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TELECONNECTION PATTERNS ASSOCIATED WITH EXTREME FREQUENCY OF GENERALIZED FROSTS. PART II: ORIGIN AND EVOLUTION OF THE ROSSBY WAVES PROPAGATION PATTERNS IN THE AUSTRAL HEMISPHERE

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1. INTRODUCTION

The identification of teleconnections and the analysis of their impact on the atmospheric circulation can be very useful for the understanding of anomalous events at many regions of the planet when one assume that local forcing may influence the atmosphere circulation at remote locations.

Hoskins and Karoly (1981) based on the theory of stationary Rossby wave dispersion on the sphere, provided a qualitative explanation about the nature of the wave trains and the teleconnection patterns. Most of their analysis was linked to the wave train patterns in the Northern Hemisphere and assuming a zonally varying basic state. Hoskins and Ambrizzi (1993) extended their linear analysis of the barotropic Rossby wave propagation considering longitudinally varying basic states. In this case, they showed a qualitative view of the atmosphere behavior related to the preferential regions of stationary Rossby wave propagation. In particular they demonstrated that a stationary forcing can create a stationary wave pattern around two weeks.

One of the most relevant results from the teleconnection pattern studies and it is related to the wave activity in the Austral winter of Southern Hemisphere is the presence of the subtropical and subpolar jets. As demonstrated by Ambrizzi et al. (1995) through simulations using a barotropic model and afterwards by Ambrizzi and Hoskins (1997) using a intermediate global circulation model, these jets can act as waveguides in the atmosphere. This feature is emphasized by the theoretical-observational study described in Müller and Ambrizzi (2006) that used composites of winters with extreme frequency of occurrence of Generalized Frost (GF) in the Wet Pampa, Argentina. In particular for the extreme represented by the winters with maximum frequency of GF (+σ –defined as one standard deviation above the average–), the composite of GF events shows Rossby wave propagation patterns along of the subtropical and subpolar jets reaching the South America (Müller et al., 2005). One interesting feature observed in these previous studies is the phase coincidence of these waves when they reach South America before the GF occurrence. Based on this result it was suggested that the wave phase coincidence is the dynamical mechanism that contribute to the GF events during the period of their maximum occurrence. In order to better understand this mechanism numerical simulations using a baroclinic model were carried out to analyze the origin and evolution of the wave trains responsible for creating the right environment for the occurrence of frosts over the productive region of the Wet Pampa in Argentina.

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2. DATA AND METHODOLOGY

The numerical simulations presented below were carried out using a baroclinic model (IGCM –Intermediate Global Circulation Model–), which is a good tool to analyze the physical mechanisms of planetary wave propagation patterns generated by a simple heating source (e.g., Ambrizzi and Hoskins 1997). As a basic state the model needs geopotential height, zonal and meridional wind and temperature at 12 sigma levels (1000, 925, 850, 700, 600, 500, 400, 300, 250, 150, and 100). The data was obtained from the NCEP/NCAR reanalysis data with a horizontal resolution of 2.5 degrees. The period used for the basic states are to the austral winters with maximum (minimum) frequency of +σ (–σ) GF as defined in Müller et al. (2005) and described by Müller and Ambrizzi (2006).

The model is integrated for 15 days which is enough to obtain a stationary pattern. It uses a heating source with a elliptical horizontal structure and fixed position (latitude and longitude). The vertical heating profile follows a cosine function with the maximum amplitude at 400 hPa corresponding to a 5ºC/day and decaying to zero at the top and surface. This value is equivalent to a latent heat release associated to 10mm of precipitation. Although one may question the realism of this heating source, its role here is purely as a Rossby wavemaker.

In order to simulate the wave trains responsible for the GF during the austral winter of maximum and minimum frequency of these events, two specific numerical experiments were done. In the first one, the forcing was placed at the Indian Ocean and the other one at the tropical west Pacific. The position of the first heating source was suggested by the analysis of Müller and Ambrizzi (2006, hereafter MA2006). The location of the second forcing coincides with the convection activity region observed in the +σ winter composites shown by Müller et al. (2005).

3. NUMERICAL SIMULATIONS

3.1 Basic State +σ

Taking into consideration the characteristics of the basic state of the GF maximum frequency obtained from MA2006, the position of the heating forcing was determined. One of the forcing is located in the region where there is a maximum in the zonal wind for the +σ basic state (Fig.1 of MA2006), i.e., around 45ºE, 40ºS, immediately upstream of the stationary wavenumber K_S=0 (Fig.3a, MA2006).The other forcing is related to the subtropical jet in the region immediately upstream of its main maximum, over the Indian Ocean (Fig.1d, Part I). Ambrizzi et al. (1995) in a numerical and observational analysis of the teleconnection patterns for the Southern Hemisphere austral winter using a basic state based on the climatological winters of the period 1979-1989, showed that this particular region has a strong teleconnection with South America. Therefore, for the numerical experiment described below two forcings were used to generate Rossby waves: one at the entrance of the zonal wind maximum (40ºE, 20ºS) and the other further south (45ºE, 40ºS) near a secondary zonal wind maximum, both characteristics as observed from the +σ winters (Fig.1b, MA2006).

The simulation of the meridional wind anomaly at 250 hPa for the day 14 of integration (Fig.1), suggests that the model is able to simulate a similar pattern to that obtained from the +σ GF composite events of Müller et al. (2005).

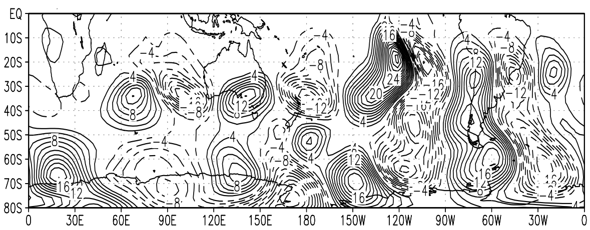

Figure 1: Meridional wind anomalies (m/s) at 250 hPa for the day 14 of integration for the basic state +σ with the heating sources at 40ºE, 20ºS and 45ºE, 40ºS.

It is seen that the wave train propagates around 30ºS from the Indian Ocean to the east Pacific along the subtropical jet. In the high latitudes, another wave train also moves along the south Pacific towards the Atlantic Ocean. Close to the South American west coast, one can clearly see the phase coincidence of the subpolar and subtropical waves, standing out the meridional extension of the pair of anomalies (positive and negative), when they merge on the windward side, as well as above the Andes mountains. In the observational analysis of Müller et al. (2005) it is possible to see the evolution of the wave trains propagating along the jets and the phase coincidence just before they entry the continent, previous a GF event. After that it moves as a unique system to the east-northeast.

It is worthy pointed out the important role that the subpolar jet has in directing the high latitude waves towards the South American continent. The theoretical analysis of MA2006 clearly shows this possibility and the baroclinic model was able to reproduce this pattern.

3.2 Basic state –σ

For the +σ, as well as the –σ basic state, the positioning of the forcings 40ºE, 20ºS and 45ºE, 40ºS is associated with the entrance region of the subtropical jet (see Fig.1b, MA2006), in the former one, while in the latter one is located upstream the region where the zonal wavenumber K_S=0 (see Fig.3, MA2006). Thus, the positioning of the exciting sources and its relationship with the mean characteristics of the basic state, are similar in both +σ and –σ cases.

Fig.2 shows the simulated field of the meridional wind anomaly at 250 hPa for the day 14 of integration.

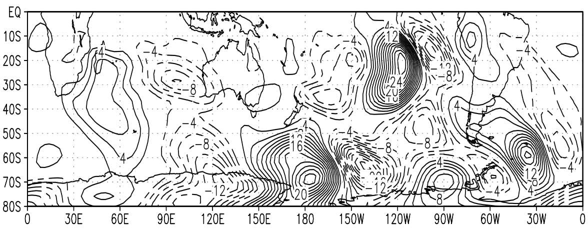

Figure 2: Same as Fig.1 but for the –σ basic state.

The wave propagation occurs along of the subtropical and subpolar waveguides, following the path suggested by the Ks field presented in Fig.3b of MA2006. Close to the South American continent there is a clear divergence between both waves over the continent upstream the Wet Pampa, just where the propagation is inhibited (see Fig.3b of MA2006). The subtropical wave acquires an equatorward curvature and the subpolar one cross the South America. Consequently, the positive meridional wind anomalies that stand out to the northeast and to the south of the continent do not merge into a single latitudinally extended anomaly as in the case of +σ. Therefore the wave phase coincidence observed in the +σ basic state does not happen here. This wave propagation pattern is in good agreement with the Ks analysis shown by MA2006. Since the subtropical waveguide is shorter than in the +σ field and the subpolar waveguide is weaker and slightly southward (Fig.3b and Fig.5 right panel, MA2006), a wave interaction seems to be much more difficult in this case.

3.3 Numerical experiment with a convective forcing

Many studies have demonstrated that a heating source and in particular over the tropical region, can disturb the atmosphere, generating planetary waves (e.g. Hoskins and Karoly 1981; Rasmusson and Mo 1993; Li et al. 1994; Ambrizzi and Hoskins 1997). Convective regions using the +σ basic state were identified by Müller et al. (2005) through the anomalies of Outgoing Long Wave Radiation (OLR) for the period 1974-1996 (NCEP/NCAR). They found two main anomalous convective regions in the Southern Hemisphere: one located in the western sub-equatorial Indian and Pacific Oceans, both with OLR values below the 240 W/m^2 thresholds, which indicates deep convective activity (Liebmann and Smith, 1996).

The result of the numerical experiment in the +σ basic state with the heat source in the sub-equatorial Indian Ocean does not show wavetrains propagating to South America (Müller, 2005). Instead, the simulation of anomalous convection over the Pacific Ocean approximately at 170ºE, 15ºS does show a wavetrain that reaches South America. From the meridional wind anomalies depicted in Fig.3, a

Rossby wave pattern is identified propagating in a arc like path towards the South America. When this wave train reaches the central part of South America, it creates a southerly wind anomaly in all the southern part of the continent. In this case the obtained pattern of propagation is not able to reproduce the observations (Müller et al., 2005), although it does create a wavetrain that reaches South America.

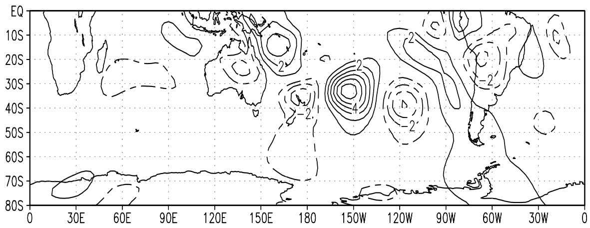

Fig.3: Same as Fig.1 but for the day 10 of integration and the heating source at 170ºE, 15ºS.

4. GENERAL DISCUSSION

The observational evidence (Müller et al., 2005) together with the knowledge obtained from the theoretical-observational analysis of MA2006 about the Southern Hemisphere teleconnection patterns associated to extreme cold events in the Wet Pampas, Argentina, were corroborated through numerical simulations using a baroclinic model (IGCM). The results found here showed the important of the Rossby waves to favor the development of Generalized Frosts (GF) as well as the role played by the jets to guide these waves towards the South American continent. In particular for the austral winters with maximum frequency of occurrence of GF (denominated here as +σ), the wave trains are conducted along of the subtropical and subpolar jets until near the continent. Before they entry the South America, their phase coincide previous to the event, forming one unique entity, favoring an intense and constant flux of polar air towards the Wet Pampa, developing more frequent and/or more persistent events of GF in the region.

The dynamical condition given by the phase coincidence of the waves that propagate along the jets, are simulated based on the physical characteristics present in the +σ basic state. Thus, the location of the heating sources used here is based in this basic state as discussed in MA2006. Through the analysis of the stationary wave patterns simulated it was possible to prove that the main wave activity occurs inside the subtropical and subpolar jets that guide the waves towards South America in both basic states, although they differ from each other in the obtained propagation pattern. However, some features of the basic state can be very important to determine the final trajectory of the waves. Simulations using +σ and –σ basic state have shown different wave propagation patterns. In particular, there is not any wave phase coincidence when –σ basic state is used. In fact a wave divergence close to the South American continent was observed in this case.

Another interesting result was obtained when the forcing was placed near the equatorial Pacific, mimicking a deep convective region. Although the wave propagation pattern produced reached the South America it did not create the right condition to develop a GF event.

In conclusion, it seems that the major frequency of generalized frost occurrences in the Wet Pampa is related to the propagation of Rossby wave trains remotely generated over the Indian Ocean, and is associated with the extension and intensity of the subtropical and subpolar waveguides linked to the respective jets.

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