Cold Surges in the Tropical and Extra tropical South America. Three cases of winter of 1994

José A. Marengo
Angel G. Cornejo
Prakky Satyamurty
Carlos A. Nobre
Centro de Previsão de Tempo e Estudos Climaticos (CPTEC),INPE
Rodovia Presidente Dutra Km. 40 . 12630-000 Cachoeira Paulista, São Paulo, Brasil

Abstract

We investigate the surges of polar air that occasionally propagate into southeastern Brazil during winter time and are harmful to coffee production, because of the freezing conditions related to them. The cooling is also felt in southern and with less intensity in the western Amazonia. We study three events of the winter of 1994: 26 June, 9 July and 4 August. These frost events caused a sharp drop in the coffee production and similarly dramatic increases in the world coffee prices. We performe an study of synoptic and climatic aspects of these cold surges episodes by using daily surface climatic observations for the June case study, and an analysis the dynamic aspects of this cold episode and to study the cooling mechanisms by using the 4-times a day surface and upper-air NCEP/NCAR reanalysis, in order to look for possible predictors.

1 Introduction

Freezing weather over the agricultural lands of southeastern Brazil is caused by outbreaks of polar air during wintertime. Events like these are known with the Portuguese name of *friagem (*plural: *friagens)* in the Amazon region, where they have a marked effect on tropical and extratropical weather. These cold surges occur several times per year producing low that could produce extensive freezes in this region, affecting a large part of the harvest of wheat, coffee, soybeans and oranges. For example, the Brazilian frosts in June and July 1994 caused a sharp drop in coffee production and similarly dramatic increases in coffee prices (according to Coffee, Sugar and Cocoa Exchange from New York, CSCE). Reports issued by the United States Department of Agriculture indicated that of losses in 1995 due to the frosts of June and July 1994 are 50-80% in Parana and Sao Paulo (Marengo et al. 1996a).

For the Amazon basin, few papers have analyzed the passage of the friagem of 1994. Marengo et al. (1996b) has showed that the greatest impact of the friagens of June was felt in southern Amazonia (site of Ji-Parána en Rondônia) as compared to sites in the north (Manaus and Marabá). On that occasion air temperatures in forested and deforested areas reached extreme low values near 10 °C. The largest minimum temperature drops in Ji-Parána took place at the same time as strong winds from the south were recorded. This implies that advection of cold air from southern latitudes would be the main mechanism for the falling temperatures. Synoptic conditions prior to and during the freezing days emphasize the role of a low-level cold-core anticyclone, which followed a track from Southern Chile to southern Brazil, have been detailed by Satyamurty et al. (1990), and Seluchi and Nery (1992).

Using quasi-geostrophic (QG) theory we will try to understand the different aspects of this phenomenon. For this purpose, dynamic fields of thermal advection, vorticity advection, and vorticity are to be used to explain the observed features. Based on our conclusions from preliminary analysis of weather patterns during some cold surges events, we will propose some working hypothesis for the mechanisms responsible for the cooling.

2 South American Cold Surges

Southeeastern Brazil, Amazonia, and adjacent regions experience a strong thrust of cool polar air from the south that manages to penetrate deeply into the tropics. These invasions represent the western flank of extensive cool air masses which have followed a continental trajectory equatorward between the Andean and Brazilian highlands. The current available literature about these South American cold surges documents the weather evolution during particular events of friagens and cold waves that affected Amazonia and the coffee growing areas of southeastern Brazil, respectively (see reviews in Fortune and Kousky 1983; Marengo et al. 1996a).

A typical weather evolution during the friagem is as follows: a transient cold core high pressure center moves onto the southern tip of South America, then intensifies while crossing Argentina 2 to 3 days later, and becomes stationary over the large Brazilian coffee region in the southeastern part of the country, 3 to 4 days after reaching the southern tip of South America. Cooling is usually preceded by an increase in surface pressure and a reduction in the atmospheric humidity. The temperature begins to drop at night, sometimes as much as 15 °C, while the pressure can rises up to 18 hPa (indicating the penetration of the cold front).

3 Data and Analysis

We used the global reanalysis produced by the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR), known as the NCEP/NCAR Reanalysis (Kalnay et al., 1996). 6-hourly surface and upper-air (1000, 925, 850, 700, 600, 500, 300 hPa) information were used with a 2.5° x 2.5° resolution. Additional information were the surface weather charts during the coldest days nearby 26 June from CPTEC, INMET, and SIMEPAR, and from the three sites of the ABRACOS experiment (Gash et al. 1996).

The NCEP/NCAR reanalysis at surface and upper-air are interpreted by using QG theory. The dynamical fields of thermal and vorticity advection were calculated in order to perform a diagnosis and to explain the observed features of the phenomena. Besides we have used diagnosed variables calculated from NCEP/NCAR as the vertical velocity and absolute vorticity. The vorticity and thermodynamic equations are used in several steps of the analysis to identify mechanisms for the observed changes. To diagnose the geopotential height field we use the QG geopotential tendency equation, and the QG omega equation will also be used for diagnosing the vertical velocity field.

4 Synoptic Near-Surface Situation

Air temperatures of -1.0 °C were registered on the 26 June at Foz do Iguaçu and on the coffee growing area near Londrina, respectively. In Londrina, air temperature dropped 15 °C from 24 to 26 June. In São Paulo, and Brasilia the coldest day was also 26 June with air temperatures 2.5, and 7.7 °C, lower than the average. In western Amazonia, the lowest temperatures reached during the coldest days were 11.3 °C for Rio Branco on 27 June, 13.6 °C for Iquitos on 28 June, and 10.5 °C on 26 June at Ji-Parana.

On the third week of June, the atmospheric flow over the South Pacific and the southwest-northeast orientation of the subtropical jet over the continent favored the movement of frontal systems and anticyclones into lower latitudes. During 23 June, an intense cold air mass entered the southern part of Brazil. The surface chart of the 12 Z 26 June, the coldest day in southern Brazil and Amazonia (Fig. 1). The high pressure center, with an intensity of 1026 hPa was located around 25 °S, 55 °W, and extending over most of Brazil between 15-30 °S, as well as over western Amazonia along the Andes as far as 5 S. It also shows the development of an intense cyclonic circulation at 52 °S and 47 °W and the interaction of this strong cyclone with the anticyclone over southern Brazil seems to produce the strong wind flow from the south detected all the way from south of 60 °S along the coast of Argentina, and reaching Uruguay and southern Brazil. The 1000-500 hPa height thickness show the relatively shallow layer over the areas affected by cold air in southern Brazil, as compared to regions such western Amazonia and central Brazil, where the 1000-500 hPa relatively thicker layer indicates less cooling on this region.

5 Dynamic Analysis and Diagnosis

We consider two steps in the evolution of the events: the *Starting* and the *Developing Periods*. In the first one, some characteristic perturbation is detected when it shows up near central and southern Chile in the Pacific Ocean. During the Developing period, several processes take place in southern South America conducing to the presence of low minimum temperatures over southeastern Brazil.

In Fig. 2 we present the basic elements of the phenomena. The upper ridge-trough pair and the High and Low Sea Level Pressure (SLP) in dark and light shaded respectively.

a Starting Period

LOW-TROPOSPHERIC (LT) TROUGHING: In this range we will consider the levels below those corresponding to the maximum vertical velocity which usually occurs at about 600 hPa. Perhaps one of the most important features in the Starting phase, is the LT trough that deepens near the Andes. The sum of the horizontal vorticity advection (AD_{vo}) and the divergence (DIVT) terms in the vorticity equation is shown in Fig. 10c. In general, both terms were of similar significance (not shown). The latter term is produced by column stretching due to the upward velocities. The most notable feature in Fig. 3 is the trough generation lee of the Andes in the 35°S-50 °S latitude range due to contributions AD_{vo} and DIV. As in the Low SLP case, this 700 hPa trough remained intense for several days east of the Andes, which may have kept substantial geopotential height gradients east of the Andes. The associated southerlies between the trough and the Cordillera may have produced equatorward cold advection channeled by the Andes.

INITIAL COOLING:In order to emphasize further the different processes in this stage we will define several indices. They all refer to an area we call CAR (Central Argentina) located lee of the Andes, where the he troughing mostly takes place during the Starting phase. In former sections we have seen that the presence of a low-tropospheric cold advection east of the Andes during the Starting phase, was a characteristic feature. In order to get an indicator for this process, an index called TAD7CAR has been defined as the average 700 hPa temperature advection over the CAR area. In Fig. 4 we notice that during the periods June 00 Z June 20 to 00 Z June 23 and 18 Z June 23 to 12 Z June 25, such an index remained negative indicating that cold air was being advected to the area. Coherently the average 500 hPa geopotential height in the same area called Z_{500} index, dropped during the same two cold periods indicating that an upper trough was being intensifying east of the Andes at those latitudes. Descending motions would have been associated with upper-level convergence, cyclonic vorticity changes and heights drops.

B Developing Period

LOW LEVEL ANTICYCLOGENESIS :In this section we will discuss the formation of the high SLP area which is shown in dark shaded in Fig. 8a. To indicate their growth rate, we define the index ΔZ_{850} as the average 850 hPa 6hr geopotential height change above the area near the Surface High (SH). It may be formed when descending motions associated with low-level cold advection tend to produce anticyclonic vorticity time changes and height rises. To test this hypothesis we define two other indices above the SH area. The $AD_{T:700}$ and ΔZ_{850} are the SH averages of the 700 hPa temperature advection and of the 850 hPa 6hr geopotential height change. In Fig. 5, we present the time series corresponding to those indices. Not unexpectedly, they were out of phase, e.g. negative (positive) $AD_{T:700}$ was associated with possitive (negative) values of ΔZ_{850}.

PROPOSED NEAR-SURFACE COOLING MECHANISM OVER SOUTHEASTERN BRAZIL (SB): The orientation of the high and low SLP (shaded) in Fig. 2, during the coldest day in SB, indicates that near-surface southwesterly winds would have been produced advecting cold air to SB from southern latitudes.

In order to diagnose the production of cold SB temperatures we define the $Z_{850}H$ index as the average 850 hPa geopotential height above the area near the SH. Similarly, $Z_{850}L$ is the average 850 hPa height near above the Surface Low (SL). Six hours time changes in the $\Delta_{Z850}H$ ($\Delta Z_{850}L$) indices are denoted by $\Delta Z_{850}H$ ($\Delta Z_{850}L$). Fig. 6 which shows the TSB and $Z_{850}H$-$Z_{850}L$ time series, suggests that the lowest SB temperatures were associated with a maximum in the near-surface geopotential heigh gradients, as indicated by the difference between $Z_{850}H$ and $Z_{850}L$, which would have produced strong southwestern winds to advect cool air from higher latitudes to SB.

6 Discussion: Conceptual Model

Fig. 7 is a schematic representation of the different common processes in the cases considered during the Starting (shaded) and Developing periods. In our discussion we will called day 0, the coldest day in southeastern Brazil. Similarly day -n (+n) will be the n-day before (after). Besides we will referred with a [] to the different instances indicated by numbers in Fig. 7. Based on the results presented in the preceding section, the following scenario for the phenomena is suggested. During day -4, a short wave upper-level trough were present west of the Andes at about central and southern Chile in the Pacific Ocean moving eastward into the continent. In response to the approaching trough, and due to the association between ascending motion [2 in the 700 hPa level in Fig. 7] with substantial CVA aloft [1; 500 hPa], a significant SLP deepening was produced initially at the western flank of the Andes and later on the other side [3; SURF]. During days -3 and -2, near surface equatorward cold advection due to the associated southerlies channeled by the Andes, was being produced [4; SURF]. At the same time due to the same upward motions [2; 700 hPa], during days -4 and -3, a trough deepening near the 700 hPa level, tended to occur near the Andes [3; 700 hPa]. Furthermore due to advective [4; 700 hPa] and adiabatic effects, a near 700 hPa cooling took place along the Andes [5; 700 hPa] which increased the zonal temperature gradients east of the cooling area [6; 700 hPa]. The end result of this phase was to have at day -2 , a deep trough in the lower-troposphere from about 600 hPa to the surface east of the Andes at about 65°W of longitude that would let cold air be advected eastward [7; 700 hPa] to amplify the upper trough [8; 500 hPa] during days -1 and 0, due to the associated descending motions with upper-level convergence, cyclonic vorticity changes and height drops during the Developing phase. At the same time, the near surface anticyclogenesis [8; SURF] is associated with the near 700 hPa cold advection [7; 700 hPa], through the descending motion with low level divergence, anticyclonic vorticity changes and height rises. On the other hand, the near surface cyclogenesis [9, SURF] is related to the upper CVA [8; 500 hPa] through the ascending motions and low-level pressure drops. The system moves estwardly eventually reaching SB producing significant temperature drops there. Our analysis suggest that the low SB [11; SURF] temperatures would be produced at least partially, by advective process [10; SURF], related to an adequate location and intensity of the near-surface anticyclogenesis and cyclogenesis regions ([8; SURF] and [9; SURF]).

7 References

Fortune, M., and V. E. Kousky, 1983: Two severe freezes in Brazil: precursors and synoptic evolution. *Mon. Wea. Rev.*, 111, 181-196.

Gash, J. H. C., C. A. Nobre, J. Roberts, R. Victoria, 1996: An overview of ABRACOS. pp. 1-14 in Amazonian Deforestation and Climate. Eds. J. H. C. Gash, C. Nobre, J. Roberts, R. Victoria. John Wiley and Sons. 1996.

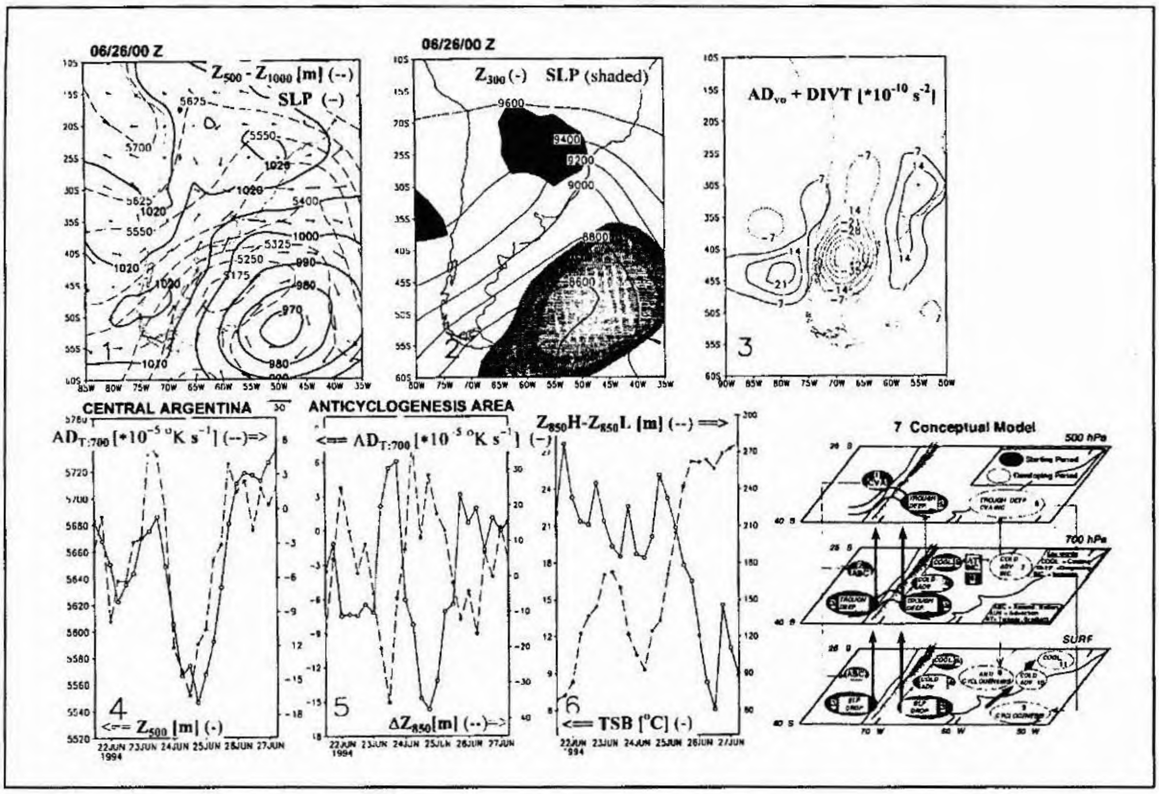
Kalnay, E., M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, S. Saha, G. White, J. Woollen, Y. Zhu, M. Chelliah, W. Ebisuzaki, W. Higgins, J. Janowiak, K. C. Mo, C. Ropelewski, J. Wang, A. Leetma, R. Reynolds, R. Jenne and D. Joseph, 1996: The NCEP/NCAR 40-Year Reanalysis Project. *Bull. Am. Met. Soc.*, **77**, 437-471.

Marengo, J., A. Cornejo, P. Satyamurty, C. Nobre, and W. Sea, 1996a: Cold surges in the tropical and extratropical South America. Three cases of winter of 1994. (Accepted, Mon. Wea. Rev.)).

Marengo, J., C. Nobre, and A. Culf, 1996b: Climatic impacts of the "Friagens" in forested and deforested regions in Amazon Basin (submitted to Journal of Applied Meteorology).

Satyamurty, P., P. Etchichury, C. Studzinsky, N. Calbete, R. Lopes, I. Glammelsbacher, and E. A Glammelsbacher, 1990: A primera friagem do 1990: Uma descripção sinótica. *Climanalise*, **5(5)**, 43-51.

Seluchi, M., and J. Nery, 1992: Condiciones meteorologicas asociadas a la ocurrencia de heladas en la region de Maringá. *Revista Brasileira de Meteorología*, **7**, 523-534.



Alguns Aspectos da Circulação Atmosférica de Grande Escala Durante O Emas

Maria Regina da Silva Aragão
Professora do Departamento de Ciências Atmosféricas - DCA
Zenaide Rosa Sobral
Professora do Departamento de Ciências Atmosféricas - DCA
Magaly de Fatima Correira
Professora do Departamento de Ciências Atmosféricas - DCA
CCT-PRAI-UFPB- Campus II

Abstract

Large-scale atmospheric systems which influenced Northeast Brazil in the period 24 March to 5 April 1995, during the "Experimento de Mesoescala na Atmosfera do Sertão (EMAS)", are identified. Daily Meteosat images in three spectral bands, surface and upper-air data are used. Preliminary results based on streamline analyses and satellite images show that during the experiment Northeast Brasil was dominated: (a) at upper levels, by the Northeast trough oriented in a northwest-southeast fashion or by an upper tropospheric cyclonic vortex centered over the oceanic region; (b) at mid-levels, by a trough with a meridionally oriented axis which is seen in most of the analyzed period and (c) at lower levels, by the South Atlantic subtropical anticyclone. Formation of upper tropospheric cyclones is seen in association with penetration of extratropical systems in south-southeastern Brazil. Cloudiness associated with the upper tropospheric trough/upper tropospheric cyclones interacts with the intertropical convergence zone over northern Northeast Brazil during the entire period of study.

1 Introdução

A realização do Experimento de Mesoescala na Atmosfera do Sertão (EMAS), no período de 24 de março a 5 de abril de 1995, possibilitou a coleta sistemática de dados com a resolução espacial e temporal necessária ao estudo da estrutura da atmosfera em mesoescala, visando sua utilização em estudos observacionais e numéricos. A área objeto do experimento foi a de um triângulo de mesoescala cujos vértices são as localidades de Fortaleza-CE (3º42'S - 38º33'W), Barbalha-CE (7º19'S - 39º18'W) e Campina Grande (7º13'S - 35º53'W). Nessas localidades foram realizadas observações de superfície e 3 a 4 sondagens de radiossonda-vento diariamente.