Transient behavior of the meridional moisture transport across South America and its relation to atmospheric circulation patterns

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Abstract. The transient behavior of meridional moisture transport across the South American continent is examined with the reanalysis data provided by the European Centre for Medium-range Weather Forecasts (ECMWF). The results show clearly the effects of the valley between the Andes and the Brazilian Plateau in canalizing the southward moisture transport: an intense jet is episodically formed in this valley. The synoptic variability of this low-level jet and its relation to the large-scale atmospheric circulation are studied.

Introduction

Atmospheric moisture transport from the warm and wet Amazonian basin is essential to maintain the hydrological conditions of Southern Brazil and Northern Argentina, a key economic area of the South American continent. This transport is strongly affected by the specific topography of South America, which presents a striking meridional orientation (Fig. 1). The Andes and the Bolivian Plateau to the west and the Brazilian Plateau to the east form a broad corridor which connects the continent's wet northern region to its drier and colder southern part. Recent studies show that the southward moisture transport carried out by a low-level jet through this corridor determines largely the hydrological balance of the latter region and its variability [*Mo and Higgins,* 1996; *Nogués-Paegle and Mo,* 1997].

Fig. 1

This moisture transport is not entirely controlled by the topography, of course, but appears to depend also on the large-scale patterns of the atmospheric circulation. Similar to the well-known Pacific-North-American pattern, a wavetrain structure also exists in the Southern Hemisphere. It extends from the central Pacific to Argentina, modulates the precipitation over South America, and is generally referred to as the Pacific-South-American (PSA) pattern [*Mo and Ghil,* 1987; *Ghil and Mo,* 1991; *Lau et al.,* 1994; *Mo and Higgins,* 1998]. The South Atlantic Convergence Zone (SACZ) is another important component of the regional atmospheric circulation, and significant convection and rain systems are associated with its variation [*Kousky and*

Kayano, 1994]. Rossby waves generated by Amazonian convection cause major perturbations on time scales from synoptic to intraseasonal [*Kalnay et al.,* 1986; *Zhou and Lau,* 1998]. Cold air surges from the Antarctica also contribute largely to regional synoptic developments. These surges occur mainly in austral winter [*Marengo et al.,* 1997], but their impact on the continent's precipitation field is even greater during summer [*Garreaud and Wallace,* 1998].

The purpose of our study is twofold: first define an index that best describes the main modes of the time evolution of the continent's North-South moisture transport; second, use this index to determine the behavior of changes in this transport and their large-scale atmospheric context. The data used in this study are from the ECMWF reanalysis (ERA) project [*Gibson et al.,* 1996], and cover the 1979 to 1993 time span. The ECMWF data assimilation system is based on a state-of-the-art spectral general circulation model at T106 resolution. The original data are given at the model's full resolution of 1.125°lat. $\times$ 1.125°long., four times per day on standard pressure levels. To reduce the data-manipulation difficulties, we have used daily averages interpolated onto a grid of 2.5°lat. $\times$ 2.5°long.

Definition of a characteristic index

To evaluate the meridional moisture transport, we consider an East-West vertical cross-section at 27.5°S, close to the southern end of the corridor, between 70°W and 45°W (see Fig. 1). We use the meridional wind v and the specific humidity q to compute respectively the mean transport $\overline{v}\ \overline{q}$ and transient transport $\overline{v'q'}$, where the overbar denotes a time average, and the prime denotes a departure from this time average. We use the calendar month as our basic averaging interval; that is, we calculate the means $\overline{v}$ and $\overline{q}$, and the covariances $\overline{vq}$ for each of the twelve calendar months. The transient transport is then obtained by $\overline{v'q'} = \overline{vq} - \overline{v}\ \overline{q}$.

Figure 2 shows the moisture transport across this section for austral summer (DJF) and winter (JJA) respectively. The seasonal quantities are the 3-month average of the monthly values defined above. A mean southward transport can be observed throughout the year (Figs. 2a,b). Its pattern is related to the Southern Hemisphere's semi-permanent centers of action and presents two maxima: the eastern is probably associated with the South Atlantic anticyclone and is slightly more intense in JJA than in DJF; the western one is probably associated with the Chaco low and is stronger in DJF than in JJA.

The transient transport reflects the effects of short-

term variations in wind and/or water vapor. It has a jet-like structure and is much more intense, as expected, during the austral winter. The geographical location of this transient-transport maximum corresponds to that of the broad North-South corridor.

In order to select the most significant modes of the moisture transport variations, an empirical orthogonal function (EOF) analysis was applied to the day-to-day variability of the moisture transport field. Figure 3a shows the leading EOF, which represents 47% of the total variance. It is clearly associated with the channel effect — visible already in Figs. 2c,d — with the core of the activity at 925 hPa and 58°W. We use therefore the principal component (not shown) of the first EOF to characterize the North-South transport variability. An index is obtained by normalizing the leading principal component by its standard deviation; it allows us to evaluate the association of intense events of southward moisture transport with large-scale conditions.

Figure 3

The power spectrum of this index (Fig. 3b) was obtained by using the multi-taper method as implemented in the toolkit of *Dettinger et al.* [1995]; the method was applied to a 3-day running average of the index. Three peaks rise above the 99% confidence level in Fig. 3b; they correspond to periods of 24, 11 and 9 days. The former corresponds to the mode of *Ghil and Mo* [1991], who found this mode to have a period of 21 to 26 days and dominate the Southern Hemisphere's intraseasonal variability; the latter two are new.

Atmospheric patterns related to intense events

We now use the day-to-day index to isolate the events of intense southward moisture transport. The threshold for intense events is chosen as 1.2, i.e., when the index is 20% larger than its standard deviation; 15% of the days are defined, in this manner, as intense events. Table 1 gives the statistics for the length of the intense-transport events. Their vast majority lasts less than four days, but several events last one week or longer.

Table 1

Figures 4a and 4b display the composite precipitation anomalies (ERA dataset's 12-hour forecasts) for the intense events for DJF and JJA respectively. For austral summer, a seesaw structure is obtained with excess wetness to the south of our east-west cross-section and a dry situation to the north of it. This is in agreement with the results of *Nogués-Paegle and Mo* [1997], obtained from the Outgoing Longwave Radiation (OLR) data. The SACZ is active in austral summer, and the precipitation seesaw structure is related to the SACZ's north-south displacement. For austral winter, the SACZ is

Figures 4

very weak or non existent, but the seesaw structure in precipitation is still visible, especially its southern pole, with excess values over the North-East of Argentina and the South of the Andes chain.

The OLR composites in Figs. 4c and 4d are obtained from the daily OLR dataset of *Liebmann and Smith* [1996] by indexing to our selected intense events. OLR is a good proxy for precipitation and changes in water vapor content: negative anomalies are a manifestation of increased cloudiness and water vapor while positive anomalies are usually indicative of suppressed cloudiness and a drier atmosphere. The wet-dry seesaw structure given by the ERA precipitation anomalies (Figs. 4a,b) is clearly confirmed by the OLR data. It follows that, all year round, this seesaw structure is tightly related to the intense southward moisture transport through the corridor.

The composite maps of geopotential height anomaly at 300 hPa are shown in Figs. 5a,b for DJF and JJA respectively. A dipole structure can be observed around the southern tip of South America for both DJF and JJA: a negative center to the southwest and a positive center to the northeast. This dipole strongly favors the southward moisture transport; it is stronger in JJA than in DJF, which explains the stronger transient moisture transport in JJA (Fig. 2).

Figs. 5

On the planetary scale, a standing wavetrain follows roughly the track of the subpolar jet and is particularly visible for DJF, when the second upstream anomaly is very strong by positive. The wavetrain is more confined to the regional scale for JJA. All these features point to the PSA pattern first described by *Mo and Ghil* [1987] and *Ghil and Mo* [1991], and by many authors since [*Lau et al.,* 1994; *Mo and Higgins,* 1998]. The intense events of southward moisture transport channeled by the north-south corridor in Fig. 1 are thus related to the particular phase of the large-scale PSA mode that favors southward circulation through the corridor. The wet or dry conditions over the South American continent are thus controlled by large-scale flow patterns that open or close the door for the southward moisture transport through the corridor. The mechanism of this teleconnection is not yet totally elucidated, but some numerical studies [*Kalnay et al.,* 1986; *Grimm and Silva Dias,* 1995] suggest a barotropic Rossby-wave propagation mechanism.

If we compare the geographical location of the centers of activity between 300 hPa (Fig. 5) and 850 hPa (not shown), we find that they are very close to each other, with a pattern correlation coefficient that reaches 0.88. An even stronger correlation (0.92) is obtained when

the upper-layer anomaly map is shifted westward by 5° in longitude, which indicates weak baroclinicity of the large-scale structure.

Conclusion

By using the ECMWF reanalysis (ERA) data from 1979 to 1993, we have examined the behavior of the meridional moisture transport across the mid-latitudes of the South American continent. Strong events of southward transient transport take place episodically in the broad corridor between the Andes and the Brazilian Plateau. Our results highlight the role of this natural corridor in connecting the continent's northern (tropical) and southern (extratropical) parts, since it channels the best-organized part of the transport variations, as described by the leading EOF of our moisture-transport analysis. We derived an index to study the association of intense transport events with large-scale atmospheric flow patterns. In austral summer, the intense events of southward moisture transport are tightly related to a north-south seesaw in precipitation as already suggested by *Nogués-Paegle and Mo* [1997]. We showed that this seesaw pattern is also present but weaker in winter.

More importantly, southward moisture transport is associated with a regional-scale dipole pattern in the geopotential field which favors strong southward winds throught the corridor. We showed that this dipole pattern is related to a particular phase of the large-scale PSA mode and is therefore teleconnected, probably through a barotropic wave-propagation mechanism, to perturbations over the South Pacific. This teleconnection is particularly strong in austral summer, while the atmospheric circulation anomalies are more regionally confined in winter. Other mechanisms can also affect the continent's north-south moisture transport, such as interaction of the subpolar jet with topography or tropical convective perturbations. Further studies using high-resolution numerical models will be needed to determine the contribution of each mechanism in controlling the alternating wet and dry situations in mid-latitude South America.

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Figure 1. Topography of the South American continent, as represented in the ECMWF T106 model; areas higher than 500 m are shaded.

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Figure 2. Mean (upper panels) and transient (lower panels) components of the meridional moisture transport for December-January-February (DJF: left panels) and June-July-August (JJA: right panels) across a vertical section at 27.5°S. Unit is 10^{-3} kg m s^{-1} and negative values indicate southward transport.

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Figure 3. (a) Leading EOF of the day-to-day moisture transport field. (b) Spectrum of the leading principal component (solid line); confidence levels of 95% (dotted line) and 99% (dashed line) are based on a null hypothesis of colored noise.

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Figure 4. ERA precipitation anomalies corresponding to intense events of southward moisture transport for (a) austral summer (DJF), and (b) austral winter (JJA). Panels (c) and (d) are the same as in (a) and (b), but for satellite-based outgoing longwave radiation (OLR) anomalies.

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Figure 5. Geopotential height anomalies at 300 hPa that correspond to events of intense southward moisture transport, for (a) DJF and (b) JJA.

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Table 1. Number of events of intense southward moisture transport, as a function of their length.

Length (days)	1	2	3	4	5	6	7	>8
Nb. of events	206	121	42	30	8	6	4	4

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