, Fig. 4 shows that, around the position of short wave trough axis on 700 hPa (25º S/57.7º W), the geopotential height falls between 12:00 UTC 21 and 12:00 UTC 22 August. This geopotential height falls first occurs at the lower levels probably as a result of the short wave trough located ahead of the long wave trough.

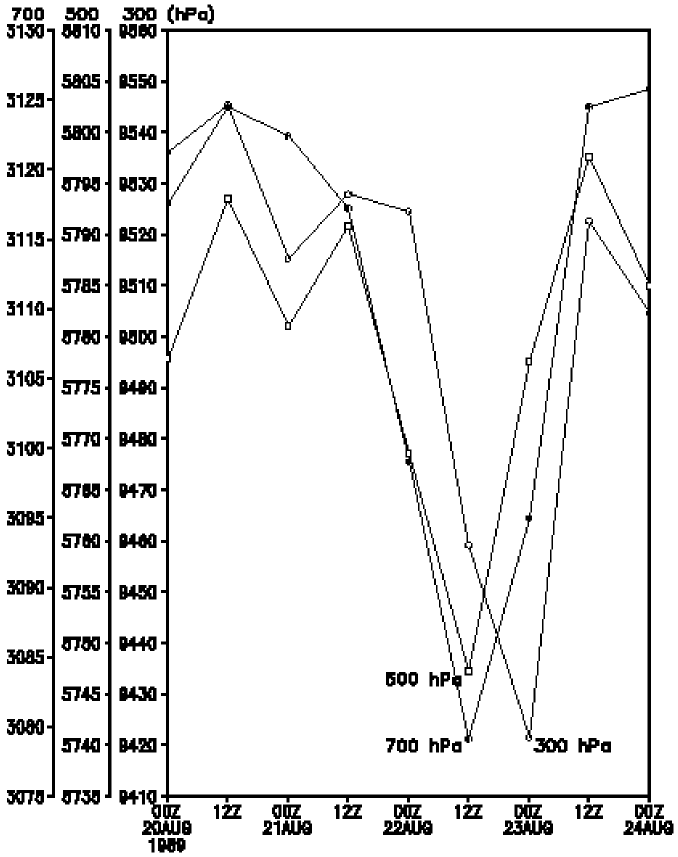
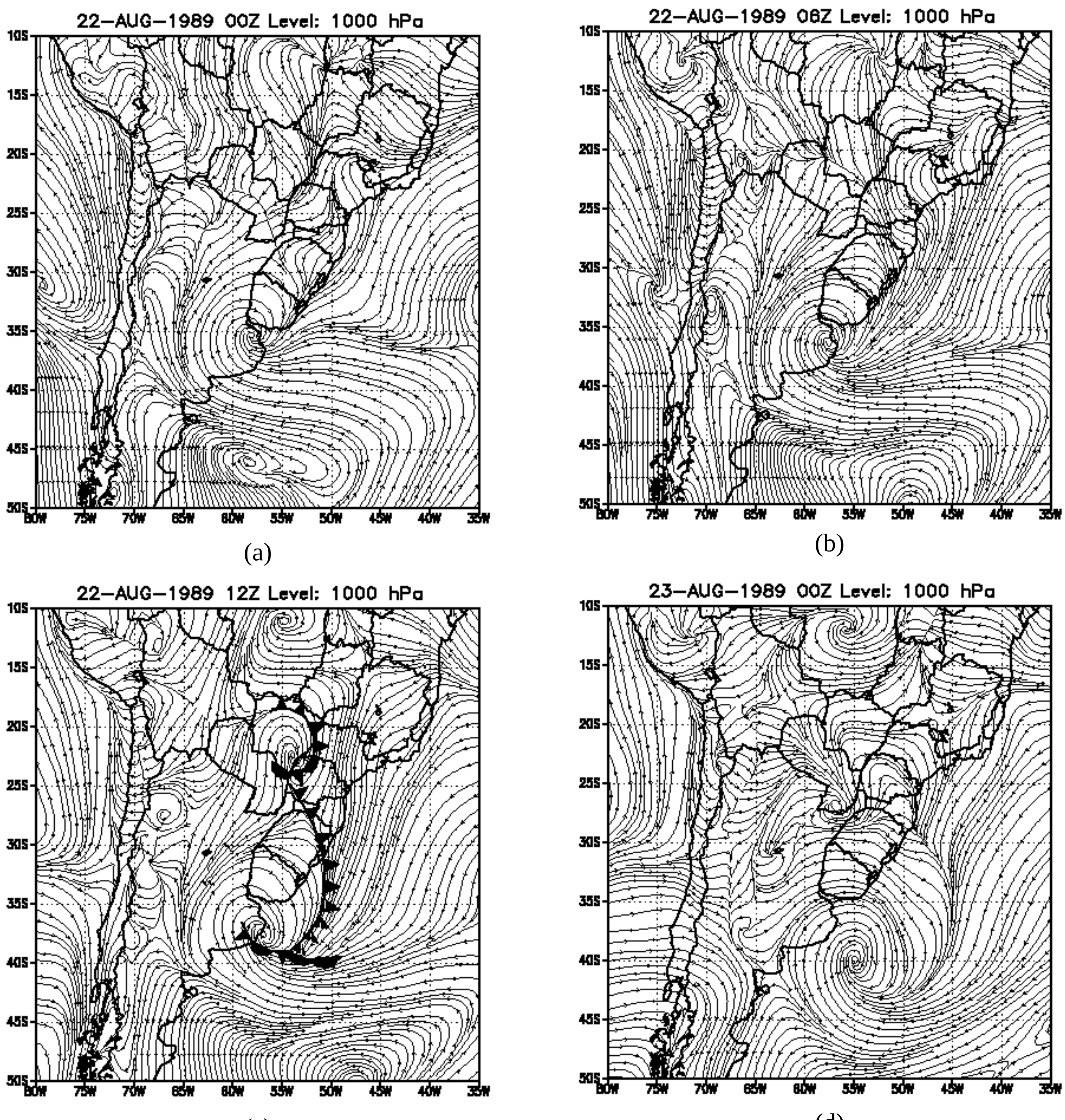


Figure 4 - Time evolution of Geopotential Height for 300, 500 and 700 hPa (25º S/57.7º W).

The streamlines fields for 1000 hPa (Fig. 5) show that the cold cyclonic circulation core appears clearly only at 12:00 UTC 22 August (Fig. 5c), visible in the border between Paraguay, Paraná, São Paulo and Mato Grosso do Sul. The position of the vortex center in the analysis is displaced to the NE of the position indicated by cloudiness in Fig. 1d. From the curvature seen in Fig. 1d, the vortex center is located in the border of Paraguay and NE Argentina. Fig. 5a shows a streamline confluence at 00:00 UTC 22 August in the same region that 6 hours later (Fig. 5b) evolves to a cyclonic curvature. Thus, the vortex evolved between 06:00 UTC and 12:00 UTC 22 August. By 00:00 UTC 23 August (Fig. 5d), the cyclonic circulation in question was replaced by an open trough on Paraná and São Paulo States. The same situation occurred at 925 hPa surface, as can be seen in Figs. 6a and 6b for 06:00 UTC and 12:00 UTC 22 August, respectively. For 22 August, in high and mid levels (figures not shown), no significant wave appears in that region, while in the 850 hPa level (Fig. 6c and 6d) the trough is clearly identified.



(c) (d)

Figure 5 - Streamlines at 1000 hPa for 22 August at (a) 00Z, (b) 06Z, (c) 12Z and (d) 00Z 23 August. The cold, warm and occluded fronts symbols in (c) are like de usual surface pressure synoptic analysis.

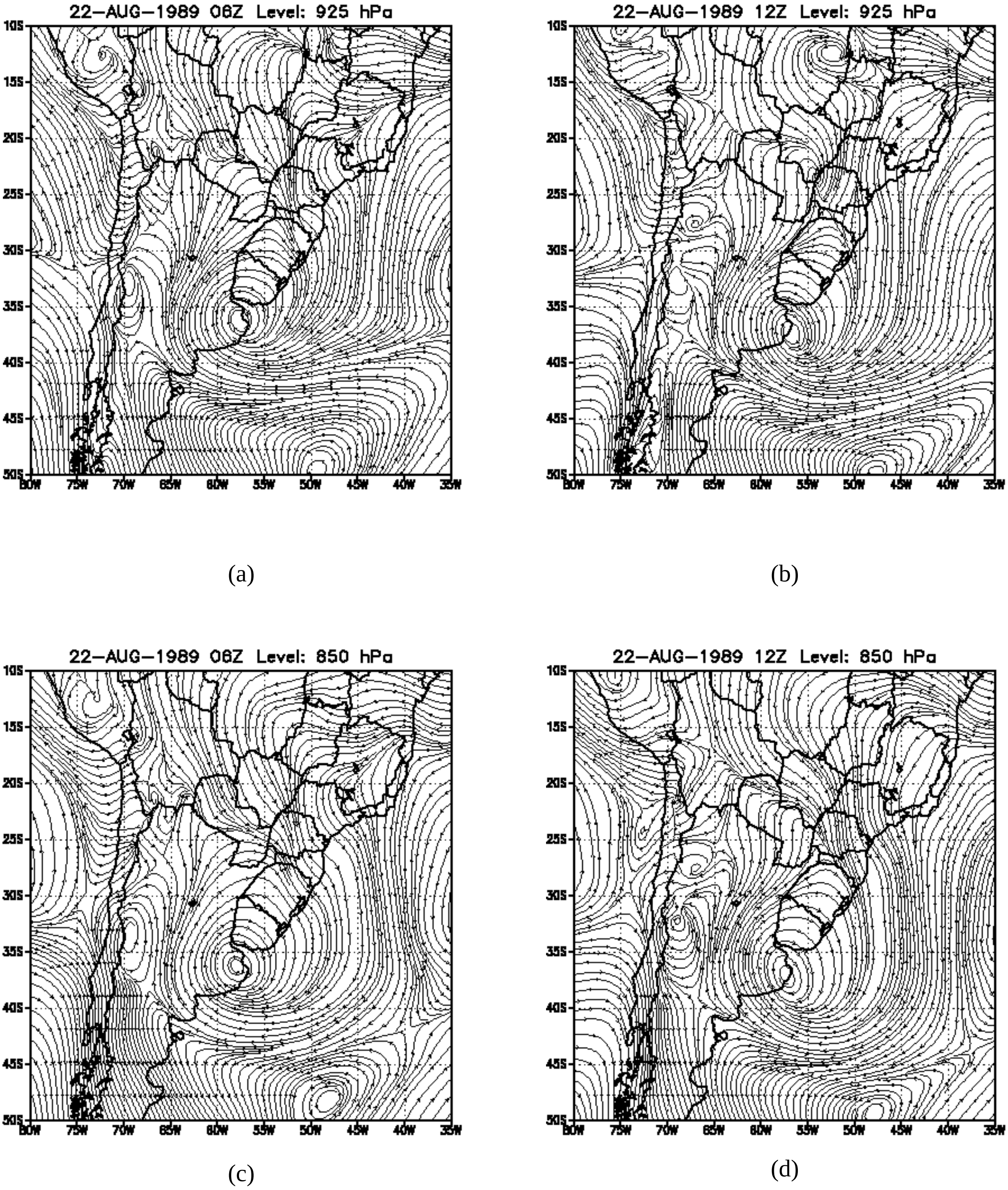
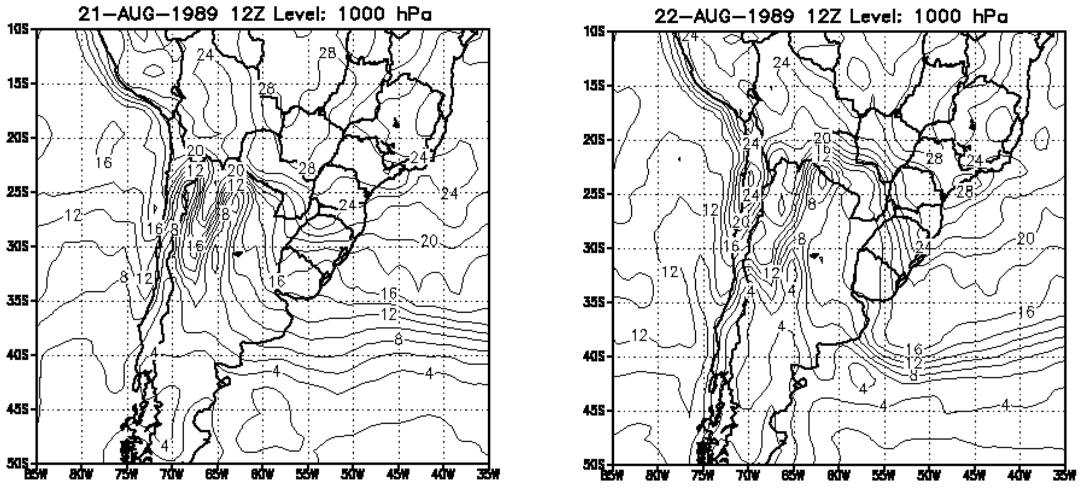


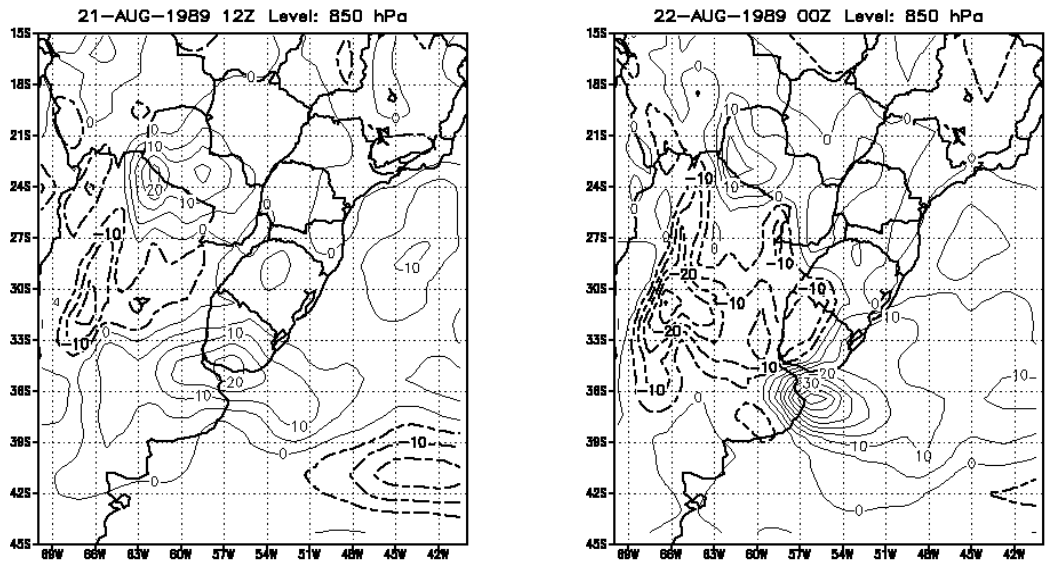
Figure 6 - Streamlines for 22 August 1989 for 925 hPa at (a) 06Z and (b) 12Z and 850 hPa at (c) 06Z and (d) 12Z.

Fig. 7 shows 1000 hPa isotherms for 21 and 22 August (12:00 UTC) where a strong temperature gradient can be seen in the region of cold air vortex development, which denotes a strong atmospheric baroclinic situation at low levels. This region was under horizontal differential temperature advection in 700 and 850 hPa, in days 21 and 22 August, strengthening the conditions for cyclogenesis, as can be observed in Fig. 8 where, in both levels, there is cold air advection to the west of the mesoscale system and warm air advection to the east. In general, the low and mid levels showed the same temperature and temperature advection contrast in their fields (figures not shown).

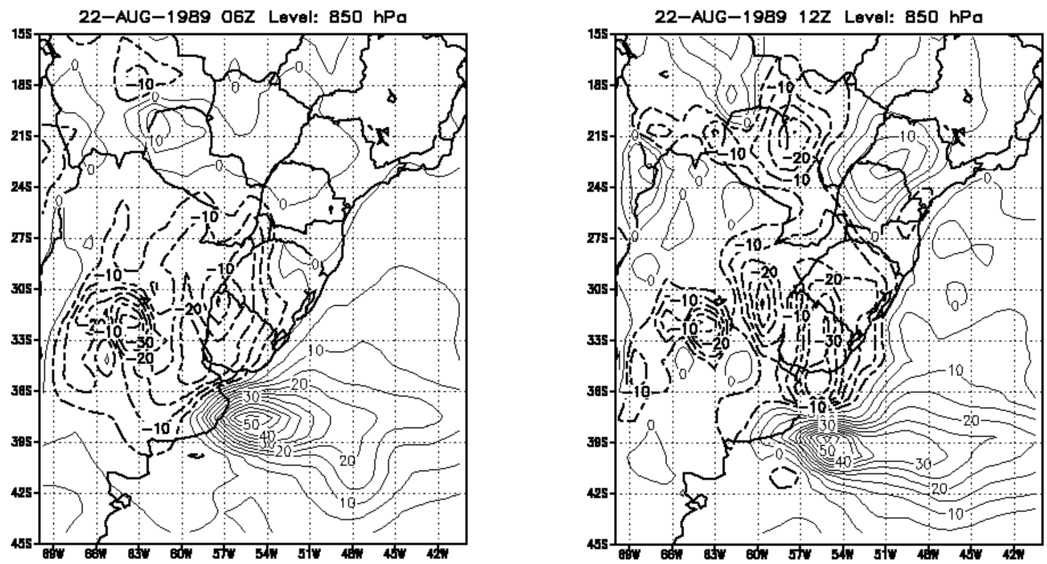


(a) i

Figure 7 - Isotherms (ºC) at 1000 hPa for (a) 12 UTC 21 August 1989 and (b) 12 UTC 22 August 1989. Contours are drawn at intervals of 2 ºC.

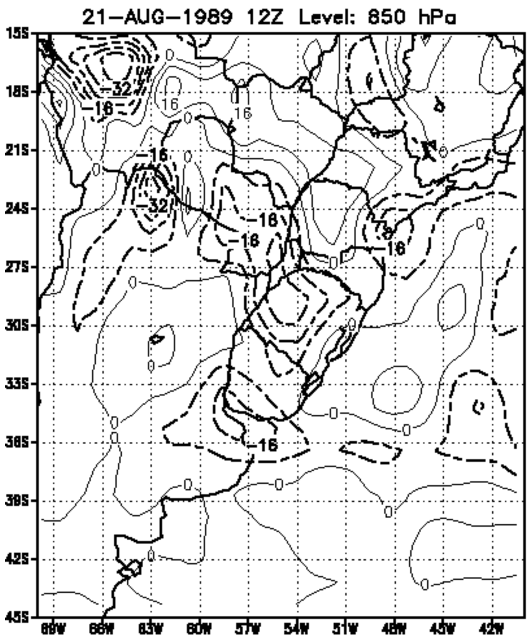


(a) (b)

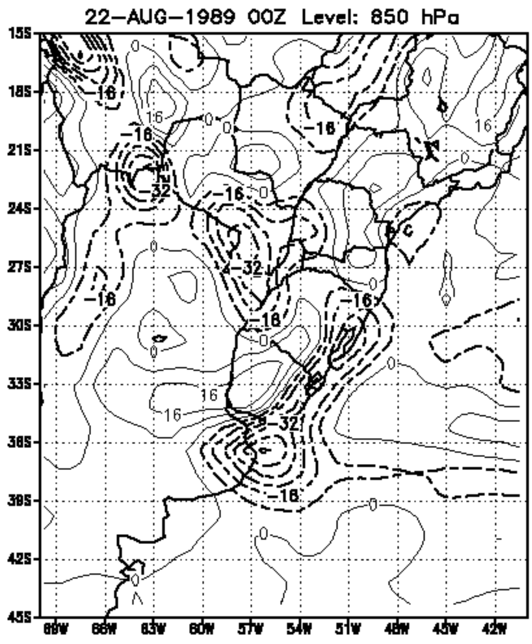


(c) (d)

Figure 8 - Horizontal temperature advection (10^{-5} ºC s^{-1}) at 850 hPa for (a) 12 UTC 21 August 1989, (b) 00 UTC 22 August 1989, (c) 06 UTC 22 August 1989 and (d) 12 UTC 22 August 1989. Contours are drawn at intervals of 5.10^{-5} ºC s^{-1}



(a)



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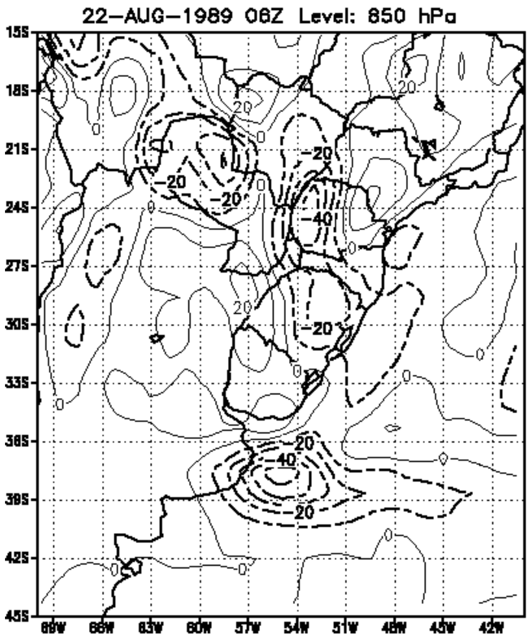

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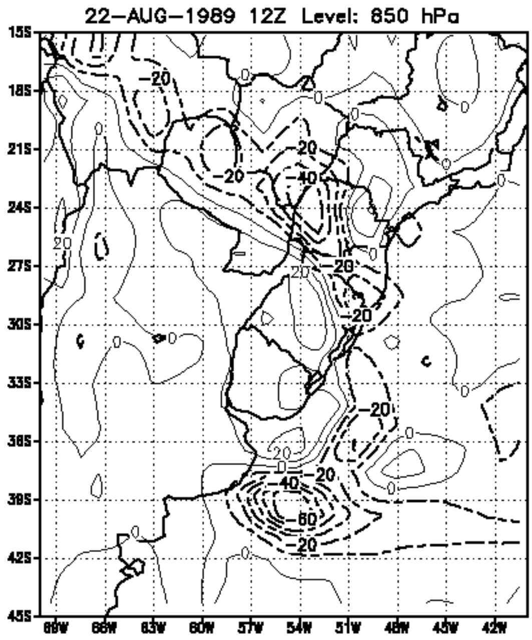
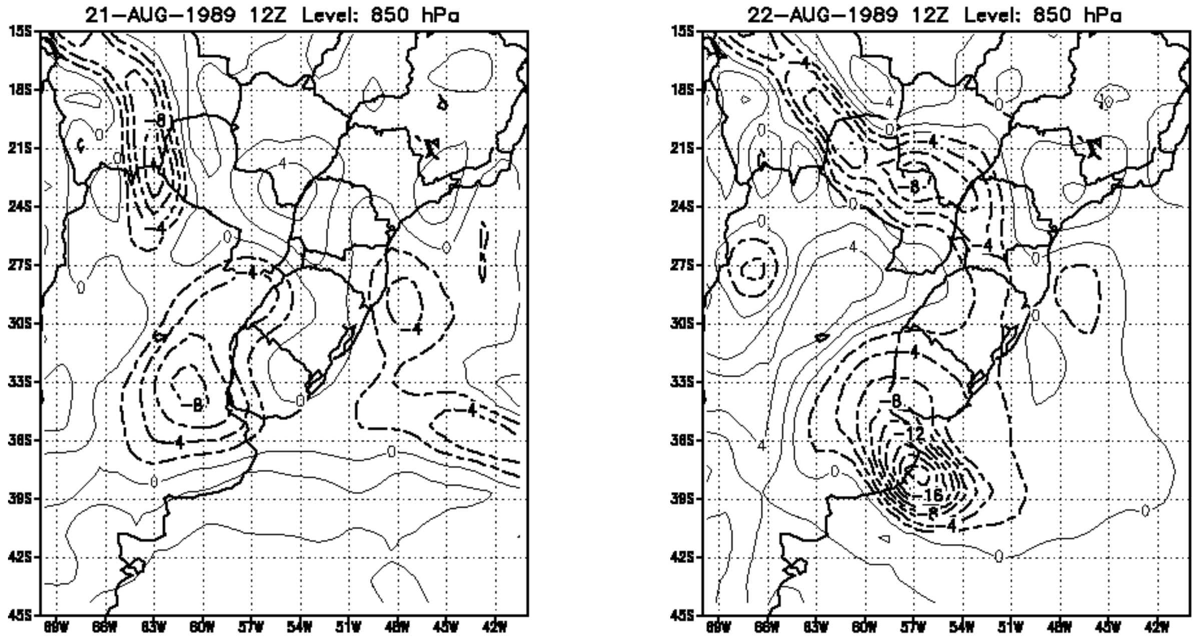


(d)

Figure 9 - Moisture Divergence (10^{-5} g $Kg^{-1}s^{-1}$) at 850 hPa for (a) 12 UTC 21 August 1989, (b) 00 UTC 22 August 1989, (c) 06 UTC 22 August 1989 and (d) 12 UTC 22 August 1989. Contours are drawn at intervals of 8.10^{-5} g $Kg^{-1}s^{-1}$ in (a) and (b) and 10.10^{-5} g $Kg^{-1}s^{-1}$ in (c) and (d).

The vortex formation took place in the region of strong low level moisture convergence acting since 21 August, after the inflow of the polar air mass that followed the cold front, as seen in Fig. 9 for the 850 hPa level.

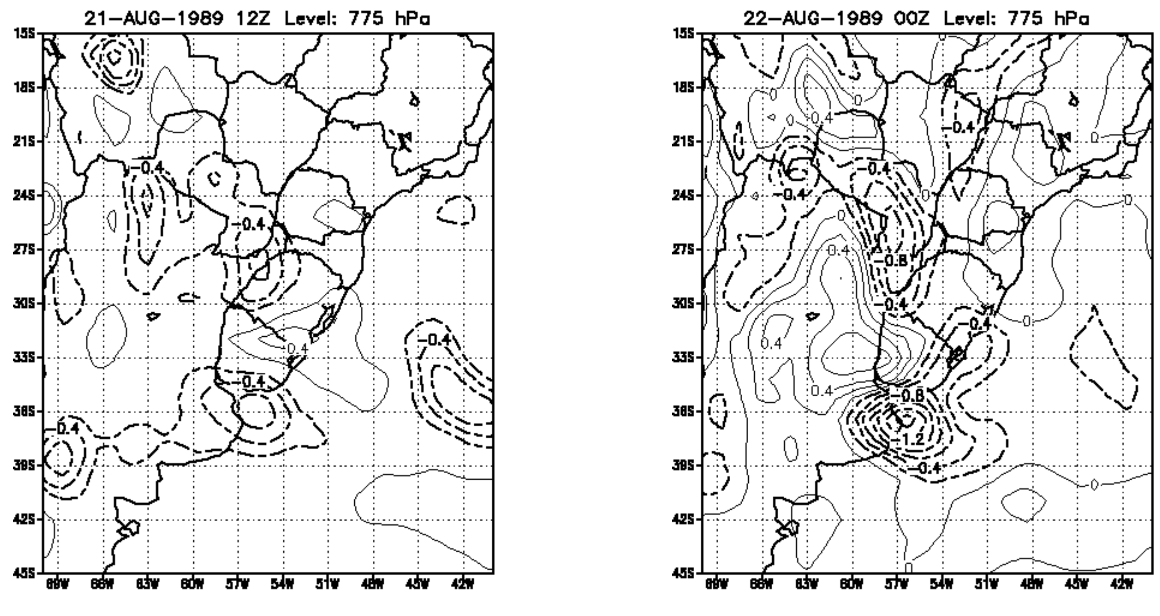
In the low-level fields of relative vorticity, since 21 August (12:00 UTC) there were indications of cyclonic activity over northern of Argentina and western Paraguay and the presence of a cyclonic vorticity core associated with the cold synoptic scale front (Fig. 10a for 850 hPa). By 22 August (12:00 UTC), in the region of the cold air vortex, there is a negative relative vorticity core between the levels of 1000 hPa and 200 hPa, denoting the intensification of the cyclonic circulation throughout the troposphere (see Fig. 10b for 850 hPa).



(a) (b)

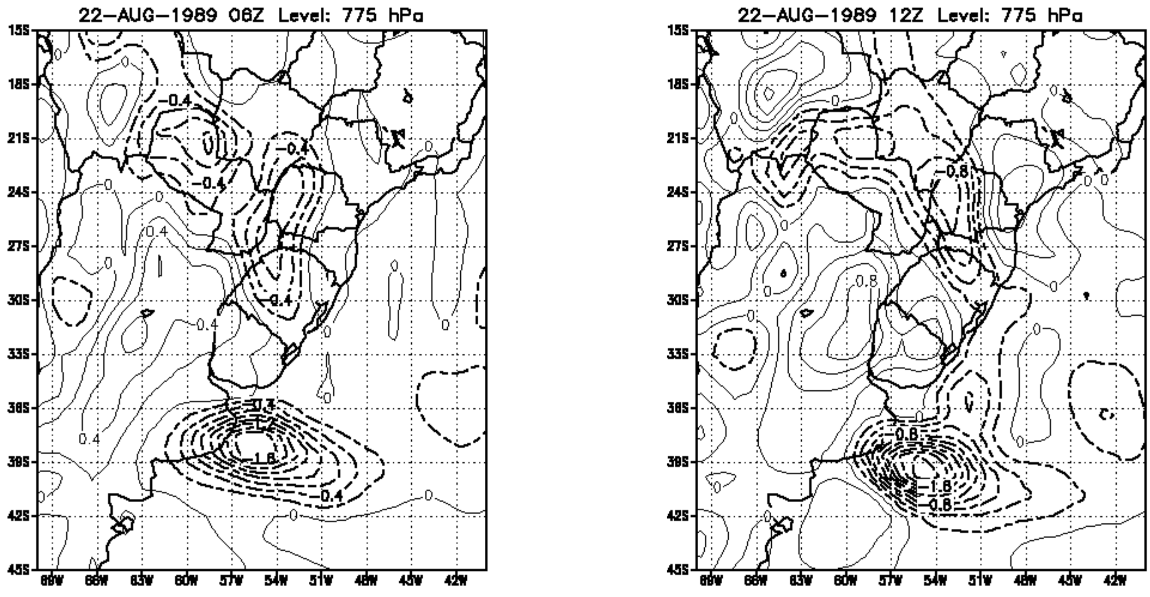
Figure 10 - Relative Vorticity (10^{-5} s^{-1}) at 850 hPa for (a) 12 UTC 21 August 1989 and (b) 12 UTC 22 August 1989. Contours are drawn at intervals of 2.10^{-5} s^{-1}.

Fig. 11 shows the time sequence of vertical velocity fields in 775 hPa, which indicate the presence of ascending motion in the region of formation of the system at 12:00 UTC of 21 August, and its intensification as it moves eastward during 22 August. Upper levels (fields not shown) did not have indications of ascending motion for 21 August. However, at 12:00 UTC 22 August, the vertical motion fields show that the disturbance intensified, reaching the whole depth of the troposphere, as it can be seen in Fig. 12 for 500 hPa and for 250 hPa.



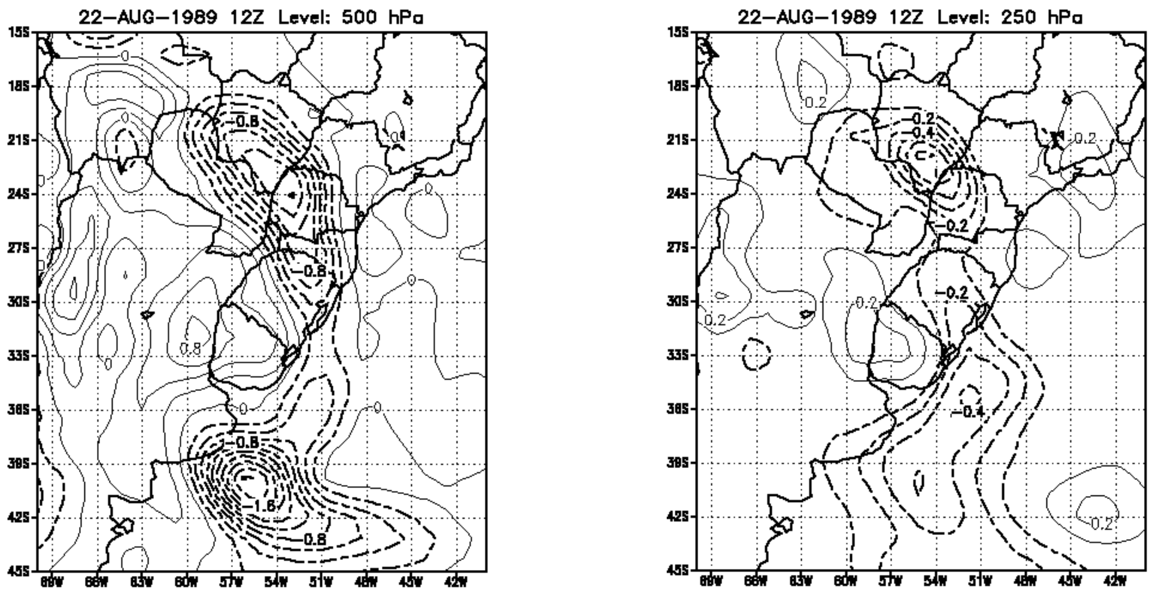
(a) (b)

Figure 11 - Vertical p-velocity (Pa s^{-1}) at 775 hPa for (a) 12 UTC 21 August 1989, (b) 00 UTC 22 August 1989, (c) 06 UTC 22 August 1989 and (d) 12 UTC 22 August 1989. Contours are drawn at intervals of 0.2 Pa s^{-1}.



(c) (d)

Figure 11 - Continued.



(a) (b)

Figure 12 - Vertical p-velocity (Pa s^{-1}) at (a) 500 hPa and (b) 250 hPa for 12 UTC 22 August 1989. Contours are drawn at intervals of 0.2 Pa s^{-1}.

(II) ISENTROPIC ANALYSIS

Fig 13 shows the streamlines with geopotential height and Fig. 14 shows streamlines and temperature fields for 12:00 UTC 22 August. A confluence of northwesterly streamlines over Paraná reaches the eastern portions of the two vortices diagnosed in the isobaric analyses. For approximately adiabatic motion, these streamlines indicate the paths of air parcels that, in this case, leave the low levels in the Amazon region in a southeastern route with a warm and moist anomaly. This belt of warm and moist air will be denoted hereafter as "Warm Conveyor Belt", according to the denomination given by Browning (1986). A "Cold Conveyor Belt" may also be identified as the confluence of streamlines proceeding from the west coast of the continent around 30° S, crossing the Andes

Mountains and gaining cyclonic curvature while descending in the region of the cold air vortex. At this point the warm and cold conveyor belts meet at the region of the vortex formation.

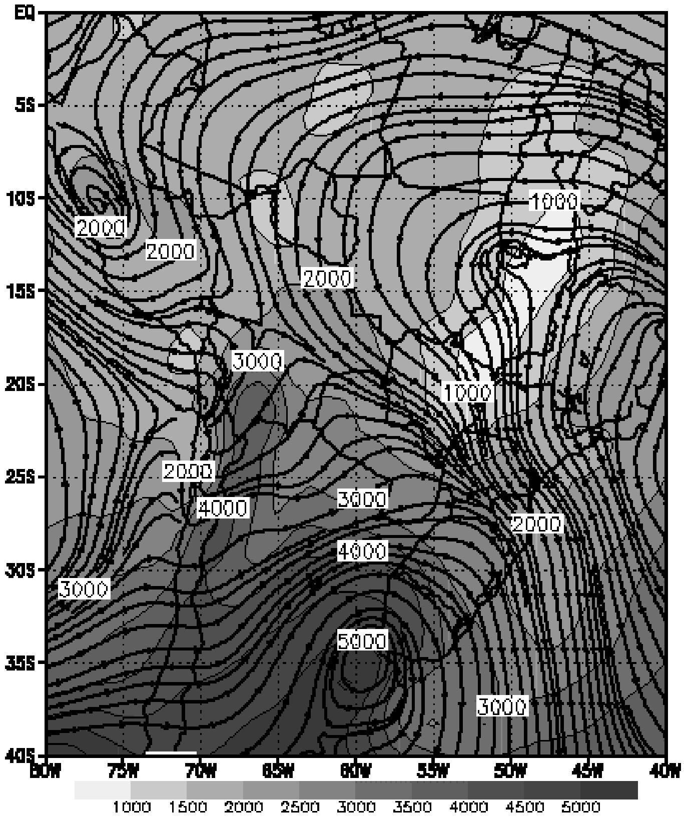


Figure 13 - Streamlines of the wind field and geopotential height (m) field on the 305 K isentropic surface for 12 UTC 22 August 1989. Geopotential height contours (also Shaded) are drawn at intervals of 500 m.

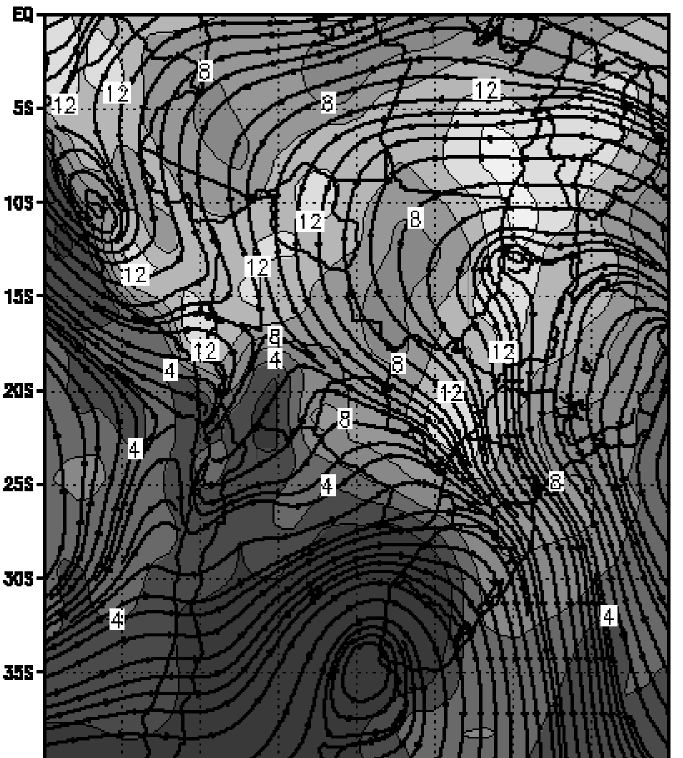
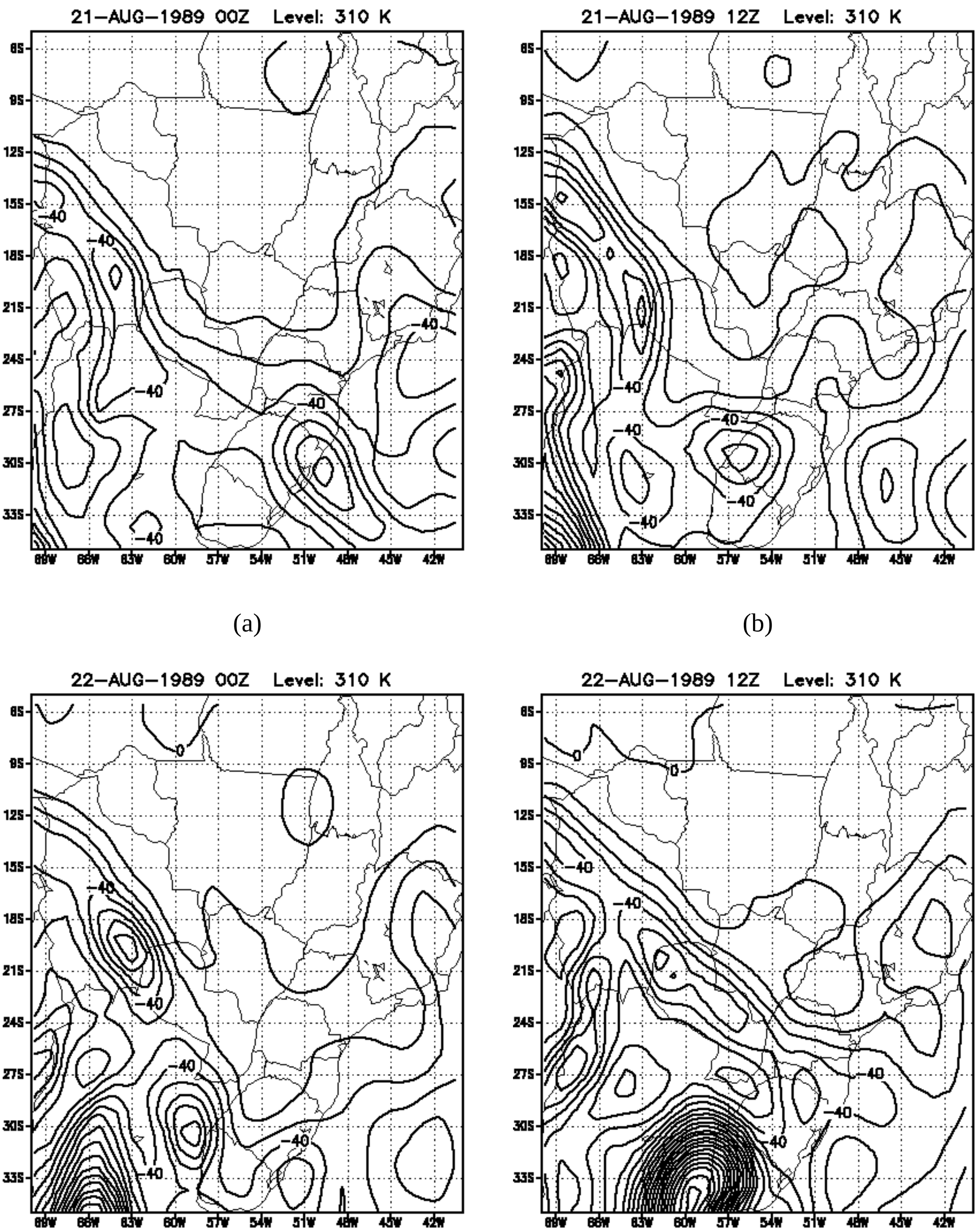


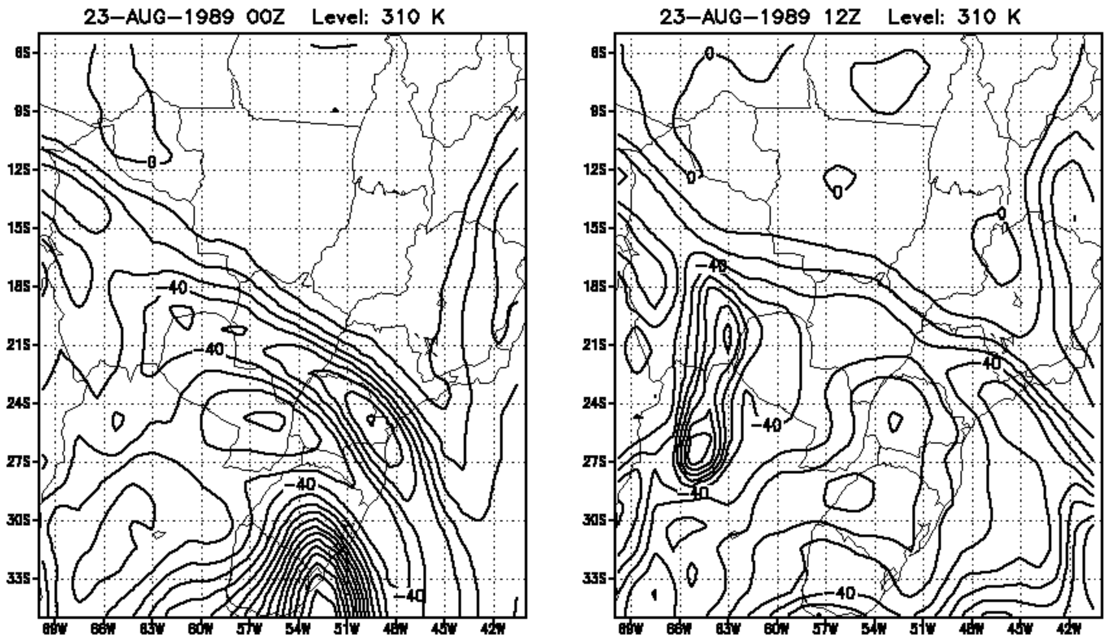
Figure 14 - Streamlines of the wind field and water vapor mixing ratio (g kg^{-1}) field on the 305 K isentropic surface for 12 UTC 22 August 1989. Mixing ratio contours (also shaded) are drawn at intervals of 2 g kg^{-1}.

The isentropic potential vorticity fields at 310 K show that there is an increase of negative potential vorticity in the border region between Argentina and Paraguay from 12:00 UTC 21 August (Fig. 15a) to 12:00 UTC 22 August (Fig. 15d), and a decreasing after that (Figs. 15e and 15f). Air masses sinking from regions of high static stability in the high troposphere and low stratosphere to regions of lower static stability, have a tendency to gain greater values of isentropic potential vorticity due its conservation property (Holton, 1992). Note that the position of the negative anomaly of potential vorticity at 12:00 UTC on 22 August (Fig. 15d) is just to the west of the region of 850 hPa moisture convergence (Fig. 9d).



(a) (b) (c) (d)

Figure 15 - Isentropic potential vorticity (10^{-4} m^2 K s^{-1} Kg^{-1}) for isentropic level of 310 K at intervals of 12 hours from 00Z 21 to 12Z 23 August 1989. Contours are drawn at intervals of 10.10^{-4} m^2 K s^{-1} Kg^{-1}.

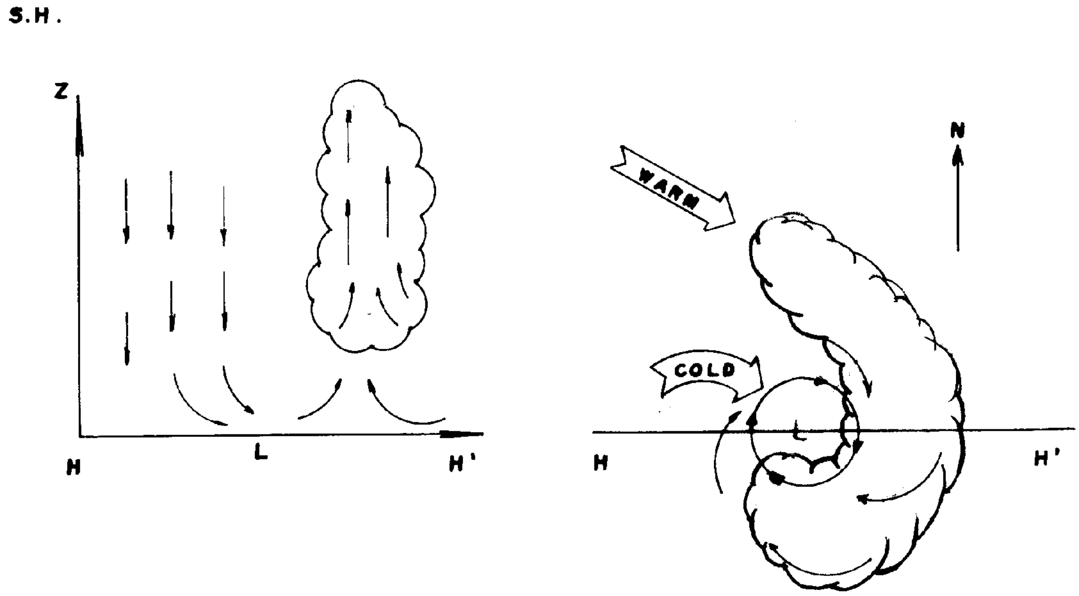


(e) (f)

Figure 15 - Continued.

(III) CONCEPTUAL MODEL

Fig. 16 shows an attempt to integrate all the information obtained through the isobaric and isentropic analyses in a conceptual model of the comma cloud system of 22 August 1989. It is shown that, as the cold conveyor belt proceeds its descending cyclonic turn with associated drying effect, it reaches the warm conveyor belt with its moist air. The low level moisture convergence is enhanced forming the precipitation band of the comma cloud, in the east side of the cold air vortex.



(a) (b)

Figure 16 - (a) Diagram showing vertical motion (thin arrows) relative to the surface low-pressure L and (b) flow relative to the comma-shaped cloud, where open arrows denote the warm and cold conveyor belts, and thin arrows the surface horizontal flow around de low-pressure L.

4. Conclusions

The inverted comma-shaped cloud occurrence in South America presented in this case study, is associated with a short wave trough in the region of formation of a cyclonic vortex in 700 and 850 hPa, as well as with the geopotential height fall and a rise in absolute values of the isentropic potential vorticity in mid levels.

Low-level moisture convergence in the rear of the cold front inside the polar air mass was evident 24 hours before the maximum manifestation of the vortex, as well as the presence of centers of ascending motion in 850 and 700 hPa to the east of the low pressure at the surface in the day of initiation of the disturbance.

The cold air vortex originated in the lower middle troposphere is a result of the sinking of a cold conveyor belt, behind the frontal system inside the cold air mass. The role of the warm conveyor belt with ascending slantwise motion in the development of the disturbance was to supply heat and moisture to the region of the vortex.

The strong cold horizontal temperature advection in the west of the vortex and the warm horizontal temperature advection to the east on the day before its mature stage established zones of strong thermal contrast in the surface and low troposphere, favoring the baroclinic instability in the region.

Acknowledgements

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5. References

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