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SOUTH ATLANTIC SST ANOMALIES IMPACTS ON THE SOUTH BRAZILIAN REGION CLIMATE THROUGH A NUMERIC EXPERIMENT WITH THE MODEL CAM 2.02 AND DATA MINING TECHNIQUES

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The aim of this work is to evaluate the influence of the South Atlantic Ocean (SAO) Sea Surface Temperature (SST) anomalies on the rain regimen of the South Brazilian Region and, consequently, in the local hydrographic basins. An analytical function based on a combination of two Gaussian distribution in space and one distribution in time was applied to the climatology of SST of the Community Atmosphere Model version 2.02 (CAM 2.02) of the National Center for Atmospheric Research (NCAR) in order to simulate an SAO SST anomaly. The Gaussian analytical function was adjusted to the February and March of 2005 observed anomaly in the SAO, on the region near 58W and 40S where those anomalies reached 2ºC. In this period a rain anomaly in the South Brazilian Region took place, with pluviometric deficits of about 100 mm in the Uruguai (SC) and Iguaçu (PR) rivers basin's. In the subsequent months the SAO SST anomaly intensity was diminished but it was increased up in area reaching 20S in September, persisting until October. In these last two months the rain levels in the south region of Brazil basins exceeded the historical values in more than 100 mm. Data mining techniques applied to some computed indexes obtained from the model results revealed some South Brazilian Region circulation anomalies patterns in response to the SAO/SST anomaly forcing. The vertical structure of the model atmosphere was strongly affected by the forcing, the humidity and latent heat flux was augmented and the planetary boundary layer height was shortened in the anomaly forced region. These preliminary results emphasize the importance of the prognostics of SST in seasonal climatic forecast, demonstrating the need of a coupled ocean-atmosphere modeling system for this kind of forecast.

1. Introduction

The interactions between ocean and atmosphere have been studied for many years in various parts of the world. The first simplified model to incorporate the dynamics of this interaction in the climate forecasting equations was presented in 1968, by Yoshihara. The best known and most popular of these interactions is related to oceanic phenomenon impacts of the type: El Nino-Southern Oscillation (ENSO) on the global climate.

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Over the last decades some researchers have alerted the world on the influence that SST anomalies in the South Atlantic Ocean (SAO) exert on the climate of a large part of the South American climate mainly during the summer precipitation regimen on the southern half of the continent. In studies made by Peagle and Mo (2002), Doyle and Barros (2002) and Carvalho et. al. (2004) these influences were studied related mainly to the intensity of the South Atlantic Convergence Zone (SACZ) in the southeast and mid-west regions of Brazil and its relation to ENOS phenomenon. In work by Drumond and Ambrizzi, 2005, an observational and numerical study was made to evaluate the influence of SST anomalies in the low frequency variability of the South American Summer Monsoon season.

During intense ENSO events, the atmospheric circulation over the SAO can be directly affected

(Cataldi and Torres Júnior, 2000), showing alterations, for example, in the position of the South Atlantic Subtropical Anticyclone (SASA). Other studies showed that ENSO impacts on the rainfall regimen in South America could increase or diminish according to the SAO SST anomalies (Enfield and Mayer, 1997; Vera et. al, 2004).

It is important to understand that, excluding the more intense events, generally these interactions only modify existing atmospheric patterns whose signal is difficult to identify through conventional observable data analyses. In these cases, numerical experiments and data mining techniques can be used aiming to extract from climatic patterns, only disturbances resulting from modeled anomalies.

In this paper we will evaluate, through computational modeling, SAO SST influence during summer pluvial and hydrologic regimens in the southern region of Brazil, based on verified anomalies recorded between January and March of 2005. In the next chapter, a brief description will be given of the climatic and hydrologic scenarios observed in Southern Brazil during the period of this study. In the following section the formulation of the mathematical equation used to generate the SST anomaly and its special distribution will be presented. Next, we will show the climatology obtained from the CAM model, evaluating some of the atmospheric parameters analyzed in the PCMDI Report nº 45 published by the AMIP (Gates et. al,1998). In the last three chapters presentation will be made of the main results recorded in this study as well as the conclusions and recommendation closing with the bibliography.

2. Climactic and hydrologic scenarios observed in Southern Brazil during the summer of 2005.

In 2005, the months of February and March were marked by intense negative precipitation anomalies in the Southern region and consequently, major anomalies in the Natural Inflows* observed at the Hydroelectric plants at the Salto Santiago, located in the Iguaçu River Basin (PR), Machadinho, located in the Uruguai River Basin (SC) and Passo Real in the Jacuí River Basin. Tables 2.1 and 2.2, respectively present the precipitation anomalies and the verified natural inflows at the Jacuí (RS), Uruguai (SC) and Iguaçu (PR) River Basins. It's important to know to that as of the month of October, when strong positive precipitation anomalies were recorded, in practically all the following months negative precipitation anomalies were observed.

Regarding the hydrological response to these anomalies, we observed that the negative natural inflow anomalies were only verified in the month of December, due to the intense positive anomalies in the month of October that influenced the average inflows observed in November.

Table 2.1 – South of Brazilian hydrographic basins precipitation anomalies in percentage of the average monthly precipitation.

	Jacuí Basin (RS)	*Uruguai Basin (SC)*	*Iguaçu Basin (PR)*
Oct-04	130 %	100 %	170 %
Nov-04	64 %	97 %	90 %
Dec-04	50 %	65 %	50 %
Jan-05	74 %	70%	87 %
Feb-05	16 %	17 %	19%
Mar-05	50 %	53 %	54%

* Natural Inflow means the measure the volume of the water inflow in a section of river or at a hydroelectric reservoir, excluding the effect of anthropogenic activities impacts due to the operation of water reserves up-stream from the hydro plant as well as irrigation and other uses.

Table 2.2 – Natural inflow anomalies recorded at hydroelectric reservoirs in the South of Brazil shown in percentage.

	Jacuí (RS) Basin (Passo Real)	*Uruguai (SC) Basin (Machadinho)*	*Iguaçu (PR) Basin (Slt. Santiago)*
Oct-04	44 %	113 %	120 %
Nov-04	101 %	108 %	174 %
Dec-04	68 %	67 %	86 %
Jan-05	47 %	73 %	77 %
Feb-05	27 %	29 %	37 %
Mar-05	35 %	46 %	32 %

During these months, intense negative SST anomalies were observed in the South Atlantic near the Prata Basin as can be the figure 2.1.

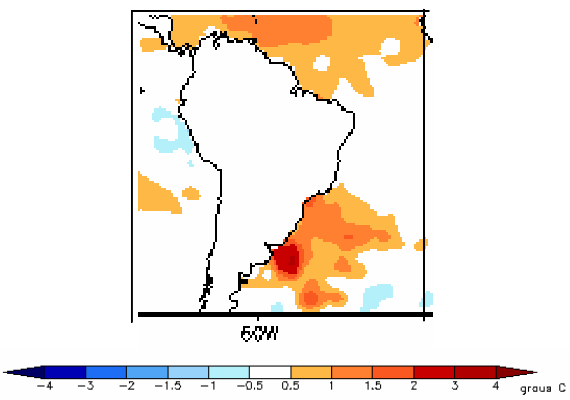

Figure 2.1. SAO SST anomalies in February, 2005. (Source: CPTEC/INPE)

The atmospheric circulation patterns also suffered modifications, presenting anomalous configurations from December 2004 to March, 2005. This period was marked by fast moving cold fronts through the south of Brazil, generally associated with an anomalous inclination of the jet stream at 200 hPa, that presented a more intense Northwest component that helped dislocate the cold fronts out over the ocean after reaching the Southern region. During this period reduced atmospheric pressure anomalies were also recorded at sea level (negative in Argentina and Uruguay and positive in the greater part of South and Southeastern Brazil) and at the 500 hPa geopotential height, with positive anomalies near Patagonia and negative over the SAO near South and Southeastern Brazil coastal regions (Climanálise, 2004-2005)

3. SST anomaly generation

SST analytic anomalies were generated through a combination of two Gaussian distributions in space (equation 3.1) and one in time (equation 3.2), according to the methodology proposed by Torres Júnior, 2005.

$$f(x) = \frac{1}{\sigma_\varphi \sqrt{2\pi}} \exp\left[\frac{(y-\eta_\varphi)^2}{2\sigma_\varphi^2}\right] \frac{1}{\sigma_\lambda \sqrt{2\pi}} \exp\left[\frac{(x-\eta_\lambda)^2}{2\sigma_\lambda^2}\right] \quad (3.1)$$

where:

f(x) Spatial Gaussian distribution
x longitude index;
y latitude index;
η_φ latitude displacement;
σ_φ latitude variance;
η_λ longitude displacement;
σ_λ longitude variance

$$g(x) = \frac{1}{\sigma_\tau \sqrt{2\pi}} \exp\left[\frac{(t-\eta_\tau)^2}{2\sigma_\tau^2}\right] \quad (3.2)$$

where:

g(x) Time Gaussian distribution;
t time index;
η_τ displacement; in time;
σ_τ variance on time or pulse width.

The SST anomaly temporal evolution can be observed in Figure 2.2. The model integration starts in September with the warming of the SAO SST starting in the second month of integration (November - 2004), reaching a maximum weight between the months of February and March, similar to the SST behavior verified in this period.

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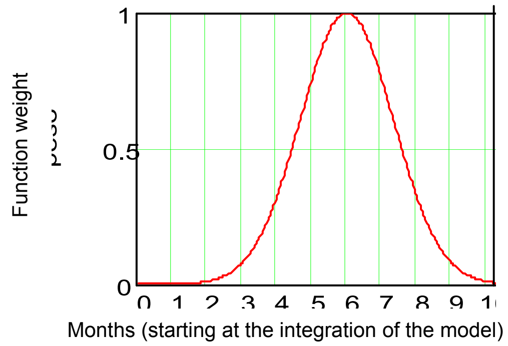

Figure2.2. Time distribution of the Gaussian function weights

These anomalies were generated analytically and after validation, were inserted in the model CAM code. An additional difficulty was experienced in the implementation of these distributions in the CAM model code due to parallelization where the model matrix is divided into sectors that are resolved individually for each processor which also requires the parallelization of the Gaussian space distribution.

4. The CAM 2.02 model "climate"

The Community Atmosphere Model (CAM) is the fifth generation of climatic models developed by the National Center for Atmospheric Research (NCAR) – (ccm0/1983, ccm1/1987, ccm2/1992, ccm3/1996 and CAM/2002). Its main characteristics include: three-dimensional and transient modeling;

Physical approximations according to the atmospheric layer; the resolution used - T42 (128 lon and 64 lat) results in a horizontal matrix of 2.2 ° of spacing (244 km); 26 vertical levels; solution of primary equations in vertical and temporal aspects through finite differences approximations in the horizontal, through spectral mode projections. The model also has deep convective parameterizations, humid convection, condensation, precipitation, cloud fractions, short and long-wave radiations, vertical diffusion and atmospheric boundary layer.

Its main improvements in relation to the previous model version – the CCM 3.6 – include: the possibility of running coupled simulations: Ground (LSM), Ocean (POP Ocean) and Ice; the possibility of using finite volumes for solving equations in the vertical; parameterization for calculating in a distinct form, liquid water and precipitation water in clouds – local and global component models; thermodynamic models for determining the concentration and thickness of ice in the ocean; determination of the flows exchange of between the atmosphere and coastal regions, islands and ice-covered surfaces; clouds geometric treatment in cloud-radiation interactions; new parameterizations for absorption and long waves emission related to water vapor; the calculation of convective precipitation and evaporation; boundary conditions – sea surface temperature (climatology - 1951 to 2001) and "real" separation in the physical and dynamic processes treatment (Collins, et. al, 2002).

In order to evaluate the model "climate", integrations were conducted in the model for four consecutive years comparing some average atmospheric parameters grouped according to seasons of the year. These integrations were made at a Silicon Graphics workstation containing four 600 MHZ IP35 processors with 4GB of RAM memory at the COPPE/UFRJ. To facilitate comparisons, the selected variables were the same as those analyzed in the PCMDI Report nº 45. Some averages variables will be presented for the period January to March: a) Reduced Atmospheric Pressure at Sea Level in hPA (RAPSL); b) Air Temperature at the Surface in ºC (TS); c) Zonal Wind Components at the 200hPa level in m/s (U200); d) Sensitive Heat Flow on the Surface (W/m²)/month (SHFS) and e) Total Precipitation Rate in mm/day (PR). In the figures 4.1 and 4.5, we can see these results. In order to construct these data for each latitude, a quarterly longitudinal average for each variable was applied. The Figures representing these results reveal great coherence with those of the AMIP Project. The distribution of air masses and heat between the polar regions and the equator have been correctly defined, as well as seasonal temperature distribution between the two hemispheres along the average latitudes, can also be observed in figure 4.2

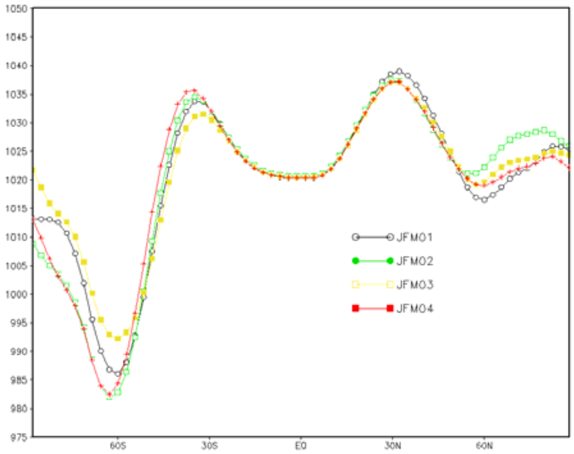

Figure 4.1. a) Average Zonal Distribution of Reduced Atmospheric Pressure at sea level in hPa (RAPSL), for the months January to March.

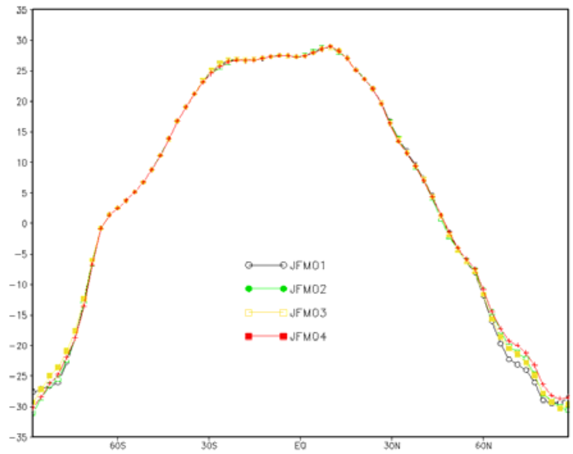

Figure 4.2. b) Average zonal distribution of air temperature on the surface in ºC (TS), for the months of January to March.

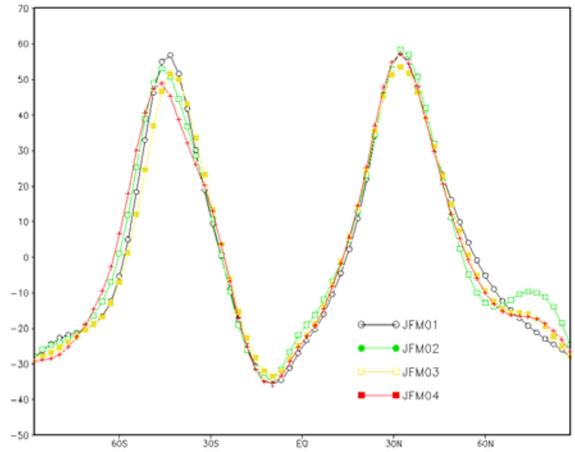

Figure 4.3. c) Average Zonal Distribution of Zonal Wind Components at the 200hPa level in m/s (U200) for the months January to March.

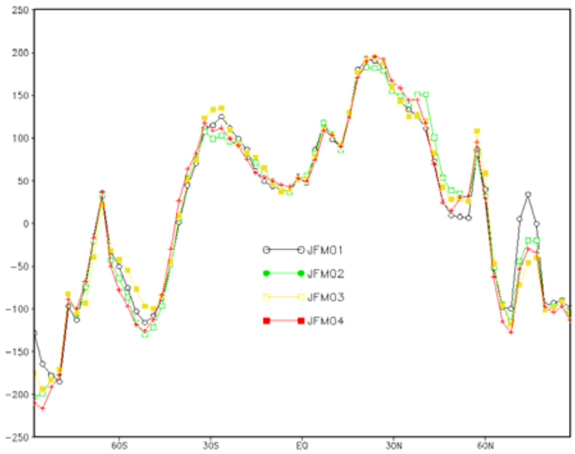

Figure 4.4. d) Average Zonal Distribution of the Sensitive Heat Flow at the Surface in W/m2 (SHFS), for the months January to March

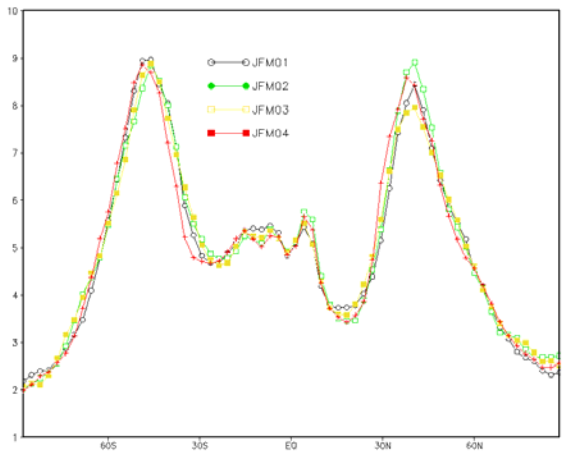

Figure 4.5. e) Average Zonal Distribution of the Zonal Precipitation Rate in mm/day (PR), for the months January to March

Based on the presented data (figures 4.1 to 4.3) we can conclude that the model is operating in climate regimen and can be used as comparison control data to the atmospheric disturbance fields resulting from SST anomalies that have been numerically generated. Its worth noting that mainly, the reduced pressure fields at sea level and the sensitive heat flow at the surface present divergences form the zonal averages of the four year integration model at latitudes grater than 60S and 60N. This behavior can also be noted in the other fields to a lesser degree. This fact may be associated to the numeric discontinuity identified by the model at the polar extremes and should be taken into consideration in studies that use the CAM model, mainly those that are applied to these regions. This behavior also was observed in the result of all the models that had been part of PCMDI Report nº 45.

5. Results

In this chapter, some of the main results will be examined in reference to the month of February during which the strongest SST anomalies, precipitation and natural inflows were observed. The weight function applied to the SST anomalies was elaborated so that the anomalies would have their maximum weights in this same month as can be observed in Figures 5.1 to 5.4. In these figures, the model surface temperature anomalies are presented for the months of December to March respectively after inclusion of the SST numeric anomaly in the model code.

All the anomalies presented in this chapter refer to the climatology of model.

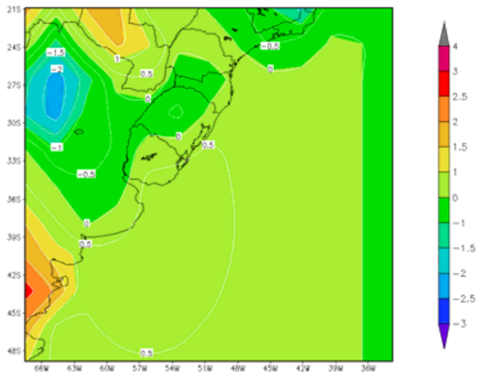

Figure 5.1. December surface temperature anomaly (°C) generated by the model before inclusion of the SST anomaly.

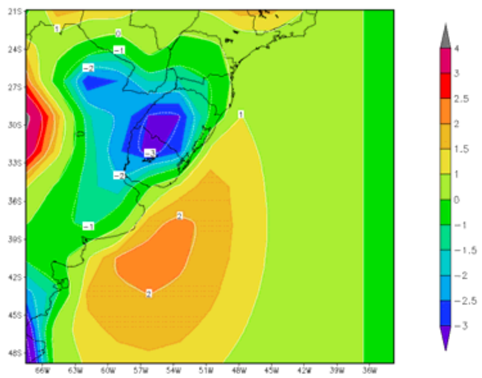

Figure 5.2. January surface temperature anomaly (°C) generated by the model before inclusion of the SST anomaly.

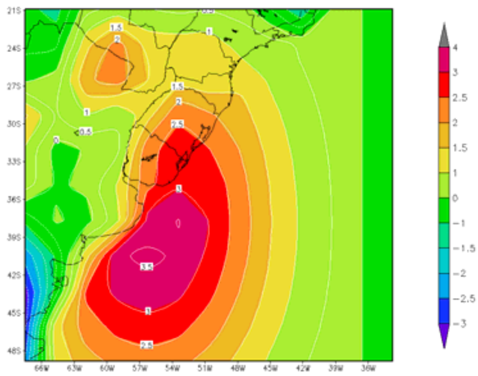

Figure 5.3. February surface temperature anomaly (°C) generated by the model before inclusion of the SST anomaly.

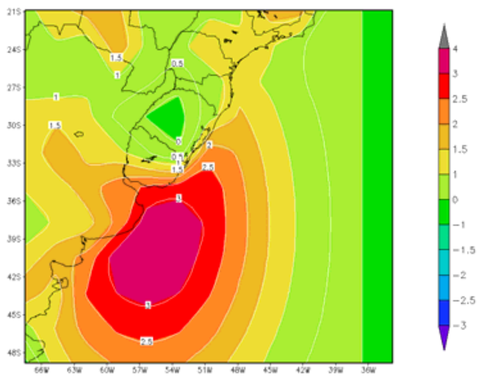

Figure 5.4. March surface temperature anomaly (°C) generated by the model before inclusion of the SST anomaly.

As we can observe in the figures the surface temperature anomalies verified over the continent are a reflex of the SST anomalies induced in the previous months.

A Data Mining technique[♣] was applied to define the most significant rules of association between the atmospheric response and SST anomalies. The variables with greatest statistical significance for the tele-connection were: reduced atmospheric pressure at sea level (hPa), wind at 850 and 200 hPa (m/s), daily average total precipitation (mm/day), long wave radiation flow (W/m² / month), relative humidity of the air integrated between 1000 and 500 hPa (%) and atmospheric boundary layer height (m). In the following figures, the differences between the values calculated by the model, with and without the SAO SST anomaly inclusion are presented. In the Figure 5.5 we can see the difference obtained in the reduced atmospheric pressure at sea level field and the wind at 850 hPa.

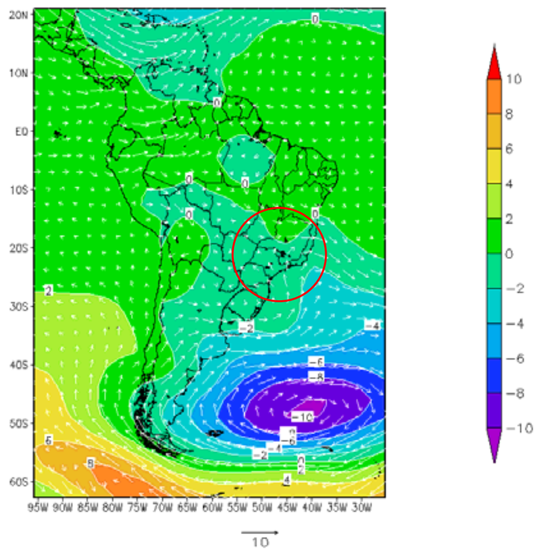

Figure 5.5. February difference obtained in the reduced atmospheric pressure at sea level (hPa) and the wind vector at 850 hPa (m/s).

In the Figures 5.6 to 5.10 - The respective differences discussed refer to: the wind vector at 200 hPa, daily average precipitation rate, long wave radiation flow, relative humidity of the air integrated between 1000 and 500 hPa and the atmospheric boundary layer height.

[♣] CBA Data Mining: http://www.comp.nus.edu.sg/~dm2/

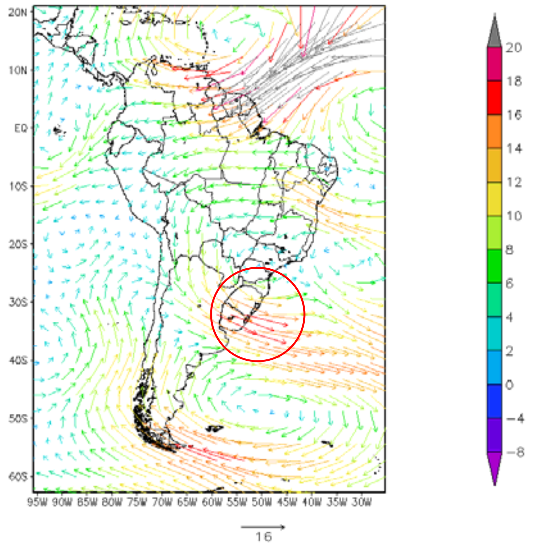

Figure 5.6. February difference obtained in the model for wind field at 200 hPa .

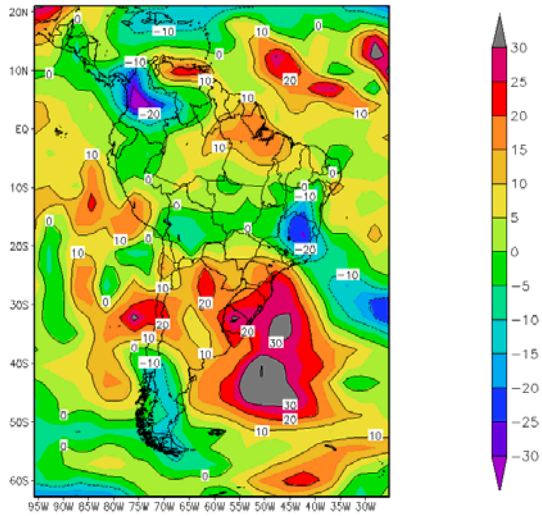

Figure 5.8. February difference obtained in t the model for the long wave radiation flow (W/m²)/month.

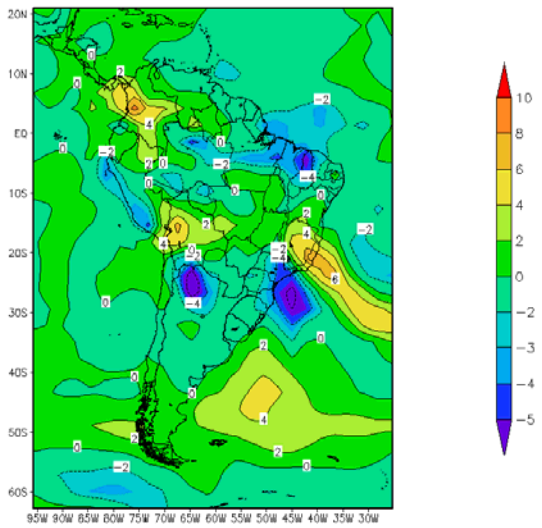

Figure 5.7. February difference obtained in the model for the daily average precipitation rate (mm/day).

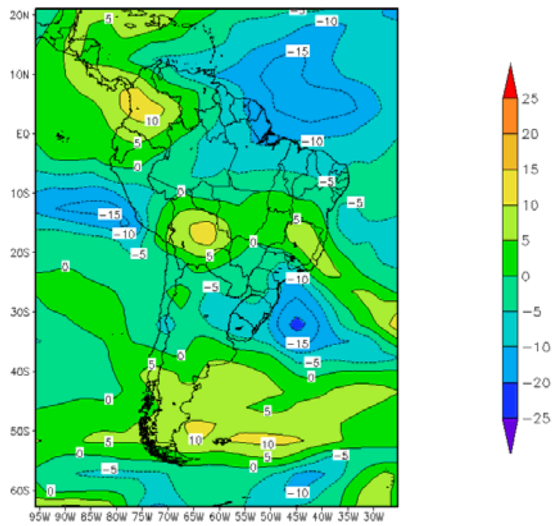

Figure 5.9. February difference obtained in the model for the relative humidity of the air integrated between 1000 and 500 hPa (%).

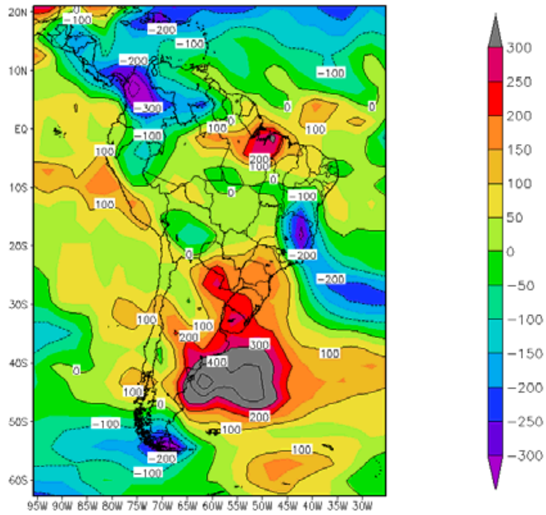

Figure 5.10. Difference obtained by the CAM 2.02 model for the atmospheric limit of the layer height (m) in February.

Some atmospheric patterns obtained with the modeling were very similar to those observed February 2004, as for example, the intensification of the west/southwest jet stream component (200 hPa) close to Rio Grande do Sul (Figures 5.6 and 5.11) and a cyclonic circulation at 850 hPa over the SAO near Rio de Janeiro (Figures 5.5 and 5.12). This jet stream behavior was very similar to the 2005 summer event which was important to assure the short permanence of frontal systems in the South of Brazil. It's worth noting the small anomaly in the Northwest, in the 850 hPa circulation, over the states of Mato Grosso, Goiás and Minas Gerais, indicating a possible increase in the movement of humid air from the Amazon region down to the Southeastern Brazil.

The effects of the SAO SST anomaly simulated by the model were well marked in the South of Brazil as well as a significant reduction of the relative humidity over all the states in the region and the increase of the atmospheric boundary layer. This increase is probably due to the reduction of the atmospheric pressure coupled to the increase in the long wave radiation flow resulting from the cloud cover reduction over the region. Another notable fact of the simulations was the significant decrease in the average daily precipitation rate in the Brazilian South.

In Figures 5.11 and 5.12 observed February 2004 wind anomalies at 200 and 850 hPa were presented.

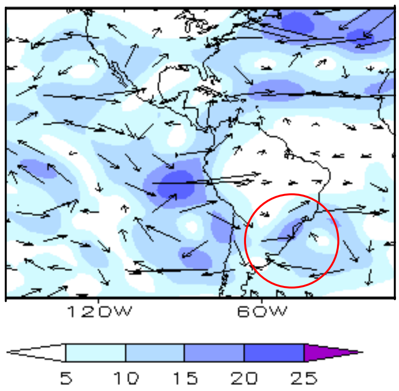

Figure 5.11. February 2005 200 hPa wind anomaly. Source: CPTEC/INPE.

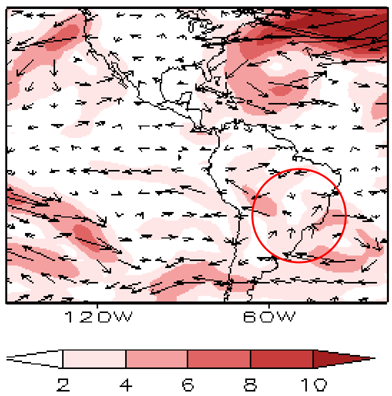

Figure 5.12. February 2005 850 hPa wind anomaly Source: CPTEC/INPE.

An additional result can be considered when observing the favorable conditions to rainfall increase in the Southeast region, mainly near Rio de Janeiro and Minas Gerais during this period. This signal, contrary to what was observed in the South region, may be related to the 850 hPa anomaly circulation observed in the Amazon humidity transport in direction to the Southeast region, event of major importance for the South Atlantic

Convergence Zone - SACZ configuration over this region.

6. Conclusions and recommendations

The results indicate a strong teleconnection between the positive SAO SST anomalies, close to the Uruguay coast and the precipitation regimen in the Southern region of Brazil and consequently, the hydrological regimen of this area. The anomalies verified in the Southern region during this period were considered significant not only in regard to their scope but in regard to their intensity as well. The negative anomaly average precipitation rates in the region recorded -2 to -5 mm/day. While the integrated relative humidity, measured at 1000 to 500 hPa, was reduced by 10%. The long wave radiation flow presented an increase of 10 to 20 (W/m²)/month, indicating a significant reduction in cloud cover over the region. These results, when compared to the date recorded in February of 2004, still presented coherence in the atmospheric circulation at 850 and 200 hPa, although this comparison is not the main objective of this study.

The January and March results, presented a behavior similar to the month of February the signals shown were weaker as was seen in the values representing precipitation variations and inflows. This fact suggests the possibility that we are dealing with an inter-zonal teleconnection and as such it would be difficult to capture seasonal forecasts.

This type of study could be expanded to include other regions in Brazil and elucidates the importance that the SAO SST anomalies exert over the entire country and consequently, the hydrological forecast scenarios.

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