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CLARIS Project: towards climate downscaling in South America

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Abstract

We explore the bias in monthly and seasonal mean precipitation simulated by ensembles of different regional climate models over South America within the context of the EU-FP6 CLARIS project (A Europe-South America Network for Climate Change Assessment and Impact Studies). We brief y described two series of coordinated simulations: (i) Case studies of anomalous months for south-eastern South America performed with an ensemble of six models, and (ii) A multiyear simulation of the period 1991–2000 performed by four models. The models have been forced with the European Centre for Medium Range Weather Forecasting Reanalysis (ERA-40) and are compared to observational data compiled by the Climatic Research Unit (CRU). The ensemble-mean bias can be large when simulating particular extreme periods in La Plata Basin. Our multi-model analysis suggests that even though the ten-year ensemble mean is able to capture the major regional characteristics of seasonal mean precipitation for South America, models individually display considerable precipitation biases especially in tropical areas. The relatively good performance of the multi-model annual average over La Plata Basin results from the cancelation of offsetting errors in the individual models.

Zusammenfassung

Im EU-FP6 Projekt CLARIS („Climate Change Assessment and Impact Studies“ – ein europäisch-südamerikanisches Netzwerk für die Abschätzung von Klimaänderungen und Wirkungsstudien) wird die Abweichung im Monats- und jahreszeitlichem mittleren Niederschlag über Südamerika für ein Ensemble von regionalen Klimamodellen berechnet. Es werden zwei Arten von Simulationen beschrieben: (i) Fallstudien mit einem Ensemble von sechs Modellen für auffällige Monate über dem Südosten von Südamerika, und (ii) eine Simulation über mehrere Jahre (1991–2000) mit vier Modellen. Die Modelle werden mit Reanalysen (ERA-40) des Europäischen Zentrums für Mittelfristige Wettervorhersage angetrieben und mit Beobachtungsdatensätzen der Climate Research Unit (CRU) verglichen. Für das Ensemblemittel ergeben sich über dem La Plata Einzugsgebiet für spezielle Extremereignisse große Abweichungen. Die Analyse mehrerer Modelle legt nahe, dass, obwohl die 10-Jahres-Ensembles die wesentlichen Eigenschaften des mittleren jahreszeitlichen Niederschlags über Südamerika wiedergeben können, einzelne Modelle jedoch wesentliche Abweichungen im Niederschlag zeigen, speziell über tropischen Gebieten. Das relativ gute Ergebnis des mittleren Jahresniederschlags im Ensemblemittel über dem La Plata Einzugsgebiet ist darauf zurückzuführen, dass sich die Fehler der einzelnen Modelle bei der Mittelung nahezu aufheben.

1 Introduction

Simulating regional climate over South America is a diff cult task owing to its large meridional extension, wide range of tropical to extratropical climatic conditions and complex physiographic features, including the high and relatively narrow Andes Mountains stretching along the entire west coast. Its climate is dominated by a seasonally varying climate regime with a warm season precipitation maximum inf uenced by the interplay of topography, land and sea surface feedbacks, and incursions of frontal systems from midlatitudes. The diff culty in simulating the South American climate is evidenced in recent transferability studies of different single regional climate models (RCM, see section list of acronyms) to diverse regions of the earth (e.g. MEINKE et al., 2007; ROCKEL and GEYER, 2008, the mean precipitation biases are the greatest for the South American domain).

This paper documents coordinated work carried out within the work package on downscaling in La Plata Basin of the European Union project 'A Europe-South America Network for Climate Change Assessment and Impact Studies' (CLARIS, www.claris-eu.org). The goal of this 3-year interdisciplinary project was to build an integrated European-South American network dedicated to promote common research strategies to observe and predict climate changes and their consequent socio-economic impacts taking into account the climate and societal peculiarities of South America. CLARIS

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was built on experience obtained through other European Projects such as PRUDENCE, MICE and ENSEMBLES and was, in a more modest way, a counterpart of these projects in South America. Obtaining reliable simulations at the regional scale over South America is a central issue in order to assess the impacts of climate change and to provide corresponding information to policy-makers. Some detailed information on CLARIS can be found in the recent literature (CLARIS group, 2010). Information on the project, its multidisciplinary research strategies and its main results are summarized in BOULANGER et al. (2010).

The CLARIS work package on downscaling has promoted the co-ordinated participation of European and South American research teams in the use and development of regional dynamical models and statistical downscaling techniques. Concerning dynamical downscaling activities within CLARIS, two multi-RCM downscaling were carried-out: (i) Case studies of months with observed extreme precipitation in south-eastern South America (hereafter EXP1), and (ii) Multiyear simulations of the recent present climate (EXP2). Models were run at horizontal spatial scales of about 50 km and were driven by reanalysis data (ERA40, UPPALA et al., 2005). Testing regional models over South America has offered a singular opportunity to share participants' expertise and to compare regional model performances in a new environment.

In addition, regional climate change scenarios were generated during the last part of the project (NUÑEZ et al., 2008; SÖRENSSON et al., 2009; see also BOULANGER et al., 2010). SÖRENSSON et al. (2010) present a regional climate change scenario developed for the CLARIS project using RCA3 nested into the coupled global climate model ECHAM5/MPI-OM. The response of precipitation both in terms of seasonal means and changes in daily extremes was assessed. This study arose through the collaboration between a European regional climate modeling group (Rossby Centre/SMHI) and a counterpart in South America (CIMA/CONICET-UBA) within the CLARIS framework.

In the present paper, we brief y describe the ability of models forced by analyzed boundary conditions (i.e. quasi-observed) to simulate case studies of intense precipitation in the monthly time-scale near the Rio de la Plata (EXP1) and a 10 year period (EXP2). For details on participating models' setup and parameterizations and for a description of results of EXP1 over South Eastern South America (southern Brazil, Uruguay, northeastern Argentina), including a comparison with station data and with results from a statistical downscaling method, we refer the reader to MENÉNDEZ et al. (2010).

Concerning EXP1, we just provide in section 2 an example of behavior of the multi-model mean on monthly time scales, highlighting some aspects not discussed in MENÉNDEZ et al. (2010). In relation to EXP2, this experiment is not even reported in the cited literature and, without aiming at a thorough discussion, we describe in section 3 the models performance for simulating mean precipitation in South America. The analysis is focused on the comparison between CLARIS ensembles and observations. Simulations were evaluated against high-resolution data compiled by the Climatic Research Unit (CRU, NEW et al., 1999, 2000). We emphasize that this is a progress report and that climate simulations carried out in the CLARIS context are still being analyzed, and new simulations are being planned and executed in the context of the new CLARIS LPB FP7 project.

2 Case studies of extreme months

At the starting point of the project, preliminary tests were performed by individual partners with models that had realistic simulation of climate over Europe. The unexpected poor results over South America lead some groups to try to adjust their models to this new domain. Moreover, participating scientists from South America were initially affected, to a certain degree, by a relative lack of resources and experience in performing regional climate simulations. In order to engage the active participation of as many groups as possible, we set up a computationally inexpensive but helpful f rst coordinated exercise to evaluate model behavior in three different month-long cases under extreme anomalous conditions affecting the Rio de la Plata area.

The CLARIS ensemble for EXP1 consists of simulations performed with f ve RCMs (MM5, PROMES, RCA3, REMO and WRF) and one stretched-grid global model (LMDZ). The domain of analysis is restricted to southern South America where CLARIS is exploring model behavior and sources of uncertainty in more detail. Length of simulations is two months, but only the last simulated months-January 1971, November 1986 and July 1996-were analyzed.

Every model has strengths and weaknesses and models performance depend on the simulated climate regime, the considered region and the variable of interest. Many studies (e.g. KRISHNAMURTI et al., 2000; PALMER et al., 2004) have demonstrated that combining the models in a multi-model ensemble gives in general the best climate depiction. In our case, the multi-model consensus is def ned as a simple equal-weighted average (the same weighting is given to each model regardless its performance). As an example of the ensemble mean performance, Fig. 1 shows monthly mean bias and spread between models for near surface temperature and precipitation for November 1986, a month with anomalously high precipitation in the southern La Plata Basin. Overall, the models ensemble tends to simulate a too warm and dry climate over large areas of south eastern South America. Relatively large intermodel spread is also noted in the downscaled temperature and rainfall. Related possible error sources in the models were discussed in MENÉNDEZ et al. (2010) and include a drying

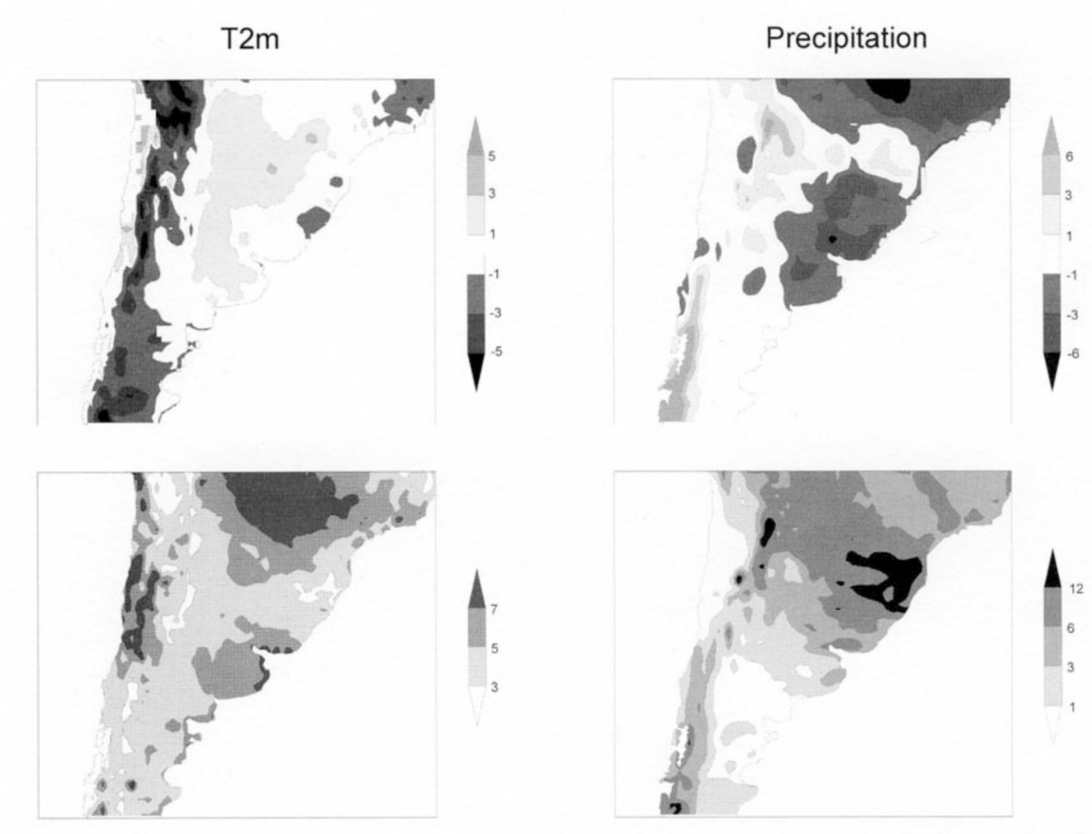

Figure 1: Bias (upper panels) and intermodel spread (lower panels) in monthly mean surface air temperature (left column) and precipitation (right column) for an ensemble of six regional models for November 1986. The intermodel spread is evaluated as the difference between the highest value of the ensemble minus the lowest value at each grid point. Domain extends between 80°W to 40°W and 50°S to 18°S.Units: °C (temperature) and mm/day (precipitation).

phenomenon (positive feedback of soil moisture drying) over La Plata Basin and a defective simulation of the regional circulation (particularly the humidity advection from the north is underestimated).

It is worth noting that areas with low ensemble bias (such as parts of Brazil or the coasts of the Rio de la Plata for temperature, and Paraguay-southern Brazil for precipitation) often coincide with areas of large intermodel spread suggesting that the small bias often results from the cancellation of offsetting errors in the individual models. The simple cancellation of errors as a result of an overall positive bias in one model and an overall negative bias in another is the most obvious – but not only – reason for the multi-model advantage (see HAGEDORN et al. (2005) for a discussion on the reasons behind the better results provided by multi-model ensembles in comparison to single models). Certainly, this cancellation of errors does not occur over the entire domain. Over other regions, the multi-model composite is not distinctively better than a single good model. For instance, in some of the areas with large ensemble bias (e.g. for precipitation in the northern part of the domain), the models spread is relatively low, indicating that the models may have similar problems in these regions. In other words, the verif cation (CRU data) lies beyond all single-model simulations and the multi-model mean constitutes an improvement with regard to some models but deterioration compared to others.

3 Multi-year present-day simulations

The CLARIS ensemble for EXP2 consists of regional simulations performed with four models (LMDZ, PROMES, RCA3 and REMO) for the period 1991–2000. Models used the same setup and parameterizations as in the previous experiment (see a summary of models conf gurations and parameterizations in MENÉNDEZ et al., 2010, their Table 1). Models domains are somewhat different from model to model but include most of South America (the domain of analysis covers from 50°S to the equator and 85°W to 35°W).

The strength of the hydrological cycle is particularly strong in South America (the continental area mean annual values of precipitation, evaporation and runoff are by far the largest among all the continents, see e.g. Table 7.2 in PEIXOTO and OORT, 1992). Therefore, the economical and environmental vulnerability of this continent to changes in precipitation is critical. Under these

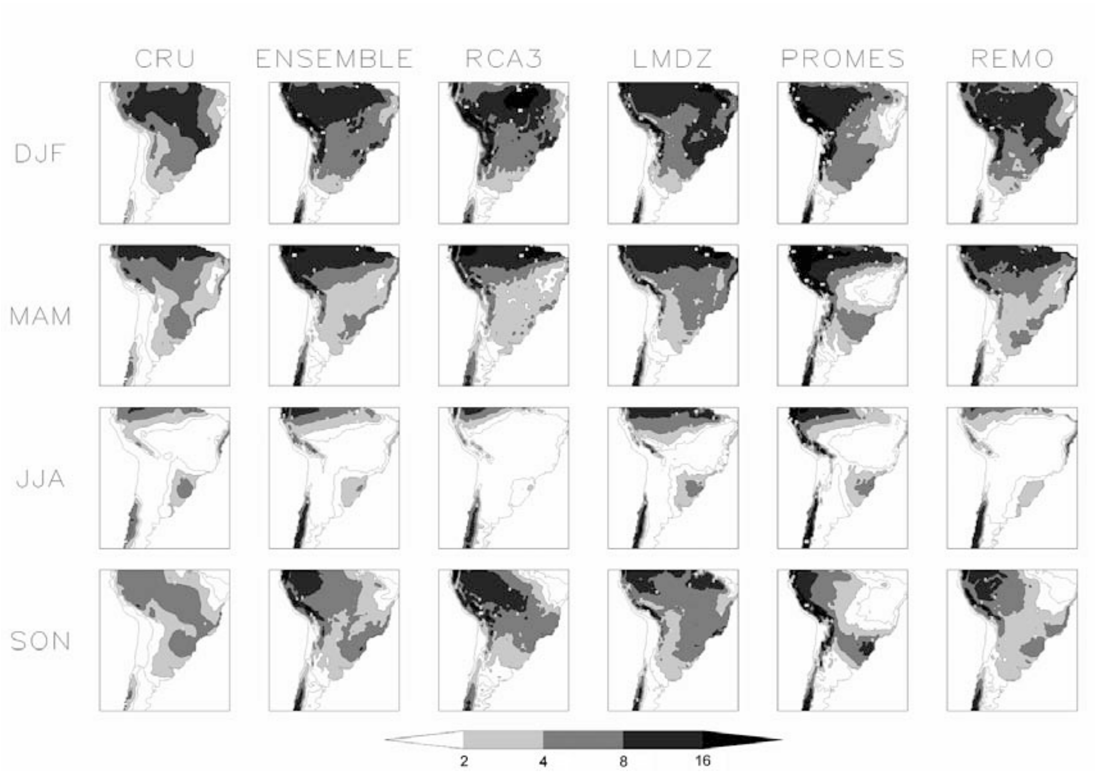

Figure 2: 10-year (1991–2000) mean precipitation for each season (in mm/day). The CRU observed climatology is shown in the left column, the mean of four models in the second column, and the individual models' results in the remaining four columns.

circumstances, it is of real practical interest to evaluate how well models can simulate the regional precipitation.

The seasonal mean precipitation in the years 1991–2000 in the multi-model mean f eld and the four individual models compared with the observation-based data set is shown in Figure 2. Some caveats should be pointed out concerning the CRU observational dataset. Over large regions in South America the density of observing stations is relatively low (see station densities in NEW et al., 2000). Consequently the interpolation procedure used in developing this precipitation dataset might affect the f ne scale structure of the actual f eld. However, our choice of analyzing broad structures/regions tends to compensate this weakness.

Large rainfall values over Amazonia extending southeastward towards the South Atlantic Convergence Zone characterize the wettest three-month period (DJF). In austral winter (JJA) the largest seasonal precipitation occurs in western Amazonia, while large areas further south are quite dry. Over the tropical rain forests, rainfall during autumn (MAM) is more intense and more evenly distributed in longitude than in spring (SON). The CLARIS ensemble is able to reproduce the major regional characteristics of the observed precipitation f eld, including the maxima over the tropical rain forest and the South Atlantic Convergence Zone, and the relatively dry areas such as north eastern Brazil and eastern Patagonia. The monthly migration of rainfall associated with the South American monsoon system tends also to be well captured by the ensemble mean (not shown).

However, the ensemble mean overestimates precipitation in the northern part of the domain and along the Andes and underestimates precipitation near the monsoon core region in central South America. Some models individually display substantial precipitation biases, especially in the tropics, and also east-west positional errors in the rainfall distribution both over the tropical forest and in southern South America. The relatively good performance of the multi-model average over La Plata Basin results from the cancellation of offsetting errors in the individual models (RCA3 and REMO are too dry whereas LMDZ and PROMES are too wet in this region for the annual mean).

In this view, it is worth stressing that any use of a multi-RCM mean for impact studies will have to carefully take into account the regional precipitation biases of the individual models. To analyze the reasons behind the biases requires further research to understand the consequences of different model formulations on a number of processes (e.g., evapotranspiration, condensation, horizontal and vertical transport) and their interactions with orographic and surface features. For this, a better understanding of key regional climate processes is a prerequisite.

4 Final remarks

Even though regional climate modeling has undergone a continuous development during the last two decades, in the recent IPCC AR4 all the regional-scale information for South America was taken from global models (CHRISTENSEN et al., 2007). This area of research is still in its early stages of development for that continent, but downscaled multi-year simulations and climate change projections are starting to become available (see e.g. SÖRENSSON et al., 2010).

Our multi-model analysis suggests that current uncertainties in regional-scale climate modeling are still high in South America. In particular, simulating the regional precipitation remains a challenging task for many RCMs. On a worldwide perspective, this is consistent with recent literature assessing the transferability of different single regional models to diverse regions of the earth including South America (MEINKE et al., 2007, ROCKEL and GEYER, 2008). In both analyses the mean precipitation biases are greatest for the South American domain.

This is due to the complexity of the processes that determine its climate, but also to a certain lack of coordinated research strategies to address the problem of simulating the South American climate. Recent projects such as the CLARIS LPB FP7 European Project (www.claris-eu.org) or the WCRP CORDEX framework (http://wcrp.ipsl.jussieu.fr/RCD_Projects/CORDEX/CORDEX.html) are valuable initiatives to improve coordination of international efforts in this topic.

Three classes of future challenges emerge for this region. Firstly, there is a need to improve the availability of observed data. The insuff cient amount of observed data over most of the region, compounded by their lack of availability, limits the capacity to analyse models biases and to develop strong regional scale statements of change. Secondly, we need to improve regional models. Important processes affecting South America are poorly represented or not presently included in current RCMs (e.g. feedbacks related with neighboring oceans, vegetation and aerosol production need to be better understood and represented in models by incorporating coupled ocean models, dynamic vegetation, biogeochemical cycles, and other components). Finally, in order for regional climate modeling to fulf ll its potential in the region, closer linkages of the South American scientists with the modeling community as well as with colleagues from other regions with common problems (e.g. modelling tropical climates) are needed.

List of acronyms

CIMA Centro de Investigaciones del Mar y la Atmósfera (Research Center for the Sea and the Atmosphere)
CLARIS A Europe-South America Network for Climate Change Assessment and Impact Studies
CLARIS LPB Europe-South American Network for Climate Change Assessment and Impact Studies in La Plata Basin
CONICET National Council of Scientif c and Technical Research of Argentina
CORDEX COordinated Regional climate Downscaling EXperiment
CRU Climatic Research Unit
DJF December through February
ECHAM5/MPI-OM Max-Planck Institute for Meteorology Global Coupled Model
ENSEMBLES Ensemble Based Predictions of Climate Changes and their Impacts
ERA-40 European Centre for Medium Range Weather Forecasting Reanalysis
FP6 EU Sixth Framework Programme for Research and Technological Development
FP7 EU Seventh Framework Programme for Research and Technological Development
IPCC AR4 Fourth Assessment Report of the Intergovernmental Panel on Climate Change
JJA June through August
LMDZ Laboratoire de Météorologie Dynamique Atmospheric General Circulation Model
MAM March through May
MICE Modelling the Impact of Climate Extremes
MM5 Pennsylvania State University/National Center for Atmospheric Research Mesoscale Model
PROMES Universidad de Castilla – La Mancha Regional Climate Model
PRUDENCE Prediction of Regional scenarios and Uncertainties for Def ning EuropeaN Climate change risks and Effects
RCM Regional Climate Model
RCA3 Rossby Centre Regional Climate Model
REMO Max Planck Institute for Meteorology Regional Climate Model
SMHI Swedish Meteorological and Hydrological Institute
SON September through November
UBA Universidad de Buenos Aires
WCRP World Climate Research Programme
WRF Weather Research and Forecasting Model

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