



**Influence of Soil Texture Type and Initial Soil Moisture on the
Simulation of Seasonal Precipitation and Extreme Precipitation in Southeast Brazil**
Influência do Tipo de Textura e Umidade Inicial do Solo Sobre a
Simulação da Precipitação Sazonal e de Extremos de Precipitação no Sudeste do Brasil

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Abstract

The objective of this paper is to investigate the influence of soil conditions (initial moisture and soil texture type) on the seasonal simulations of precipitation extremes over Upper São Francisco River basin in Brazil. The Eta regional climate model is used to produce simulations for the dry and rainy seasons in southeast Brazil between the years 1979 and 2012. These are 4.5-month integrations. Two maps of soil texture type and two initial soil moisture conditions are tested. Eta rainfall simulations are more sensitive to soil texture than to the changes in the initial soil moisture. The runs using the map of 26 soil texture types represent better the climate of South America compared to the simulations using the map of 9 soil texture types. In general, the extreme climatic indices and the total accumulated precipitation for the dry and rainy seasons in Brazil are underestimated by the Eta regional climate model over the study region, which suggests the necessity of tests with convection precipitation schemes to improve the model's performance.

Keywords: Extremes events; Eta model; soil texture; soil moisture

Resumo

O objetivo deste trabalho é investigar a influência das condições iniciais do solo (umidade e tipo de solo) na previsão sazonal de extremos climáticos de precipitação, em parte da bacia do rio São Francisco no Brasil. O modelo climático Eta é usado para produzir simulações para estações secas e chuvosas no sudeste do Brasil entre os anos de 1979 e 2012. O modelo realiza integrações de 4,5 meses durante os anos analisados. Foram estudados diferentes mapas de tipo de solo e umidade inicial do solo. O modelo Eta mostra sensibilidade às mudanças no solo quando é integrado com diferentes condições iniciais do solo. As mudanças no mapa do solo possuem maior influência sobre a precipitação simulada do que a umidade inicial do solo. Os experimentos com o mapa do solo de 26 tipos tendem a representar melhor o clima da América do Sul, quando comparado aos experimentos com mapa de 9 tipos. Todas as integrações, em geral, indicaram que os índices de extremos climáticos e a precipitação acumulada total para as estações seca e chuvosa no Brasil foram subestimados pelo modelo Eta na região de estudo. Isso indica a necessidade de estudos com potencial para melhorar a performance do modelo, como por exemplo, a partir de ajustes no esquema de parametrização da convecção cumulus.

Palavras-chave: eventos extremos; Modelo Eta; tipo de solo; umidade do solo

1 Introduction

The knowledge about climate is essential to help the management of activities, such as agriculture, water resources, energy supplies, and others socioeconomic sectors. Climate models are valuable tools to support climate studies and extreme events such as droughts and floods, and the decision making in the various activities on economic sectors mentioned above. Regional Climate Models (RCM's) use the technique so-called dynamical downscaling to detail the coarse horizontal resolution of global climate models. In the RCM, the reliability of the simulations at high resolution depends on the quality of the lateral boundary conditions, and also on the ability of the regional model to develop realistic features of this climate (Chou *et al.*, 2000; 2002). Regional models incorporate higher-resolution topography which helps to represent the effects of orographic phenomena on the spatial distribution of the rain in the area of interest. In addition, the smaller grid space allows simulation of more extreme values. However, on the seasonal time scale, numerical prediction models have limitation in their simulations, due to the chaotic behavior of the atmosphere, model simplifications, and the error growth during the integrations. Studies have shown that regional models, in particular, the Eta model reproduces simulations of meteorological variables in seasonal and intra-seasonal ranges (Seluchi & Chou, 2001; Marengo *et al.*, 2003; Cavalcanti *et al.*, 2002).

Extreme climate events have a great impact on the socioeconomic activities. To support the detection of extreme events, researchers often use indices to analyze these events. Some analysis of extreme events using climate indices were conducted by Marengo & Valverde (2007). The analysis using numerical models can indicate changes in the intensity or frequency of extreme events in the long-term future climate. In addition, the improvement of regional models to simulate extreme events in the seasonal forecast can support, for example, better planning of hydropower plants (HPP) in control of their reservoirs. One way to achieve this improvement is through model parametrization of the surface processes such as soil water balance. This balance is obtained from hydrological parameters defined for each soil

texture type and the initial soil moisture used as initial conditions. In this paper, we examine the effects of initial soil conditions and soil texture types in the simulations of seasonal precipitation extremes over the Upper São Francisco River basin in Brazil. The objective of this study is to evaluate the Eta model seasonal simulations of precipitation. The results can provide information for the improvement of the Eta model skill.

2 Methodology

2.1 Regional Climate Eta Model

The regional Eta model (Mesinger *et al.*, 1988; Black, 1994; Chou *et al.*, 2005; Mesinger *et al.*, 2012) was integrated to construct model seasonal climatology. The model topography is represented by a discrete step; whose tops coincide exactly with the model layer interface. The model vertical coordinate is represented by the Greek letter η (Mesinger, 1984) which names the model. This coordinate was developed to reduce the errors in the calculation of the horizontal derivatives, mostly the pressure gradient forces near mountain slopes. Considering the coordinate as a horizontal surface, the variables obtained from horizontal derivatives are better calculated by the Eta model.

The equations of the model have been solved on the Arakawa horizontal E grid (Arakawa & Lamb, 1977). The prognostic variables are temperature, horizontal wind components, surface pressure, specific humidity, turbulent kinetic energy, and cloud hydrometeors. Turbulent processes and planetary boundary layer are solved using Mellor-Yamada scheme level 2.5, and in the surface layer profiles are adjusted using Paulson stability functions (Paulson, 1970). Total precipitation is produced by Betts-Miller-Janjic (Janjic, 1994) convection scheme, and the Zhao cloud microphysics scheme (Zhao & Carr, 1997). The radiation scheme was developed by Geophysical Fluid Dynamics Laboratory (GFDL), with long and shortwaves parameterized by Fels & Schwarzkopf (1975) and Lacis & Hansen (1974), respectively. The energy exchanges between soil, vegetation, and atmosphere is solved by the land-surface NOAH model (Ek *et al.*, 2003; Chen *et al.*, 1997). More details on the Eta model can be found in Mesinger *et al.* (2012).

2.2 Study Area

The study area is located in the Upper São Francisco river basin. The errors of the Eta model

simulations are identified for entire South America. The Climatic Research Unit (CRU) observational dataset was used to evaluate the model systematic errors of precipitation simulated over South America. The areas of higher and lower accuracy are identified by comparing the climatological data from CRU against the Eta model simulations. Numerical experiments based on different soil conditions are tested and evaluated in terms of model skill to reproduce the climatology of precipitation in the region. We also included 14 surface meteorological stations from INMET (Brazilian National Institute of Meteorology) in order to analyze the extreme precipitation indices in the study area. Figure 1 shows the location of the Upper São Francisco river basin and the 14 INMET's meteorological stations.

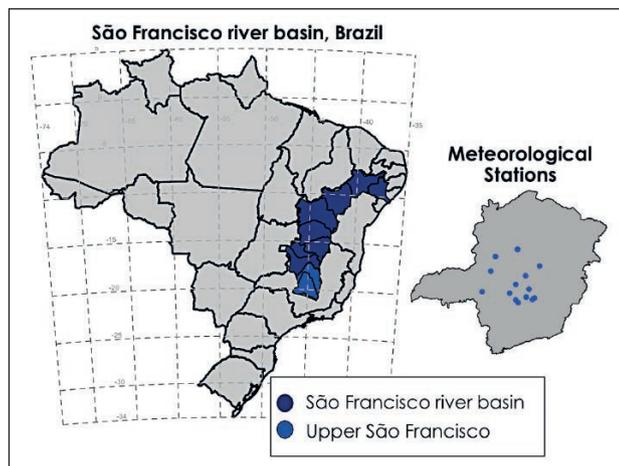


Figure 1 Location of the Upper São Francisco river basin and meteorological stations.

2.3 Numerical Experiments: Initial Soil Moisture and Soil Texture Types

Four experiments of seasonal simulations at 15-km resolution and 4.5-month integrations (starting on April 15th and October 15th) are carried out using the regional Eta model. The study period is the dry and the rainy seasons in the southeast of Brazil, which occur in the months between May to August and November to February, respectively, and the years between 1979 and 2012. The initial and lateral boundary conditions

use the Climate Forecast System Reanalysis (CFSR; Saha *et al.*, 2010). In the experiments, the soil texture map is modified from 9 to 26 soil texture types. The soil types are defined by Zobler (1986) and Doyle *et al.* (2013).

Different values of soil moisture were used as initial condition: climatological soil moisture and water balance calculated moisture (Doyle *et al.*, 2013). The horizontal resolution of the climatological soil moisture data is 1.5° latitude and longitude. Soil moisture was calculated for the years 1979-2012, at 0.5° resolution. The soil characteristics are modified in order to assess the impacts on the seasonal simulations of precipitation extremes in Brazil. The configurations of the experiments are shown in Table 1. The difference in the experiment runs will be analyzed using the Test Tukey (Miller, 1981) of significance, with a confidence level of 5%.

Exp.	Configuration
E9CLI	Zobler (1986) soil types, climatological moisture
E26CAL	Doyle et al. (2013) soil types, water balance moisture
E9CAL	Doyle et al. (2013) soil types, water balance moisture
E26CLI	Zobler (1986) soil types, climatological moisture

Table 1 Configuration of experiments with Eta model.

2.4 Detecting Extreme Events

The studied climate extremes indices were proposed by the World Meteorological Organization (WMO) and the Climate Research Program Variability and Predictability (CLIVAR) established by the Expert Team Climate Change Detection Monitoring and Indices (ETCCDMI) to enable a comprehensive analysis of weather extremes (Karl *et al.*, 1999). Studies involving climate extremes are necessary because of the increasing frequency or severity of extreme weather events. Groisman *et al.* (2005) and Marengo *et al.* (2009) identified in southeastern of Brazil an increase in the frequency of extreme rainfall events since the 1950s. Frich *et al.* (2002) using observed data showed an increasing trend in the frequency of intense precipitation events in some regions of the world, accompanied by changes in the frequency of dry days in some areas. The results of these analyses also indicated that the world has become warmer.

Instead of an annual basis, as applied to climate change studies, here the extreme indices are calculated for dry and rainy seasonal basis.

Table 2 describes the indices used in this work. More information on these indices can be found in Karl *et al.* (1999), and Meehl *et al.* (2000).

Index	Description	Unit
RX1day	Maximum rainfall occurred in one day, during the season.	mm
RX5day	Maximum rainfall occurred in interval of five consecutive days, during the season.	mm
R95P	Indicate heavy rainfalls. Accumulated rainfall in the days which precipitation was higher than the 95th percentile in the season.	mm
CDD	Consecutive Dry Days. Maximum number of consecutive days with precipitation amount lower than 1mm in the season.	Days
CWD	Consecutive wet days. Maximum number of consecutive days with precipitation amount higher than 1 mm in the season.	Days

Table 2 Indices of extreme precipitation events on a seasonal basis.

These indices generally indicate the yearly rainfall extremes. However, in this research, the indices indicate the seasonal extreme (wet and dry season in Brazil) rainfall events. One novelty of this research is the use of extreme climate indices on a seasonal time scale, rather than on a climate change or multi-decadal scale.

3 Results and Discussion

The sensitivity of the model varies with the different soil texture types maps and the initial soil moisture used in each experiment run. Figure 2 shows the climatological and the calculated initial soil moisture in the model, considering the months of April and October, which are the starting dates of the model integration. The calculated soil moisture has lower initial moisture than the climatological values for April and October. In both experiments, the largest groundwater storage is found in April, which is explained by the precipitation water stored in the previous rainy season. Normally the onset of the rainy

season occurs in October, so the initial soil moisture is still low. Higher soil moisture values in April and October were found in the northwestern part of South America and southern part of Brazil, and the lower values within the northeastern and central Brazil. The experiments (described in Table 1) using the Eta model shows sensitivity to the changes in the soil when different soil texture types are used. However, changes in soil texture map affected more the simulated rainfall than the changes in initial soil moisture. Figures 3 and 4 show the differences between precipitation simulated by the Eta model and observed by CRU, respectively in dry and rainy seasons.

Figure 3 shows that in the dry season the model tends to underestimate the precipitation, mostly in North of Brazil and part of Venezuela and Colombia. E26CAL and E26CLI experiments show smaller errors than the other experiments, probably due to the better representation of the type of soil texture in South America. The error pattern of precipitation in the rainy season is different from the dry season (Figure 4). Precipitation is underestimated in most part of Brazil during the dry season for all experiments. In the rainy season, the model skill to reproduce the seasonal climate depends on the study area. For example, the E9CLI and E9CAL experiments underestimate precipitation in some parts of Northeast of Brazil, but in general, these two runs reproduce the mean pattern of precipitation over South America between the years 1979 and 2011. Therefore, the experiments using 26 types of soil texture (E26CLI and E26CAL) show higher skill to reproduce the rainfall in south and southeast of Brazil. The average of the experiments using the 26 soil textures map reproduce the climate of South America (from 1979 to 2011), in both dry (Figure 3) and rainy (Figure 4) seasons. Figure 5 shows the box plot of the extreme precipitation indices, calculated from the average over the 14 meteorological stations, in the period of 1979 to 2012.

The results (Figure 5) emphasize that precipitation simulated in the dry season seems relatively more accurate than precipitation simulated in the rainy season, due to the smaller amount of precipitation in the average of the 14 sites. In both dry and rainy season, E26CLI and E26CAL experiments represent better the average precipitation. These results

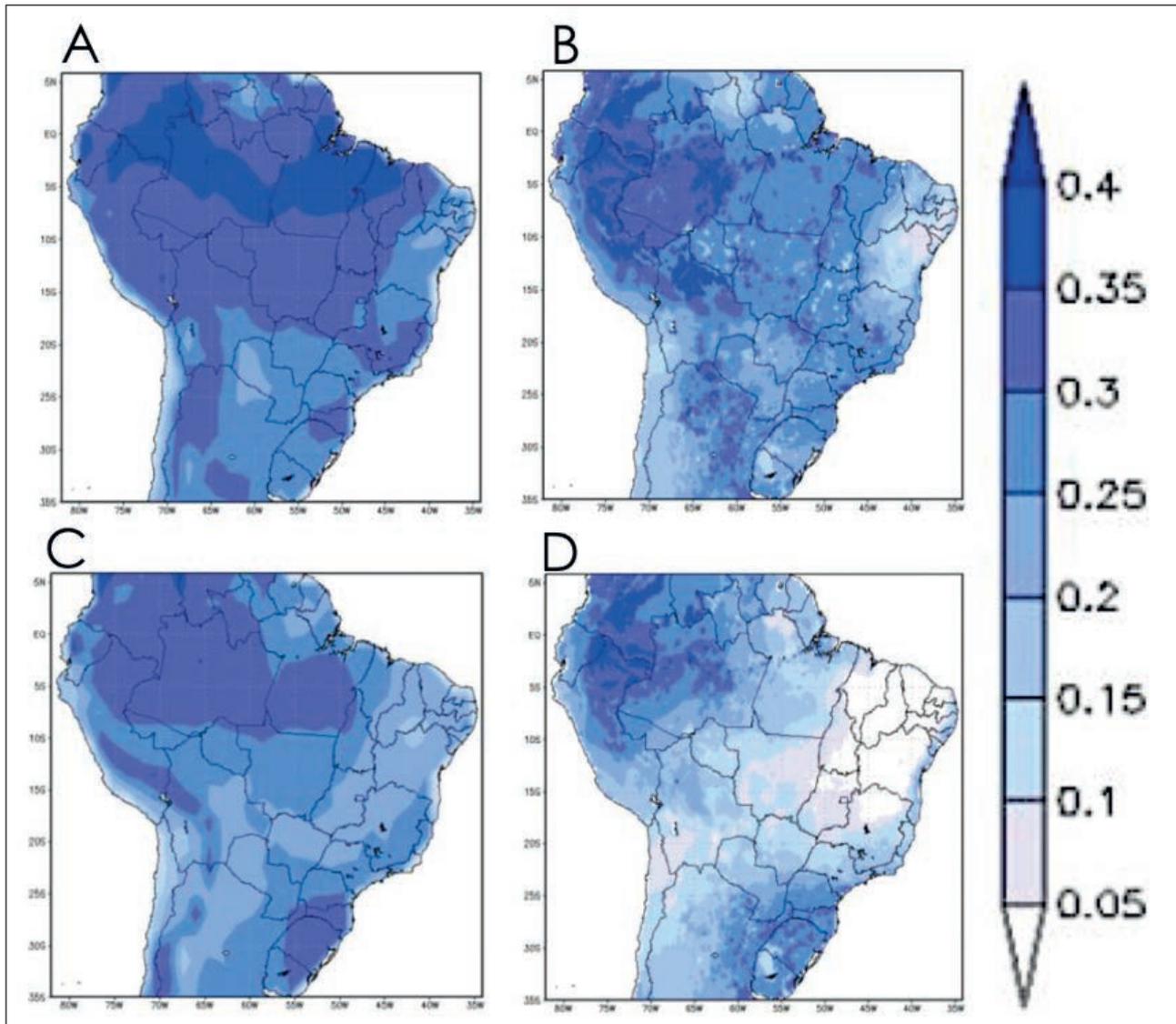


Figure 2 Initial soil moisture (m^3/m^3) used in the experiments. Top row (A, B) refers to April (month of initial condition of the dry season) and bottom row (C, D) October (rainy season). The left column (A, C) refers to climatological soil moisture and right column (B, D) the calculated soil moisture.

indicate that the experiments with 26 types of soil texture have a better performance than the experiments with 9 types in the region of Upper Sao Francisco river basin, showing less underestimation. For the RX1DAY, RX5DAY, and R95P indices, the average of E26CLI and E26CAL experiments also approach the average of the observed data, exhibiting better performance than the experiments using 9 types of soil. In terms of variability, which is represented by the length of the bar, E9CLI and E9CAL reproduce better the variations of the extreme precipitation indices

(Figure 5 B, C, D). Results for simulated mean CDD and CWD indices show that the E9CLI and E9CAL experiments are closer to observation than the other runs (26 texture types), in the dry season (Figure 3 E, F). On the other hand, in the rainy season, E26CAL reproduces better the extreme precipitation CDD and CWD indices. From the boxplot (Figure 5) we can conclude that the experiments using 26 types of soil texture reproduce better the climate in the region in the rainy season.

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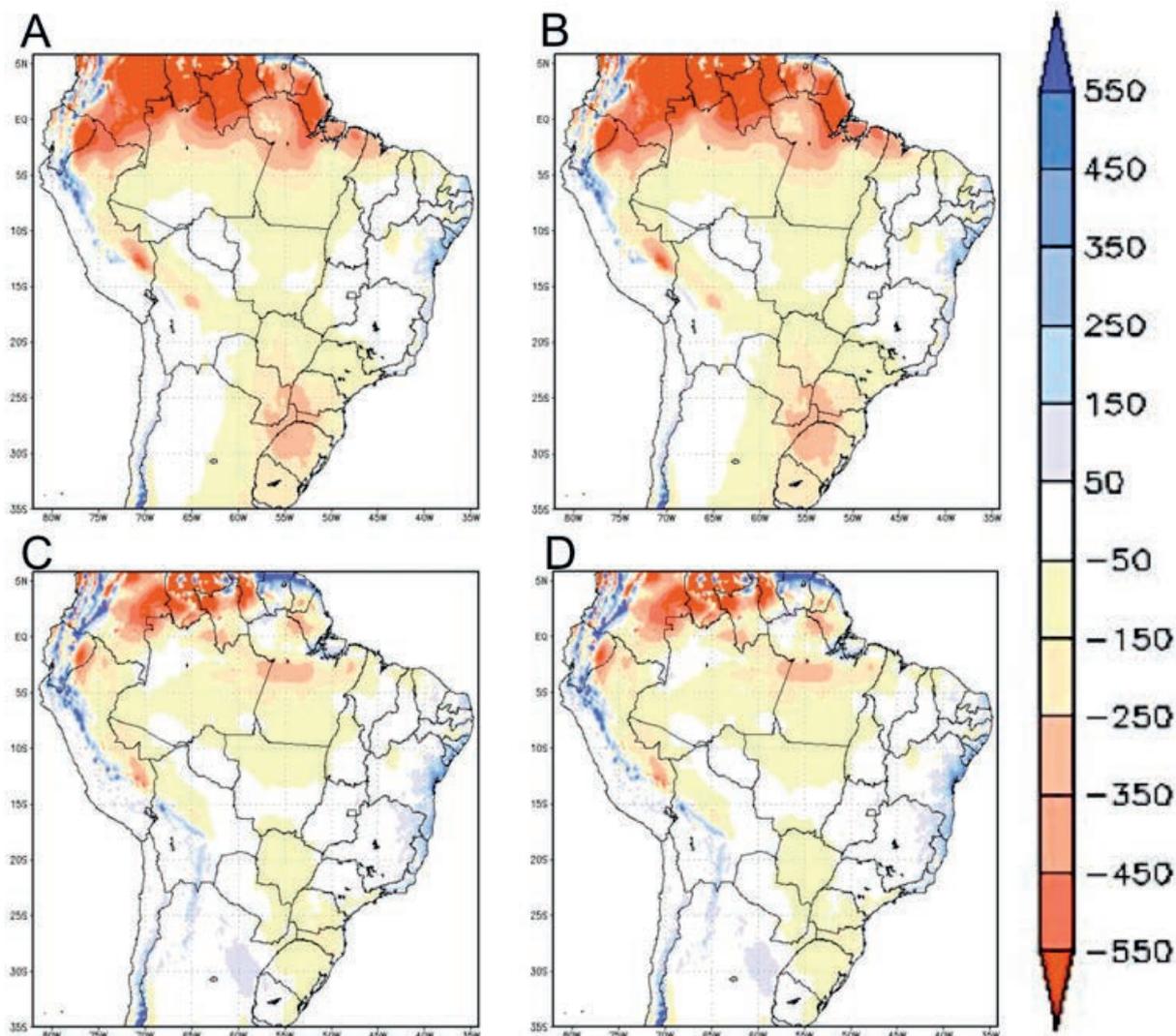


Figure 3 Difference between precipitation (mm/4 months) simulated by Eta model and observed by CRU in the dry season, according to the experiment run (Table 1).

Figures 6 and 7 show the indices of extreme precipitation after the Test Tukey (Miller, 1981) of a difference of the experiment runs, with a confidence level of 5%. The values of non-significant differences cross the zero line. We can conclude that the precipitation simulated for the dry season using 26 types of texture soil has no significant differences in comparison with the observations, which indicates good simulations. On the other hand, experiments using 26 and 9 types of soil are clearly different. Considering the indices RX1DAY and R95P, there is no difference between the experiments, although the E26CAL and E26CLI are closer to observation. No significant difference between experiments with

E26CAL and E26CLI and observation are found in RX5DAY. Therefore, the differences between the experiment runs for the RX5DAY index are small. The indices CDD and CWD are better reproduced within the experiment using 9 types of soil.

Figure 7 shows the difference of the experiments in the rainy season and indicate that the simulations of total precipitation, RX1DAY, and RX5DAY from the experiments are not significantly different. In addition, the experiments using 26 types of texture are closer to observation. Results from R95P, CDD, and CWD show that the experiments using 26 types of soil are not significantly different from the

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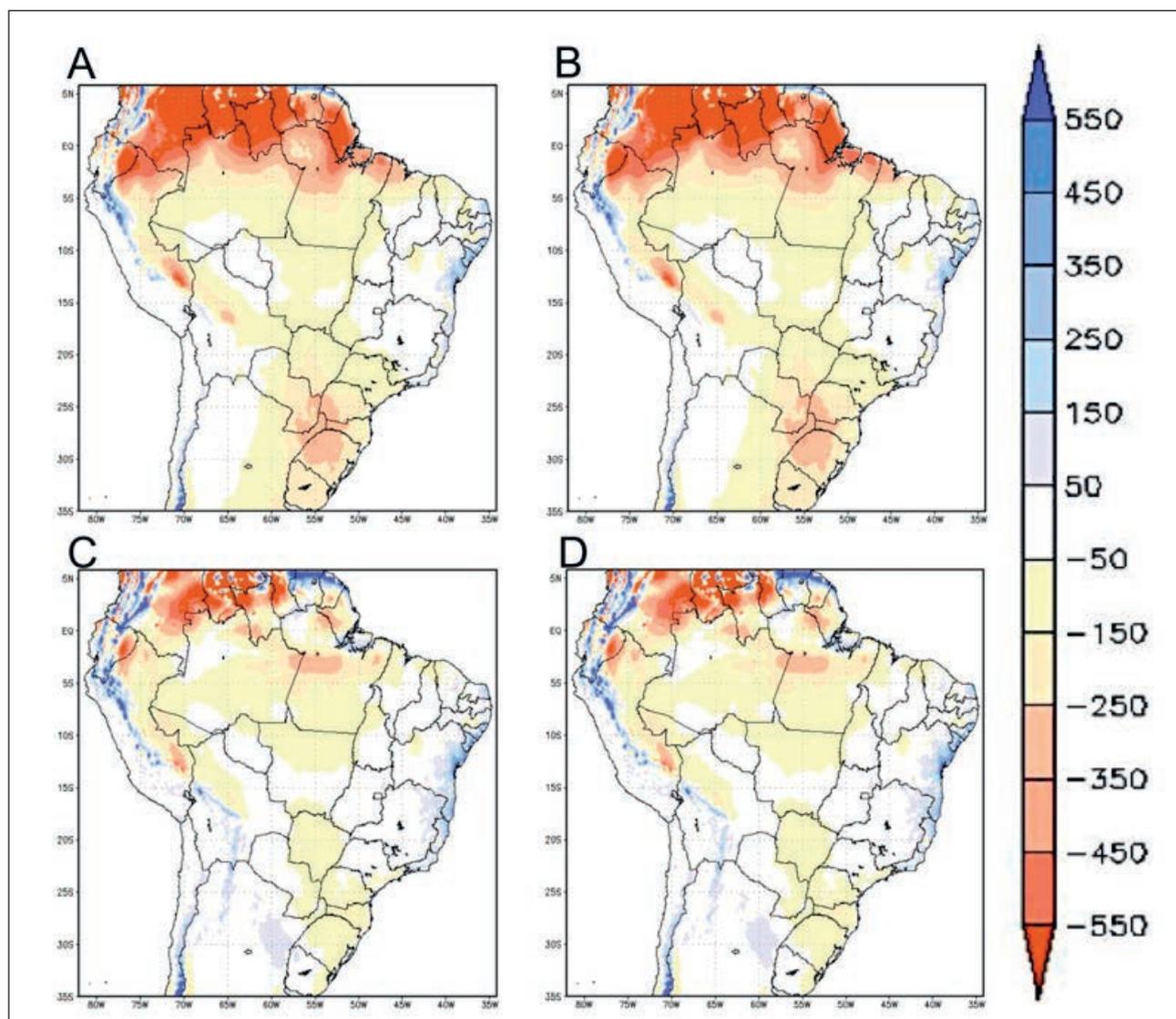


Figure 4 Difference between precipitation (mm/4 months) simulated by Eta model experiments and observed by CRU in the rainy season, according to the experiment run (Table 1).

observations. These results indicate that changes in the soil texture map affect more the simulations of extreme precipitation. This shows the potential for improving the seasonal forecasts through the improvement of the soil characteristics. In all cases (both season and all indices), there is no significant difference in the simulations using different initial soil moisture (calculated or climatological).

In general, the dry and rainy seasons were well simulated by the experiment with 26 soil texture types. The fact that total precipitation and RX5DAY index in the dry season, and R95P and CDD in rainy season show no significant differences

between the experiments with 26 soil texture types and the observations, indicates that the 26 soil texture experiments were able to simulate reasonably well the climate.

4 Conclusions

The Eta regional climate model is used to produce 4.5-month integrations for the dry and rainy seasons in southeast Brazil between the years 1979 and 2012. Two maps of soil texture type (26 and 9 types) and two initial soil moisture conditions (climatological

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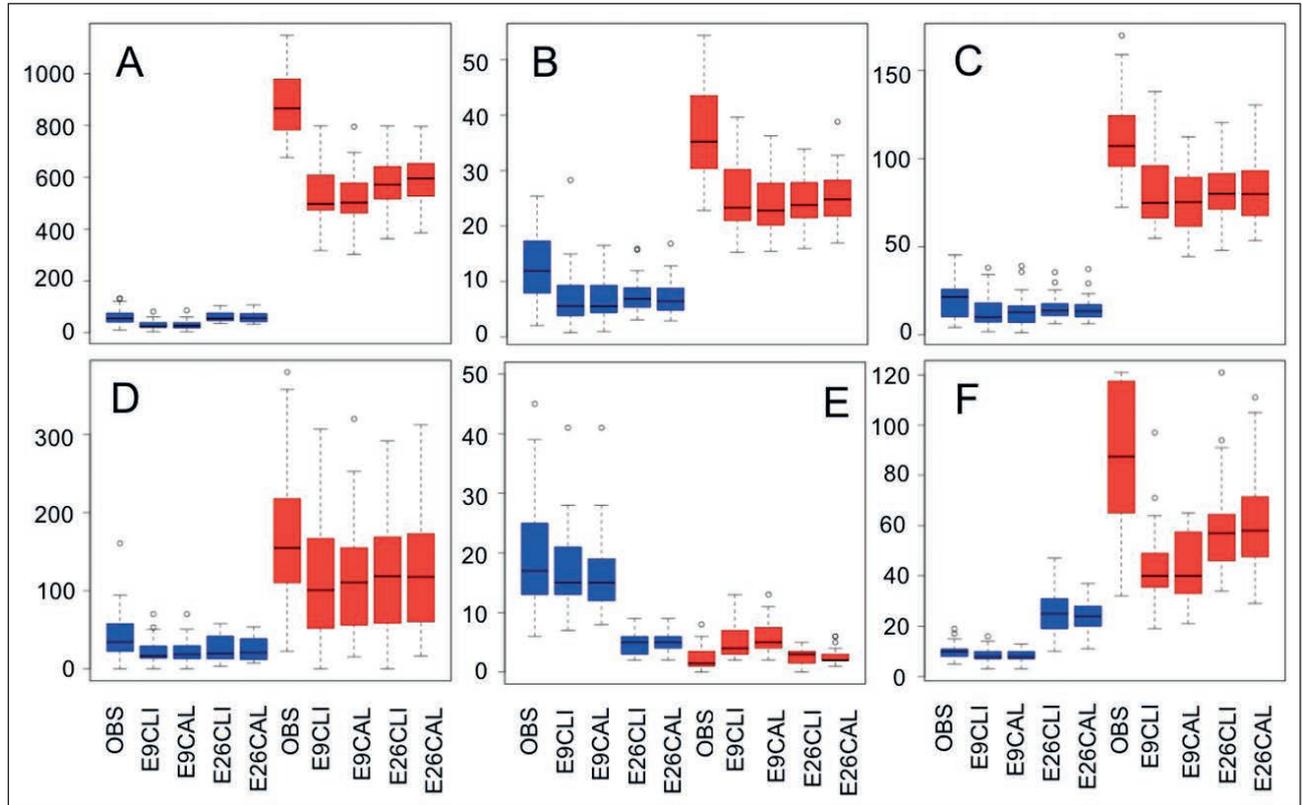


Figure 5 Boxplots of (A) precipitation (mm/4 months) and extreme precipitation indices (B) RX1DAY (mm), (C) RX5DAY (mm), (D) R95P (mm), (E) CDD (days) and (F) CWD (days) for the dry (blue) and rainy (red) seasons.

soil moisture and water balance calculated moisture) are tested. We conclude that changes in the soil texture affected more the variation of simulated rainfall than the change in the initial soil moisture. The average of the experiments with 26 soil texture reproduced better the climate of South America compared to the simulations using the map of 9 soil texture types. In all Eta model experiments, the calculated indices RX1DAY, RX5DAY and R95P, and the total accumulated precipitation for the dry and rainy seasons in Brazil were underestimated over the stations in southeast Brazil. However, the underestimation was smaller using the 26 soil texture types, which indicates that this experiment has a higher skill to represent extreme events of precipitation in the region of Upper Sao Francisco river basin. According to the experiments, it was possible to verify that the Eta model has potential to improve from the changes in soil map texture. Another way to improve the Eta model seasonal forecast is through the adjustment of the convection parametrization scheme.

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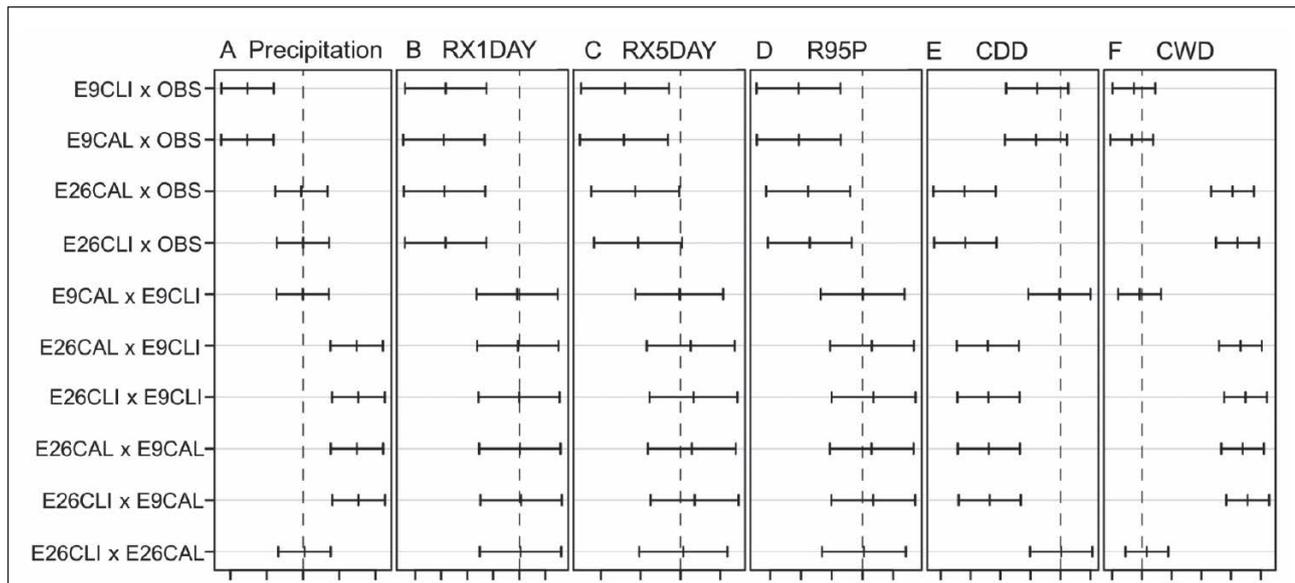


Figure 6 Difference of the indices between the experiments in dry season, according to Test Tukey.

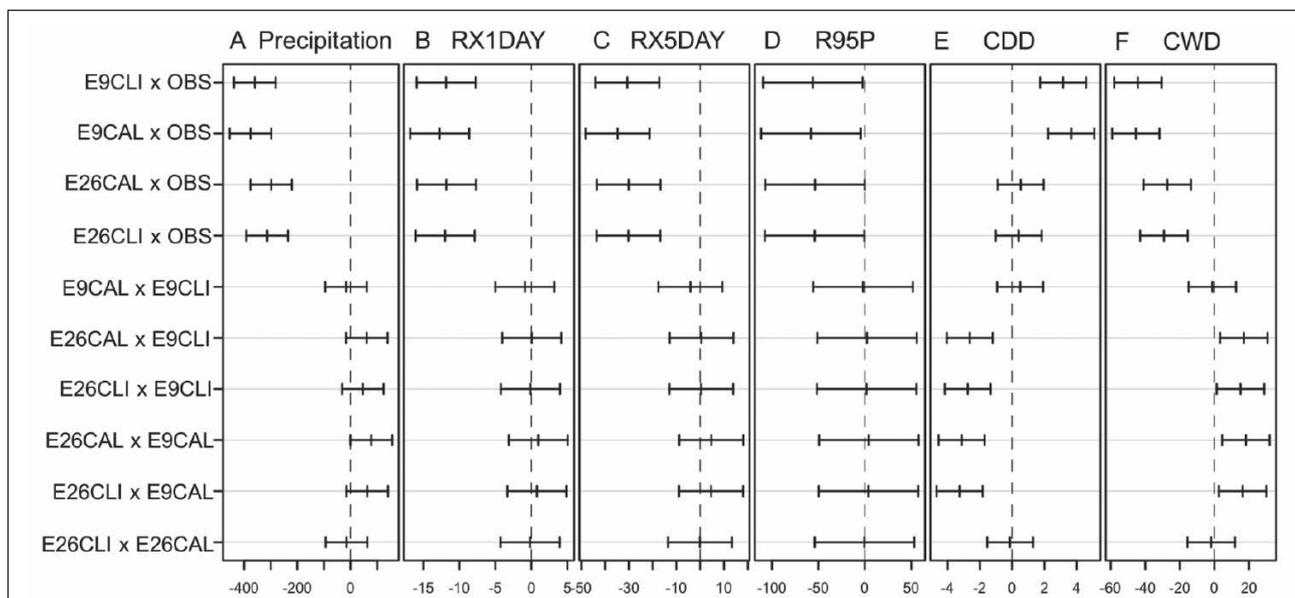


Figure 7 Difference of the indices between the experiments in rainy season, according to the Test Tukey.

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