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The role of Amazon Basin moisture on the atmospheric branch of the hydrological cycle: a Lagrangian analysis

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Abstract

We used a Lagrangian model (FLEXPART) and the 1979–2012 ERA Interim reanalysis data to investigate the role of Amazon Basin moisture in the regional hydrological budget along the year. FLEXPART computes budgets of evaporation minus precipitation by calculating changes in the specific humidity along forward and backwards trajectories. The Tropical Atlantic (TA) is the major remote moisture source for Amazon Basin. Northern TA contributes during the Austral Summer mainly, while the contribution of southern TA prevails in the rest of the year. On the other hand, moisture contribution from Amazon Basin occurs for southeastern South America predominantly. A focus was given for the modulation of ENSO over the inter annual variations in the hydrological budget over Amazon. During El Niño events, the contribution from NA increases from June/year 0 to January/year 1 slightly and the contribution from SA is enhanced during Austral Autumn/year 1. Enhanced transport from Amazon towards Southeastern South America prevails during an El Niño episode.

1 Introduction

The Amazon Basin presents a large variety of ecosystems, including the largest tropical forest of the planet. The annual precipitation is approximately 2300 mm and the discharge of Amazon river into the Atlantic Ocean corresponds to 18 % of the total discharge of freshwater into the oceans (Marengo and Nobre, 2009). It is known that the Amazon forest exhibits an important role in the global energy and hydrological budgets, and has been suffering of intense deforestation of anthropogenic origin. Unfortunately, the temporal and spatial data coverage is poor over the basin and most of the studies are based on numerical products (reanalysis projects) and observational measures over few points.

The climatological annual cycle of precipitation is not homogeneous over Amazon and the onset and demise of the rainy season migrate from southern basin northwards gradually (e.g. Marengo et al., 2001; Liebmann and Marengo, 2001; Carvalho et al., 2011). The rainy season over the southern basin occurs between Austral Spring and Autumn, while over the western and northern Amazon it extends from Austral Autumn to Spring.

Almost all studies concerning moisture transport over Amazon are based on Eulerian methodologies (e.g. Costa and Foley, 1999; Curtis and Hastenrath, 1999; Chen at al., 2001; Arraut and Satyamurty, 2009; Arraut et al., 2012; Satyamurty et al., 2013a, b). According to them, the moisture flux from Equatorial Atlantic associated with the trade winds is the main remote moisture source for the Amazon. The climatological role of Atlantic subtropical ocean as moisture sources for Amazon has also been reported in the Lagrangian 5 yr period analysis developed by Stohl and James (2005), besides in the recent results about the role of oceanic regions published by Gimeno et al. (2013). On the other hand, air masses trajectories crossing Amazon uptake moisture for other regions in the continent, particularly La Plata Basin and Central Brazil (e.g. Roads et al., 2002; Marengo, 2005; Drumond et al., 2008; Arraut and Satyamurty, 2009). Van der Ent et al. (2010) verified that the La Plata Basin depends on evaporation from the Amazon forest for 70 % of its water resources. The role of vegetation in feeding the moisture transport over Amazon has been discussed in the work of Spracklen et al. (2012). They found that air that has passed over extensive vegetation in the preceding few days produces at least twice as much rain as air that has passed over little vegetation.

Some of several drought episodes documented in Amazon have occurred during intense El Niño episodes, such as the ones registered in 1926, 1983, 1997/1998, 2010 with reduction in the discharge in the main rivers and serious ecological and economical damages due to fire events (e.g. Williams et al., 2005; Sternberg, 1987; Marengo et al., 2008, 2013; Richey et al., 1989). The influence of El Niño Southern Oscillation (ENSO) in the inter annual variability of the Amazon climate may occur due to its role in the positioning of Inter Tropical Convergence Zone (ITCZ) (e.g. Coe et al., 2002; Uvo et al., 1998; Marengo et al., 2013). Although the impact of ENSO on Amazon precipitation and rivers discharge was investigated extensively, its influence on the moisture transport into and from the basin has not been explored in detail. It is known that, during ENSO events, changes in precipitation regimes are more intense during the Amazon rainy season and they are not homogeneous over the basin (Foley et al., 2002, Marengo et al., 2008). In general, negative precipitation anomalies are observed in Amazon during El Niño episodes, while positives anomalies predominate over the basin during La Niña events. Nevertheless, not all El Nino events are related to drought in Amazonia (Marengo et al., 2013). Recent studies have also pointed out the importance of tropical Atlantic (TA) in the modulation of Amazon climate (Yoon and Zeng, 2010), which was observed during the 2005 and 2010 drought events (e.g. Marengo et al., 2008; Lewis et al., 2013), as well as during the 2012 flood in the Amazon River (Satyamurty et al., 2013a).

Given the importance of Amazon Basin in the moisture budget and believing that a Lagrangian approach may complement the Eulerian analysis of moisture transport due to the tracking of air parcels and consequent links between evaporation and precipitation regions, this paper aims to investigate the annual cycle of the main sources of moisture for Amazon Basin, as well as its contribution as a moisture source for the rest of continent. We will make use of the Lagrangian method developed by Stohl and James (2004, 2005), which diagnoses net changes in specific moisture along the trajectories. This methodology was successfully applied in studies of sources of moisture for different regions in the world, including South America, such as the Orinoco River Basin (Nieto et al., 2008), the South American Monsoon System (SAMS) and Northeastern Brazil (Drumond et al., 2008, 2010). Here we make use of a 33 yr data set that allow us to corroborate the climatological aspects pointed out by the 5 yr analysis provided by Stohl and James (2005) and to explore aspects of inter annual variability in an inedited way. The modulating effect of ENSO on some elements of the Amazon climate discussed in previous works will be studied here through an analysis of how ENSO events have impacted the moisture transport over the region.

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2 Data and methods

The localization of the Amazon Basin is shown in Fig. 1. The spatial limits adopted for this domain are in accordance to those defined by the Observatoire de Recherche en Environnement (ORE HYBAM) through the webpage http://www.ore-hybam.org/index.php/por/Dados/Cartografia/Bacia-amazonica-hidrografia.

The present study is based on the method developed by Stohl and James (2004, 2005), which uses the FLEXPART V9.0 Lagrangian particle dispersion model and ERA-Interim Reanalysis data (Dee et al., 2011) to track atmospheric moisture changes along trajectories. The model run considers that the atmosphere is divided homogeneously into three-dimensional finite elements hereafter called "particles", each representing a fraction of the total atmospheric mass (Stohl and James, 2004). These particles are advected using the three-dimensional wind data, with superimposed stochastic turbulent and convective motions. The increases (e) and decreases (p) in moisture along the trajectory can be calculated through changes in (q) with time ($e - p = m\mathrm{d}q/\mathrm{d}t$), with ($m$) being the mass of the particle. When adding ($e - p$) for all the particles residing in the atmospheric column over an area we end up obtaining the aggregated ($E - P$) field, where the surface freshwater flux (E) is the evaporation and (P) the precipitation rate per unit area. The method is mostly limited by the trajectory accuracy and also to the use of a time derivative of the humidity (unrealistic fluctuations in humidity could be considered as moisture fluxes). However, such random errors may cancel each other out given the large number of particles in an atmospheric column. A detailed review of this methodology against other Eulerian and Lagrangian approaches was presented by Gimeno et al. (2012).

The FLEXPART data set used in this work comes from a global simulation dividing the entire globe atmosphere into approximately 2.0 million "particles". Each particle is tracked for a transport time of 10 days because that is the average residence time of water vapour in the atmosphere (Numaguti, 1999). The tracks were computed using ERA-Interim Re-analysis data available at an interval of six hours (00:00, 06:00, 12:00

and 18:00 UTC), at a 1° horizontal resolution and at a vertical resolution in 61 vertical levels, from 0.1 to 1000 hPa. The analysis covers a 33 yr period, from June 1979 to May 2012. As Gimeno et al. (2013) pointed out, the FLEXPART model requires consistent high-quality data of wind and humidity, thus hampering the application to older reanalysis data (~ 1979), i.e. prior to the significant decrease of the errors of these variables (namely, over the oceans) due to the inclusion of satellite data (Bengtsson et al., 2004).

The first question we intend to explore through a Lagrangian analysis is: where does the atmospheric moisture observed over Amazon come from? To answer it, a backward analysis allows us to identify where the particles gain humidity along their trajectories towards the target area, regions hereafter denominated as sources of moisture. From this set of experiments, regions where ($E - P > 0$) indicate that air particles located within that vertical column and bound to reach the target area gain moisture. A complementary question would be: what is the final destination of the moisture carried out by moisture transport air trajectories leaving Amazon? A forward analysis may identify all trajectories crossing the basin and follow them to find where they lose moisture. In this case, the ($E - P < 0$) values indicate the most important sinks of moisture. All figures show $E - P$ averaged over the whole tracking period (10 days) at the monthly scale allowing for the study of the annual cycle. We have followed the austral definition of the seasons (Summer is from December to February, Autumn from March to May, Winter from June to August, and Spring from September to November).

The influence of ENSO over the moisture transport into and from Amazon is investigated through the technique of composites differences. The events were selected based on the Oceanic Niño Index (ONI) developed by the US Climate Prediction Center CPC (www.cpc.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml). According to CPC, ten El Niño episodes (1982/1983, 1986/1987, 1987/1988, 1991/1992, 1994/1995, 1997/1998, 2002/2003, 2004/2005, 2006/2007, 2009/2010) and eleven La Niña events (1984/1985, 1988/1989, 1995/1996, 1998/1999, 1999/2000, 2000/2001, 2005/2006, 2007/2008, 2008/2009, 2010/2011, 2011/2012)

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were observed along 1979–2012 period. Differences of composites El Niño–La Niña were calculated at monthly scale considering the annual cycle from (June/year 0) to (May/year 1). We followed the methodology proposed by Wei et al. (2012) to evaluate the statistical significance of the composite differences through the Bootstrap method, applied in our case with 1000 interactions at the 90 % confidence level. We repeated 1000 times the calculation of the difference of two samples (one with 10 elements, and the other with 11) selected at random (a total of 21 elements) from the 33 yr climatology. To be considered significant, the absolute value of the composite of the differences must be larger than 90 % of the 1000 differences obtained randomly.

3 Results

3.1 Annual cycle

Figure 1 shows the monthly averages of 10 day ($E-P$) backward trajectories from Amazon Basin along 33 yr period (June 1979–May 2012). The backwards tracking allows identifying where the particles gain humidity along their trajectories towards the target area (hereafter sources of moisture). Results suggest the role of the TA as the most important remote source of moisture for Amazon Basin, probably associated with the seasonal migration of ITCZ and the confluence of trade winds. The figure suggests that part of the oceanic region increase its moisture contribution during the corresponding hemisphere's winter. Nieto et al. (2008) have also reported a quite similar annual cycle of the role of TA as a source of moisture for Orinoco Basin, placed northwards of Amazon. Some moisture from the Pacific South American coast also reaches Amazon along the year. Amazon receives some contribution of moisture from subtropical South America probably through the transportation by frontal systems. Figure 1 also suggests the contribution of local evaporative processes in Amazon as a moisture source for the basin along the year.

In order to illustrate the annual cycle of the contribution of TA with more detail, we have divided the region into two hemispheric sub areas: northern and southern TA (NA: 55–35° W and 2–12° N; SA: 37–17° W and 4–14° S), as it has been indicated in Fig. 2a. Both boxes present same spatial dimensions and their positions were defined to include the contour line of 0.4 mm day^{-1} observed in the annual average of 10 day ($E-P$) backward trajectories from Amazon Basin along 33 yr period. Integrating the monthly averages of 10 day ($E-P$) backward trajectories showed in Fig. 1 over both source regions (Fig. 2b), it is evident that NA (continuous black line) contributes to the Amazon Basin moisture from October to May. During this period the ITCZ migrates southwards and the northern trade winds reach southern American coast. It is interesting to observe that NA does not act as a moisture source for Amazon Basin from June to September. On the other hand, the contribution of SA (traced black line) occurs all year and it reaches its maximum during the Austral Winter. Our results compare well to the previous study of Bosilovich and Chern (2006), which made use of a 50 yr atmospheric general circulation model simulation including water vapor tracers to investigate the water budget for the Amazon River and its respective sources of water. The authors have also found the importance of South Atlantic ocean in providing moisture to the Amazon Basin along the year, except during the Austral Summer when the contribution of tropical North Atlantic dominates.

The role of Amazon as a moisture source can be inferred from the 10 day ($E-P$) forward trajectories from the basin along 33 yr period presented in the Fig. 3. The method identifies those particles that leave the basin and follows them to find where they lose moisture. Agreeing with previous results obtained through different methodologies (e.g. Roads et al., 2002; Marengo, 2005; Drumond et al., 2008; Arraut and Satyamurty, 2009), contribution from the basin occurs toward southeastern South America (including La Plata Basin, hereafter LP) predominantly. Moisture is also transported towards Southeast Brazil during Austral Spring and Summer months, period characterized by the active phase of the South American Monsoon System (Vera et al., 2006). The Orinoco Basin, the Atlantic ITCZ, and part of the Caribbean Sea also receive some moisture from Amazon region, except during the Austral Summer. Using a different data set and analysing a 5 yr period, Nieto et al. (2008) verified some contribution of moisture from Amazon into Orinoco during the months of JJAS, period characterized by drought conditions in southern Amazon. Moisture from Amazon is also transported towards parts of the Pacific ITCZ and the Western Hemisphere Warm pool (Drumond et al., 2011, and references therein) regions. Figure 3 also suggests contribution of moisture from Amazon Basin to itself along year, with local moisture sinks areas expanding over central and southern basin from September to April, while sinks reduce spatially towards northern and southern basin from May to August.

In order to investigate the annual cycle of the contribution from Amazon towards LP region, a similar analysis applied to the backward case was performed for the forward experiment. The LP box (67–50° W; 20–34° S) was defined over southeastern South America based on the contour line of $-0.4\,\mathrm{mm\,day^{-1}}$ observed in the annual average of 10 day ($E-P$) forward trajectories from Amazon Basin along 33 yr period (Fig. 4a). We integrate monthly averages of 10 day ($E-P$) forward trajectories showed in Fig. 3 over LP region, and in order to facilitate the visualization of the results Fig. 4b shows the absolute values of ($E-P$) because all values obtained over the area are negative ($(E-P) < 0$, meaning that LP acts a sink of moisture from Amazon along the year). Figure 4b shows maxima contributions during June (a secondary maximum), October and January, and minima in August, December (a secondary minimum) and March. The causes of this quite seasonal variability are unknown and deserve further attention in a future work.

3.2 Role of ENSO on the moisture transport over Amazon Basin

Figure 5 shows the differences of composites of moisture sources of Amazon Basin of El Niño and La Niña events. We consider the ENSO cycle extending from June/year 0 to May/year 1. Both composite fields were elaborated considering only positive ($E-P$) values (source regions) obtained in the backward analysis. In order to understand this figure, we must keep in mind that pink (green) colors indicate regions where their contribution as a source intensifies during El Niño (La Niña) events. From the results we can see that the moisture contribution from the Equatorial Atlantic enhanced during El Niño events. In comparison to La Niña episodes, it seems that the contribution from the Tropical and Subtropical Atlantic was weakened during an El Niño cycle.

If we analyse the variability of $(E-P)$ integrated over NA and TA boxes during ENSO cycle through a composite analysis (Fig. 2b, green lines indicate the contribution during La Niña years and the pink ones, during El Niño events), the contribution from NA presents a light increasing (decreasing) from June/year 0 to January/year 1 of El Niño (La Niña) years with respect to the climatology. From January/year 1 afterwards, there is a reverse in the signal of the NA anomalies, and the contribution from this box region towards Amazonian Basin decreases (increases) during FMAM/year 1 of an El Niño (La Niña) event. In comparison to NA, the anomalies of SA contribution present higher variability in their signal during an ENSO cycle. Some increase in the SA contribution prevails from September/year 0 to February/year 1 during La Niña events. Figure 2b also indicates the change in the signal of the anomalies over SA boxes at the end of the ENSO cycle. This means that during El Niño (La Niña) event, the contribution from SA is enhanced (decreases) from February/year 1 afterwards.

Looking for some interannual joint variability between ENSO and the contribution from both sources, a correlation analysis was applied between the month time series of ONI and of $(E-P)$ integrated over each box. Values of correlation are indicated in Table 1, and only coefficients significant at the 90 % level according to the T-Student test will be commented. Considering the linear relationship between ENSO and NA time series, the negative correlation value during MAM means that during La Niña (El Niño) the contribution from NA to Amazon Basin increases (decreases), what is in accordance with the Fig. 2b. The positive correlation obtained during the period from June to October might have some influence to the establishment of the transition phase of the role of NA as a moisture source (climatologically it occurs during September). When we consider SA contribution, positive ONI/SA correlation coefficients observed during MAM mean that the contribution from SA towards Amazon increases (decreases) during El Niño (La Niña) events, agreeing with results presented in Fig. 2b. The negative ONI/SA correlations observed in September and January mean that the contribution from SA increases (decreases) during La Niña (El Niño) events. A comparison of the results obtained for both boxes reveals that NA and SA present opposite behaviour concerning their joint linear variability with ENSO, except during June and July when both indexes present positive correlation coefficients. During Spring, the contribution from NA increases in El Niño events, while the one from SA reduces during September. It will not be explored here, but a theme that deserves be investigated in a further work with more detail is the possible role of the interaction ENSO/NA and SA contribution on the onset of the active phase of SAMS during Austral Spring (Vera et al., 2006). Furthermore, autumn is the season presenting the most contrasting coefficients, and it coincides with the rainy season in Amazonian Basin. While the contribution from SA increases in MAM of El Niño events, the one from SA reduces.

In order to investigate the impact of ENSO on the moisture transport from Amazon, Fig. 6 shows the differences of composites of moisture sinks of El Niño and La Niña events. In the composite figures we have considered only negative ($E-P$) values (sink regions) obtained in the forward analysis from the basin. Now pink (green) colors indicate regions where moisture sinks intensify during El Niño (La Niña) events. It seems that the transport from Amazon was enhanced towards Southeastern South America (particularly La Plata Basin) during the El Niño phase. During the onset of El Niño events (from June/0 until August/0) the moisture contribution increased towards northwestern Amazon and the Pacific ITCZ (pink color). Instead, moisture transport is enhanced towards northwestern South America and the Atlantic ITCZ during the onset of La Niña events (from June/0 until September/0, green color). During La Niña events, the transport of moisture is enhanced towards the South Atlantic Convergence Zone (SACZ) region and tropical latitudes from Austral Spring afterwards. The anomalous patterns of moisture transport from Amazon indicated in this figure are in accordance with the precipitation anomalies observed during El Niño: precipitation displaced from

SACZ region towards La Plata Basin and values reduced over Northern continent (Vera et al., 2006).

The variability of the contribution from Amazon Basin towards LP region during an ENSO cycle obtained through our composite analysis was quantified in Fig. 4b, where the green line indicates the contribution during La Niña years and the pink one for El Niño events. Figure 4b confirms the changes in the transport towards tropics or subtropics according to the ENSO phase discussed in the previous paragraph. In general, the contribution towards LP increases during El Niño episodes, particularly during July/year 0, October/year 0–January/year 1, March–May/year 1. The increased contribution towards LP during October/year 0–January/year 1 of El Niño events coincides to the slight higher supply of moisture from NA towards Amazon (Fig. 2b) observed during these years. However, the increased contribution from Amazon towards LP during March–May/year 1 coincides to a higher supply from SA (Fig. 2b). The results for La Niña composite indicate a reduction of the contribution from Amazon towards LP region particularly during October–December/year 0 and March–May/year 1. The linear correlation analysis applied between the time series of ONI and of absolute values of $(E-P)$ from the forward experiment integrated over LP (Table 1) shows the predominance of positive correlation coefficients, presenting higher values in October–December/year 0 and April–May/year 1. This indicates that during El Niño (La Niña) events the supply of moisture from Amazon Basin towards LP area is enhanced (reduced), agreeing with the results from the composite analysis (Fig. 4b).

4 Summary

An analysis of the moisture sources for the Amazon Basin, as well as its role as a source of humidity was performed using a Lagrangian method of diagnosis through numerical experiments with the FLEXPART model and ERA-Interim data set. This assessment was undertaken for a 33 yr period (from June 1979 to May 2012) and has focused on the climatological annual cycle and the modulation of ENSO, one of the climatic variability modes with impacts over South America more extensively investigated, on the hydrological budget over Amazon.

The results obtained show the role of the Tropical Atlantic as a remote source of moisture for Amazon Basin. Northern Tropical Atlantic (NA) contributes mainly during the extended Austral Summer, and this region does not act as a moisture source for Amazon Basin from June to September, and the transition sink/source of the role of NA occurs in September. On the other hand, the contribution of Southern Tropical Atlantic (SA) occurs all year and it predominates from April to November, reaching its maximum during the Austral Winter. Considering the Amazon Basin as a source of moisture, the main contribution from Amazon occurs for southeastern South America along the year and also for Southeast Brazil during Austral Spring and Summer months. Orinoco Basin and Pacific ITCZ also receives some moisture from Amazon region, except during the Austral Summer.

During El Niño (La Niña) events, the contribution from NA increases from June/year 0 to January/year 1 slightly and the contribution from SA (NA) is enhanced during Austral Autumn/year 1, while the transport from Amazon is enhanced towards Southeastern South America (Tropical continental areas).

The results discussed here can contribute to a better understanding not only of the moisture transport over a region of extreme importance in the world, but also of how ENSO may influence its hydrological budget. In any case, some recent drought Amazon events not configured during El Niño years may reveal the importance of other climatic variability modes, such as the one observed over the Tropical Atlantic, for modulating the Amazon hydrological characteristics. These aspects must be taken into account in a further work.

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Table 1. Correlation coefficients between the monthly time series of ONI and: of 10 day ($E-P$) backward trajectories from Amazon Basin and integrated over NA and SA source regions; of absolute values of 10 day ($E-P$) forward trajectories from Amazon Basin and integrated over LP sink area. All time series expands along 33 yr period. Values statistically significant at the level of 90 % according to T Test are followed by *.

Month	ONI × NA	ONI × SA	ONI × LP
Jun	0.36*	0.32*	0.05
Jul	0.47*	0.37*	0.27
Aug	0.55*	0.24	−0.11
Sep	0.31*	−0.41*	−0.10
Oct	0.33*	−0.16	0.69*
Nov	0.24	−0.01	0.48*
Dec	0.26	0.04	0.47*
Jan	0.09	−0.34*	0.04
Feb	−0.19	−0.03	0.03
Mar	−0.37*	0.34*	0.18
Apr	−0.53*	0.50*	0.48*
May	−0.38*	0.46*	0.51*

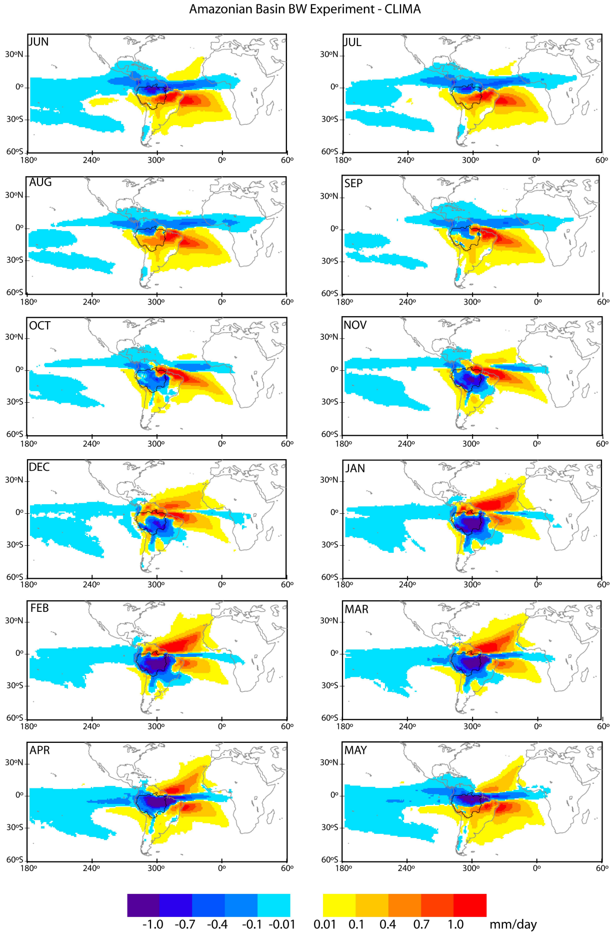

Fig. 1. Climatological monthly 10 day integrated ($E-P$) fields obtained through the Backward Amazon experiment for the period June 1979–May 2012. Black contour line indicates the basin area.

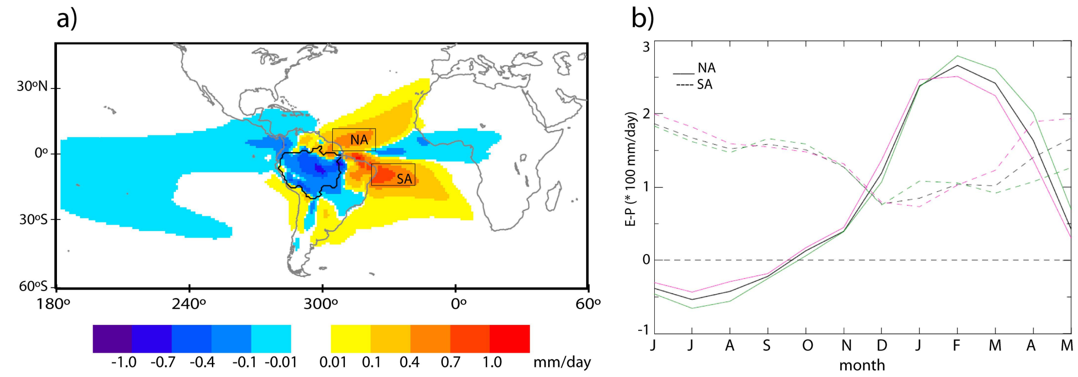

Fig. 2. **(a)** Climatological annual average of 10 day integrated ($E-P$) obtained through the Backward Amazon experiment for the period June 1979–May 2012. Black contour line indicates the basin area, and the boxes NA and TA indicate the source areas selected. **(b)** Annual cycle of the monthly averages of 10 day ($E-P$) backward trajectories showed in Fig. 1 and integrated over NA (continuous line) and SA (traced line) source regions indicated in **(a)**. Black lines represent the 33 yr average values, while pink and green lines indicate the average of El Niño and La Niña events selected, respectively.

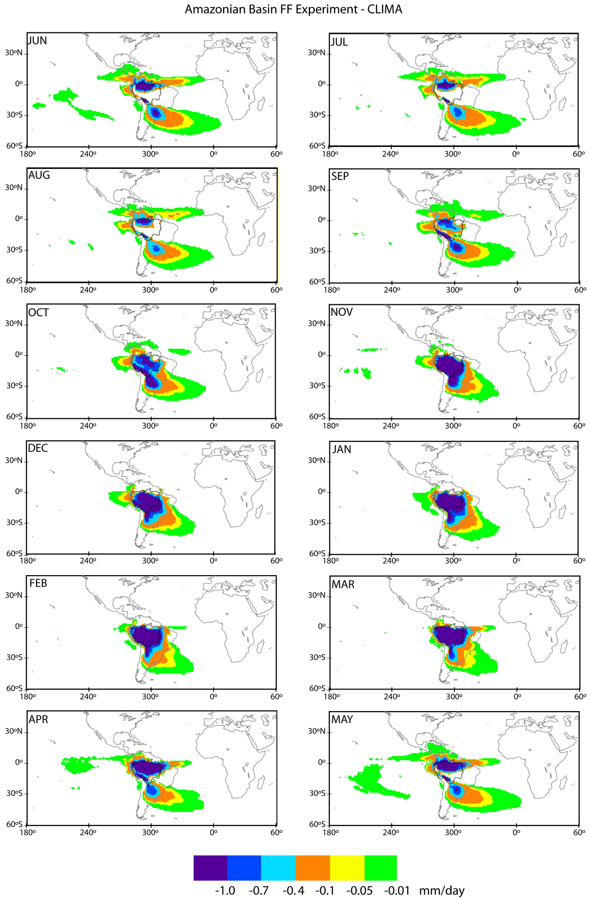

Fig. 3. Climatological monthly 10 day integrated ($E - P$) fields obtained through the Forward Amazon experiment for the period June 1979–May 2012. Only negative values are shown in order to emphasize the sink regions. Black contour line indicates the basin area.

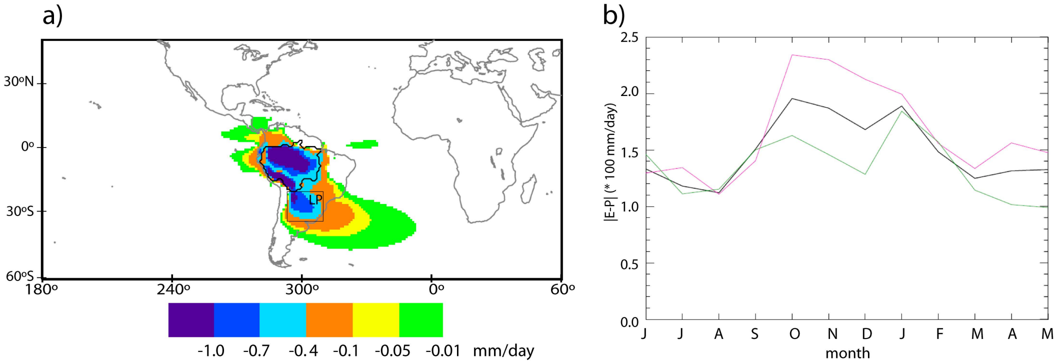

Fig. 4. (a) Climatological annual average of 10 day integrated ($E-P$) obtained through the Forward Amazon experiment for the period June 1979–May 2012. Black contour line indicates the basin area, and the LP box indicate the sink area selected. **(b)** Annual cycle of the monthly averages of absolute values of 10 day ($E-P$) forward trajectories showed in Fig. 3 and integrated over LP region indicated in **(a)**. Black lines represent the 33 yr average values, while pink and green lines indicate the average of El Niño and La Niña events selected, respectively.

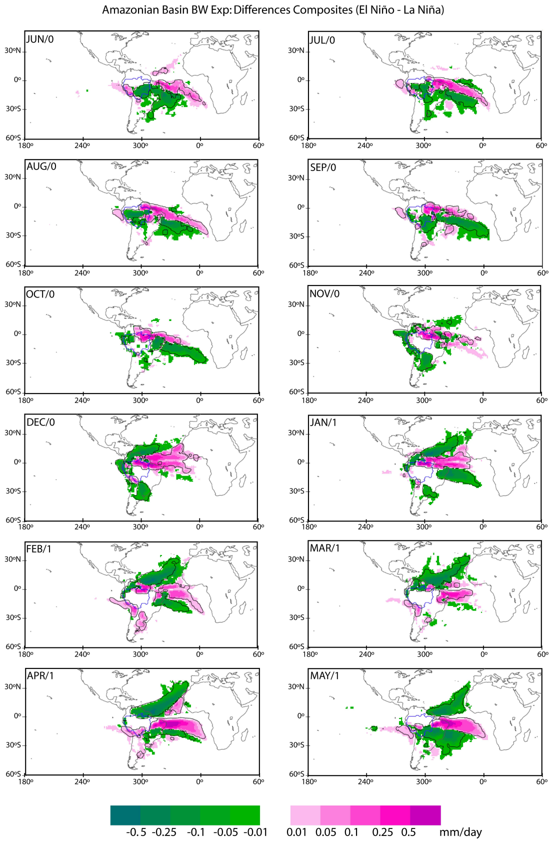

Fig. 5. Differences of composites of moisture sources of Amazon Basin (considering only positive $E - P$ values in the composites using backward analysis) of El Niño and La Niña events. Black contour lines indicate regions where the differences are significant at the level of 90 % according to the bootstrap test. Pink (green) colors indicate regions where the sources are more intense during El Niño (La Niña) events. Blue contour line indicates the basin area.

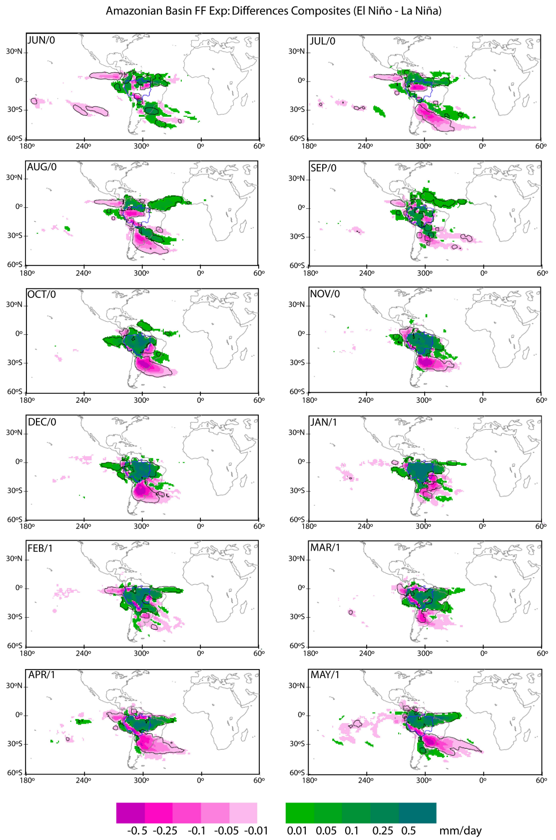

Fig. 6. Differences of composites of moisture sinks of Amazon Basin (considering only negative $E-P$ values in the composites using forward analysis) of El Niño and La Niña events. Black contour lines indicate regions where the differences are significant at the level of 90 % according to the bootstrap test. Pink (green) colors indicate regions where the sinks are more intense during El Niño (La Niña) events. Blue contour line indicates the basin area.

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