THE EFFECTS OF A NEW BOUNDARY FORCING APPROACH ON MODEL'S NEAR-SURFACE VARIABLES

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1. INTRODUCTION

Physical parameterization schemes are among the main sources of uncertainty in numerical weather and climate predictions. Numerical prediction models can be used to assess regional climate information through dynamical downscaling of general circulation model solutions what might increase uncertainty.

Roads et al. (2003) showed that downscaling of precipitation of global reanalysis with regional models does not produce improvements in the field of precipitation over South America. In fact, in many cases, regional simulations produce degraded results compared to the overall analysis. Even with regional models providing a better characterization of the topography, shape of the coast, distributing land-sea-ice, land use, etc., regional simulations are not able to improve the reanalysis. It is believed that the incorporation of rainfall data can be a useful tool to provide better regional simulations, instead of simply using reanalysis alone (Nunes and Roads 2005).

Nunes and Roads (2007) described the implementation of a precipitation assimilation scheme, and evaluated its impact on the regional climate model's surface water and energy budgets. They showed that continuous assimilation of precipitation produces changes in radiation fluxes by modifying the surface albedo and the distribution of clouds, which is directly related to changes in the moisture profile produced by the assimilation scheme. They also verified the assimilation scheme positive impact on the simulation of hydrological processes and energy balance at the surface, which can be linked to changes in soil moisture, in addition to the original goal of increasing the ability of short-term forecasting discussed in Nunes and Cocke (2004).

Many climate aspects depend on the physical processes of land-atmosphere interactions, because the flow of net radiation at the surface during long periods (annual averages) is balanced by the sensible heat and latent heat fluxes, and the soil moisture leads to the partitioning of sensible and latent heat fluxes in the surface energy balance (Betts et al. 1996). Selective adjustments of individual components of the hydrological cycle can cause significant improvements in other aspects of the hydrological cycle (Dirmeyer and Zhao 2004; Nunes and Roads 2007).

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In order to solve smaller scale phenomena, a dynamical downscaling is general applied to a global model solution. The dynamical downscaling is to consider a regional model set in the area of interest and a larger area or global model providing lateral boundaries and surface conditions. This technique of regionalization has many limitations, such as erroneous wave scale developed into the regional model, plus the fact that the regional model simulates all local characteristics without input from direct observations and without the entry of large-scale, except for the boundaries. A technique that corrects some of these inaccuracies is the Spectral Nudging (von Storch et al. 2000), because it preserves large-scale features within the regional model, allowing the regional model solves only the smallest scale. With similar results the Scale-Selective Bias Correction (SSBC; Kanamitsu et al. 2010) is used as boundary forcing in a regional climate model.

The effects of a new boundary forcing that combines SSBC with precipitation assimilation, which was implemented in a regional climate model to reduce the uncertainty in downscaled global fields, are discussed below.

2. EXPERIMENTAL DESIGN

The Regional Spectral Model (RSM; Juang et al. 1997) is a primitive equation model, which has similar physics to the NCEP-DOE Reanalysis AMIP-II (R2; Kanamitsu et al. 2002). In this study, the global reanalysis, R2, provides 6-hourly boundary conditions to the RSM experiments.

The land-surface model (LSM) coupled to RSM is Noah (Ek et al. 2003), which shows improved features in comparison to the Oregon State University land surface model (OSU LSM; Pan and Mahrt 1987) used in R2, especially the increase of soil layer number within two soil layers on OSU (10- and 190-cm thickness) to four soil layers on Noah (10-, 30-, 60- and 100-cm thickness).

To investigate the impact of the precipitation assimilation (PA; Nunes and Roads 2007) procedure on the RSM-extended simulations over South America, together with the SSBC scheme, three 40-km RSM experiments were organized as in the following: i) SSBC is a control experiment, strongly forced with R2 large-scale features; ii) PA is an RSM experiment in which only precipitation analyses obtained from Climate Prediction Center (CPC) morphing method (CMORPH; Joyce et al 2004) are 3-hourly assimilated using the model's full physics code; iii) PA+SSBC combines the two methodologies as suggested in Nunes (2012), during the RSM extended integrations.

Comparisons between simulations of RSM and fields of R2 are required to see how each of the schemes modifies the model's response with respect to the boundary forcing. The RSM fields are also compared with analyses of precipitation and temperature that are the main variables for the extended forecast evaluations.

Table 1 briefly describes the datasets used in the comparisons, as well as in the assimilation scheme.

Table 1: Satellite-based products and station datasets

Satellite-based Products	Res.	Description	Reference
CMAP	2.5°	Enhanced version (satellite, observation and reanalysis), monthly means of precipitation	Xie and Arkin (1997)
1DD-GPCP	1°	One-degree daily mean precipitation from version 1.1	Huffman et al. (2001)
CMORPH	25 km	From satellite; 3-hly precipitation, assimilated in RSM	Joyce et al. (2004)
Station dataset	**Res.**	**Description**	**Reference**
GTS	0.5°	Daily precipitation analyses from global gauges	WMO
CRU	0.5°	CRU TS3.21: Climatic Research Unit (CRU) Time-Series (TS) Version 3.21 of High Resolution Gridded Data of Month-by-month Variation in Climate (Jan. 1901 - Dec. 2012)	University of East Anglia CRU 2013; NCAS British Atmospheric Data Centre

The selected period is January of 2004. This is a representative month of the austral summer, and much of rainfall occurs at this period of year over northwestern South America. Neutral conditions are associated with Niño 3.4 region in late 2003 and early 2004. Although this is not the focus of this study, an atypical phenomenon hit the southern coast of Brazil in late March 2004, the Catarina tropical cyclone.

3. RESULTS

Fig. 1 shows several precipitation analyses for January 2004. The NOAA Climate Prediction Center (CPC) Merged Analysis of Precipitation (CMAP; Xie and Arkin 1997) monthly mean is displayed in Fig. 1a. Fig. 1b displays monthly mean precipitation from Version 1.1 of the One-Degree Daily (1DD) Global Precipitation Climatology Project (GPCP) product (Huffman et al. 2001). Daily precipitation analyses at 0.5-degree resolution, from the Global Telecommunication System (GTS) reports, and made available through the CPC servers, are shown in Fig. 1c. In Fig. 1d, the assimilated precipitation analysis from CMORPH datasets, which was degraded from 25-km to a 40-km resolution to match the experiment resolution, is shown for January 2004.

Figs. 1a, b, c and d show well agreement except over Amazon Region, which presents more precipitation in CMORPH analysis (Fig. 1d). During January, it is expected a large amount of rain in this area.

Fig. 2 shows precipitation fields from the observational global forcing (R2) and the 40-km RSM simulations. In Figs. 2c and 2d, both PA and PA+SSBC are highly correlated with the precipitation analyses (Figs. 1a-d) in comparison with R2 and SSBC. The SSBC precipitation (Fig. 2b) is similar to R2 (Fig. 2a) as expected due to the strong constraint imposed by the SSBC scheme.

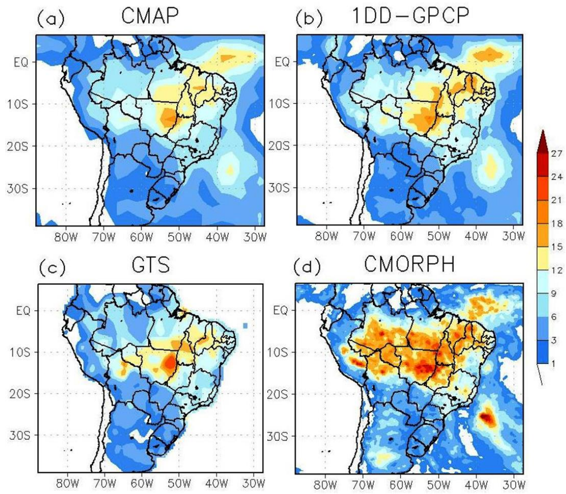

Figure 1: Precipitation analysis (mm/day): (a) R2; (b) SSBC; (c) PA; (d) PA+SSBC. Displayed: January 2004.

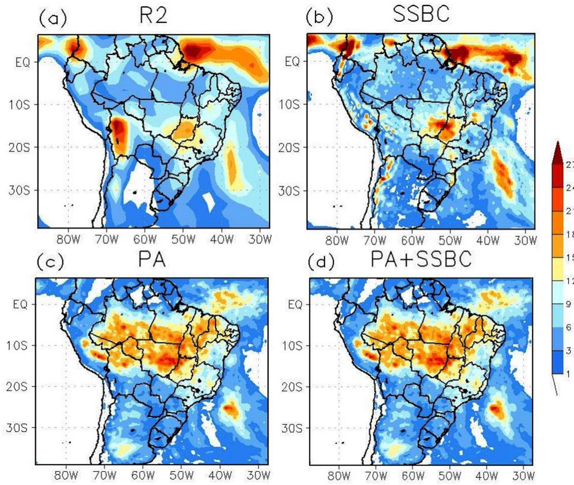

Figure 2: Precipitation (mm/d): (a) R2; (b) SSBC; (c) PA; (d) PA+SSBC. Displayed: January 2004.

Fig. 3 shows 2-m air temperature fields for R2, SSBC, PA and PA+SSBC. SSBC, PA and PA+SSBC compare well with the near-surface temperature analysis from Climatic Research Unit (CRU) data that is presented in Fig. 4. PA+SSBC (Fig. 3d) has lower temperature values in comparison with SSBC and PA, but still shows higher values in Amazon compared to R2. The analysis of temperature (Fig. 4) shows more conformity with PA than PA+SSBC.

The SSBC scheme strongly constrained the R2 large-scale features in the SSBC RSM simulation. In this sense, it is expected SSBC RSM to show good agreement with R2. However, in Figure 3, comparing the R2 (Figure 3a) with SSBC (Figure 3b) discrepancies between those fields are observed, especially over Amazon, with lower values in R2.

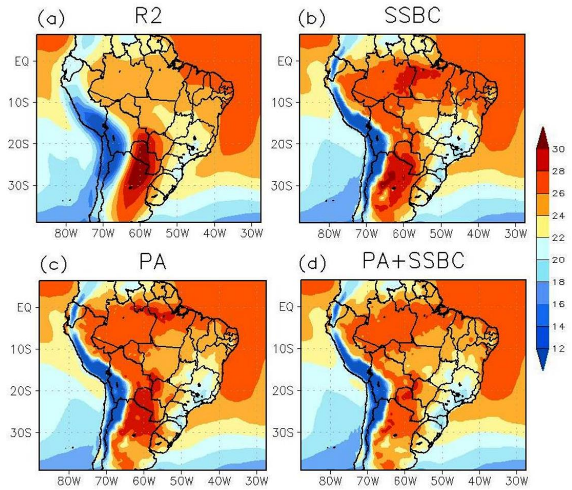

Figure 3: 2-m air temperature (^{o}C): (a) R2; (b) SSBC; (c) PA; (d) PA+SSBC. Displayed: January 2004.

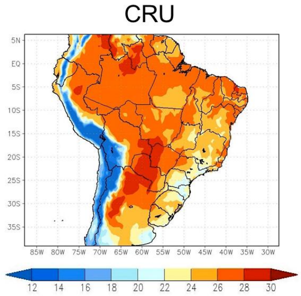

Figure 4: Near surface temperature (°C) from CRU. Displayed: January 2004.

Figs. 5, 6 and 7 show R2, SSBC, PA and PA+SSBC near-surface variables, namely: 2-m specific humidity, latent heat flux and 10-m wind, respectively.

Specific humidity is the variable directly changed by the assimilation scheme as described in Nunes and Roads (2007), and is in better agreement with R2 (Fig. 5a) for both PA (Fig. 5c) and PA+SSBC (Fig. 5d), however poor agreement is found in a comparison with SSBC, in which that variable is left unchanged (Fig. 5b).

Comparisons with specific humidity (Fig. 5) and precipitation (Fig. 2) show that R2 has a lot of moisture over the continent (Fig. 5a) and low rainfall (Fig. 2a), whereas precipitation and specific humidity of SSBC, PA and PA+SSBC (Figs. 2b and 5b, 2c and 5c, 2d and 5d, respectively) show agreement between moisture availability and precipitation patterns.

Fig. 6 reinforces the inconsistency between R2 and SSBC, whereas in R2 (Fig. 6a), the latent heat flux is relatively high over Amazon, which indicates the presence of evaporation, than for SSBC (Fig. 6b) where the latent heat flux is lower. In contrast, Figs. 6c and 6d agree with the precipitation pattern observed in the region (Fig. 2), because there is water vapor available for evaporation.

R2 fields are colder, wetter and have more latent heat flux, which would lead to a lot of precipitation over the area, but in reality, does not match the one shown in Fig. 2a where no significant rainfall occurs. This inconsistency in R2 might have some possible causes: (1) the low resolution of R2 does not allow more detailed fields; (2) the vertical distribution of moisture in R2 inhibits model's deep convection.

SSBC remains mass and flow balances in the synoptic scale (Kanamitsu et al. 2010). In that regard, one expects SSBC and PA+SSBC show better agreement with the R2 near-surface wind, as displayed in Fig. 7b and 7d, respectively.

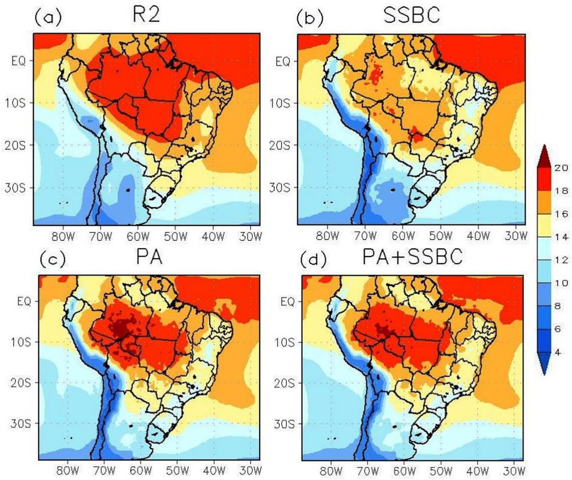

Figure 5: 2-m specific humidity (g/kg): (a) R2; (b) SSBC; (c) PA; (d) PA+SSBC. Displayed: January 2004.

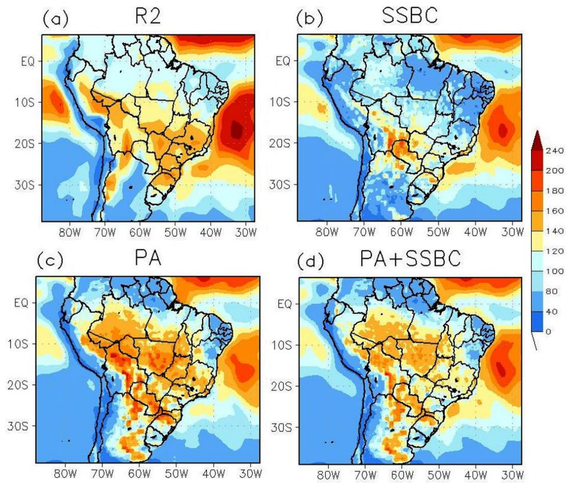

Figure 6: Latent heat flux (W/m²): (a) R2; (b) SSBC; (c) PA; (d) PA+SSBC. Displayed: January 2004.

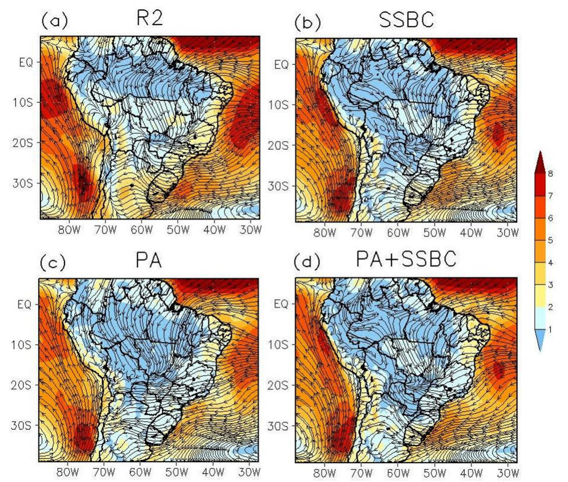

Figure 7: 10-m wind (m/s): (a) R2; (b) SSBC; (c) PA only; (d) PA+SSBC. Displayed: January 2004.

Differently from PA, the SSBC scheme mainly acts on the wind rotational component what could explain the SSBC (Fig. 8b) and PA+SSBC (Fig. 8d) upper-level summer circulations, such as the Bolivian High and the Subtropical Jet, better agreement with R2 (Fig. 8a) than PA (Fig. 8c) alone.

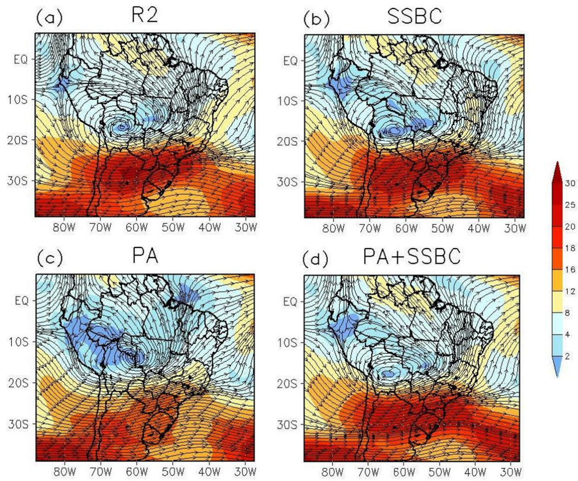

Figure 8: 250-hPa wind (m/s): (a) R2; (b) SSBC; (c) PA; (d) PA+SSBC. Displayed: January 2004.

4. CONCLUDING REMARKS

In this study, the effects of a new boundary forcing on long-term simulations of a regional climate model were examined and revealed that near- and surface variables were mostly improved, in comparison with a control solution in which only a scale-selective bias correction was applied.

Similar to the spectral nudging, scale-selective bias correction prevents internal states generated by the regional model that are inconsistent with the large-scale solution, and places systems correctly, due to nudging applied to the rotational component of the wind.

Satellite-based estimates were used in the precipitation assimilation procedure to improve the regional model's cumulus-convection scheme. From those analyses, it was observed that the combined forcing brought model's dynamic fields closer to analyses as well as the values of the thermodynamic variables (temperature, specific humidity and latent heat flux). Therefore, precipitation assimilation, together with spectral nudging-type scheme, can eventually improve land-atmosphere interactions that might prove useful in the initialization of long-term predictions with improved forecast ability.

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