

TROPICAL-MID LATITUDE EXCHANGE OF AIR MASSES IN SOUTH AMERICA. PART. I: SOME CLIMATIC ASPECTS

José A. Marengo (1); Marcelo E. Seluchi

(1) Centro de Previsão de Tempo e Estudos Climáticos CPTEC/INPE, São Paulo, Brasil

ABSTRACT

Meridional transports of air masses between tropics and extra tropics in South America are the most intense in the entire Southern Hemisphere, mainly due to the presence of the Andes. The incursions of tropical air into mid-latitudes occur on the eastern side of the Andes in two preferred regions. The first is located in the tropical latitudes, close to the mountains between 20 and 30°S, and the second region is a function of the position of South Atlantic Convergence Zone (SACZ). The variability of the meridional transport is larger on the lee side of the Andes, due to the channeling effect of the mountain range, which favors baroclinic activity and allows an active exchange of air masses in both senses, especially during winter. The relevance of the air mass transport is also evident on the precipitation and surface temperature fields.

Introduction

South America is characterized by its unique topographic features. The Andes Mountains extend meridionally for more than 7,000 km, from 55 °S to the Northern Hemisphere, becoming a true wall for zonal flow in the entire Southern Hemisphere. The influence of this mountain range is larger on the latitudinal band between 10° and 40°S since the high altitude of the Andes completely blocks the westerly flow in the lower troposphere, and tends to strongly channel the meridional flow. In this respect several authors agree on the occurrence of a rapid northward propagation of transient pressure systems coming from the west, after crossing the Andes between 35-40°S (Gan and Rao, 1994, Seluchi et al., 1998, Marengo et al. 1997). This process favors the entrance of cold front systems into low latitudes, producing an exchange of air masses between the tropics and mid-latitude during both summer and winter (Marengo et al. 1997; Garreaud and Wallace 1998).

The main objective of this paper is to describe some climatic aspects of the air mass exchange between tropical and extra tropical latitudes of South America, the preferred regions where these exchanges take place, some of their possible origins and their most important effects on regional weather. To that purpose we used the NCEP/NCAR reanalyzes. The study is based on the analysis of mean annual fields of some dynamic and thermodynamic variables during the 1979-1995 period.

Results

The meridional component of the wind at 950 hPa (Fig.1) shows the contrast generated by the Andes: on the windward side the mountains tend to channel the northward flux from the subtropical Pacific high contributing to introduce air masses of polar origin

into equatorial latitudes, and to maintain the Humboldt oceanic current. On the other hand, on the lee side the northeasterly wind of tropical and subtropical origin is deflected to the south when it meets the Andes, resulting in an abrupt contrast in the meridional component of the wind. A map of the entire hemisphere meridional wind (not shown here) reveals that this “dipole” is the largest of any in the entire Southern Hemisphere.

The northerly flux at the lee side shows two regions of maximum speed: The first is located at the east side of the Andes between the Equator and 35°S and is divided south of 20°S in two subsections: one located over northeast Argentina-southern Brazil and the other on the eastern side of the Andes between 25-30°S. The second maximum is found over the Atlantic coast of the Brazilian southeastern states of Rio de Janeiro and Espirito Santo (20-25°S), and is related to the SACZ.

The nucleus of northerly wind velocity located inside the continent between 20-30°S (Fig. 1) is related to the transient activity. In particular, the section placed over northwestern Argentina and southeastern Brazil (near 55°W) is related to the Chaco Low (Lichtenstein 1989). This thermal-orographic low system (located around 25°S and 65°W), together with the subtropical Atlantic high, form a channel of northerly winds (see also Fig. 5), that brings moist warm air from equatorial and tropical latitudes into the Chaco-Pampa region. The northerly winds located immediately to the east of the Andes have different origins: even with the presence of the Chaco Low, the wind between it and the Andean slopes is not from the South, instead it is generated locally and displays an strong ageostrophic component. Several authors (Lichtenstein 1989; Gan and Rao 1994; Seluchi et al. 1998) indicated that transient anticyclones over South America usually migrate northward behind cold fronts. Due to the channeling effect of the Andes these high-pressure systems move northward following a meridional track over the center of the continent, leaving a region to the west which is dominated by northerly winds.

The vertical cross section of meridional component of the wind along 25°S (Fig. 2) helps identify the channeling effect of the Andes, which is stronger in the lower troposphere, and gradually decreases upward. Southerly wind at the windward side of the mountains is maximum at the lower levels, and reverses above approximately 500 hPa. On the leeward side, two maximum of southward flow can be detected nearby the 900 hPa level, located over the 53°W and 37°W, associated to the Chaco Low and the SACZ, respectively. In the upper-troposphere, it is detected an anticyclonic circulation between 90°W and 35°W related to the upper-level Bolivian high.

Fig. 3 shows a vertical cross section of mean annual potential temperature, at 25°S. Differences in the vertical gradient of potential temperature at both sides of the Andes reveal stability conditions very different in the lower troposphere. On the windward side, strong subsidence produced by the Subtropical Pacific high generates a stationary thermal inversion between 800 and 900 hPa, which practically does not allow the surface air masses to cross the Andes, where heights are lower than 5000m. This is one reason why the winds from the south tend to decrease their intensity above 900 hPa. Above this inversion, the upper air mass from the west can cross the Andes easily, producing a Föhn effect on the lee side, which can be detected by the abrupt decrease of the potential temperature gradient at the lee side. The warming generated by the vertical stretching that systematically is experienced the air masses coming from the west, is one of the causes of generation of the Chaco Low (Lichtenstein 1989).

The mean annual 1000 hPa geopotential height and 925 hPa winds at lower levels (Fig. 4) reveal that the westerly winds extend from high latitudes to the 38-40°S band. In particular, south of 38°S the Andes are relatively low, that is why the surface winds can

cross the mountains producing a Foehn effect that dries the air at the lee side. The channeling effect of the Andes is, on the other hand, evident north of 35°S where the air currents are parallel to the mountain range without crossing the Andes at lower levels. Over the continent, one of the main features is the Chaco Low, centered at 23°S and 60°W. However, comparisons made with older climatic maps (Hoffmann 1975) prepared with a relatively larger number of surface stations, reveal that this thermal depression normally is located around 65°W and 25 °S, which is 5° to the west of the position depicted by the NCEP reanalyzes. This could also indicate that the maximum of northerly wind observed at 60-55°W in Fig. 4 could be actually located 5° to the west. Thus, comparing Figs. 1 and 4, it is possible to conclude that in general the incursion of tropical air masses occurs between the Chaco Low and the subtropical Atlantic high, from the equator to 40-45°S.

The channeling effect of the Andes can be also observed using the standard deviation of the geopotential height at the 1000 hPa level (Fig. 5). The strong variability observed on the east of the mountains, indicates that the persistent baroclinic activity associated with the transient pressure systems sometimes moves to lower latitudes. In contrast, on the windward side, the presence of the subtropical Pacific high and the frontolitic action of the Andes (Seluchi et al. 1998) makes the migration of cold fronts to the north more difficult. The diurnal variability of the meridional wind component (not shown) displays a behavior similar to that of geopotential height (Fig. 6), but in this case the standard deviation associated with the SACZ is slightly larger than the one obtained over 65°W. This indicates that the slow movement typical of the SACZ produces local variations in the meridional wind, which are larger than the variations in height.

Fig. 6 displays the specific humidity in the lower troposphere (925 hPa) in which the contrast due to the orography is again evident. The humidity content shows a minimum over the Pacific coast due to the dominance of southerly winds that bring dryer air masses. On the other hand, the predominance of northerly flow on the lee side extends the influence of tropical air masses until 35 or 40°S depending on the season of the year. The humidity contents in the southern part of the continent, specially at the lee side of the Andes, is quite small since the air masses coming from the Pacific Ocean are affected by a Foehn effect. In contrast, a relative maximum can be observed on the windward side around 73°W originating from orographical precipitation. The largest mixing ratios in South America are found over the region where the SACZ is located and over the northern part of the continent.

The variability of the equivalent potential temperature (Fig. 7) can be considered an indicator of the frontal activity, as well as of the exchange of air masses. The strong frontogenetic effect of the Andes is suggested in Fig. 7, where the major air mass exchanges take place immediately to the east of the mountains, with a maximum near the Chaco Low. In fact, even though the northerly flow dominates over the continent on the average (see Fig. 1), alternations of incursions of cold or warm air masses due to frontal penetrations is noted. Over oceanic regions, there is greater homogeneity in air masses behavior due to weaker frontal activity.

The mean annual outgoing longwave radiation (OLR) shows areas with convective activity (values less than a 240 w m^{-2}) over the Amazon basin, extending to the south encompassing the SACZ (Fig. 8). Compared to Fig. 1, it is observed that the convective clouds associated to the SACZ are located on average, to the south of the maximum of northerly wind in the region where largest speed gradients and wind convergences are found. Mean annual precipitation (Fig. 9) closely resembles the OLR pattern, with large

rainfall amounts in Amazonia extending to the southeast along the SACZ. The rainfall maps are consistent with the observational analyses of Figueroa and Nobre (1990). A comparison between Fig. 9 and Fig. 1 shows that precipitation north of 35°S depends mainly from the contribution of tropical and humid air masses from the north, which are later intercepted by the frontal systems coming from higher latitudes. It is important to note that other rainfall maps based on station data with a better coverage show the precipitation band located on the east side of the Andes extending meridionally reaching 30°S latitude, without the maximum of 3000 mm around 23°S shown on Fig. 9. Moreover, a region of large rainfall amounts located on the southern extreme of the continent appears as a narrower band immediately west of the Andes in the maps of Hoffmann (1975). This may be due to the lower resolution of the NCEP reanalysis.

Acknowledgments: This research was supported by the (CNPq), the IAI and the Commission of the European Communities.

References

- Figueroa, S., and Nobre, C., 1990: Precipitation distribution over central and western tropical South America. *Climanálise*, **5**, 36-40.*
- Gan M.A.; Rao V.B., 1994: The influence of the Andes Cordillera on Transient disturbances. *Mon. Wea. Rev.* **122**, 1141-1157.*
- Garreaud, R., Wallace, J. M., 1998: Summertime incursions of Mid-Latitude air into subtropical and tropical South America. In press. *Mon Wea Rev.**
- Hoffmann J.A., 1975: *Climatic Atlas of South America I OMM-UNESCO*, Printed by Cartographia, Budapest, Hungary. 33 pp.*
- Lichtenstein E.R., 1989: Some influences of the Andes Cordillera on the synoptic scale circulation.. *Third Int.l Conh on S.H. Met. and Oc.. Bs As, Arg . pp. 146-148. AMS**
- Marengo J., A. Cornejo., P. Satyamurty, C. Nobre, W. Sea: 1997: Cold waves in tropical and extratropical South America. The strong event of June 1994, *M. W. R.* **125**, 2759-2786.*
- Seluchi, M.E., H. Le Treut and V.Y. Serafini, 1998: The Impact of the Andes Cordillera on the Transient Activity: A Comparison between Observations and The LMD_GCM. *M. W. R.*, **126**.*

Figure Captions

Figure 1: Mean annual meridional component of the wind at 950 hPa (each 2m/s). Full (broken) lines represent southern (northern) winds.

Figure 2: Vertical cross section of the meridional component of the wind (each 1m/s) at 25°S. Full (broken) lines represents southern (northern) winds.

Figure 3: Vertical cross section of the mean annual potential temperature (each 3°K) at 25°S.

Figure 4: Mean annual 1000 hPa geopotential height (each 40 gpm) and 950 hPa wind (m/s).

Figure 5: Mean annual standard deviation of the 1000 hPa (gpm). Contour interval is 40 gpm.

Figure 6: Mean annual specific humidity (g/Kg). Contour interval is 0.5 g/Kg.

Figure 7: Mean annual standard deviation of the equivalent potential temperature (each .5°K).

Figure 8: Mean annual outgoing long-wave radiation OLR (each 10 W m⁻²).

Figure 9: Mean annual precipitation (mm year⁻¹). Contour interval is 1000 mm year⁻¹

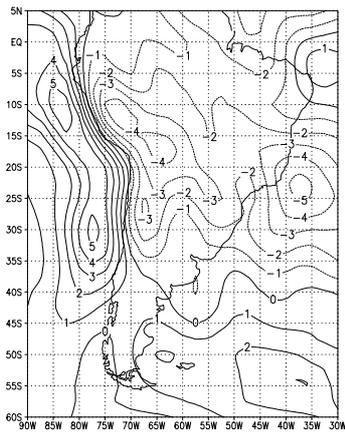


Fig. 1

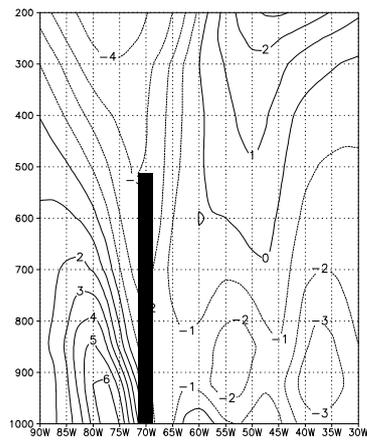


Fig. 2

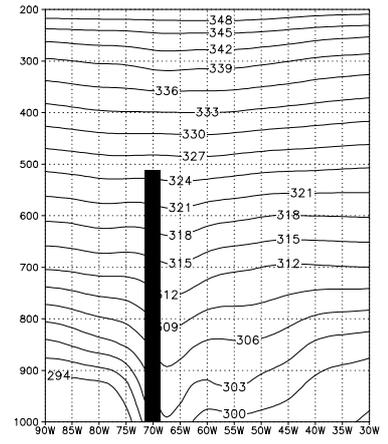


Fig. 3

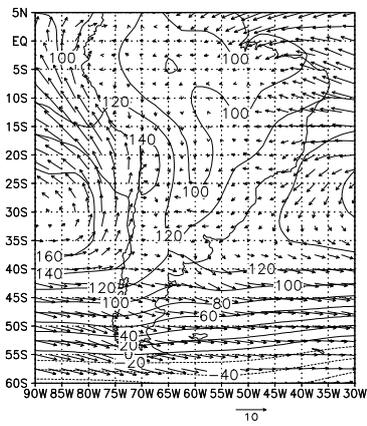


Fig. 4

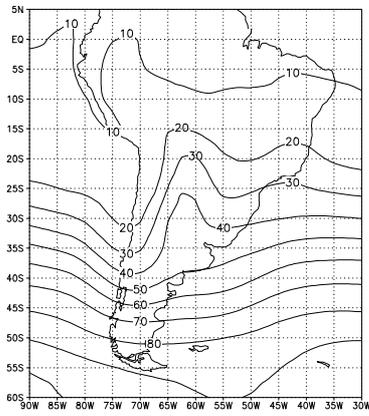


Fig. 5

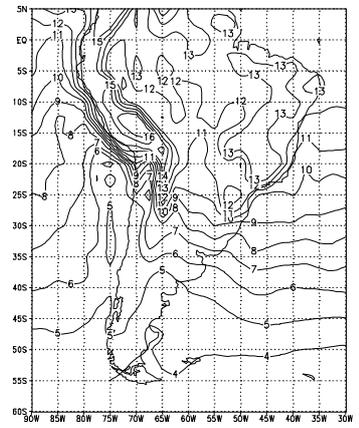


Fig. 6

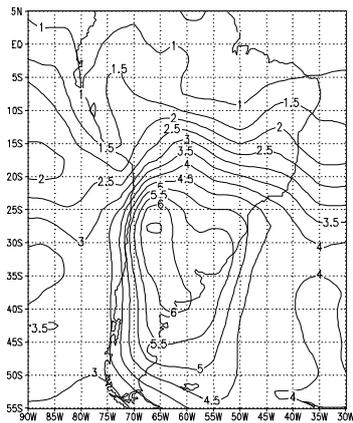


Fig. 7

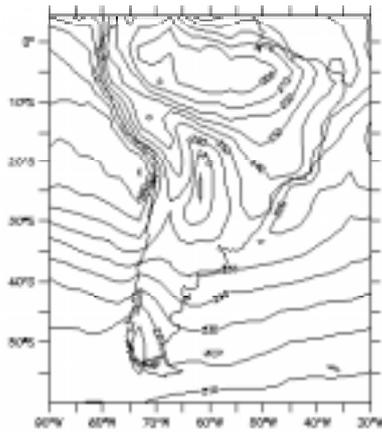


Fig. 8

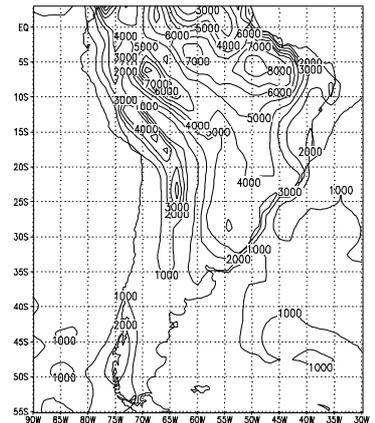


Fig. 9