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TELECONNECTION PATTERNS ASSOCIATED WITH EXTREME FREQUENCY OF GENERALIZED FROSTS. PART I: ROSSBY WAVES PROPAGATION REGIONS IN THE AUSTRAL HEMISPHERE

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1. INTRODUCTION

Teleconnection analysis allows a global vision of the atmospheric circulation local anomalies and its influence on remote regions through wavelike organized structures. One way to analyze the wave propagation over the globe is through the stationary Rossby wave linear theory in a barotropic atmosphere.

An extension of the barotropic Rossby wave propagation linear theory over the sphere was done by Hoskins and Ambrizzi (1993), when they considered longitudinally varying basic state. In this case, their results provided a qualitative vision of the atmosphere behavior related to preferential regions of Rossby wave propagation. They used a stationary wavenumber field (K_S) to identify the wave paths. One of their main results was the recognition of the subtropical and subpolar jet regions as waveguides which was in agreement with previous studies (e.g. Berbery et al. 1992).

Using the conceptual idea of the basic linear wave theory demonstrated by Hoskins and Ambrizzi (1993 –hereafter referred as HA–), this study analyzes the Rossby wave propagation behavior in two different Austral winter basic states. These two basic states represent the composites of the maximum (+σ –one standard deviation above the average–) and minimum (–σ –one standard deviation below the average–) frequency of occurrence of Generalized Frosts (GF) over the Wet Pampa (Pampa Húmeda) in the centre-east of Argentina, as defined by Müller et al. (2005).

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The main motivation of this study came from the results of Müller et al. (2005). They showed that for the basic state +σ there is an intensification of the subtropical jet in South American which can contribute to higher frequency of occurrency of GF, which may be related to the amplification of the pressure gradient in the region due to the increase in Rossby wave activity. On the other, during the –σ winters the basic state characteristics seem not to favor the GF formation. These results suggest that large scale patterns can influence extreme cold events over the Wet Pampa through the propagation of Rossby waves generated remotely.

2. DATA AND METHODOLOGY

The spatial criterion defined by Müller et al. (2000) considers that one GF event occurs when the area covered by the frost is above 75% of the total Wet Pampa surface (for further details see Müller, 2006). The GF events that occurred during the austral winter (June, July and August) in the period 1961-1990 are selected. Following the Müller et al. (2005) criterion, the identification of the winters with +σ and –σ GF occurrence is given in Table 1.

+σ	–σ
1970	1968
1976	1973
1988	1982
	1986

Table 1: Years of extreme frequency of Generalized Frosts (GF) during June, July, August over the Wet Pampa, Argentina.

The data used in the present analysis is from the NCEP/NCAR reanalysis data with a horizontal resolution of 2.5 degrees.

3. RESULTS

Using the concept of the linear wave theory, the characteristics of the basic state represented by the mean zonal wind for the winter composites of +σ and –σ is given in Figs. 1a and 1b.

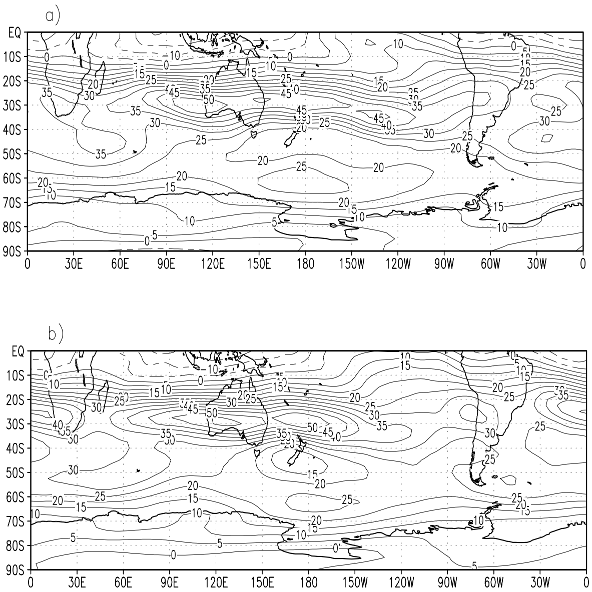

Figure 1: Zonal wind component at 250 hPa (m/s) for the composites of (a) +σ and (b) –σ. Contour interval is 5 m/s.

Fig.1a shows the +σ zonal wind at 250 hPa. Large values extending from the Indian Ocean up to the west coast of South America around 30ºS can be observed. A maximum value of 50 m/s occurs in the east of the Indian Ocean near the Australian coast and the contour of 35 m/s reaches the South American continent, with another nucleus of 35 m/s that extends from the south of South Africa to the southeast. One should notice the zonal wind gradient over that region the southwestern Indian Ocean. At high latitudes the zonal wind maxima, between 20 and 25 m/s, is located along 60ºS. A subpolar jet extending from the Indian up to the southeast Pacific Ocean, close to the South American coast is also observed.

For the –σ composites (Fig.1b) the subtropical jet is divided in two zones, one from the Atlantic Ocean up to the South Africa and the other one from the Indian Ocean to the central Pacific. The two maximum values occur at southwest of Australia and near the data line around 30ºS. The subpolar jet in this case seems less intense and further south when compared to the +σ field.

The region where there is the maximum value of the jet is where the meridional gradient of the absolute vorticity (β_M defined by equation 12 in HA) reaches its maximum, with minimum to the north and south of it (Fig.2). This configuration is important to determine the K_S field defined as $\left(\beta/\overline{U}\right)^{1/2}$ (see equation 4 from HA), where $\overline{U}$ is the westerly zonal wind.

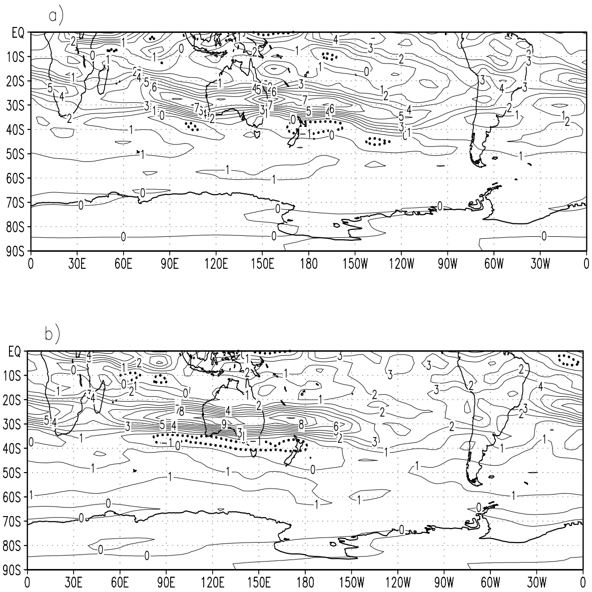

Figure 2: Meriodional gradient of the absolute vorticity in Mercator coordinate (β_M) at 250 hPa for the (a) +σ and (b) –σ composites. Negative values are dashed and the contour interval is $1x10^{-11}$ 1/ms.

Fig.3 shows the global distribution of K_S for the +σ and –σ GF composites. One should notice from the figures that when the zonal wind is zero a thick contour is exhibited and when β_M is zero or negative a dashed line is used. During winter the equatorial region is dominated by easterly wind where the wave propagation is inhibited (critical latitude). This region is marked by thick contours indicating high values of wavenumber (K_S > 16). A maximum value of K_S in the region of maximum wind, i.e., along of the subtropical jet, shows typical wavenumbers of 6 and 7 for both σ cases. It is interesting to notice that this region has K_S uniform values flanked by small ones. As pointed out by HA this region will act as a waveguide, where the waves are trapped.

On the polar side of the subtropical jet, the K_S=0 region inhibits the propagation of Rossby waves since, according to the wave theory, they deflect before reaching that region. It is interesting to note in this last case the difference in latitudinal extension of K_S for +σ (Fig. 3a) with respect to –σ (Fig.3b). In the first group the region extends up to the proximity of the Southamerican continent, to the south of Argentina. The other K_S "nucleus" with similar characteristics is located over the continent between 35º -40ºS in western Argentina during the –σ winters (Fig.3b), coincident with the main region of the synoptic systems entrance in South America (Garreaud 2000; Seluchi and Marengo 2000 and others). Instead, in the case of +σ there is no wave propagation inhibiting region over the continent. This fact may have consequences in the Rossby wave propagation and, therefore, in the studied events.

From the comparison of Figs.3a and 3b, one can see many interesting differences in the subtropical and subpolar waveguides for the +σ and –σ GF composites. The subtropical waveguide during +σ has a large longitudinal extension, reaching the South American continent in the south of Argentina. On the other hand, for –σ, the subtropical waveguide is shorter. It seems that in the first case, the Rossby waves can be more easily guided towards the South American continent than the second one. The possible implication for the generation of GF will be discussed below.

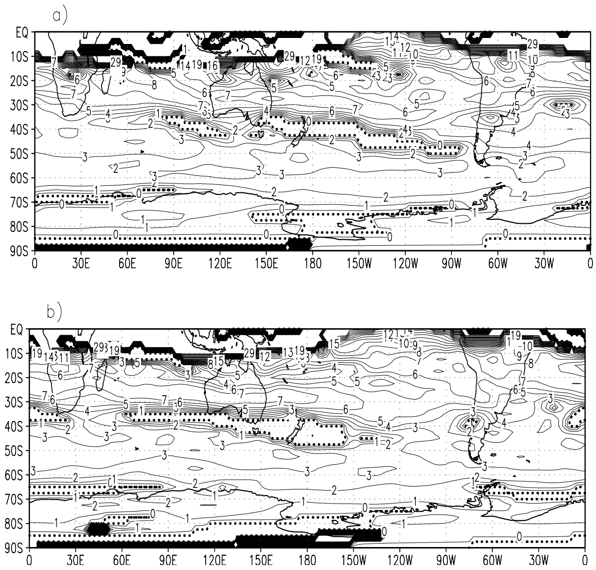

Fig.3: Stationary wavenumber K_S at 250 hPa for the (a) +σ and (b) –σ winters. Thick contour as singular values and dash lines represent K_S=0.

In order to better see the K_S characteristics in the region of the synoptic systems entrance, particularly important for the studied events, Fig.4 shows a meridional cross section centered on 85ºW.

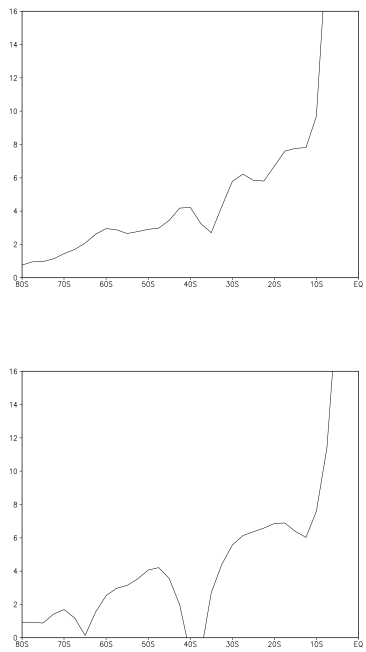

Fig.4: Stationary wave number meriodional cross section at 85ºW for +σ (bottom panel) and –σ (top panel).

One can clearly see the discontinuity of K_S around 35º-40ºS for the –σ composites (bottom panel). Comparing with the +σ case (top panel), the K_S meridional profile shows decreasing values towards high latitudes with wavenumbers 3 and 4 around the region where –σ case presents a value of K_S=0. These figures suggest that the entrance of Rossby waves in South America is favored during +σ events.

Continuing the K_S analysis, one can see that at high latitudes the predominant wavenumber is 3 for both cases (Figs. 3a and 3b), with a slight tendency towards relatively lower minimum values of K_S, in the average, for the –σ case. This characteristic become smore evident when analizing different K_S meridional cross sections (Fig.5a-d). The longitudes (a) 45ºE, (b) 120ºE, (c) 170ºE and (d) 110ºW (Fig.5) were selected. The first case (a) is related to the secondary maximum of the zonal wind component in the southeast of South Africa for the +σ composite (see Fig.1a). The following two cuts are coincident with the maximum of the subtropical (b) and subpolar (c) jets and the last one is positioned at the subtropical jet exit region (d).

The K_S profiles shown in Fig.5, clearly indicate two ranges of latitudes with maximum values for +σ (left panel) and –σ (right panels). These regions correspond to the latitudes of the subtropical and subpolar jets. As mentioned before, these regions act as waveguides for the Rossby wave propagation (Ambrizzi et al. 1995; Ambrizzi and Hoskins 1997). The subtropical jet is associated with shorter wavenumbers, typically 6 and 7 while the subpolar jet present wavenumbers around 3 and 4 (Figs. 5b and 5c). In fact, for the higher latitudes the K_S profiles have values decreasing towards zero in agreement with the results obtained by Karoly (1983) based on a climatological winter basic state.

The K_S meridional profiles suggest that, for example, a given wavenumber 3 wavetrain, or eventually a wavenumber 4 wavetrain, would propagate in the high latitudes provided that there is a discontinuity along the minimum K_S belt to the north of the polar maximum, inhibiting the northward propagation. This region in fact extends on the proximity of the Southamerican continent in the +σ case, as can be seen in the 110ºW cross-section (Fig.5d). At these latitudes of minimum K_S, which coincide with the southern flank of the subtropical jet, all waves are trapped and in the –σ case this region also extends over lower latitudes (Fig.5b-c). This discontinuity in Ks was also found by Berbery *et al.* (1992) for a basic state comprised by five winters (MJJAS).

From the analysis of global distribution of K_S (Fig.3) and the meridional cross sections in key places (Figs.4 and 5), some hypothesis can be made about the trajectories followed by the Rossby waves. It seems that a wave disturbance generate, for instance, somewhere in the Indian Ocean will propagate to the east trapped inside the subtropical and subpolar waveguides (Ambrizzi et al., 1995). However a close look at the waveguides exit shows that they can be very different depending on the basic state. For the +σ the waves are trapped up to the west coast of South America, where the two waveguides seems to coincide allowing an interaction between both. On the other hand, the –σ basic state shows shorter waveguides and the waves are free to propagate to the north or south of the jet exits regions before it reaches the South American continent. Therefore, a possible wave interaction in this case seems to be more difficult.

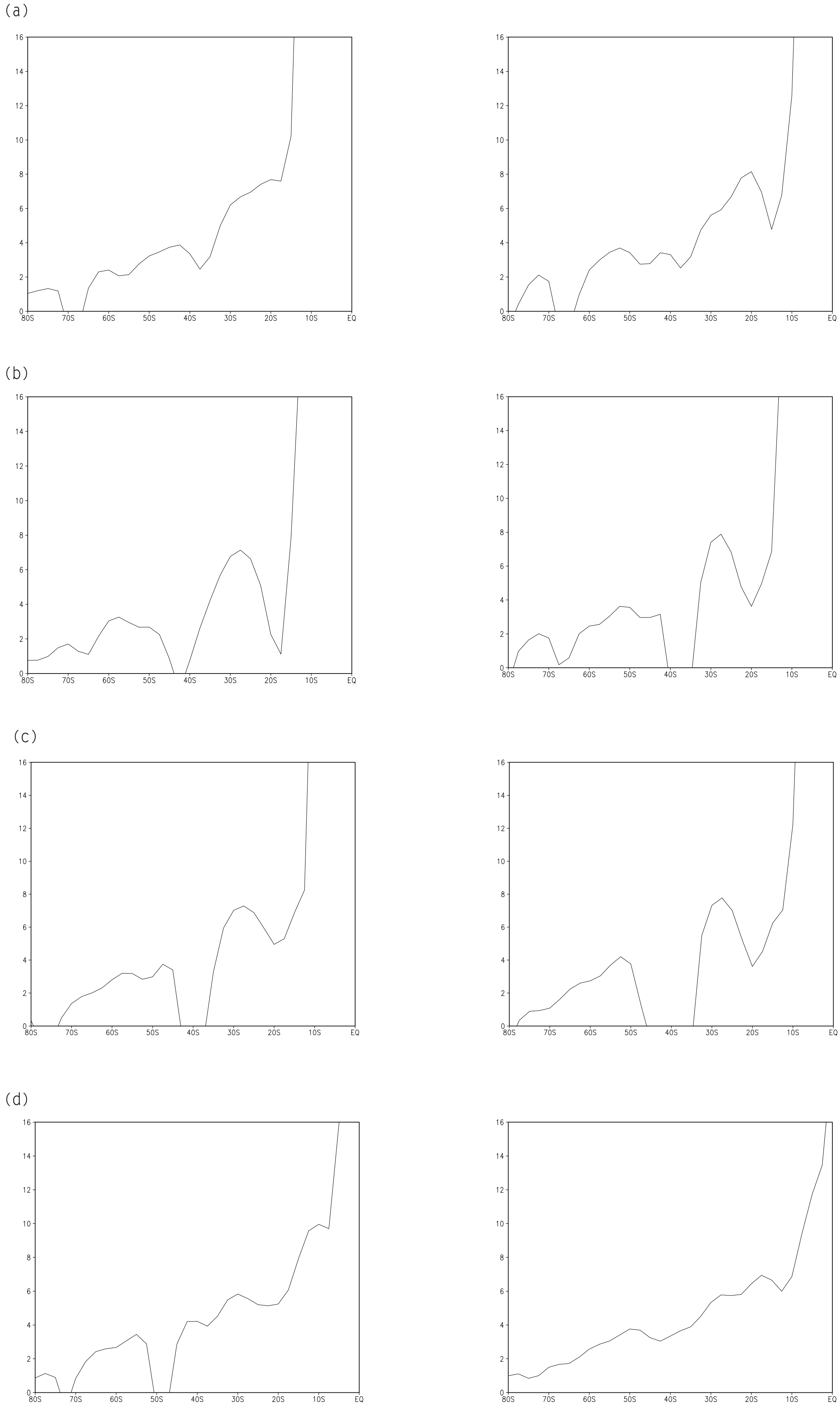

Fig.5: Stationary wavenumber meriodional cross section at (a) 45ºE, (b) 120ºE, (c) 170ºE and (d) 110ºW for +σ (left panel) and –σ (right panel).

4. GENERAL DISCUSSION

The linear wave theory offers a simple and useful interpretation of many studies about barotropic Rossby wave propagation. In accordance with this theory, the atmospheric basic state can be analyzed through a K_S field which provides a general view of the possible Rossby wave propagation paths. Using this theoretical basic concept, the distribution of the stationary wavenumber K_S for the austral winters with maximum (+σ) and minimum (–σ) frequency of occurrence of Generalized Frosts (GF) in the Argentina Wet Pampas was built.

The results showed that the distribution of K_S emphasizes the importance of the atmospheric jet as efficient waveguides –as indicated by the linear theory-, which is in agreement with previous studies (e.g., Hoskins and Ambrizzi 1993). However, important differences between both basic states were observed here.

The zonal extension of the K_s gradient on the polar side of the subtropical jet is a characteristic of the +σ winters. This region is delimited by an extended area where the wavenumber presents a discontinuity, i.e. K_S=0. The inhibited propagation of Rossby waves in this region would explain the curious separation of wave patterns that is observed on the previous days of generalized frost events in the +σ winters (Müller et al. 2005).

The basic state for the winter with minimum frequency of occurrence of frosts (–σ) there is a region of discontinuity of K_S on the polar side of the subtropical jet that covers a particularly large and latitudinally extended region over the midlatitudes of the Pacific Ocean. This configuration does not favor the trapping of Rossby waves before they reach the South America. The other K_S "nucleus" with similar characteristics is located over the continent upstream the Wet Pampa, there is a region of K_S=0 which can be responsible for moving the Rossby waves away from there. This region coincides with the main entrance region of synoptic systems in South America. This pattern suggests that although you can have synoptic systems activity during the winter, a generalized frost event only occurs if there is the right large scale atmospheric circulation environment.

In summary, from the analysis of global distribution of the stationary wavenumber (K_S) and the meridional cross sections in key places of the Southern Hemisphere, some hypothesis can be made about the trajectories followed by the Rossby waves particularly during the +σ and –σ GF periods over the Wet Pampa in Argentina. It seems that a wave disturbance generate, for instance, somewhere in the Indian Ocean will propagate to the east trapped inside the subtropical and subpolar waveguides. However a close look at the waveguides exit shows that they are dependent on the basic state. For the +σ basic state the waves are trapped up to the west coast of South America, where the two waveguides seems to coincide allowing an interaction between both. On the other hand, the –σ basic state shows shorter waveguides and the waves are free to propagate to the north or south of the jet exits before it reaches the South American continent. Therefore, a possible wave interaction in this case seems to be more difficult. In order to better understand the wave interaction Müller and Ambrizzi (2006) have carried out some numerical experiments using a primitive equation model. Their results showed a good agreement with those presented in the present analysis, suggesting that the hypothesis proposed here is robust.

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