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Analysis of moisture transport from Amazonia to the Southeastern Brazil during the austral summer

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Abstract: The moisture transport from the Amazon to the southern part of Brazil is an important atmospheric mechanism that contributes to the high precipitation rates during the austral summer (DJF) in this region, or more specifically, in the Sao Paulo state. This transport originates from the entrance of moisture from the Equatorial Atlantic Ocean, moving inland of the Amazon, where it's quantity was increased by the rain forest evapotranspiration. After this supply, the moisture flow is diverted to higher latitudes (South and Southeast parts from Brazil) due to the Andes mountain range. The integrated vertical moisture transport (from the surface up to 500hPa) was studied for contrasting years (during El Niño Southern Oscillation (ENSO) events and for neutral years). The results show an intensification of this flow for El Niño events. In neutral years, there approximately 45.1 kg / kg enter the Amazon territory and around 27.5 kg / kg of this moisture exits, and while the region of São Paulo receives an average amount of 8.9 kg / kg and looses 7kg / kg. When a ENSO phenomenon occurs, the flow pattern increases significantly in the two regions: the input (54.8 kg / kg) and the outflow (47.4 kg / kg) in Amazon are larger, while São Paulo receive 42, 2 kg / kg and looses 11.8 kg / kg of all moisture received. In years of ENSO, there is an intensification of the jet stream in the central part of Brazil, blocking the passage of frontal systems.

Keywords: Climate; Moisture Transport; Aerial Rivers

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1. Introduction

The summers of 2013/14 and 2014/15 were marked by extreme drought events, especially in the Southeast region of Brazil. This event reflected directly in the Society, as, water rationing occurred in many cities in the state of Sao Paulo due to the small quantity in the reservoirs. This event, caused by a global atmospheric scale phenomenon, originate a very strong system of high pressure in the central part of Brazil acting as an atmospheric blockade, thus preventing formation of rain clouds and the passage of frontal systems (COELHO, 2015). Observing the accumulated annual rainfall of the entire affected area for the Summer 2013/14, we can observe that it was a very anomalous period in relation to both the climatological normal (1.450 mm) and the recorded minimum (1,169 mm) (KOUSKY 1988; LIEBMANN et al 2002). One of the most important atmospheric phenomena in South America is the transport of moisture from the Amazon forest region to the South and Southeast of Brazil, is a process carried out by the general circulation of the atmosphere with oceanic and continental influence responsible for the distribution of rainfall in throughout the continent (ARRAUT and SATYAMURTY, 2009). This process has several mechanisms, one of the most important being the South Atlantic Convergence Zone (SACZ). This phenomenon was studied by HERDIES et al., (2002), who observed an intense low level jet (JBN) transporting tropical moisture from the Amazon to the subtropics, generating convergence of the moisture flow and precipitation in Amazonas and to the Southeast region. However, a divergence of this flow is observed in eastern Brazil, northeast Argentina, Paraguay, southern Bolivia and northern Chile, due to the weakening of moisture transport to the Rio de la Plata basin. The ZCAS is the atmospheric system responsible for large volumes of rain in the austral summer, ie in the months of December, January and February (DJF). During this season, the zone of maximum cloud coverage, precipitation and mass convergence is located to the north of the SACZ. Another phenomenon of ocean / atmosphere interaction that affects South America is the El Niño Southern Oscillation (ENSO) (SAMPAIO, 2001). At the global scale, the El Niño occurs due to the abnormal heating of the waters of the Equatorial Pacific Ocean, thus causing changes, especially in South America, in temperature and precipitation. In particular, in Brazil, El Niño causes significant effects in the different parts of the country, causing an increase in precipitation in the South (due to the increase in the intensity of the jet stream which, in turn, prevents the advancement of cold fronts for the Southeast of Brazil). In na opposite way precipitation decrease in the Northeast and part of the North region (Amazon). The main objectives of this work are: to quantify the transport of moisture from the Amazon to the southeast region, analyzing the possible effect of the ENSO events on the rainfall at Sao Paulo state.

2. Experiments

Initially, a study of the climate, in particular the distribution of rainfall in the regions of the Amazon rainforest and of the state of Sao Paulo was performed to understand all the mechanisms that act on normal and anomalous conditions in these regions. For this purpose, a series of maps and graphs of moisture transportation in Brazil were elaborated on annual and seasonal time scales.

All data related to calculation of moisture transport were obtained from NCEP/NCAR website and precipitation dataset from GPCP (https://www.esrl.noaa.gov/psd/data/gridded/data.gpcp.html) datas. It was possible to perform several calculations, such as: monthly total averages, annual averages, anomalies and composites, among other operations. With all the files treated and using the variables: wind, atmospheric pressure and specific humidity, the integrated vertical moisture flow (from the surface up to the 500hPa level) was performed to analyze the behavior on a temporal scale, highlighting extreme years, that is, years with heavy rain (higher above climatological mean) and high transport of humidity and years with little rain (lower than climatological mean) and with a low intensity transport. This integrated flow is calculated by the following equation:

$$Qu = \frac{1}{g} \int_{pt}^{po} qudp$$

$$Qv = \frac{1}{g} \int_{pt}^{po} qvdp$$

where Qu and Qv represent moisture transport by the zonal (u) and meridional wind components, g is the acceleration due to gravity, q is specific humidity, Pt represents the pressure in the upper part of the integration domain (500hPa) and Po is the pressure on the surface.

After these processes, the data were organized in graphs with a chronological scale, for a better understanding of the behavior, the precipitation and the integrated unit flow. According to the calculation of the anomalies, X '= Xi - $(\overline{X})$, where X' = anomaly, Xi = observed year and $(\overline{X})$ = climatological average. The composite method was also used in many maps, especially those that analyze the El Niño events (the years of 1982, 1986, 1991, 1997) (Tedeschi, Grimm, & Cavalcanti, 2015). The technique of composition consists of the measurement of a sum of a period, in the case it was used in the months of December, January and February, corresponding to the austral summer.

Figure 1 represents the areas/boxes that will be addressed during this work: the Amazon rainforest, which is located in the latitudes from 10°S up to 3°N and longitudes from 75°W up to 50°W, while that of São Paulo located in the latitudes from 20°S up to 27°S and longitudes from 53°W up to 45°W.

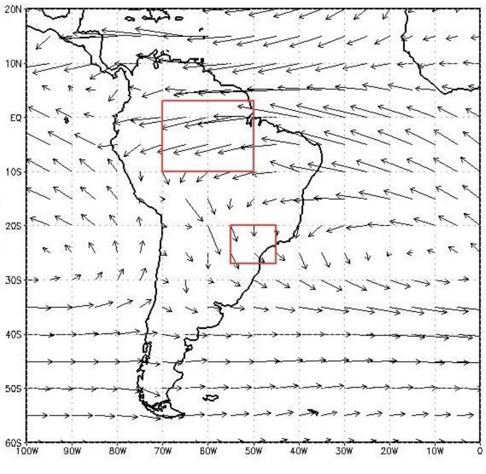

Figure 1. The box regions studied and arrows means the way of vertically integrated moisture flow.

3. Results

The time series of rainfall in the Amazon (Figure 2) and São Paulo (Figure 3) are necessary to verify if there is a possible pattern in rainfall volumes during the summer and any tendencies of precipitation increase or decrease. In the Amazon, the average precipitation is 670 mm and the time series also show, a negative trend (dotted line), with 16 years below average, 4 years in average and 18 years above average. In the last 13 years, the volume of rainfall in the region showed a sysitematic reduction, being mostly below the climatological average line. Highlight for the year 1982/83 (ENOS) which registered a rainfall total far below the average (560mm). It is known that the pre-rainy season

(SON) of that year was also marked by a low precipitation accumulation (VEIGA et al., 2017) and there was a general drought in Amazon (BORMA and NOBRE, 2013).

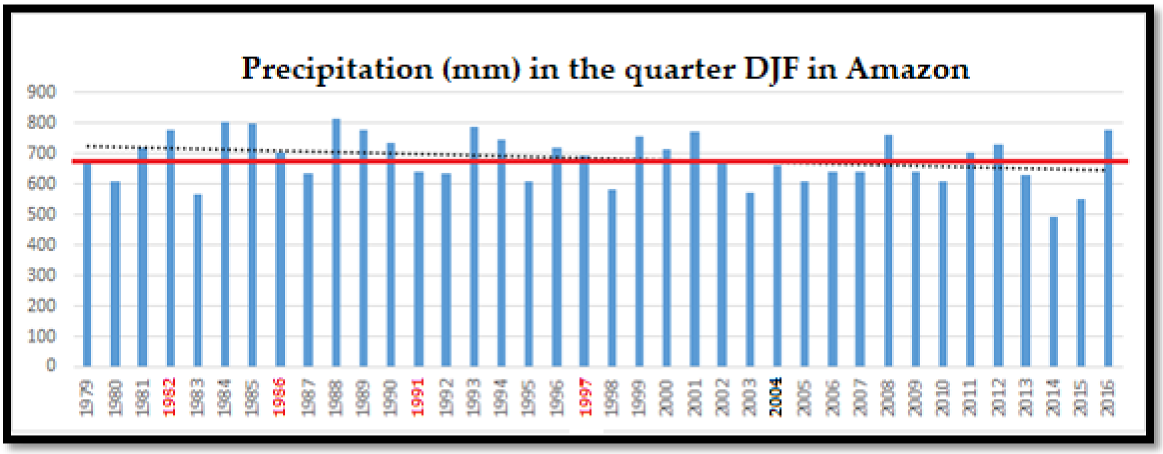

Figure 2. Time series of precipitation (mm) in the quarter DJF in the Amazon. ENSO years in red.

Figure 3 shows the precipitation histogram in the region of São Paulo, using the same methodology as in the previous figure. As in the Amazon, a trend was found negative. As of 2005, one year after the decline in the Amazon, most of the years were below average (2005 - 2008 - 2012 - 2013 - 2014). The year 2014 is considered to be much below average (the climatological average of the series is 520mm), accounting for 369mm of the total volume accumulated over the summer. In addition, considering the years after 2005, only 2010 and 2015 had numbers well above the climatology.

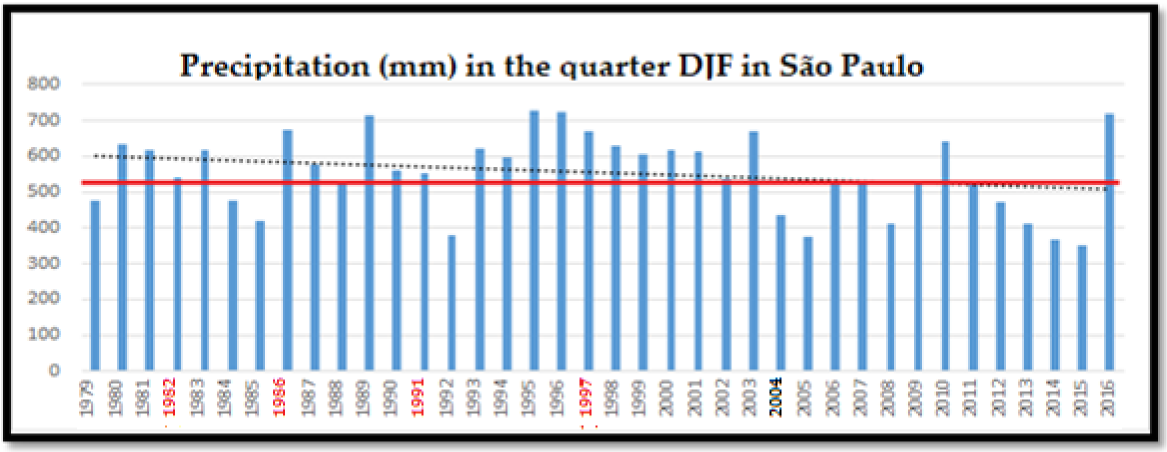

Figure 3. Time series of precipitation (mm) in the quarter DJF in São Paulo. ENSO years in red.

Figure 4 shows the mean integrated vertical moisture flow pattern, during the austral summer, between the surface and 500hPa. For these numbers, the ENSO´s years have been excluded from the estimates. The entry of moisture in the Amazon occurs by the east and north edges (positive numbers in blue), while the humidity leaves the region (negative numbers in red) by the west and south edges. Late, much of the moisture input in the region of São Paulo represented by positive values (in blue), on the north and west edges comes from the Amazon. It is known (ARRAUT and NOBRE, 2012) that a considerable amount of precipitation in this region occurs from this transport. There is an increase in this contribution in years of ENSO, with changes in atmospheric circulation and a higher intensity of jet stream the moisture flow when compared to the climatological average.

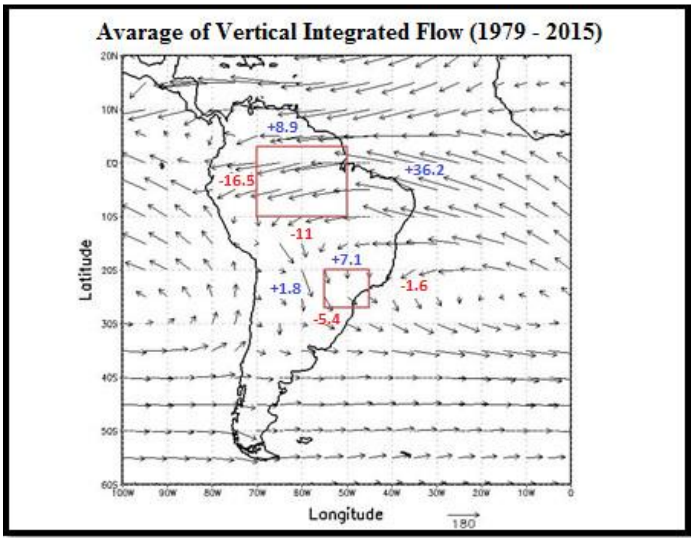

Figure 4. Vertically Integrated Moisture Flow (kg/s) of the entire study period (1979 - 2015), excluding years of ENSO.

Figures 5 and 6 exemplify the amount of moisture (anomalies) that remained in the regions of Amazon and Sao Paulo during the period from 1979 to 2015, that is, how much precipitated in the areas. As of 2011, the region of São Paulo has a large decrease in that amount of moisture that remained consistent with the precipitation data, which indicated a reduction in this same period (Figure 3). On the other hand, the Amazon presents a greater amount of moisture from the years 2000 with some points below the average: 2002, 2006, 2012, 2013 and 2014.

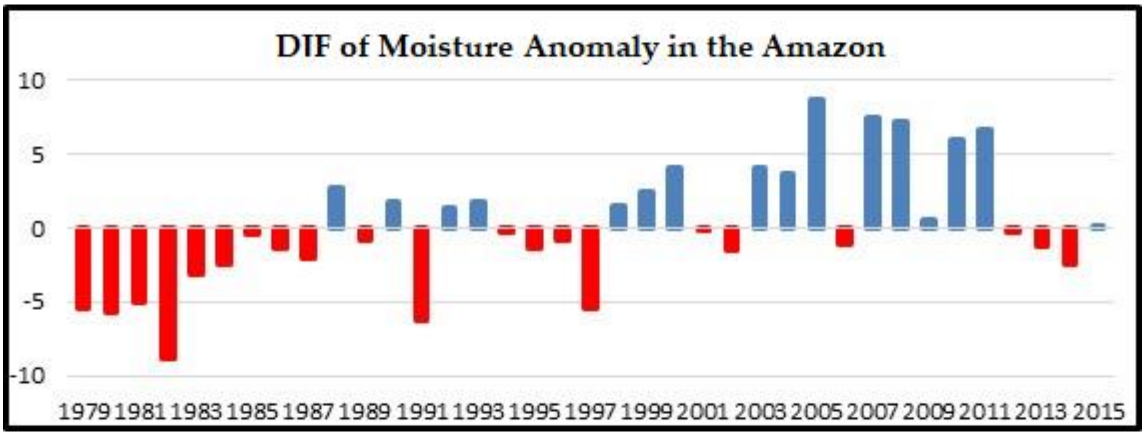

Figure 5. Time series of the anomaly of moisture (kg / s) that remained in the Amazon.

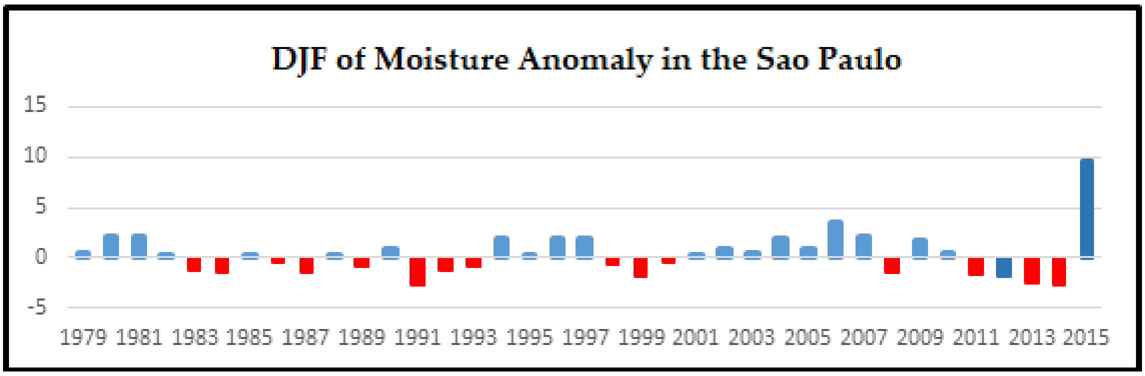

Figure 6. Time series of the anomaly of moisture (kg / s) that remained in São Paulo.

Figure 7 illustrates the moisture flux composite in representative years of El Niño event. It is possible to make a comparison with Figure 4, since the intensity of the vertical integrated flow of moisture is greater when this phenomenon is present (around 30 kg / s of exit), whereas the the average value of the climatological value is around 27.5 kg / s, that is, in only 4 years with the presence of ENSO, a low number when compared to neutral years, its mean is great expression to identify an increase of intensity of this flow of moisture, which does not necessarily accompanied by rain, but rather by an increase.

In São Paulo, this same intensification of the transport of moisture in the region was identified, there was an increase of humidity entering the territory. However, the quantity that left the territory remained constant, so that a convergence of humidity occurred in the areas marked on the map.

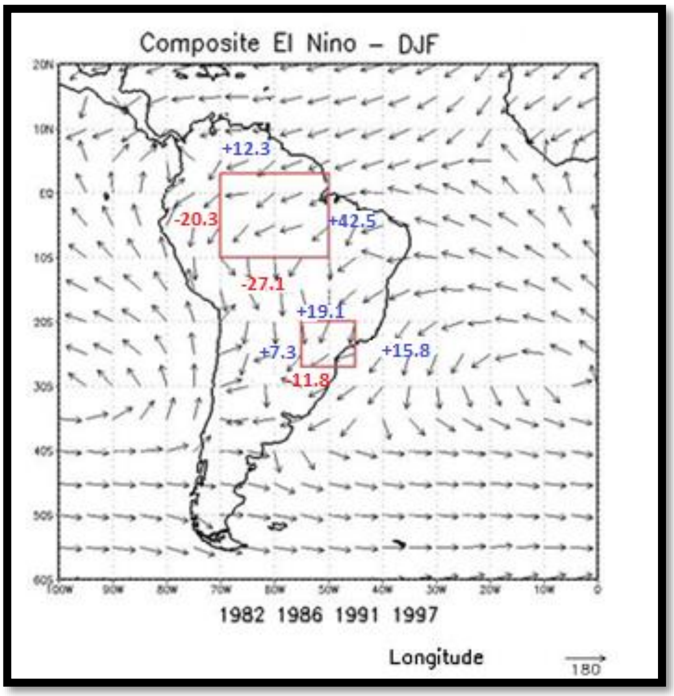

Figure 7. Vertically Integrated Moisture Flow (kg/s) Composite on the DJF quarter for years as an El Niño event.

4. Conclusions

The detailed study of moisture transport in the DJF quarter, from the Amazon forest, to the Southeast region of Brazil, especially in São Paulo state, presented concrete data regarding the reduction of the integrated vertical moisture flow transport, which in the turn results in a decrease in precipitation. The years considered ENSO presented a difference of intensity when compared with neutral years, this means that the forest plays a fundamental role in the balance of these years, since in years of ENOS, the cold fronts can not advance to the southeast of Brazil.

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Abbreviations

JBN: Low Level Jet
DJF: December – January - Febuary
SON: September – October - November
ENOS: El Niño Southern Oscillation
ZCAS: South Atlantic Convergence Zone

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