Theor. Appl. Climatol. 86, 261–270 (2006)
DOI 10.1007/s00704-005-0213-5

Theoretical and Applied Climatology
Printed in Austria

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Simulation of the summer circulation over South America by two regional climate models. Part II: A comparison between 1997/1998 El Niño and 1998/1999 La Niña events

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With 6 Figures

Received December 17, 2004; revised April 14, 2005; accepted June 29, 2005
Published online May 26, 2006 © Springer-Verlag 2006

Summary

This study investigates the capabilities of two regional models (the ICTP RegCM3 and the climate version of the CPTEC Eta model – EtaClim) in simulating the summer quasi-stationary circulations over South America during two extreme cases: the 1997–1998 El Niño and 1998–1999 La Niña. The results showed that both the models are successful in simulating the interannual variability of summer quasi-stationary circulation over South America. Both the models simulated the intensification of subtropical jet stream during the El Niño event, which favoured the blocking of transient systems and increased the precipitation over south Brazil. The models simulated the increase (decrease) of precipitation over north (west) Amazonia during the La Niña (El Niño) event. The upper level circulation is in agreement with the simulated distribution of precipitation. In general, the results showed that both the models are capable of capturing the main changes of the summer climate over South America during these two extreme cases and consequently they have potential to predict climate anomalies.

1. Introduction

Interannual variations such as the El Niño and La Niña events strongly affect the summer climate of South America (Kousky et al., 1984; Kayano et al., 1989; Grimm et al., 1998; Grimm, 2003). In particular, the 1997/1998 El Niño and 1998/1999 La Niña events were the strongest of the century (Wang and Weisberg, 2000; Coughlan, 1999) and greatly influenced the summer quasi-stationary circulations and precipitation associated over South America. Rao et al. (2002) studied the effects of quasi-stationary waves over the Southern American continent during the 1997/1998 El Niño event. They found that the low level jet (LLJ) on the eastern side of the central Andes is stronger and transports more moisture during the El Niño event. This was suggested to be responsible for the higher rainfall over south east South America during El Niño years. Lau and Zhou (2003) noted that during the 1997/1998 El Niño episode excessive rainfall occurred over north Peru and over southeast South America while in the north and central Brazil precipitation was lower. During the 1998/1999 La Niña event the anomalies of precipitation were weaker and not well organized.

More recently, Fernandez (2004), using the reanalysis data of the National Centers for Environmental Predictions/National Center for Atmospheric Research (NCEP/NCAR) and the Global Precipitation Climatology Project (GPCP) data, described the main features of the quasi-stationary circulations and associated precipitation for January (1998) and January (1999). Comparing the El Niño and La Niña cases, he noted that during the El Niño event stronger anomalies of precipitation occurred, mainly in the coastal north Peru, south Brazil, northeast Argentina and north Brazil. During the La Niña event the Amazonian region and the region of the South Atlantic Convergence Zone (SACZ) were wetter than normal. At the upper levels, the subtropical jet stream was stronger during the El Niño episode, which favoured the blocking of transient systems and enhancement of rainfall in the south Brazil (Marques and Rao, 1999, 2000). During the El Niño event the Bolivian high (BH) was located in the regions of south Peru and north Chile, and the Nordeste low (NL) and SACZ were weaker compared with the La Niña event. In the case of the La Niña event the NL is better defined. The SACZ is stronger and shifted southward compared with its climatological position. Since the precipitation maximum in the Amazonian region was shifted northward, probably the BH became more meridionally extended in relation to its mean position.

The studies mentioned above showed that the quasi-stationary summer circulations over South America and the associated precipitation are greatly altered during the El Niño/La Niña events. The objective of the present paper is to simulate the summer quasi-stationary circulations over South America during the 1997/1998 El Niño and 1998/1999 La Niña events, using two regional models implemented at the Centro de Previsão de Tempo e Estudos Climáticos (CPTEC): 1) the version 3 of the Abdus Salam International Centre for Theoretical Physics (ICTP) regional climate model (RegCM3), and 2) the climate version of the CPTEC Eta model (hereafter called as EtaClim). In the first part of this work, Fernandez et al. (2006) showed that both the RegCM3 and EtaClim are capable of reproducing the mean climatological features of the summer quasi-stationary circulations over South America, although there are areas in need of further improvement. In the present study, we propose to assess the capabilities of these models to capture the changes in the summer climate over the South American continent during extreme cases, such as the strongest El Niño and La Niña events of the last century. The descriptions of the two regional models and the experiment design are presented in Sect. 2. Section 3 shows the simulations using the RegCM3 and EtaClim, and Sect. 4 contains the summary and conclusions.

2. Description of the two regional models

2.1 RegCM3

The ICTP RegCM3 is the latest version of the regional climate model (RegCM) originally developed at NCAR (Giorgi et al., 1993a, b). The dynamic component of the model is based on the NCAR-Pennsylvania State University mesoscale model (MM5). It is a primitive equation, σ_p vertical coordinate, grid-point limited area model with compressibility and hydrostatic balance. The model contains 18 vertical levels with the top at 100 hPa and uses an Arakawa B horizontal grid. The main physical parameterizations contained in the RegCM3 used in this study are: a detailed atmospheric radiative calculation package based on the version 3 of the NCAR Community Climate Model (CCM3) (Kiehl et al., 1996); a surface physics package, the Biosphere-Atmosphere Transfer Scheme (BATS1e) (Dickinson et al., 1993); an explicit planetary boundary layer formulation (Holtslag et al., 1990); large-scale cloud and precipitation scheme which accounts for the subgrid-scale variability of clouds (Pal et al., 2000); and Grell's cumulus convection parameterization (Grell, 1993). The primary changes included in the RegCM3 in relation to the other versions of the RegCM are described by Elguindi et al. (2004).

2.2 EtaClim

The EtaClim is a climate version of the actual operational numerical weather prediction model implemented at NCEP, which is available by the Cooperative Program for Operational Meteorology Education and Training (COMET). The main differences between this version of the model and that used operationally at CPTEC for seasonal predictions refer to the inclusion of sophisticated parameterizations of physical processes and some options which are not present in the operational CPTEC Eta model. It is a primitive equation, eta vertical coordinate, hydrostatic model. The model contains 38 vertical levels (17 levels from the surface to 700 hPa) with the top at 25 hPa and uses an Arakawa E horizontal grid. A detailed description of the dynamic component of the model is given by Black (1994). The parameterizations of the physical processes in the model used in this study are: a 2.5 and a 2.0 Mellor-Yamada schemes for the formulations of the planetary boundary layer and the surface layer, respectively (Mellor and Yamada, 1974); a radiation calculations package derived from the Geophysical Fluid Dynamics Laboratory (GFDL), where the longwave and solar radiation are parameterized according to Fels and Schwartzkopf (1975) and Lacis and Hansen (1974), respectively; a modified version of the Oregon State University surface physics package (NOAH 2.2) (Chen et al., 1997; Chen and Mitchell, 1999); a microphysics processes scheme (Ferrier et al., 2002); and a cumulus convection parameterization (Kain, 2004).

2.3 Data and methodology

In order to simulate the characteristics of summer climate over the South American region during the 1997/1998 El Niño and 1998/1999 La Niña events, the two models are integrated for January 1998 (El Niño) and January 1999 (La Niña). The models are integrated from 00:00 UTC of 15th December 1997 till 00:00 UTC of 1st February 1998 for the El Niño case and from 00:00 UTC of 15th December 1998 till 00:00 UTC of 1st February 1999 for the La Niña case. In each case the first 17 days of integration

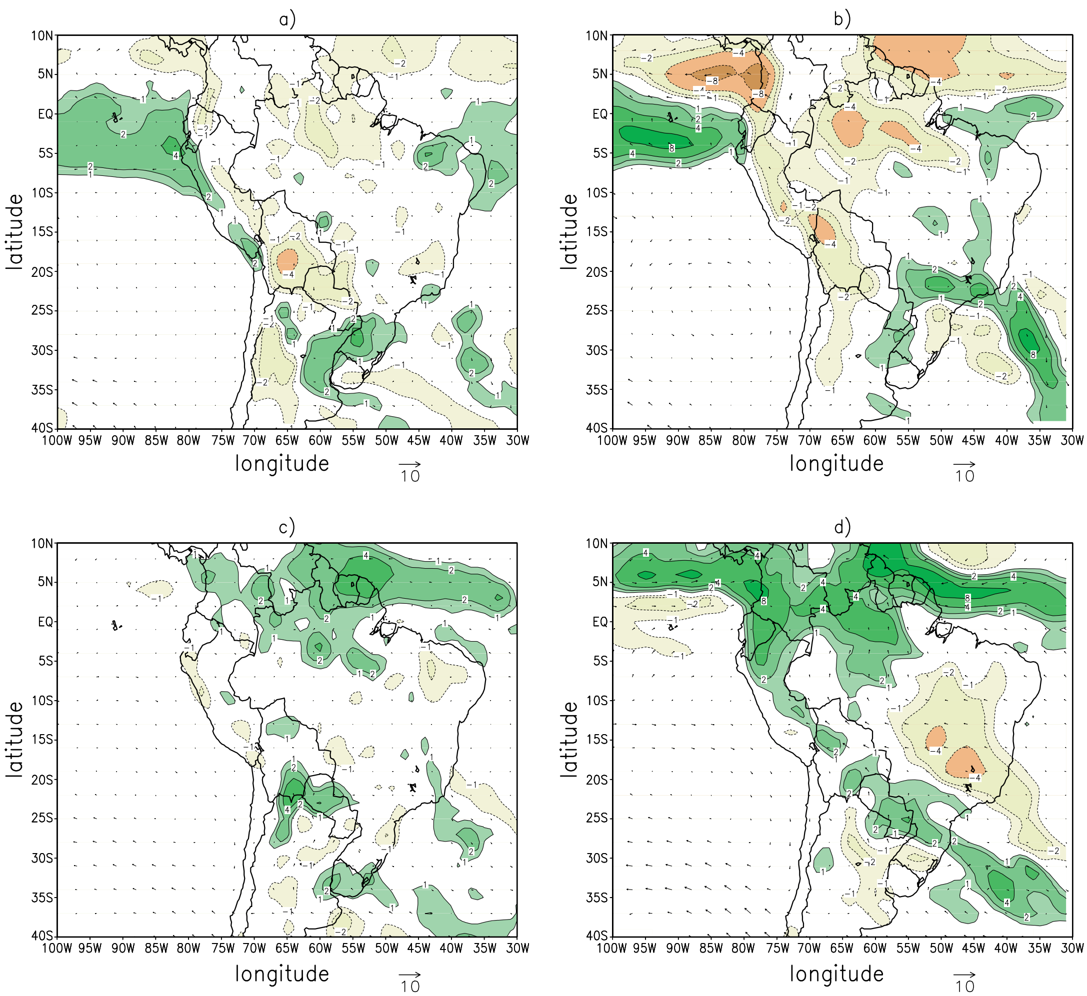

Fig. 1. Differences between the simulated precipitation for January 1998: **a**) RegCM3, **b**) EtaClim, and January 1999: **c**) RegCM3, **d**) EtaClim, and the model climatology for January

are neglected in order to avoid spin-up problems (Fernandez et al., 2006; this issue). To obtain the anomalies for the El Niño and La Niña events the mean climatological values for January (control experiment) are subtracted from the simulated values for January 1998 and January

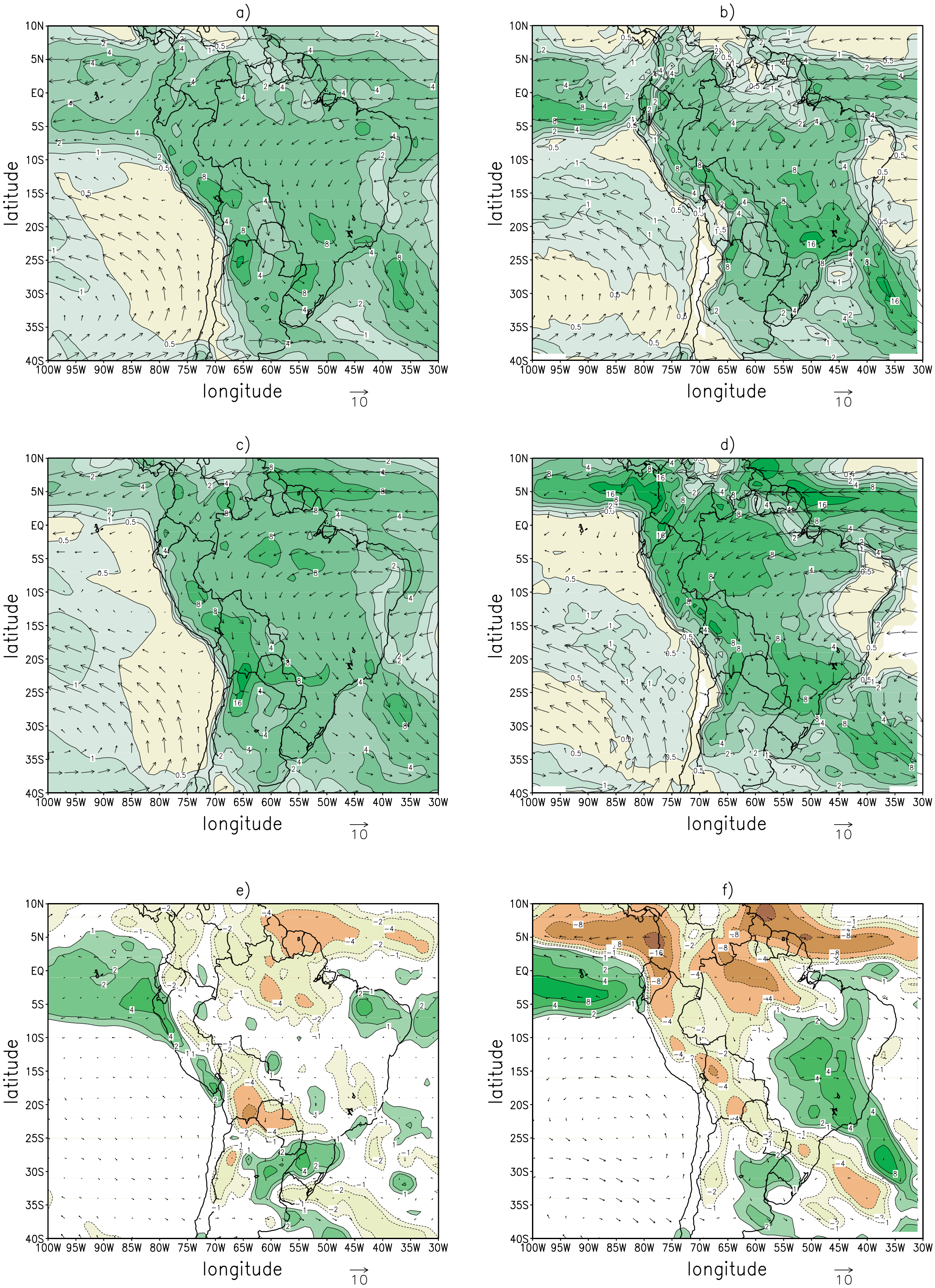

Fig. 2. Simulated precipitation and atmospheric low level circulation at 850 hPa for January 1998: **a**) RegCM3, **b**) EtaClim, and for January 1999: **c**) RegCM3, **d**) EtaClim, and the differences (January 1998 minus January 1999): **e**) RegCM3, and **f**) EtaClim

1999. The mean climatological values are obtained from an average over the 10 years of integration (1991–2000), as mentioned in Fernandez et al. (2006).

The NCEP/DOE reanalysis II data (Kanamitsu et al., 2002) are used as initial and boundary conditions. The SST values are obtained from the monthly mean data given by Reynolds and Smith (1995). The model domains in the two models consist of the region between 110° W–20° W and 45° S–15° N, centered at 15° S, 65° W. The horizontal resolution is approximately 80 km. First, a nesting procedure is developed using the NCEP/DOE data. The reanalysis data are linearly interpolated to the model's grid points at time intervals of 6 hours. The SST values are also interpolated to the model's grid points. Due to the different horizontal grids used in the RegCM3 and EtaClim, the model assessment and intercomparisons are made for the region between 100° W–30° W and 40° S–10° N.

3. Results

Figure 1 shows the differences between the simulations of precipitation for January 1998 (El Niño) and January 1999 (La Niña) and the model climatology for January from the RegCM3 and EtaClim. As can be seen, the two models are capable of simulating the anomalies of precipitation close to their climatological position. Both the models reproduce a decrease in the precipitation in the west Amazonia and north Brazil, and an increase in the precipitation in the north Peru and south Brazil during the El Niño event. During the La Niña episode the north Amazonian region is wetter and the SACZ is stronger. The EtaClim shows a systematic error in the simulation of the SACZ: the precipitation is overestimated in the El Niño case while in the La Niña case the SACZ is shifted southward compared with its climatological position. The RegCM3 simulates a stronger than observed SACZ in both the events. However, the differences between the simulated and observed values are lower in the case of the El Niño event.

Figure 2 shows the precipitation and low level atmospheric circulation at 850 hPa simulated by the RegCM3 and EtaClim during the El Niño and La Niña events and their differences. The precipitation data from the GPCP (Huffman et al., 1997) and the values of the wind at 850 hPa from the NCEP/DOE reanalysis II data for the same periods are shown in Fig. 3. From Figs. 2a, b and 3a, it can be seen that during the El Niño event both the models underestimate the precipitation

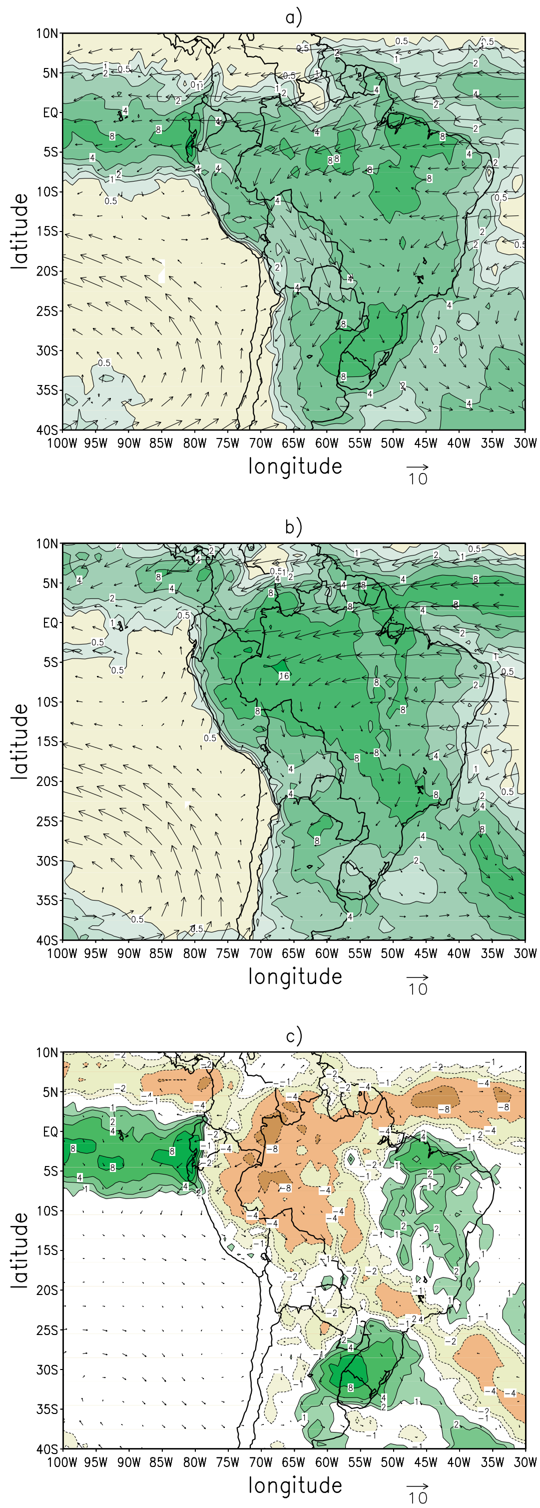

Fig. 3. Precipitation data (GPCP) and atmospheric low level circulation at 850 hPa (NCEP/DOE data) for: January 1998, **b**) January 1999, and **c**) the differences between them

compared with the GPCP data, mainly in the Amazonian region and the north Peru. However, the precipitation maxima in the southeast of the continent (55° W, 25° S) are better simulated in the RegCM3. This is due to fact that the EtaClim simulates a stronger low level flow from the equatorial Atlantic to west Amazonia and a stronger low level jet (LLJ) near Bolivia which

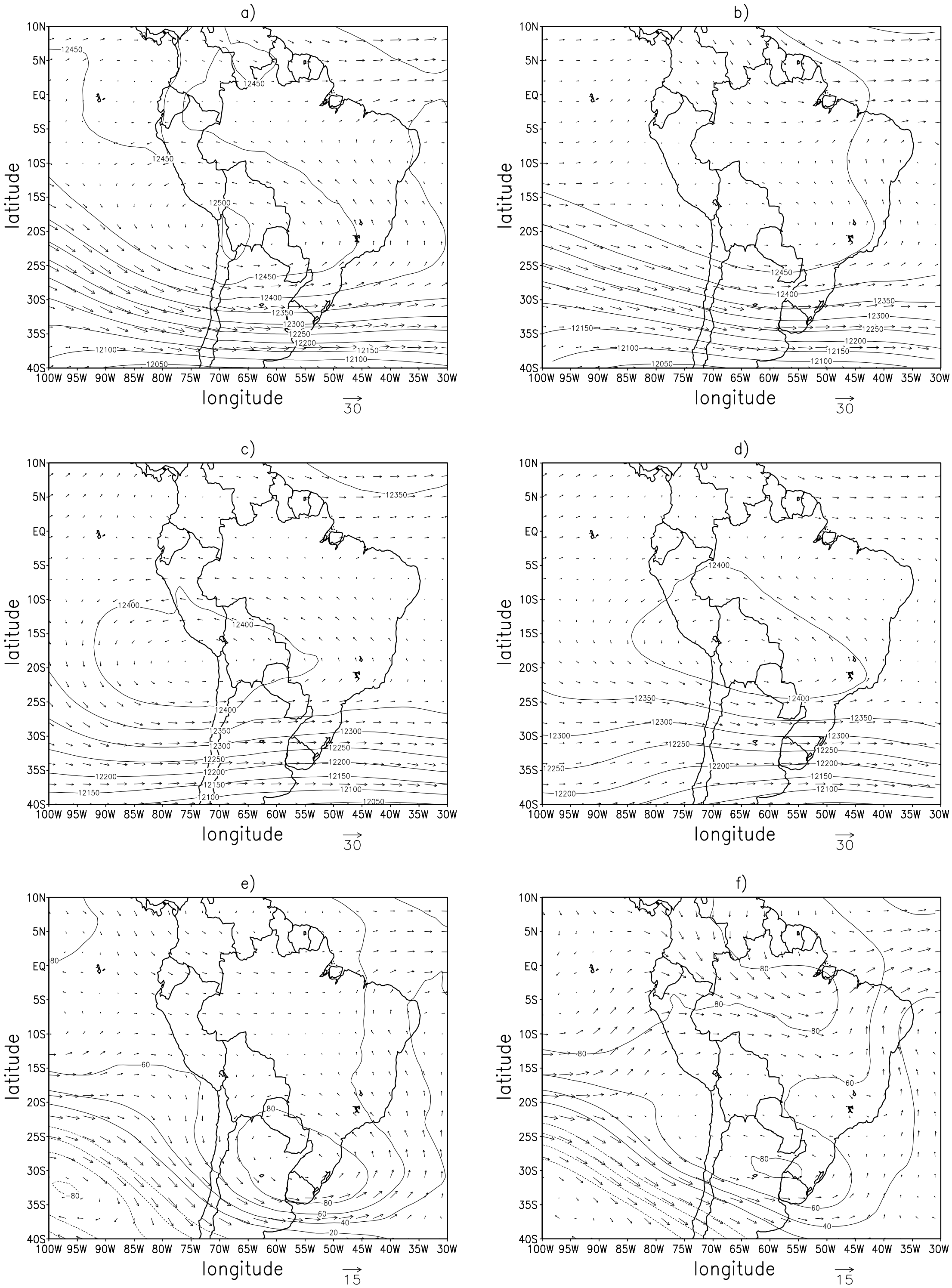

Fig. 4. Simulated atmospheric circulation and geopotential at 200 hPa for January 1998: **a**) RegCM3, **b**) EtaClim, and for January 1999: **c**) RegCM3, **d**) EtaClim, and the differences (January 1998 minus January 1999): **e**) RegCM3, and **f**) EtaClim

implies in a stronger moisture transport to the southeast Brazil (figure not shown) and, consequently, a stronger SACZ compared with the observations (a systematic error). In the case of the La Niña event (Figs. 2c, d and 3b), although the two models underestimate the precipitation in Amazonia, the EtaClim simulation shows a better agreement with the GPCP data. The EtaClim simulates a stronger Inter-Tropical Convergence Zone (ITCZ). However, its position is correctly simulated by the model. In the case of the RegCM3 the simulation of the ITCZ is not clearly defined in both the El Niño and La Niña events. Both the models simulate spurious precipitation maxima to the east of Andes and over the cordillera. This systematic error is also noted in the simulation of the mean climatological features for January (an average over 10 Januarys), as shown in Fernandez et al. (2006).

Comparing the simulated and observed differences (El Niño minus La Niña) (Figs. 2e, f and 3c) it can be noted that the RegCM3 simulates successfully the regions of positive precipitation anomalies in the north Peru and the southeast of the continent, although the simulated values are lower than in the observations. Regions of negative anomalies are simulated in the north and southeast Brazil. The values of model positive anomalies relative to the observational anomalies in the Amazonian region are lower in the RegCM3 than in the EtaClim. Comparing with the observations, the northeast Brazil is drier in the EtaClim simulation than in the observations (Figs. 2e and 3c). Both models simulate well defined SACZ in the El Niño case which is not evident in the observation. While the location and intensity of the SACZ simulated by RegCM3 does not change much, the intensity of it compares favorably to the observations for the La Niña case. The intensity of the SACZ simulated by EtaClim is too strong in both El Niño and La Niña cases.

Figures 4 and 5 show the atmospheric circulation at 200 hPa simulated by the two models and in the NCEP/NCAR data, respectively. From Figs. 4a, b and 5a it can be seen that during the El Niño event the BH is stronger (weaker) than in the reanalysis data in the simulation of the RegCM3 (EtaClim). This may be due to the higher latent heat release over the Andes in the RegCM3 (Fernandez et al., 2006). In the La Niña

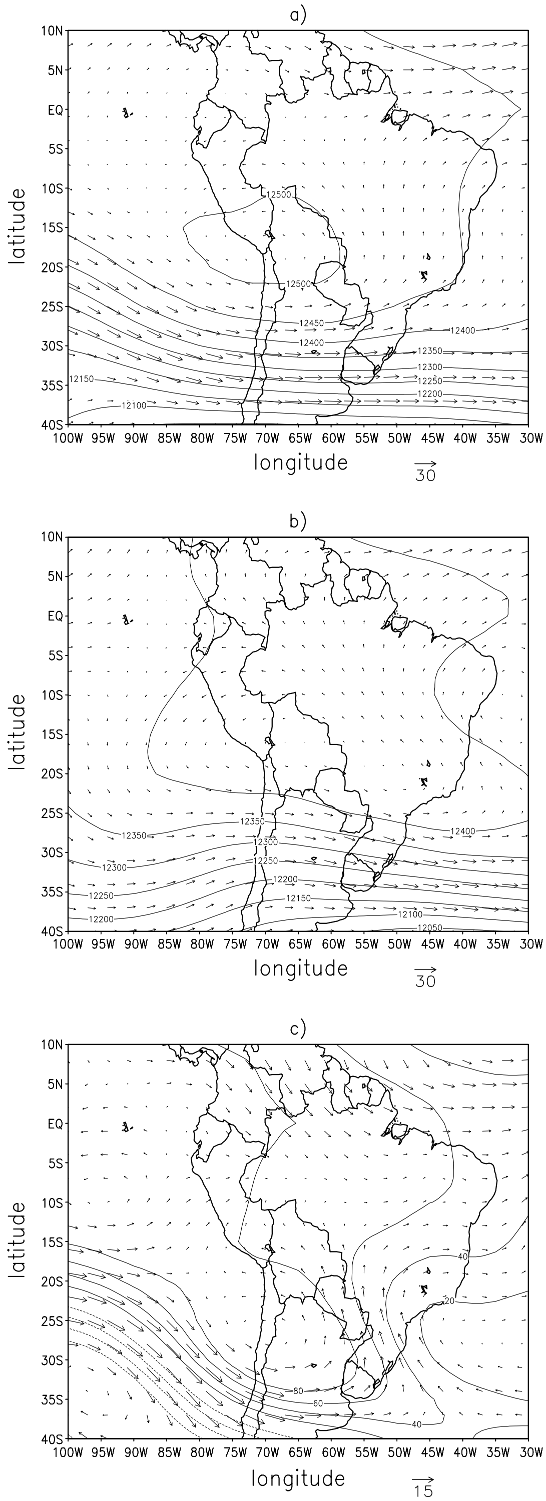

Fig. 5. Atmospheric circulation and geopotential at 200 hPa (NCEP/DOE data) for: **a**) January 1998, **b**) January 1999, and **c**) the differences between them

case (Figs. 4c, d and 5b) the two models simulate a more meridionally extended BH (see geopotential field) compared with the NCEP/DOE data.

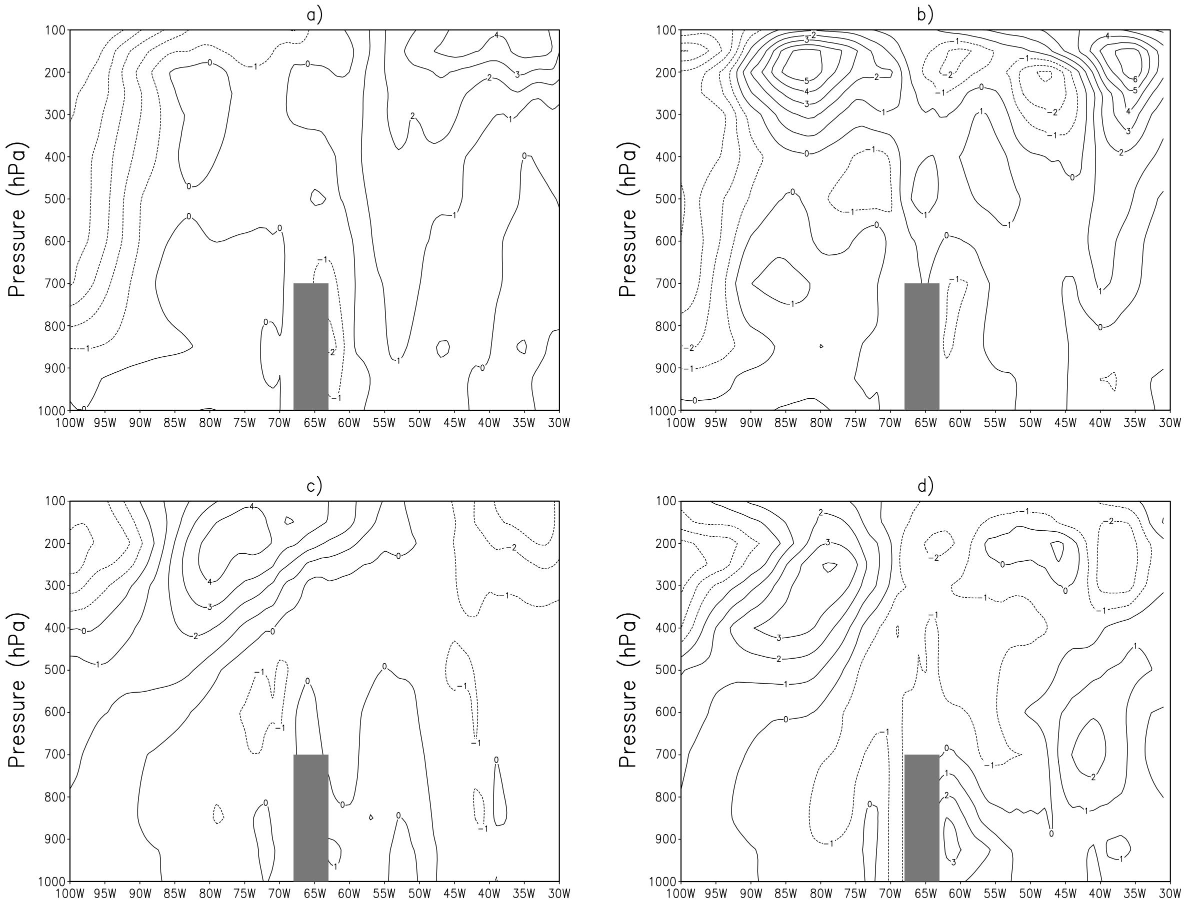

Fig. 6. Vertical cross-sections of the meridional wind anomalies (perturbed minus model climatology) for January 1998: **a**) RegCM3, **b**) EtaClim, and for January 1999: **c**) RegCM3, and **d**) EtaClim

This is more clearly seen in the EtaClim simulation. As shown in Figs. 4e, f and 5c, both the models reproduce a stronger NL in the La Niña case than in the El Niño case. As can be seen in these figures, the two models are able to reproduce an intensification of the subtropical jet stream in the southwest and center south regions of the model domain in the El Niño case. This increase in the subtropical jet favours the blocking of transient systems and enhancement of rainfall over the south Brazil (Marques and Rao, 1999, 2000). It can be also noted in Figs. 4e, f and 5c that both the models are capable of simulating a stronger ridge in the upper levels associated with the SACZ during the La Niña event.

Figure 6 shows the vertical cross-sections of the meridional wind anomalies at 18° S (perturbed minus model climatology) for the simulations of the El Niño and La Niña events in the RegCM3 and EtaClim. As can be noted, both the models are able to reproduce the LLJ, negative anomalies at low levels with core around 800 hPa to the east of the Andes during the El Niño episode. In the La Niña case the LLJ is not present over the region, this feature is well simulated by the models, and particularly in the case of the EtaClim the positive anomalies are strong. In the upper levels the Figs. 4 and 5 showed a more intense circulation associated with the BH in the EtaClim simulation during the La Niña and in the case of El Niño the BH was weak. The RegCM3 simulation shows opposite results. Despite the differences in the model simulations, in general both models reproduce the main characteristics in strong events (El Niño – La Niña).

4. Summary and conclusions

The present paper investigates the capabilities of two regional models implemented at CPTEC (the ICTP RegCM3 and the climate version of the

CPTEC Eta model – EtaClim) in simulating the summer quasi-stationary circulations over South America during two extreme cases: the 1997–1998 El Niño and 1998–1999 La Niña. For this purpose the two models are integrated for January 1998 (El Niño) and January 1999 (La Niña). The model simulations are compared with the NCEP/DOE reanalysis II data and the GPCP data.

The results showed that both the models are in general able to reproduce the main observed features during the 1997/1998 El Niño and 1998/1999 La Niña. The two models simulated an increase of precipitation in the west Amazonia in the La Niña case and a decrease over the Amazonian region in the El Niño case. The regions of north Peru and south Brazil were wetter during the El Niño event while the opposite occurred during the La Niña event. The general patterns of the summer circulation over South America during these extreme events simulated by the two models were also similar to that in the observations. There was an intensification of the subtropical jet and a southward shift of the BH in the El Niño case while in the La Niña case the BH was located north of its climatological position.

In general, the results of both the models were similar. However, they differ in the exact magnitude and position of the anomalies. Both the models show systematic errors such as the spurious precipitation maximum over the Andes. The EtaClim simulates a stronger moisture transport from Amazonia to the southeast Brazil and, consequently, a stronger SACZ compared with the observations. The systematic errors indicate that the two models must be more adequately tuned in order to simulate accurately the climate of the different regions of South America. However, the models are capable of capturing the main changes of the summer climate over South America during these two extreme cases. This indicates that they have potential to predict climate anomalies.

Acknowledgments

This paper forms part of the PhD Thesis of the first author. We thank Filippo Giorgi, Lisa C. Sloan and Jason L. Bell for their critical comments which led to improvement of the paper. Thanks are also due to the anonymous reviewers for their helpful comments. The original code of ETA model was kindly made available by Bob Rozumalski from COMET. The first author was supported by the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP).

References

Black T (1994) The new NMC mesoscale Eta model: description and forecast examples. Weather and Forecasting 9: 265–278

Chen F, Janjic Z, Mitchell K (1997) Impact of the atmospheric surface layer parameterization in the new land-surface scheme of the NCEP mesoscale Eta numerical model. Bound-Layer Meteor 85: 391–421

Chen F, Mitchell K (1999) Using the GEWEX/ISLSCP forcing data to simulate global soil moisture fields and hydrological cycle for 1987–1988. J Meteor Soc Japan 77: 167–182

Coughlan MJ (1999) Retrospective on the 1997/1998 El Niño event. CLIVAR Exchanges 4: 7–8

Elguindi N, Bi X, Giorgi F, Nagarajan B, Pal J, Solmon F (2004) RegCM version 3 User's guide. Physics of Weather and Climate Group. The Abdus Salam International Centre for Theoretical Physics. Trieste, Italy

Fels SB, Schwartzkopf MD (1975) The simplified exchange approximation: A new method for radiative transfer calculations. J Atmos Sci 32: 1475–1488

Fernandez JPR (2004) Quasi-stationary waves in the Southern Hemisphere and their role on South America climate: observations and simulations using two regional models. (In Portuguese). PhD Thesis. Instituto Nacional de Pesquisas Espaciais. São Jose dos Campos, São Paulo, Brazil

Fernandez JPR, Franchito SH, Rao VB (2006) Simulation of the summer circulation over South America by two regional climate models. Part I: Mean climatology. Theor Appl Climatol (this issue)

Ferrier B, Jin Y, Lin Y, Black T, Rogers E, DiMego G (2002) Implementation of a new grid-scale cloud and precipitation scheme in the NCEP Eta model. Preprints, 15 Conf. on Numerical Weather Prediction, AMS, San Antonio, TX, 280–283

Giorgi F, Marinucci MR, Bates GT (1993a) Development of a second-generation regional climate model (RegCM2). Part I: Boundary-layer and radiative transfer process. Mon Wea Rev 121: 2794–2812

Giorgi F, Marinucci MR, Bates GT, Decanio G (1993b) Development of a second-generation regional climate model (RegCM2). Part II: Convective process and assimilation of lateral boundary conditions. Mon Wea Rev 121: 2814–2831

Grell GA (1993) Prognostic evaluation of assumptions used by cumulus parameterization. Mon Wea Rev 121: 764–787

Grimm AM, Ferraz SET, Gomes J (1998) Precipitation anomalies in Southern Brazil associated with El Niño and La Niña events. J Climate 11: 2863–2880

Grimm AM (2003) The El Niño impact on the summer monsoon in Brazil: Regional process versus remote influences. J Climate 16: 263–280

Holtslag AAM, DeBruijn EIF, Pan HL (1990) A high resolution air mass transformation model for short range weather forecasting. Mon Wea Rev 118: 1561–1575

Huffman G, Adler RF, Arkin PA, Chang A, Gruber A, Janowiak J, McNab A, Rudolf B, Schneider U (1997) The global precipitation climatology project (GPCP) combined precipitation dataset. Bull Amer Meteor Soc 78: 5–20

Kain JS (2004) The Kain-Fritsch convective parameterization: An update. J Appl Meteor 43: 170–181

Kanamitsu M, Ebisuzaki W, Woollen J, Yang S-K, Hnilo JJ, Fiorino M, Potter GL (2002) NCEP-DEO AMIP-II Reanalysis (R-2). Bull Atmos Meteor Soc 83: 1631–1643

Kayano MT, Rao VB, Moura AD (1989) Walker circulation and atmospheric water vapour. Int J Climatol 9: 243–251

Kiehl JT, Hack JJ, Bonan GB, Boville BA, Briegleb BP, Williamson DL, Rash PJ (1996) Description of the NCAR Community Climate Model (CCM3). NCAR/TN-420 + STR, NCAR, Boulder, Co

Kousky VE, Kagano MT, Cavalcanti IFA (1984) A review of the Southern Oscillation: oceanic-atmospheric circulation changes and related rainfall anomalies. Tellus 36A: 490–504

Lacis AA, Hansen JE (1974) A parameterization of absorption of solar radiation in the earth's atmosphere. J Atmos Sci 31: 118–133

Lau KM, Zhou J (2003) Anomalies of the South America summer monsoon associated with the 1997–1999 El Niño-Southern Oscillation. Int J Climatol 23: 529–539

Marques RFC, Rao VB (1999) A diagnosis of a long-lasting blocking event over the Southeast Pacific Ocean. Mon Wea Rev 127: 1761–1775

Marques RFC, Rao VB (2000) Interannual variations of blockings in the Southern Hemisphere and their energetics. J Geophys Res 105(D4): 4625–4636

Mellor GL, Yamada T (1974) A hierarchy of turbulence closure models for planetary boundary layer. J Atmos Sci 31: 118–133

Pal J, Small E, Eltahir E (2000) Simulation of regional-scale water and energy budgets: representation of subgrid cloud and precipitation process within RegCM. J Geophys Res 105(D24): 29579–29594

Rao VB, Chapa SR, Fernandez JPR, Franchito SH (2002) A diagnosis of rainfall over South America during the 1997/98 El Niño event. Part II: Roles of water vapor transport and stationary waves. J Climate 15: 512–521

Reynolds RW, Smith TA (1995) A high-resolution global sea surface temperature climatology. J Climate 8: 1571–1583

Wang C, Weisberg RH (2000) The 1997–98 El Niño evolution relative to previous El Niño events. J Climate 13: 488–501

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