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Analysis of dry and wet episodes in eastern South America during 1980-2018 using SPEI

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Abstract: A large part of the population and the economic activities of South America are located in eastern continent (ESA), where extreme climate dry and wet episodes are a recurrent phenomenon. Besides other oceanic and terrestrial sources, the precipitation over ESA may be modulated by air masses from the subtropical South Atlantic along the year. This study analyzes the extreme climate conditions at domain-scale occurring over ESA in the last four decades through the multi-scalar Standardized Precipitation-Evapotranspiration Index (SPEI). The study area was defined according to the results of a Lagrangian approach developed for moisture analysis. It consists in the major continental sink of the moisture transported from the Subtropical South Atlantic Ocean towards South America, comprising the Amazonia, almost all the Brazilian territory, and La Plata regions. The SPEI for 1-, 3-, 6-, and 12-months of accumulation was calculated for the period 1980-2018 using monthly CRU (TS4.03) precipitation and potential evapotranspiration time series averaged on the study area. The wet and dry climate conditions were identified and classified through the SPEI values (mild, moderate, severe, and extreme). The results indicate the predominance of dry conditions in the decade of 2010, while wet periods prevailed in the 1990s and 2000s.

Keywords: SPEI; eastern South America; extreme climate conditions; drought; wet episodes

1. Introduction

It is known that climate change may affect the frequency and intensity of extreme climate events [1]. In the last decades, South America has suffered from the alternation of extremely wet and dry climate conditions [2-5]. Currently, the dry conditions observed over the Amazon rainforest and the Pantanal wetlands during 2020 are an example of how drought events could enhance the propagation of fires, with enormous socio economic and environmental damages [e.g., 6]. In the last decade, the 2014 drought over Southeastern Brazil affected the water supply in the Metropolitan Area of Sao Paulo (MASP), one of the most populous areas in South America [3]. On the other hand, the observed positive trend in the frequency and intensity of extreme rainfall events in MASP, particularly during the austral Summer, triggers flash floods and landslides over the area [7,8]. The increasing number of consecutive dry days also observed in MASP [8] indicates that intense precipitation is concentrated in fewer days, separated by longer dry spells.

Focusing on how the atmospheric circulation may contribute to these climate changes in MASP, Marengo et al. [8] verified that during the last six decades the South Atlantic Subtropical High (SASH) has intensified and slightly moved southwestward of its normal position, probably affecting the transport of humidity towards South America and the precipitation associated.

The importance of the South Atlantic as one of the major oceanic sources of moisture in the globe and its contribution to the precipitation over different regions located in eastern South America (ESA) has already been reported in previous works, such as the ones based on the Lagrangian approach developed by Stohl and James [9,10] to analyze moisture transport [e.g 5; 11-17]. These works pointed out the joint role of the moisture transport predominantly by air masses from the Tropical North Atlantic and the South Atlantic to the precipitation over ESA, besides the terrestrial sources. However, a systematic definition of the region which consists as a climatological sink of the moisture transported by air masses from the South Atlantic, and an identification of the associated extreme climate periods at domain-scale has not been conducted yet.

Therefore, this work aims to identify the extreme wet and dry periods at domain-scale over ESA during 1980-2018 through the multi-scalar Standardized Precipitation-Evapotranspiration Index (SPEI) [18]. The SPEI includes precipitation (PRE) and potential evapotranspiration (PET) in calculation of anomalies in climatic water balance. It was calculated at 1-, 3-, 6-, and 12-months allowing the identification of extreme conditions at different accumulation periods, which may affect different components of the hydrological cycle.

2. Data and Methodology

2.1. Data

The analysis covers the period from 1980 to 2018. ERA-Interim global reanalysis dataset from the European Centre for Medium-Range Weather Forecasts (ECMWF) [19], with a horizontal resolution of 1º on 61 vertical levels from the surface to 0.1 hPa, is used both in the identification of the South Atlantic moisture source region and as input for FLEXPART model. According to Gimeno et al. [14], ERA-Interim reanalysis data are appropriate to feed the model because of the high-quality data for wind and humidity required by FLEXPART, besides the reproduction of the hydrological cycle in a satisfactory way. The dataset are available at https://www.ecmwf.int/en/forecasts/datasets/archive-datasets/reanalysis-datasets/era-interim.

The SPEI was computed using datasets of PRE and PET from the Climate Research Unit (CRU) Time-Series (TS) Version 4.03 [20] at a spatial resolution of 0.5º. Data are available at https://catalogue.ceda.ac.uk/uuid/10d3e3640f004c578403419aac167d82.

2.2. Lagrangian approach for the analysis of moisture transport

The South Atlantic moisture source region (SAT) was firstly defined by Gimeno et al. [13,14], based on the maxima of the annual climatological vertically integrated moisture flux (VIMF) divergence (values higher than 750 mm/year, which corresponds to approximately the 60^{th} percentile of the positives values from the respective global climatology on the annual scale).

The same methodology of Gimeno et al. [13-14] for the identification of the SAT moisture sinks at seasonal scale was applied here, but now the sink was defined on annual basis. More details of the Lagrangian approach applied here for the identification of major moisture sinks for oceanic sources may be found in [13,14]. In comparison with the Eulerian approachs [e.g., 21], the Lagrangian methodology enables the tracking of air parcels, allowing the establishment of moisture source–

receptor relationships in a more realistic way [22]. The Lagrangian approach applied here was developed by Stohl and James [9,10] and it is based on the FLEXPART (FLEXiblePARTicle dispersion model, [9]). In the FLEXPART simulation, the global atmosphere was divided homogenously into nearly 2.0 million particles with constant mass transported using 3D wind fields from the global reanalysis data ERA-Interim. The changes in specific humidity (q) of each particle along its path were computed every 6h, and they can be expressed as: $e-p=m(dq/dt)$ where m is the mass of the particle and e-p represents the freshwater flux associated with each particle (evaporation e minus precipitation p). The total (E-P) represents the surface freshwater flux associated with the tracked particles per unit area and was obtained by adding (e-p) for all the particles residing in the atmospheric column over a given area.

In this study, the trajectories were tracked forward in time to identify the sinks of the moisture (areas where the particles lost moisture $E - P<0$) transported by particles leaving the SAT moisture source and tracked for a period of 10 days (i.e., the average residence time of water vapor in the atmosphere [23]. The orange area in Figure 1 (left) delimits the major moisture sink area in South America selected using the 90th percentile of the negative part of (E – P) (i.e., -0.1 mm day^{-1}) obtained from the respective global climatology (from 1980 to 2018) on the annual scale.

2.3. Extreme wet and dry climate periods identification and analysis

Following the method applied by Drumond et al. [5] and Stojanovic et al. [24], 1-, 3-, 6-, and 12-months SPEI time scales for 1980-2018 are calculated through time series of monthly PRE and PET with the purpose to identify the domain-scale extreme wet and dry climate periods occurred over the ESA region.

SPEI was first proposed by Vicente-Serrano et al. [18] as an improved drought index that is particularly suitable for studying the effect of global warming on drought severity [25]. The SPEI follows the same conceptual approach as the Standardized Precipitation Index (SPI) [26-28], but it is based on a monthly climatic water balance (precipitation minus evapotranspiration) rather than on precipitation solely. The climatic water balance is calculated at various time scales (i.e. accumulation periods), and the resulting values are fit to a log-logistic probability distribution to transform the original values to standardized units that are comparable in space and time and at different SPEI time scales. Details of the SPEI calculation can be found in [18,29,30].

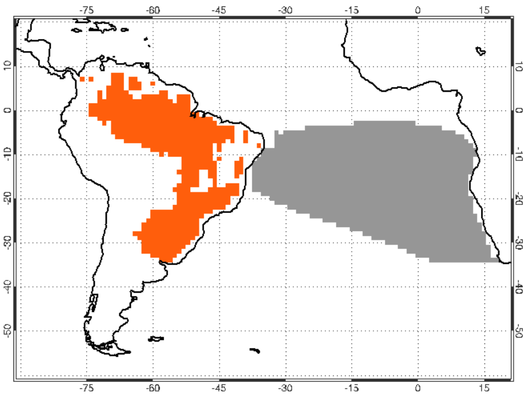
The criteria proposed by McKee et al. [26] based on the SPI value is applied in the present work to characterize the domain-scale wet and dry periods according to the SPEI values (Table 1).

Table 1. Classification of SPEI values according to their magnitude. Adapted from [26]

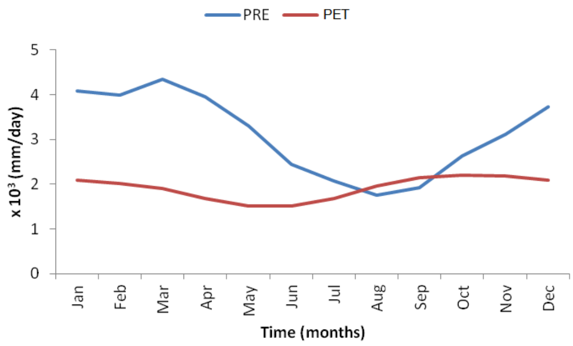
SPEI values	Category
2.0 and more	Extremely wet
1.5 to 1.99	Severely wet
1.0 to 1.49	Moderately wet
0.0 to 0.99	Mild wet
-0.99 to 0.0	Mild dry
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2.0 and less	Extremely dry

3. Results and Discussion

Figure 1a shows a schematic representation of the South Atlantic moisture source (grey) and its major sink over South America (ESA, orange) identified according to Gimeno et al.[13,14]. The source is placed over the South Atlantic Subtropical High region, the main feature of the atmospheric circulation over the South Atlantic Ocean which affects the South American and African weather and climate [31]. In the South American continent, the Lagrangian approach results show that during the year the moisture transported by air masses from the South Atlantic precipitates mainly over the Amazon, Central Brazil and southeastern continental regions, configuring an area affected by the South American monsoon system [32]. In terms of the climatological annual cycle of the freshwater flux (PRE-PET) over the ESA (Figure 1b), PRE prevailed over PET during the year, except from August to September. Climatological PRE presents a well-defined annual cycle over the ESA, characterized by rainier Summer months and a drier Winter season. Climatological PET over the ESA presents a minimum in the late Autumn season.



(**a**)



(**b**)

Figure 1. (**a**) Schematic representation of the South Atlantic source (grey) identified using the maximum vertically integrated moisture flux divergence according to Gimeno et al. [13,14] and its respective moisture sink over eastern South America (ESA, orange) defined using a forward-in-time experiment; (**b**) The annual climatological precipitation cycle (PRE, blue line) and potential evapotranspiration (PET, red line) integrated over the ESA for 1980–2018. Scale: mm/day. Data are from the CRU TS 4.03.

Figure 2 shows the time series of the SPEI on the scale of 1-, 3-, 6-, and 12-months over ESA to illustrate the evolution of the index on different time scales (conditions accumulated over monthly, seasonal, semiannual, and annual periods, respectively). Positive values in blue indicate wet periods, and negative values in red show dry conditions. Looking at Figure 2, one can see the predominance of wet periods during mid-90s and the decade of 2000, and of dry conditions during the decade of 2010.

Looking at how wet and dry conditions (and the magnitude associated) over ESA varied during the decades, Figure 3 shows the number of occurrence of SPEI-1, -3, -6, and -12 values at each one of the categories defined in Table 1 during the periods of 1980-89, 1990-99, 2000-09, and 2010-18. This figure confirms the predominance of wet conditions during the decade of 2000. On the other hand, Figure 3 confirms that the period 2010-2018 (even shorter in comparison with the remaining decades) concentrates the highest number of occurrences of dry SPEI values, particularly in the categories moderate and severe (at the scales -6 and -12). It deserves to mention that the extremely dry conditions were reached in the four accumulation scales during 2010-2018; moreover, the only extreme dry value at SPEI-12 was registered during this decade.

A joint analysis of dry and wet conditions at the different accumulation periods reveals that extreme wet conditions also occurred during the decade of 1980, although it was predominantly dry at seasonal, semiannual and annual accumulation scales. A similar pattern was verified for the predominant dry conditions (reaching the category extreme) during the 1990′s at the SPEI-1 scale in contrast to the wet conditions prevailing at the remaining scales.

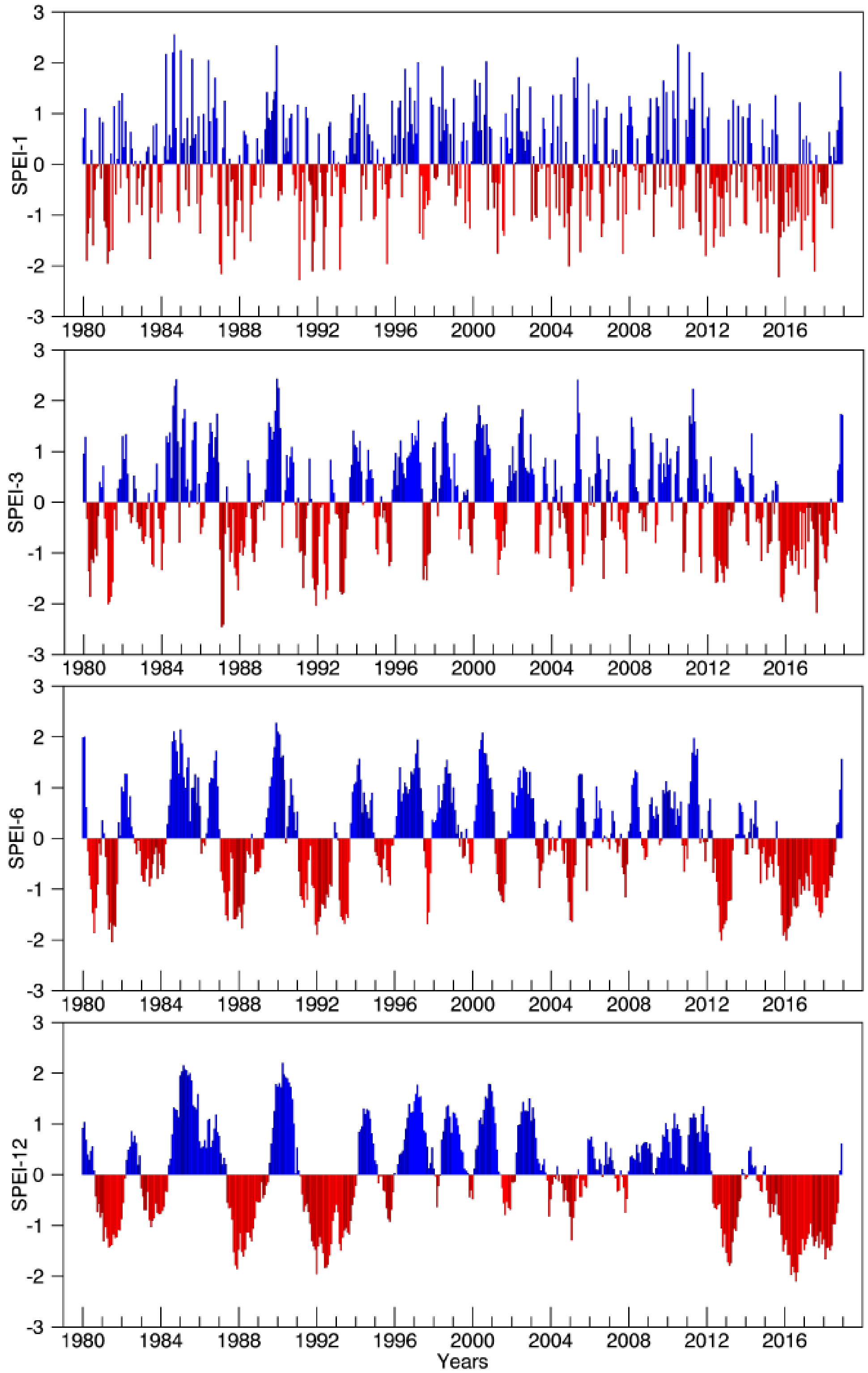


Figure 2. Time series of SPEI-1, SPEI-3, SPEI-6, and SPEI-12 for the ESA during 1980–2018. Data are computed from CRU TS 4.03.

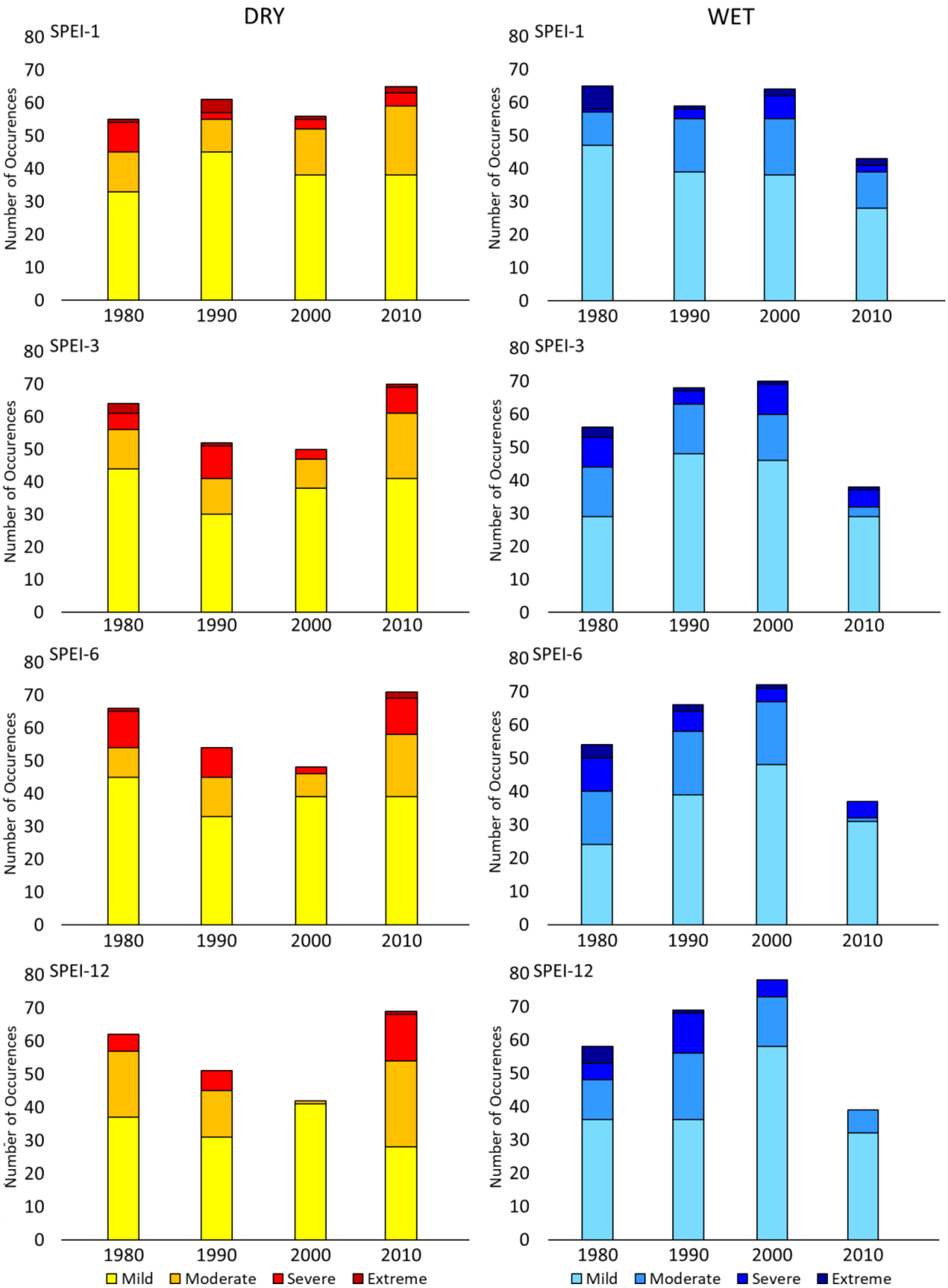


Figure 3. Number of occurrence of ESA SPEI-1, SPEI-3, SPEI-6, and SPEI-12 values at each one of the categories defined in Table 1 during the periods 1980-89, 1990-99, 2000-09, and 2010-18. Data are computed from CRU TS 4.03.

4. Conclusions

In the present study, the dry and wet climate periods at domain-scale occurring over the eastern South American (ESA) region during 1980-2018 were identified and characterized through the multi-scalar Standardized Precipitation-Evapotranspiration Index (SPEI) at the SPEI-1, SPEI-3, SPEI-6, and SPEI-12 months accumulation periods. The spatial domain of ESA covers an area extending from the Amazon, crossing central Brazil, and reaching the southeastern continental areas, and it consists in the major continental sink of the moisture transported from the Subtropical South Atlantic Ocean towards South America according to a Lagrangian approach developed for moisture transport analysis. The wet and dry climate conditions over ESA were identified and classified through the SPEI values (classified as mild, moderate, severe, and extreme). The main conclusions are then summarized:

- The climatological annual cycle of the freshwater flux over ESA shows that precipitation prevailed over potential evapotranspiration during the year, except from August to September. ESA is characterized by rainier Summer months and a drier Winter season;
- Although the decade of 1980 presented the highest number of extremely wet values in the SPEI-1, -3, -6, and -12 time series, it was also characterized by the predominance of dry values in the SPEI-3, -6 and -12 scales. In other words, results indicate that extreme wet and dry conditions occurred during this period;
- There was predominance of wet conditions during the decades of 1990 and 2000, except for the SPEI-1. It is worth to note that the decade of 1990 presented the highest number of extremely dry values in the SPEI-1time series;
- The period of 2010-2018 (even shorter in comparison with the remaining decades) concentrates the highest number of occurrences of dry SPEI values. Extremely dry conditions were reached in the four accumulation scales during 2010-2018, and the only extreme dry value at SPEI-12 was registered during this decade.

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