A STATISTICAL-DYNAMICAL DIAGNOSTIC OF COLD-AIR OUTBREAKS IN TROPICAL SOUTH AMERICA

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ABSTRACT

A rotated extended empirical orthogonal function analysis was made over South America during winter in order to identify the significant patterns associated with the passage of migratory anticyclones across the extratropical portion of the Andes. The analysis of the structure and evolution of these patterns revealed that cold surge events that may produce freezing over southern Brazil are associated with the interaction between a cold front entering South America from the southwest and an upper-level trough that propagates eastward along subtropical latitudes. This interaction seems to take place two to three days before the freezes occur over southern Brazil.

1. INTRODUCTION

The passage of migratory anticyclones across the Andes at extratropical latitudes of South America is always associated with cooling and drying conditions there. Occasionally some of those systems, introduce cold surges that can lead to freezing temperatures (geadas) over south and central Brazil. The mechanisms that produce such differences in the propagation and evolution of anticyclonic systems are not yet well understood. Several papers have examined cold surges in tropical South America [Marengo et al. (1997) made an excellent compilation of them]. But most of them analyzed the associated mechanisms over individual cases.

The objective of this paper is to identify the differences in the structure and evolution of migratory anticyclones that evolve over South America during winter from a statistical analysis and to better understand the dynamical processes involved during cold surges.

2. DATA AND METHODOLOGY

The data set consists of six years (1983-1988) of European Centre for Medium-Range Weather Forecasts (ECMWF) daily 12 UTC analyses on a $2.5° \times 2.5°$ latitude-longitude grid.

A rotated extended empirical orthogonal function (REEOF) analysis was used to describe both the spatial and temporal evolution of synoptic scale disturbances during winter (in this paper winter refers to the austral season and is defined as the period from 1 June through 31 August). The extended empirical orthogonal function technique (Weare and Nasstrom, 1982) is designed to include the temporal structure in the basic observation vectors. Then, successive spatial patterns can describe the spatial and temporal evolution of the dominant modes. To maximize the local variance within the domain, the EEOF modes were rotated using the Varimax method.

To examine the structure and temporal evolution of waves over South America during winter, an REEOF analysis for four 1-day lag units was performed. The domain of our study is from 130^{o}W eastward to 20^{o}W and from 80^{o}S to $10\,^{o}$S. The REEOF analysis was applied to the unfiltered, normalized 850 hPa meridional wind perturbation series, defined as the difference between each value and the time mean for each season, thus removing any interannual variability from the series. No further filtering of the series was performed, since there is evidence that

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meridional wind variability is concentrated in the higher frequencies (e.g. 2-8 days), a fact that is more so in the Southern Hemisphere (Berbery and Vera, 1996).

In general the most significant patterns display the typical horizontal structure of baroclinic waves and they appear in pairs that have a quadrature phase shift, representing the propagation of the same local wave. The first pair of REEOFs is associated with fast eastward propagating waves along the subpolar jet region while the second pair of patterns is associated with slower waves that cross the Andes along the subtropical jet latitudes. In particular, the analysis of temporal coefficient series associated with the REEOF 4 shows that positive values of these coefficients are associated with the passage of an anticyclonic perturbation over South America. “Significant” situations are defined as when corresponding temporal coefficients have values larger than 0.8 times the standard deviation of the series.

Algarbe and Cavalcanti (1994) analyzed the series of extreme minimum temperature data from several stations over south Brazil and identified the strongest cooling episodes over that area during the winters of 10 years (1980-1989). Nine of them occurred during the period considered here (1983-1988). It was found that in the mean, those episodes took place one day after REEOF 4 was maximum. Therefore two sets of composite fields were constructed, one averaged over the situations that produced freezing episodes over southern Brazil (hereafter they will referred as GEADA event) and the other averaged over the rest of the significant situations associated with REEOF 4 but that did not give rise to cold-air outbreaks into subtropical and tropical latitudes (NO GEADA event). The statistical significance of all the composite anomaly fields was checked using a *t-test* at the 5% significance level. In the following section, attention will be focused on the description of the composites for GEADA event.

3. RESULTS

Figure 1(a)-(d) display the temporal evolution of the composite fields of 850 hPa geopotential height and temperature perturbations for the composites for GEADA event. This evolution is shown such that day 0 is the time that REEOF 4 is maximum (i.e., one day previous to the minimum temperature extreme determined by Algarbe and Cavalcanti (1994) over south of Brazil). At day -3 (Fig. 1a) an intensifying anticyclonic perturbation is slowly entering the continent from the Pacific ocean at around 42°S. From day -2 until day 0 (Fig. 1b-d), the perturbation surrounds the mountains with an anticyclonic “corner-effect” migrating abruptly to the north on the lee side of the Andes. The perturbation is associated with strong equatorward meridional heat fluxes that introduce cold air into subtropical and tropical regions. As a consequence, at day 0 (Fig. 1d) the negative temperature perturbation is largest over southern Brazil, Uruguay and east of Argentina. Downstream of the anticyclonic center, there are two cyclonic perturbations evolving. One of them is centered on day -3 (Fig. 1a) at 20°W, 55°S and is associated with a weakening frontal system that produces a temperature decay over the continent. The other cyclonic perturbation with center in 55°W, 60°S at day -2 (Fig. 1b) propagates very fast northeastwards. At day 0 (Fig. 1d) this perturbation intensifies and becomes more meridionally elongated. This perturbation is associated with another cold front that penetrates very deeply into South America above 20°S.

The temporal evolution of the composite fields of geopotential height and vorticity perturbations at 300 hPa is depicted in Figs. 1e-h . These figures show a strong anticyclonic perturbation over the Pacific ocean that propagates very slowly eastwards. At day -3 three main centers of cyclonic vorticity are evident (Fig. 1e), one located at 40°W, 40°S and associated with the frontal system in decadence over southeastern Brazil , a second center located at 75°W, 50°S and associated with the new frontal system entering from the southwest and a third center located at 75°W, 25°S associated with an upper-level trough that propagates very slowly from the Pacific ocean eastwards. From day -2 to day -1 (Fig. 1f-g) as both systems (the subtropical upper-level trough and the intensifying front) propagate, the corresponding geopotential height perturbations merge, forming a long wave pattern with a NW-SE horizontal tilt. Fig. 1h shows that at day 0 this cyclonic perturbation maximizes over the coast of Uruguay and south of Brazil.

The terms of the relative vorticity equation were computed, based on the composite fields for GEADA event at 850 hPa (figures not shown). It was found that the divergence term ($-\eta\nabla\bullet\mathbf{V}$, with η as the absolute vorticity and **V** as the wind vector) is the main term responsible for local changes of relative vorticity associated with the strong cold surge occurred between day –1 and day 0 (Fig. 1c-d). Fig. 2 displays a latitude-height section of vertical wind and horizontal divergence perturbations at day -2, averaged between 70°W and 60°W. A strong secondary circulation was found that is typical of growing synoptic scale waves (e.g., Lim and Wallace, 1991). The northern branch of such circulation locates at subtropical latitudes and is characterized by a region of strong convergence in lower levels, ascending flow with maximum in the middle troposphere and a region of enhanced divergence above. The southern branch is located at middle latitudes and exhibits a region of strong convergence in upper levels and descending flow below . It was found that the subtropical upper-level trough produces a flow to the south (Fig. 1f) in high levels that reinforces the descending branch of this secondary circulation. This fact seems to enhance the northwards flow in lower levels which is responsible for the abrupt entrance of cold air over south Brazil (Fig. 3).

From the analysis of the composite fields for NO GEADA event (figures not shown), it was found that anticyclonic systems that cross the Andes without leading to cold-air outbreaks in southern Brazil, are not accompanied by the presence of an upper-level trough at subtropical latitudes. The secondary circulation associated with those systems presents a weaker descending branch, located further south and thus, producing a weaker northward transport of cold air in lower levels.

From these results it can be concluded that the interaction between the upper-level trough, that propagates eastward at subtropical latitudes, and the cold front, that enters over the continent from the southwest, has a strong influence on the cold-air outbreak intensity. This interaction seems to take place around two to three days before the freezes occur over south Brazil.

Acknowledgments
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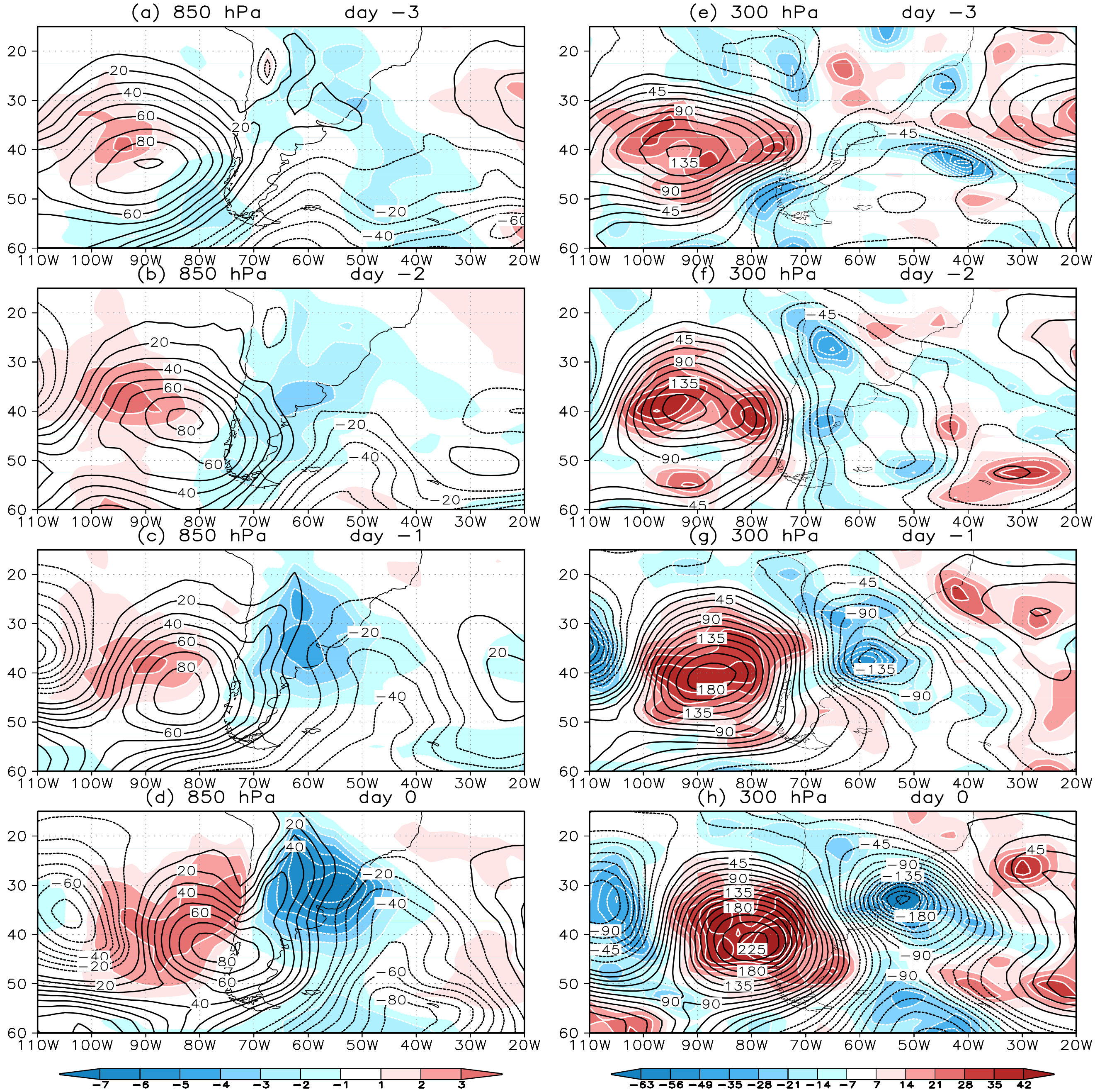

Figure 1: Composites for GEADA event from day –3 to day 0. (a)-(d) Geopotential height (contours) and temperature (shaded) perturbations at 850 hPa. Contour interval is 10 m. Shading interval is 1℃. (e)-(h) Geopotential height (contours) and vorticity (shaded) perturbations at 300 hPa. Contour interval is 15 m. Shading interval is $7x10^{-5}$ s^{-1}.

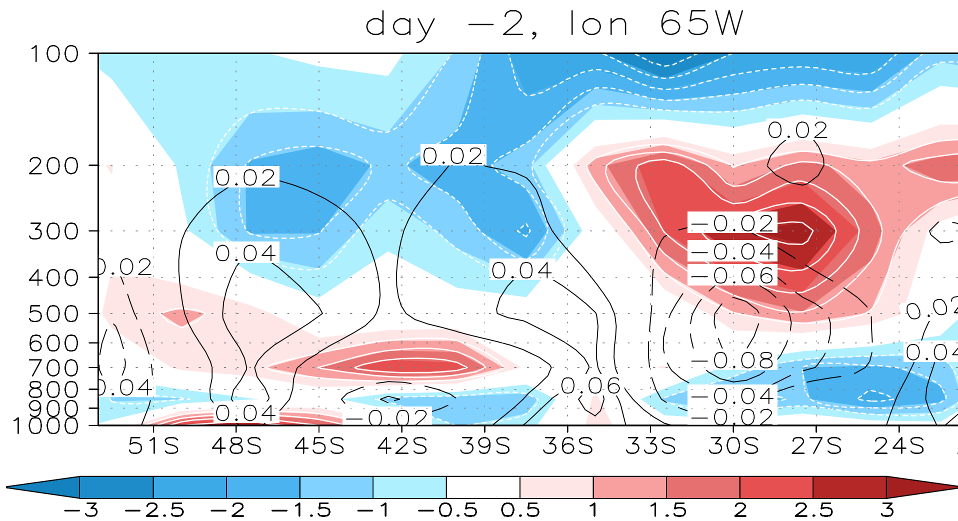

Figure 2: Latitude-height section of divergence (shaded) and vertical wind (contours) perturbations, averaged between 70°W and 60°W for GEADA event at day -2. Contour interval is 0.2 Pa s^{-1}. Shading interval is 0.5x10^{-5} s^{-1}

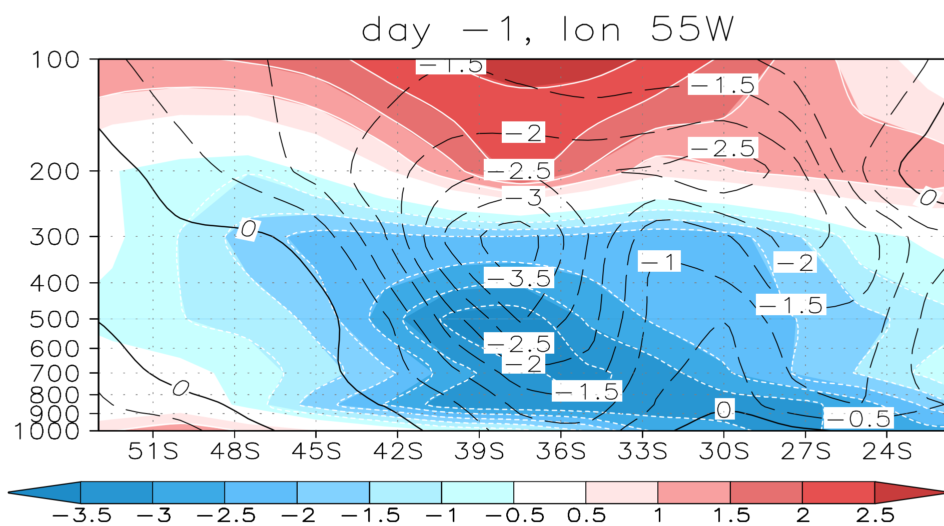

Figure 3: Latitude-height section of vorticity (contours) and temperature (shaded) perturbations, averaged between 60°W and 50°W for GEADA event at day -1. Contour interval is 0.5x10^{-5} s^{-1}. Shading interval is 0.5 °C.