AIACC Final Reports

# Climate Change and Variability in the Mixed Crop/Livestock Production Systems of the Argentinean, Brazilian and Uruguayan Pampas

A Final Report Submitted to Assessments of Impacts and Adaptations to Climate Change (AIACC), Project No. LA 27

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A Final Report Submitted to Assessments of Impacts and Adaptations to Climate Change (AIACC), Project No. LA 27

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# About AIACC

Assessments of Impacts and Adaptations to Climate Change (AIACC) enhances capabilities in the developing world for responding to climate change by building scientific and technical capacity, advancing scientific knowledge, and linking scientific and policy communities. These activities are supporting the work of the United Nations Framework Convention on Climate Change (UNFCCC) by adding to the knowledge and expertise that are needed for national communications of parties to the Convention.

Twenty-four regional assessments have been conducted under AIACC in Africa, Asia, Latin America and small island states of the Caribbean, Indian and Pacific Oceans. The regional assessments include investigations of climate change risks and adaptation options for agriculture, grazing lands, water resources, ecological systems, biodiversity, coastal settlements, food security, livelihoods, and human health.

The regional assessments were executed over the period 2002-2005 by multidisciplinary, multi-institutional regional teams of investigators. The teams, selected through merit review of submitted proposals, were supported by the AIACC project with funding, technical assistance, mentoring and training. The network of AIACC regional teams also assisted each other through collaborations to share methods, data, climate change scenarios and expertise. More than 340 scientists, experts and students from 150 institutions in 50 developing and 12 developed countries participated in the project.

The findings, methods and recommendations of the regional assessments are documented in the *AIACC Final Reports* series, as well as in numerous peer-reviewed and other publications. This report is one report in the series.

AIACC, a project of the Global Environment Facility (GEF), is implemented by the United Nations Environment Programme (UNEP) and managed by the Global Change SysTem for Analysis, Research and Training (START) and the Third World Academy of Sciences (TWAS). The project concept and proposal was developed in collaboration with the Intergovernmental Panel on Climate Change (IPCC), which chairs the project steering committee. The primary funding for the project is provided by a grant from the GEF. In addition, AIACC receives funding from the Canadian International Development Agency, the U.S. Agency for International Development, the U.S. Environmental Protection Agency, and the Rockefeller Foundation. The developing country institutions that executed the regional assessments provided substantial in-kind support.

For more information about the AIACC project, and to obtain electronic copies of AIACC Final Reports and other AIACC publications, please visit our website at www.aiaccproject.org.

# Summary Project Information

### Regional Assessment Project Title and AIACC Project No.

Climate Change/Variability in the Mixed Crop/Livestock Production Systems of the Argentinean, Brazilian and Uruguayan Pampas: Climate Scenarios, Impacts and Adaptive Measures (LA 27)

### Abstract

The Pampas (central Argentina, southern Brazil and Uruguay) constitute a major food producing region of the world. The objective of the proposed research was to establish, use and maintain an agricultural systems network in the Pampas to assess the impact of climate change/variability and explore adaptive responses for the mixed grain/livestock production systems.

The observed climate data revealed increases in the rainfall (especially in the summer and spring), decreases in summer maximum temperatures, and increases in the minimum temperatures throughout the year. During our study period (1930 – 2000) the frost regime became milder: frosts start later, end earlier and their temperatures are usually higher.

Climate change scenarios were created using two methods: (a) projecting the trends observed in climate in the last 70 years using a weather generator (LARS), and (b) using a GCM (Hadley center -HADC). The climate scenarios projected with the two methods used in this study were considerably different. In both cases rainfall increased (especially in spring and summer) but LARS projected changes that were much larger than HADC. Both methods projected increases in minimum temperatures, but opposite results in maximum temperatures.

Linking the climate scenarios with crop and pasture simulation models, we assessed the impacts of climate change scenarios on annual crops and pastures, and explored adaptive measurements better adjusted to expected future climate scenarios. Soybean was greatly benefited under the enhanced $CO_2$ environment and the climatic conditions projected for HADC for 2020, 2050 and 2080. The impact of the climate change scenarios used in our study on the sown pastures of the Pampas was much smaller than the one observed for annual crops. In all studied locations a wheat disease (*Fusarium* head blight) was greater under the climate change scenario than in the historical weather.

Finally, we tested the ability of incorporating South Atlantic Ocean (SAO) surface temperatures to improve applications of ENSO-based seasonal rainfall forecasts in agriculture. Warm SAO anomalies in August and September were consistently associated with mean or high maize yield levels, even under La Niña or Neutral years. Complementing ENSO phases with SAO information led to increase the economic value of ENSO-based climate forecast by 5.

### Administering Institution

Instituto Nacional de Investigación Agropecuaria (INIA), Andes 1365 Piso 12, Montevideo, Uruguay

### Participating Stakeholder Institutions

Ministerio de Ganadería, Agricultura y Pesca (MGAP) Uruguay; FUCREA (Federación Uruguaya de grupos CREA), Uruguay; ARU (Asociación Rural del Uruguay); FRU (Federación Rural del Uruguay); AGROTERRA (agricultural inputs and grain export) Uruguay; COOPAGRAN (Cooperativa Agropecuaria Nacional) Uruguay; Grupo de Trabajo de Seguros Agropecuarios (MGAP) Uruguay; AACREA (Argentina); APRESID (Argentina); Federación de Acopiadores de Granos (Argentina); ACA (Asociación de Cooperativas Argentinas); Bolsa de Cereales, Argentina; Fundación Producir Conservando, Argentina; Interlink Sur Biotechnologies, Argentina; PRODEFER (Proyecto Federal de Apoyo al Desarrollo Rural Sustentable) (Argentina); SAGPyA (Secretaría de Agricultura, Ganadería, Pesca y Alimentos) (Argentina); Cooperativas do Sul Brasil, Brazil; and FUNDACAO ABC, Brazil.

### Countries of Primary Focus

Argentina, Brazil and Uruguay

**Case Study Areas**

Argentinean, Brazilian and Uruguayan Pampas

**Sectors Studied**

Mixed crop-livestock production systems

**Systems Studied**

Regional Economy and Food Production

**Groups Studied**

Commercial cereal / livestock producers

**Sources of Stress and Change**

Changes in mean seasonal climate; changes in seasonal climate variability; and technological change

**Project Funding and In-kind Support**

AIACC: US$ 274,370; INTA: US$ 70,500; INIA: US$ 138,500; and EMBRAPA: US$ 53,400

**Investigators**

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# Executive Summary

## Research problem and objectives

A long history of collaborative research exists in the study region. Numerous studies have been conducted to assess the impacts of interannual climate variability and long-term climate change on agriculture. Recent studies were oriented to develop applications of seasonal climate forecasts for the agricultural sector.

National agricultural research centers in the Pampas have been developing and establishing decision support systems for the agricultural sector, which consider information on climate variability. In order to benefit from decision aid tools, stakeholders must possess flexibility to change their management practices in response to the improved information. For that reason, activities in the region have been aimed at specifying alternative management options that are feasible and reasonable from the perspective of stakeholders. Research in the Pampas has been focused on crop production decisions that are sensitive to possible future climatic conditions and simulation models are being used to identify optimal management. The selected optimal options are also allowing the estimation of the efficacy and value of climate forecasts, and identifying options for decision makers.

A common characteristic of all these studies is that they have been oriented to identify agronomic practices that could reduce potential negative impacts of climate change and variability on crop production (e.g., sowing dates, cultivar characteristics, fertilizer use, etc.). However, no research has been conducted to assess the impact of climate change and climate variability on the pasture component of the mixed systems of the Pampas, where crops and livestock production are integrated in the same farm.

Crop/livestock (mixed) systems are the most economically important livestock systems in Latin America. The entire crop production in Uruguay is integrated with livestock: farming systems in the cropped areas include a rotation with 3-4 years of annual crops and 3-4 years of sown pastures utilized for beef, milk and wool production. The Argentinean Pampas region can be divided into three sub-regions with different farming systems: one mainly used for annual crop production (N of Buenos Aires, S of Santa Fe and SE Cordoba) covering 7.5 million ha; a second one used mainly for livestock production (Salado river basin) with 9.5 million ha; and a third sub-region with mixed crop-livestock systems which covers 38 million ha. The latter includes the largest proportion of the animal population of the Argentinean Pampas region (24.3 million cattle out of a total of 34.2 million heads).

The mixed production systems of the Pampas are characterized by mild climatic conditions, which can allow for annual double cropping, fertile (although often degraded) soils, and the co-existence of livestock and annual crops in the same farm. These characteristics provide farmers with very high flexibility for modifying management practices to better adapt to climate variability and climate change. On the other hand, that same flexibility results in a huge challenge from the research methodology stand point since the tools to improve planning and decision making must consider a very wide range of possible activities, mixes and interactions.

The objective of the proposed research was to further develop capacity and to establish, use and maintain an agricultural systems network in the Pampas to assess the impact of climate change/variability and develop adaptive responses for the mixed grain/livestock production systems.

## Approach

The premise of the proposed research is that an effective way for assisting agricultural stakeholders to be prepared and adapt to possible climate change scenarios consists of helping them to better cope with current climate variability. One of the advantages of this approach is that it provides immediate assistance to the public and private agricultural sector: in addition to preparing stakeholders to possible future climate scenarios, it helps them to manage the existing climate variability that is affecting current agricultural systems.

Our research activities integrated crop and pasture simulation models with climate change scenarios to assist planning and decision-making at the farm level. The developed system was used to assess the impacts of climate change/climate variability on farmers' income and to study the vulnerability of different components of the mixed production systems. The system developed in the current project can now be used to identify whole-farm adaptive measurements for global climate change scenarios and impact assessment of policy decisions.

# Scientific findings

## Climate Change Scenarios

The regression analyses performed on the 1930-2000 climate data, and the comparison of 1931-1960 vs. 1970-2000, revealed increases in the rainfall (especially in the summer and spring), decreases in maximum temperatures in the summer (and no change in the rest of the seasons), and increases in the minimum temperatures throughout the year.

The absolute maximum temperatures in 2000, in the sites showing significant changes were on the average 4.3ºC higher than in 1930 (range: 1.5 to 12.3ºC). The absolute minimum temperatures increased an average of 1.9ºC (range: 0.9 to 3.5ºC) during the period 1930 – 2000. These changes were only observed in Argentinean and Uruguayan locations while no changes were seen in the Brazilian sites.

Throughout our period of study (1930 – 2000) the frost regime became milder: frosts start later, end earlier and their temperatures are usually higher. These changes were only evident in some Argentinean and Uruguayan sites, while no changes were observed in the Brazilian locations.

The climate scenarios projected with the two methods used in this study were considerably different. In both cases rainfall increased (especially in spring and summer) but LARS projected changes that were much larger than HADC. Both methods projected increases in minimum temperatures, but opposite results in maximum temperatures (LARS resulted in decreased values in the summer and no changes in the rest of the year, and HADCD projected increases throughout the year)

## Impacts and Vulnerability

The increased temperature expected with the climate change scenarios used in our study would result in shorter growing seasons and consequently in lower soybean and maize grain yields. However, this negative impact could be greatly mitigated by adjusting the crop sowing time to earlier dates. Once the sowing date is adjusted, the increased expected rainfall during the maize and soybean growing season and the expected direct $CO_2$ effects on soybeans results in increased grain yields for all future scenarios simulated by HadCM3.

According to these results soybean would greatly benefit under the enhanced $CO_2$ environment and the climatic conditions projected for HadCM3 for 2020, 2050 and 2080 for SRES A2 and B2 scenarios. However, crop responses to $CO_2$ enrichment under field conditions are yet not fully understood. Most of experiments have been carried out in controlled or semi-controlled conditions and there are still uncertainties related to interactions among crops, weeds, pests, water, nutrients, etc. under climate change.

However, the expected direct effects of $CO_2$ on crops in the long term are still uncertain. Research over the last few years has suggested that the initial stimulation of photosynthesis observed when plants grow at elevated $CO_2$ may be counterbalanced by a long-term decline in the level and activity of photosynthetic enzymes as the plants acclimate to their environment, an event referred to as 'down-regulation' which is not included in the crop models that we used in our study.

The impact of the climate change scenarios used in our study on the sown pastures of the Pampas was much smaller than the one observed for maize and soybeans. Two likely explanations for this differential behavior are: (a) pastures grow throughout the entire year and during 3 or 4 consecutive years (annual crops grow for 4-5 months) and this much longer growing period could allow for some "buffering" capacity for reacting to possible unfavorable climate conditions; and (b) the harvested yield in annual crops, is the result of a reproductive stage (flowering, grain filling, etc.) while in the case of the pastures, the harvested yield corresponds to the vegetative growth (total biomass

In all studied locations *Fusarium* head blight was greater under the climate change scenario than in the historical weather. The highest risk index of FHB was probably due to the presence of more rainy days during September-November period in the climate change scenario. If confirmed, this would have a significant impact on wheat production and mycotoxin contamination for this part of the world

## Adaptation

### Adaptive measures for maize and soybeans

Considering increased $CO_2$ concentration, adaptive measures including optimal planting dates and nitrogen rates would result in maize mean yield increases of 14%, 23% and 31% for 2020, 2050 and 2080 respectively under SRES A2, and 11%, 15% and 21% respectively, over the same period, under SRES B2. The corresponding figures for mean soybean yields were: 35%, 52% and 63% for 2020, 2050 and 2080 respectively under SRES A2, and 24%, 38% and 47% respectively, over the same period under SRES B2.

In the case of current $CO_2$ concentrations, our results suggest that simple measures such as changes in planting dates or N rates in maize would not be sufficient to compensate for the losses in yields under climate change scenarios. When supplementary irrigation was applied, an overall yield increase was observed with changes in yield close to 20% under all scenarios. Soybean yields without any adaptation measures decreased under all scenarios (1-12%). Changing planting dates led to a weak increase in yields (2-9%) only for 2020 and 2050. The addition of supplementary irrigation strongly reverted this situation increasing yields between 30% (A2 2080) and 43% (A2 2020). Thus, our results suggest that rather simple adaptation measures for soybeans could be beneficial, even if $CO_2$ effects are not considered.

### Improving applications in agriculture of ENSO-based seasonal rainfall forecasts considering South Atlantic Ocean (SAO) surface temperatures

Upper quartile SAO anomalies in August and September were consistently associated with mean or high maize yield levels, even under La Niña or Neutral years.

Complementing ENSO phases with warm SAO led to the increase of the economic value of ENSO-based climate forecast by 5.4%.

Differences in optimal planting dates between El Niño and warm SAO years can be attributed to differences in rainfall distribution.

Results obtained in our research could contribute to improving the applications of ENSO-based seasonal forecasts.

# Capacity building outcomes and remaining needs

## Capacity building outcomes

New regional climate change scenarios locally adjusted via downscaled GCM runs for the region and through the use of statistical techniques (with a weather generator) were developed.

Crop and pasture models able to simulate the mixed crop/livestock production systems of the Pampas were calibrated and tested.

Climate scenarios and crop/pasture models were linked in a simulation platform useful for conducting scenario analyses of mixed crop/livestock systems and their responses to climate change/variability and management intervention.

An agronomic database characterizing the mixed crop/livestock production systems of the Pampas including soil information crop and pasture management practices and rotations was developed.

Links were established between the climate scientific community, agricultural researchers, agricultural practitioners and policy makers to improve the planning and decision making processes in the public and private agricultural sectors.

An established generic methodology was developed for developing agricultural systems networks that can be adapted to other environments and production systems for comparing possible adaptive responses at the farm and policy level against the background of a variable and changing climate.

A cadre of scientists was trained in the development and implementation of methodologies to address issues of vulnerability to climate for and thus assisting farmers and policy makers of the agricultural sector to improve their planning and make better management decisions.

## Remaining capacity building needs

Regional climate change scenarios locally adjusted via dynamically downscaled GCM runs for the region need to be developed.

Results of specific studies are required on the impact of climate and management practices in the mixed crop/livestock systems of the Pampas on crop, pasture and animal productivity levels and stability, the resource base (runoff and nutrient leaching), and the regional water resources

# National communications, science-policy linkages and stakeholder engagement

## National Communications, Science-Policy Linkages

The Uruguayan government completed the "Second National Communication of Uruguay" in 2004. AIACC's project LA 27 contributed to the National Communication with a section entitled: "Assessing the impacts of Climate Variability and Climate Change on the Mixed Crop-Livestock Systems of the Pampas in Argentina, Brazil and Uruguay".

### COP 10 Buenos Aires, December 2004

"Science in Support of Adaptation to Climate Change, Recommendations for an Adaptation Science Agenda and a Collection of Papers", Side Event of the 10th Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change: Walter E. Baethgen presented a paper entitled "Climate Change Adaptation and the Policy and Development Agendas of Developing Countries".

### IPCC Fourth Assessment Report

Working Group II: Chapter 13 (The Latin America Region) - Coordinating Leader Author: Graciela O. Magrin; Contributing Author: María I. Travasso; and Reviewer: Walter E. Baethgen.

Working Group II: Chapter 17 (Assessment of Adaptation practices, options, constraints and capacities) – Reviewer: María I. Travasso

## Stakeholder Engagement

### Uruguay

1st National Workshop AIACC. INIA Tacuarembo, Tacuarembo, Uruguay, June 30, 2004: To disseminate and discuss information about climate variability and climate change, and possible impacts in cattle beef production systems in Uruguay. More than 40 individuals from different stake holders and research organizations participated.

2nd National Workshop AIACC. INIA La Estanzuela, Colonia, Uruguay. August 18, 2004: To disseminate and discuss information about climate change results from the LA27 AIACC Project, and possible impacts in crop production in Uruguay. More than 100 individuals from different stakeholder and research organizations participated.

### Argentina

1st National Workshop AIACC, Federación Argentina de Acopiadores, Buenos Aires, Argentina, October 7, 2004: To disseminate information related to climate variability**. Participants included** members of Federación Argentina de Acopiadores, Bolsa de Cereales, Fundación Producir Conservando, Interlink Sur Biotechnologies.

2nd National Workshop AIACC, Bolsa de Cereales de la República Argentina, Buenos Aires, Argentina, October 27, 2004: To disseminate results obtained under AIACC activities related to changes occurred in climate during the last century and climate variability in the Pampas Region. Participants included more than 200 people, representing farmers associations, policy makers, agribusiness, and Secretary of Agriculture.

### Brazil

1st National Workshop AIACC, Secretaria da Agricultura do Rio Grande do Sul, Porto Alegre, Rio Grande, Brazil. October 7, 2004: To disseminate and discuss information about climate variability and climate change, and possible impacts in crop fields production in Southern Brazil. Participants included 30 individuals from different stake holder groups and research organizations.

# Policy implications and future directions

The results of our project on the expected impacts of climate change in the mixed systems of the Pampas are based on generated, possible future climate scenarios. These scenarios were generated using GCMs or projecting the observed trends in climate variables over the last century, and have an intrinsic large degree of uncertainty. All the communications (publications, presentations, discussions, etc.) resulting from the project activities to both, scientific audiences as well as to policy/decision makers have noted this uncertainty.

## Implications for Soybeans production

Our results suggest that by establishing rather simple adaptation measures soybean would be benefited by the projected climatic changes. The continuing expansion of this crop observed in the study area during the last few years could continue to put at risk the sustainability of the agricultural systems. Soybean is a high nutrient extractive crop with low level of crop residues, and therefore, the monoculture lead to negative nitrogen (N) and carbon (C) balances. The expansion of soybean monoculture raises concern and there is a need to establish management practices that help to preserve the natural resources such as adequate crop rotations (using grasses as cover crops and a higher proportion of corn and wheat in the rotation).

Other alternative measures could be related to the destination of crop production. Assuming that the trend to increase annual crop production will continue in the future, regardless of climate change, promoting the so called “transformation in origin” would to contribute to both, the sustainability of agricultural systems and economic returns. “Transformation in origin” means that a part of the production (for example of maize) remains at the place where it is produced and is used to feed animals or for local industry, adding value to the primary product. This contrasts, with the traditional sale of grain as a commodity, which often implies important costs of transportation to ports and fiscal retentions, among others. Assuming that half of the maize production is transformed in origin, economic benefits could be more than duplicated.

## Implications for the mixed annual crops / pastures systems

Our results also suggest that the pasture component of the mixed systems is much less affected by any of the climate change scenarios used in our research. Thus, in addition to the well-known risk reduction resulting from the diversification of a production system, the pastures would contribute to the system in two major ways: by decreasing the income variability under climate change scenarios, and by improving the C and N balances of the entire production system (as discussed above).

# 1 Introduction

Climate change is already affecting agricultural systems in several regions of the world. IPCC's Third Assessment Report (IPCC, 2001) includes a list of cases (including agro-ecosystems) in which there is sufficient scientific evidence of such effect. Societies, cultures and economies in the world's history have successfully developed by mastering their abilities to adapt to climatic conditions. However, the last decades have been characterized by a dramatic growth in human population that is imposing unprecedented pressures on natural ecosystems and on existing agricultural production systems. In addition to this pressure, societies are expected to face changes in climate at also unprecedented rate. Agricultural production systems will require effective adaptive strategies to overcome these expected pressures in the immediate future.

The Pampas constitute one of the major food producing regions of the world. Against the very unfavorable economic scenarios of the last decades, farmers in the region have been struggling to maintain their income by continuously trying to increase yields in their production systems. But these higher productive systems have often become more vulnerable to climate variability and climate change, and consequently, a large number of farmers and rural workers are being pushed to abandon the farms and migrate to metropolitan areas.

These existing pressures demand the development and implementation of methodologies to address issues of vulnerability to climate for assisting farmers and policy makers of the agricultural sector to improve their planning and make better management decisions. This proposal is oriented to address these issues by assessing the impacts of climate change on agricultural production at the farmer level, and by developing the capacity for determining best adaptive management practices to improve the agricultural systems performance.

A long history of collaborative research exists in the proposed region. Studies have been conducted to assess the impacts of expected long-term climate change on agriculture (e.g., Baethgen and Magrin, 1995; Baethgen, 1997, Magrin et al, 1997a, 1997b; Díaz et al, 1997, Magrin et al., 1998). More recently several research efforts were oriented to study the impacts of interannual climate variability and to develop applications of seasonal climate forecasts for the agricultural sector (e.g., Myneni et al., 1996; Baethgen, 1997, Baethgen, 1998, Baethgen, 1999; Podestá et al., 1999; Magrin et al., 1998; Magrin et al., 1999a; Magrin et al., 1999b; Travasso et al., 1999; Hansen et al., 1996; Messina et al., 1999).

National agricultural research centers in the Pampas are developing and establishing decision support systems for the agricultural sector which consider information on climate variability (Baethgen et al, 2001). In order to benefit from decision aid tools, stakeholders must possess flexibility to change their management practices in response to the improved information. For that reason, activities in the region have been aimed to specify alternative management options that are feasible and reasonable from the perspective of stakeholders. Research in the Pampas has been focused on crop production decisions that are sensitive to possible future climatic conditions and simulation models are being used to identify optimal management. The selected optimal options are also allowing the estimation of the efficacy and value of climate forecasts, and identifying options for decision makers. Following this approach, a number of activities have been conducted to evaluate the acceptance and value of ENSO-based climate forecasts for agricultural decision making (Magrin et al., 1999b; Travasso et al., 1999; Hansen et al., 1996; and Messina et al., 1999)

A common characteristic of all these studies is that they have been oriented to identify agronomic practices that could reduce potential negative impacts of climate change and variability on crop production (e.g., sowing dates, cultivar characteristics, fertilizer use, etc.). However, no research has been conducted to assess the impact of climate change and climate variability on the pasture component of the mixed systems of the Pampas, where crops and livestock production are integrated in the same farm.

Crop/livestock (mixed) systems are the most economically important livestock systems in Latin America (Von Kaufman, 1999). Mixed systems provide 50% of the world's meat and 90% of the world's milk, and employ 70% of the world's poor livestock producers (Thornton and Herrero, 2001). Regarding the proposed study region, the entire crop production in Uruguay is integrated with livestock. Farming systems in the cropped areas of Uruguay include a rotation with 3-4 years of annual crops and 3-4 years of sown pastures utilized for beef, milk and wool production. The Argentinean Pampas region can be divided into three sub-regions with different farming systems (SAGPyA, 2001): one mainly used for annual crop production (N of Buenos Aires, S of Santa Fe and SE Cordoba) covering 7.5 million ha, a second one used mainly for livestock production (Salado river basin) with 9.5 million ha, and a third sub-region with mixed crop-livestock systems which covers 38 million ha. The latter includes the largest proportion of the animal population of the Argentinean Pampas region (24.3 million cattle out of a total of 34.2 million heads).

Diversification of farming activities in space and time is a common strategy used to increase the stability of production systems in the Pampas (Viglizo et. al, 1989). Traditionally the mixed systems were based on crop-pasture rotations with varying proportion of the different components (pastures and crops) depending on the zone (Agromercado, 2000). During the early 1990's, favorable prices for grain crops caused an increase in cropped lands in Argentina (Basualdo, 1995) and shorter duration of the pasture component, resulting in increased threats of soil degradation.

The mixed production systems of the Pampas are characterized by mild climatic conditions which can allow for annual double cropping, fertile (although often degraded) soils, and the co-existence of livestock and annual crops in the same farm. These characteristics provide farmers with very high flexibility for modifying management practices to better adapt to climate variability and climate change. On the other hand, that same flexibility results in a huge challenge from the research methodology stand point since the tools to improve planning and decision making must consider a very wide range of possible activities, mixes and interactions.

Crop/livestock systems of the Pampas are very variable in complexity, they include a large number of interactions, they are cyclic in nature, and they include resource competition as a key issue. The only realistic way to assess the impact of climate variability and climate change in these systems, and to explore adaptive strategies is through the development of a generic conceptual framework for modeling crop/ livestock systems.

The objective of the proposed research is to further develop capacity and to establish, use and maintain an agricultural systems network in the Pampas to assess the impact of climate change/variability and develop adaptive responses for the mixed grain/livestock production systems.

Our research activities integrated crop and pasture simulation models with climate change scenarios to assist planning and decision-making at the farm level. The developed system was used to assess the impacts of climate change/climate variability on farmers' income and to study the vulnerability of different components of the mixed production systems. The system developed in the current project can now be used to identify whole-farm adaptive measurements for global climate change scenarios and impact assessment of policy decisions.

The premise used in our research is that one of the most effective manners for assisting agricultural stakeholders to be prepared and adapt to possible climate change scenarios is by helping them to better cope with current climate variability. One of the advantages of this approach is that it provides immediate assistance to the public and private agricultural sector: in addition to preparing stakeholders to possible future climate scenarios, it helps them to manage the existing climate variability that is affecting current agricultural systems.

The used methodology for developing the agricultural systems network for the Pampas is generic and can therefore be adapted to other environments and production systems, including the tropics where crop/livestock systems are the backbone of agricultural production.

# 2 Characterization of Current Climate and Scenarios of Future Climate Change

## 2.1 Description of Scientific Methods and Data

### 2.1.1 Current climate

A comprehensive database was constructed with monthly weather data. In the case of precipitation we used monthly data from 49 weather stations (26 from Argentina, 14 from Uruguay and 9 from Brazil) covering a region from latitude 27 south to 39 south, and from longitude 51 west to 64 west (Figure 1). All data covered the period January 1931 to December 2000, although some weather stations have data starting in the 1900's.

We performed the statistical analyses of the observed weather data of the entire available period as well as for two separate periods: 1931-1960 and 1971-2000. Using the software called SURFER we mapped the climatological values for each climate variable.

### 2.1.2 Changes in climate

#### 2.1.2.1 General trends in the 20th century observed data

For each one of the 49 weather stations we adjusted linear regression models of the observed rainfall (per month and per trimester) and studied the statistical significance (using the non-parametric Kendall test) of the obtained regression coefficients. We then kept only the regression coefficients that were significant at the 90% level and mapped the changes in monthly or trimester precipitation for the entire study region. The interpolation of the regression coefficients (monthly or trimester rainfall change in mm per year) to produce the map for the study region was performed using krieging. We performed similar analyses for monthly temperatures using 23 sites: 7 from Argentina, 13 from Brazil and 3 from Uruguay. Maps were then produced for each trimester (i.e., JFM, FMA, MAM, etc.) with the regression coefficients of changes in T Max, T Min and rainfall.

#### 2.1.2.2 Climate change scenarios

Given the uncertainties of climate change scenarios at regional and local levels, we used two different approaches to generate the climate change scenarios that were thereafter used with the crop/pasture simulation models.

**Method 1:**

In the first method, the changes observed between the periods 1930-1960 and 1970-2000 in temperatures and frost regime were used to develop a future climatic scenario using the LARS weather generator (WG) (Semenov et al. 1998). This analysis was based on the daily temperature data from 10 weather stations described above. LARS-WG is a stochastic weather generator that can be used for the simulation of weather data at single sites. Required input data are daily time-series of precipitation, maximum and minimum temperature and solar radiation. LARS-WG calculates a set of statistical properties of the used database, creates empirical distributions and generates daily weather datasets.

The simulation of precipitation occurrence is modeled as alternate wet and dry series, where a wet day is defined to be a day with precipitation > 0.0 mm. The length of each series is chosen randomly from the wet or dry semi-empirical distribution for the month in which the series starts. In determining the distributions, observed series are also allocated to the month in which they start. For a wet day, the precipitation value is generated from the semi-empirical precipitation distribution for the particular month independent of the length of the wet series or the amount of precipitation on previous days. Daily minimum and maximum temperatures are considered as stochastic processes with daily means and daily standard deviations conditioned on the wet or dry status of the day. Separate semi-empirical distributions are used to describe solar radiation on wet and dry days. Solar radiation is modeled independently of temperature.

The semi-empirical distribution Emp= { a0, ai; hi, i=1,….,10} is a histogram with ten intervals, where ai-1 < ai, and hi denotes the number of events from the observed data in the i-th interval. Random values from the semi-empirical distributions are chosen by first selecting one of the intervals (using the proportion of events in each interval as the selection probability), and then selecting a value within that interval from the uniform distribution. The intervals [ai-1, ai) are chosen based on the expected properties of the weather variables.

The LARS-WG was used to characterize the two study periods (1930-1960 and 1970-2000) by calculating statistical properties and developing the semi-empirical distributions of the observed data in each period. The trends found in the changes of those properties were used to create a synthetic set of statistical properties that were thereafter used to generate weather datasets representing possible climate scenarios for the next 10-20 years.

**Method 2:**

This method was based on the runs of a GCM developed by the Hadley Center (HadCM3). HadCM3 runs were obtained for one IPCC socioeconomic scenario for future greenhouse gas emissions (SRES) identified as A2.

GCM projections were obtained for the six sites in the region. The spatial resolution of the HadCM3 climate scenarios is 2° latitude by 2° longitude. Once the grid cell containing each one of the six sites was selected, monthly climatic values (maximum and minimum temperature and precipitation) for 2030 were extracted and the rate of change of each variable was obtained by comparison with the GCM climatology (base period 1960-1990). The n, these coefficients of change were applied to the observed data (1971-2000) to obtain the future climatic scenario on a daily basis.

#### 2.1.2.3 Changes in temperatures and in the frost regime during the last century

Daily temperature data for the period 1930-2000 was obtained from 10 weather stations: 5 from Argentina (Azul, Cordoba, Pergamino, Santa Rosa and Tres Arroyos), 2 from Brazil (Passo Fundo and Pelotas) and 3 from Uruguay (La Estanzuela, Mercedes and Paysandú) (Table 1). The daily data was used to study the changes in absolute maximum and minimum temperatures, and in the frost regime. Simple linear regression models were adjusted to absolute maximum and minimum temperatures, dates of the first and last frost (defined as temperatures at 2m lower than 2ºC), number of days with frost and average temperature of frosts.

Analyses were also performed for two thirty-year periods (1930-1960 and 1970-2000) to study the changes in the same variables as above. Differences between periods were analyzed by trimester and the Wilcoxon test (Wilcoxon, 1945) was used for identifying significant differences.

## 2.2 Results

### 2.2.1 Changes in climate

#### 2.2.1.1 General trends in the 20th Century observed data

The changes in precipitation and in temperatures were most evident during the austral Summer and Spring months. In these seasons, precipitation throughout the region usually increased, maximum temperature usually decreased and minimum temperature usually increased. Our results also show that changes in precipitation and in maximum temperature were more evident in the western region of the Pampas in Argentina which coincides with previous published work. (Figure 2). The regression coefficients (ºC year$^{-1}$) for maximum and minimum temperatures of moving trimesters in the period 1930-2000 are presented in Table 2 and 3, respectively.

### 2.2.1.2 Changes in extreme temperatures and in the frost regime during the last century

The frost regime (dates of first and last frost, number of days with frost, and temperature of the days with frost) is crucial for the agricultural production systems. In many cases optimal planting dates of annual crops are defined considering the chances of avoiding the coincidence of critical growth stages (e.g. flowering) with the frost period. When late frosts occur in the Pampas coinciding with the flowering of wheat or barley crops (September-October, depending on the location) both, crop yields and grain quality is drastically affected. Regarding the livestock production systems of the Pampas, which are based on a mixture of annual and perennial summer and winter grasses and legumes, the occurrence of the first frost results in the death of all the summer species. From that time and until the following spring the pasture production is almost exclusively dependent on the winter species.

On the other hand, the frost period also affects the crop, pasture and animal diseases. In the absence of frosts, many pathogens survive throughout the year and can result in higher disease pressures for plants and animals in the following spring.

The changes observed in the frost regime of our study region in the period 1930-2000 are shown in Table 4. The date of the first frost changed in 4 of the 10 studied sites (3 in Argentina and one in Uruguay). The regression model estimates indicate that the frost period in 2000 start 18 to 33 days later than in the 1930's. The dates of the last frost changed in 5 of the 10 sites (the same 3 Argentinean sites and one additional site in Uruguay), and the regression estimates show that the frost period in 2000 ends 22 to 35 days earlier than in 1930. Consequently, the duration of the frost period became 28 to 68 days shorter in 2000 as compared to 1930. Examples of the changes observed in two sites (one in Argentina and one in Uruguay) are shown in Figure 5.

Also, comparing the year 2000 with 1930, there were 13 to 26 less days with frost (i.e., days with air temperatures at 2m below 2oC within the frost period), and the mean temperature of those frost days was 0.3 to 0.5 higher (with one exception in a Uruguayan site where temperature was lower).

Thus, the results show that throughout our period of study (1930 – 2000) the frost regime became milder: frosts start later, end earlier and their temperatures are usually higher. These changes were only evident in some Argentinean and Uruguayan sites, while no changes were observed in the Brazilian locations.

Extreme temperatures (absolute TMax and absolute TMin) are also important for agricultural production systems. Both, very high TMax and very low TMin can strongly affect the development and growth of crops and pastures and result in important productivity losses. The comparison of the extreme temperatures in our study showed similar trends to the ones observed in the monthly mean values (Table 5). Hence, in the year 2000 the absolute TMax in the sites showing significant changes was on the average 4.3oC higher than in 1930 (range: 1.5 to 12.3oC). Also, the absolute TMin increased an average of 1.9oC (range: 0.9 to 3.5oC) during the period 1930 – 2000. These changes were only observed in Argentinean and Uruguayan locations while no changes were seen in the Brazilian sites.

### 2.2.1.3 Climate change scenarios

The obtained climate change scenarios were very different for the two methods used in the current study. The Hadley center GCM (HADC) projected changes in precipitation that were much smaller than the ones resulting from the use of LARS weather generator (LARS) based on continuing the trends of observed climate in the last 70 years (Figure 3). The differences between future rainfall scenarios varied for the different sites of the study region, but in general rainfall projected by LARS was higher than the corresponding to HADC in all seasons except for the Austral winter (JAS) where both methods predicted very small change (Figure 3a).

The scenarios of minimum temperatures projected with the two methods were similar except for the fall months (AMJ) where HADC projected higher temperatures (Figure 3b). The results of maximum temperatures were much more conflicting: HADC projected increases throughout the year, while LARS projected important decreases in the summer months and no changes in the other three seasons (Figure 3c). The results of maximum temperature obtained with LARS are more consistent with the rainfall results: higher rainfall during the summer months usually results in lower maximum temperatures (due to higher cloudiness). The HADC results are more difficult to interpret, since they show some increment in the summer rainfall and increases in the maximum temperatures.

Examples of the variability found in the three variables for the different sites of the study region are presented in Figure 4 a, b and c. The complete analysis for maximum and minimum temperature changes in all sites are listed in Table 6.

## 2.3 Conclusions

- The regression analyses performed on the 1930-2000 climate data, and the comparison of 1931-1960 vs. 1970-2000, revealed increases in the rainfall (especially in the summer and spring), decreases in maximum temperatures in the summer (and no change in the rest of the seasons), and increases in the minimum temperatures throughout the year.
- The absolute maximum temperatures in 2000 in the sites showing significant changes was on the average 4.3ºC higher than in 1930 (range: 1.5 to 12.3oC). The absolute minimum temperatures increased an average of 1.9oC (range: 0.9 to 3.5oC) during the period 1930 – 2000. These changes were only observed in Argentinean and Uruguayan locations while no changes were seen in the Brazilian sites.
- Throughout our period of study (1930 – 2000) the frost regime became milder: frosts start later, end earlier and their temperatures are usually higher. These changes were only evident in some Argentinean and Uruguayan sites, while no changes were observed in the Brazilian locations.
- The climate scenarios projected with the two methods used in this study were considerably different. In both cases rainfall increased (especially in spring and summer) but LARS projected changes that were much larger than HADC. Both methods projected increases in minimum temperatures, but opposite results in maximum temperatures (LARS resulted in decreased values in the summer and no changes in the rest of the year, and HADCD projected increases throughout the year)

# 3 Impacts and Vulnerability

## 3.1 Activities Conducted

The activities on "Impacts" consisted of assessing the expected crop grain yields and pasture production for the different climate change scenarios, using simulation models, in six sites of the study region. We also used a model that simulates disease dynamics to study the changes expected in the incidence of a wheat disease (Fusarium) in the study region for the different climate change scenarios.

## 3.2 Description of Scientific Methods and Data

### 3.2.1 Sites

We selected six sites in the region representing areas with contrasting environmental conditions (from the humid subtropics in southern Brazil to the humid and semiarid Pampas): Azul (AZ, 36.78S; 59.85W), Pergamino (PE, 33.90S ; 60.58W), Santa Rosa (SR, 36.62S; 64.28W) and Tres Arroyos (TA, 38.37S; 60.27W) in Argentina; La Estanzuela (LE, 34.33S; 57.68W) in Uruguay and Passo Fundo (PF, 28.26S; 52.41W) in Brazil.

### 3.2.2 Climate scenario

Future climate scenarios were established using two methods: (a) using the LARS weather generator (Semenov et al. 1998), where changes observed between 1930-1960 and 1970-2000 in rainfall and temperatures were used to develop a future climatic scenario, and (b) based on the runs of a GCM developed by the Hadley Center (HadCM3). HadCM3 runs were obtained for two IPCC socioeconomic scenarios for future greenhouse gas emissions (SRES) identified as A2 and B2. GCM projections were obtained for the six sites in the region. The spatial resolution of the HadCM3 climate scenarios is 2° latitude by 2° longitude. Once the grid cell containing each one of the six sites was identified, monthly climatic values (maximum and minimum temperature and precipitation) for three time periods (2020, 2050 and 2080) were extracted and the monthly rate of change of each variable was obtained by comparison with the GCM climatology (base period 1960-1990). Then, these coefficients of change were applied to the daily observed data (1971-2000) to obtain the future climatic scenario on a daily basis.

### 3.2.3 Crop simulation models

Crop simulation models included in DSSAT (Tsuji et al, 1994) were used in each of the six sites to assess the expected impacts of climate scenarios on crops yields (CERES for maize and CROPGRO for soybean) as well as to evaluate the impact of some adaptive measures. The crop models that integrate DSSAT (including CERES and CROPGRO) are detailed biological simulation models of crop growth and development that operate on a daily time step. The models simulate dry matter production as a function of climate conditions, soil properties and management practices. The dry matter produced on any given day is partitioned between the plant organs that are growing at that time. Crop development in DSSAT models is driven by the accumulation of daily thermal time or degree days. The inputs required to run the models are daily weather variables, management information (planting date, fertilizer use, irrigation, etc.), cultivar characteristics and soil profile data. Output from the models includes final grain yield, total biomass, and biomass partitioning between the different plant components at harvest.

Model inputs used in our study, including initial water and nitrogen content in the soil profile, date of planting, plant density, sowing depth, date and rate of fertilizers application and cultivars were defined according to the typical conditions and farmer practices in each site. Climatic inputs for the crop simulation models included observed daily maximum and minimum temperatures, precipitation and solar radiation corresponding to the period 1971-2000 and the climate change scenarios obtained as described above. Crop models were run under rainfed and irrigated conditions for different atmospheric

$CO_2$ concentrations: 330 ppm (current) and those corresponding to each SRES scenario (A2, B2) and time period ( 2020, 2050, 2080), according to IPCC (2001). Adaptive management practices included in the analyses were changes in the planting dates for maize and soybeans, and in nitrogen rates for maize.

### 3.2.4 Pasture simulation model

Simulations for the pasture component in the mixed crop/livestock systems) were carried out using the CENTURY model developed in the Natural Resource Ecology Laboratory (NREL) of Colorado State University (Parton et al, 1987). The CENTURY model simulates the long-term dynamics of carbon (C), nitrogen (N), phosphorus (P), and sulfur (S) for different plant-soil systems. The model can simulate the dynamics of grassland/pasture systems, agricultural crop systems, forest systems, and savanna systems. The grassland/pasture system has a plant production submodel that is linked to the soil organic matter submodel. The soil organic matter submodel simulates the flow of C, N, P, and S through plant litter and the different inorganic and organic pools in the soil. The model runs using a monthly time step and the major input variables for the model include:

(1) Monthly average maximum and minimum air temperature,

(2) Monthly precipitation,

(3) Lignin content of plant material,

(4) Plant N, P, and S content,

(5) Soil texture,

(6) Atmospheric and soil N inputs, and

(7) Initial soil C, N, P, and S levels.

The CENTURY model includes a simplified water budget model, which calculates evaporation and transpiration, water content of the soil layers, and saturated flow of water between soil layers. The grassland/crop production submodel in CENTURY simulates plant production for different herbaceous crops and plant communities (e.g. warm or cool season grasslands, sown pastures, improved pastures, etc.). Existing crop or pasture options may be altered to suit particular varieties, mixes of pasture species or environments. The effects of harvest, grazing, fire, fertilization and cultivation on the aboveground biomass are all considered in the model, as well as the impacts of grazing and fire on root to shoot ratios and nutrient content. CENTURY's plant production models assume that the monthly maximum plant production is controlled by moisture and temperature and that maximum plant production rates are decreased if there are insufficient nutrient supplies (the most limiting nutrient constrains production).

The CENTURY model has been successfully calibrated, tested and applied in Uruguay with sown pastures (mixtures of grasses and legumes), with natural grasslands and with improved pastures (surface broadcasted legumes and phosphorous fertilizers), which are key components of the mixed crop-livestock production systems of the Pampas (Andregnette and Baethgen, 2004).

### 3.2.5 Wheat disease model

We studied the expected changes in the "head blight" wheat disease was conducted by linking a wheat simulation models (DSSAT, same as above) with a disease simulation model (GIBISM). The GIBSIM model used in the present study is a modified version of a model previously developed (Del Ponte et al. – unpublished). The original model starts by the time of emergence of the first group of heads, which is simulated in the wheat model. The daily proportion of heads emerged is a function of the heading rate. Anther's extrusion rate calculates the daily proportion of extruding anthers in a cohort of heads. The coupling of both heading and flowering models results in the daily proportion of exposed anthers in the field . Empirical rules define anther longevity. Inoculum is assumed to be present on the residues. The density of an airborne *G. zeae* spore cloud is a function of the dispersal rate. Infections take place during an infection event which is defined by means of a combination of daily records of rainfall and mean relative humidity in a two-day window. Infection rate is a function of mean temperature during each infection event. Empirical rules were defined to take into account potential infections up to 14 days after flowering. The daily risk index is the product of the proportion of susceptible tissue, infection rate and spore cloud density. Final risk is calculated by the summation of partial indices. Rates and rules in the models are influenced by weather variables as daily mean temperature, daily mean relative humidity, daily solar radiation, precipitation, and consecutive rainy days. The model evaluation with disease data from 5 years of epidemics in Passo Fundo, Brazil, showed that risk estimated by model explained over 95% of variation in disease field severity (unpublished).

In the present study adjustments were made in the original model in order to use weather dataset without information of relative humidity. Hence, infections events are defined by means of observations of rainfall (>0,5mm) in a two-day window. Hence, daily risk index is the product of the proportion of susceptible tissue and infection rate.

Epidemics risks were investigated using nine planting dates for each year from 1970 to 2000 and from a 30 year scenario, respectively. Climate change scenarios were originated from trends observed in the daily climate records from Passo Fundo, La Estanzuela and Pergamino for the 1970-2000 period.

## 3.3 Results

### 3.3.1 Climate scenarios

The SRES A2 scenario, which assumes higher $CO_2$ concentration than SRES B2, led to larger increases in temperature and precipitation, particularly for 2050 and 2080 (Tables 7 and 8). Increases in mean temperature for the warm semester (October-March) ranged from 0.8ºC to 4.1ºC in SRES A2 and 0.7ºC to 2.9ºC under SRES B2 depending on site and time period (Table 7). Precipitation increased 253mm and 172mm for SRES A2 and B2 respectively during the warm semester (October-March), and decreased 46mm and 34mm for SRES A2 and B2 respectively, during the coldest months (May-Aug, Table 8). These changes in precipitation were more consistent in the climate model runs for the 2050 and 2080 time periods

### 3.3.2 Impacts of expected climate scenarios on crop yields

Under LARS scenario and with current $CO_2$ wheat yield changes were positive in SR, decreased in PE and remained almost constant in the other sites, while for maize and soybean an overall yield increase was observed, averaging 21% and 27% respectively. Under increased CO2 , yield increases attained 15%, 29%, and 76% for wheat, maize and soybean.

Considering the climate scenarios obtained from the HADC GCM, irrigated maize yields decreased in almost all sites and scenarios when the direct effects of $CO_2$ were not considered (Table 9). Yield reductions were larger for the later time periods, and were stronger under SRES A2 (up to -23%). We found a significant correlation between maize yield changes and temperature increases during the crop growing season ($R^2 = 0.74$), resulting in a reduction of 5% in yields per ºC of temperature increase.

Irrigated soybean yields were less affected and varied between -8% and 5% (Table 9). The correlation between yield changes and temperature increases was weaker (R2 = 0.4) and the yield reduction was smaller (decreases of 1.8% in yields per ºC of temperature increase) than in maize.

When the direct CO2 effects were considered under irrigated conditions, the obtained maize yields were higher but the increase was insufficient to offset the temperature effects (Table 8). In contrast, huge increases in soybean yields were detected under both SRES scenarios (up to 43% and 38% for A2 and B2, respectively).

Under rainfed conditions and without considering the direct CO2 effects, maize yield changes under ranged between -9 and 9% for SRES A2, and -12 and 3%. for SRES B2. Rainfed soybean yield changes varied between -22% and 10.5% for SRES A2 and between -18 and 0.5 for SRES B2 (Table 9). When the direct effects of CO2 on the crops was taken into account, grain yield increased for both crops but a greater impact was observed in soybean (up to 62.5 %).

Under A2 scenario irrigated and rainfed soybean yields and rainfed maize yields were higher than current climate yields: the direct effects of the high concentration of CO2 and the higher Spring-Summer precipitation more than compensated for the negative effect of increased temperature. As expected, the changes in crop yield under B2 scenario were in the same direction of those under the A2 scenario but smaller in magnitude.

The differences in crop behavior can be attributed to the interaction between temperature and CO2 effects. In soybean (a C3 plant) CO2 effects on photosynthesis are greater than in maize (a C4 plant) (Derner et a., 2003). The soybean simulation model used in our research assumes a 40% increase of the photosynthesis efficiency at a CO2 concentration of 660 ppm, while the corresponding value for maize is only about 10%. Consequently, the obtained yields in irrigated maize crops are more dependent on the effect of temperature. On the other hand, the effect of CO2 on stomatal resistance is known to be higher in C4 than in C3 plants, contributing to higher water use efficiency in maize (Kimball et al, 2003).

### 3.3.3 Impacts of expected climate scenarios on crop phenology

Projected increases in temperature led to shortening crops growing seasons (Figure 5). For both crops the worst situation was found with highest temperature increases (A2, 2080). Impacts were much more important in maize, since the most affected phases were planting-flowering and flowering-maturity. Under A2 scenario and in 2080 maize crops growing season was reduced on average 27 days. In soybean the worst scenario resulted in growing seasons that were only 2 - 7 days shorter, mostly due to reductions in the planting-flowering period. The stronger shortening of the crop growing season observed in maize is coincident with the greater reductions in grain yields.

### 3.3.4 Impacts of expected climate scenarios on pasture production

The results of the simulated pasture yields for all climate scenarios included in our study (two periods of observed climate and two methods of generated climate change scenarios) were similar (Table 10). In all cases the maximum differences were less than 10%, with the exception of one site in Argentina (AR-TA) under one climate scenario.

These results suggest that the perennial sown pastures of the Pampas included in our study, are less sensitive than annual crops to the ranges of climate change with which we worked. One of the possible reasons for this behavior is that while crops have a few months to react to changes in climate for producing the grain yields, the perennial pastures grow for the entire year, and during three or four consecutive years. This much longer growing period could allow a greater “buffering” capacity as compared to the 4-5 months growing seasons of the annual crops. Furthermore, the harvested yield in annual crops, is the result of a reproductive stage (flowering, grain filling, etc.). In the case of the pastures, the harvested yield corresponds to the vegetative growth (total biomass). Thus, if we had used total biomass as the studied variable for the annual crops, it is very likely that the differences among climate scenarios would have also been smaller.

### 3.3.5 Impacts of expected climate scenarios on head blight disease in wheat

Fusarium Head Blight (FHB), is an important disease throughout much of the world’s wheat (Triticum aestivum L.) growing areas. Several Fusarium species can cause head blight, although Gibberella zeae Schwain (Petch.) (anamorph Fusarium graminearum Schwabe) is the predominant pathogen in most of the regions. Contamination of wheat with the mycotoxin Desoxinivalenol (DON) at levels exceeding the permitted levels results in rejection of sale or severe price dockage in countries that have adopted DON regulation

Our results showed that Fusarium head blight risk index in Passo Fundo, Brazil was higher than in La Estanzuela and Pergamino. In all locations Fusarium head blight was greater under the climate change scenario than in the historical weather. The results are shown in Figure 6. The highest risk index of FHB was probably due to the presence of more rainy days during September-November period in the climate change scenario. If confirmed, this would have a significant impact on wheat production and mycotoxin contamination for this part of the world.

## 3.4 Conclusions

The increased temperature expected with the climate change scenarios used in our study would result in shorter growing seasons and consequently in lower soybean and maize grain yields. However, this negative impact could be greatly mitigated by adjusting the crop sowing time to earlier dates. Once that sowing date is adjusted, the increased expected rainfall during the maize and soybean growing season and the expected direct $CO_2$ effects on soybeans resulted in increased grain yields for all future scenarios simulated by HadCM3.

According to these results soybean would be greatly benefited under the enhanced CO2 environment and the climatic conditions projected for HadCM3 for 2020, 2050 and 2080 for SRES A2 and B2 scenarios. However, crop responses to CO2 enrichment under field conditions are yet not fully understood. Most of experiments have been carried out in controlled or semi-controlled conditions and there are still uncertainties related to interactions among crops, weeds, pests, water, nutrients, etc. under climate change.

Even regarding only the expected direct effects of CO2 on crops in the long term is still uncertain. Thus, research of the last few years had suggested that the initial stimulation of photosynthesis observed when plants grow at elevated CO2 may be counterbalanced by a long-term decline in the level and activity of photosynthetic enzymes as the plants acclimate to their environment, an event referred to as 'down-regulation'. Recently published results from a field experiment that lasted more 14 years (Adam et al., 2004) with Citrus aurantius (sour orange), and included treatments of 400 and 700ppm CO2. indicated that in fact long-term CO2 enrichment can result in photosynthetic down-regulation in leaves of trees, even under non-limiting nitrogen conditions. Acclimation to CO2 enrichment, is not included in crop models that we used in our study.

The impact of the climate change scenarios used in our study on the sown pastures of the Pampas was much smaller than the one observed for maize and soybeans. Two likely explanations for this differential behavior are: (a) pastures grow throughout the entire year and during 3 or 4 consecutive years (annual crops grow for 4-5 months) and this much longer growing period could allow for some “buffering” capacity for reacting to possible unfavorable climate conditions; and (b) the harvested yield in annual crops, is the result of a reproductive stage (flowering, grain filling, etc.) while in the case of the pastures, the harvested yield corresponds to the vegetative growth (total biomass). Thus, if we had used total biomass as the studied variable for the annual crops, it is very likely that the differences among climate scenarios would have also been smaller.

Finally, in all studied locations Fusarium head blight was greater under the climate change scenario than in the historical weather. The highest risk index of FHB was probably due to the presence of more rainy days during September-November period in the climate change scenario. If confirmed, this would have a significant impact on wheat production and mycotoxin contamination for this part of the world.

# 4 Adaptation

## 4.1 Activities Conducted

The research activities in "Adaptation" consisted of (a) exploring crop management practices to adapt maize and soybean production to possible climate change scenarios, and (b) assessing the potential for improving applications in agriculture of ENSO-based seasonal rainfall forecasts considering Atlantic Ocean surface temperatures.

## 4.2 Description of Scientific Methods and Data

***Note:*** *Much of the methods, data sources and experimental sites included in this section have been described in Section 3 ("Impacts").*

### 4.2.1 Sites

For the work in crop management practices to adapt maize production to possible climate change scenarios we selected six sites in the region representing areas with contrasting environmental conditions (from the humid subtropics in southern Brazil to the humid and semiarid Pampas): Azul (AZ, 36.78S; 59.85W), Pergamino (PE, 33.90S ; 60.58W), Santa Rosa (SR, 36.62S; 64.28W) and Tres Arroyos (TA, 38.37S; 60.27W) in Argentina; La Estanzuela (LE, 34.33S; 57.68W) in Uruguay and Passo Fundo (PF, 28.26S; 52.41W) in Brazil.

For the work in assessing the potential for improving seasonal climate forecasts by considering sea surface temperatures from the Tropical Pacific and south Atlantic oceans we selected the Argentinean site "Azul".

### 4.2.2 Climate scenarios

Future climate scenarios were based on the runs of a GCM developed by the Hadley Center (HadCM3). HadCM3 runs were obtained for two IPCC socioeconomic scenarios for future greenhouse gas emissions (SRES) identified as A2 and B2. GCM projections were obtained for the six sites in the region. The spatial resolution of the HadCM3 climate scenarios is 2º latitude by 2º longitude. Once the grid cell containing each one of the six sites was identified, monthly climatic values (maximum and minimum temperature and precipitation) for three time periods (2020, 2050 and 2080) were extracted and the monthly rate of change of each variable was obtained by comparison with the GCM climatology (base period 1960-1990). Then, these coefficients of change were applied to the daily observed data (1971-2000) to obtain the future climatic scenario on a daily basis.

### 4.2.3 Seasonal climate forecasts

We compared different types of seasonal climate forecasts based on: a) ENSO phases (Neutral, El Niño and La Niña) based on the Japan Meteorological Agency classification; b) observed November-December-January (NDJ) rainfall divided in terciles; and c) South Atlantic Ocean SST anomalies (SAO).

For the observed NDJ rainfall terciles, we used smoothing techniques (Cleveland et al., 1988) for isolating the low frequency variability in monthly precipitation record. The anomalies (difference between observed and smoothed values) were then classified in terciles obtaining three rainfall categories: wet (upper tercile), normal and dry (lower tercile).

South Atlantic Ocean SST anomalies (SAO) (0-20ºS, 30ºW-10ºE) were obtained from NOAA through IRI's Data Library (http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/ NCEP/ .EMC/ .CMB/.GLOBAL/.Reyn_SmithOIv2/). We used the SAO values corresponding to August and September which are significantly related to maize yield in this location (Travasso et al., 2003). SAO anomalies were classified in quartiles and 3 categories were used: warm (warm SAO=upper quartile), neutral (between probability of 75 and 25%) and cold (cSAO=lower quartile).

### 4.2.4 Crop simulation models

The maize and soybeans simulation models included in DSSAT (Tsuji et al, 1994) were used in each of the six sites to assess the expected the impact of some adaptive measures. DSSAT includes detailed biological simulation models of crop growth and development that operate on a daily time step. The models simulate dry matter production as a function of climate conditions, soil properties and management practices. The dry matter produced on any given day is partitioned between the plant organs that are growing at that time. Crop development in DSSAT models is driven by the accumulation of daily thermal time or degree days. The inputs required to run the models are daily weather variables, management information (planting date, fertilizer use, irrigation, etc.), cultivar characteristics and soil profile data. Output from the models includes final grain yield, total biomass, and biomass partitioning between the different plant components at harvest.

Model inputs used in our study, including initial water and nitrogen content in the soil profile, date of planting, plant density, sowing depth, date and rate of fertilizers application and cultivars were defined according to the typical conditions and farmer practices in each site. Climatic inputs for the crop simulation models included observed daily maximum and minimum temperatures, precipitation and solar radiation corresponding to the period 1971-2000 and the climate change scenarios obtained as described above. The crop model was run under rainfed and irrigated conditions for different atmospheric $CO_2$ concentrations: 330 ppm (current) and those corresponding to each SRES scenario (A2, B2) and time period (2020, 2050, 2080), according to IPCC (2001). Crop models were run under rainfed and irrigated (water non limiting) conditions for different atmospheric CO2 concentrations: 330 ppm (current) and those corresponding to each SRES scenario (417, 532, 698 ppm for A2, and 408, 478, 559 ppm for B2 in 2020, 2050 and 2080 respectively) according to IPCC (2001). Adaptive management practices included in the analyses were planting dates and supplementary irrigation for maize and soybeans, and nitrogen rates for maize. In each site planting dates were tested by anticipating/delaying the actual ones. Supplementary irrigation was added during the reproductive period, starting 20 days before flowering at a rate of 20mm every 20 days. Incremental nitrogen rates where also tested for maize in all sites.

## 4.3 Results

### 4.3.1 Adaptive measures for maize and soybeans

#### 4.3.1.1 Increased $CO_2$ concentration

*Maize:* In general, advancing planting dates led to increase maize yields under both SRES scenarios, especially for 2050 and 2080, although there are differences among sites (Figure 8). Anticipating planting dates contributed to longer planting-flowering periods (Figure 7) and earlier maturity dates. This measure would allow maize crops to develop under more favorable thermal conditions and to take advantage of its sensitivity to photoperiod, increasing the vegetative phase duration (Figure 7) which would benefit grain number and hence crops yield. An additional advantage is related to the anticipation of crop maturity and therefore the harvest. Under current planting dates maize crops are usually harvested during March- April or later, depending on the zone. Expected future climatic scenarios are projecting important increases in rainfall for these months (see Table 8) and it could be constraining harvest security. It should be noted that the CERES model does not take into account this issue.

Regarding nitrogen fertilization, under expected future conditions and for the optimal planting dates nitrogen rates might increase in Passo Fundo and Santa Rosa. In summary, adaptation measures including optimal planting dates and nitrogen rates would result in mean yield increases of 14%, 23% and 31% for 2020, 2050 and 2080 under SRES A2, while under SRES B2 these figures would be 11%, 15% and 21%, respectively.

*Soybeans:* Although soybean was less affected than maize by temperature increases, changing planting dates resulted in higher yields. In three out of the six sites (AZ, SR, and PF) earlier planting dates resulted in higher yields while in the other sites the best option under future conditions would be to delay them (Figure 9). In summary, optimal planting dates would result in soybean mean yield increases of 35%, 52% and 63% for 2020, 2050 and 2080 under SRES A2, while under SRES B2 these figures would be 24%, 38% and 47%.

#### 4.3.1.2 Current $CO_2$ concentration

*Maize:* Under current $CO_2$ simulated yields decreased between 1 and 5% under all future scenarios. Optimal planting dates and N rates were the same as the ones mentioned above although yields response was different. Changes in maize yields were positive under all scenarios and time periods only in PF, SR and AZ. Inversely, in TA we obtained a generalized yield decrease, while in PE and LE we found both, positive and negative responses to nitrogen fertilizer depending on the scenario (Figure 10).

Mean changes for the six sites ranged between 4% (B2 2020) and 12% (A2 2050 and 2080).

These results suggest that without $CO_2$ fertilization simple measures such as changes in planting dates or N rates would not be sufficient in some places. When supplementary irrigation was applied an overall yield increase was observed with changes close to 20% under all scenarios (Figure 10).

*Soybeans*: Without any adaptation measure soybean yields decreased under all scenarios (1-12%). Changing planting dates led to a weak increase in yields (2-9%) only for 2020 and 2050 (Figure 11). The addition of supplementary irrigation strongly reverted this situation increasing yields between 30% (A2 2080) and 43% (A2 2020) (Figure 11). Thus, our results suggest that rather simple adaptation measures for soybeans would be beneficial, even if $CO_2$ effects are not considered.

### 4.3.2 Improving applications in agriculture of ENSO-based seasonal rainfall forecasts considering Atlantic Ocean surface temperatures

Climate uncertainties, derived from interannual climatic variability, often lead to conservative crop management strategies that sacrifice some productivity to reduce the risk of losses in bad years. The availability of ENSO-based climate forecast has led many to believe that such forecasts may benefit decision-making in agriculture. The forecasting capability may allow the mitigation of negative effects of ENSO-related climate variability as well as taking advantage of favorable conditions (Stern and Easterling, 1999).

Benefits of using ENSO-based climate forecast have been demonstrated in the region. Changing crop mix (Messina et al., 1999) or crop management options were proposed as adaptive measures to cope with climatic variability (Magrin et al.2000; Jones et al., 2000). However, the large inconsistency of the precipitation signal within ENSO phases lead to considerable overlap in yields and net returns for the various ENSO phases (Ferreyra et al., 2001), decreasing the potential usefulness of the forecast (Magrin and Travasso, 2001; Podestá et al., 2002)

ENSO is not the only source of climate variability in Southeastern South America. The influence of South Atlantic Ocean (SAO) on precipitation was evidenced for Uruguay and south Brazil by Díaz et al., (1998) and Barros et al. (2002) signaled the influence of the South Atlantic Convergence Zone (SACZ) on midsummer interannual variability of the low-level circulation and precipitation in subtropical South America. Recently Berri and Bertossa (2004) reported that the Atlantic Ocean influence seasonal precipitation over the northwestern and southeastern parts of Southern Central South America.

Furthermore, in previous works we found significant relationships between SAO SST anomalies and crop yields or precipitation anomalies in the Pampas. Comparing with SSTs from the Pacific, SAO SST's presented a stronger signal on crops yields in the southern part of the region, especially for maize (Travasso et al., 2003a,b).

These antecedents encouraged the consideration of SAO SST anomalies as a way to improve climate forecasting and decision making in agriculture. The aim of the work described in this section was to explore the capability of considering SAO by itself and in conjunction with ENSO phases, to optimize maize agronomic management practices and to assess the additional economic value of including SAO information in an ENSO-based seasonal forecast.

The cumulative probability for grain yields under the typical farmer management for the different climate predictions methods (precipitation terciles, ENSO, and SAO anomalies) are presented in Fig 12. The best method allowing to discriminate among yield categories was "precipitation terciles" (i.e., assuming a "perfect" forecast). The use of "ENSO phases" was useful only in the 50% of the years, while "SAO anomalies" clearly separated the highest yields.

This result suggests that maize yields are likely to be driven not only by the influence of ENSO phases but also by South Atlantic Ocean conditions. Figure 13 shows the relationship between maize yields and SAO temperature anomalies. Upper quartile SAO anomalies were consistently associated with mean or high yield levels, with only one exception. It is important to emphasize that our results suggest that even under La Niña or Neutral years, high or normal maize yields could be expected if SAO anomalies in August and September are higher than normal. However, with normal or low SAO anomalies yield behavior was erratic.

After these results we combined ENSO phases with SAO anomalies as an attempt to improve yield predictions. In Figure 14 maize yields were regrouped as La Niña (all La Niña years except those with warm SAO anomalies), Neutral (all Neutral years except those with warm SAO anomalies) and a third group including El Niño years plus warm SAO years. Because this combination seems to be a better approach to separate yields categories, we decided to consider it as a fourth climate forecasting method .

Optimal management options, grain yields and gross margins for each one of the considered climate forecast are summarized in Table 11. Expected yields in Azul averaged 7.70, 8.48, 8.18, 8.02 and 8.39 t ha-1 for most common farmer management and management optimized by rainfall terciles, ENSO, SAO and ENSO+warm SAO, respectively. For gross margin these figures were 140, 172, 155, 147, and 162 US$ ha-1.

Optimal crop management options for less favorable years (La Niña, Dry) resulted in later planting dates and lower N rates. For more favorable years (El Niño, Wet and warm SAO) higher N rates was a better option, although the optimal planting date differed among methods (Table 11). These differences in optimal crop management evidenced between El Niño and Warm SAO could be attributed to differences in their signal on precipitation. During El Niño years rainfall tends to be higher than normal in November-December (Barros et al., 1996; Magrin et al., 1998), while Warm SAO episodes are positively correlated with October-February precipitations (Travasso et. al,. 2003b ). Because maize crops are highly sensitive to water shortage during the preflowering-flowering period, for planting dates in mid October (like in El Niño years) water availability will be crucial during December, but late planting dates (warm SAO) will be more dependant on January rainfall. As shown in Fig 15 precipitation anomalies in Azul tended to be higher in January during the warm SAO years.

The economic value (EV) of forecast (Table 12) was obviously the best when considering precipitation terciles (22.9%). The EV for individual ENSO phases (10.5%) or SAO anomalies (5%) was considerable lower. However using ENSO forecast and taking into account warm SAO anomalies during August and September could significantly increase the incomes (15.9%). It is important to remark that in dry years the EV attained 90% while in the wets ones it ranged between 15 and 30% (Figure 16).

Variability in precipitation within an ENSO phase is one of the most important obstacles for forecast's adoption. For example, if dry conditions are expected during a given ENSO event but do not materialize (as happened in 1999-2000 in the western Pampas), cold events will not appear to be very salient or memorable. (Podestá et al., 2002). In this particular year, classified as La Niña according to Pacific conditions, SAO temperatures were significantly higher than normal and, as mentioned above, warm SAO is associated with positive rain/yield anomalies in the southern Pampas. Precipitations occurred in December, January and February in Azul were 25.0, 9.0 and 134.0 mm over the mean values.

Therefore combining both approaches (ENSO + SAO) could be promissory for improving the applications of ENSO-based seasonal forecasts in agriculture

## 4.4 Conclusions

### 4.4.1 Adaptive measures for maize and soybeans

- Considering increased $CO_2$ concentration, adaptive measures including optimal planting dates and nitrogen rates would result in maize mean yield increases of 14%, 23% and 31% for 2020, 2050 and 2080 under SRES A2, and 11%, 15% and 21%, under SRES B2. The corresponding figures for mean soybean yields were: 35%, 52% and 63% for 2020, 2050 and 2080 under SRES A2, under SRES B2 24%, 38% and 47%.
- In the case of current CO2 concentrations, our results suggest that simple measures such as changes in planting dates or N rates in maize and in some places, would not be sufficient to compensate for the losses in yields under climate change scenarios. When supplementary irrigation was applied an overall yield increase was observed with changes close to 20% under all scenarios. Soybean yields without any adaptation measures decreased under all scenarios (1-12%). Changing planting dates led to a weak increase in yields (2-9%) only for 2020 and 2050. The addition of supplementary irrigation strongly reverted this situation increasing yields between 30% (A2 2080) and 43% (A2 2020). Thus, our results suggest that rather simple adaptation measures for soybeans would be beneficial, even if $CO_2$ effects are not considered.

### 4.4.2 Improving applications in agriculture of ENSO-based seasonal rainfall forecasts considering Atlantic Ocean surface temperatures

- Upper quartile SAO anomalies in August and September were consistently associated with mean or high maize yield levels, even under La Niña or Neutral years.
- Complementing ENSO phases with warm SAO led to increase the economic value of ENSO-based climate forecast by 5.4%.
- Differences in optimal planting dates between El Niño and warm SAO years can be attributed to differences in rainfall distribution.
- Results obtained in our research could contribute to improve the applications of ENSO-based seasonal forecasts.

# 5 Capacity Building Outcomes and Remaining Needs

## 5.1 Participation in AIACC Workshops,

AIACC Global Kick-off Meeting, 11-15 February 2002, Nairobi, Kenya. Hosted by United Nations Environment, M. Travasso, G. Magrin, R. Romero

AIACC Project Development Workshop: Development and Application of Scenarios in Impacts, Adaptation and Vulnerability Assessments, 15-26 April 2002, Norwich, UK. Hosted by the Tyndall Centre for Climate Change Research at the University of East Anglia, R. Romero

AIACC Project Development Workshop: Climate Change Vulnerability and Adaptation, 3-14 June 2002, Trieste, Italy. Hosted by the Third World Academy of Sciences, G. Rodriguez, A. Giménez, J.P. Castaño, W.E. Baethgen

First AIACC Regional Workshop for Latin America and Caribbean, 27-30 May, 2003, Tryp Corobicí Hotel, San Jose, Costa Rica, A.Giménez, J.P. Castaño, G. Magrin, M. Travasso, G. Cunha

Second AIACC Regional Workshop for Latin America and Caribbean, 24-27 August, 2004, Regente Palace Hotel, Buenos Aires, Argentina, A. Giménez, J.P. Castaño, G. Magrin, M.I. Travasso, G. Rodriguez, G. Cunha, M. Fernandes

## 5.2 Workshops and Other Activities Implemented by your Project.

### 5.2.1 1st Regional Workshop AIACC, Montevideo, Uruguay, November 9-11, 2003

Participants:

*Brazil*

1. Gilberto Rocca da Cunha (Senior Scientist – Embrapa Trigo)
2. José Maurício Cunha Fernandes (Senior Scientist – Embrapa Trigo)
3. Emerson Del Ponte (Junior Scientist)
4. João Leonardo Fernandes Pires (Junior Scientist – Embrapa Trigo)

*Uruguay*

1. Walter Baethgen (Senior Scientist – IFDC Uruguay Office)
2. Jose Pedro Castaño (Junior Scientist – INIA Colonia)
3. Rafael Terra (Senior Scientist, University of Uruguay)

*Argentina*

1. Graciela Odilia Magrin (Senior Scientist – INTA Castelar)
2. María Isabel Travasso (Senior Scientist – INTA Castelar)

Venue: Hotel Holiday Inn, Montevideo, Uruguay

Objective: To obtain and standardize long-term climate data from the three countries to create a climatic database for: (a) characterizing climatic changes occurred in the last 70-90 years in South Brazil, Central Argentina and Uruguay, and (b) use the data as input for a weather generator (LARS) to create climate change scenarios for the following 10-20 years.

### 5.2.2 2nd Regional Workshop AIACC, Bento Gonçalves, RS, Brazil, April 26-29 2004

Participants:

*Brazil*

1. Gilberto Rocca da Cunha (Senior Scientist – Embrapa Trigo)
2. José Maurício Cunha Fernandes (Senior Scientist – Embrapa Trigo)
3. Emerson Del Ponte (Junior Scientist)
4. João Leonardo Fernandes Pires (Junior Scientist – Embrapa Trigo)
5. Aldemir Pasinato (Technician – Embrapa Trigo)

*Uruguay*

1. Walter Baethgen (Senior Scientist – IFDC Uruguay Office)
2. Jose Pedro Castaño (Junior Scientist – INIA Colonia)

*Argentina*

1. Graciela Odilia Magrin (Senior Scientist – INTA Castelar)
2. María Isabel Travasso (Senior Scientist – INTA Castelar)
3. Gabriel Rodolfo Rodríguez (Junior Scientist – INTA Castelar)

Venue: Hotel Villa Michelon, Vale dos Vinhedos, Bento Gonçalves, RS

Objective: To characterize climatic changes occurred in the century XX in the South of Brazil, Argentina and Uruguay and its consequences in the main agricultural cultures of each country.

## 5.3 Priority Capacity Building Needs That Remain.

- Training in methods for statistical and dynamical downscalling of climate model (GCM) outputs for both, climate variability and climate change
- Training more local scientists in crop/pasture simulation models
- Work in strategies for communicating climate information and climate related risks to policy makers and decision makers from the agricultural public and private sectors.
- Methods for farm-level studies on the impact of climate and management practices in the mixed crop/livestock systems
- Methods for understanding the existing institutional map of the agricultural sector including the existing formal and informal networks to tailor the information required to improve the decision-making process.

## 5.4 Increased Abilities Of Individuals for Technical Analyses

A key outcome of our project is that a cadre of scientists is now trained in the development and implementation of methodologies to address issues of vulnerability to climate for assisting farmers and policy makers of the agricultural sector to improve their planning and make better management decisions.

## 5.5 Increased Abilities to Work in Multidisciplinary Contexts

One of the most positive results our AIACC project was the consolidation of an international, multidisciplinary team that started to apply the holistic approach required to study the impacts of and adaptation to climate change and climate variability. The research team has been interacting online, through visits of group members, and in workshops attended by all team members. This new, consolidated group has jointly produced different types of publications (scientific and intended for general audiences) and has started to prepare new, joint proposals to continue working in these issues.

## 5.6 Increased Abilities to Work with Stakeholder Groups and to Engage in Policy Applications

The organization of national workshops with agricultural stakeholders helped the participating researchers (especially the junior scientists) to identify formats for communicating and discussing climate information with non-scientific audiences, as well as to improve their understanding of the stakeholders needs and priorities.

## 5.7 Institutional Capacity Building

As a result of our AIACC project, young researchers from the participating institutions with strong and almost exclusive background in agricultural science, started to work with climate change scenarios and assessing climate related risks resulting in strengthened research capabilities for further investigations of climate change.

In the last few years societies have become concerned with the general issue of “climate change” and its impacts. However, the concepts of climate change, climate variability, El Niño, are very often confused and misunderstood. The national workshops with stakeholders organized under our AIACC project included presentations and discussions specifically oriented to clarify these concepts.

## 5.8 Graduate Students

One of the young researchers from the Argentinean participating institute (Gabriel Rodriguez) was a student enrolled in the PhD program of the University of Buenos Aires. Some of the activities he established in our AIACC project were part of his dissertation research.

Gabriel Rodríguez also participated in a training course held in Australia entitled: “Cropping Systems modeling”, an activity of APN Project “Applying Climate information to enhance the resilience of farming systems exposed to Climatic Risk in South and Southeast Asia”. Toowoomba/Brisbane, Australia 26/08/02 to 09/09/02.

He also returned to Toowoomba and worked for several weeks in the APSIM crop/pasture simulation models under the supervision of Dr Holger Meinke (DPI, Queensland, Australia)

# 6 National Communications, Science-Policy Linkages and Stakeholder Engagement

## 6.1 National Communications under the UNFCCC and IPCC

The Uruguayan government completed the "Second National Communication of Uruguay" in 2004. AIACC's project LA 27 contributed to the National Communication with a section entitled: **"Assessing the impacts of Climate Variability and Climate Change on the Mixed Crop-Livestock Systems of the Pampas in Argentina, Brazil and Uruguay".**

(See:http://www.cambioclimatico.gub.uy/modules/DownloadsPlus/uploads/Programa_Cambio_Climático/Publicaciones/SCN.pdf)

### 6.1.1 COP 10 Buenos Aires, December 2004

"Science in Support of Adaptation to Climate Change, Recommendations for an Adaptation Science Agenda and a Collection of Papers", Side Event of the 10th Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change: Walter E. Baethgen presented a paper entitled "Climate Change Adaptation and the Policy and Development Agendas of Developing Countries".

#### *6.1.1.1* IPCC Fourth Assessment Report, Working Group II: Chapter 13 (The Latin America Region).

Graciela O. Magrin: Coordinating Leader Author

María I. Travasso: Contributing Author

Walter E. Baethgen, Reviewer

## 6.2 Stakeholder Engagement

During the scope of our AIACC project we organized several workshops for agricultural stakeholders (see list below). During those workshops it became clear that the different communities have become concerned with the general issue of "climate change" and its impacts. However, the concepts of climate change, climate variability, El Niño, are very often confused and misunderstood and consequently, the national workshops included presentations and discussions specifically oriented to clarify these concepts.

Our project activities initiated a process in which successful stakeholder engagement started to be facilitated by developing and testing sets of "discussion-support tools" (linking simulation models, climate scenarios, decision support systems) that started to be used to jointly explore options for reducing the impacts of expected climate change and climate variability scenarios with government advisors, policy makers, and in with other decision makers acting in the public and private agricultural sectors.

### 6.2.1 List of national workshops with stakeholders

#### 6.2.1.1 1st NATIONAL WORKSHOP AIACC, INIA Tacuarembo, Tacuarembo, Uruguay, June 30, 2004

Objective: disseminate and discuss information about climate variability and climate change, and possible impacts in cattle beef production systems in Uruguay.

Participants: more than 40 participants from different stake holders and research organizations.

Publication: *"La Variabilidad Climática, el Cambio del Clima y el Sector Agropecuaio"*, Walter. E. Baethgen, IRI, and Agustin Gimenez, INIA.

#### 6.2.1.2 2nd NATIONAL WORKSHOP AIACC, INIA La Estanzuela, Colonia, Uruguay. August 18, 2004

Objective: disseminate and discuss information about climate change results from the LA27 AIACC Project, and possible impacts in crop fields production in Uruguay.

Participants: more than 100 participants from different stake holders and research organizations.

Publication: *"Evidencias de Cambio Climático en Uruguay"*, Agustín Giménez, José Pedro Castaño, Laura Olivera, y José Furest, Unidad GRAS del INIA; Walter Baethgen, Instituto Internacional de Investigación en Predicciones Climáticas (IRI); Daniel L. Martino, Consultor y Asesor del INIA, y Ricardo Romero, USDA, Uruguay.

#### 6.2.1.3 3rd NATIONAL WORKSHOP AIACC, Federación Argentina de Acopiadores, Buenos Aires, Argentina, October 7, 2004

Participants: Members of Federación Argentina de Acopiadores, Bolsa de Cereales, Fundación Producir Conservando, Interlink Sur Biotechnologies.

Objective: to disseminate information related to climate variability:

Output: CD-ROM "Analysis of precipitations during 1923-2000 in the Pampas Region of Argentina", with the analysis of monthly precipitation data from 53 weather stations distributed in the Pampas Region of Argentina considering the period 1923-2000. In each site the interannual variability was assessed considering precipitation anomalies (difference between observed values and trend) for each month of the year. Results are shown in 936 maps presented as individual maps (one year, one month) or grouped maps (years/months).

#### 6.2.1.4 4th NATIONAL WORKSHOP AIACC, Bolsa de Cereales de la República Argentina, Buenos Aires, Argentina, October 26, 2004

Participants: More than 200 people representative of farmers associations, policy makers, agribusiness, Secretary of Agriculture.

Objective: to disseminate results obtained under AIACC activities related to changes occurred in climate during the last century and climate variability in the Pampas Region.

#### 6.2.1.5 5th NATIONAL WORKSHOP AIACC, Secretaria da Agricultura do Rio Grande do Sul, Porto Alegre, Rio Grande, Brazil, October 7, 2004

Objective: disseminate and discuss information about climate variability and climate change, and possible impacts in crop fields production in Southern Brazil.

Participants: 30 participants from different stake holders and research organizations.

Publications: (1) *"Mudanças Climáticas globais e seus possíveis impactos em agricultura e alimentação"*, Gilberto R. Cunha, Embrapa Trigo, (Fitopatologia Brasileira, v.29 –Suplemento, p.s8-s10, 2004), (2)*"Construindo nossa capacidade para lidar com as mudanças climáticas globais e seus possíveis impactos em agricultura e* *alimentação"*, Gilberto R. Cunha, Embrapa Trigo, (In. CUNHA, G.R. ed. Lidando com riscos climáticos: clima, sociedade e agricultura. Passo Fundo: Embrapa Trigo, 2004. P. 357-399.)

Articles for media and one book in Portuguese were produced for agricultural stakeholders and general audience in Brazil.

# 7 Outputs of the project

## 7.1 Peer-reviewed articles:

- Del Ponte, E. M., Fernandes, J. M. C. and Pierobom, C. R. 2005. Factors affecting density of airborne Gibberella zeae inoculum. Fitopatol. Bras., vol.30 (1), p.55-60.
- Del Ponte, E.M., Fernandes, J.M.C. & Pavan, W.A. 2005. Risk infection simulation model for Fusarium head blight of wheat. Fitopatologia Brasileira (In Press)

## 7.2 Other Publications

- Baethgen, W.E., G. Magrin, M.I. Tavasso, J.M. Fernandes, G. Cunha, A. Giménez. 2005. Changes in Climate and their Impacts on the Mixed Crop-Livestock Production Systems of South Eastern South America. I: Maximum and Minimum Temperatures, Frost Regime and Crop-Pasture Potential Yields. (In preparation)
- G. Magrin, M.I. Tavasso, W.E: Baethgen, W.E., J.M. Fernandes, G. Cunha, A. Giménez. 2005. Changes in Climate and their Impacts on the Mixed Crop-Livestock Production Systems of South Eastern South America. II: Precipitations and Crop-Pasture Rainfed Yields. (In preparation)
- Emerson Del Ponte, José Mauricio C. Fernandes, Willingthon Pavan, and Rodrigo Tsukuhara. 2005. Predicting Head Blight Epidemics in Southern Brazilian Wheat-growing Areas. Proceedings of the American Phytopathological Society - APS Annual Meeting. August 2005, Austin, TX, USA. (in Press).
- Graciela O. Magrin, María I. Travasso, Walter E. Baethgen; Rosa T. Boca. 2005. Improving applications in agriculture of ENSO-based seasonal rainfall forecasts considering Atlantic Ocean surface temperatures. Proceedings of the II International Workshop on Climate Prediction and Agriculture - Advances & Challenges, World Meteorological Organization, Agricultural Meteorology Division. Geneva, Switzerland, 11-13 May 2005.
- Adaptation measures for maize and soybean in South Eastern South America. 2005. M.I. Travasso, G.O. Magrin, W.E.Baethgen, J.P. Castaño, G.R. Rodriguez, J.L. Pires, A. Gimenez, G.Cunha, M.Fernandez. *(AIACC Adaptation Synthesis Workshop, 2005)*
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- Baethgen, W.E: and A. Gimenez. 2004. La Variabilidad Climática, el Cambio del Clima y el Sector Agropecuaio. Serie Actividades de Difusion, INIA, (Jun-2004).

  http://www.inia.org.uy/disciplinas/agroclima/publicaciones/ambiente/clima_tcbo_0406.pdf
- Giménez, A.; J. P. Castaño, L. Olivera, J. Furest, W. E. Baethgen, D. L. Martino, R. Romero. 2004. Evidencias de Cambio Climatico en Uruguay. INIA, Uruguay, (Ago-2004).

  http://www.inia.org.uy/disciplinas/agroclima/publicaciones/ambiente/evi_cambio_clima.pdf
- Giménez, A.; J. P. Castaño, L. Olivera, J. Furest, W. E. Baethgen, D. L. Martino, R. Romero. 2004. El clima, la producción agropecuaria y la toma de decisiones. Revista Plan Agropecuario.112:34-37.
- Baethgen, W.E:; H. Meinke, A. Gimenez. 2004. Adaptation of agricultural production systems to climate variability and climate change: lessons learned and proposed research approach IN: Insights and Tools for Adaptation: Learning from Climate Variability, NOAA-OGP, Washington, D.C.

- Meinke, H., S. M. Howden, W.E. Baethgen, G. L. Hammer, R. Selvaraju and R. C. Stone. 2004. Can climate knowledge lead to better rural policies and risk management practices? IN: Insights and Tools for Adaptation: Learning from Climate Variability, NOAA-OGP, Washington, D.C.
- Magrin G., Rodriguez G., Travasso M.I. 2004. Análisis de la precipitaciones ocurridas durante 1923-2000 en la región pampeana. CD ROM, INTA-Instituto de Clima y Agua, 1712 Castelar, Argentina.
- Magrin, G.O., M.I. Travasso, G. R. Rodríguez. La agricultura ante el cambio climático Revista CREA. Año XXXV- Número 291 - Enero 2005.
- Gilberto R. Cunha, 2004. Mudanças Climáticas globais e seus possíveis impactos em agricultura e alimentação. Fitopatologia Brasileira, v.29 –Suplemento, p.s8-s10, 2004.
- Gilberto R. Cunha, 2004. Construindo nossa capacidade para lidar com as mudanças climáticas globais e seus possíveis impactos em agricultura e alimentação. In: CUNHA, G.R. ed. Lidando com riscos climáticos: clima, sociedade e agricultura. Passo Fundo: Embrapa Trigo, 2004. P. 357-399.
- Fernandes, J.M, Cunha, G.R., Del Ponte, Pavan, W., Pires, J., Baethgen, W., Gimenez, A, Magrin, G. and Travasso, M.I. 2004. Modeling Fusarium Head Blight In Wheat Under Climate Change Using Linked ProcesBased Models. Proceedings of the 2nd International Symposium on Fusarium Head Blight, Incorporating the 8th European Fusarium Seminar, 11-15 December, 2004, Orlando, Florida USA

# 8 Policy Implications and Future Directions

The results of our project on the expected impacts of climate change in the mixed systems of the Pampas are based on generated, possible future climate scenarios. These scenarios were generated using GCMs or projecting the observed trends in climate variables of the last century, and have intrinsic large degree of uncertainty. All the communications (publications, presentations, discussions, etc.) resulting from the project activities to both, scientific audiences as well as to policy/decision makers, always contained such uncertainty.

Consequently, the discussions on policy implications of our results are all subject to the confirmation of the projected climate scenarios, or al least to the confirmation of the general trends. Conditioned to this confirmation, our results have some important national and regional policy implications that we summarize below.

## 8.1 Implications for Soybeans production

Our results suggest that establishing rather simple adaptation measures soybean would be benefited by the projected climate. The important expansion of this crop observed in the study area during the last few years could continue putting in risk the sustainability of the agricultural systems. Soybean is a high nutrient extractive crop with low level of crop residues, and therefore, the monoculture lead to negative nitrogen (N) and carbon (C) balances. Experiences in Argentina have shown that for crops yielding 4000 kg/ha some 120 kg N/ha/year and 950 kg C/ha/year are lost from the system (Garcia, 2003).

The expansion of soybean monoculture raises concern and there is a need to establish management practices that help preserving the natural resources such as adequate crop rotations. Grasses as cover crops and a higher proportion of corn and wheat in the rotation could help to improve soil C and N balances among other benefits. Crop-pasture rotations, that used to be the main rotation in the Pampas, are another possibility to improve soil organic matter balances and, thus, soil C and N (García, 2004). In the same way in Uruguay, traditional rotations included 3-4 years of crops and 3-4 years of pastures but the recent expansion of agriculture and in particular the soybean crop, led to reduce the pasture component resulting in a more vulnerable system. In South Brazil, Costamilan. & Bertagnolli, (2004) recommend a three year's crop rotation including the sequence oats/soybean, wheat/soybean and spring vetch/maize.

Other alternative measures could be related to the destination of crop production. Assuming that the trend to increase annual crop production will continue in the future, regardless of climate change, Oliverio & Lopez (2005) analyzed two possible scenarios to estimate Argentina's crops production in 2015. In the first one they extrapolated the actual trend in sown areas (with increasing importance of oilseeds, especially soybean). A second scenario consisted of a maximum ratio of 2.5:1 of oilseeds and cereals, promoting the so called "transformation in origin" as a way to contribute to both, the sustainability of agricultural systems and economic returns. "Transformation in origin" means that part of the production (for example of maize) remains at the place where it is produced and is used to feed animals or for local industry, adding value to the primary product. This contrasts, with the traditional sale of grain as a commodity which often implies important costs of transportation to ports and fiscal retentions, among others. Assuming that half of the maize production is transformed in origin, economic benefits could be more than duplicated.

## 8.2 Implications for the Mixed Annual Crops / Pastures Systems

Our results also suggest that the pasture component of the mixed systems is much less affected by any of the climate change scenarios used in our research. Thus, in addition to the well-known risk reduction resulting from the diversification of a production system, the pastures would contribute to the system in two major ways: by decreasing the income variability under climate change scenarios, and by improving the C and N balances of the entire production system (as discussed above).

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# 10 Figures and Tables

## 10.1 Tables

| ID | Site Name | Lat | Lon |
|---|---|---|---|
| AR-ATY | Anatuya | -28.50 | -62.80 |
| AR-AZU | Azul | -36.78 | -59.85 |
| AR-BCA | Bblanca | -38.73 | -62.26 |
| AR-BOL | Bolivar | -37.85 | -63.02 |
| AR-CAS | Casilda | -33.05 | -61.18 |
| AR-CON | Concordia | -31.40 | -58.02 |
| AR-COR | Cordoba | -31.41 | -64.20 |
| AR-CSZ | Csuarez | -37.47 | -61.93 |
| AR-DOL | Dolores | -36.31 | -57.67 |
| AR-FRI | Frias | -28.60 | -65.10 |
| AR-GUA | Gualeguaychu | -33.02 | -58.52 |
| AR-JUN | Junin | -34.58 | -60.97 |
| AR-LAB | Laboulaye | -34.12 | -63.38 |
| AR-LFL | LasFlores | -36.03 | -59.12 |
| AR-MDP | Mar del Plata | -38.00 | -57.57 |
| AR-MJZ | Mjuarez | -32.70 | -62.12 |
| AR-NDJ | Nueve Julio | -35.45 | -60.88 |
| AR-OLA | Olavarría | -36.88 | -60.33 |
| AR-PAR | Paraná | -31.73 | -60.53 |
| AR-PEH | Pehuajó | -35.80 | -61.87 |
| AR-PER | Pergamino | -33.90 | -60.58 |
| AR-RAF | Rafaela | -31.25 | -61.48 |
| AR-RCU | RioCuarto | -33.13 | -64.37 |
| AR-ROS | Rosario | -32.95 | -60.67 |
| AR-SES | Sgo Estero | -27.80 | -64.30 |
| AR-SRO | Santa Rosa | -36.62 | -64.28 |
| AR-TAN | Tandil | -37.33 | -59.13 |
| AR-TAR | Tres Arroyos | -38.37 | -60.27 |
| AR-VIL | Villegas | -35.03 | -63.03 |
| BR-BAG | Bage | -31.35 | -54.11 |
| BR-CAS | Castro | -24.47 | -50.00 |
| BR-CUR | Curitiba | -25.24 | -49.15 |
| BR-EDS | Encr. Sul | -30.32 | -52.31 |
| BR-FLP | Floripa | -27.35 | -48.34 |
| BR-LAG | Lages | -27.49 | -50.20 |
| BR-PEL | Pelotas | -31.76 | -52.34 |
| BR-PFU | PassoFundo | -28.26 | -52.41 |
| BR-POA | Porto Alegre | -30.03 | -51.22 |
| BR-SDL | Sta Ana Livram. | -30.53 | -55.31 |
| BR-SLZ | São Luiz | -28.40 | -54.98 |
| BR-SMA | Sta Maria | -29.69 | -53.81 |
| BR-SRS | Sta Rosa | -27.86 | -54.43 |
| BR-SVT | Sta Vitoria | -33.52 | -53.37 |
| BR-TOR | Torres | -29.20 | -49.43 |
| BR-UGA | Urussanga | -28.31 | -49.19 |
| BR-URU | Uruguaiana | -29.76 | -57.09 |
| UY-ART | Artigas | -30.40 | -56.51 |
| UY-BUN | Bella Union | -30.27 | -57.58 |
| UY-DUR | Durazno | -33.35 | -56.50 |
| UY-EST | La Estanzuela | -34.33 | -57.68 |
| UY-FDA | Florida | -34.25 | -56.25 |
| UY-MEL | Melo | -32.37 | -54.19 |
| UY-MER | Mercedes | -33.25 | -58.07 |
| UY-PAY | Paysandu | -32.35 | -58.04 |
| UY-PDT | Paso de los Toros | -32.80 | -56.53 |
| UY-RCH | Rocha | -34.49 | -54.31 |
| UY-RIV | Rivera | -30.90 | -55.54 |
| UY-STO | Salto | -31.40 | -57.97 |
| UY-TAC | Tacuarembo | -31.71 | -55.98 |
| UY-TYT | Treinta y Tres | -33.22 | -54.39 |

*Table 1: Names, abbreviation (ID) and location (latitude, longitude) of the sites where precipitation data was obtained for this article (AR = Argentina, BR = Brazil, UY = Uruguay).*

| ID | Site Name | Lat | Lon |
|---|---|---|---|
| AR-AZU | Azul | -36.78 | -59.85 |
| AR-COR | Cordoba | -31.41 | -64.20 |
| AR-PER | Pergamino | -33.90 | -60.58 |
| AR-SRO | Santa Rosa | -36.62 | -64.28 |
| AR-TRA | Tres Arroyos | -38.37 | -60.27 |
| BR-BAG | Bage | -31.35 | -54.11 |
| BR-CUR | Curitiba | -25.24 | -49.15 |
| BR-EDS | Encr. Sul | -30.32 | -52.31 |
| BR-FPA | Florianopolis | -27.35 | -48.34 |
| BR-PAF | PassoFundo | -28.26 | -52.41 |
| BR-PEL | Pelotas | -31.76 | -52.34 |
| BR-POA | Porto Alegre | -30.03 | -51.22 |
| BR-SDL | Sta Ana Livramento | -30.53 | -55.31 |
| BR-SLZ | São Luiz | -28.40 | -54.98 |
| BR-SMA | Sta Maria | -29.69 | -53.81 |
| BR-SRB | Sta Rosa | -27.86 | -54.43 |
| BR-SVT | Sta Vitoria | -33.52 | -53.37 |
| BR-TOR | Torres | -29.20 | -49.43 |
| BR-URU | Uruguaiana | -29.76 | -57.09 |
| BR-USS | Urussanga | -28.31 | -49.19 |
| UY-EST | La Estanzuela | -34.33 | -57.68 |
| UY-MER | Mercedes | -33.25 | -58.07 |
| UY-PAY | Paysandu | -32.35 | -58.04 |

*Table 2: Names, abbreviation (ID) and location (latitude, longitude) of the sites where temperature data was obtained for this article (AR = Argentina, BR = Brazil, UY = Uruguay).*

| | Trimester | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SITE** | **JFM** | **FMA** | **MAM** | **AMJ** | **MJJ** | **JJA** | **JAS** | **ASO** | **SON** | **OND** | **NDJ** | **DJF** |
| AR-AZU | -0.010 | ns | ns | ns | ns | ns | 0.013 | 0.013 | ns | ns | -0.012 | -0.019 |
| AR-COR | -0.037 | -0.022 | ns | ns | ns | ns | ns | ns | ns | -0.029 | ns | -0.054 |
| AR-PER | -0.012 | ns | ns | ns | ns | ns | ns | 0.009 | ns | ns | ns | ns |
| AR-SRO | -0.028 | -0.016 | ns | ns | ns | ns | ns | ns | -0.013 | -0.021 | -0.034 | -0.043 |
| AR-TRA | -0.024 | -0.017 | -0.004 | ns | -0.004 | ns | ns | ns | -0.008 | -0.016 | -0.025 | -0.031 |
| BR-BAG | ns | ns | ns | ns | -0.009 | ns | ns | ns | ns | ns | ns | ns |
| BR-CUR | 0.017 | 0.016 | ns | 0.007 | ns | ns | ns | ns | 0.014 | 0.022 | 0.028 | 0.026 |
| BR-EDS | ns | ns | ns | ns | ns | ns | ns | ns | 0.008 | 0.013 | 0.009 | ns |
| BR-FPA | 0.008 | 0.014 | 0.010 | ns | ns | ns | ns | 0.008 | 0.016 | 0.019 | 0.013 | 0.011 |
| BR-PAF | -0.001 | ns | ns | 0.007 | ns | ns | ns | ns | ns | ns | ns | -0.007 |
| BR-PEL | -0.012 | -0.008 | -0.008 | ns | -0.010 | ns | ns | ns | ns | ns | -0.009 | -0.016 |
| BR-POA | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| BR-SDL | -0.018 | -0.016 | -0.016 | ns | -0.013 | -0.017 | -0.020 | -0.020 | -0.020 | -0.015 | -0.018 | -0.018 |
| BR-SLZ | ns | ns | ns | 0.005 | ns | ns | ns | ns | ns | ns | ns | ns |
| BR-SMA | -0.013 | -0.013 | ns | ns | -0.014 | -0.023 | -0.025 | ns | ns | ns | -0.009 | -0.015 |
| BR-SRB | -0.031 | -0.028 | -0.018 | ns | -0.011 | -0.018 | -0.022 | -0.023 | -0.017 | ns | -0.021 | -0.030 |
| BR-SVP | -0.025 | ns | ns | ns | -0.013 | ns | ns | ns | ns | ns | -0.023 | -0.033 |
| BR-TOR | 0.022 | 0.026 | 0.026 | 0.017 | 0.015 | 0.011 | 0.015 | 0.019 | 0.024 | 0.027 | 0.025 | 0.024 |
| BR-URU | -0.023 | -0.025 | -0.014 | -0.015 | -0.012 | -0.017 | -0.018 | ns | ns | ns | -0.014 | -0.026 |
| BR-USS | ns | 0.016 | 0.011 | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| UY-EST | -0.015 | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | -0.023 |
| UY-MER | ns | ns | ns | -0.006 | ns | ns | ns | ns | ns | ns | ns | ns |
| UY-PAY | ns | ns | ns | -0.002 | ns | ns | ns | 0.003 | ns | ns | ns | ns |
| Percent | 69.6 | 52.2 | 34.8 | 30.4 | 39.1 | 21.7 | 26.1 | 30.4 | 34.8 | 34.8 | 56.5 | 65.2 |

*Table 3: Regression coefficients ($^{o}$C year$^{-1}$) for maximum temperature of moving trimesters in the period 1930-2000 with significant Kendall's Tau values (P<0.10). The last row shows the proportion of sites showing significant regression coefficients. (AR = Argentina, BR= Brazil, UY = Uruguay; ns = non significant Kendall's Tau value).*

|  | Trimester |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SITE** | **JFM** | **FMA** | **MAM** | **AMJ** | **MJJ** | **JJA** | **JAS** | **ASO** | **SON** | **OND** | **NDJ** | **DJF** |
| AR-AZU | 0.022 | ns | ns | 0.024 | ns | ns | ns | ns | ns | ns | 0.023 | 0.028 |
| AR-COR | 0.015 | ns | ns | 0.020 | ns | ns | ns | 0.009 | ns | ns | 0.014 | 0.018 |
| AR-PER | 0.021 | 0.012 | 0.031 | 0.034 | 0.005 | ns | ns | 0.015 | 0.018 | 0.033 | 0.026 | 0.032 |
| AR-SRO | 0.025 | 0.026 | 0.014 | 0.039 | ns | ns | 0.016 | ns | 0.019 | 0.029 | 0.035 | 0.040 |
| AR-TRA | 0.033 | 0.028 | 0.027 | 0.034 | 0.032 | ns | ns | 0.006 | ns | 0.026 | 0.032 | 0.038 |
| BR-BAG | 0.014 | ns | ns | 0.010 | ns | ns | ns | ns | ns | ns | 0.010 | 0.024 |
| BR-CUR | ns | ns | -0.020 | ns | -0.034 | -0.054 | -0.029 | -0.034 | -0.014 | ns | ns | ns |
| BR-EDS | 0.015 | ns | ns | ns | ns | -0.040 | ns | ns | ns | ns | 0.015 | 0.018 |
| BR-FPA | 0.014 | ns | ns | 0.027 | ns | ns | ns | 0.008 | ns | 0.020 | 0.016 | 0.028 |
| BR-PAF | 0.027 | 0.020 | 0.035 | 0.042 | ns | ns | ns | 0.024 | 0.019 | 0.030 | 0.032 | 0.031 |
| BR-PEL | 0.043 | 0.038 | 0.027 | 0.036 | 0.013 | ns | 0.015 | 0.027 | 0.012 | 0.023 | 0.040 | 0.039 |
| BR-POA | 0.044 | 0.021 | 0.030 | 0.034 | ns | ns | ns | 0.013 | 0.024 | 0.030 | 0.037 | 0.052 |
| BR-SDL | 0.010 | 0.011 | ns | 0.029 | ns | ns | ns | ns | ns | ns | 0.011 | 0.021 |
| BR-SLZ | 0.030 | ns | ns | 0.036 | ns | ns | 0.022 | 0.021 | 0.014 | 0.028 | 0.026 | 0.029 |
| BR-SMA | 0.037 | 0.023 | 0.032 | 0.048 | 0.022 | ns | 0.026 | 0.025 | 0.018 | 0.036 | 0.033 | 0.047 |
| BR-SRB | 0.019 | 0.018 | 0.016 | 0.023 | ns | -0.024 | ns | ns | ns | 0.026 | 0.028 | 0.034 |
| BR-SVP | 0.039 | 0.017 | 0.031 | 0.031 | ns | ns | 0.026 | 0.031 | ns | 0.028 | 0.037 | 0.038 |
| BR-TOR | 0.012 | ns | 0.040 | 0.036 | 0.010 | ns | ns | 0.029 | 0.027 | 0.021 | 0.025 | 0.025 |
| BR-URU | 0.033 | 0.015 | ns | 0.018 | ns | ns | ns | ns | ns | ns | 0.018 | 0.024 |
| BR-USS | 0.027 | 0.027 | 0.029 | 0.029 | ns | ns | 0.016 | 0.003 | 0.016 | 0.031 | 0.031 | 0.043 |
| UY-EST | 0.024 | ns | 0.015 | 0.009 | ns | ns | ns | 0.006 | ns | ns | 0.016 | 0.019 |
| UY-MER | ns | ns | ns | 0.016 | ns | -0.029 | ns | ns | ns | ns | 0.011 | 0.021 |
| UY-PAY | 0.032 | 0.032 | 0.022 | 0.044 | ns | ns | ns | ns | 0.014 | 0.023 | 0.037 | 0.048 |
| Percent | 91.3 | 56.5 | 60.9 | 91.3 | 26.1 | 17.4 | 30.4 | 60.9 | 47.8 | 60.9 | 95.7 | 95.7 |

*Table 4: Regression coefficients (ºC year$^{-1}$) for minimum temperature of moving trimesters in the period 1930-2000 with significant Kendall's Tau values (P<0.10). The last row shows the proportion of sites showing significant regression coefficients. (AR = Argentina, BR= Brazil, UY = Uruguay; ns = non significant Kendall's Tau value).*

| Site | Date of First Frost (day of year) | | Date of Last Frost (day of year) | | Frost Period (days) | | Days with frost (days) | | Mean Frost Temp ( $^{o}$C) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1930 | 2000 | 1930 | 2000 | 1930 | 2000 | 1930 | 2000 | 1930 | 2000 |
| AR-AZU | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| AR-COR | 122 | 140 | 270 | 248 | 148 | 109 | 42 | 23 | -0.8 | -0.3 |
| AR-PER | 107 | 133 | 293 | 261 | 187 | 127 | 49 | 33 | -0.6 | -0.2 |
| AR-SRO | 82 | 114 | 312 | 278 | 231 | 163 | 79 | 52 | -1.2 | -1.0 |
| AR-TRA | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| BR-PEL | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| BR-PAF | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| UR-EEL | ns | ns | 257 | 233 | 257 | 233 | 20 | 7 | 0.5 | 0.9 |
| UR-MCD | ns | ns | ns | ns | ns | ns | 21 | 31 | 0.1 | -0.4 |
| UR-PAY | 136 | 163 | 267 | 241 | 131 | 78 | 27 | 11 | -0.5 | 0.6 |

*Table 5: Changes in the dates of first and last frost, duration of the frost period, number of days with frost, and mean frost temperature in the period 1930-2000. Values were estimated with significant (P<0.10) regression models.*

| Location | Absolute Maximum T Max ( $^{o}$C) | | Absolute Minimum T Min ( $^{o}$C) | |
|---|---|---|---|---|
| | 1930 | 2000 | 1930 | 2000 |
| AR-AZU | 46.0 | 33.7 | ns | ns |
| AR-COR | 41.1 | 37.5 | -6.3 | -4.3 |
| AR-PER | ns | ns | -5.9 | -4.2 |
| AR-SRO | 41.2 | 38.3 | -8.9 | -7.1 |
| AR-TRA | 40.2 | 36.0 | ns | ns |
| BR-PEL | ns | ns | ns | ns |
| BR-PAF | ns | ns | ns | ns |
| UR-EEL | 38.9 | 36.3 | -1.6 | -0.7 |
| UR-MCD | 40.4 | 37.5 | ns | ns |
| UR-PAY | 39.8 | 38.3 | -4.5 | -1.1 |

*Table 6: Changes in the absolute maximum temperature (T Max) and absolute minimum temperature (T Min) in the period 1930-2000. Values were estimated with significant (P<0.10) regression models. (ns = non significant).*

| | | LARS-WG | | HadleyCM3 | |
|---|---|---|---|---|---|
| Site | Trimester | T Min (ºC) | T Max (ºC) | T Min (ºC) | T Max (ºC) |
| AR-SR | JAS | **1.1** | *-0.3* | 0.6 | 1.3 |
| | OND | **0.7** | *-0.7* | 1.0 | 0.8 |
| | JFM | **1.0** | **-0.9** | 1.1 | 0.4 |
| | AMJ | **0.7** | *-0.3* | 1.1 | 1.3 |
| AR-TR | JAS | *0.1* | *0.0* | 0.6 | 1.0 |
| | OND | **0.4** | **-1.0** | 0.9 | 1.0 |
| | JFM | **0.4** | **-1.7** | 0.8 | 0.5 |
| | AMJ | *-0.1* | **-0.7** | 1.0 | 1.1 |
| AR-AZ | JAS | *0.1* | **0.7** | 0.6 | 1.0 |
| | OND | **0.5** | *0.1* | 0.9 | 1.0 |
| | JFM | **0.3** | **-0.6** | 0.8 | 0.5 |
| | AMJ | *0.1* | **0.7** | 1.0 | 1.1 |
| AR-PE | JAS | **0.7** | *0.3* | 0.7 | 1.2 |
| | OND | **1.5** | *0.3* | 0.9 | 1.0 |
| | JFM | **1.1** | **-0.9** | 1.0 | 0.7 |
| | AMJ | **0.8** | 0.0 | 0.9 | 1.1 |
| UY-LE | JAS | *0.1* | *0.6* | 0.5 | 0.8 |
| | OND | **0.4** | **-0.4** | 0.7 | 1.0 |
| | JFM | **0.3** | **-0.7** | 0.8 | 0.7 |
| | AMJ | *-0.1* | *0.0* | 0.9 | 1.0 |
| BR-PF | JAS | *0.4* | *-0.5* | 1.5 | 1.2 |
| | OND | **0.2** | *0.2* | 0.9 | 0.6 |
| | JFM | **0.4** | *0.3* | 0.8 | 1.1 |
| | AMJ | *0.0* | *0.3* | 0.9 | 1.0 |

*Table 7: Changes in mean minimum (T Min) and maximum (T Max) temperatures as calculated with the LARS weather generator (LARS-WG) and with the Hadley Center GCM (Hadley CM3) per trimester for 5 sites in Argentina (AR), one in Uruguay (UY) and one in Brazil (BR). Statistically significant changes (P<0.1) are in bold.*

| **Mean Temperature** (October-March) | | | | | | |
|---|---|---|---|---|---|---|
| | **HadCM3 A2** | | | **HadCM3 B2** | | |
| | 2020 | 2050 | 2080 | 2020 | 2050 | 2080 |
| | *$CO_2$ 417 ppm* | *$CO_2$ 532 ppm* | *$CO_2$ 698 ppm* | *$CO_2$ 408 ppm* | *$CO_2$ 478 ppm* | *$CO_2$ 559 ppm* |
| SR | 0.9 | 2.1 | 3.4 | 0.7 | 1.7 | 2.5 |
| TR | 0.8 | 1.9 | 3.1 | 0.7 | 1.6 | 2.4 |
| AZ | 0.8 | 1.9 | 3.1 | 0.7 | 1.6 | 2.4 |
| PE | 0.9 | 2.1 | 3.4 | 0.8 | 1.7 | 2.7 |
| LE | 0.8 | 2.0 | 3.2 | 0.8 | 1.5 | 2.6 |
| PF | 0.9 | 2.4 | 4.1 | 0.9 | 1.8 | 2.9 |
| **Mean** | **0.9** | **2.1** | **3.4** | **0.8** | **1.7** | **2.6** |

*Table 8: Projected changes in mean temperature for the warm semester (October-March) according to HadCM3 under SRES A2 y B2 scenarios for 2020, 2050 and 2080. $CO_2$ concentration for each scenario is also shown.*

| | **HadCM3 A2** | | | | | | | **HadCM3 B2** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **SR** | **TA** | **AZ** | **PE** | **LE** | **PF** | **Mean** | **SR** | **TA** | **AZ** | **PE** | **LE** | **PF** | **Mean** |
| | ***2020 ($CO_2$ =417 ppm)*** | | | | | | | ***2020 ($CO_2$ =408 ppm)*** | | | | | | |
| Jan | 11.5 | -3.2 | -4.3 | -24.7 | -4.3 | 8.3 | **-3** | -1.1 | 4.7 | 2.2 | -11.3 | 0.7 | -22.8 | **-5** |
| Feb | 17.1 | 11.5 | 18.7 | 26 | 6.8 | 4.9 | **14** | -7.8 | -18.7 | 2.8 | 17.8 | -21.9 | 22.8 | **-1** |
| Mar | 1.7 | -3.5 | -8.4 | 1.4 | -2.2 | -4 | **-3** | 38.7 | 25.7 | 42.6 | 49 | 27.1 | 15.2 | **33** |
| Apr | -4.9 | 1.7 | 1.9 | 0.3 | 0.6 | -8.3 | **-1** | -12.9 | -10.7 | 3.2 | -27 | 4.7 | -6.3 | **-8** |
| May | -6.3 | -10.4 | -9.6 | -3.3 | -10.8 | -8 | **-8** | -16.8 | -11.8 | -13.2 | -6.1 | -11.9 | -34.1 | **-16** |
| Jun | -3.7 | -7.1 | -7.8 | -11.7 | -18.7 | 0 | **-8** | -0.7 | 13.5 | 13 | -3 | -7.5 | 3.7 | **3** |
| Jul | -7.7 | -6.9 | -6.9 | -7.2 | -6.2 | 18.4 | **-3** | -4.1 | -0.2 | -2.8 | -6.4 | -16.1 | -17.4 | **-8** |
| Aug | -5.2 | -2.1 | -0.8 | 1.3 | -1.8 | 19.4 | **2** | -3.6 | 5.3 | 6.3 | 17.1 | 26.2 | 17.4 | **11** |
| Sep | -7 | -4.6 | -3.3 | 0.2 | 0.6 | 3.9 | **-2** | 0.3 | -5.3 | 3.4 | 17.7 | 11.3 | 16.9 | **7** |
| Oct | 11.8 | -2.1 | 2.9 | -12.7 | -2.2 | 46.3 | **7** | 2 | -2.4 | 2.3 | -1.8 | 0.4 | -23.5 | **-4** |
| Nov | 5.1 | 5 | 4.7 | -6.3 | -13.7 | 23.1 | **3** | -3.8 | -3.9 | -5.3 | 0.4 | -5.7 | -12.7 | **-5** |
| Dec | 39.8 | 4.9 | 6.6 | -2.1 | -1.3 | -5.4 | **7** | 15.8 | 6.9 | 4.2 | -4.3 | 5.7 | 24.4 | **9** |
| **Year** | **52** | **-17** | **-6** | **-39** | **-53** | **99** | | **6** | **3** | **59** | **42** | **13** | **-16** | |
| | ***2050 ($CO_2$ =532 ppm)*** | | | | | | | ***2050 ($CO_2$ =478 ppm)*** | | | | | | |
| Jan | 13.3 | 1.7 | 3 | 10.8 | 21.2 | 2.2 | **9** | 4.8 | -8.2 | -11.5 | -19.6 | -3.1 | 13.6 | **-4** |
| Feb | 7.6 | 0 | 5.4 | 7.6 | -5.1 | -12.3 | **1** | 15.8 | 14 | 21.6 | 40.5 | 24.9 | 10.1 | **21** |
| Mar | 60.1 | 29.4 | 39.9 | 32.4 | 25.8 | 14.8 | **34** | 44.3 | 23.2 | 30.9 | 14.4 | 12.7 | 3.6 | **22** |
| Apr | 6.1 | 26.2 | 29.5 | 31.2 | 14.1 | 13.5 | **20** | -6.8 | 15.6 | 17.5 | 20.4 | 18.5 | 17.5 | **14** |
| May | -6.9 | -4.8 | -4 | 3.2 | -1.7 | -14.5 | **-5** | -6.4 | -6.9 | -6.3 | 8.1 | 17.1 | 11.6 | **3** |
| Jun | -0.5 | 0 | 0.7 | -3.6 | -17 | 7.6 | **-2** | -6.8 | -5.5 | -5.8 | -6.1 | -12.4 | -11.7 | **-8** |
| Jul | -8.6 | -9.5 | -9.3 | -9 | -8.8 | -16.1 | **-10** | -9.4 | -10.7 | -10.5 | -16.1 | -21.5 | -30.7 | **-16** |
| Aug | -9.8 | -10.9 | -8.6 | -8.8 | -7.7 | -8.3 | **-9** | -11.3 | -13.1 | -10.5 | -13.8 | -15.8 | 16.8 | **-8** |
| Sep | 4.3 | 6.9 | 8.6 | 16.5 | 29.8 | 0.8 | **11** | -7.7 | 0.9 | 1.4 | 11.9 | 25.2 | -11 | **3** |
| Oct | 8.8 | -2.6 | 2.4 | 1.7 | 15.2 | 22.7 | **8** | 6.8 | 8.6 | 17 | 2.4 | 7.1 | 36.6 | **13** |
| Nov | 32.3 | 18.8 | 20.1 | 19.8 | 2.1 | 45.3 | **23** | 6.1 | 3.9 | 3.4 | 7.3 | 6.5 | 21 | **8** |
| Dec | 18.7 | 21.1 | 26.5 | 11.1 | 19 | -3.2 | **16** | 3.9 | -5.1 | -6 | -1 | 9.3 | 13.5 | **2** |
| **Year** | **125** | **76** | **114** | **113** | **87** | **53** | | **33** | **17** | **41** | **48** | **69** | **91** | |
| | ***2080 ($CO_2$ =698 ppm)*** | | | | | | | ***2080 ($CO_2$ =559 ppm)*** | | | | | | |
| Jan | 17.5 | 8.9 | 13.3 | -3.8 | 7.9 | 18.2 | **10** | 4.8 | -4.5 | -6.2 | 0.8 | 10 | 12.4 | **3** |
| Feb | 13.1 | 8.7 | 15.5 | 27 | 13.1 | 16.2 | **16** | 8.6 | -0.2 | 5.1 | 25.3 | -5.1 | -0.2 | **6** |
| Mar | 55.5 | 37.7 | 52.2 | 37.3 | 16.3 | 42.4 | **40** | 59 | 37.6 | 52 | 41.3 | 24.2 | 43.4 | **43** |
| Apr | 47.2 | 51.4 | 57.7 | 44.7 | 23.1 | 13.1 | **40** | 9.9 | 24.1 | 27.1 | 31.4 | 10.3 | 44.4 | **25** |
| May | -15.5 | -22.9 | -22.8 | -11.2 | -13.6 | 17 | **-12** | -10.9 | -8.3 | -7.6 | 2.9 | -3.7 | 10.6 | **-3** |
| Jun | -2.1 | -1.9 | -1.5 | 1 | 6.8 | 26.3 | **5** | -0.5 | 1.8 | 2.9 | 5.6 | 8 | 17.4 | **6** |
| Jul | -9.1 | -12.5 | -12.2 | -13.8 | -21.9 | 5.3 | **-11** | -3.1 | -0.8 | -1.1 | -11.5 | -24.5 | -9.2 | **-8** |
| Aug | -6.7 | -8.3 | -6.2 | -6.2 | -1.9 | -20 | **-8** | -6 | -8.2 | -6.1 | -2.3 | 2.8 | -48 | **-11** |
| Sep | 7.3 | 17.1 | 17.7 | 16 | 27.4 | 18.1 | **17** | 5.8 | 16.6 | 17.2 | 19.8 | 33.4 | 0.4 | **16** |
| Oct | 35.7 | 16.5 | 26.6 | 35.1 | 19.3 | 84.4 | **36** | 2.1 | 5.2 | 13 | 11.9 | 21.5 | 56.4 | **18** |
| Nov | 57.2 | 32.2 | 35.1 | 35.7 | 22.9 | 70.8 | **42** | 3.1 | 11.7 | 12.1 | 14.8 | 3.7 | 44.9 | **15** |
| Dec | 47.4 | 17.1 | 21.5 | 13.9 | 17.8 | 21.2 | **23** | 34 | 14.4 | 18.1 | 1.4 | 12.5 | 14.8 | **16** |
| **Year** | **248** | **144** | **197** | **176** | **117** | **313** | | **107** | **89** | **127** | **141** | **93** | **187** | |

*Table 9: Projected changes in monthly precipitation according to HadCM3 under SRES A2 y B2 scenarios for 2020, 2050 and 2080. $CO_2$ concentration for each scenario is also shown*

| | SRES = A2 | | | | | | SRES = B2 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Without CO2 effects | | | With CO2 effects | | | Without CO2 effects | | | With CO2 effects | | |
| Site | 2020 | 2050 | 2080 | 2020 | 2050 | 2080 | 2020 | 2050 | 2080 | 2020 | 2050 | 2080 |
| ***Maize Rainfed*** | | | | | | | | | | | | |
| SR | 8.4 | -0.2 | -1.5 | 11.8 | 9.2 | 10.1 | -4.2 | -4.7 | -1.6 | 2.5 | 2.7 | 8.4 |
| TA | -3 | -1.2 | -8.6 | 10.6 | 12.9 | 18 | -11.6 | -10.8 | -11.7 | 1.5 | 2.9 | 5.2 |
| AZ | -1.2 | 4.6 | -2.3 | 9.3 | 15.3 | 15.6 | -2.3 | 0 | -1.6 | 1.7 | 8.9 | 11.4 |
| PE | -5.5 | -3.3 | -4.5 | 0.4 | 7.7 | 11.5 | -4.9 | -6.5 | -8.7 | 0.1 | 2.5 | 5 |
| LE | -9 | 1 | -0.8 | 8.4 | 17.6 | 33.4 | -6.1 | -4.9 | -4.8 | 12.1 | 7.1 | 14.5 |
| PF | 0.2 | -5 | -4 | 5.8 | 2.3 | 8.1 | 2.7 | -0.9 | -0.8 | 10.3 | 3.9 | 6.9 |
| ***Mean*** | ***-1.7*** | ***-0.7*** | ***-3.6*** | ***7.7*** | ***10.8*** | ***16.1*** | ***-4.4*** | ***-4.6*** | ***-4.9*** | ***4.7*** | ***4.7*** | ***8.6*** |
| ***Maize Irrigated*** | | | | | | | | | | | | |
| SR | -6.5 | -14.8 | -23.4 | -4.5 | -10.4 | -15.4 | -5.8 | -11.7 | -16.4 | -4 | -8.4 | -11.4 |
| TA | -5.3 | -10.9 | -16 | -1.3 | -6.3 | -7.5 | -1.2 | -5.4 | -8.7 | 3 | -1.8 | -3.3 |
| AZ | -0.7 | -7.5 | -15.6 | 3.4 | -2.8 | -6.9 | 0.1 | -3.2 | -8.1 | 2 | 0.5 | -2.7 |
| PE | -6.7 | -14.8 | -19.8 | -4.7 | -10.4 | -11.6 | -2.4 | -12.8 | -16.1 | -0.5 | -9.5 | -11.2 |
| LE | -3.9 | -10.8 | -13 | 0.2 | -6.2 | -4.1 | -5.9 | -10.1 | -12.5 | -1.8 | -6.7 | -7.5 |
| PF | -2.7 | -9.5 | -17.6 | 1.5 | -4.9 | -9.1 | -5 | -8.8 | -9.9 | -0.9 | -5.4 | -4.6 |
| ***Mean*** | ***-4.3*** | ***-11.4*** | ***-17.6*** | ***-0.9*** | ***-6.8*** | ***-9.1*** | ***-3.4*** | ***-8.7*** | ***-12*** | ***-0.4*** | ***-5.2*** | ***-6.8*** |
| ***Soybean Rainfed*** | | | | | | | | | | | | |
| SR | 10.5 | 0.5 | -4.9 | 38.1 | 48.6 | 60.1 | -8.5 | -3.8 | -6.5 | 14.1 | 34.9 | 42.3 |
| TA | 0.6 | 1.1 | -4.6 | 27.7 | 51.6 | 62.5 | -15.3 | -9.7 | -13.8 | 6.4 | 28.5 | 34.5 |
| AZ | -0.6 | -0.3 | -4.4 | 23.9 | 44 | 53.9 | 0.5 | -8.9 | -11.4 | 23.1 | 26.2 | 34.1 |
| PE | -5 | -6.9 | -22 | 17.2 | 35.3 | 26.7 | -8.7 | -13.5 | -18.3 | 10.2 | 18.8 | 22.6 |
| LE | -8.5 | 3.2 | -13.7 | 14.4 | 45 | 43.9 | -17.6 | -4.8 | -11.4 | 1.2 | 35.3 | 27 |
| PF | -4.3 | -17.1 | -15.7 | 20.9 | 25.5 | 43.2 | 1.8 | -4.3 | -9.8 | 26.8 | 33.3 | 38.6 |
| ***Mean*** | ***-1.2*** | ***-3.2*** | ***-10.9*** | ***23.7*** | ***41.7*** | ***48.4*** | ***-8*** | ***-7.5*** | ***-11.9*** | ***13.6*** | ***29.5*** | ***33.2*** |
| ***Soybean Irrigated*** | | | | | | | | | | | | |
| SR | 1.1 | 0.5 | -3.8 | 20.7 | 34.7 | 39.5 | 5.2 | 0 | 0.3 | 23.9 | 28.2 | 37 |
| TA | 0.2 | 1.7 | -0.1 | 18.8 | 35.8 | 43.1 | 2.3 | 0.5 | 1.9 | 19.7 | 27.7 | 38.1 |
| AZ | -1.5 | -0.7 | -3.1 | 17.9 | 34.3 | 41.7 | 0.2 | -1.9 | -0.9 | 18.4 | 26.4 | 36.4 |
| PE | -0.1 | -2 | -7.5 | 17.9 | 30.5 | 32.9 | 0.1 | -1.7 | -3.9 | 16.8 | 24.6 | 29.9 |
| LE | -2.6 | -1.7 | -5.6 | 14.2 | 29.3 | 32.3 | -1.5 | -2.5 | -2.9 | 14.2 | 22.2 | 29.1 |
| PF | 1.2 | -0.8 | -7.7 | 16.4 | 25.6 | 24.3 | -2.7 | -0.3 | -5 | 10.7 | 21.6 | 21.8 |
| ***Mean*** | ***-0.3*** | ***-0.5*** | ***-4.6*** | ***17.7*** | ***31.7*** | ***35.6*** | ***0.6*** | ***-1*** | ***-1.7*** | ***17.3*** | ***25.1*** | ***32.1*** |

*Table 10: Relative changes (%) in irrigated and rainfed maize and soybean yields for each site under the different climatic scenarios and time periods, with and without considering CO2 effects.*

| **Site** | **AR-AZ** | | **AR-PE** | | **AR-TA** | | **UY-LE** | |
|---|---|---|---|---|---|---|---|---|
| | Mean | S.Dev. | Mean | S.Dev. | Mean | S.Dev. | Mean | S.Dev. |
| **Scenario** | ---------------------------kg Dry Matter /ha ----------------------------------- | | | | | | | |
| 1930-1960 | 4950 | 367 | 6539 | 577 | 4358 | 292 | 6828 | 470 |
| 1970-2000 | 5433 | 385 | 6960 | 553 | 4662 | 364 | 7088 | 487 |
| LARS | 5639 | 239 | 7551 | 703 | 6028 | 317 | 7213 | 472 |
| Hadley A2 | 5913 | 574 | 7003 | 607 | 4812 | 422 | 7573 | 640 |

*Table 11: Changes in pasture yields (kg dry matter / ha) for 4 sites and 2 observed climate scenarios (1930-1960 and 1970-2000) and two generated climate change scenarios (LARS and Hadley center GCM)*

## 10.2 Figures

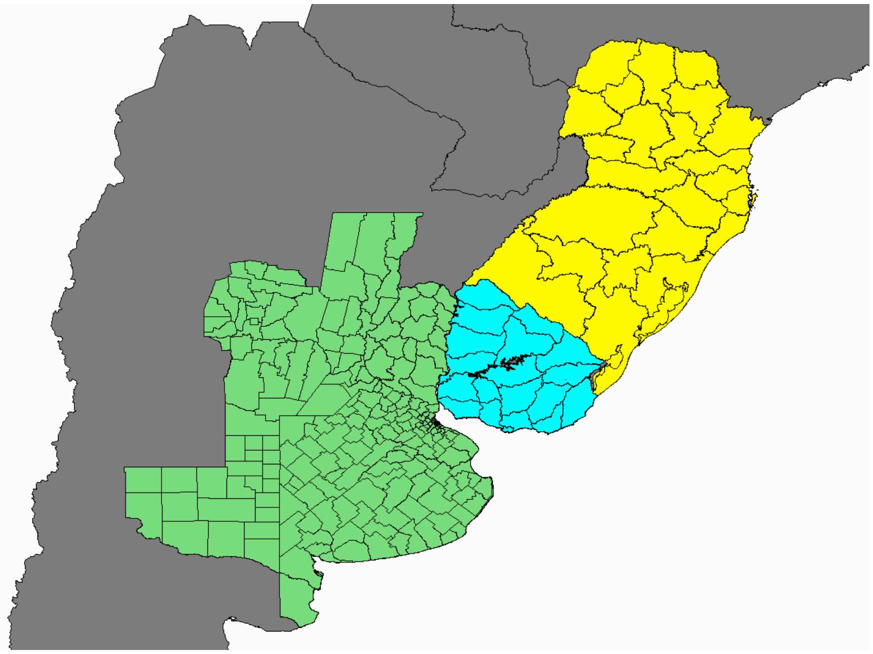


*Figure 1: Map of the study region*

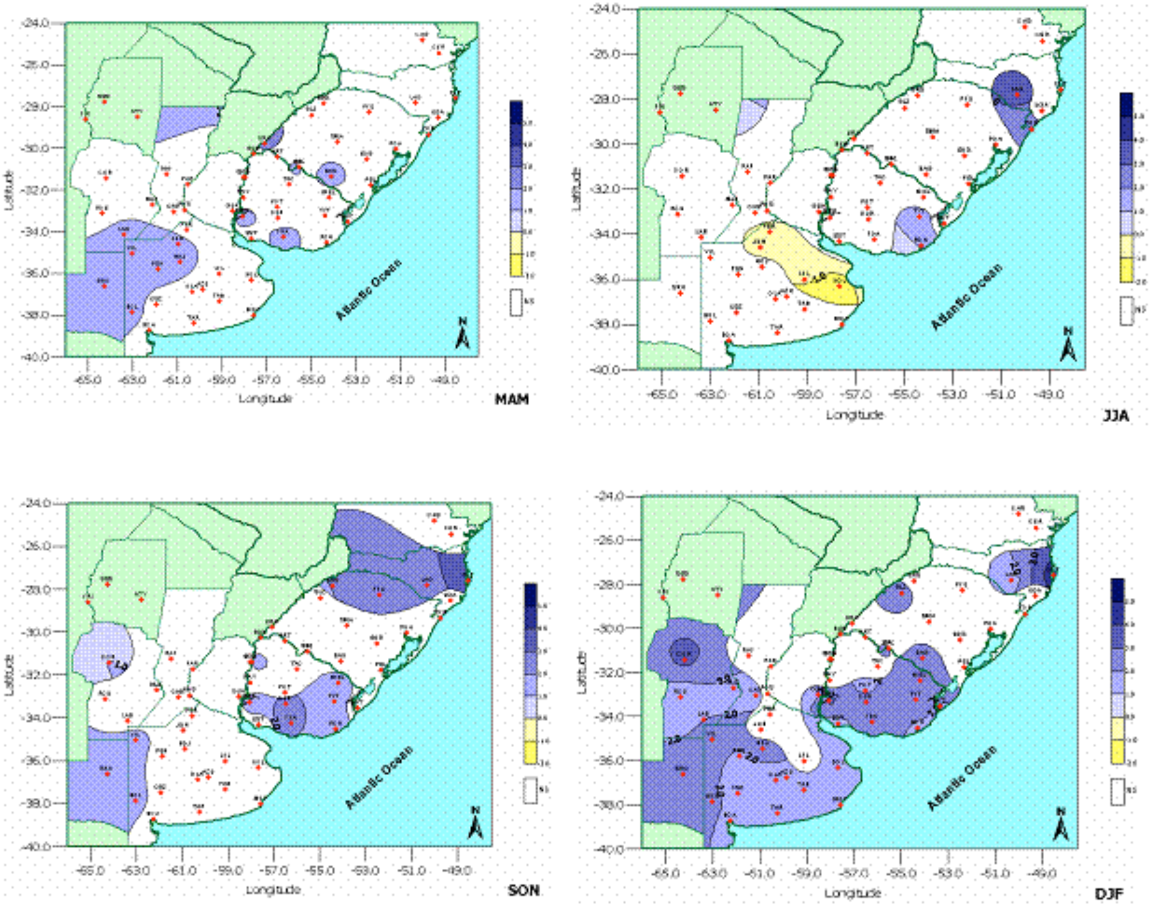


*Figure 2a: regression coefficients of changes in climate per trimester during 1930-2000 – Precipitation*

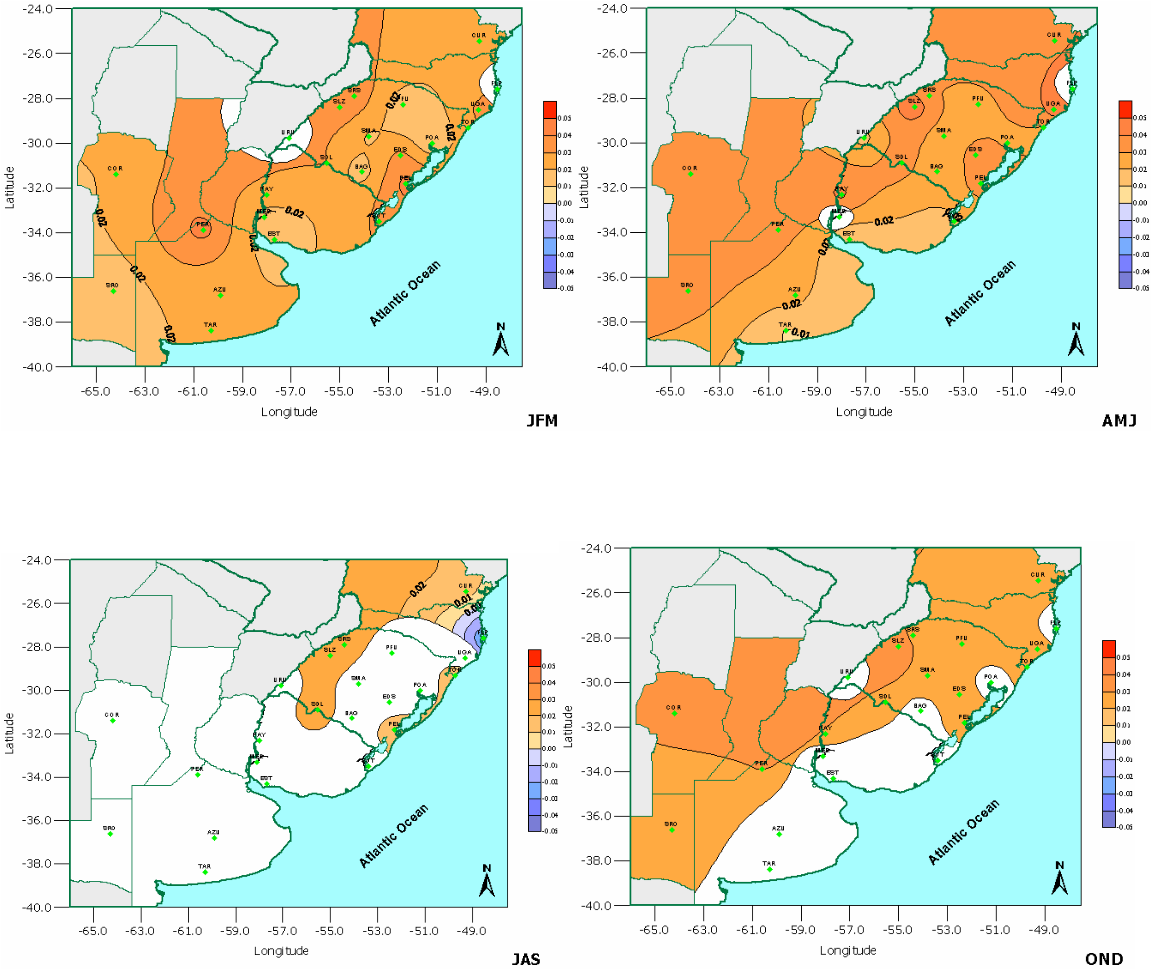


*Figure 2b: regression coefficients of changes in climate per trimester during 1930-2000 – Minimum temperature*

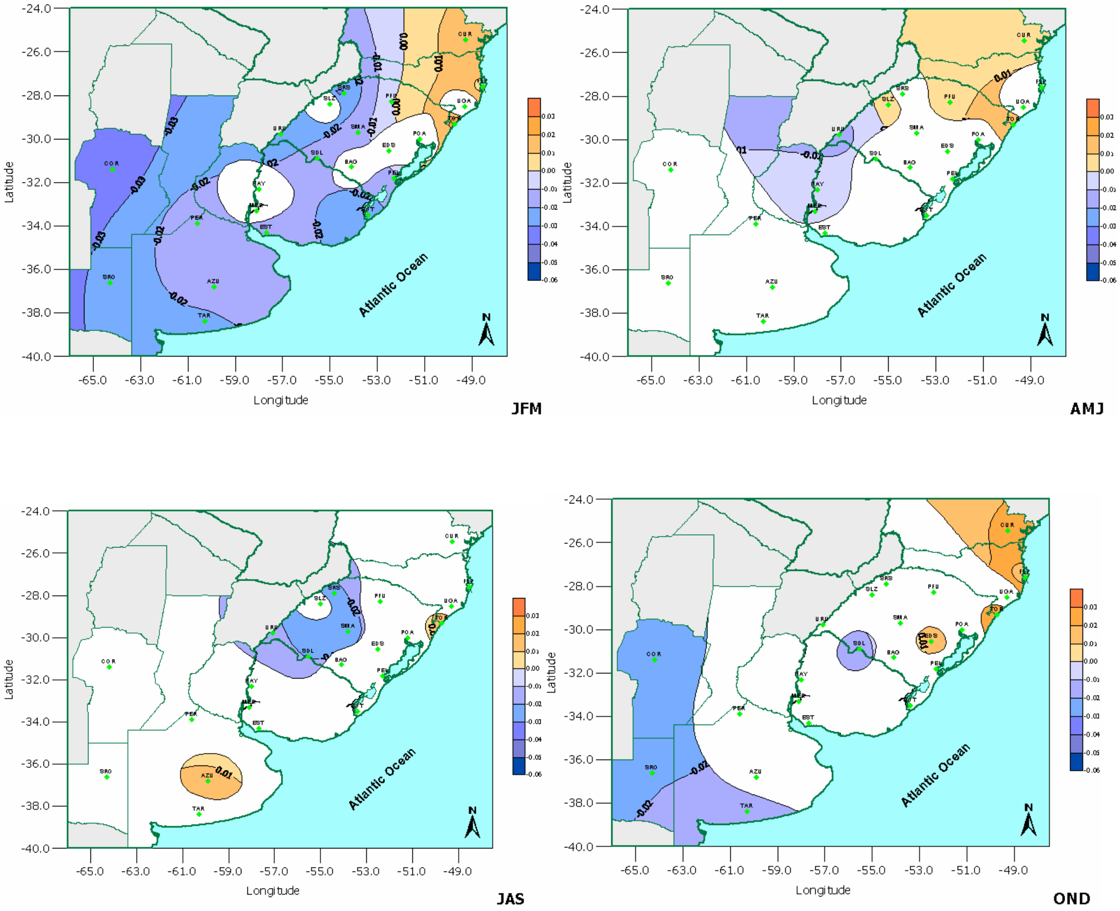


*Figure 2c: regression coefficients of changes in climate per trimester during 1930-2000 – Maximum temperature*

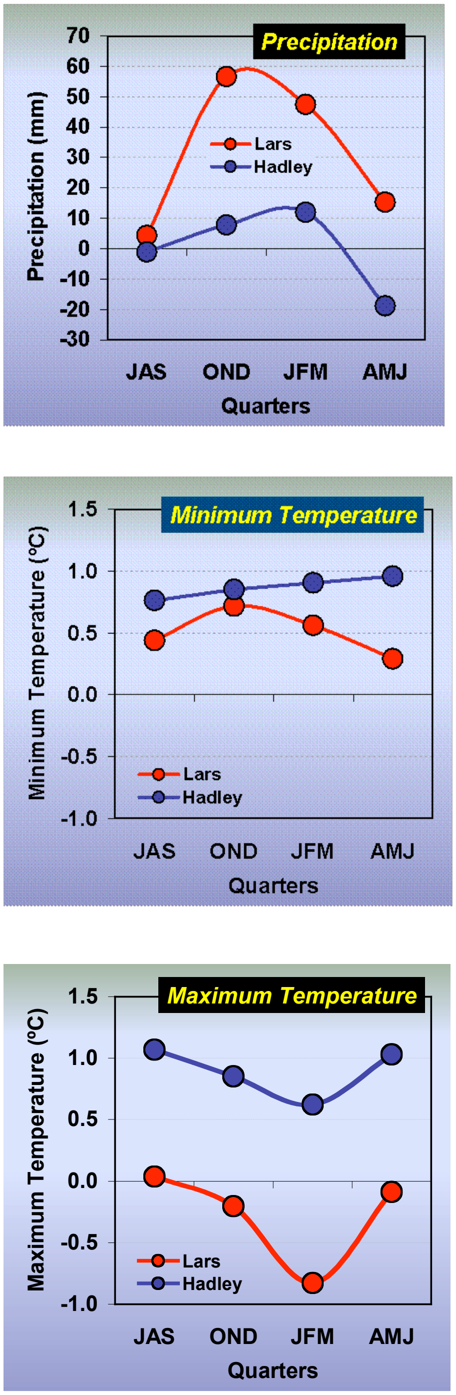
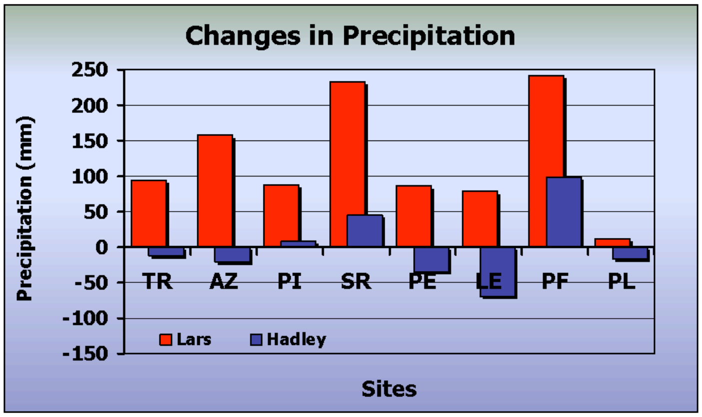
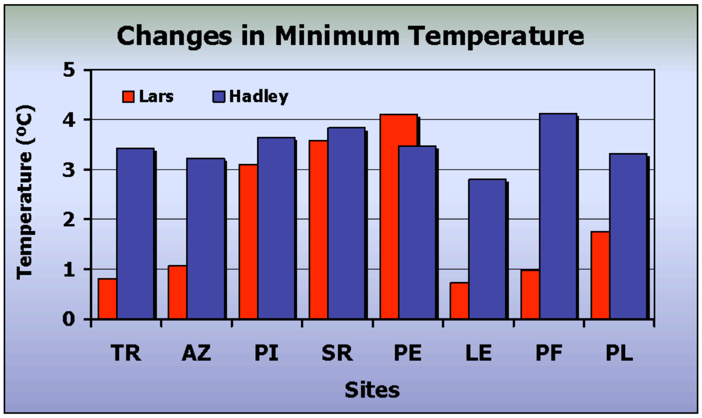


*Figure 3: Changes in climate as projected by the Hadley GCM and using a weather generator (LARS) based on continuing the trends in the observed climate in 1930-1961 vs 1970-2000. Results of mean values from 8 sites*





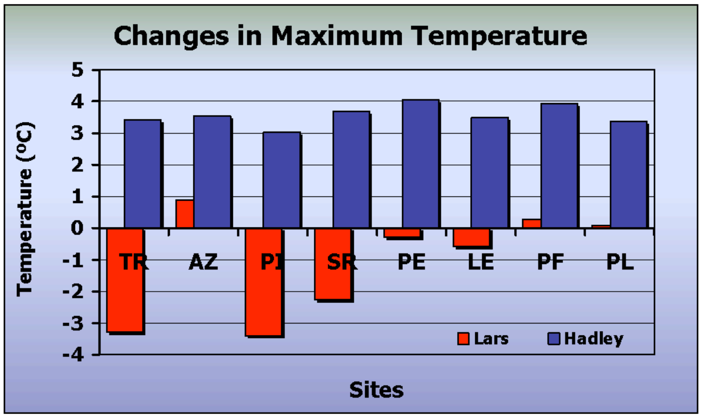


*Figure 4: Changes in climate as projected by the Hadley GCM and using a weather generator (LARS) based on continuing the trends in the observed climate in 1930-1961 vs 1970-2000. Results from 5 sites in Argentina (TR, AZ, PI, SR, PE), 1 in Uruguay (LE) and 2 in Brazil (PF, PL).*

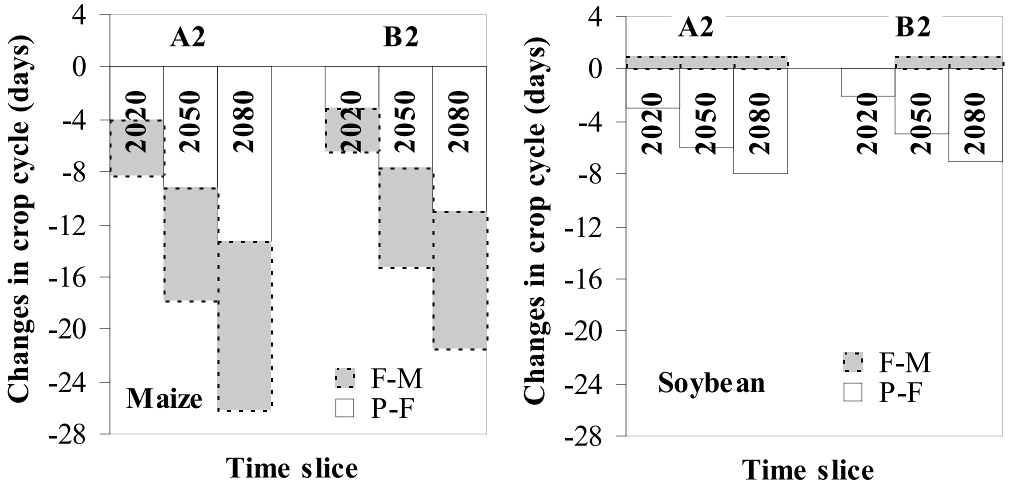


*Figure 5: Changes in the duration of planting-flowering (P-F) and flowering-maturity (F-M) periods, expressed as mean values for the 6 sites, for maize and soybean crops under different SRES scenarios and time periods.*

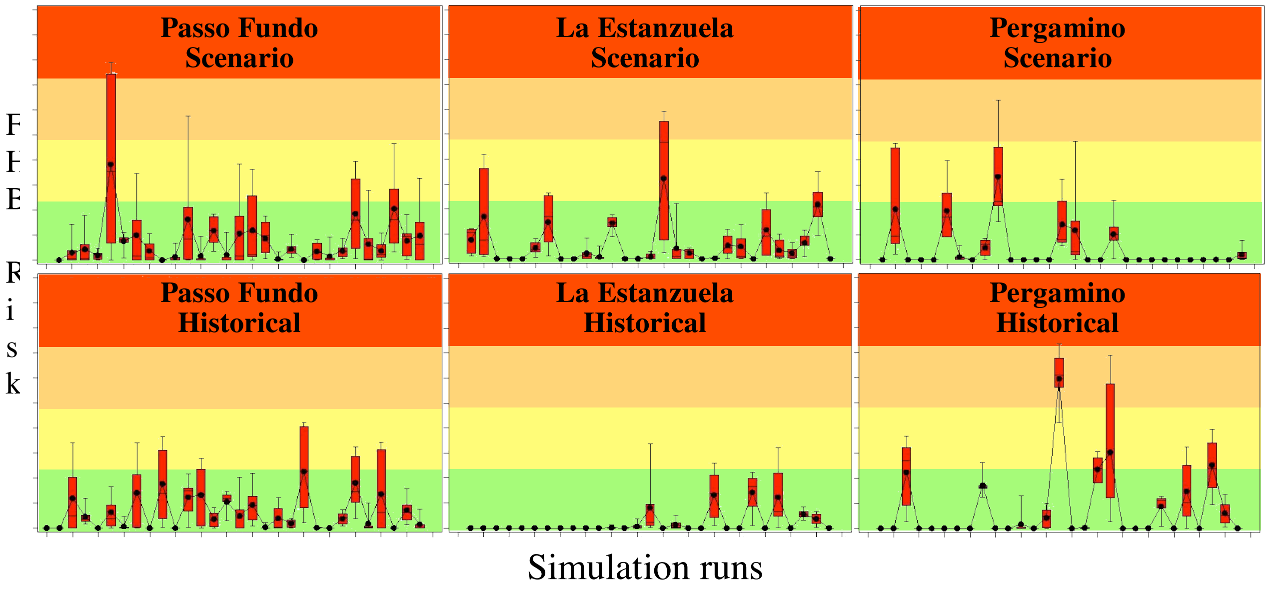


*Figure 6. Simulated Fusarium Head Blight incidence under a scenario and historical weather data from three sites (Passo Fundo, Brazil; La Estanzuela, Uruguay and Pergamino, Argentina).*

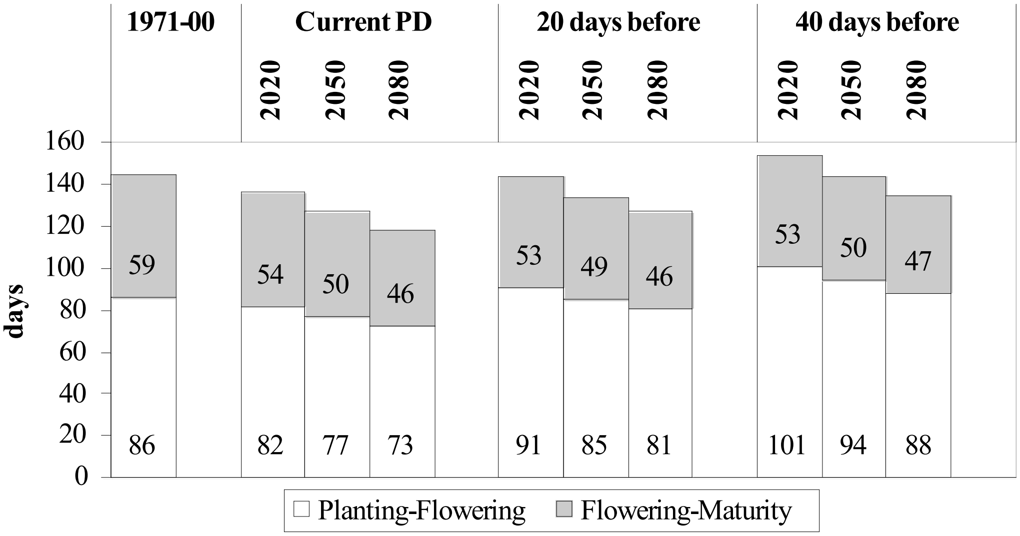


*Figure 7: Length of planting-flowering and flowering-maturity periods for maize planted at current date (Current PD), and 20 and 40 days before; under SRES A2 scenario for the years 2020, 2050 and 2080.*

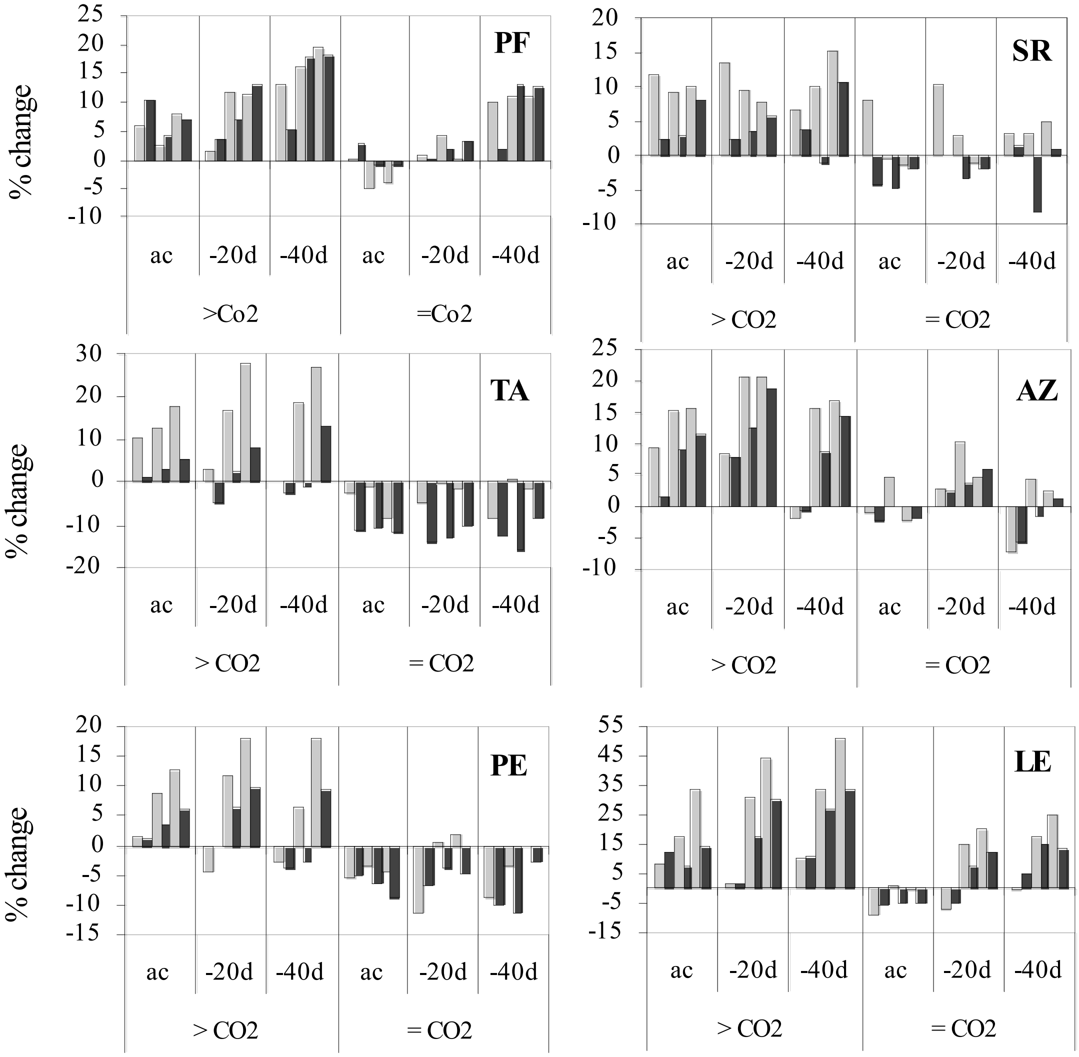


*Figure 8: Maize yield changes (%) for different planting dates (current, -20 and -40 days) in the six sites under different scenarios (A2 in grey, B2 in black) and CO2 concentrations*

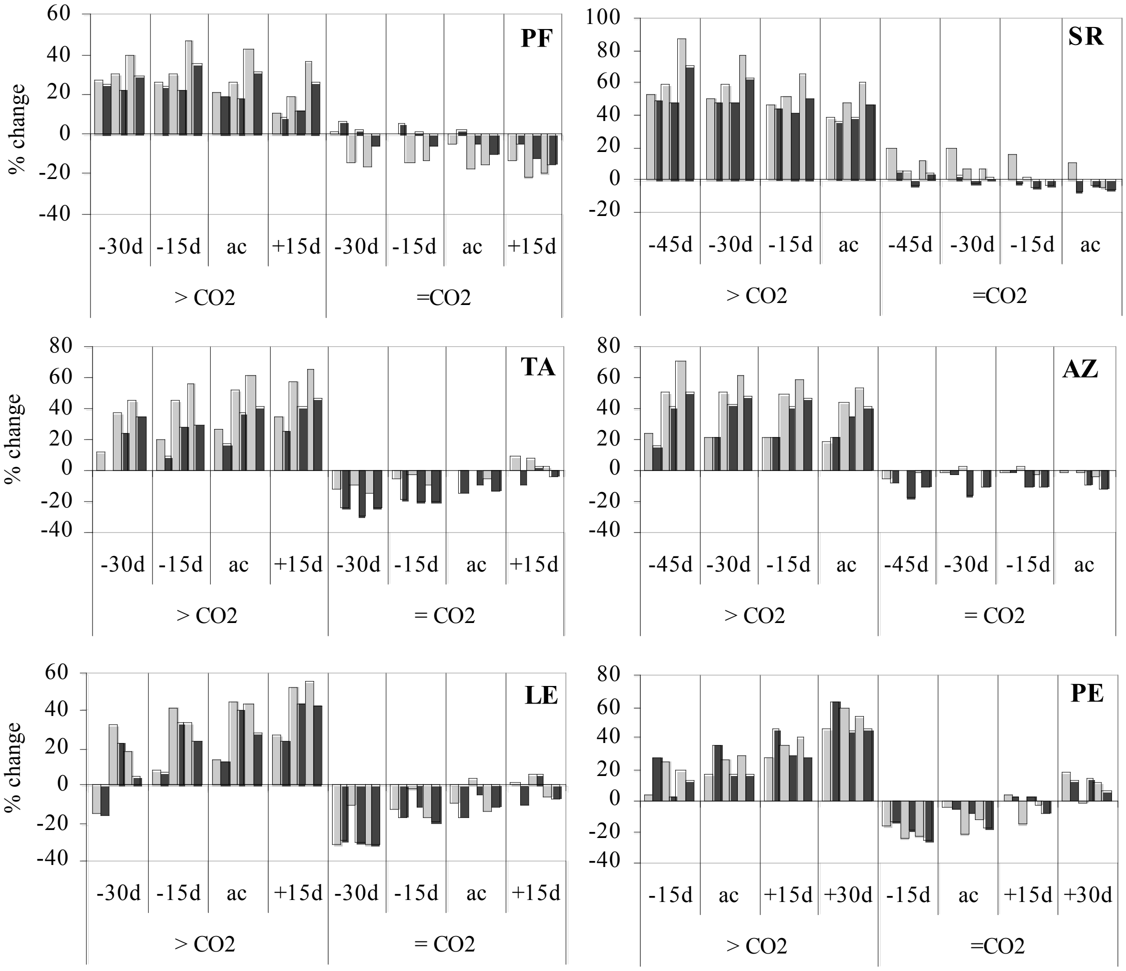


*Figure 9: Soybean yield changes (%) for different planting dates (current, +/- 15, 30 days) in the six sites under different scenarios (A2 in grey, B2 in black) and $CO_2$ concentrations*

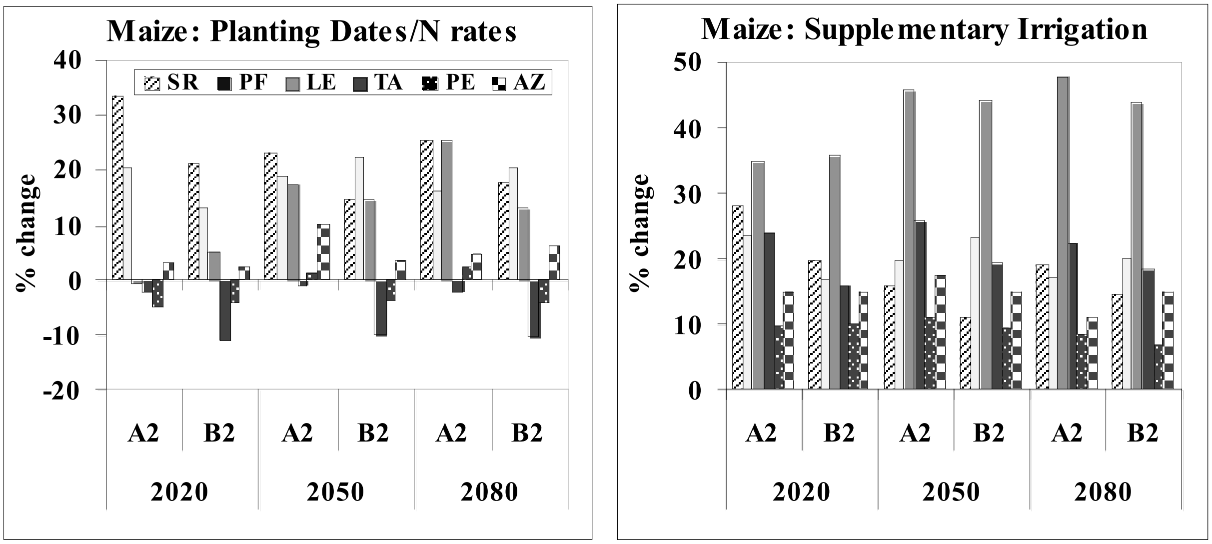


*Figure 10: Adaptation measures for maize: yield change (%) under optimal planting dates/nitrogen rates and supplementary irrigation for the six sites under current $CO_2$.*

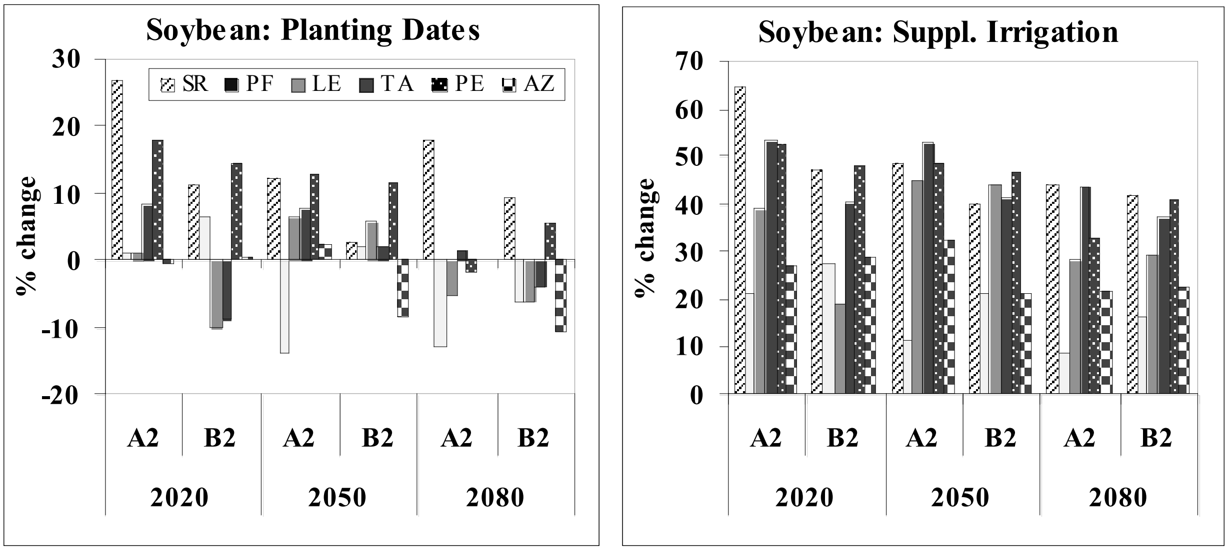


*Figure 11: Adaptation measures for soybeans: yield change (%) under optimal planting dates/nitrogen rates and supplementary irrigation for the six sites under current $CO_2$.*

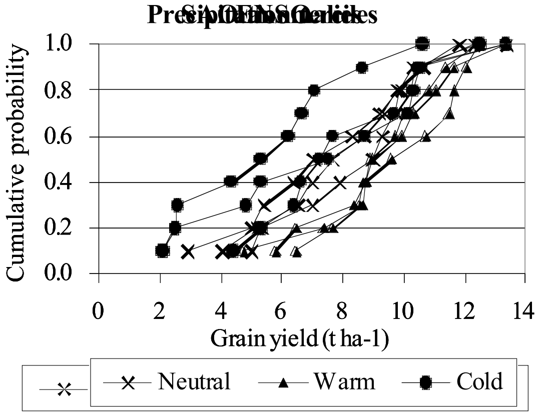


*Figure 12: Cumulative probability for simulated grain yields for each of weather category.*

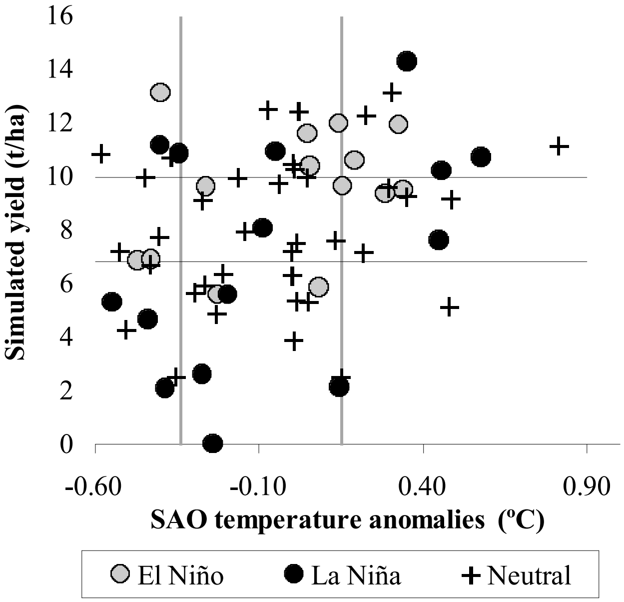


*Figure13: Relationship between simulated maize yield and South Atlantic Ocean surface temperature anomalies.*

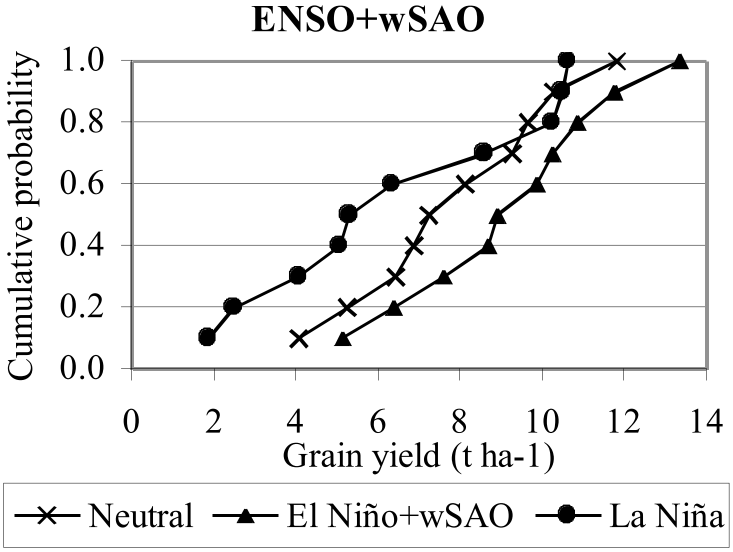


*Figure 14: Cumulative probability for simulated grain yields for ENSO+warm SAO forecast*

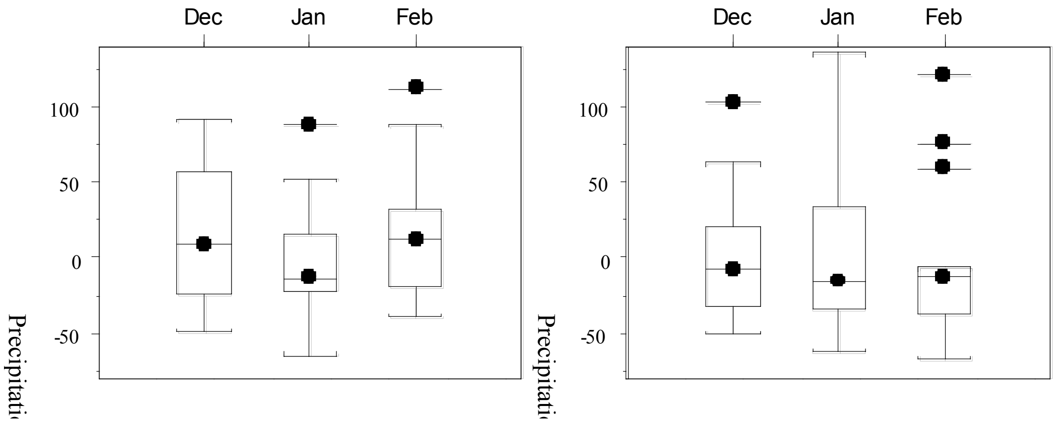


*Figure 15: Precipitation anomalies during December, January and February for El Niño years (a), and Warm SAO years (b).*

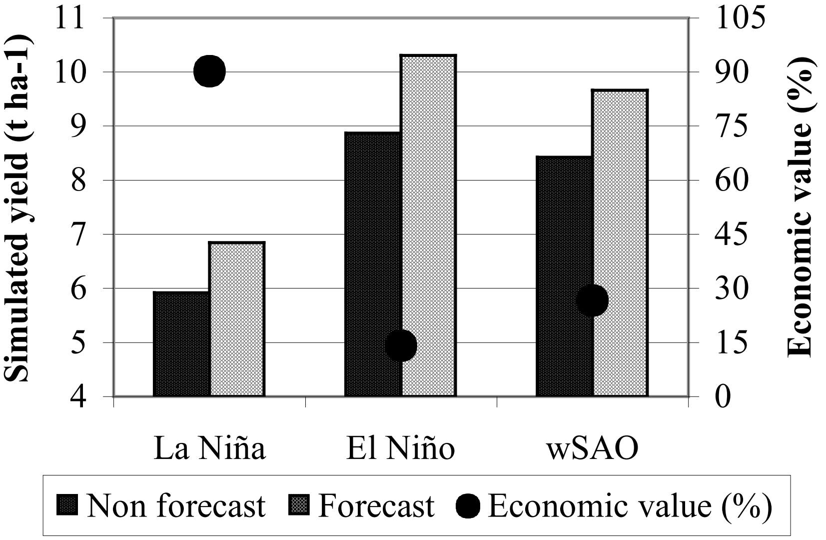


*Figure 16: Predicted yields and economic value of ENSO-SAO climate forecast.*

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