

## **A Europe–South America network for climate change assessment and impact studies**

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**Abstract** The goal of the CLARIS 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. Reaching that goal placed the present network as a privileged advisor to contribute to the

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design of adaptation strategies in a region strongly affected by and dependent on climate variability (e.g. agriculture, health, hydro-electricity). Building the CLARIS network required fulfilling the following three objectives: (1) The first objective of CLARIS was to set up and favour the technical transfer and expertise in earth system and regional climate modelling between Europe and South America together with the providing of a list of climate data (observed and simulated) required for model validations; (2) The second objective of CLARIS was to facilitate the exchange of observed and simulated climate data between the climate research groups and to create a South American high-quality climate database for studies in extreme events and long-term climate trends; (3) Finally, the third objective of CLARIS was to strengthen the communication between climate researchers and stakeholders, and to demonstrate the feasibility of using climate information in the decision-making process.

## 1 Introduction

The CLARIS project (“A Europe South America Network for Climate Change Assessment and Impact Studies”; <http://www.claris-eu.org>) aimed at strengthening collaboration between research groups in Europe and South America to develop common research strategies on climate change and impact issues in the subtropical region of South America through a multi-scale integrated approach (continental–regional–local).

First, CLARIS encouraged the transfer of knowledge and expertise on earth system models, their different components and coupling procedures. Furthermore, CLARIS provided European and South American scientists involved in climate

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modelling in South America the necessary framework to compare and exchange their methodologies. This framework was also complemented by an easy-access database, compiling the observed and simulated climate data required for models to be both validated and properly forced.

Second, complementary to that modelling aspect, CLARIS facilitated access to large scale climate data sets and climate simulations. A major goal for CLARIS was to initiate the setting-up of a high-quality daily climate database for temperature and precipitation. The European expertise acquired through the European Climate Assessment Project was essential to meet this objective.

Finally, on a local scale, CLARIS aimed at creating a bridge between the climate research community and stakeholders in the framework of three pilot activities designed to integrate multi-disciplinary components and to demonstrate the potential and feasibility of using climate information in the decision-making process. Three major areas were addressed: agriculture, health and air-pollution.

Moreover, the opening towards stakeholders promoted future initiatives on climate impact analysis, thus contributing to related sustainable development strategies.

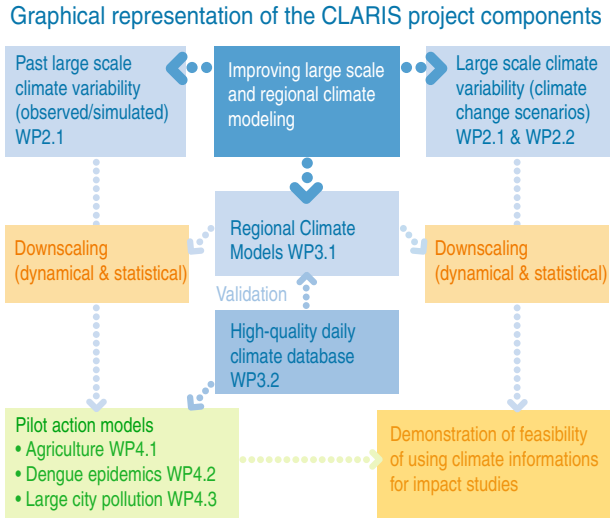
The project was organized around four network coordination themes and nine workPackages:

- NCT1: Project coordination
  - WP1.1: CLARIS and the European Commission
  - WP1.2: CLARIS communication and dissemination activities
- NCT2: Observing and modelling South American climate at continental scale
  - WP2.1: Earth system modelling
  - WP2.2: Climate observations and earth system simulations
- NCT3: From continental to regional and local scales
  - WP3.1: Climate change downscaling in sub-tropical and mid-latitude South America
  - WP3.2: High-quality regional daily database for climate trends and extreme event studies
- NCT4: From climate to impact studies
  - WP4.1: Climate and agriculture: a pilot action in the Argentinean Pampa Humeda
  - WP4.2: Climate and vector-borne epidemics: a pilot action on dengue and yellow fever in Brazil
  - WP4.3: A pilot action on continental-scale air pollution produced by South American megacities

The scientific project components were organized according to the spatial scale of the issues they addressed (Fig. 1). WP2.1 (II) aimed at transferring knowledge, expertise, models and tools related to large-scale climate modelling between the European and South American partners (e.g. transfers of atmosphere-chemistry modules to the study of air pollution in South American megacities).

WP2.2 provided data requested by WP2.1 to evaluate the performance of global models. WP2.2 also provided boundary and large-scale conditions to evaluate earth system models and to apply downscaling methods (dynamical and statistical) to

**Fig. 1** Graphical representation of the CLARIS project components



climate change scenarios. It aimed at building the CLARIS Data Archive Centre, which was hosted by CIMA in Argentina.

WP3.1 (Section 3) contributed to the evaluation of earth system models in simulating the South American climate. Therefore, it gave foresights of future improvements to the WP2.1 partners. WP3.1 provided regional simulations for climate impact studies in NCT4.

WP3.2 (Section 4) allowed evaluating large-scale and regional simulations in terms of climate trends and extreme event studies (changes in frequency and amplitude).

The three pilot actions in NCT4 (Sections 5 to 7) made the link between the climate research strategies developed in NCT2 and NCT3 and the stakeholders to demonstrate the potential value of climate information for the decision-making process and, thus, develop confidence between the research community and the stakeholders.

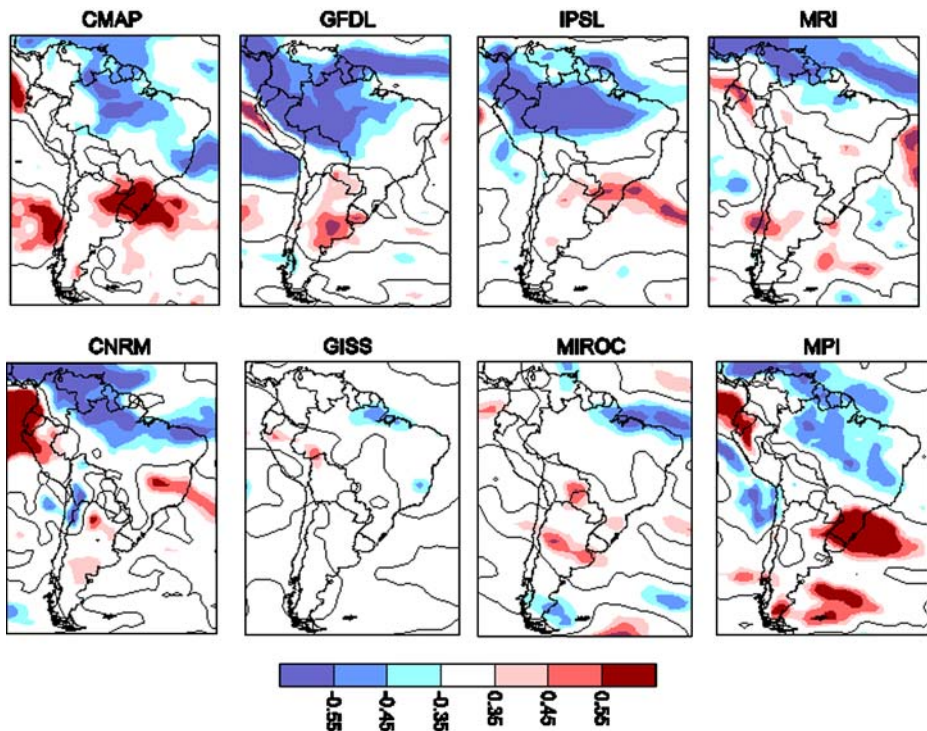
Finally, the CLARIS project was built on the expertise acquired in other European Projects (STARDEX, <http://www.cru.uea.ac.uk/projects/stardex/>; PRUDENCE, <http://prudence.dmi.dk/>; MICE, <http://www.cru.uea.ac.uk/projects/mice/>; ENSEMBLES, <http://ensembles-eu.metoffice.com/>) and is, in a more modest way, a counterpart of these projects in South America.

## 2 Earth system modelling

Climate models are one of the main tools to guide us in the prediction of climate evolution and impacts and in the study of the physical processes involved. Climate models are powerful tools that accumulate long-term scientific development data at several first class research centres. Yet, when confronted with the monumental task of climate prediction, they regularly give conflicting results. The multi-model

approach helps to evaluate these discrepancies based on the spread among models and thus gives, together with performance in present-day climate, an objective assessment of their reliability. In this spirit, CLARIS partners performed a set of analysis projects based on the IPCC AR4 modelling effort. The aim of these projects was to assess the state-of-art of global models in simulating the regional climate and relevant physical processes and to construct climate change projections. The CLARIS community responded to the request of the IPCC AR4 WG1 authors when alerted about the lack of numerical analysis over South America and one of the tasks of the CLARIS community was to contribute by analysing the model climate output from the various global models made available by the IPCC AR4, focusing on the South American climate (Ch 11.6).

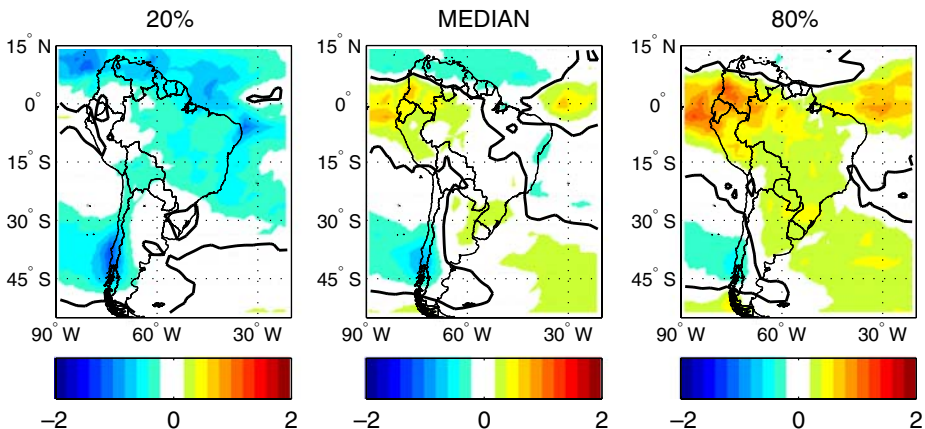
Precipitation and temperature are the main variables of interest for climate applications (health, agriculture, water resources) and are usually required at very high spatial and temporal resolution in order to be able to evaluate the impact of climate change. Global models are not capable of directly generating reliable information at these scales and usually model data is first downscaled to the needs of any particular application. Instead, global model performance of climate to-day is evaluated using



**Fig. 2** Correlation maps between ENSO index (SST anomalies at EN3.4) and OND precipitation anomalies in South America of observations (CMAP, top left) and climate models (from Vera and Silvestri 2009)

a set of key features of South American climate, identified at the beginning of the project (Vera et al. 2006a): SST in surrounding oceans and mean annual circulation, low-level moisture fluxes advected into the South American continent, southern hemisphere low level variability modes, intra-seasonal and synoptic scale variability patterns. These factors are also used to describe regional climate change for various scenarios.

IPCC-AR4 analyses of climate simulations in the twentieth century show that models are able to reproduce the main features of the precipitation seasonal cycle over South America, although the precipitation in the South American convergence zone (SACZ) region and peak precipitation over South Eastern South America (SESA) during the cold season are not well represented. Moreover, few models capture the ENSO (Fig. 2; Leloup et al. 2008) and Southern annular mode (SAM) signature observed in the South American hydro-climate (SAM is the principal atmospheric circulation variability mode in the southern hemisphere extratropics, characterized by a meridional seesaw in atmospheric mass between the high and the mid-latitudes, accompanied by an out-of-phase relation in the strength of the westerlies along 55°–60° S and 35°–40° S; see e.g., Thompson and Wallace (2000)). In spite of the discrepancies in the models in reproducing the present climate, the models coincide when predicting some patterns of climate change (Fig. 3) such as an increase of precipitation over La Plata Basin, a decrease over Southern Chile and Argentina and an increase along the equatorial Pacific coasts (Ecuador, Peru). There is a generalized consensus (Boullanger et al. 2007; Vera et al. 2006b) that the projected changes consist mainly of: (1) an increase of summer precipitation over SESA; (2) a reduction of winter precipitation over most of the continent; and (3) a reduction of precipitation throughout the year along the southern Andes (30°–40° S). Moreover, most of the models predict decreasing precipitation during October–November (the period of monsoon onset) in the South American Monsoon Region



**Fig. 3** Mean annual precipitation changes (mm/day) between the periods 2081–2100 (SRES A2) and 1981–2000 (20c3m) based on the IPCC-AR4 ensemble. 20%, 50% and 80% cumulative probability changes are presented

(SAMR; 60°–40° W, 5°–20° S), a simultaneous increase in precipitation over SESA, an increase of the vertically integrated moisture transport (VIMT) convergence over the SESA and a slight decrease of VIMT convergence over SAMR (Seth et al. 2009). These changes can be explained by a southward shift of the South Atlantic subtropical high.

Mid to high southern latitudes climate change signals, associated with increasing greenhouse gases (GHG), project strongly into the positive phase of the SAM. Warming in the neighbourhood of the Antarctic Peninsula and sea-ice volume reduction in the sea-ice edge region in the Amundsen and Weddell Seas become more intense with increasing GHG, suggesting that recent observed sea-ice trends around the Antarctic Peninsula could be associated to anthropogenic forcing (Carril et al. 2005; Menéndez and Carril 2005). The extent to which SAM is linked to extreme events is also studied. Results show significant correlations between variations in SAM and variation in the number of frost days (Fd) in some areas of the Southern Ocean, seemingly because changes in the SAM are associated with changes in the location and intensity of the meridional flow. The number of frost days during present-day climate seems to be related to the SAM along the Andes between about 20°–40° S and over central Argentina, with more frost days occurring when a positive phase predominates. Associated with a general increase of temperatures, the number of frost days diminish almost everywhere in the future climate, and the magnitude of the differences in Fd between the positive and negative phases of the SAM is consistently reduced (Menéndez and Carril 2006, 2008).

Moving to higher frequencies, the most distinctive feature that characterizes regional summertime rainfall variability on intra-seasonal timescales is the South American seesaw (SASS). Increased precipitation over the subtropics is associated with southward intensification in the South American low level jet (SALLJ) and increased moisture flux from the Amazon region, while the opposite phase shows an enhancement in the SACZ (Díaz and Aceituno 2003). The analyses show that models represent the low-level-circulation anomalies and the divergence patterns associated with the SASS well, but misrepresent the convergence areas in subtropical regions (convergence areas are misplaced and stronger than the observed ones). The differences between future and present climate simulations show a general decrease of the variance on intra-seasonal timescales with no significant changes in the SASS pattern and weaker associated convergence/divergence in the regional low-level circulation. While the convection anomalies in the tropical Pacific are stronger in a climate change scenario, there are no clear changes in the Rossby-like circulation anomalies related with the SASS.

Another objective of the CLARIS network was to facilitate the transfer of technical and scientific know-how in the field to enable partners to address the specific climate complexities of the region. In this context, a training activity on practical applications for climate variability studies was conducted for scientists and graduate students from South American laboratories. The training activities were based on MATLAB (MATrix LABORatory) applications. MATLAB is a high-level language for interactive environment that makes it possible to perform computationally intensive tasks faster than with traditional programming languages, providing an outstanding tool to analyse climate datasets (see Carril and Scoccimarro 2006; Scoccimarro and Carril 2006).



### 3 Climate change downscaling in sub-tropical and mid-latitude South America

Downscaled multi-year simulations and climate change projections have recently become available for South America and a great part of the effort has been channelled through the CLARIS framework. Our objectives focused on dynamical and statistical downscaling development and calibration as well as first attempts to create regional climate change scenarios.

*Dynamical downscaling experiments* We performed a series of coordinated simulations, to assess model behaviour in particular month-long extreme cases and in multi-year runs. The models used and experiments are listed in Table 1. A concerted approach in terms of model domain and resolution, time periods and model forcing was established for the first two experiments (all models were run at horizontal spatial scales of ~50 km and were driven by reanalysis data ERA-40). The following summarizes the dynamical downscaling experiments:

1. *Case studies of extreme precipitation and temperature events.* Three months (January 1971, November 1986 and July 1996) were simulated by an ensemble of models, which includes one global model with a stretched grid (LMDZ) and five RCMs. Dates were characterized by either extreme precipitation or temperature conditions in the southern La Plata Basin. Different ways of treating regional processes and feedbacks are responsible for a relatively large inter-model spread. Progress is being made to achieve a better appreciation of the sources of model error, leading to the improvement of regional simulations. More detail on this

**Table 1** Summary of dynamical models and regional experiments carried out during the project

Model	HadRM3P/ PRECIS	LMDZ	MM5	RCA3	PROMES	REMO	WRF
Institution	CPTEC, UCH	LMD	CIMA, UCH	RC/SMHI, CIMA	UCLM	MPI-M	CIMA
Case studies of extreme months <sup>a</sup>		X	X	X	X	X	X
Multi-year simulation (1990–1999) <sup>b</sup>		X		X	X	X <sup>c</sup>	
Climate change simulations	X <sup>d</sup>		X <sup>e</sup>	X <sup>f</sup>			

<sup>a</sup>Three month-long cases characterized by extreme precipitation conditions in the southern La Plata Basin (Menéndez et al. 2009). All models were driven by reanalyses (ERA-40). Horizontal resolution: ~50 km

<sup>b</sup>Models driven by reanalysis (ERA-40). Horizontal resolution: ~50 km

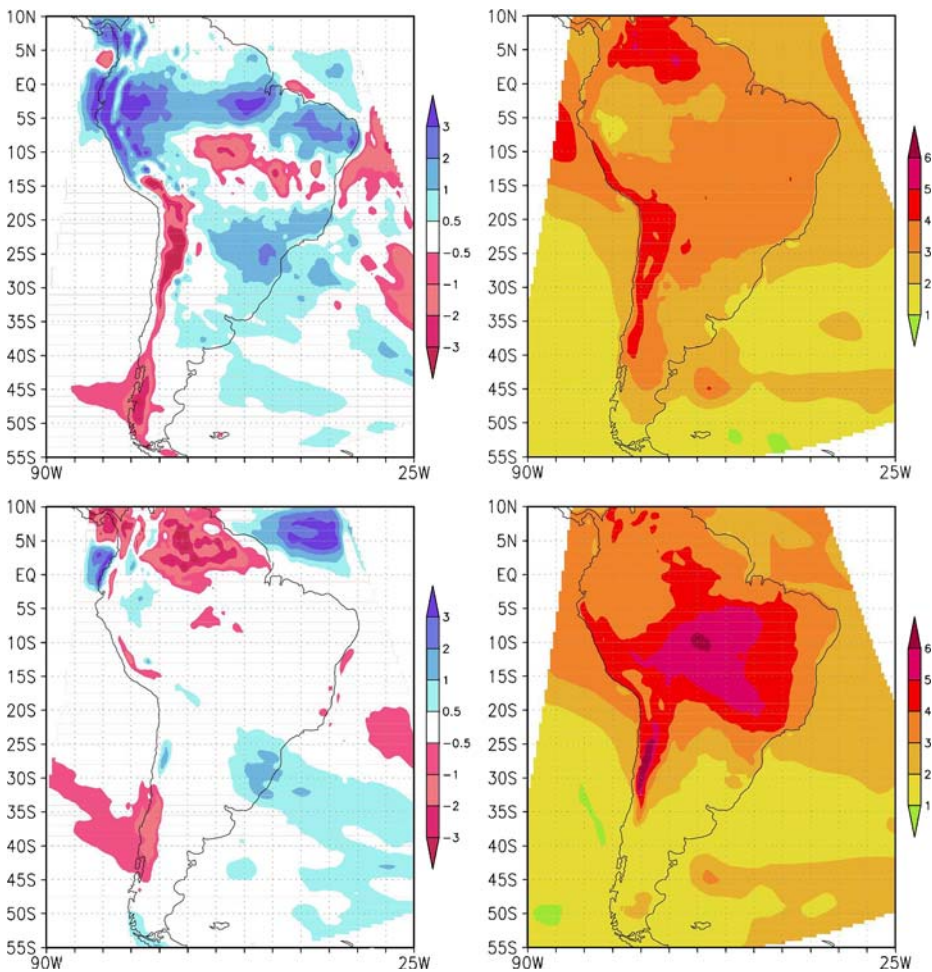
<sup>c</sup>An extended simulation (1958–2000) has been carried out with REMO (Silvestri et al. 2009)

<sup>d</sup>HadRM3P/PRECIS driven by HadAM3, scenarios A2 and B2, periods: 1961–1990 and 2071–2100 with domains centered over Chile (carried out at UCH, 25 km resolution) and Brazil (carried out at CPTEC, 50 km resolution)

<sup>e</sup>MM5 driven by HadAM3, scenarios A2 and B2, periods: 1981–1990 and 2081–2090, domain: 50 km resolution, southern South America (Núñez et al. 2008). Changes for the 2020s and the 2050s were obtained with a pattern scaling technique (Cabre et al. 2009)

<sup>f</sup>RCA3 driven by ECHAM5/MPI-OM, scenario A1B, periods: 1980–1999 and 2080–2099, 50 km resolution, continental-scale domain (see Fig. 4)





**Fig. 4** Precipitation and temperature changes over South America between 1980–1999 and 2080–2099 simulated by RCA3 driven by ECHAM5-OM. *Left panels:* seasonal mean precipitation changes for DJF (*top*) and JJA (*bottom*). *Right panels:* same for temperature changes

regional modelling inter-comparison exercise may be found in Menéndez et al. (2009).

2. *Multi-year present-day regional simulations.* The overall goal was to assess the performance of high-resolution models in reproducing the mean climate, seasonality and interannual variability in southern South America, by comparison with available observations and analyses. The simulation period of this common multi-year run was 1990–1999, though two models were also run for longer periods (20 and 43 years with RCA3 and REMO, respectively). Results are being independently analysed by different groups, e.g., Silvestri et al. (2009) performed an evaluation of the 43 year run, but a collaborative research for studying the regional climate as simulated by an ensemble of four models is under

consideration. For this purpose, an archive with output data from the different models is being created (work in progress).

- 3 *Climate change simulations.* The overall objective of this experiment was to help understanding the physical processes underpinning the regional climate change and the changes in its variability. Two different sets of climate change scenarios were generated in the WP3.1 framework:

- 3.1 *Regional simulations driven by boundary conditions provided by CLARIS partners.* The IPCC AR4 standard (SRES A1B scenario and 20 year time slices corresponding to the last two decades of the twentieth and twenty-first centuries) was suggested for regional climate change simulations. To this end, six-hourly boundary condition data sets have been provided by INGV and MPI-M from two state-of-the-art global coupled models (INGV-SINTEX and ECHAM5/MPI-OM). At the end of the project, only one climate change simulation was completed. A regional climate change simulation with RCA3 driven by lateral and surface conditions from ECHAM5/MPI-OM for two 20-year periods (1980–1999 and 2080–2099) was carried out as part of the ongoing collaboration between CIMA and Rossby Centre. Results are being analysed and a preliminary study was presented during the CLARIS final meeting (Sörensson et al. 2007; see also Fig. 4).

- 3.2 *Regional simulations forced by Hadley Centre boundary conditions.* Dynamical downscaling of future scenarios was developed by some groups in Argentina (CIMA), Brazil (CPTEC) and Chile (UCH) in the framework of the National Communications on Climate Change to the United Nations Framework Convention on Climate Change (UNFCCC), driving their models with data from the Hadley Centre and considering other emission scenarios (A2, B2). Experience of downscaling experiments of climate change scenarios over Brazil (as part of the CREAS project, Marengo and Ambrizzi 2006) and Chile have also been shared in the context of CLARIS (see Table 1). CPTEC and UCH carried out simulations using the HadRM3P regional model forced by regional boundary conditions produced in the Hadley Centre by means of HadAM3P global atmospheric model and observed sea surface temperatures modified with a positive trend provided by the HadCM3 coupled global model (Marengo 2007). The same boundary conditions from Hadley Centre were used at CIMA to provide surface and lateral forcing for MM5 (Núñez et al. 2008).

*Statistical downscaling* Two downscaling statistical methods have been developed. They are currently being inter-compared. The first method is based on the classification of daily atmospheric weather patterns to simulate daily precipitation and temperature variability at meteorological stations, and it is described in D'onofrio et al. (2009). The second method is a two-step statistical method, to estimate daily precipitation and maximum and minimum temperatures in the La Plata Basin, from a six-hourly ERA 40 reanalysis dataset (work under preparation, preliminary results in Bettolli et al. 2008).

*Complementary researches* Because of the large biases in the monthly averages of precipitation and temperature in the case studies of extreme months (Menéndez et al.

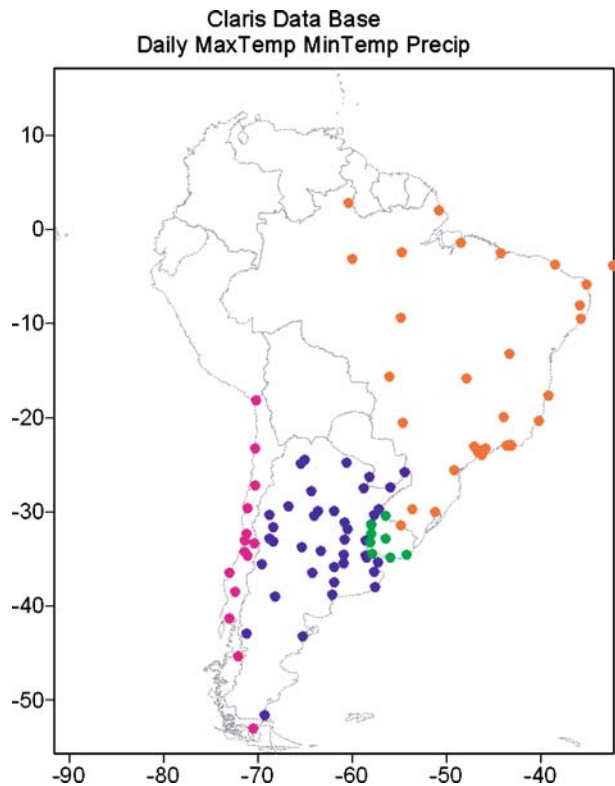
(2009), several sensitivity experiments were performed with MM5, PROMES, RCA3 and WRF in order to try to improve model performance. These experiments include sensitivity tests to different or modified physical parameterisations, land surface conditions, model domains and horizontal resolution. The most important results were presented at the final CLARIS meeting ([http://eolo.cima.fcen.uba.ar/la\\_plata.html](http://eolo.cima.fcen.uba.ar/la_plata.html)). In addition, different sets of climatic integrations, using RCA3 with a continental scale domain nested in reanalysis data, were carried out to help understanding the variety of regional feedbacks between rainfall and soil moisture (Menéndez et al. 2007; Sörensson et al. 2009).

#### 4 High-quality regional daily database for climate trends and extreme event studies

The second objective of CLARIS was to create a South American high-quality climate database for studies of extreme events and long-term climate trends.

The CLARIS database gathered a large set of available official data in the region under study (Fig. 5; Paraguay, Uruguay, Argentina, Chile and Brazil), by collecting archived historical data and promoting the collaboration of all national institutes involved in meteorological survey, forming a network for the scientists and data

**Fig. 5** The CLARIS database. Colours correspond to the different countries where the stations are located (*blue* for Argentina, *pink* for Chile, *green* for Uruguay, *orange* for Brazil)



managers in the region. Most of the stations cover the post-1950 period. Although the data quality had been controlled by the National Services and by the research groups who provided them (e.g. Rusticucci and Barrucand 2004; Rusticucci and Renom 2007), a common set of tests was applied to all data before they were entered in the database (see Table 2). During the course of the project and in order to provide an automatic procedure for historical daily data quality-control, Boulanger et al. (2009) developed the first component of an automatic procedure (APACH: a procedure for automated quality control and homogenization of weather station data) to control the quality and homogenize the historical daily temperature and precipitation data from meteorological stations.

These efforts of collecting and sometimes digitalizing historical daily weather station data have been recognized by the GCOS (global climate observing system)/WCRP Atmospheric Observation Panel for Climate, in its XII and XIII sessions, which included some references in their lists of conclusions:

The AOPC commended the progress being made in the CLARIS (Europe–South America Network for Climate Change Assessment and Impact Studies) project to assemble data from a number of countries in South America. It encouraged additional countries to contribute data to this effort and to make them openly available for climate monitoring purposes (XII session).

The AOPC noted the update on the Climate Change Assessment and Impact Studies (CLARIS) project in South America and welcomed the progress being achieved, particularly in the area of improved coordination and capacity-building in the region. It also noted, however, the considerable difficulty in assembling the required database for studies of extreme events and climate trends in the South America region. The Panel strongly urged nations to make their daily historical climate data openly available to the CLARIS project and to the GSN Archive. The AOPC also noted the proposal to the European

**Table 2** Quality control tests applied to the CLARIS data

1: Number of minimum temperature errors (tested with sigma = 4)
2: Number of maximum temperature errors (tested with sigma = 4)
3: Number of errors of the difference between $T_{\max}$ and $T_{\min}$ (tested with alpha = 0.1)
4: Number of missing values for minimum temperatures
5: Number of missing values for maximum temperatures
6: Total number of data
7: Percentage of the number of minimum temperature errors (tested with sigma = 4)
8: Percentage of the number of maximum temperature errors (tested with sigma = 4)
9: Percentage of missing values of minimum temperatures
10: Percentage of missing values of maximum temperatures
1': Number of minimum temperature errors (tested with sigma = 5)
2': Number of maximum temperature errors (tested with sigma = 5)
7': Percentage of the number of minimum temperature errors (tested with sigma = 5)
8': Percentage of the number of maximum temperature errors (tested with sigma = 5)

The percentages of the number of maximum and minimum temperature errors were calculated over the total number of available data

Union 7th Framework Programme (FP7) to continue the CLARIS project beyond 2007, with a focus on the La Plata basin, and expressed its strong support for this initiative (XIII session).

Another important result of this work package was the calculation of trends during the twentieth century and indices of extreme temperature and precipitation for the region during both the twentieth and the twenty-first centuries:

- Penalba and Robledo (2009) analyzed trends, interdecadal variability, and the quantification of the changes in the frequency of daily rainfall for two thresholds: 0.1 mm and the 75th percentile, using high quality daily series from 52 stations in the La Plata Basin (LPB).
- Rusticucci et al. (2009) and Marengo et al. (2009) computed indices of extreme temperature and precipitation for the region (following Frich et al. 2002) for observations and for the global climate models used in the IPCC AR4 model inter-comparison. First, Rusticucci et al. (2009) assessed the model skill during the last half of the twentieth century in simulating observed, mean and interannual variability of frost days (FD), warm nights (Tn90), heavy rainfall (R10), extreme precipitation (R95t) and dry spells (CDD) as indices of extreme events, over South America (SA) for 1961–2000. The most important conclusion is that warm nights and extreme precipitation are the indices best represented by the GCMs. Second, Marengo et al. (2009) found differences in the relative magnitude of the observed and simulated trends of extreme indices. Consensus and significance are less evident when regional patterns are considered, with the exception of the La Plata Basin, where observed and simulated trends in warm nights and extreme rainfall are evident.

## 5 Climate and agriculture: a pilot action in the Argentinean Pampa Humeda

The CLARIS Climate–Agriculture Pilot Project aimed at strengthening the collaboration between climate researchers and decision-makers in the agricultural production systems in the Argentine Pampas, and at assessing how current agricultural systems may be affected in a changing climate scenario. To achieve these objectives, the study was focused on three locations: Pergamino (33.90° S, 60.57° W), Anguil (36.50° S, 64.02° W) and Marcos Juárez (32.68° S, 62.10° W), which characterize different precipitation and temperature regimes. In these locations, crop systems include maize, soybean and wheat–soybean double-crop. The working group identified four major objectives:

- To investigate climate information needs and the expectations of agriculture stakeholders.
- To identify the role of climate changes over the last decades in the evolution of the Argentine agricultural systems, with a focus on the marginal areas, west of the Humid Pampa.
- To quantify the climate variables and characteristics affecting crop yields at the three selected sites.
- To assess the impact of IPCC climate change scenarios on crop yields during the twenty-first century and the possibility for adaptation strategies.

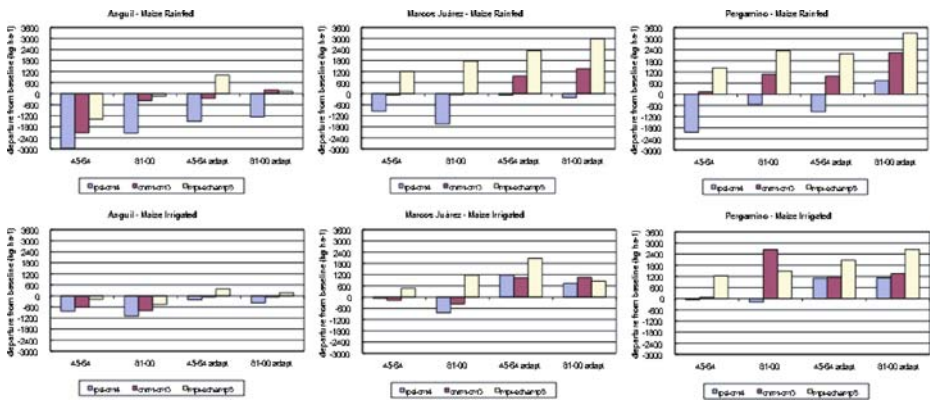
*Agricultural stakeholders' needs in climate information and their expectations from climate research* Most of the assessments of climate needs for agriculture were done on the basis of farmer surveys. Representatives of seventeen companies from three major agro business sectors were interviewed (Boulanger and Penalba 2009), regional cooperatives, insurance companies and international companies (cereal producers, agro-chemistry and agro-seeds) among them. While all the interviewees recognized the strong impact of climate on their activities, they all pointed out that, at decision making time, they considered the political and economic risks rather than the climate ones, so that the most relevant information used is the short and medium forecast. There is still little knowledge about the current capabilities and limitations of climate prediction. An interesting result is the confidence of the private sectors in the climate information provided by public sources. Boulanger and Penalba (2009) also describe how new financial contracts (weather derivatives) can be useful to help protecting Argentine agriculture against climate risks.

*Role of climate changes over the last decades* This economic study (not published in the Special Issue but available as a CLARIS deliverable) aimed at determining whether the process of land use change from pasture to crops was due to observed climate changes since the 1970s, or if it responded to external factors (international market). Indeed, the transition observed from livestock to crops has occurred gradually in the Argentine Pampas since the beginning of the 1970s. The Pampas region, still an important livestock producing region, has undergone a gradual decrease of its cattle herd that reached around 35 millions heads in 2000, or 75% of the national herd (Champredonde 2001). Due to a lack of long term data on land covered by pasture in Argentina, this study was carried out only in one of our three sites (Marcos Juarez). The most important conclusion is that the transition from livestock to crops is not restricted to the regions where climate change could be a major determinant and that international economic factors were the main forces behind this process.

*Climate variables affecting crop yields* This analysis, described in detail in D'Orgeval et al. (2009), aimed at determining if interannual climate variability is likely to affect crop yields in the Humid Pampa and if so which type. The DSSAT (decision support system for agrotechnology transfer) crop model (Jones et al. 2003) was used to simulate crop yields at our three selected sites. The model was forced by weather station observations (quality-controlled by WP3.2 partners; see for instance in this issue related papers by Marengo et al. 2009, Rusticucci et al. 2009 and Boulanger et al. 2009) who used different farm management options such as sowing date and fertilization amount. The main results highlight that sunflower and maize at Anguil, but also soybean at Marcos Juarez are the most sensitive crops to climate variability. It is worth pointing out that these are marginal sites for these types of crops. Therefore, the most important conclusion of this work is that climate information is most valuable in marginal areas where the vulnerability to climate (variability and changes) is the greatest.

*Impact of IPCC climate change scenarios on crop yields* The objective was to analyze the impact of climate change on agriculture through the evaluation of water/nitrogen use in a cropping system (CropSyst). This work (see Meira et al. 2007) is under preparation. Despite the fact that three IPCC climate change model projections under scenarios A2 displaying different temperature and precipitation





**Fig. 6** Non-irrigated and irrigated maize yield (and water use) changes (scenario A2) at three sites and using three future climate conditions from the IPCC models

changes show a decrease of crop yields for all models, it determines that simple crop management (sowing date–fertilizer use) adaptation strategies make it possible to cope quite easily with climate change in the long term (Cropsyst simulations) for only two of the three model projections (Fig. 6). The impact on crop yields of the third model is such that no simple adaptation strategy can be offered. This is a major outcome of the project as it points out different issues:

- First, it is crucial to evaluate the confidence in model projections with metrics specific for the impact under study (this result is a feedback to the climate model community).
- Second, considering the uncertainty in climate change projections, impact studies must evaluate whether the uncertainty grows or not when assessing the climate impact (e.g. on crop yields). A potential plan is to design three impact scenarios (best, median, worst) and their corresponding adaptation strategies, together with cost–benefit evaluations.

### 6 Climate and vector-borne epidemics: a pilot action on dengue and yellow fever in Brazil

Dengue is a disease caused by a Flavivirus (four serotypes) transmitted by mosquitoes (Arbovirus<sup>1</sup>). It is now recognized by the World Health Organization (WHO) as the most important human viral disease in the world (Gubler 2002). Unlike urban Yellow Fever, transmitted to man by the same mosquito, there is no vaccine available yet to protect at-risk populations from dengue. The only method of prevention is the control of mosquito vectors through their elimination. However, as control measures mainly rely on chemical insecticides, mosquitoes are developing resistance (Carvalho et al. 2004), and prevention policies would be more efficient,

<sup>1</sup>A contraction of arthropod-borne-virus or viruses transmitted biologically by insects or ticks.



educating the population to destroy domestic water containers where mosquitoes breed.

Dengue fever transmission in South America actually depends on many physical, biological and socio-anthropological factors (Chongsuvivatwong et al. 2000; Ramalho et al. 2006). (Degallier et al. 1988a, b; Focks et al. 1995). The same factors also influence, although indirectly, epidemic dynamics, through their action on the frequency of blood meals and the duration of the extrinsic cycle of the virus (Otero et al. 2006; Hales et al. 2002; Hopp and Foley 2003; McMichael et al. 2006; Patz et al. 2005). Dengue fever epidemiology also depends greatly upon human environment and behaviour (density, habitat, sanitation, control measures, disease perception etc.), which influence vector populations (Reiter 2001; Reiter et al. 2003).

WP4.2's main objective was to explore the possibilities of building a model to be used in an early warning system (Favier et al. 2005; Degallier et al. 2009). As a first step, a web-driven database was designed to archive dengue and yellow fever cases and observed mosquito population levels. The web interface allowed showing search results as maps or tables, useful to stakeholders, people in charge of prevention and control, and scientists. Such a database was also very helpful to validate the epidemic risk model.

Then a model of dengue epidemic risk was designed to estimate a climate-related risk index of dengue transmission, proportional to the maximum number of mosquito pupae per inhabitant required for the basic reproduction rate of the disease ( $R_0$ ) to remain below one.  $R_0$  actually represents the ratio between the number of new and of existing infected human cases. When  $R_0$  is lower than 1, the epidemic does not spread. When  $R_0$  is larger than 1, the epidemic is in a growth phase. The larger  $R_0$ , the faster the growth of the epidemic. The model was calibrated at global scale (on a  $2.5^\circ$  by  $2.5^\circ$  grid) against the known distribution of dengue fever, entering the mean monthly climate of the last 10 years (CRU database). The extension of areas under risk showed good correlation with the observed spatial and temporal distribution of both the vector (mosquito) and dengue epidemics (see Fig. 3 in Degallier et al. 2009). Further regional validations were also done, comparing the temporal variation of dengue cases and the monthly risk estimates during past epidemics, when the number of cases was known. Good correlations were found in all the studied cases such as in Athens, Bangkok, Fortaleza, Brasilia, and Belém (Favier et al. 2006a; see Fig. 4 in Degallier et al. 2009). Furthermore, the model simulated well the spatial variation of the month of maximum risk (see Fig. 7 in Degallier et al. 2009), confirming that our model could be used to forecast the seasonal climate-related epidemic risk.

Finally, in an attempt to improve the model, data from a field study in Brasilia (DF) was used to define a new risk index, specific to each type of water container where mosquitoes breed. It was concluded from this study (Favier et al. 2006b) that the pupae density per human inhabitant was a good indicator of pre-adult mosquito density, as emphasized in the recent literature (Barrera et al. 2006). Then a new risk model was designed based the estimation of the threshold density of pupae per inhabitant necessary to sustain a female population able to transmit dengue with  $R_0 \geq 1$ .

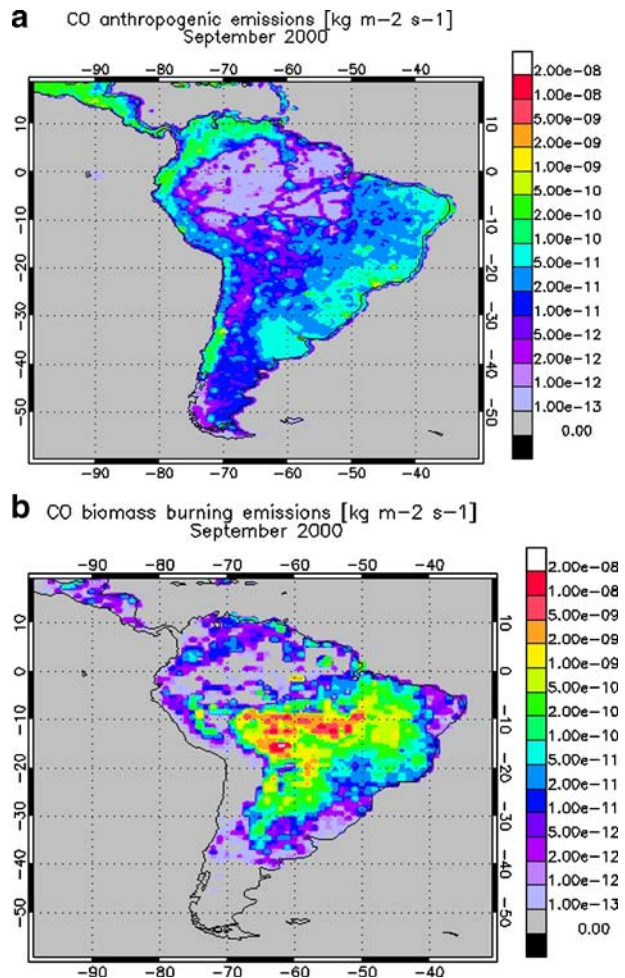
To conclude, due to the nature of the dengue transmission cycle through mosquitoes, viruses and human beings, a selected set of key factors should be studied among those which regulate (1) mosquito distribution, populations and vectorial

capacity, (2) virus multiplication and transmission, and (3) human behaviour. Obviously these factors are interconnected and are mainly influenced by changes in the global and local climate. It is thus proposed to use and adapt the CLARIS model of dengue epidemic risk in order to integrate the above key factors of dengue fever transmission and estimate local risk indices, according to climate variability, change and forecast. Regional adaptations of the model may thus make it possible to design predictive early warning systems, based on meteorological predictions.

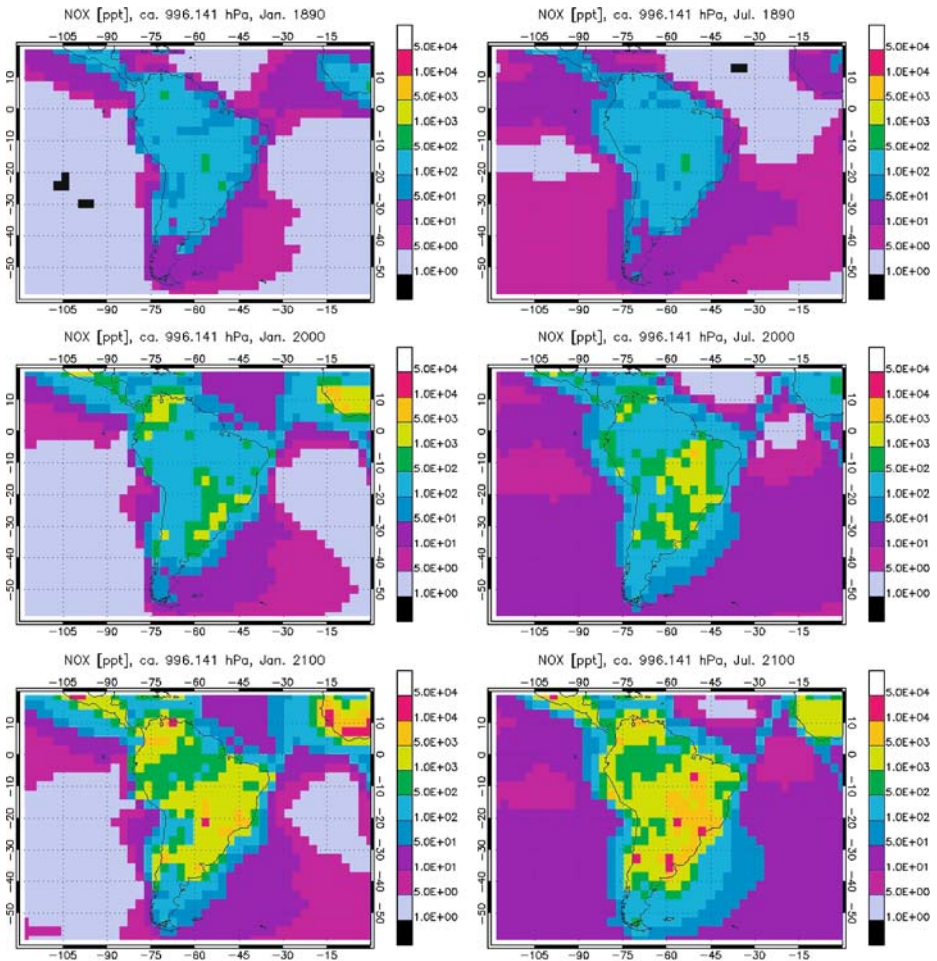
## 7 A pilot action on continental-scale air pollution produced by South American mega cities

Perhaps a century ago, the atmospheric chemical composition in South America was determined primarily by natural processes: Chemical compounds (e.g.,

**Fig. 7** Emissions of carbon monoxide ( $\text{kg m}^{-2} \text{s}^{-1}$ ) in South America, estimated for January 2000, due to (a) anthropogenic activities and (b) biomass burning



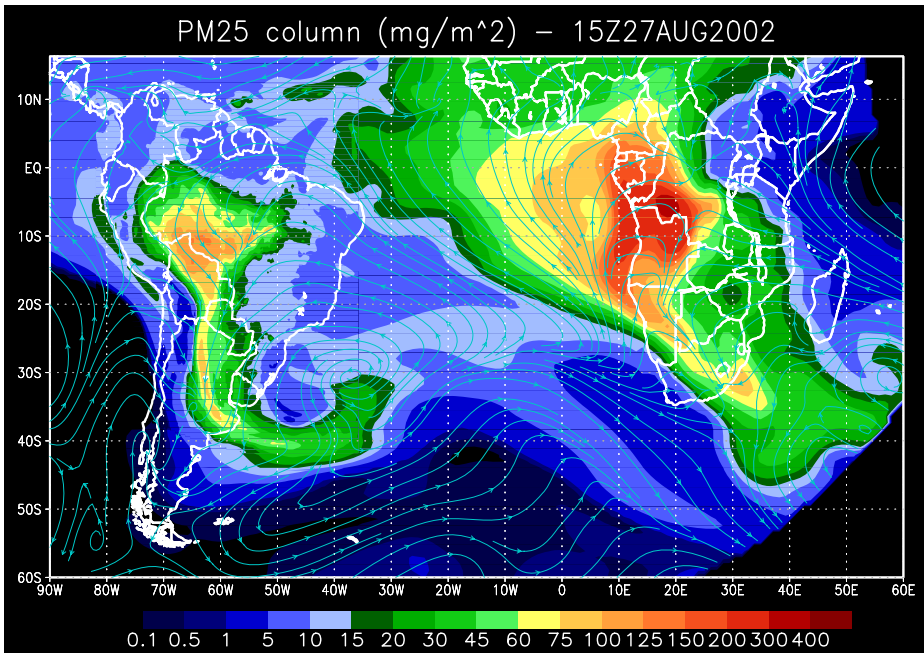
hydrocarbons, nitric oxide, carbon monoxide, etc.) released by the biosphere (vegetation and microbes in soils) or by wildfires were chemically transformed to produce secondary compounds including ozone molecules or organic aerosol particles. Today, human activities have dramatically changed the chemical emissions and hence the atmospheric concentration of trace constituents. Intensive deforestation, more frequent fires, now often triggered for agricultural purposes, and the development of large urban and industrial complexes have produced unprecedented levels of air pollution. Figure 7 shows an estimate of the anthropogenic surface emissions of carbon monoxide in South America, which are particularly intense in highly populated regions. Automobile exhausts and industrial activities as well as shipping over the oceans are important contributors to these emissions and very particularly the large emissions in the big urban areas of Sao Paulo and Rio de Janeiro in Brazil, Buenos Aires in Argentina, and Santiago in Chile.



**Fig. 8** Nitrogen oxide surface mixing ratio in January (*left*) and July (*right*) calculated for 1890 (*upper panels*), 2000 (*middle panels*) and 2100 (IPCC scenario A2) (*lower panels*)

Until recently, only limited information was available to quantify the emissions of pollutants and their impacts on regional air quality. Thus, an important task of CLARIS was to assess the impact of megacity development and of land-use changes on air quality at the sub-continental scale. The relative effects of anthropogenic versus biogenic emissions on atmospheric oxidants were assessed, and the resulting tropospheric ozone concentrations were estimated. Figure 8 shows the surface mixing ratio (pptv) of surface nitrogen over the South American continent. Dramatic changes have occurred between 1890 and the present time, but even larger concentration increases are expected in the future, if one follows, for example, the A2 scenario for future development.

Diligent efforts were made during the CLARIS period to establish emission inventories and regional chemical transport models were developed to investigate the role of chemistry and transport and to simulate the behaviour of trace gases and aerosols under specific weather conditions. The INPE/CPTEC group in Brazil, for example, has developed an operational modelling system that simulates on a daily basis the evolution of regional air quality in response to wildfire occurrence. Figure 9 shows the distribution of aerosol particles over the South American and South African continental areas as simulated by this system on 3 August 2002. Here, the effects of intense fires on both continents are visible, and the plumes produced by these burning events are predicted to affect remote regions including highly populated areas.



**Fig. 9** Vertically integrated aerosol column ( $\text{mg cm}^{-2}$ ) simulated by the CATT-BRAMS modelling system of INPE/CPTEC on 13 August 2002. Biomass burning plumes are visible over the South American and South African continental areas (From Freitas et al. 2009)

The study has highlighted, for example, the important impact of biomass emissions on urban air quality. In addition, when convective activity is intense, pyrogenic pollutants can reach the upper troposphere and be transported intercontinental distances by atmospheric circulation.

## 8 Conclusions and perspectives

During the CLARIS project, a research network bringing together European and South American Institutes was built. This network defined priorities to analyze climate change conditions and potential impacts on society. Special efforts were made to (1) evaluate climate change conditions in South America such as projected by the IPCC AR4 community; (2) coordinate dynamical downscaling efforts in South America; (3) build a high-quality daily temperature and precipitation database for extreme event studies; (4) quantify potential impacts of climate change on agricultural activities at pilot sites in Argentina; (5) map changes in dengue epidemic risks in South America; and (6) evaluate the evolution of air quality in South American mega cities in the context of climate change.

The major results achieved are:

1. The projections and uncertainties on climate change characteristics in South America
2. The coordinated regional dynamical downscaling simulations for extreme event cases and for a 10-year period.
3. Various regional dynamical downscaling climate change scenarios
4. The integration of Argentina, Brazil, Uruguay and Chile daily weather data stations in one common quality controlled database.
5. The projections of climate change impact on yields in the CLARIS pilot sites with an evaluation of impact uncertainty.
6. The projections of climate change impact on dengue risk evolution.
7. Moreover, the project has made it possible to foster a closer collaboration and integration between European and South American institutes on topics related to climate (climate variability, climate modelling, and climate impacts) and to create the interest of various stakeholders in strengthening the links with the climate change and impact research community.

As a consequence, the work carried out during the last 3 years, led the CLARIS consortium to include new partners in order to suggest new priorities to study climate change impacts in La Plata Basin and to design effective adaptation strategies for various topics related to agriculture and hydrology. These research priorities (which represent the ultimate goal of the CLARIS SSA Project) are funded by the 7th EC Framework Programme under the name CLARIS LPB (La Plata Basin; Oct. 2008–Sep. 2012).

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