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An intercomparison of model-simulated in extreme rainfall and temperature events during the last half of the twentieth century. Part 1: mean values and variability

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Abstract In this study we examine the performance of eight of the IPCC AR4 global coupled climate models used in the WCRP CMIP3 Multimodel Dataset, as well as their ensemble mean, in simulating annual indices of extreme temperature and precipitation climate events in South America. In this first part we focus on comparing observed and modeled mean values and interannual variability. Two extreme temperature indices based on minimum temperature (warm nights and frost days) and three indices of extreme precipitation (R95t, R10 and consecutive dry days), obtained both from meteorological stations during 1961–2000 and model outputs, were compared. The number of warm nights are better represented by models than the FD. The interannual variability pattern is also in good agreement with the observed values. For precipitation, the index that is best represented by the models is the R95t, which relates the extreme precipitation to local climate. The maximum of dryness observed over the central Argentinian Andes or the extensive dry season of the Amazon region could not be represented by any model.

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1 Introduction

One of the key aspects of climate change is to understand the behavior of extremes. It is recognized that changes in frequency and intensity of extreme events are likely to have a larger impact than changes in mean climate. Because of differences among model formulation in the various IPCC AR4 global coupled models, some differences can be expected in the projection of mean climate and extremes in the present and also in the future. One of the high-priority fields of the WCRP CMIP3 Multimodel Dataset (Taylor 2007) is the extremes indices calculated from daily data; five temperature-related indices and five precipitation-related indices, from Frich et al. (2002, their Table 1).

Observational studies by Rusticucci and Barrucand (2004), Vincent et al. (2005), Groissman et al. (2005), Haylock et al. (2006), Alexander et al. (2006), Marengo and Camargo (2007), Rusticucci and Renom (2008), Penalba and Robledo (2009) and Marengo et al. (2009) have documented trends in extremes during the last 50 years, using different methodologies for defining extremes, from threshold values to percentiles. Most of these studies have detected positive extreme rainfall trends in regions such as southeastern South America, while indices based on minimum temperature have shown substantial increases basically everywhere in South America where daily data were available. An intercomparison between observed and simulated trends in South America during 1960–2000 (Marengo et al. 2009) using various indices of extremes defined by Frich et al. (2002) and eight GCMS from the IPCC AR4 20C3M WCRP CMIP3 has shown that even though all models simulate quite well the observed trends in warm nights, trends of extreme rainfall indices are not so well represented. Basically, all models show trends that are different from those observed in all regions of South America, except for southeastern South America where positive trends are found both in the observations and the model outputs.

Vincent et al. (2005), Alexander et al. (2006) and Haylock et al. (2006) have shown observational aspects of some extreme indices, but few studies have provided an evaluation of the simulated extremes. Tebaldi et al. (2007) compared differences between future and present climate, simulated with WCRP CMIP3 models, but we still do not know how well the models represent the observed mean values and whether there are systematic biases. So, as a previous step, there is still a need to analyze whether the models are able to simulate well the observed mean values and their variability.

Table 1 List of the GCMs used

Model designation	Institution
MRI-CGCM2.3.2	Meteorological Research Institute, Japan Meteorological Agency, Japan
CNRM-CM3	Centre National de Recherches Meteorologiques, Meteo France, France
GFDL-CM2.0	Geophysical Fluid Dynamics Laboratory, NOAA, USA
GFDL-CM2.1	Geophysical Fluid Dynamics Laboratory, NOAA, USA
INM-CM3.0	Institute of Numerical Mathematics, Russian Academy of Science, Russia
MIROC3.2	Center for Climate Systems Research, Japan
NCAR-CCSM3.0	National Center for Atmospheric Research, USA
DOE-NCAR-PCM	Department of Energy, National Center for Atmospheric Research, USA

In this paper we analyze climate extremes over South America through the analysis of the WCRP CMIP3 indices used for the IPCC 4th Assessment Model Output for the present climate during the XX Century (IPCC20C3M). These “extreme indices” are derived data, calculated from simulated daily temperature and precipitation, in the form of annual indicator time series. In this paper, mean, standard deviation and mean squared error between grid points of different models and the nearest station were calculated for the common period 1961–2000. More details of these indices can be found in Frich et al. (2002).

2 Data

This study is part of the CLARIS-EU project (“A Europe South America Network for Climate Change Assessment and Impact Studies”; Boulanger et al. 2009), which aimed to create a high-quality regional database of daily temperature and precipitation by gathering all currently available data in the region of study for extreme events and long-term climate trends. Another objective of this project was to facilitate the exchange of observed and simulated climate data between climate research groups. Since the beginning of the project, we started gathering all current available data in the region of study. The complete dataset of the CLARIS-EU project consists of the following information: for Argentina, daily Maximum and Minimum Temperature and Precipitation were updated to the period 1950–2003. The information was mainly provided by the Argentinian National Weather Service (Servicio Meteorológico Nacional from Argentina). Some raingauge stations, like Santa Rosa and Pergamino which belong to Argentinian local organizations such as the Agricultural National Institute (INTA, Instituto Nacional de Tecnología Agropecuaria), were also used. A quality control was performed, with some common controls and others more exhaustive (Rusticucci and Barrucand 2004; Penalba and Robledo 2006; Llano 2006), that led to a 41-station database for the period 1950–2003 (mostly starting on 1959). For Uruguay, we updated the records of Daily Maximum and Minimum Temperature and Precipitation. The Uruguayan National Weather Service (DNM, Dirección Nacional de Meteorología from Uruguay) has a relatively rich dataset of long daily temperature records, between 50 and 100 years long. Previous to the CLARIS-EU project, all data from the DNM were in paper format; however, this changed 3 years ago when, under WP3.2 objectives, CLARIS-EU contributed to the digitalization of a selected part of this data as a contribution to the long regional daily dataset. All data were quality controlled with the same methodologies as in the Argentinian database (more details in Rusticucci and Renom 2008). The daily precipitation dataset mainly belongs to the DNM. As in the case of Argentina, maximum and minimum temperature and raingauge data from other organizations were used, such is the case of the meteorological station La Estanzuela that belongs to the National Agricultural Research Institute (INIA, Instituto Nacional de Investigación Agropecuaria). In the case of Brazil, daily temperature and precipitation from some airports were available.

In this study, observed indices for extremes were also obtained from the WMO/CCl-CLIVAR/ETCCDMI ‘Workshop on Enhancing South American Climate Change Monitoring and Indices’ held in Maceió, Brazil, 2004, for the regions of South America where no data was available in the CLARIS-EU database. This workshop was organized by the Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDMI) WMO Commission for Climatology (CCl)/World Climate Research Program project on Climate Variability and Predictability (CLIVAR) based on the study of Frich et al. (2002, two of the authors participated in the workshop). Homogeneity testing was performed in all stations data in order to check their quality. Only homogeneous series presenting less than 10% of missing data for their period of record have been used in this study (more details in Vincent et al. 2005 and Haylock et al. 2006). This high-quality database enhances previous regional studies, adding new quality-controlled daily data that made the region better covered by observational datasets.

In this paper we compare the ability of models to represent the following indices, considered on an annual basis:

For temperature

- Frost days (FD): annual occurrence of frost days (days with MinT $<0°C$),
- Warm nights (Tn90): percentage of days with MinT above the 90th percentile of the 1961–1990 base period.

For precipitation

- R10: number of heavy precipitation days, defined as precipitation ≥ 10 mm/day,
- Consecutive dry days (CDD): maximum number of consecutive days with precipitation <1 mm
- R95t: fraction (%) of annual total precipitation due to events exceeding the 95th percentile of the 1961–1990 base period.

Extreme indices were calculated using the RClimDex software (freely available at http://cccma.seos.uvic.ca/ETCCDMI) and the CLARIS-EU database, as well as data obtained at the workshop in Maceió. To make R95t, (model output index) comparable to R95p (RClimDex output index), an additional calculation was performed. We did R95t as R95p/total annual precipitation. Data and processing are completely described in Vincent et al. (2005) and Haylock et al. (2006). These indices are evaluated at 90 stations from Argentina, Brazil, Bolivia, Chile, Ecuador, Paraguay, Perú, and Uruguay.

The models calculate ten different extreme indices related to daily temperature and precipitation extremes (Frich et al. 2002, Table 1). Nevertheless, there are some differences in the calculation of indices so we choose to analyze a subset of relevant indices that can be compared. For these indices, we have two different thresholds: one is fixed and the other is defined according to the local climate.

As it is mentioned in Rusticucci and Barrucand (2004), Rusticucci and Renom (2008) and Marengo et al. (2009), minimum temperature is the most sensitive variable, and the one that shows the greatest changes. So, the indices we use for temperature are based on the available indices for minimum temperature.

The available indices calculated by models are from NCAR CCSM3, USA; CNRM-CM3, France; GFDL-CM2.0 (GFDL0) and GFDL-CM2.1, USA; INM-CM3.0, Russia; MIROC3.2 MEDRES-Medium resolution, Japan; DOE-NCAR PCM, USA; and MRI-CGCM2, Japan. See Table 1 for more information on the models.

3 Results

3.1 Mean values

For the mentioned indices we calculated the 1961–2000 observed mean, the model ensemble mean, and the difference between these two values, expressed as a percentage of the observed values. The nearest grid point to each station was used for this calculation. We preferred not to use gridded data because gridding would smooth geographical patterns of differences with local significances.

We had to consider that, in general, model simulated values over the Andes are difficult to evaluate because of the model's failure to interpret the topography, as it was seen in the comparison performed between station extreme daily temperatures and the NCEP/NCAR reanalysis over Argentina (Rusticucci and Kousky 2002).

In Fig. 1 we can see 1961–2000 mean values of the percentage of warm nights (Tn90). Top and bottom: the outputs of the eight mentioned models, middle line: the observed mean, the ensemble of the eight models mentioned above, and the difference between both values. In general, the entire continent shows values between 5% and 12.5% (it is necessary to explain here that since the percentile-base period is 1961–1990, values for the period under study are not all equal to 10%). Over the southeastern part of the continent, the ensemble is closer to the observed mean, with absolute differences less than 33%, but larger differences appear in some stations over central and eastern Brazil and in Bolivia. In Peru, the similarity is also noted, even though models overestimate the observed values.

In general, models can properly reproduce this percentile-based index, with the exception of NCAR-PCM1 that clearly overestimate it over tropical South America. For the analysis of the number of frost days (FD) per year it is important to mention that there are no observed cases of frost days north of 20° S in lowlands, even though some models give values different from zero. In Fig. 2, it can be seen that the observed FD shows the largest values over the Andes (between 30 and 60 days/year) as well as in Central Argentina, and less than 20 days/year in Uruguay and southern Brazil. The model ensemble shows the highest values over southwestern South America, a smaller amount in the southeastern region, and the smallest values in the tropical regions. Models overestimate the number of frost days in La Plata Basin and underestimate them over the Andes in Bolivia and northwestern Argentina.

Overall, models simulate quite well the pattern of FD, with the exception of INM-CM 3.0. The differences among models on the northward extend of high FD over the south eastern part of the continent causes the largest differences between the ensemble mean and the observations already highlighted. The best model on capturing this north–south pattern is MRI-CGCM 2.3.2.A.

In comparison with the temperature index analyzed before, it seems that the number of warm nights are better represented than the FD.

The number of days with precipitation over 10 mm (R10) is shown in Fig. 3. The observations show R10 values around 80 to 100 days at stations nearby the Equator, while in La Plata basin R10 values vary from 20–40 days over Uruguay and Argentina and between 40–60 days over southern Brazil. Over the southeastern part of the continent, the climatic differences between regions (NE_SW) are well represented by the model ensemble. In general, it is easy to see that models highly overestimate the number of heavy precipitation days over the western part of the continent and underestimate them over the eastern part. If a model overestimates

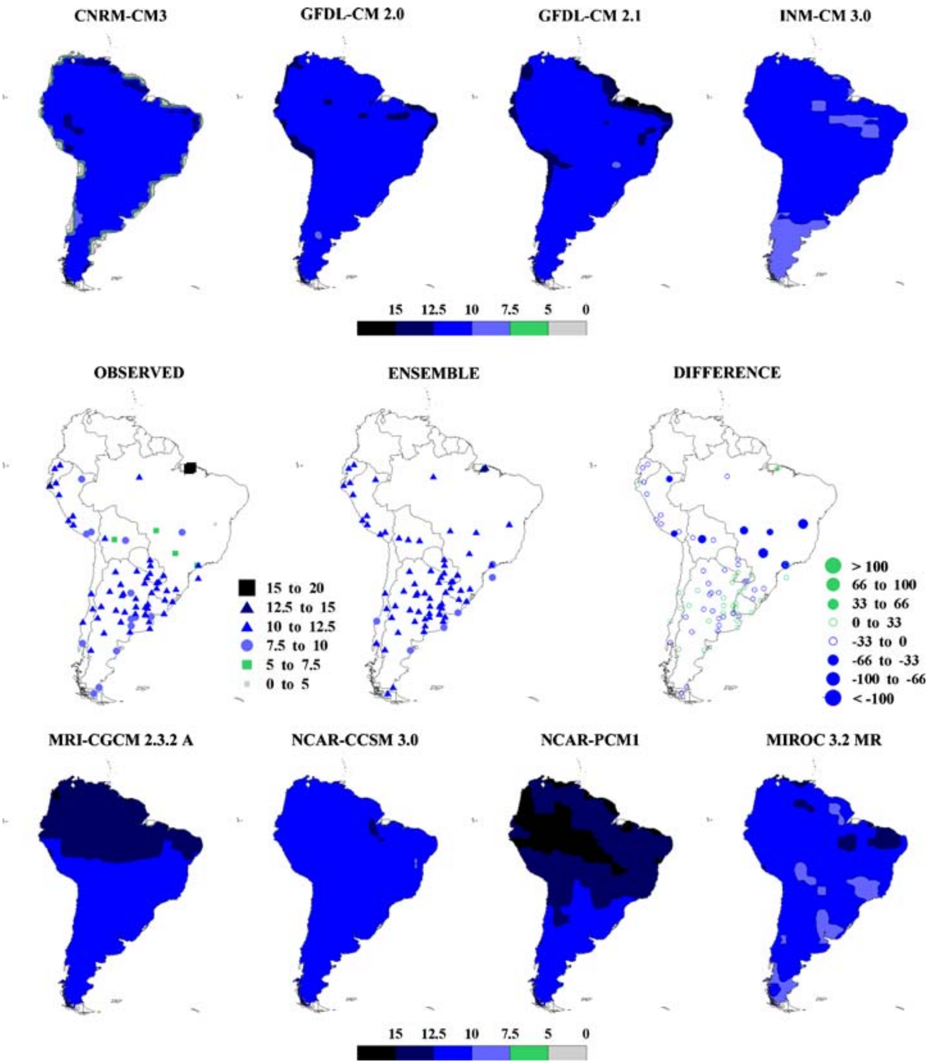

Fig. 1 Mean values of warm nights (Tn90) for the period 1961–2000, units are percentage over the observation. GCM outputs (*top* and *bottom lines*), observed, ensemble means and their difference, observed minus ensemble (*center*)

heavy precipitation days, there are different reasons due to the complexity of the physics mechanisms involved. We can assert that the model perhaps is over simulating the atmospheric circulation or the precipitation mechanisms. But if a model underestimates heavy precipitation days, we cannot say if the model is doing a good job or not, because we are comparing grid point values, representing average conditions for the grid cell, to station values. GCMs are known to have difficulties on reproducing precipitation fields and in particular extreme values.

Different precipitation regimes related to this extreme value are better estimated over extratropical South America but some models (GFDL, NCAR,) estimate also

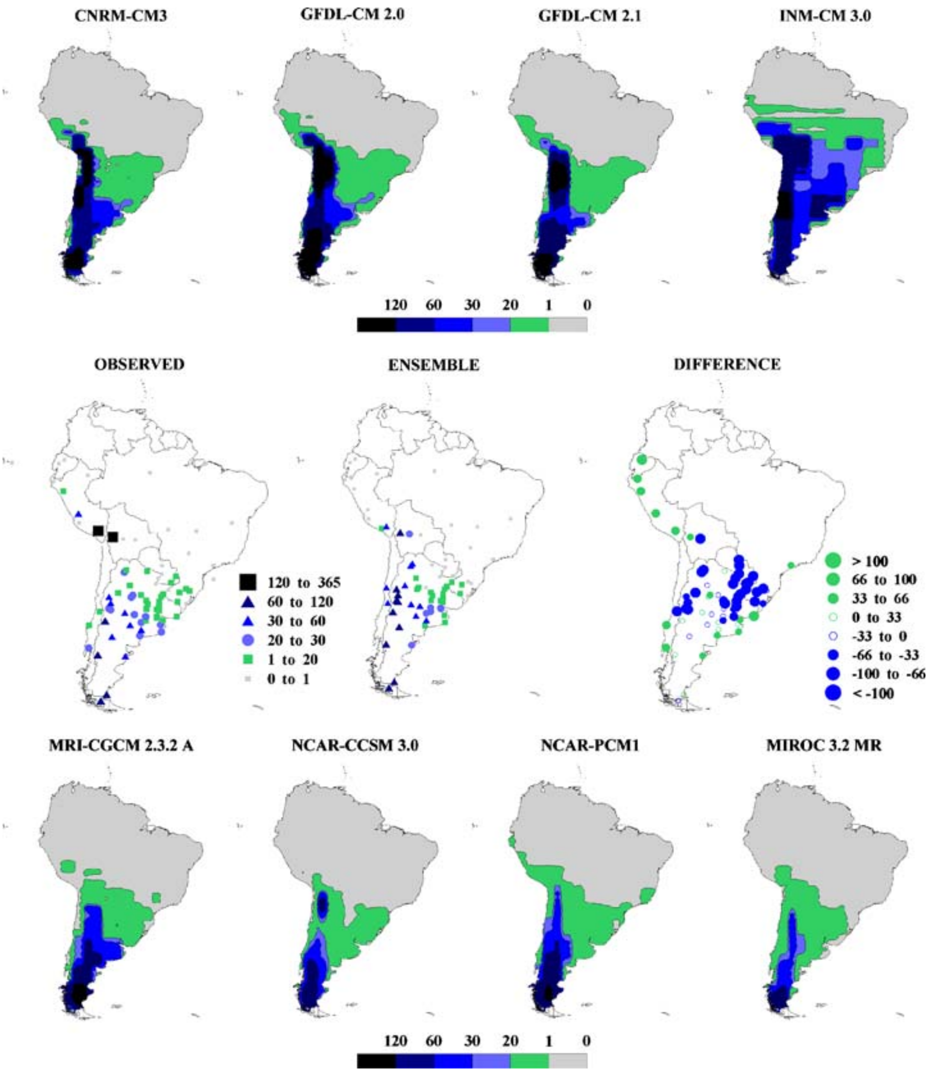

Fig. 2 The same as Fig. 1 except for FD: number of days where the minimum temperature was below 0°C

quite well the tropical precipitation region. The pattern in INM-CM 3 looks very unrealistic in general, and in particular over the southeastern part the northeast–southwest gradient is reversed, revealing the difficulties this model has on reproducing extreme values of precipitation. Taking into account the importance of the extreme rainfall value in La Plata Basin, only two models (GFDL-CM 2.1 and NCAR-CCSM 3.0) can represent it.

The other precipitation index, the observed fraction of extreme precipitation events (as shown by the R95t index) varies between 20% and 30% in some regions of tropical South America and the La Plata Basin (see Fig. 4). In general, the model ensemble shows that simulated values are closer to observations, while

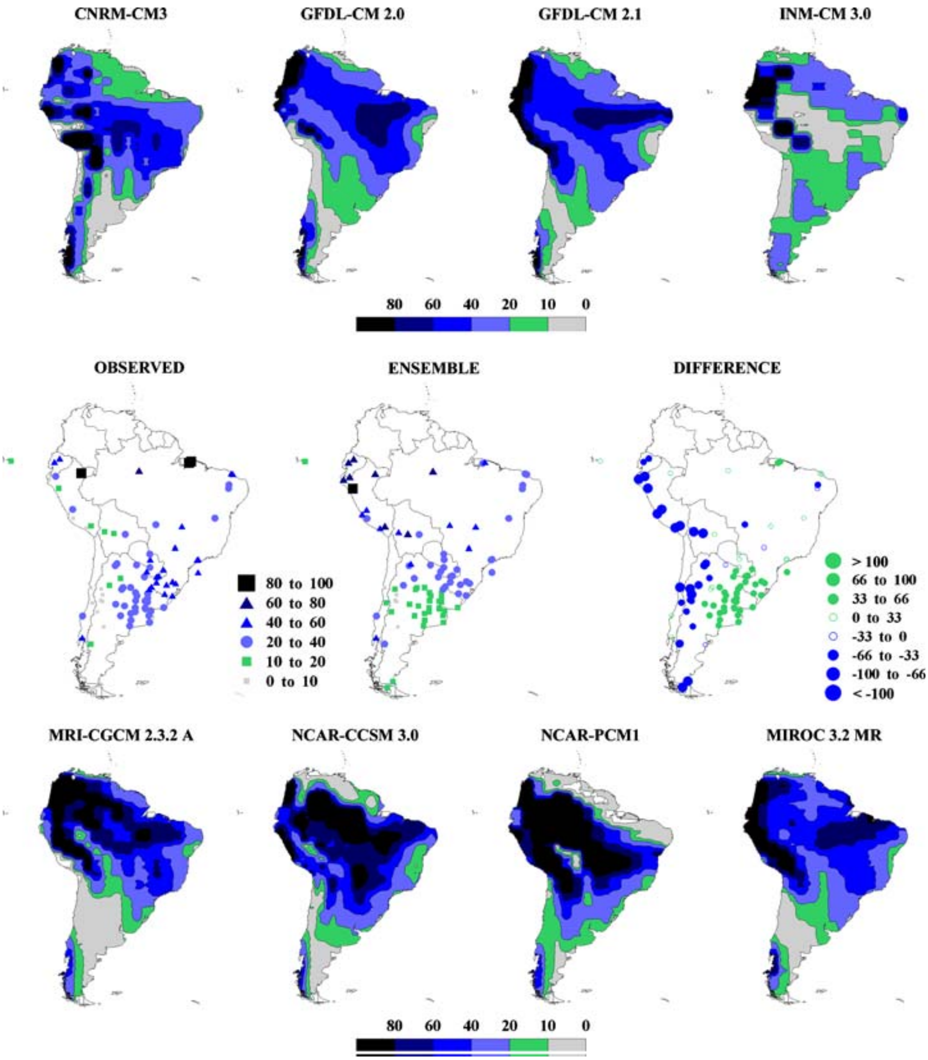

Fig. 3 The same as Fig. 1 except for R10: number of days where the precipitation was over 10 mm/day

model overestimation is noticed over the Province of Buenos Aires. The pattern of this extreme index varies among models most GCMs presents a north–south gradient with large differences of its characteristics. for example, between CNRM-CM3 and MRI-CGCM 2.3.2.A. Nevertheless, there are five to eight models which underestimate this extreme index in the interior of tropical Brazil.

R95t is better represented than R10 by the GCM ensemble mean, even though there are differences among the models. The consecutive dry days index (CDD) represents well the climatic regions with a strong annual precipitation wave or a very dry climate with negligible precipitation (see Fig. 5). The observed CDD shows the highest values in the northern part of the desert of the western part of

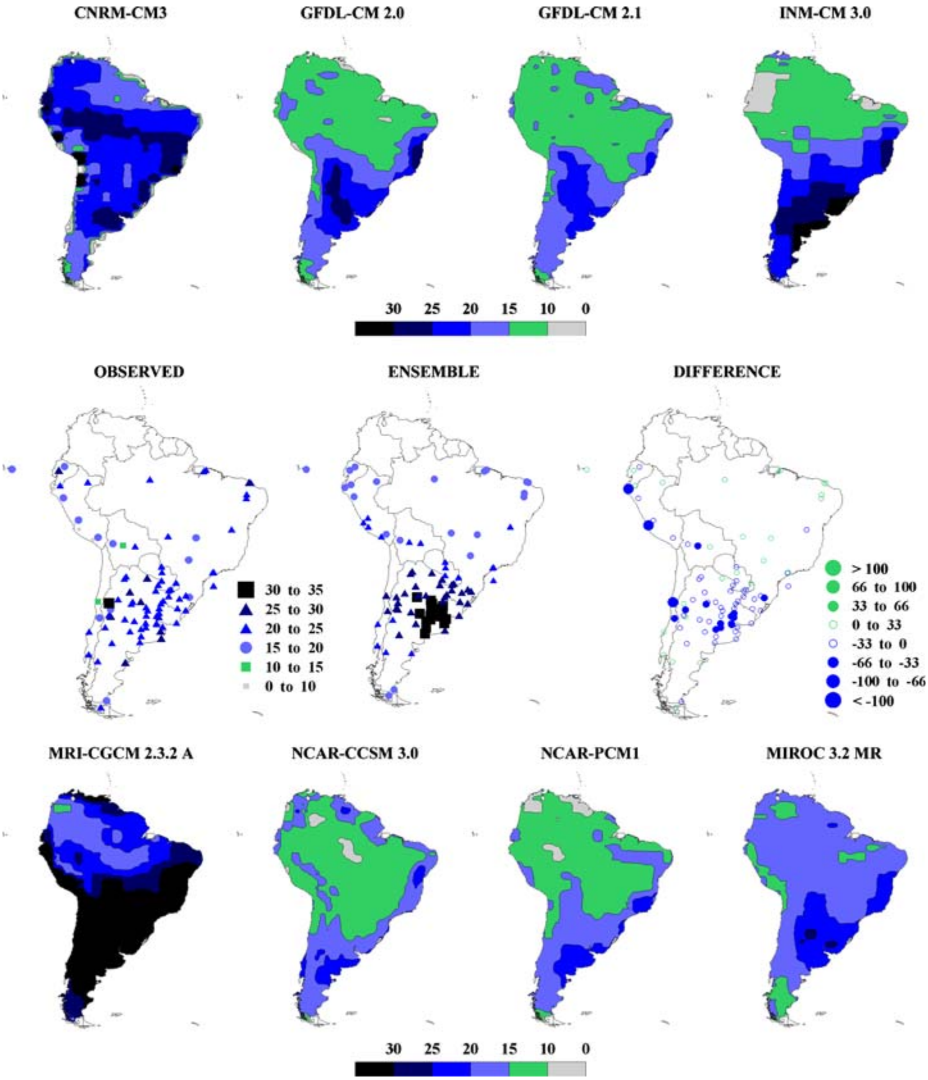

Fig. 4 The same as Fig. 1 except for R95t fraction (%) of annual total precipitation due to events exceeding the 95th percentile

South America, in Peru and northern Chile. It also shows a strong annual wave in western Argentina and mean values between 60 to 90 days over central Brazil and northwestern Argentina (see Rusticucci and Penalba 2000 for a better description of the precipitation regimes over southern South America; and Penalba and Llano 2006 for the temporal variability of dry spells in Argentina). The ensemble overestimates the number of consecutive days without precipitation over the La Plata Basin and northern Brazil, and underestimates it on the Pacific coast of the continent as well as in southern Argentina. The models should have the ability to simulate the climate regimes with strong annual precipitation waves, which is the region of the South

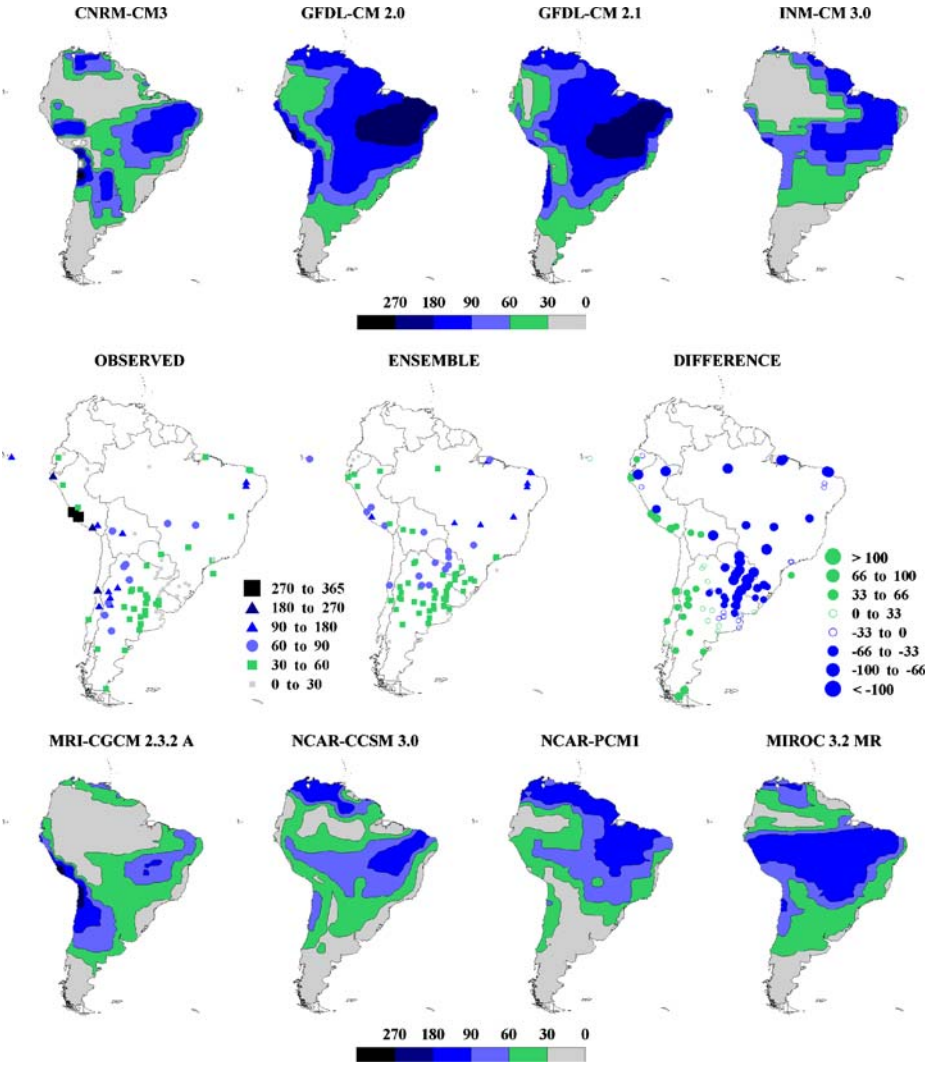

Fig. 5 The same as Fig. 1 except for consecutive dry days (CDD)

American Monsoon System, unless there are very few observations there. GFDL-CM2.0 and 2.1, NCAR_PCM1 and MIROC 3.2 show good agreement with that. The model ensemble tries to represent this but looses some climatic regimes, due to the large differences among models, giving an east–west difference in regimes, overestimating the dry periods to the east and underestimating them over the west. Differences could be due to the 1 mm-threshold choice since model grid points represent areas, and therefore, dry day simulated sequences could be less frequently interrupted than observations, giving higher simulated values.

Another way to evaluate the models' capability on reproducing the indices is by calculating the Mean Squared Error (MSE). Figure 6 shows the MSE of the CDD index for each model. Most of the models fails to represent this index over the La

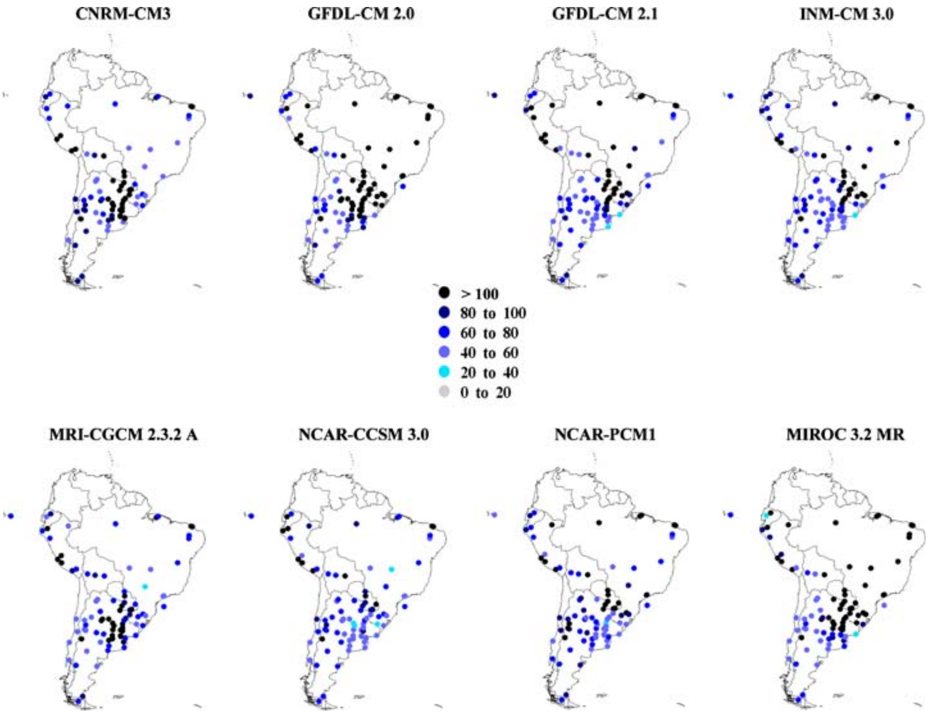

Fig. 6 CDD mean square error (% over observed index) calculated over 1961–2000 for each GCM

Plata Basin region and the western coast of South America, with NCAR model having the smallest error, between 30 and 60 over the La Plata basin. The frequency distributions of MSE for the CDD split into intervals for each model are shown in Fig. 7. In some models, the mode of the MSE is greater than 100%, showing that the representation of the CDD in these cases is useless.

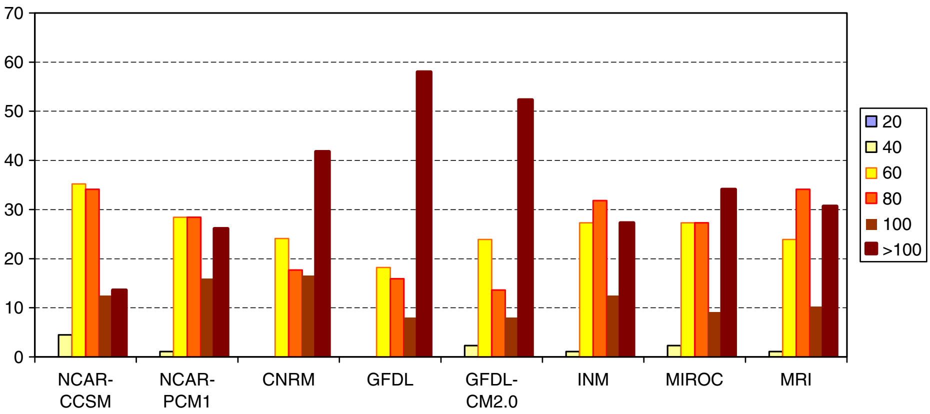

Fig. 7 Frequency (%) distribution of CDD MSE for each GCM

Other MSE were calculated for all indices, and in general they present almost the same pattern for all the models: from 20% to 60% over Argentina and over 60% up to more than 100% in the tropical and western South American coast. The exception is FD, where almost over all La Plata Basin, the MSE were over 100%.

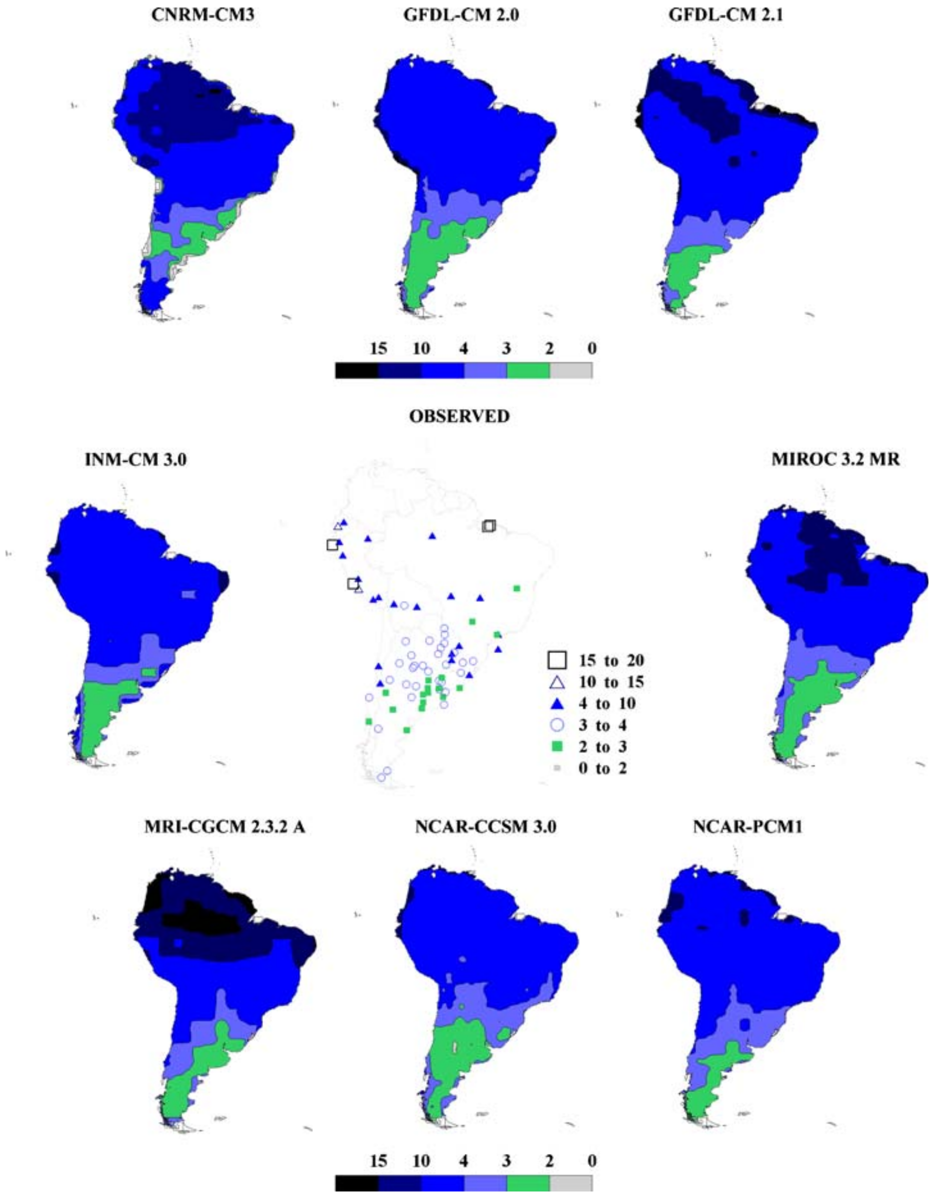

Fig. 8 Interannual variability index for warm nights. *Center* observed warm nights, *other* model results (number of days per year)

3.2 Interannual variability

We identify the interannual variability using the standard deviation of the observed and modeled indices. Overall, the comparison of observed and simulated interannual variability indicates that models show a better representation of the interannual variability in those indices where mean values are better represented, such as Tn90

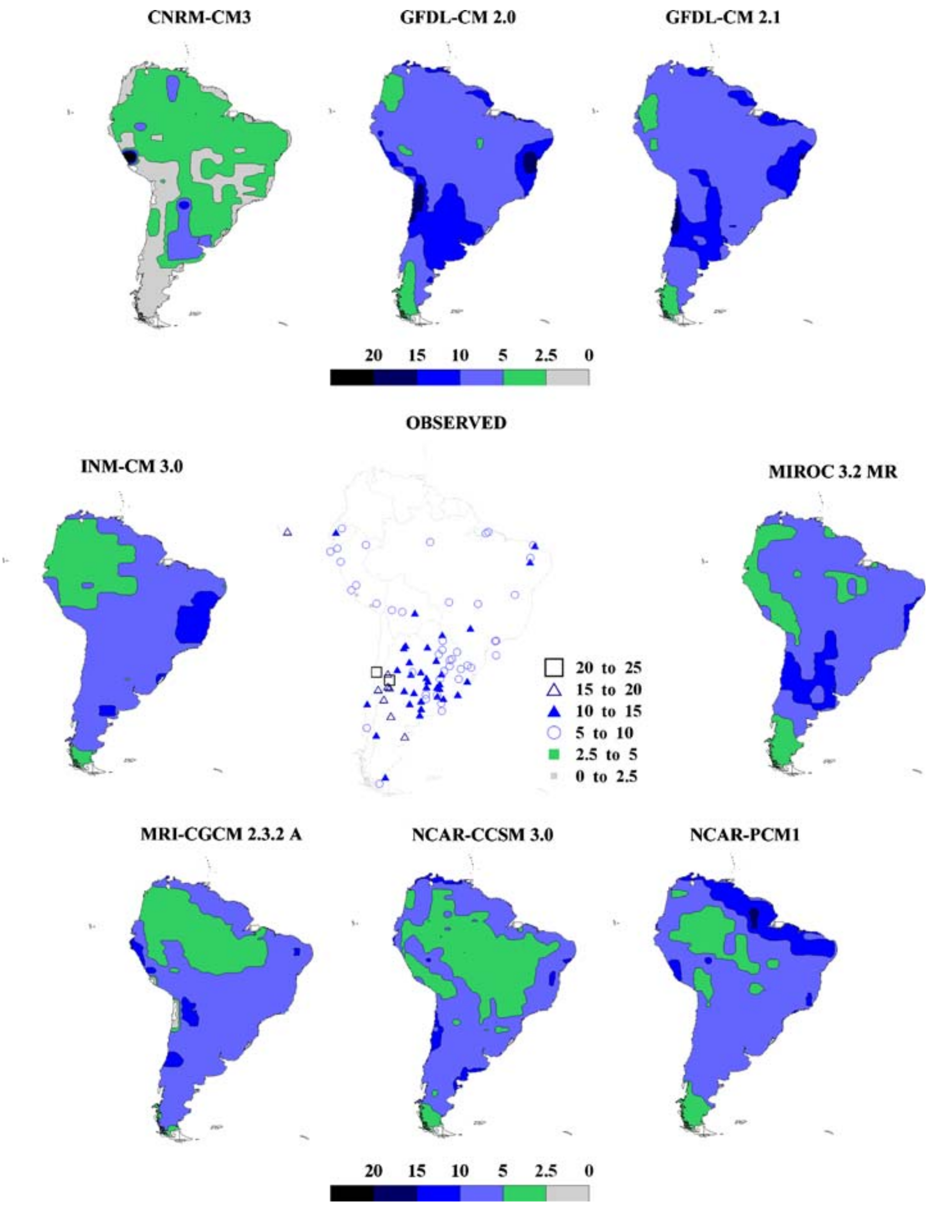

Fig. 9 Same as Fig. 8 but for R95t

and R95t. For FD, all models, except INM, can reproduce the observed pattern of standard deviation (not shown). CDD presents different patterns in all the models so it is the worst simulated index as expected given the results on the mean values. For R10, observations show two regions of high variability: northeastern Brazil and northern La Plata Basin. The models that can simulate better this variability are the MRI and the NCAR models (not shown).

These examples shown in Figs. 8 and 9 also illustrate differences among models. In Fig. 8, observed warm nights interannual variability lies between 2% and 4% in southern South America, and more than 4% up to 20% in tropical regions. Models represent well this north–south pattern. In Fig. 9, the observed and simulated R95t standard deviation are shown. In the observations, three areas of homogeneous values can be identified over the southern part of the continent (15–20, 10–15, 5–10), while the rest of the stations present values of 5–10. Over the southern part of the domain, three out of eight GCMs simulate a broad area with values between 10 and 15, while the other five do not show any pattern. Over the north-western coast of SA, where many observations are collected, the GCMs present a broad range of values, which does not seem plausible.

4 Discussion

In this paper we investigate mean values and interannual variability of observed and simulated indices for extremes in South America, for the period 1961–2000. Over southeast South America, a low land region which has more dense information, FD average values are well simulated. But over tropical regions, were there is no frost at all, some models give a number of occurrences different from zero.

The other temperature index analyzed is the number of warm nights per year. In some cases, warm nights average values are well simulated. The interannual variability pattern is also in good agreement with the observed values. In comparison, the number of warm nights are better represented than the FD.

For precipitation, the index that is best represented by models is the R95t. This index defines extreme precipitation relatively to the local climate, and the models could capture that relation. The consecutive dry days (CDD) and the number of days over a fixed amount of precipitation (R10) are more difficult to simulate, since the region has a marked precipitation gradient that is not properly represented (not shown). The maximum of dryness observed over the central Argentinian Andes or the extensive dry season of the Amazon region could not be represented by any model.

Warm nights and extreme precipitation events, both indices relative to the local climate, are the ones that are best represented by the GCMs.

The region where all simulated extreme indices, except FD, are more similar to the observations is the La Plata Basin region.

We can assume that models represent well some extremes. The possibility of modeling the occurrence of present climate extremes over South America allows us to project the probability of occurrence of extreme events in the future. This is particularly relevant considering that regions in southeastern South America include the most economically important and populated cities in South America (Buenos Aires, Sao Paulo, Rio de Janeiro, Montevideo) and are the one where the models perform better. There are two important basins in the region under study: the La Plata and the Amazon where extreme events, mainly rainfall, play an important role in the region. In the southeastern part of the La Plata Basin, this research counts with a dense network of stations with good quality of data. Changes in extremes in those cities and basins on the interannual time scale have shown to be important and have strong impacts on human activities. Unfortunately, Amazonia is the worst represented region in Southern South America, because there were very few stations with long records available to the climate community to do this kind of studies. This is extremely important if we consider the prospects of climate change on the region, as discussed on Part II of this study (Marengo et al. 2009).

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References

Alexander LV, Zhang X, Peterson TC, Caesar J, Gleason B, Klein Tank A, Haylock M, Collins D, Trewin B, Rahimzadeh F, Tagipour A, Ambenje P, Rupa Kumar K, Revadekar J, Griffiths G, Vincent L, Stephenson D, Burn J, Aguilar E, Brunet M, Taylor M, New M, Zhai P, Rusticucci M, Vazquez-Aguirre JL (2006) Global observed changes in daily climate extremes of temperature and precipitation. J Geophys Res 111:D05109. doi:10.1029/2005JD006290

Boulanger JP, Brasseur G, Carril A, Castro M, Degallier N, Ereño C, Marengo J, Le Treut H, Menendez C, Nuñez M, Penalba O, Rolla A, Rusticucci M, Terra R (2009) The European CLARIS project: a Europe-South America network for climate change (this issue). doi:10.1007/s10584-009-9734-8

Frich P, Alexander P, Della-Marta P, Gleason B, Haylock M, Klein Tank A, Peterson T (2002) Global changes in climatic extremes during the 2nd half of the 20th century. Clim Res 19: 193–212

Groissman P, Knight P, Easterling D, Karl T, Hegerl G, Razuvaek V (2005) Trends in intense precipitation in the climate record. J Climate 18:1326–1350

Haylock MR, Peterson TC, Alves LM, Ambrizzi T, Anunciação YMT, Baez J, Barros VR, Berlato MA, Bidegain M, Coronel G, Corradi V, Garcia VJ, Grimm AM, Karoly D, Marengo JA, Marino MB, Moncunill DF, Nechet D, Quintana J, Rebello E, Rusticucci M, Santos JL, Trebejo I, Vincent LA (2006) Trends in total and extreme South American rainfall 1960–2000 and links with sea surface temperature. J Climate 19:1490–1512

Llano MP (2006) Variabilidad espacio—temporal de las secuencias de días sin lluvia en la Argentina. Master thesis, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires

Marengo J, Camargo CC (2007) Surface air temperature trends in Southern Brazil for 1960–2002. Int J Climatol 28(7):893–904. doi:10.1002/joc.1584

Marengo J, Rusticucci M, Penalba O, Renom M (2009) An intercomparison of model-simulated in extreme rainfall and temperature events during the last half of the twentieth century: part 2: historical trends. Clim Change (this issue)

Penalba O, Llano M (2006) Temporal variability in the length of no-rain spells in Argentina. In: 8th international conference on southern hemisphere meteorology and oceanography, American Meteorological Society, Foz de Iguazu, Brasil, 24–28 Abril 2006

Penalba O, Robledo F (2006) Trends in extreme daily rainfall events in La Plata Basin. In: 8th international conference on southern hemisphere meteorology and oceanography, American Meteorological Society, Foz de Iguazu, Brasil, 24–28 April 2006

Penalba O, Robledo F (2009) Trends in extreme daily rainfall events in La Plata Basin. Clim Change (this issue)

Rusticucci M, Barrucand M (2004) Observed trends and changes in temperature extremes in Argentina. J Climate 17:4099–4107

Rusticucci M, Kousky V (2002) A comparative study of maximum and minimum temperatures over Argentina: NCEP/NCAR reanalysis versus station data. J Climate 15(15):2089–2101

Rusticucci M, Penalba O (2000) Inter-Decadal changes in the precipitation seasonal cycle over Southern South America. Relationship with surface temperature. Clim Res 16:1–15 (ISSN 0936-577X)

Rusticucci M, Renom M (2008) Variability and trends in indices of quality-controlled daily temperature extremes in Uruguay. Int J Climatol 28:1083–1095. doi:10.1002/joc.1607

Taylor K (2007) The WCRP CMIP3 Multimodel data set. A new era in climate change research. Bull Am Meteorol Soc. doi:10.1175/BAMS-88-9-1383

Tebaldi C, Haohow K, Arblaster J, Meehl G (2007) Going to extremes. An intercomparison of model-simulated historical and future changes in extreme events. Clim Change 79:185–211

Vincent LA, Peterson TC, Barros VR, Marino MB, Rusticucci M, Carrasco G, Ramirez E, Alves LM, Ambrizzi T, Berlato MA, Grimm AM, Marengo JA, Molion L, Moncunill DF, Rebello E, Anunciação YMT, Quintana J, Santos JL, Baez J, Coronel G, Garcia J, Trebejo I, Bidegain M, Haylock MR, Karoly D (2005) Observed trends in indices of daily temperature extremes in South America 1960–2000. J Climate 18:5011–5023