Instrument: **SP1 Cooperation**

Thematic Priority: **Priority Area 1.1.6.3 "Global Change and Ecosystems"**

FP7 Collaborative Project – Grant Agreement 212492

CLARIS LPB
A Europe-South America Network for Climate Change Assessment and Impact Studies in La Plata Basin

DELIVERABLES

D8.4: The agricultural sector: Modeling of climate change impacts on crop yield and adaptation strategies

Due date of deliverable: Month 42

Start date of project: **01/10/2008** Duration: **4 years**

Organization name of lead contractor for this deliverable: ZALF

Deliverable No	Deliverable title	WP	Lead beneficiary	Estimated indicative person-months (permanent staff)	Nature	Dissemination level	Delivery date
D8.4	The agricultural sector: Modeling of climate change impacts on crop yield and adaptation strategies	WP8	P3 - ZALF	76.80	R	PU	42

BRIEF REPORT OF DELIVERABLE 8.4

Climate is the main input and limiting factor of agricultural systems. Increasing the prediction capacity of climate change impacts for stakeholders has become a major challenge in La Plata Basin, which economic wealth strongly depends on agriculture. In this region, the agricultural landscape have faced major changes during the last 30 years due to new technologies for crops, to a strong increase in cereal and oil crop world demand and also to favorable climate conditions. As result, yields increased in the former crop land and, pushed by world`s demand for agricultural products, favored the expansion of cereal and oil crops to other marginal areas, which can also be the most vulnerable ones.

As forecast, the world demand for cereal and oil crops (and derived products) is likely to increase by 75% in the next decades, considering both the growing demand for food and biofuel. This will increase even more the importance of the agricultural sector, so as its vulnerability to climatic factors.

The objective of this work is to analyze the main current cropping systems of major socio-economic relevance and perform simulation studies for different climate scenarios using a decision support system (DSSAT) for agricultural significant study sites within the basin. The vulnerability of these sites and the crops cultivated to climate variability will be analyzed. Projection of cropping systems under climate change forcing, sustainability of present cropping systems and adaptation strategies will be discussed and analyzed.

Data of main agricultural productions was collected in order to identify the main crops in the selected study sites within LPB, namely Chapeco and Passo Fundo in Brazil, San Justo, Balcarce and Junin in Argentina.

. Two weather inputs were used in the simulations: (i) RCM`s available at CLARIS LPB CLDAC and (ii) actual weather series changed using the incremental method. RCM`s were evaluated against observed weather data. Simulations were run with observed weather data (1960-1990 period) and with RCM`s series (also for 1960-1990 period). The RCM`s were not satisfactorily match the results generated with observed data, the next step was used the Bias Correction method, and the data generated will be employed as weather input on Crop Models.

The main agricultural products from the study sites are summer crops with a predominance of maize and soybeans.

For maize, the simulations results derived from the selected RCM`s showed some level of uncertainty, restraining the possibility of more solid integrated analysis.

Although the variability presented, some patterns can be identified, as: (i) reduction in yields of the earlier planting dates in Chapeco; (ii) a difference in crop response related to site-specific conditions, when Chapeco presented a higher range of yields when compared to Passo Fundo; (iii) the RCM`s presented a lower disagreement for Passo Fundo region, especially in the late planting dates; (iv) the variety AS1548 presented a lower disparity in yields generated with the RCM`s than the MPA01. For soybeans, the RCM`s showed a lower level of disagreement when compared with maize.

The results identified in this analysis suggest, for Chapeco, (i) a reduction in yields for all scenarios, so as (ii) higher losses in early and late planting dates. For Passo Fundo region the scenarios (i) present not only reduction, but also increments in yield, so as (ii) almost the same pattern of yield related to planting date.

The results obtained for maize yield in Argentina, with the RCM`s (time series of 1960-1990), showed a high level of disagreement when compared with simulations run with observed data (1960-1990). Also this pattern of variability was found in all study sites and for maize and soybean.

For the Argentina´s environments, this disagreement was important for San Justo and Junín at the end of the century (2071-2100) with a high reduction in yield, while Balcarce environment shown increment in yield in the most of RCMs, also in the first period (2011-2040).

These results showed that yield would increase from the San Justo environment to Balcarce environment, from warmer to cooler sites. Junin showed an intermediate response, where 4 RCMs increased yield, basically during the early planting dates.

In San Justo environment early planting dates as adaptation strategy will allow mitigating the climate change impact. In Junin and Balcarce environments, early planting dates will increase the yield compare to the actual yield.

In soybean, for both future periods, the earlier planting dates, 01 and 15 August, all RCMs shown higher yields compared with the results of observed values. The yield variability is higher in Balcarce environments for both periods, basically at the end of the century. The slope of response to planting date for each environment showed a particular different pattern, where the San Justo environment presented an optimum planting window between October 15 and November 15. Junin and Balcarce environments presented a linear response and a linear-plateau response respectively, according to the delay in the planting date.

1. INTRODUCTION

Climate change is of global concern, and regardless of all the initiatives and scientific advances to understand and forecast changes, the determination of future climate is still a very hard task. The high level of complexity and the nature of climatic interactions is a challenge to forecasting, although there are scenarios that point to possible directions of change. The Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (Parry et al., 2007) predicts that food production around the world could suffer a dramatic impact in the coming decades due to climate change caused by global warming. The increase in temperature threatens the cultivation of several crops and may worsen the already serious problem of hunger in the most vulnerable parts of the planet. Poor countries of Africa and Asia would be most affected, but big agricultural producers like Brazil will also feel the impacts of climate change (Assad and Pinto, 2008).

The impact of climate change on agricultural production is actually the core issue of several investigations. The accumulation of carbon dioxide (CO_2) and other greenhouse gases in the atmosphere at unprecedented rates will cause increased radiative forcing (Le Quere et al., 2009; Shindell et al., 2009). The continued emissions of greenhouse gases will also promote an increase in annual temperatures by 2.5°C to 4.3°C in important crop-growing regions of the world by 2080 to 2099, according to the A1B scenario of the Intergovernmental Panel on Climate Change (IPCC) (Christensen et al., 2007). Growing season temperatures are expected to increase more than the annual averages, with reduced precipitation expected to accompany higher temperatures in some regions. Additionally, heat waves are expected to increase in frequency, intensity, and duration (Christensen et al., 2007; Tebaldi et al., 2006). End-of-century growing season temperatures in the tropics and subtropics may exceed even the most extreme seasonal temperatures measured to date (Battisti and Naylor, 2009). Not considering all the inherent variability of crop production factors, all climate changes described above can lead to modifications of maize yields, posing a threat to agricultural systems that will affect the whole maize production and consumption chain, impacting especially agroecosystems and populations with low availability of or access to financial and natural resources. The global food and financial crises of 2007 and 2008, which have pushed an additional 115 million into hunger, highlight the severity of the hunger and poverty crisis that has challenged the world for decades (Viatte et al., 2009). Price volatility remains a concern, with weather-related yield variability the main threat as long as stocks remain low (OECD et al., 2012). This risky situation will be worsen by the present effects of drought on maize and soybean yields of USA (UNL, 2012), which will impact the whole world food supply.

The assessment of risk from climate change is constrained mainly by the availability of long-term weather data and the reliability of the climate change projections. Crop models usually require long-term weather data to test their prediction ability and also to account for natural climate variability. However, as stated by Tsuji et al. (1998), at most sites the length of observed weather data record is insufficient for such analyses, preventing agricultural scientists and other potential users from utilize crop simulation models. Besides that, there are also issues related to the uncertainty of scenarios of climate change (Visser et al., 2000).

Increasing the prediction capacity of climate change impacts for stakeholders has become a major challenge in La Plata Basin, covering an area of about 3 million km² (Tucci and Clarke, 1998), and including parts of five countries (Argentina, Bolivia, Brazil, Paraguay and Uruguay), which economic wealth strongly depends on agriculture (AQUASTAT, 2010). In this region, the agricultural landscape have faced major changes during the last 30 years due to new technologies for crops, to a strong increase in cereal and oil crop world demand and also to favorable climate conditions with increases of about 20%-30% in annual precipitation over large parts of the basin (Magrin et al., 2005). That precipitation change increased the yields in the former crop land and, pushed by world`s demand for agricultural products, favored the expansion of cereal and oil crops to marginal areas, being also the most vulnerable ones. As forecast, the world demand for cereal and oil crops (and derived products) is likely to increase by 75% considering both the growing demand in food and biofuel (Food and Agriculture Organization of the United Nations, 2011).

Crop models can be a useful tool to assess the influence of climatic and other environmental or management factors on crop development and yield (Batchelor et al., 2002; Challinor and Wheeler, 2008; Dhakhwa et al., 1997; Hoogenboom, 2000; Reidsma et al., 2010), although the validation at regional levels is still not satisfactory (Tubiello and Ewert, 2002). The Decision Support System for Agrotechnology Transfer – DSSAT v. 4.5 contains the Crop System Model CERES – Maize model (Jones et al., 2003). The DSSAT is one of the most known decision support systems among crop modelers (Rivington and Koo, 2011), with registered users in more than 100 countries, and is used to a) determine best planting dates (d'Orgeval et al., 2010; Soler et al., 2007), b) for fertilization timing (Asadi and Clemente, 2001), c) in precision agriculture (Thorp et al., 2008), and d) also for detecting/investigating potential impacts of climate change on agriculture (Fischer et al., 2005; Jones and Thornton, 2003; Lobell and Burke, 2010). In the embedded CERES – Maize model the development and growth of the crop is simulated on a daily basis from the planting until the physiological maturity. The model calculations are based on environmental and physiological processes that control the phenology and dry matter accumulation in the different organs of the plant. The DSSAT also has other embedded models that can simulate the flow of nutrients and water balance in the soil. The minimum data set necessary to run DSSAT (Jones et al., 2003) consists of daily weather data of maximum and minimum temperature, rainfall and solar radiation, soil chemical and physical parameters for each layer, genetic coefficients for each cultivar with information about development and biomass accumulation, and management information, such as soil preparation, planting dates, plant density, fertilization amounts and timing or other agricultural practices. Experimental data like soil available water, plant phenology, biomass partitioning and other morphological components like leaf area index are necessary to calibrate the genetic coefficients and check the accuracy of the model.

1.1. SCENARIOS OF CLIMATE CHANGE

Climate change is a complex biophysical process. Although it is not possible to predict precise future climate conditions, there is scientific consensus that global land and sea temperatures are warming under the influence of greenhouse gases, and will continue to warm regardless of human intervention for at least the next two decades (Parry et al., 2007). Climate changes projections are very dependent on General Circulation Models (GCM), Atmosphere-Ocean Global Climate Models (AOGCM). However, the horizontal atmospheric resolution of the majority of these models is still relatively coarse, of an order of 300 km, and regional climate is often affected by forcings and circulations that occur at much smaller scale (Marengo and Ambrizzi, 2006). To increase the resolution of this information, techniques like dynamic downscaling are employed. Among different methods of downscaling, the use of experiments with numeric models over the region of interest is one of the most used. Although presenting a intense computational demand, they can obtain estimations at sub-grid level with 20 km resolution, and differently from GCM, are capable of taking into account important local forcings such as coverage of soil and topography (Cavalcanti et al., 2006).

For the study sites almost all global models analyzed by the IPCC AR4 (Parry et al., 2007) show a rainfall increase and warmer climate by the end of the twenty-first century (2071-2100). Simulations performed using three Regional climate models (Eta CCS, RegCM3 and HadRM3P) nested within the Hadley Centre Global Atmospheric Model (HadAM3P) in A2 emissions scenario showed consistently an increase in temperature by 1,5°C to 3°C, but changes in rainfall showed conflicting signals among the RCMs (Marengo et al., 2010).

1.2. IMPACTS ON AGRICULTURE

General projected changes include higher atmospheric CO_2 concentration, increases in average temperature, reduction in minimal temperatures and also changes in precipitation. The general assumption is that temperature increments in mid-latitudes may shorten the length of the growing period for crops and, in the absence of compensatory management responses, reduce yields (Porter and Gawith, 1999; Tubiello and Fischer, 2007). In contrast, a higher concentration of CO2 should increase photosynthesis efficiency and water use efficiency (Asseng et al., 2009). In conclusion, the impacts of climate change on crops yields will be the result of a balance between these negative and positive effects on plant growth and development (Magrin, 2005). Until the present, different groups, using distinct models and scenarios, run simulations of future climate in the Brazilian part of La Plata Basin, and all of them suggest an increase in total precipitation, increase of temperature and increase of minimum temperature (Bates et al., 2008; Cavalcanti et al., 2006; Cavalcanti and Vasconcelos, 2009; Lagos and Sanchez, 2008; Marengo, 2008b; Parry et al., 2007; World Bank, 2009). This can change the area of cultivation by rendering unsuitable some currently cultivated areas and suitable other not currently cultivated. More specifically, cropping patterns i.e. crop preferences may change due to local alterations in growth conditions. As an example, the Pampa's region, in Argentina, experienced an increase in precipitation during the last 30 years, which increased yields of soybean, maize and wheat on 38%, 18% and 13% respectively (Magrin et al., 2005).

As an approach to assess the impact of climate change on crops and areas currently suitable for agriculture, several crop models and decision support systems have been developed. These systems encompasses process-based computer models that predict growth, development and yield as function of local weather and soil conditions, crop management scenarios and genotypic information (Jones et al., 2001). To generate this information, an input of daily weather data, soil profile information, crop management data and crop responses (genetically determined) of each variety are necessary. The outputs are normally compared with local experimental data in order to evaluate model performance and determine the genetic characteristics of local varieties (Jones et al., 1998). For this work, simulations of the impacts of different climatic scenarios on major crops of the study sites were done using RCM and the incremental method.

1.3. ADAPTATION STRATEGIES

Adaptation or mitigation to climate change aims to mitigate and develop appropriate coping measures to address the negative impacts of climate change on agriculture. Most agricultural systems have a measure of in-built adaptation capacity ("autonomous adaptation") (Reilly and Schimmelpfennig, 2000) but the current rapid rate of climate change will impose new and potentially overwhelming difficulty on existing adaptation capacity (Ziervogel et al., 2008). This is particularly true given that changes induced by climate change are expected to undermine the ability of people and ecosystems to cope with, and recover from, extreme climate events and other natural hazards. To deal with this question the IPCC promotes "planned adaptation", deliberate steps aimed at creating the capacity to cope with climate change impacts (Parry et al., 2007). So, climate adaptation should focus on support for the decision-making and capacity building processes that shape social learning, innovation, development pathways and technology transfer. Adaptation is most relevant when it influences decisions that exist irrespective of climate change, but which have longer-term consequences (Stainforth et al., 2007). As part of adaptation strategies, climate-resilient crop varieties can have reduced losses and could be cultivated in areas that are not currently suitable or that will become unsuitable (Lane and Jarvis, 2007). The large majority of actual crop varieties have been bred for improved resistance to pests and diseases, with an intense narrowing of its genetic basis and reduction of the plasticity to adapt to different environments. Yet it is claimed that abiotic stress is the primary cause of crop loss, reducing average yields of most major crops by more than 50% (Lane and Jarvis, 2007; Wang, 2005). This proportion will probably rise with increasing irregularity of climate and higher frequency of extreme climate events. In terms of agricultural management strategies, the adjustment of planting date is known to be of central importance for agricultural productivity (Banterng et al., 2010; Kamara et al., 2009; Laux et al., 2010), particularly for temporary crops like maize, soybeans and wheat, which have low or no phenological plasticity.

To cope with this situation, crop models help to identify the impacts of climate change on the current agricultural systems, identify important characteristics in crops (for example higher thermal sum requirements) and also identify the varieties that can perform better in future scenarios. Another important tool for mitigation or adaptation is the management of planting date: by changing it, the timing of crops will be altered, avoiding the exposition of the crop to droughts or frosts at most susceptible stages, for example.

The main objectives of deliverable 8.4 are:

- Analysis of current cropping systems of major socio-economic relevance in LPB;
- Simulation of impacts of forcing scenarios on major crops of selected regions;
- Elaboration and assessment of adaptation strategies for selected crops and regions.

2. CASE STUDIES

Five representative sites in the LPB where selected for a deep analysis of the major crops in each region. Two regions of Brazil and three regions in Argentina where chosen. The regions were selected based on availability of data for simulations studies *Figure 1*.

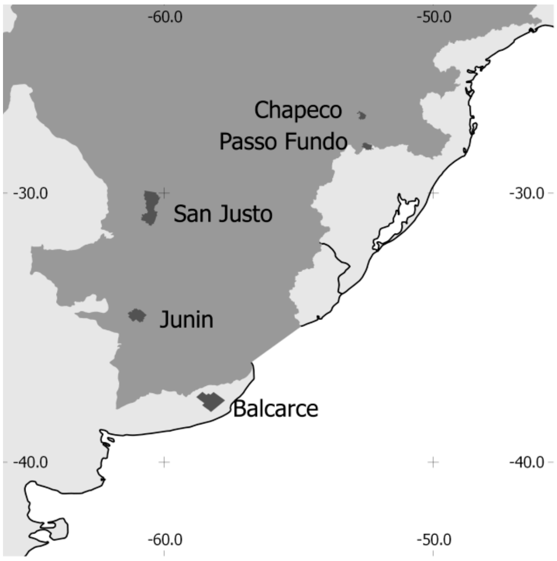

Figure 1. Map showing the LPB and the study sites in Argentina and Brazil.

2.1. Chapecó, Santa Catarina State, Brazil;

Chapecó region is located in Santa Catarina State, Brazil, and can be characterized by small rural establishments (more than 60% of all rural establishments have less than 10 ha - *Figure 2*) in a sloppy landscape. The farms are usually operated by the family, and production is more or less diversified with a strong component of subsistence agriculture. The land use in the region (*Figure 3*) is dominated by pastures, followed by land devoted for temporary crops. Other land uses such as permanent crops, forests, timber and aquaculture occupy no more than 13,5% of the land. However, as the use of pastures as cropland during the summer is widespread and dynamic, a clear characterization of the land use in the region is not precise. The main agricultural productions (*Table 1*) are soybeans and maize, produced mainly as feed for the intense livestock production that takes place in the region, especially poultry and pigs. Wheat, beans and cassava are the other main crops in the region, considerably less representative than soybeans and maize. Depending on environmental conditions farmers can grow up to three crops per year in the same area: wheat winter, soybeans in late spring and maize in midsummer. Other classic crop sequences are winter – soybeans, fallow – soybeans – maize and soybeans – maize. For this reason the sum of main crops area (24050 ha, according *Table 1*) is always superior to the area dedicated for temporary crops (11038 ha, *Figure 3*). It is also important to remark that no-tillage is used in 46.63% of the land dedicated for temporary crops (IBGE, 2010).

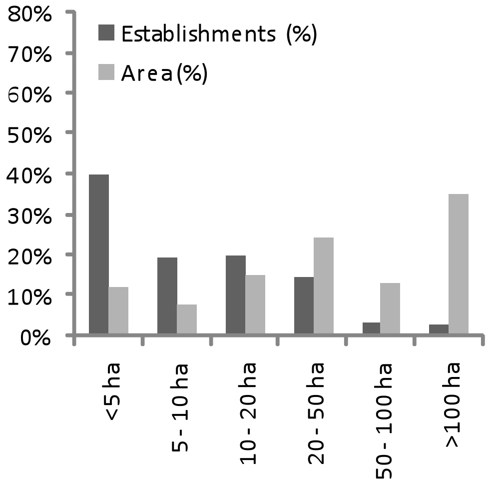

Figure 2. Percentage of number of rural establishments and area occupied according size categories in Chapecó. Source: IBGE (2012).

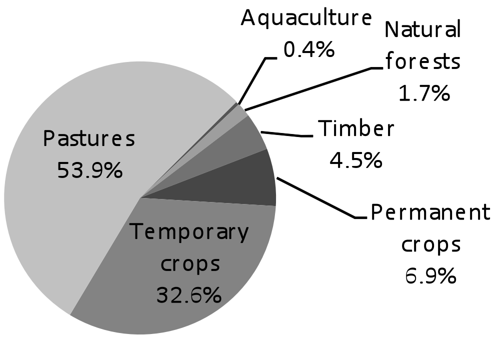

Figure 3. Share of main rural land use categories in Chapecó according 2006 agricultural census. Total area: 33859 ha. Source: IBGE (2012).

Main crops	Harvested area (ha)	Yield (kg.ha^{-1})
Soybeans	10000	3120
Maize	8800	5800
Wheat	3500	2700
Beans	1500	1427
Cassava	250	18000

Table 1. Top five crops cultivated in Chapecó including harvested area (ha) and average yields (in kg) in 2010. Source: IBGE (2012).

2.2. Passo Fundo, Rio Grande do Sul State, Brazil;

Passo Fundo is located in Rio Grande do Sul State, Brazil, and is characterized by an almost equal proportion of rural establishments according farm size (*Figure 4*). The farms, as in the case of Chapecó, are in their majority run by the family. The production is focused in few commodities, mainly for export. The land use in the region (*Figure 5*) is dominated by temporary crops (88.5%), followed by pastures (10,1% of the total land use) and other minor fractions of timber and permanent crops (circa 1.4%). This land use share shows how intensive is farming in the region. Soybean is by far the main agricultural production (IBGE, 2012); the area of wheat, the second main crop, is more than 12 times smaller than the one of soybean. Oats are the third main crop in the region, followed by maize and barley. So as in the Chapecó region, double or even triple cropping can take place depending on the environmental local conditions. An indication of this multiple cropping system is that the five main crops in *Table 2* can be divided in winter crops (wheat, oats and barley) and summer crops (soybeans and maize). In this region, according dada from IBGE (2010), more than 88% of cropland is cultivated under no-tillage systems.

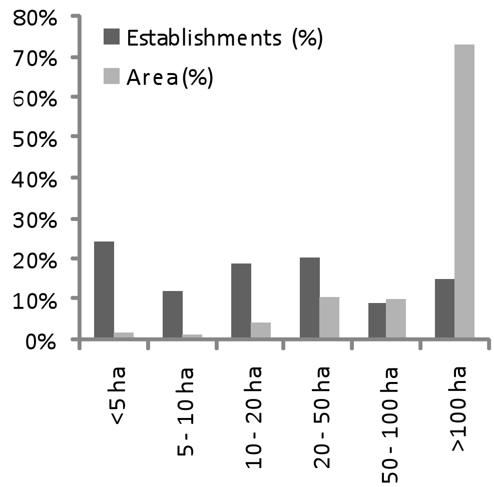

Figure 4. Percentage of number of rural establishments and area occupied according size categories in Passo Fundo. Source: IBGE (2012).

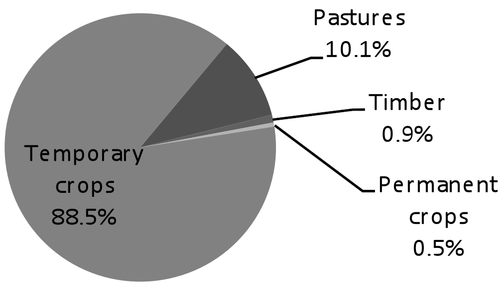

Figure 5. Share of main land use categories in Passo Fundo according 2006 agricultural census. Total area: 54000 ha. Source: IBGE (2012).

Main crops	Harvested area (ha)	Yield (kg.ha^{-1})
Soybeans	38300	2700
Wheat	3000	3600
Oats	2600	3000
Maize	2000	8100
Barley	600	3000

Table 2. Top five crops crops cultivated in Passo Fundo including harvested area (ha) and average yields (in kg) in 2010. Source: IBGE (2012).

2.3 Junín and Balcarce, Buenos Aires Province, Argentina

The Argentine environments are located in the main region of agriculture production with intensive land use pattern, and farms size are divided in <500 hectares, between 500-2500 hectares, and between 2500-10000, most of the land is used for cereals and oil crops production, and the lowlands are used for pasture (Figure 6). In the Buenos Aires province more than 70% of farms area is less than 500 ha, (Figure 7) where the main crops are cereals and oil crops with more than 62% of the planted area and pasture are in 36% of the land (Figure 8).

Wheat is the predominant cereal crop with 70% of cereal area, and maize is the second crop with 22%, the soybean is the principal oil crops in the region with 74% of oil crops production area, and sunflower are the second important oil crop with 26% of the total oil crops hectares planted (Figure 9)

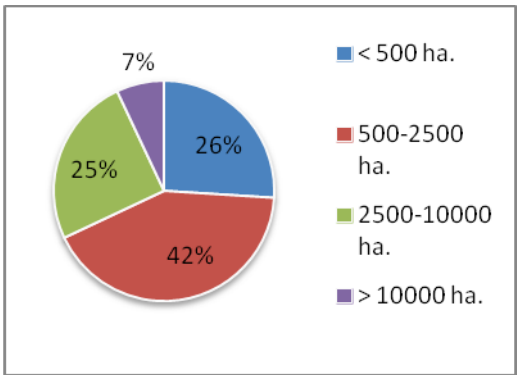

Figure 6: Distribution of land extension in the main provinces (Buenos Aires, Córdoba and Santa Fe). Source: INDEC/Agricultural census 2002.

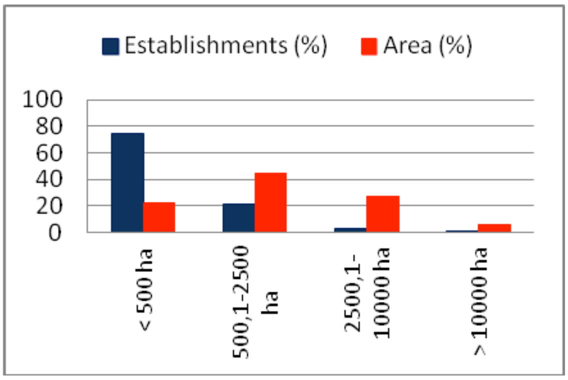

Figure 7: Percentage of number of rural establishments and area occupied according size categories in Buenos Aires Source: INDEC/Agricultural census 2002.

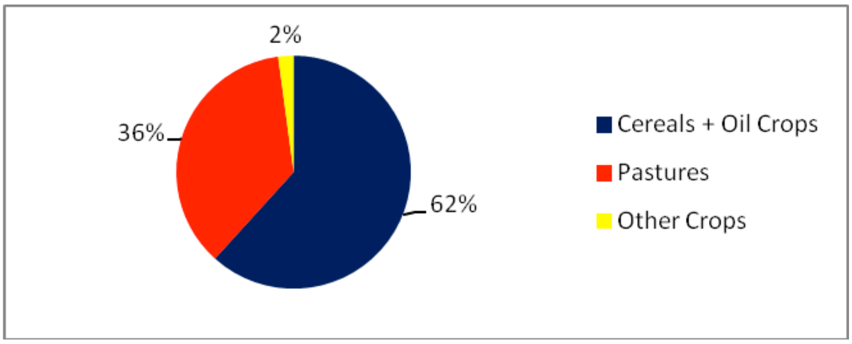

Figure 8: Share of main land use categories in Buenos Aires according 2002 agricultural census. Source: INDEC 2012.

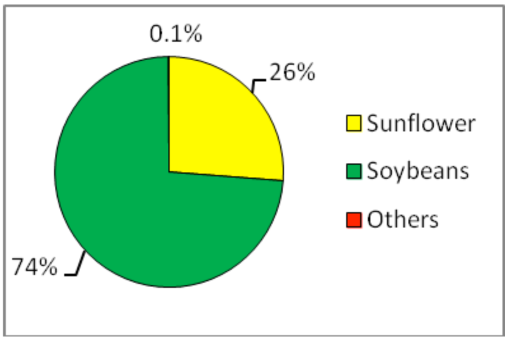

Figure 9: Share for Oil Crops in Buenos Aires INDEC/Agricultural census 2002.

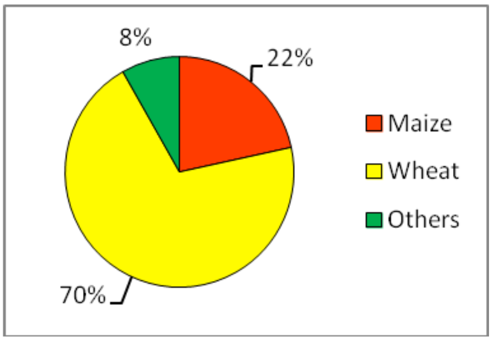

Figure 10: Share for cereals in Buenos Aires. . INDEC/Agricultural census 2002

Junín environment showed higher yields for the main crops as soybean, maize, sunflower and wheat as well as more intensive land use for soybean and maize, and Balcarce environment presented more wheat and sunflower production area (table 3 and 4).

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Main Crops	Harvested area (ha)	Yield (Kg.ha-1)
Soybeans	146700	3600
Maize	22000	9108
Wheat	30500	5577
Sunflower	800	3000

Table 3. Top four crops cultivated in Junín including harvested area (ha) and average yields (in Kg ha^{-1}) in 2010-11. Source SIIA (2012).

Main Crops	Harvested area(ha)	Yield (Kg.ha^{-1})
Soybeans	54200	1976
Maize	7200	7453
Wheat	40020	5345
Sunflower	23250	2800

Table 4. Top four crops cultivated in Balcarce including harvested area (ha) and average yields (in Kg ha^{-1}) in 2010-11. Source SIIA (2012)

2.4 San Justo, Santa Fe Province, Argentina

San Justo environment is located in the north part of Santa Fé province with most of the farms with less than 500 hectares (Figure 11), with 77% of land use with cereals and oil crops and 21% with pasture (Figure 12). Wheat occupied 64% of the land for cereal production, and maize 29% with average yield close to 2900 kg ha-1, and 6200 kg ha-1, respectively (Table 4 and figure 13). Soybean is a very important oil crop for this region, and 97% of the oil crop production area is occupied by this crop, and the average yield is close to 2550 kg ha-1 (Table5, and figure14)

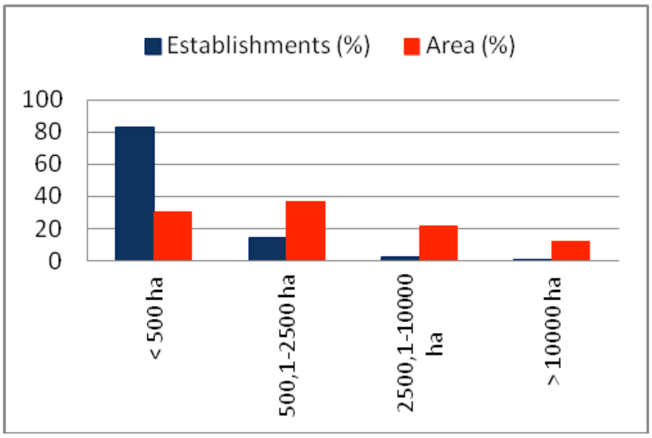


Figure 11: Percentage of number of rural establishments and area occupied according size categories in Santa Fe. Source: INDEC/Agricultural census 2002.

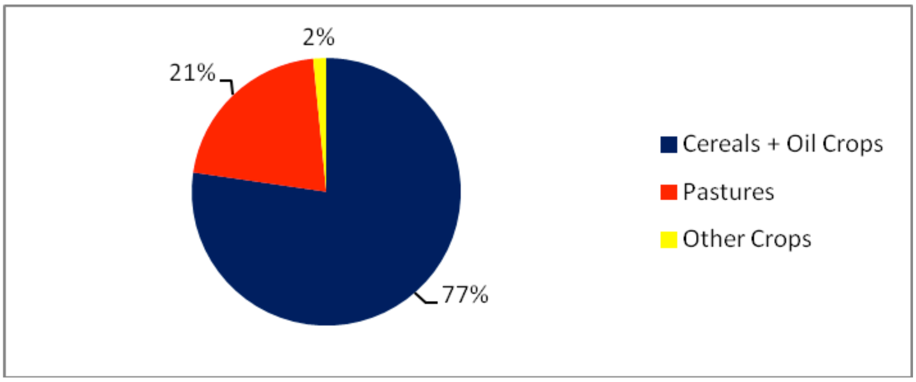


Figure 12: Share of main land use categories in Santa Fe according 2002 agricultural census. Source: INDEC 2012.

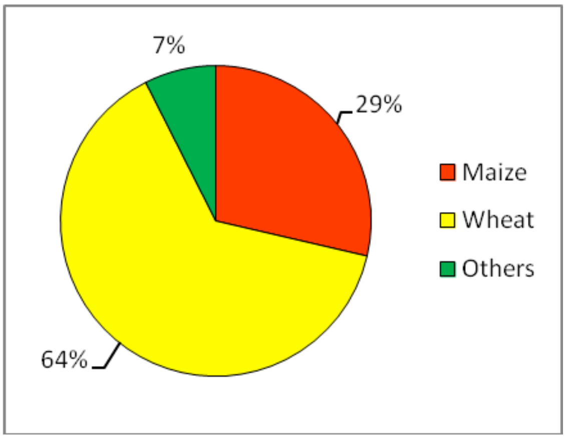


Figure 13: Share for cereals in Santa Fe. INDEC/Agricultural census 2002.

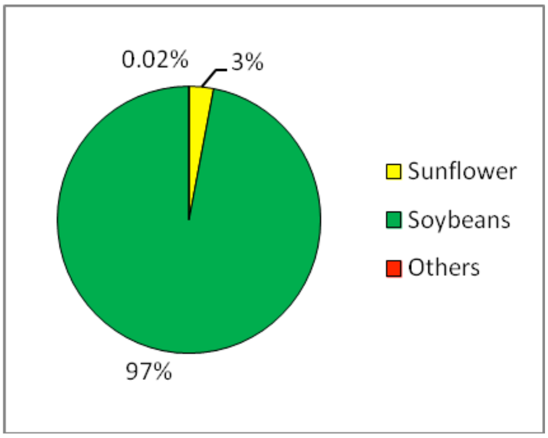


Figure 14: Share for Oil Crops in Santa Fe. INDEC/Agricultural census 2002.

Main Crops	Harvested area (ha)	Yield (Kg.ha-1)
Soybeans	370000	2554
Maize	44000	6210
Wheat	79000	2892
Sunflower	3200	1500

Table 5. *Top four crops cultivated in San Justo including harvested area (ha) and average yields (in Kg ha^{-1}) in 2010-11. Source SIIA (2012).*

3. MATERIALS AND METHODS

3.1. MODEL CALIBRATION AND VALIDATION

3.1.1. Maize

In order to ensure the DSSAT correct simulation, field experiments were set up in different locations of Brazil and Argentina to obtain the standard crops genetic coefficients recommended by He et al. (2010) and proceed with the model validation. In Brazil, one field experiment was done in the Western part of Santa Catarina State during the 2010-2011 crop season. Four varieties of maize were tested: three open pollinated varieties (MPA01, Ivanir and Fortuna) and one commercial hybrid (AS 1548). The variety MPA01 development started in 1999 by an intercross of 25 varieties (commercial hybrids, landraces and local varieties) using recurrent convergent–divergent selection in a participatory process with small farmers, as described by Kist et al. (2010); the variety Ivanir is the result of a farmer mass selection from an uncontrolled mixture of varieties; the variety EPAGRI Fortuna is an open-pollinated variety developed from six different hybrids by the Agricultural Research and Rural Extension Enterprise of Santa Catarina State and is adapted for low to medium input farming systems (Vogt et al., 2011). The AS1548 is a commercial short season simple hybrid from the AGROESTE Company. The field experiment was conducted according the recommendations of Boote (1999) and Soler et al. (2007), and the validation was done using observed data from different field experiments (Balbinot Jr et al., 2005; Balbinot Jr et al., 2007; Mergener, 2007; Ogliari et al., 2007; Vogt et al., 2011) containing all required data set for model validation (Hunt et al., 2001). The DSSAT was then instructed to simulate the same observed situations, and the results were compared with observations *Table* .

Table 6. Calculated statistics RMSE, CRM, IA and averages of anthesis day, maturity day and yield of four maize varieties during validation.

	Variety	RMSE	CRM	IA	Simulated (average)	Observed (average)
Anthesis (days after planting)	AS1548	2.9%	-0.01	0.93	71	70
	IVANIR	6.1%	-0.04	0.81	76	73
	FORTUNA	2.4%	-0.01	0.99	80	79
	MPA	6.1%	-0.04	0.81	76	73
Maturity (days after planting)	AS1548	3.1%	0.03	0.57	129	132
	IVANIR	2.8%	0.00	0.60	131	131
	FORTUNA	12.9%	-0.06	0.56	145	137
	MPA	2.4%	-0.02	0.67	143	140
Yield (kg/ha^{-1})	AS1548	10.9%	0.09	0.74	4729	5201
	IVANIR	39.8%	-0.31	-0.61	5892	4490
	FORTUNA	13.1%	0.02	0.87	5901	6044
	MPA	12.5%	-0.08	0.78	5762	5347

For the three environments in Argentina the CERES-Maize Model was calibrated and evaluated since 1991, in several experimental Station in a wide range of soils type and weather situations. During these years, 35 cultivars were characterized in different experiment and different environment in order to get the genetic coefficient for each cultivar. In the process of evaluated cultivar, the fitness between the observed values for yield, silking date and physiological maturity date, were 10% of normalized mean square error (nsqrt). Also, in the process of model evaluation, farmers field were used to validate the observed vs simulated values for yield, and phenology. In this study, the hybrid DK 670 was used in the three environments and for all planting dates simulated.

3.1.2. Soybean

In order to run simulations for soybeans data from field experiments and literature were used. For simulation in the Brazilian sites data from literature was obtained from Dallacort et al. (2008), which conducted experiments in Parana State evaluating four soybean varieties. The varieties were characterized, calibrated and validated for the CROPGRO-soybean (Banterng et al., 2010). The four varieties, namely CD 202, CD 204, CD 206 and CD 210, were tested for both Brazilian sites using census data and generic agronomic management. The two varieties (CD202 and CD204) with lowest RMSE for yield were selected to run further analysis.

In Argentina, as the CERES-Maize Model, the soybean model CROPGRO was evaluated and calibrated since 1991 with the same methods than for maize, as well as evaluated in farmers field, with similar results and the fitness of observed and simulated values were 10% of normalized mean square error. In this study, two maturity group (MG) were used, DM 4800 MG IV for San Justo and Junín environment and DM 3800 MG III for Balcarce environment.

3.2. CLIMATE SCENARIOS

Two approaches will be used regarding climate scenarios: the first one, using downscaled scenarios from RCM`s for the 2011-2040 and 2071-2100 periods; and the second one, using the incremental method on series of observed weather.

3.2.1. Regional Circulation Models

After calibrating and validating the genetic parameters and the model itself, scenarios provided by CLARIS LPB Project WP5 were downloaded and formatted for the DSSAT standard using Weatherman Software (Wilkens, 2004). From the CLARIS-LPB Project Data Archive Center seven weather series of RCM`s (and matching the same location of the study sites weather stations) were downloaded, converted and adjusted to be used as weather input for DSSAT using Weatherman software (Wilkens, 2004). The RCM`s are RCA1, RCA2 and RCA3, from the Rossby Centre Regional Climate model (SAMUELSSON et al., 2011); PROMES, from Universidad de Castilla-La Mancha (Domínguez et al., 2010); LMDZ version 4 Configuration South America with IPSLA1B and EC5OM-R3 boundaries, from Laboratoire de Meteorologie Dynamique (Hourdin et al., 2006); and ETA, from Instituto Nacional de Pesquisas Espaciais (Marengo et al., 2012). Due their high complexity and variation from site to site, the RCM`s will not be detailed here: further information about each one can be obtained from the above mentioned references.

Due to the lack of knowledge about geophysical processes , strong assumptions have to be made during the development of CGMs , in terms of squemes of parameterizations and mathematical simplification in theirs formulations.

Because of these assumptions GCMs not simulate climate variables accurately and there is a difference between the observed and simulated climate variables. This difference is known as BIAS. It is very important to remove the bias from GCM output to Project the future climate scenario accuratly to be used for impact studies.

The methodology used (Li et al.(2010)) is a quartile bases mapping method on cumulative distribution functions of observed, current climate (RCM) , and projected scenario (RCM) .

“The basic principle, regardless of the complexity of the statistical model, is to establish a statistical relationship or transfer function between model outputs and observations based on available historical data sets and then apply the established transfer function to future model projections to infer the possible trajectory of future observations.”

“The major advantage of the method is that it adjusts all moments (i.e., the entire distribution matches that of the observations for the training period) while maintaining the rank correlation between models and observations.”

Tmax,Tmin, Solar radiation:

$$\tilde{x}_{MP.adjust} = x_{MP} + F_{OC}^{-1}\left(F_{MP}(x_{MP})\right) - F_{MC}^{-1}(F_{MP}(x_{MP}))$$

Precipitation:

$$\tilde{x}_{MP.adjust} = x_{MP} * \frac{F_{OC}^{-1}\left(F_{MP}(x_{MP})\right)}{F_{MC}^{-1}(F_{MP}(x_{MP}))}$$

$\tilde{x}_{MP.adjust}$: bias corrected model projection.

x_{MP} : Value of model projection.

F_{MP} :CDF model projection.

F_{MC}^{-1} : inverse CDF model current climate.

F_{OC}^{-1} : Inverse CDF obsevations.

The crop model was run with each one of the seven RCM`s for the same 30 years of the observed data and in nine planting dates. To determine the best RCM or ensemble of RCM`s in Brazil, the maize yields were paired and compared alone and in multiple combinations of RCM (n=127) against the yields generated with observed weather. The RCM or ensemble with lowest departure from the yields obtained with observed data was selected to perform the further analysis.

3.2.1 Incremental scenarios

Scenarios were also constructed using the incremental method. This method was chosen due the lack of correct representation by GCM (general circulation models) (Barros et al., 2006) and its downscaled RCM (regional circulation models) for the study region. In this approach, the climate parameters (daily values of Tmax, Tmin, precipitation and solar radiation) are changed by realistic but arbitrary amounts. The incremental scenarios are commonly applied to study the sensitivity of an exposure unit to a wide range of variations in climate and to construct impact response surfaces over multivariate climate space (McCarthy et al., 2001). For this deliverable, the observed weather data from agrometeorological weather stations of all study sites form the baseline data (daily observations of at least 30 planting seasons). Maximum and minimum temperatures were increased by 0.5ºC until a total increment of +5ºC (11 levels); precipitation was changed at 10% intervals, from –30% to +30% (7 levels), summarizing 77 combinations or scenarios. These changes were done in DSSAT, with the instruction "environmental modifications". These temperature and precipitation change ranges are coherent for the study region according other studies (Cavalcanti et al., 2006; Cavalcanti and Vasconcelos, 2009; Marengo, 2008a; Marengo and Ambrizzi, 2006). Solar radiation wasn't changed because the reduction of direct radiation (due clouds in the case of scenarios with positive increments of precipitation) is usually accompanied by an increase in diffuse radiation (Farquhar and Roderick, 2003), which is even more effective for photosynthesis than the direct radiation, and therefore radiation is not a significant limiting factor in the study region. The levels of CO_2 were adjusted to 430 ppm. (parts per million), a concentration expected for the for the middle of 2012-2040 period, and to 667 ppm, the average concentration of the 2071-2100 period, according the ISAM model – scenario A1B (Cubasch et al., 2001). The effect of CO_2 increment will not be discussed here, as the differences between the simulations with current level (395 ppm.) and projected level for 2040 decade (491 ppm.) did not present consistent and systematic changes. The changes in yield range from 0 to 4%, in agreement with recent studies (Leakey et al., 2006; Markelz et al., 2011).

3.3. YIELD FORECAST

To reduce inter-annual and intra-annual variation, DSSAT was run for 30 cropping seasons using the distinct weather scenarios in combination with 11 different planting dates including the present recommended planting window for soybean and maize in the study regions (01.08 until 01.01, each 15 days). The model employed the same management (fertilization, no irrigation) and environmental conditions (soil) used for model calibration. The yield base line for each planting date was calculated using observed data weather (1982-2012).

The results were plotted on a filled contour plot using SigmaPlot (Systat Software, 2006). For the effect of planting dates, simple medians of each scenario and planting date were taken.

3.4. ADAPTATION STRATEGIES EVALUATION

Two main adaptation strategies will be tested: effect of planting date and crop variety. For the Brazilian region the varieties of maize and soybeans used will be the ones calibrated in item 3.1. All simulations will run with nine (for maize) and eleven (for soybeans) planting dates, considered a broad planting date window for present. The objective is to explore a higher number of possibilities of planting dates and eventually identify, for each scenario, the best ones.

4. RESULTS AND DISCUSSION

4.1. ACTUAL WEATHER AND SCENARIOS

Charts with actual weather and scenarios for the 2011-2040 and 2071-2100 corrected with bias correction, using the delta method were done to show and compare the differences in parameters like total monthly precipitation, Tmax, Tmin and solar radiation (see 3. Materials and Methods)

4.1.1. Chapecó

For Chapecó region, all RCM`s (*Figure 15*, *Figure 16* and *Figure* ) presented a tendency of increase in Tmax and Tmin along the year, but the amplitude of change varied drastically between RCMs. Some RCM`s, like RCA2 and RCA1 presented relatively small increase in temperature (+0.8º and +1ºC, respectively) for the 2011-2040 periods, while PROMES and IPSL presented the highest increment for the same period (+1.7º and +1.5º, respectively). For the 2071-2100 period changes were more apparent: the lowest increase in average temperature was found for the RCA1 (+3.2ºC), while the highest was identified in IPSL (+4.6ºC). It is also important to pay attention to the thermal amplitude, measured between the distance of increment in Tmax and Tmin: almost all RCM`s for the so called end-of-century period (2071-2100) presented a reduction of thermal amplitude (except IPSL), especially due larger increment of Tmin than in Tmax.

More important than the annual trend of temperature is the seasonal differences, as it can exacerbate or compensate changes. It was observed a clear trend of increase in temperatures during Southern Hemisphere Spring, with scenarios like PROMES showing increments of +6ºC and +8ºC in

September for the 2011-2040 and end-of-century periods, respectively. This situation poses a risk for crops due intensification of phenology and increase in water demand.

Regarding radiation, the largest reduction was observed in the RCA1 for the 2071-2100 period (-0.4 $MJ.m^2.d^{-1}$), as the largest increase is expected in PROMES for the 2011-2040 period. In general, radiation presented a slight decrease for the 2011-2040 period (average of -0.1 $MJ.m^2.d^{-1}$), while end-of-century scenarios presented higher reductions (average of -0.7 $MJ.m^2.d^{-1}$). The causes are not clear, but one reason could be the increase on clouds, reducing direct insolation. However, the amount of radiation is actually not a limiting factor in the region.

Precipitation is by far the main climatic input for agricultural systems. For the 2011-2040 period, all RCM`s presented a reduction on monthly average, ranging from -5.2% (RCA3) to -16% (PROMESS and RCA1). For the end-of-century, RCM`s showed divergences, from reductions (-20% and -5% for IPSL and PROMES, respectively) to increments of 30% (RCA1 and RCA2). In an analog situation to temperatures, seasonal trends are more important than annual trends. Regarding monthly precipitation, all RCM`s presented differences in trends and magnitudes. ETA showed increases in precipitation in early winter, followed reduction during late winter, spring and summer for the 2011-2040 period. This pattern is then exacerbated for the end-of-century period, with intense increase in precipitation during early winter. For 2011-2040 period, IPSL showed a slight increase in precipitation during winter, followed by a reduction during early spring and a slope in November; for end-of-century period, an almost generalized reduction of precipitation, except for a slender increase during spring and early summer. The ECHAM5 RCM showed an intense variability in rainfall, alternating increases and reductions for the 2011-2040 period; for the end-of-century period, a general increase is expected, with one slope in fall and other in early spring. PROMES, for the 2011-2040 period, presented a slight increase during late fall and early winter, but followed by a strong reduction in late winter and early spring; for end-of-century, an increased variability makes it difficult to identify a pattern, except for the reduction of rainfall during late winter. The RCA1 showed a widespread reduction of precipitation, especially during winter, for the 2011-2040 period; as opposite, for the end-of-century, a general increase o precipitation is identified, except for September. The RCA2 has a similar behavior to the RCA1 for the 2011-2040 period; for the end-of-century, an increase variation can be observed, and the only clear trend is a late fall with more precipitation. The last RCM, RCA3, shows an intense variation for the 2011-2040 period, with an almost constant reduction of precipitation during winter and spring; for end-of-century, fall and winter will expect a strong reduction in precipitation, while spring and summer can expect increases in precipitation.

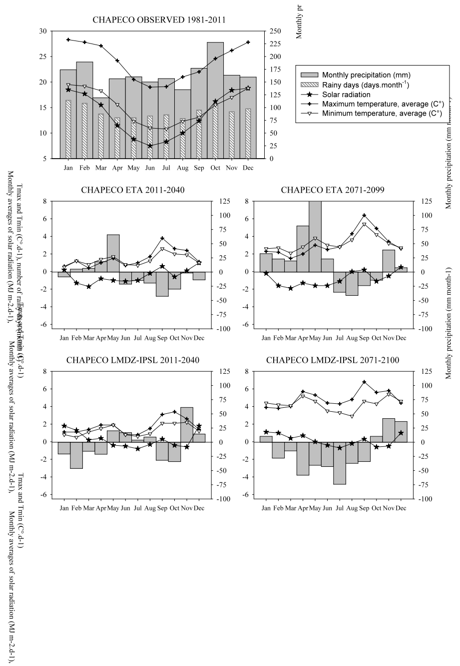


Figure 15. Charts showing the observed climate in Chapecó (1981-2011) and the departure of each RCM from the present weather of Chapecó.

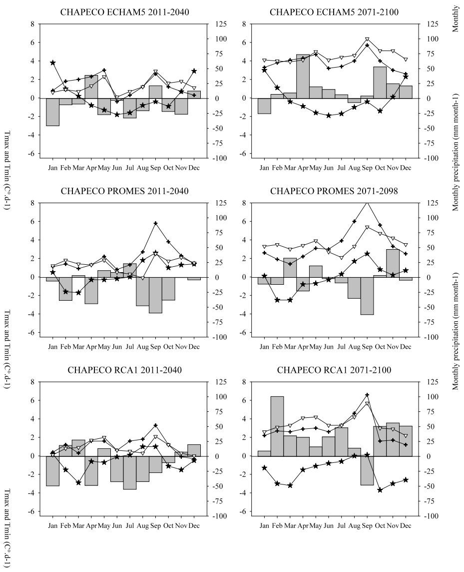


Figure 16. Charts showing the departure of each RCM from the present weather of Chapecó.

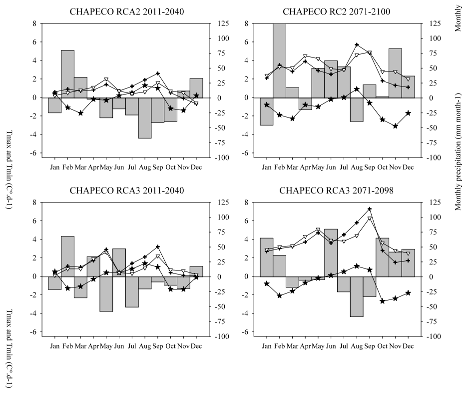


Figure 17. Charts showing the departure of each RCM from the present weather of Chapecó.

4.1.2. Passo Fundo

For Passo Fundo region, all RCM`s (**Erreur ! Référence non valide pour un signet.**, Figure19, and *Figure* ) presented a tendency of increase in Tmax and Tmin along the year, but the amplitude of change varied drastically between RCMs. Some RCM`s, like RCA2 and RCA1 presented relatively small increase in temperature (+0.6º and +0.8ºC, respectively) for the 2011-2040 periods, while PROMES and IPSL presented the highest increment for the same period (+1.6º and +1.35º, respectively). For the 2071-2100 period changes were more apparent: the lowest increase in average temperature was found for the RCA1 and RCA2 (+2.9ºC), while the highest was identified in ECHAM5 (+3.85ºC). The thermal amplitude of change, measured between the distance of increment in Tmax and Tmin showed that almost all RCM`s for all periods presented a reduction of thermal amplitude (except for IPSL and PROMES in the 2011-2040 period), especially due larger increment of Tmin than in Tmax.

More important than the annual trend of temperature is the seasonal differences, as it can exacerbate or compensate changes. It was observed a clear trend of increase in temperatures during Southern Hemisphere Spring, with scenarios presenting up +6ºC and +8ºC in September for the 2011-

2040 and end-of-century periods, respectively. This situation poses a risk for crops due intensification of phenology and increase in water demand. Generally, winter and spring are the seasons experiencing the highest increases in temperatures.

The largest reduction in radiation was observed in the RCA1 for the 2071-2100 period (-1.8 $MJ.m^2.d^{-1}$), as the largest increase is expected in PROMES for the 2011-2040 period (+0.28 $MJ.m^2.d^{-1}$). In general, radiation presented a trend of reduction during spring and summer. A slight decrease for the 2011-2040 period (average of -0.16 $MJ.m^2.d^{-1}$), while end-of-century scenarios presented higher reductions, similar to the Chapecó region (average of -0.7 $MJ.m^2.d^{-1}$). As for Chapecó, the amount of radiation is actually not a limiting factor in the region.

Precipitation is the main climatic input for agricultural systems. For the 2011-2040 period, RCM`s presented distinct effects on rainfall monthly average, ranging from -3% (PROMES) to +8% (ETA). For the end-of-century, RCM`s showed divergences, from reductions (-21% for IPSL) to increments of 30% (RCA1 and RCA2). In a similar situation to temperatures, seasonal trends are more important than annual trends. Regarding monthly precipitation, all RCM`s presented differences in trends and magnitudes. ETA showed increases in precipitation in summer and fall, followed by intense variation during spring of the 2011-2040 period. For the end-of-century period, with exception of winter, all other seasons expected an increase in rainfall, especially late summer and early fall. For 2011-2040 period, IPSL showed an intense variation, showing no pattern of change; for end-of-century period, an almost generalized reduction of precipitation is evidenced, except for a slender increase during midsummer. The ECHAM5 RCM showed an intense variability in rainfall, alternating increases and reductions for the 2011-2040 period; for the end-of-century period, a general increase is expected, especially during fall and winter. PROMES, for the 2011-2040 period, also presented intense variability: the only pattern to be identified was a reduction of precipitation during the winter and a slight increase during Springer; for end-of-century, an increased variability makes it difficult to identify a pattern, except for the reduction of rainfall during winter and increase during early spring. The RCA1 showed a widespread reduction of precipitation for the 2011-2040 period; as opposite, for the end-of-century, a general increase of precipitation is identified, except for August. The RCA2 has a similar but not so strong behavior as the RCA1 for the 2011-2040 period; for the end-of-century, an increase variation can be observed, with a trend of more precipitation. The last RCM, RCA3, shows an intense variation for the 2011-2040 period; for end-of-century, the variability is more present in spring and summer months, although may shows a high increment in precipitation.

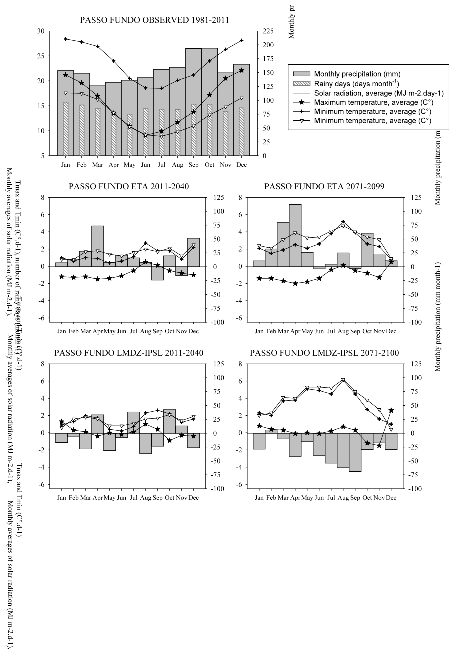


Figure 18. Charts showing the observed climate in Passo Fundo (1981-2011) and the departure of each RCM from the present weather of Passo Fundo.

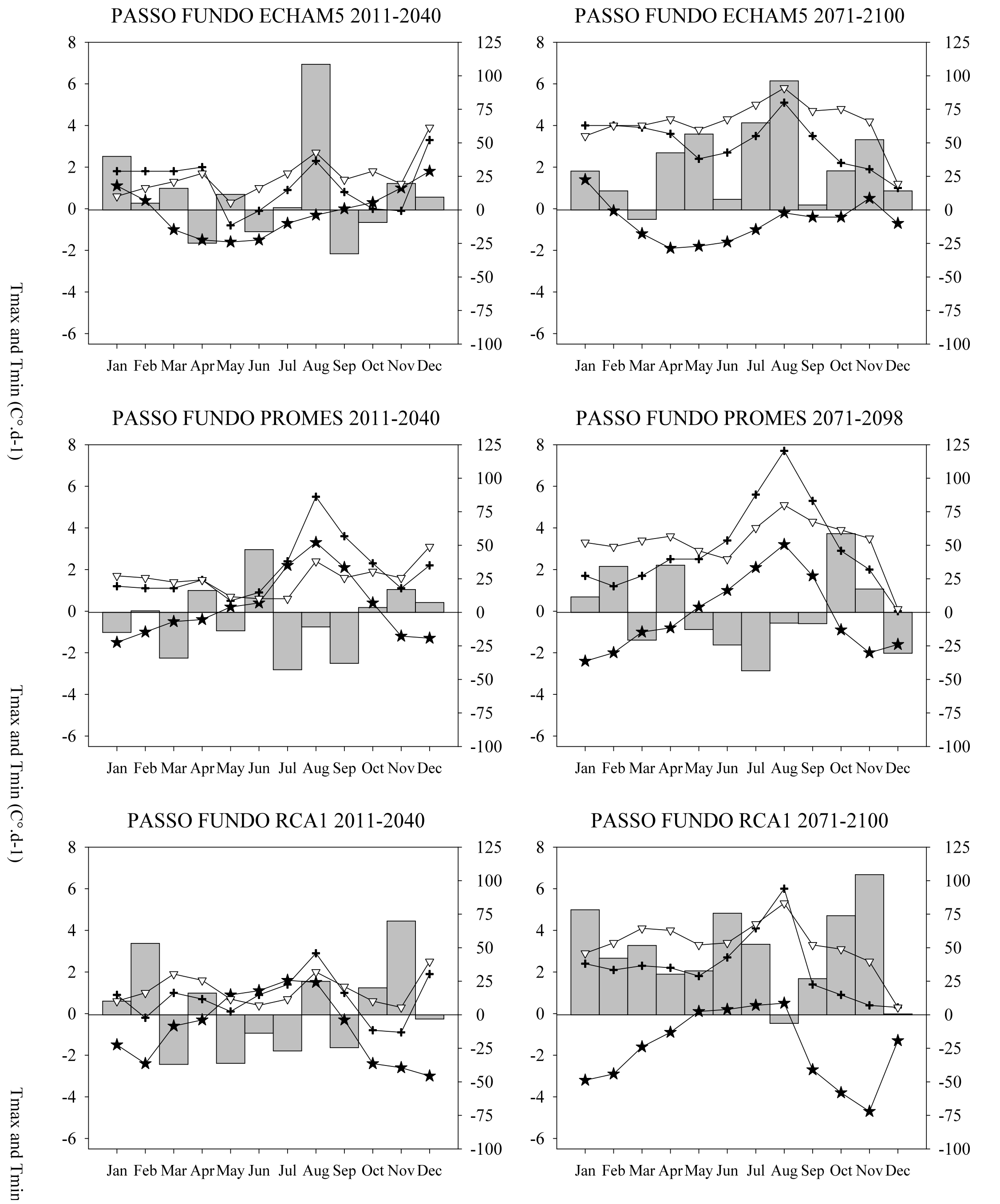


Figure 6. Charts showing the departure of each RCM from the present weather of Passo Fundo.

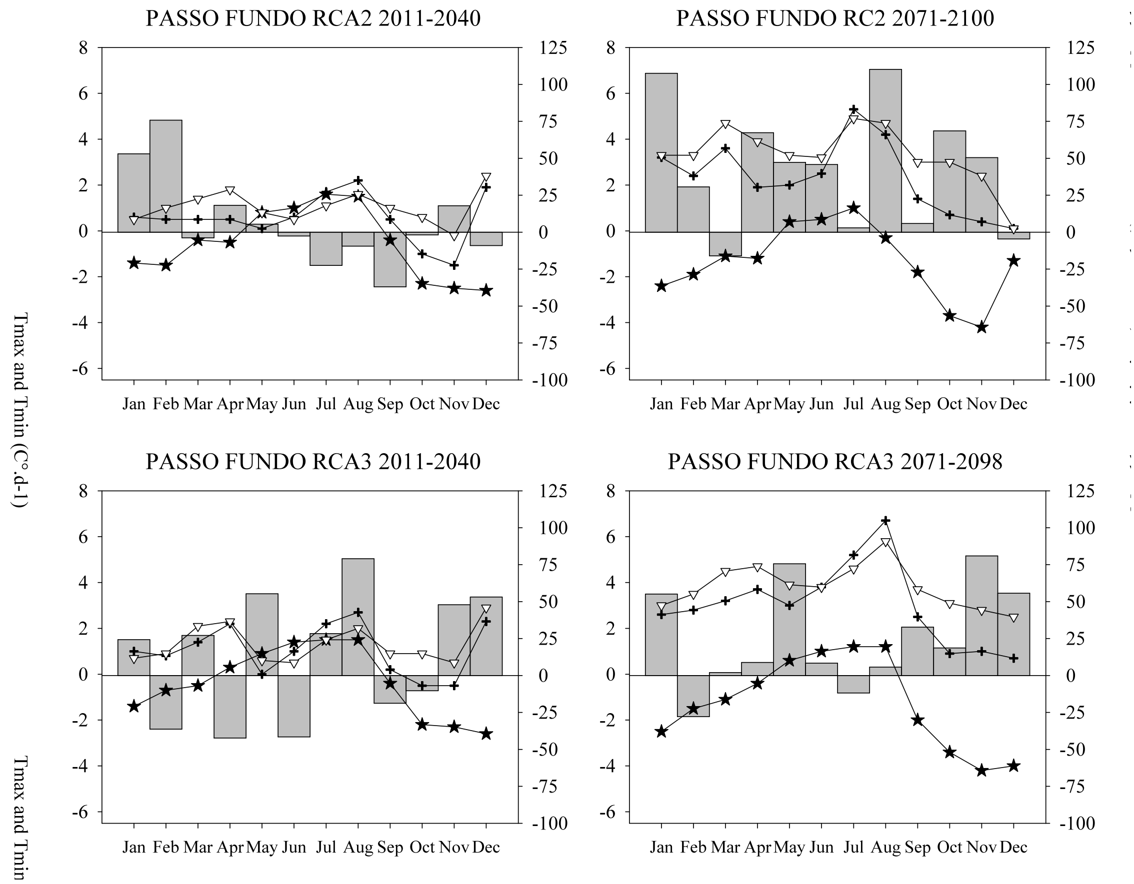


Figure 20. Charts showing the departure of each RCM from the present weather of Passo Fundo.

4.1.3 RCMs and Argentinian Environments

The future weather scenarios design by RCMs show strong temporal and spatial interaction. Analyzing the windows planting dates during the growth season for maize crop, all RCMs show future scenarios wetter and hotter at the end of the century (2071-2100). ETA RCM presented lower rainfall for all environments for the period 2011-2040, with 44.3 mm, and 24.0 mm and 20.9 mm for San Justo, Junín and Balcarce respectively. The wetter RCM was RCA-R2, for Junín and Balcarce and RCA-R1 for San Justo.

The most RCM showed higher increment in rainfall for San Justo environment, except LMDZ- IPSL, PROMES, and RCA-R2. For Junín environment, RCM RCA2 presented the higher rain for both periods. While LMDZ-IPSL presented the dryers scenarios for all environments, however shows the higher increment with 56.5 mm, and 97.7 for Balcarce 2011-2040 and Junín 2071-2100 respectively. The higher increment in rainfall scenarios for PROMES were 82.5 mm and 182.5 mm for San Justo 2011-2040 and Balcarce 2071-2100 respectively.

The temperature increment was higher in San Justo for almost all RCMs, ETA and RCA2 did not show significant differences in the higher values for San Justo and Junín environments. RCA1 and RCA3 showed the higher increments for Junín environment for both periods. LMDZ-ECH5 did not show significant differences among the environments.

The warmer RCMs were LMDZ-IPSL, PROMES and ETA, the increment ranges of temperature were 1.47ºC-1.97ºC, 1.82ºC-2.32ºC and 1.62ºC-1.88ºC respectively for the period 2011-2040 and for all environments. At the end of the century, these ranges were 3.27ºC-4.46ºC, 2.96ºC-4.20ºC, 3.08ºC-3.39ºC, with the same sequence of warmer RCMs.

Rainfall, maximum and minimum temperature are the main weather inputs for the crop models. The variability of these parameters indicates the necessity of more specific analysis in each environment.

The scenarios were defined by different RCMs for 2011-2040 and 2071-2100 periods in A1B emission scenario with 430 CO_2 and 677 CO_2 concentrations respectively. These scenarios will be used to assess the impact on crop productivity.

Four RCMs ETA, RCA1, RCA2, and RCA3 showed lower solar radiation principally for the San Justo Environment, with values -0.94 MJ m^{-2} d^{-1}, -1.84 MJ m^{-2} d^{-1}, -1.83 MJ m^{-2} d^{-1}, -1.94 MJ m^{-2} d^{-1} respectively and for the end of the century. The southern environments showed less decreased values with extreme values of -0.14 MJ m^{-2} d^{-1}, -0.80 MJ m^{-2} d^{-1}. The rest of RCMs showed an smooth increment in solar radiation with extreme values of 0.5 MJ m^{-2} d^{-1}, and 0.88 MJ m^{-2} d^{-1}, for both periods and the three environments.

Except the solar radiation reduction of -2.0 MJ m^{-2} d^{-1} (9%) in San Justo, that could have negative impact on crop production, no impact of solar radiation variability could be find in Junín or Balcarce. Each environment showed different patterns for the maize or soybean crop impact due to differences in crop season as well differences in windows planting date.

The soybean crop resulted that during the period 2011-2040, ETA RCM was the hotter scenario, for the three locations, and LMDZ-IPSL was the RCM with lower increment in rainfall. For the period 2071-2100 and for the three environments, the RCM RCA3 showed the low temperature increment, and LMDZ-IPSL the hotter RCM, while the LMDZ-ECH5 was the wetter.

4.1.3. Balcarce

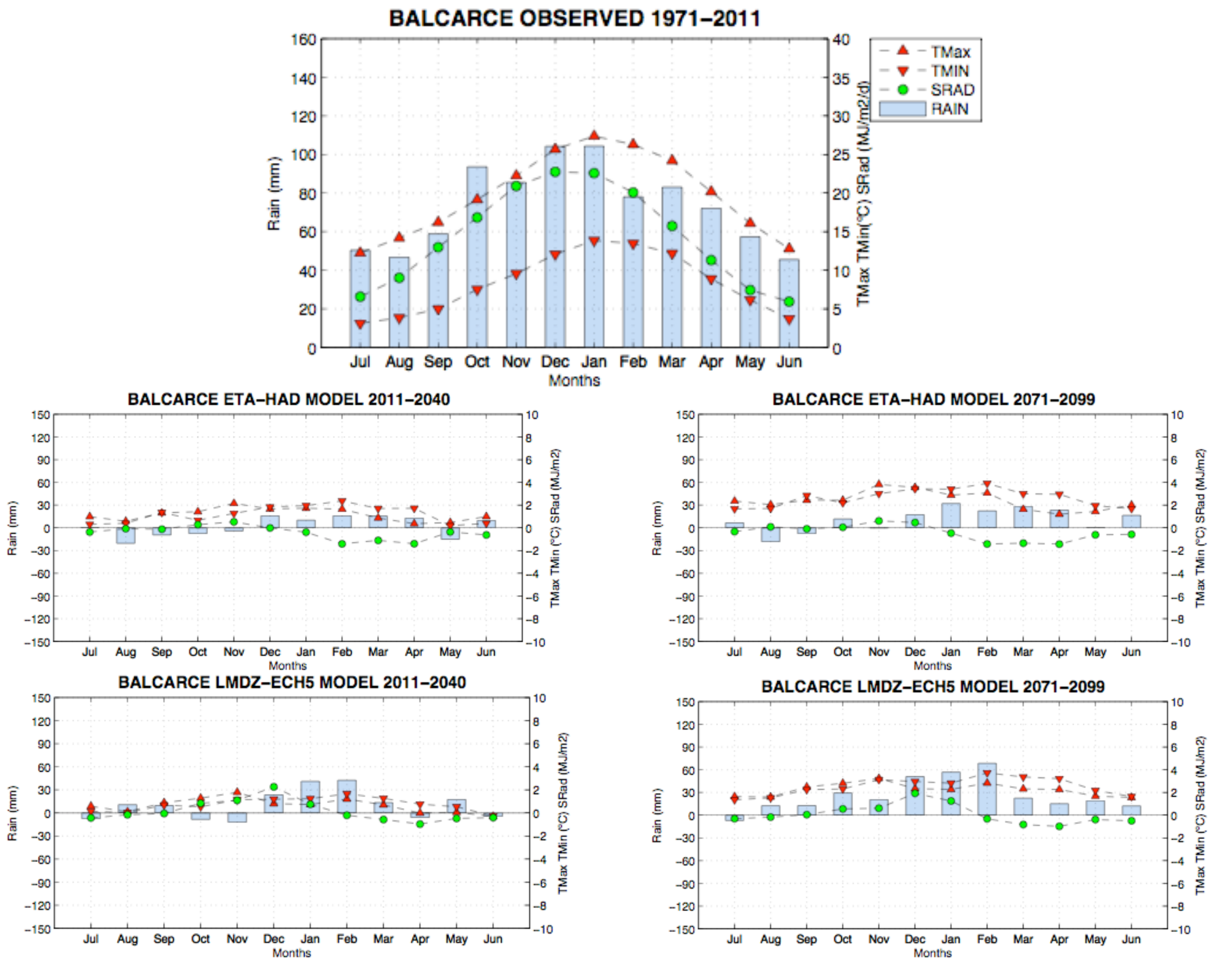
For crop maize in both periods, Balcarce showed the lower temperature increment. In the period 2011-2040 the temperature increment interval was 0.15ºC (RCA2) to 1.82ºC (PROMES), at the end of the century the temperature increment interval was 1.87ºC (RCA1) to 3.27ºC (LMDZ-IPSL).

Even when this environment showed the lower temperature increment, it is important because for this latitude, a temperature increment will allow new crop management in order to improve the crop productivity.

The variability of rainfall increment was higher for the period 2071-2100 compared with the 2011-2040 period, with values of 20.9mm and 104.0mm as extreme values to 60.1mm and 239.0mm at the end of the century.

For this environment the RCM during the soybean crop season for 2011-2040, presented a wide range of temperature and precipitation. The range of temperature increment was 0.2ºC to 1.7ºC for RCA2 and ETA respectively. The precipitation range for the same period is 44.0mm to 108.3 mm, for LMDZ-IPSL and LMDZ-ECH5 respectively.

During the period 2071-2100, the range of temperature will increase to 2.0ºC to 3.4ºC for RCA3 and LMDZ-IPSL respectively. Also the precipitation range will increase to 82.6mm to 219.5mm for LMDZ-IPSL and LMDZ-ECH5 respectively (Figure 21)



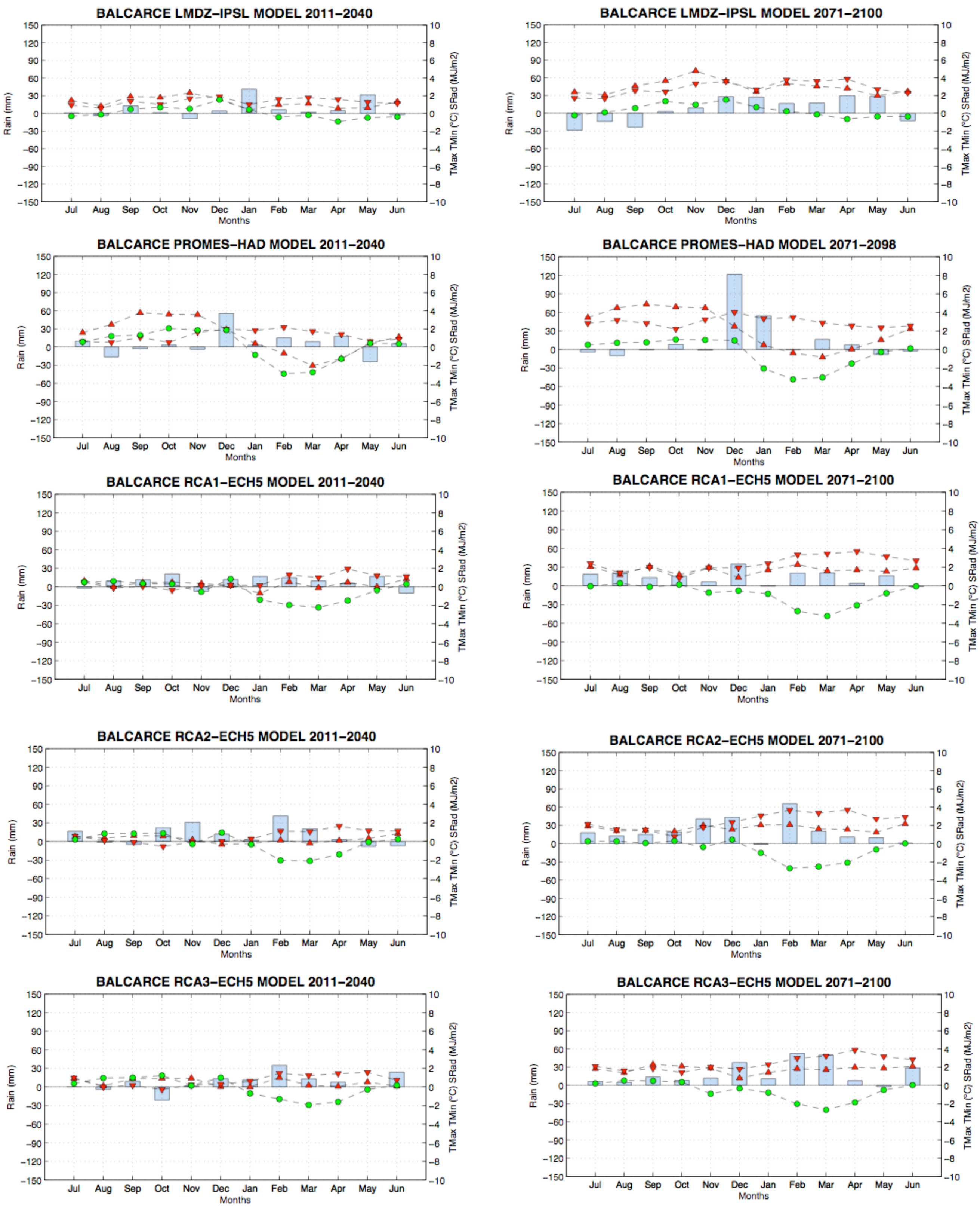


Figure 21: Mean Anual Cycle for Balcarce environment, Observed Data (1971-2011) and 7 RCMs, for Maximum Temperature (Tmax), Minimum Temperature(TMIN), Solar Radiation (SRAD) and Rainfall (RAIN) in two periods, near future (2011-2040) and end of the century (2071-2100)

4.1.4. Junín

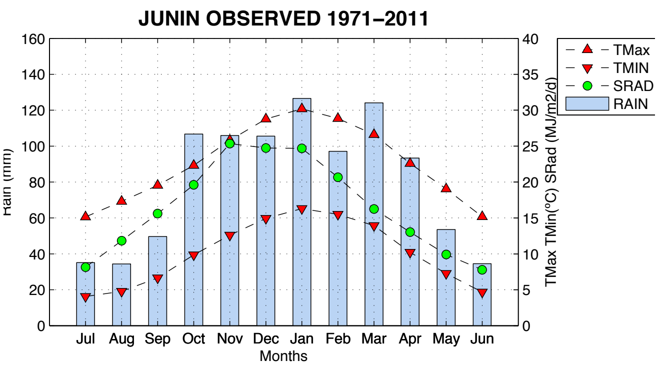
The temperature increment during the maize crop season for the period 2011-2040 was 0.39ºC for the RCM RCA1 and 2.02ºC for the RCM PROMES. At the end of the century the difference between extreme temperatures were closer with range of 2.21ºC and 3.77ºC for RCMs RCA3 and LMDZ-IPSL respectively.

The rainfall increment was the highest among environment for RCM RCA2 with values of 189.4mm and 281.5mm for the period 2011-2040 and 2071-2100 respectively. The RCMs RCA1, RCA2, RCA3 and LMDZ-ECH5 showed the higher increment of rainfall for both period, with values of 103.1mm and 189.4mm for RCA3 and RCA2 during the 2011-2041 period. At the end of the century the range of the same RCMs was 138.1mm and 281.5mm for RCM RCA1 and RCA2 respectively.

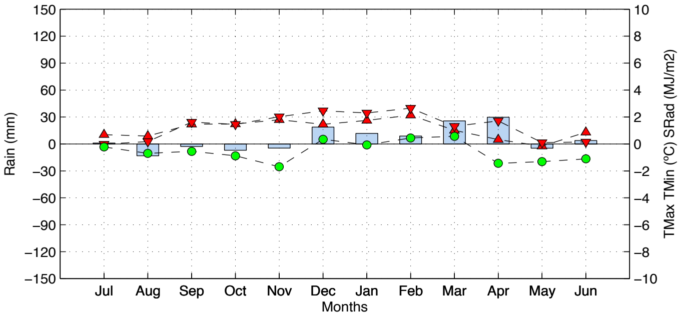
The RCMs PROMES, LMDZ-IPSL, and ETA shown very low rainfall increment of 3.5mm, 23.7mm and 4.9mm respectively for the period 2011-2040.

The RCM during the soybean crop season for 2011-2040, presented a wide range of temperature and precipitation. The range of temperature increment is 0ºC to 1.9ºC for RCA1 and ETA respectively. The precipitation range for the same period is 46.3mm to 161.4 mm, for LMDZ-IPSL and RCA2 respectively.

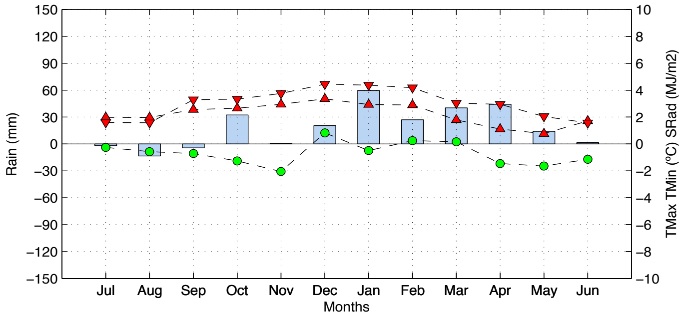
At the end of the century, the range of temperature will increase to 1.9ºC to 3.7ºC for RCA3 and LMDZ-IPSL respectively. Also the precipitation range will increase to 147.8mm to 249.7mm for ETA and ECH5 respectively (Figure 22)



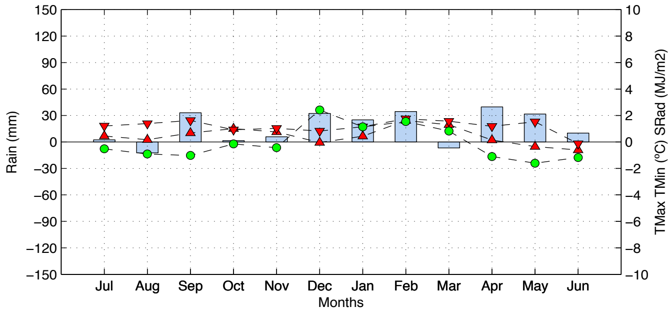
JUNIN ETA–HAD MODEL 2011–2040



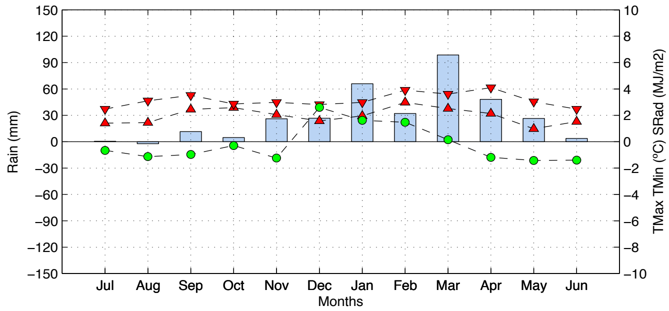
JUNIN ETA–HAD MODEL 2071–2099



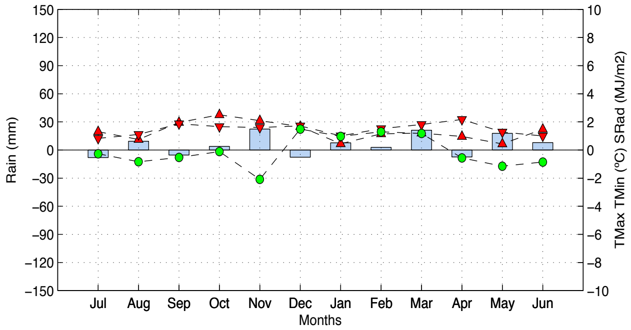
JUNIN LMDZ–ECH5 MODEL 2011–2040



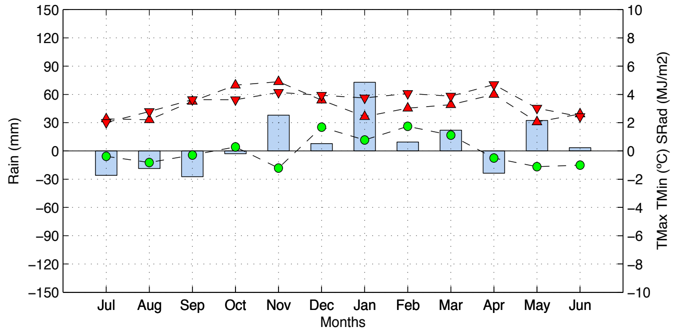
JUNIN LMDZ–ECH5 MODEL 2071–2099



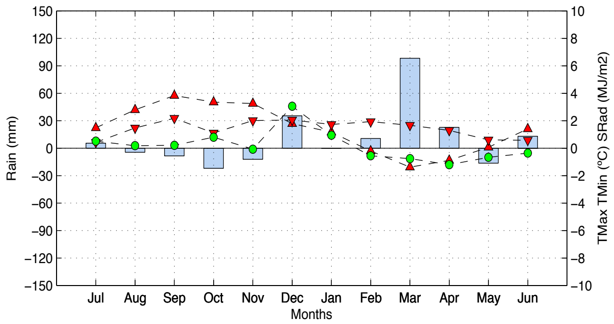
JUNIN LMDZ–IPSL MODEL 2011–2040



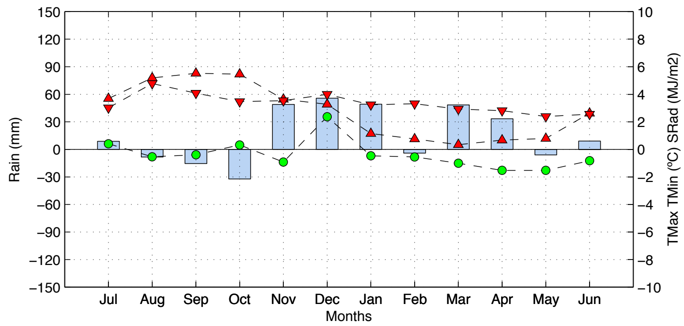
JUNIN LMDZ–IPSL MODEL 2071–2100



JUNIN PROMES–HAD MODEL 2011–2040



JUNIN PROMES–HAD MODEL 2071–2098



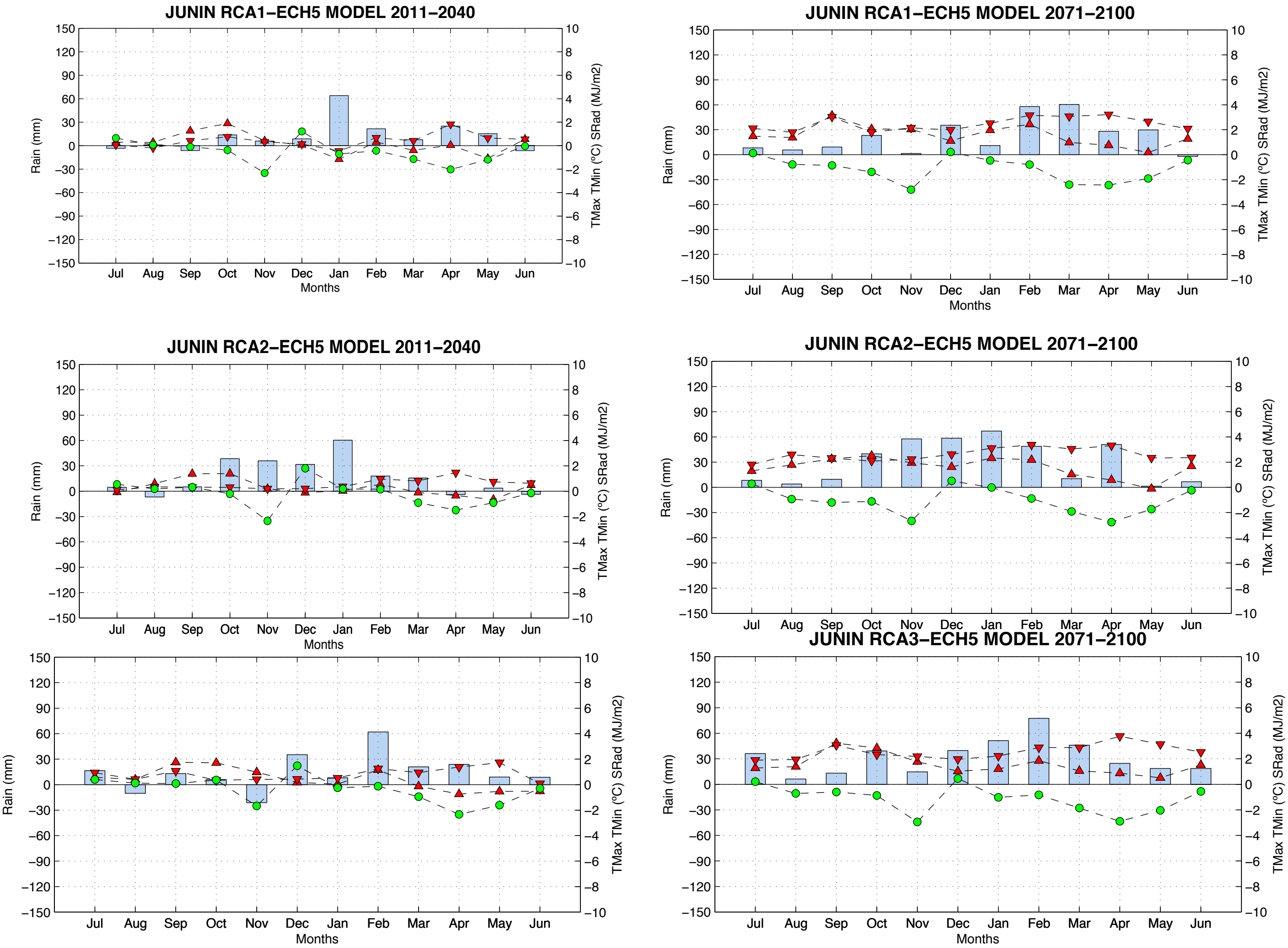


Figure 22: Mean Anual Cycle for Junín environment, Observed Data (1971-2011) and 7 RCMs, for Maximum Temperature (Tmax), Minimum Temperature(TMIN), Solar Radiation (SRAD) and Rainfall (RAIN) in two periods, near future (2011-2040) and end of the century (2071-2100)

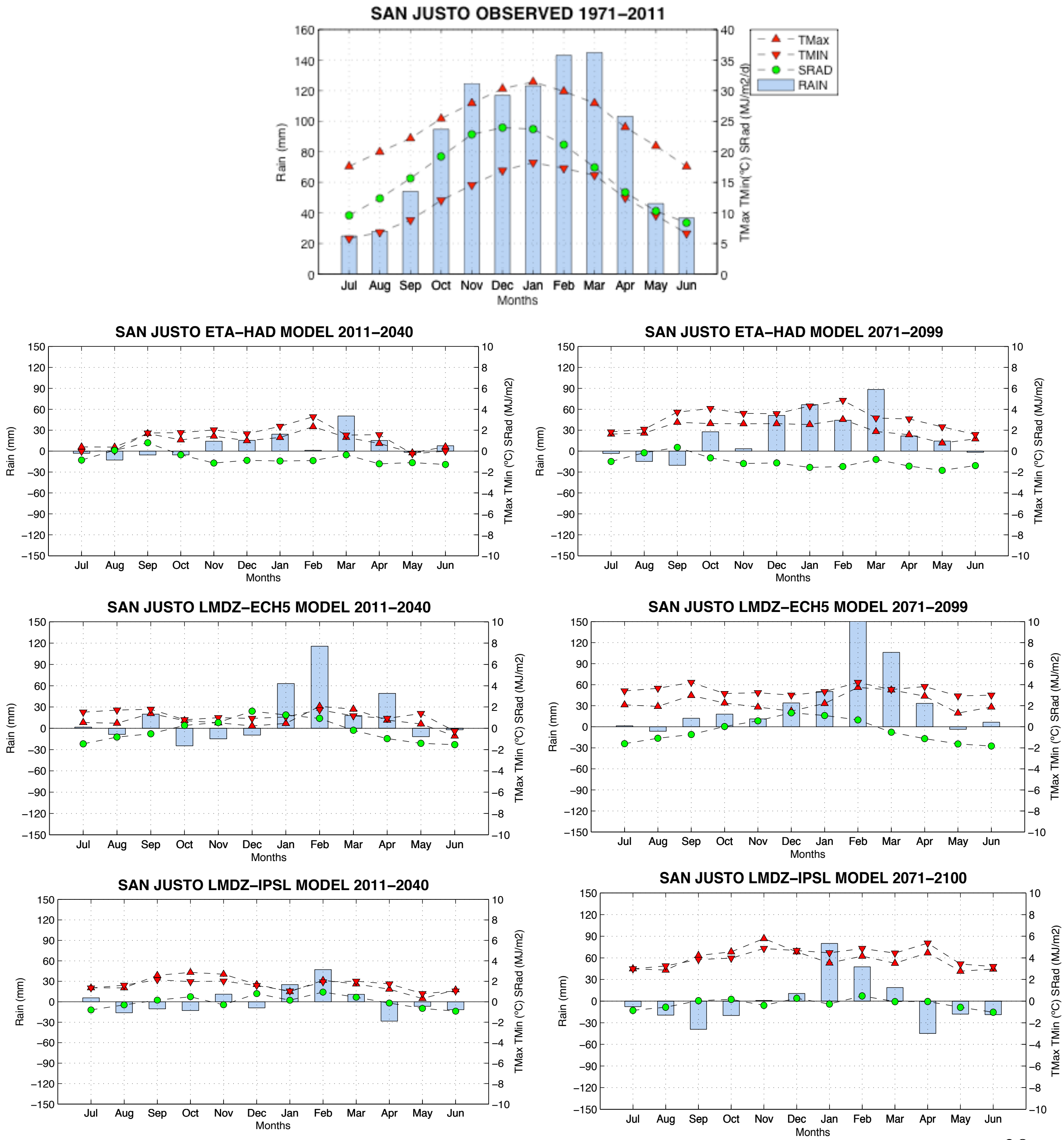
4.1.5. San Justo

In maize, the temperature range for the period 2011-2040 was 0.16ºC to 2.32ºC for the RCM RCA1 and PROMES respectively. The warmer RCMs were PROMES, LMDZ-IPSL and ETA with values of 2.32ºC, 1.97ºC and 1.80ºC respectively. For the end of the century, the increment of temperature was 2.09ºC and 4.46ºC for the RCA3 and LMDZ-IPSL respectively. The warmer RCMs were the same than in the first period.

This environment presented the higher increment rainfall for five RCM models, with 233.1mm of increment during the crop season for 2011-2040, and 345.4mm of rainfall increment at the end of the century, for the RCMs RCA1 and RCA3 respectively. The model LMDZ-ECH5 showed similar values to RCA1 and RCA3.

During the soybean crop season for 2011-2040, this site presented a wide range of temperature and precipitation. The range of temperature increment is 0ºC to 1.8ºC for RCA1 and ETA respectively. The precipitation range for the same period is 85.4 mm to 156.0mm, for LMDZ-IPSL and RCA1 respectively.

During the period 2071-2100, the range of temperature will increase to 1.5ºC to 4.5ºC for RCA3 and LMDZ-IPSL respectively. Also the precipitation range will increase to 157.8mm to 387.2mm for LMDZ-IPSL and ECH5 respectively (Figure 23).



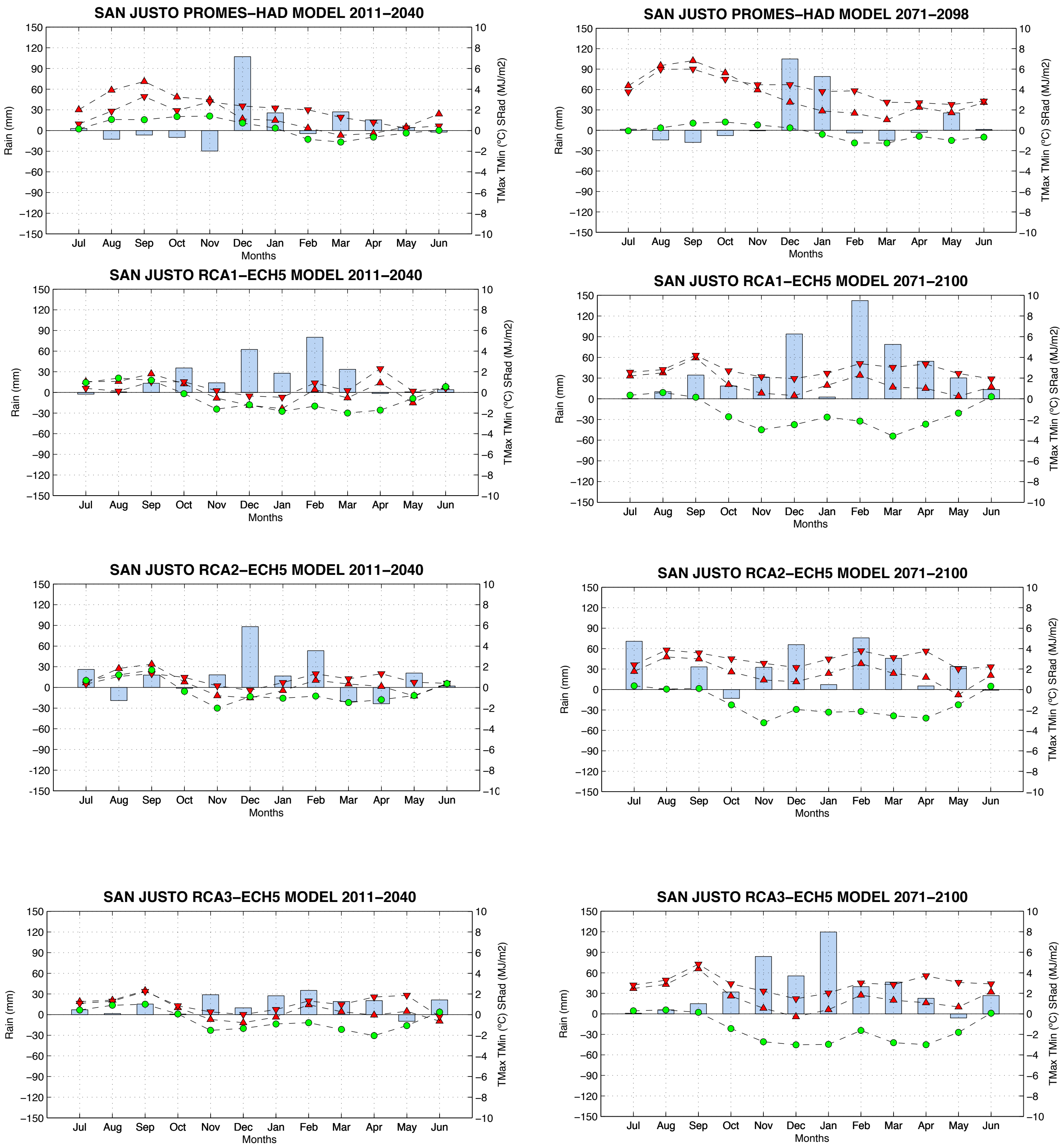


Figure 23: Mean Anual Cycle for San Justo environment, Observed Data (1971-2011) and 7 RCMs, for Maximum Temperature (Tmax), Minimum Temperature(TMIN), Solar Radiation (SRAD) and Rainfall (RAIN) in two periods, near future (2011-2040) and end of the century (2071-2100)

4.2 SIMULATIONS USING THE DOWNSCALED SCENARIOS

The results of simulations will be grouped by country (in this case, Brazil and Argentina), crop and variety. All simulations already include planting date and variety with the aim of discussing the role of these two agronomic managements as adaptation strategy.

4.1.6. Impacts of scenarios of RCM`s on maize in Brazil

Simulations were run for two locations in Brazil: Chapecó and Passo Fundo. For each location two maize varieties were tested: one commercial hybrid called AS1548 and an improved open-pollinated variety called MPA01. All simulations were conducted for nine different planting dates. By doing so, it was possible to investigate if the best planting date changes from the present. The first analysis (*Figure*) showed the impact of seven RCM`s on maize yield of the variety MPA01, in two locations and two time periods: 2011-2040 and 2071-2100.

For Chapecó 2011-2040, all the yields generated with RCM`s agree only in one planting date: 15/August. With the advancement of the spring, the RCM`s tend to diverge and form two groups: one, with ECHAM5, ETA and IPSL, pointing an increase of actual yields; another group, containing PROMES, RCA1, RCA2 and RCA3, predict a reduction of yields. This kind of distribution does not permit the identification of a trend of yield. For the same location but for end-of-century period, RCM`s showed a reduced discrepancy, when compared with the first period. The RCM that presented the highest difference from the other was ETA, indicating yields higher than any other RCM. All the other RCM`s followed more or less the same pattern, indicating a probable reduction of maize yields for this study site in the 2071-2100 period.

Yields in Passo Fundo simulated with RCM`s for 2011-2040 period presented an almost similar pattern (except for IPSL and PROMES), but differ from the observed line after the fourth planting date (after 01st September). The large range of yields also makes difficult a reasonable estimate, despite the trend of slight reduction of yields when maize is planted in after 15th October. For the 2071-2100 RCM`s, with except ETA, present a similar trend and a reduced range of yields, when compared with the first period. This behavior could give arguments to the assumption that under those circumstances yield in Passo Fundo, for the 2071-2100 period, could be reduced significantly.

The second set of analysis (*Figure*) showed the impact of seven RCM`s on maize yield of the variety AS1548, in two locations and two time periods: 2011-2040 and 2071-2100. The yields of this variety are lower than the MPA01. The probable cause is that the MPA01, as local developed and improved variety, has a batter adaptation than the hybrid, especially for Chapecó location. The same pattern observed for the MPA1 variety in Chapecó for the 2011-2040 period can be seen in its equivalent with the AS1548 variety: during the first planting dates RCM`s keep certain similarity, and after 01/Oct they form two distinct groups: one, with increases in yield (ECHAM5, ETA and IPSL) and another, with reductions. The results in this figure assume that the RCM`s have a higher level of conformity for the early planting dates, but with an important reduction of agreement along the season. For the 2071-2100 period this trend can still be identified, but in a reduced scale, at the same time that the difference among the RCM`s in each group is also reduced.

The use of the variety AS1548 in Passo Fundo for 2011-2040 period didn't produced results that are substantially distinct from the ones obtained with variety MPA01, maintaining a high level of uncertainty of For the period 2071-2100, with changes.exception of IPSL, all RCM`s agree that there could be a reduction in yields, especially in the very early of late planting dates.

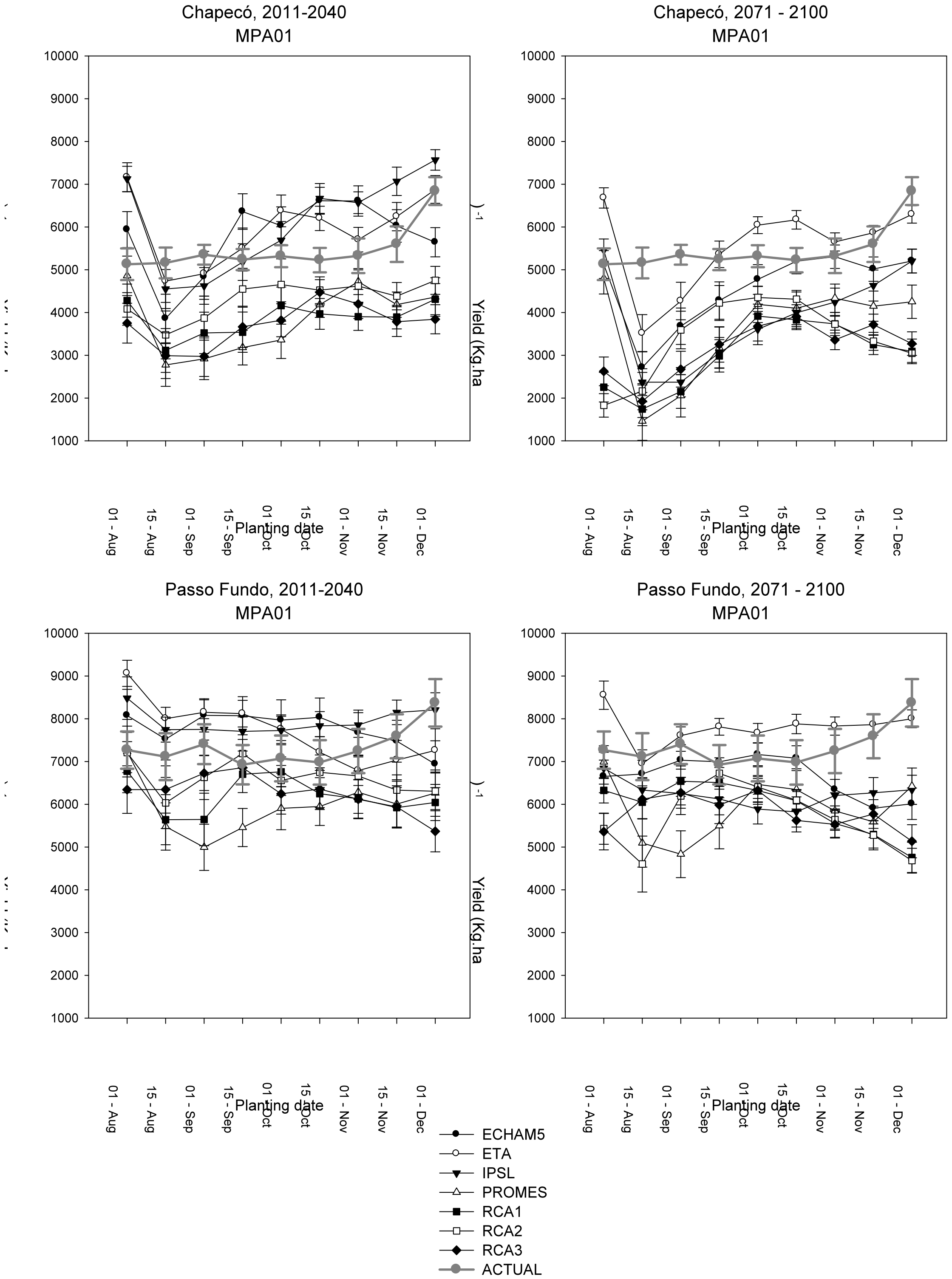


Figure 24. Simulations of the impact of RCM`s scenarios on maize (variety MPA01) planted in nine different dates, in two locations (Chapecó and Passo Fundo), and two time periods (2011-2040 and 2071-2100): black lines represent RCM`s and black bars represent the standard error of each planting date; the grey line represent actual yields with respective planting dates and standard error.

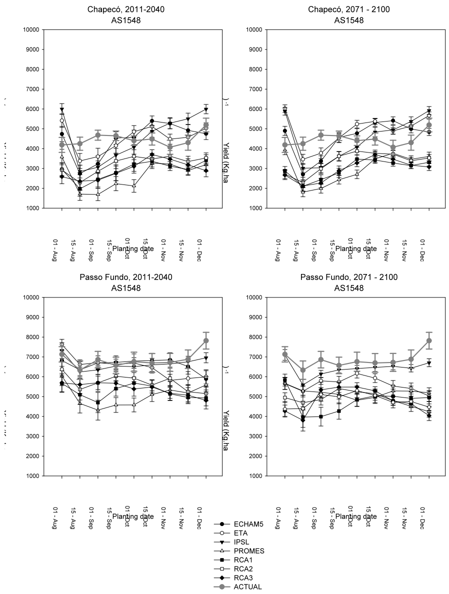


Figure 25. Simulations of the impact of RCM`s scenarios on maize (variety AS154) planted in nine different dates, in two locations (Chapecó and Passo Fundo), and two time periods (2011-2040 and 2071-2100): black lines represent RCM`s and black bars represent the standard error of each planting date; the grey line represent actual yields with respective planting dates and standard error.

4.2.2 Impacts of scenarios of RCM`s on soybean in Brazil

For soybeans, simulations were also run for Chapecó and Passo Fundo. For each location two commercial soybean varieties were tested: CD202 and CD204. All simulations were conducted for eleven different planting dates. By doing so, it was possible to investigate if the best planting date changes from the present. The first analysis (*Figure* and 27) showed the impact of seven RCM`s on the yield of the soybean variety CD202, in two locations and two time periods (2011-2040 and 2071-2100), while the second analysis investigated the variety CD204 for the same locations and periods. It is important to mention that both soybean varieties, besides having some differences in genetic coefficients, presented very similar results. Due a lack of available data, no other varieties could be used. All the following analysis will approach both varieties CD202 (Figure 26) and CD204 (*Figure*).

For Chapecó 2011-2040 (Figure 26 and *Figure* , above), the majority of RCM`s projected very low yields when compared with actual yields. Only ETA, IPSL and ECHAM5 presented a trend of increase in yields, and after the 01/Oct planting date. Even so, only IPSL could mimic the actual yields for the late planting dates. This assessment is also applicable for the 2071-2100 period, but with a further reduction of projections of all RCMs. An integrated analysis indicates with high level of agreement that early planting dates – prior to 01/Oct – will generate lower yields; planting after 01/Oct shows that three out of seven RCM`s (namely, ETA, ECHAM5 and IPSL) have a tendency to follow the actual yields, while the others remain with very low yields, jeopardizing the viability of this crop in the region.

The results presented for Passo Fundo (Figure 26 and *Figure* , lower) showed significant difference from the ones of Chapecó, with RCM yields following the trend of actual yield. It also presents a situation where RCMs project even significant increments in yield in the 2011-2040 period. This can be observed especially in the early planting dates, where all but one RCM are equal or significantly higher than the actual yield. For the end-of-century period a generalized reduction of yield was calculated, with exception of IPSL, which showed significant increases. Though a trend of yield reduction, all RCMs presented at least one planting date that did not differ significantly from the actual best yields.

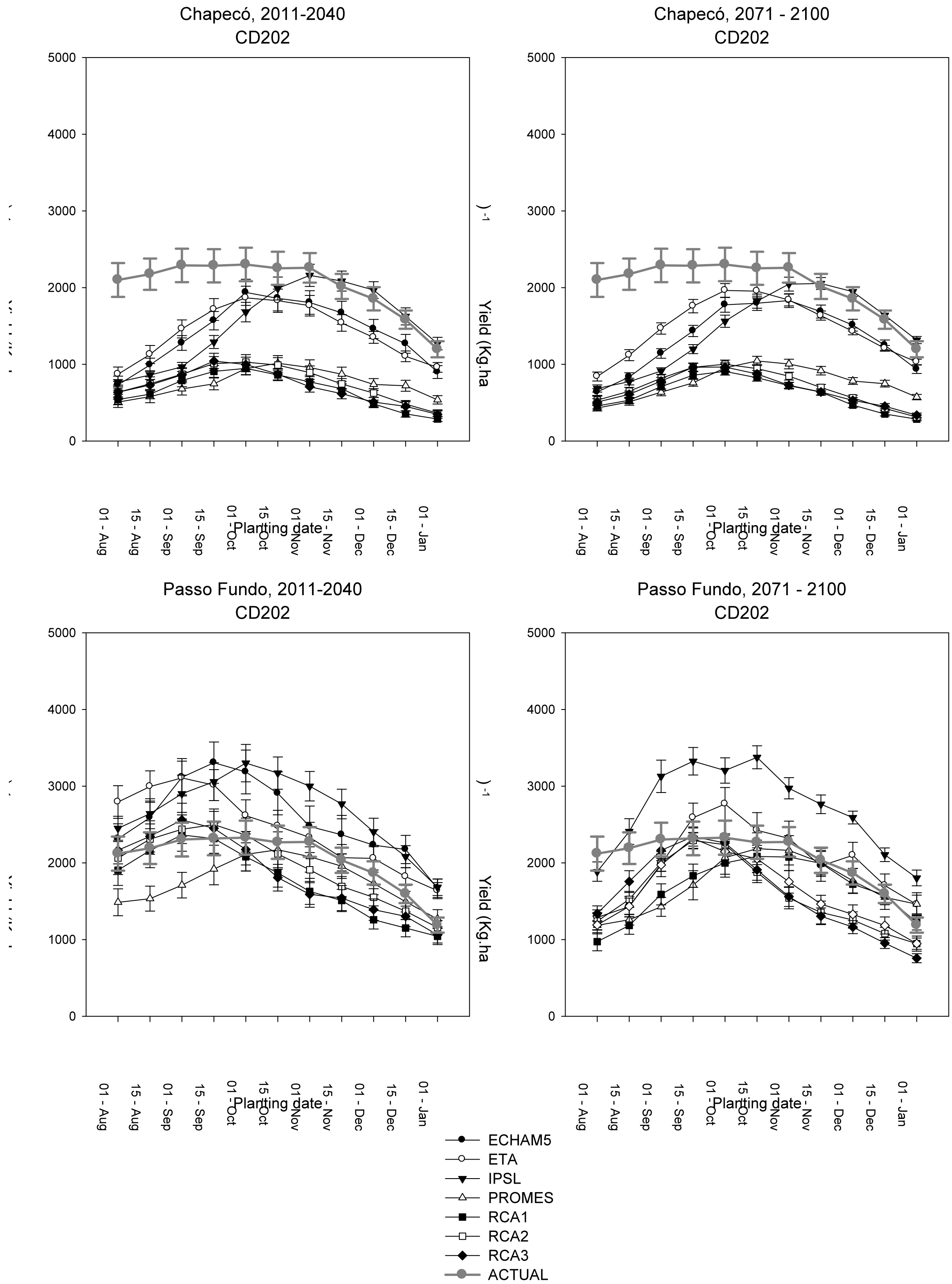


Figure 26. Simulations of the impact of RCM`s scenarios on soybean (variety CD202) planted in eleven different dates, in two locations (Chapecó and Passo Fundo), and two time periods (2011-2040 and 2071-2100): black lines represent RCM`s and black bars represent the standard error of each planting date; the grey line represent actual yields with respective planting dates and standard error.

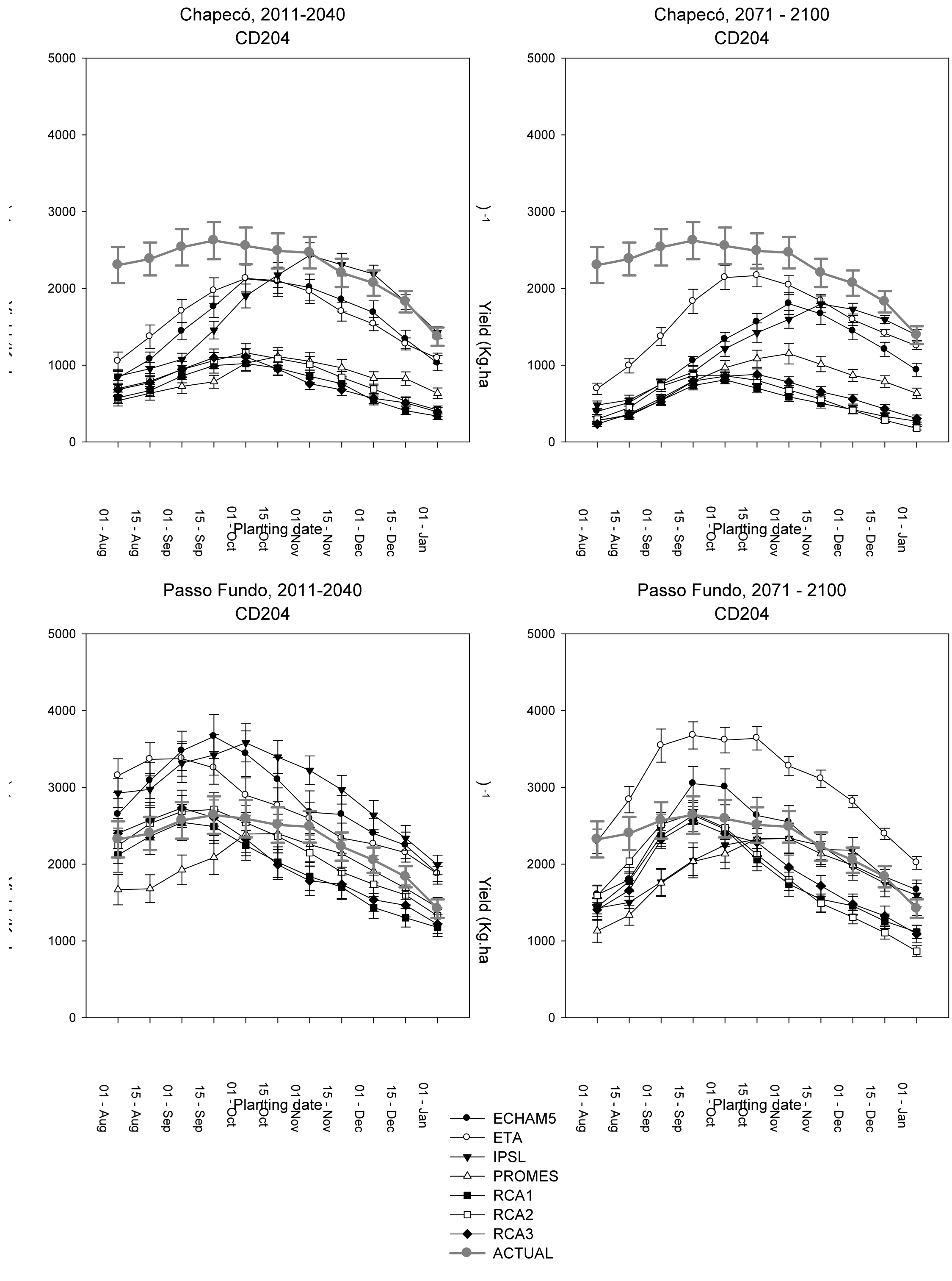


Figure 27. Simulations of the impact of RCM`s scenarios on soybean (variety CD204) planted in eleven different dates, in two locations (Chapecó and Passo Fundo), and two time periods (2011-2040 and 2071-2100): black lines represent RCM`s and black bars represent the standard error of each planting date; the grey line represent actual yields with respective planting dates and standard error.

4.2.3 Impacts of scenarios of RCM`s on maize in Argentina

The RCMs data as weather input in CERES-Maize crop model indicated different behavior among environment and more variability for all the planting date for the end of the century, basically for the San Justo and Junín environments. The purpose of use eight planting dates for each environments from 01 August to 15 November is to evaluate the interaction soil-genetic-weather –management and to spread the planting windows. The observed weather data were used to build the base line and the yield variability for Junín environment was higher than San Justo and Balcarce environments. The observed average yield for different planting dates presented similar values for Junín and Balcarce, while San Justo the observed yield was lower.

In San Justo environment most of the RCMs showed similar or slight lower yield values when were compared with observed yield but the warmer RCMs models (LMDZ-IPSL and PROMES) showed a significance difference compared with the yield base line value in the first five planting dates.

At the end of the century, the RCMs can be divided in two groups, the lower yield with significance differences among them, and the group which yield are similar to the base line, except for the last two planting dates. (Figure 28A)

For the period 2011-2040, in Junín environment all RCMs except PROMES, showed the same behavior as the base line yield, but with significance difference in the last three planting dates. PROMES showed the lowest yield for all planting dates with a high significance difference and the yield range for this RCM was 4000 kg ha^{-1} and 5800 kg ha^{-1} (Figure 28B). Probably the temperature increment of 2.02ºC for the maize growth season and no change in rainfall, only + 3.5mm caused a hard seasonal drought that affected the productivity in all planting dates.

For the end of the century the high increase of temperature for the two warmer RCMs, LMDZ-IPSL and PROMES, associated with a slightly increase in rainfall, with the uneven rainfall distribution with a dryer December for LMDZ-IPSL. These combinations resulted in a lowest yield for this RCM scenario for the four earlier planting dates, with significance difference between both and a strong difference with the others RCMs. Basically four of them, RCA1, RCA2, RCA3 and LMDZ-ECH5 showed a significance increment of yield for the four earlier planting dates.

Balcarce 2011-2040 environment, showed a similar behavior that Junín environment, where PROMES RCM presented the lower yield for all planting dates with a significance difference compared with the yield base line, while the rest of RCMS showed a yield levels slightly higher than yield base line although without significance difference.

For the end of the century, these two warmer RCMs did not show difference with the yield base line, with a kind of compensation of temperature increment and high increases of rainfall for PROMES (182.0mm) and a slightly for LMDZ-IPSL (60.6mm) but with a constant distribution during the critical growth period. The rest of RCMs showed a higher yield compare with the base line, basically for the five earlier planting dates. This difference was highest for the earliest sowing date and continues with significance difference during the next five dates of sowing (Figure 28C).

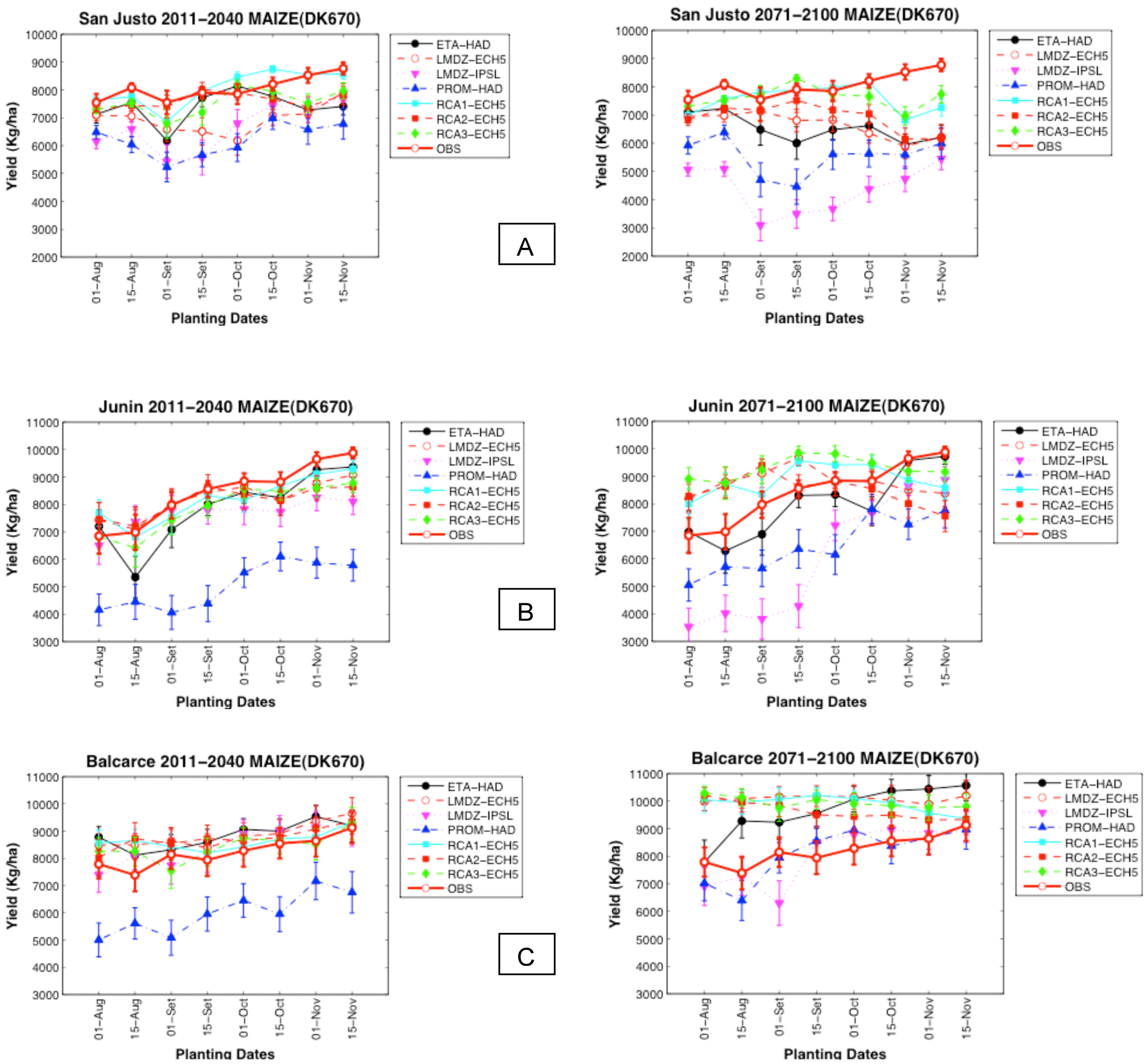


Figure 28. Simulations of the impact of RCM`s scenarios on maize ( cv. DK 670) planted in eight different dates, in three locations- San Justo (Santa Fe)(A), Junín (Buenos Aires) (B) and Balcarce (Buenos Aires) (C), in two time periods (2011-2040 and 2071-2100): lines represent RCM`s and bars represent the standard error of each planting date; the solid red line represent actual yields with respective planting dates and standard error.

4.2.4. Impacts of scenarios of RCM`s on soybean in Argentina

For the environment San Justo, and for the period 2011-2040, in the early planting dates (01 and 15 August), the observed yield presented the lower yield, and for the same planting dates, the RCM ETA presented the higher yield, with the wider yield variability between them. For the observed yield, these early planting matching cool temperatures during the first months of growth, on the other hand, the RCM ETA is the hottest RCM, and showed the higher yield in the first three planting dates. As planting dates were delayed, the observed yield increase and from the planting date 15 Sept showed the higher yield until planting date 01 Nov. After this planting date, again the RCM ETA showed the higher yields for all later planting, except the last one, were the RCM ECHAM5 showed the higher yield but the yield suffer an important reduction compared with the better planting dates, in the planting windows of 15 Oct – 15 Nov.

For the period 2071-2100, the yield pattern was similar, but the yield values were different, as well as the yield variability due to high temperature increment, and also high variability in rainfall among the RCM. In the two first planting dates, and for the windows planting dates among 15 Nov and 15 Dec, RCM ETA showed the higher yield. The impact of this RCM could be associated to better rainfall distribution, because was not the cooler or wetter RCM for this period.

For the planting date among 01 Set and 01 Nov, the observed values showed higher yield, while the RCM IPSL showed the lower yield in most of the planting dates, due to high increment in temperature, as well the lower rainfall during the crop season (Figure 29A)

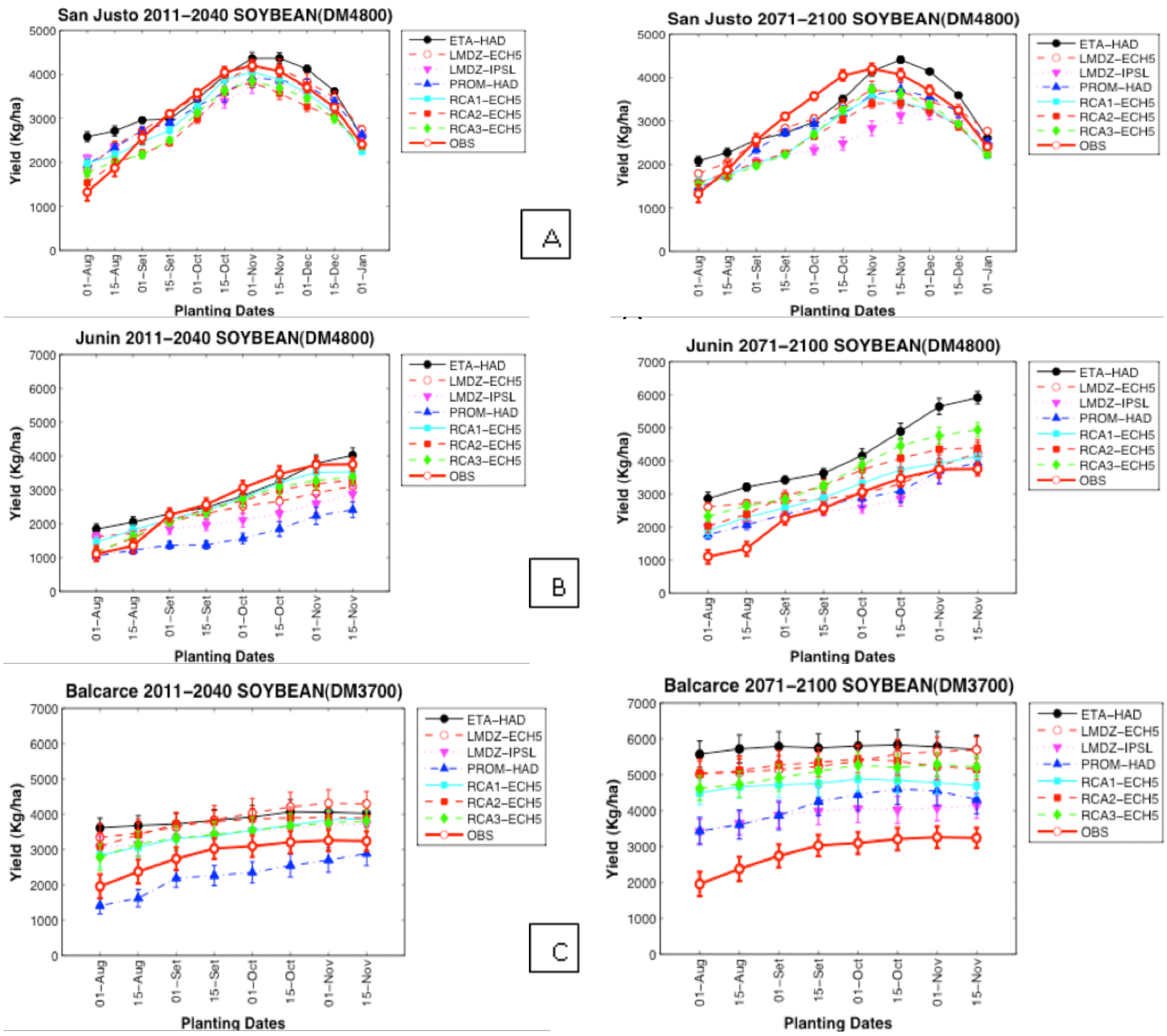


Figure 29. Simulations of the impact of RCM`s scenarios on soybean ( cvs. DM4800 and DM 3700) planted in eight different dates, in three locations- San Justo (Santa Fe)(A), Junín (Buenos Aires) (B) and Balcarce (Buenos Aires) (C), in two time periods (2011-2040 and 2071-2100): lines represent RCM`s and bars represent the standard error of each planting date; the solid red line represent actual yields with respective planting dates and standard error.

For the environment Junín, and for the period 2011-2040, the yield observed values for the planting dates 01 and 15 Aug showed the lower yield, and from 01 Sep to 01 Nov the observed values showed the higher yield, in the last planting date, only the RCM ETA was higher to the observed yield and showed the higher average temperature during the crop season. In this period RCM PROMES showed the lower yield during the eight planting dates and also showed the higher amplitude between temperature minimum and maximum during the crop season.

During the period 2071-2100, RCM ETA showed the higher yield for all planting dates, where the last planting date is the higher, and the observed yield in most of the cases, was the lower. In this period, the temperature for all RCM increase, but the higher yield variability could be explained by an important increment in rainfall for all RCM comparing with the observed rainfall (Figure 29 B).

Balcarce is the cooler environment, for instance any increment in temperature will improve the soybean yield and also increase the planting date windows. For the period 2011-2040, most of the RCMs showed better yields, except the PROMES, and the yield pattern showed a slight increment when the planting date was delayed. The range of temperature increment was 0.2ºC – 1.7ºC, and the range of rainfall was 44.0mm – 117.6mm during the crop season. These modifications in rainfall and temperature explained the increment of the most RCMs (Figure 29C).

The phonological period planting-flowering presented two RCMs group, the RCA1, RCA2 and RCA3 with small or null changes and the rest of RCMs where this period is approximately six days shorter than the observed base line.

At the end of the century, all RCMs showed yield increment where RCM ETA obtained the higher yield with a range of average yield between 5000 kg ha-1 – 6000kg ha-1. During this period the range of increment in temperature was 2.0ºC – 3.4ºC and the range of increment in rainfall was 82.6mm – 219mm.

4.3 SIMULATIONS USING THE INCREMENTAL SCENARIOS

4.3.1 Maize in Brazil

Simulations carried out using the incremental method show the influence of arbitrary changes in temperature and precipitation on yields (*Figure*).

Changes in precipitation and temperature affect differently each study site: it can be observed that for Passo Fundo the isolines keep an almost diagonal orientation, while in Chapecó isolines present a more horizontal orientation. This indicates that in Passo Fundo yields are balanced by temperature and precipitation, at the same time as in Chapecó temperature (the Y axis) are the main factor that influences yield change. One possible reason is that the soil from Chapecó has lower water holding capacity, so higher temperatures will rapidly dry out the soil and promoting a water stress in the crops. This is a sign that Chapecó has a lower resilience capacity against changes in temperature and precipitation than Passo Fundo.

Regarding variety, it can be observed that in Chapecó the variety MPA01 is less susceptible to increments in temperature and changes in precipitation: the dark grey area (indicating losses of at least 50% of baseline yield) in the upper left side is smaller than in AS1548; For the same study site is possible to identify that the isolines of the variety AS1548 are closer than the ones related to MPA01, indicating lower stability. In Passo Fundo, both varieties presented a similar performance.

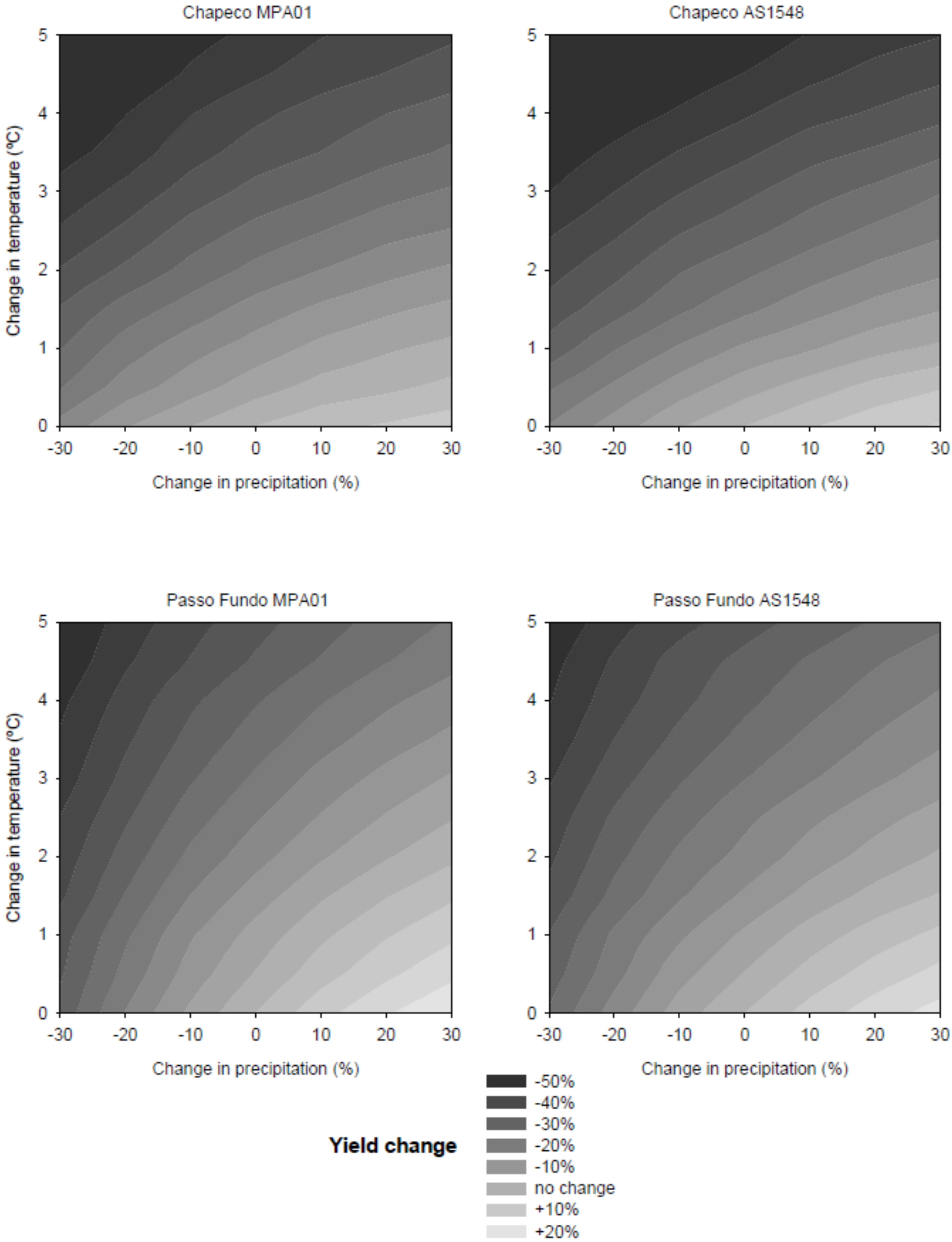


Figure 30. Yield departure (%) from the base line (median of 1981-2011 yields) using different maize varieties in scenarios with increments of precipitation and temperature. For Chapecó and Passo Fundo.

4.3.2 SSoybean in Brazil

For soybeans, changes in precipitation and temperature have different responses across the study sites (*Figure*).

As in the simulation with maize, in Passo Fundo the isolines have a diagonal pattern, indicating a more balanced influence of precipitation and temperature. In Chapecó, soybean yield change is more dependent on temperature than precipitation, and the possibilities of yield losses are higher than the possibilities: it can be observed that the isoline in the point 0 x 0 (X and Y axis) is more horizontal than its equivalent in Passo Fundo, which, in other way, shows an almost diagonal pattern. The presence of light gray areas in Passo Fundo also point to the possibility of increment in yield due increment in precipitation and slight raises in temperatures.

Regarding variety, it can be observed that in both study sites the varieties presented a similar performance, with minor differences in Passo Fundo.

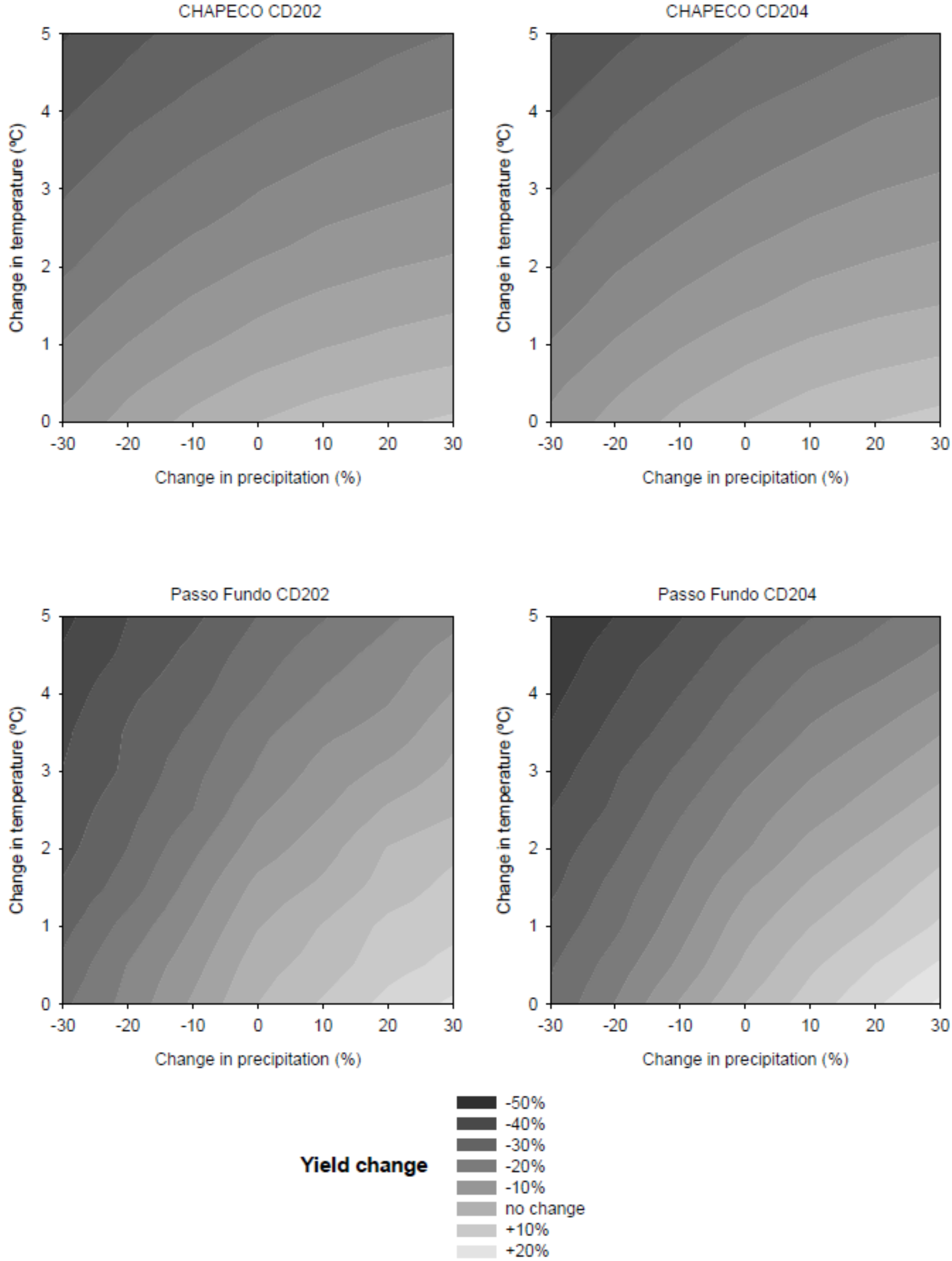


Figure 31. Yield departure (%) from the base line (median of 1981-2011 yields) using different soybean varieties in scenarios with increments of precipitation and temperature. For Chapecó and Passo Fundo.

4.3.3. Maize in Argentina

The maize crop show different responses when we used 77 weather scenarios built with the incremental method for each environment – San Justo, Junín and Balcarce -

Balcarce, the cooler environment, presented a very low sensibility to scenarios of temperature increment in the future climate. The environment response is different according to the gradient of temperature, from the cooler, Balcarce, to the warmer, San Justo.

For the current planting date in both location, September 20 = day 263 and October 10 = day 283, to San Justo and Balcarce, respectively, the temperature present a lower significance compare with the rainfall. In San Justo, for the future scenarios the temperature shows more sensibility response. On the other hand, Balcarce is strongly rainfall dependent's with a relative low weight of thermal modifications in future climates. Finally Junin present an intermediate situation with similar significance for these parameters, temperature and rainfall.

Also we observed, an increment of yield variability from warmer to cooler environments in the current planting dates. This correlation of a higher thermal sensibility in the warmer environment, repeat the similar pattern in each environment when we planted in the late crop season.

In Junín environment, the sensibility to temperature increases when the planting dates, are in the window from the middle October to middle November, while in Balcarce this behavior begins after middle November. We did not explore later planting dates in Balcarce, because when the planting date is after the normal planting window (September 30 to November 20), the genetic coefficient needs to be recalculated and recalibrated the crop model, due to a modification on the thermal grain filling duration and grain filling rate, two important parameters in the genetic cultivars' characterization.

For San Justo environment the planting date of middle September (planting day 259) show the higher stability with yields greater than 8000 kg ha^{-1} with a limit line obtained by 3ºC, 2.5ºC and 1.0ºC and 0%, -10% and -20% variation in rainfall, respectively. (Figure 32). When the planting date is delayed we can highlight two behaviors according to the crop season, after the current planting date the yield variability shows a smooth increase until middle October, after that we observed a high increase in yield variability with a strong effect of temperature and a decreasing rainfall's impact until beginning of November.

Also when we use the earlier planting date from day 259, we observed a yield decreased with a threshold of 6500 kg ha^{-1} and maximum values around 8000 kg ha^{-1}, the probability of these maximum yields are 5% to 11%. The loss of productivity is associated with a higher yield stability .

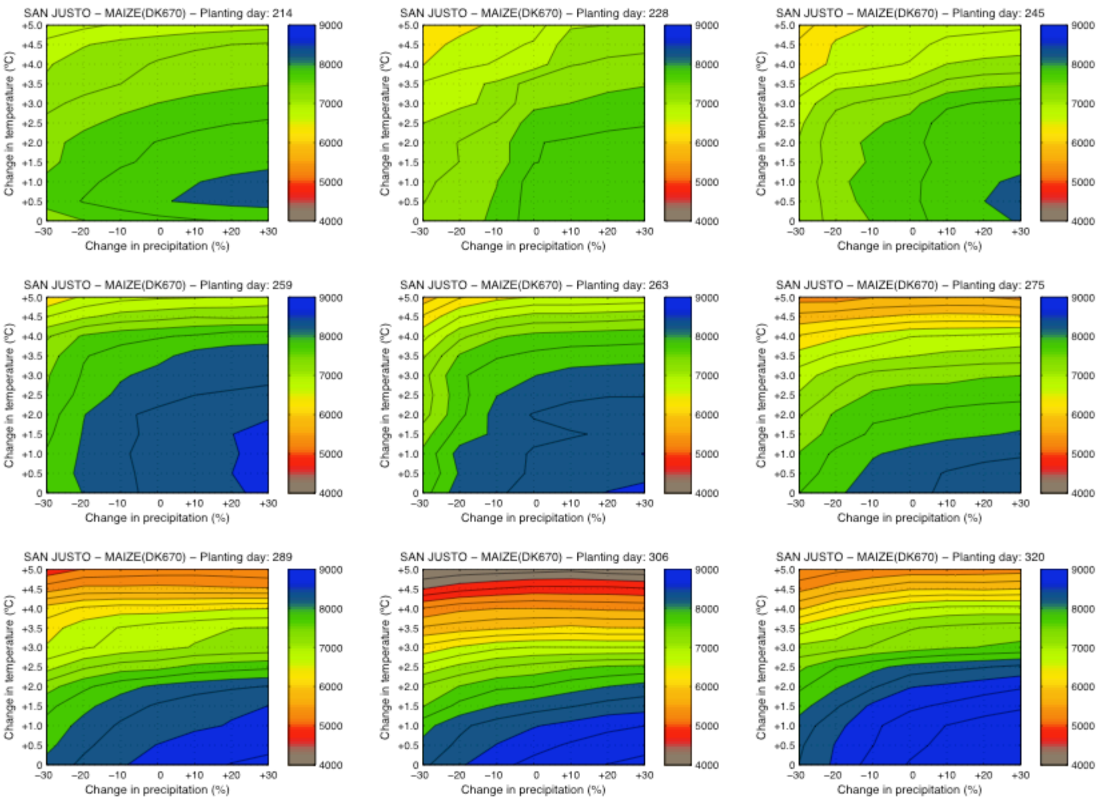


Figure 32: Response of Maize Crop against scenarios of variation in temperature and rainfall built with Incremental Method for San Justo environment, in nine planting dates from August 01 to November 15, including the current planting date (Planting day = 263).

Junín environment shows a high sensibility to temperature increase scenarios from middle of October to middle of November. In early planting dates, at beginning October, the more significant factor will be the water available, as total rainfall variation. For this environment the relative weight of rainfall result an increase of yield variability in early planting dates. These dry scenarios with lower rainfall early in the crop season, shows a strong interaction with the soil texture, basically sandy and sandy loam soils, and result in a negative water balance, with critical values for de crop development and growth (Figure 33).

For this environment early or late planting date can modify the yield variability, but the more significant responses are the sensibility to available water in early planting date, until two months before to current planting date. The increment of sensibility to temperature in the future climate allow a large planting window and use climatic forecast and crop tools to choose the better strategies to mitigate the impact on yield in these scenarios of climate change.

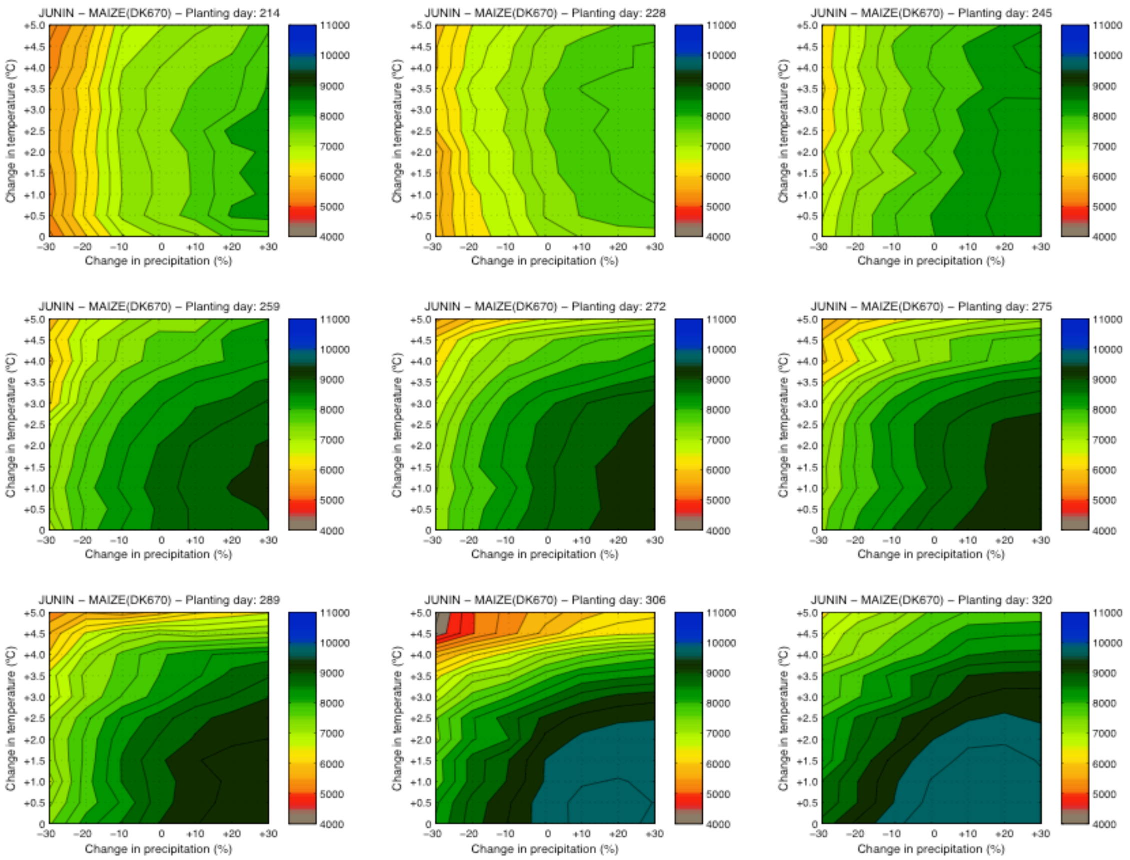


Figure 33 : Response of Maize Crop against scenarios of variation in temperature and rainfall, built with Incremental Method for Junín environment, in nine planting dates from August 01 to November 15, including the current planting date (Planting day = 272).

Balcarce is the most productive environment of the three studies sites, with maximum yield higher than 11000 kg ha^{-1} and also show the highest yield variability, with high sensibility to rainfall and without sensibility to temperature in the current planting window, until middle of November (Figure 34).

The impact mitigation strategies, analyzing with this incremental method for the future scenarios of climate change on maize productivity, show a strong association with the spatial distribution of the three different studies environments.

An earlier planting date show different advantages for each environment, in a warmer environment, as San Justo, this management can decrease in potential productivity with lower yield variability, a more sustainable model at natural resources level.

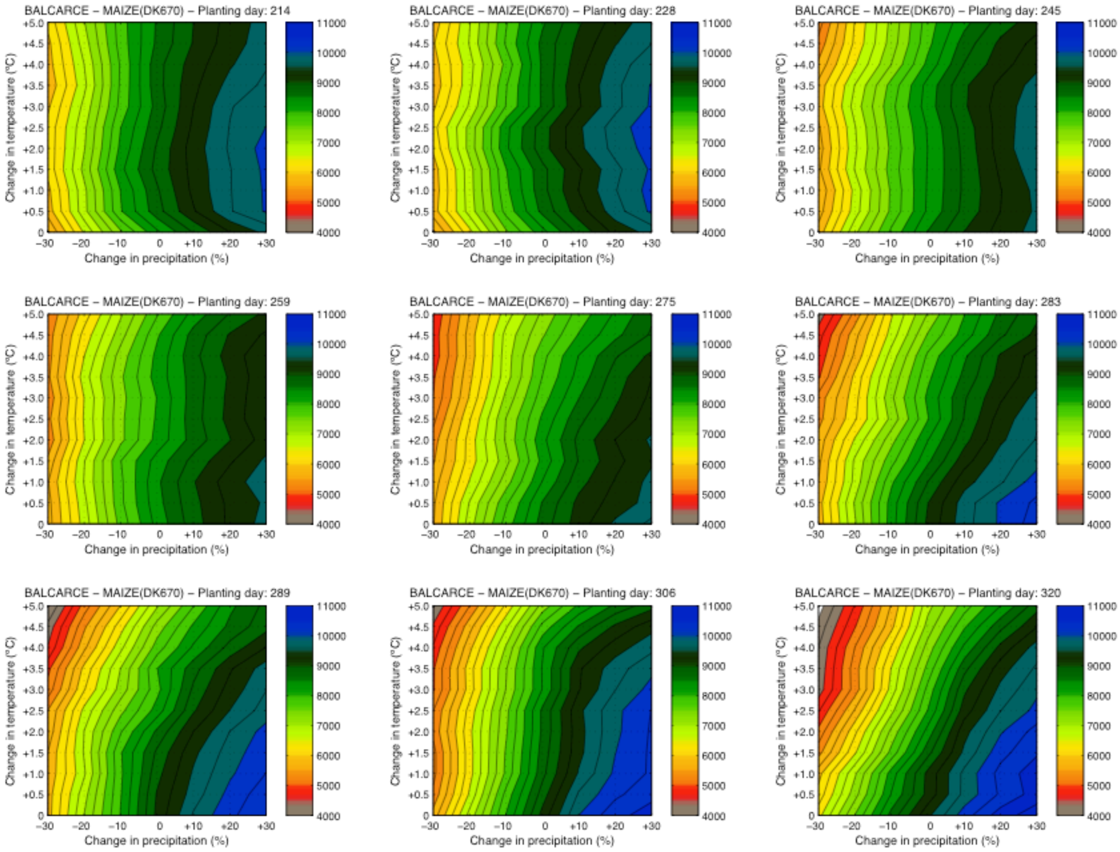


Figure 34: Response of Maize Crop against scenarios of variation in temperature and rainfall, built with Incremental Method for Balcarce environment, in nine planting dates from August 01 to November 15, including the current planting date (Planting day = 283).

4.3.4. Soybean in Argentina

The three environments under study showed that yield increased when the planting date is delayed, but also the yield variability decreased. Even when the yield patterns are different, San Justo, the warmer environment shown strong association between yield and temperature, while Balcarce, the cooler environment present strong association between yield and rainfall. Junín environment is an intermediate situation, not only geographically, but also in term of temperature-rainfall interaction The intermediate planting dates for all environments showed an intermediate behavior for yield but also for yield variability.

San Justo environment present the higher yield frequency for the late planting date (day 320) even when the rainfall percentage decreased -26%, and the yield range was 4000-5000 kg ha^{-1}.

When the temperature increased 2ºC, the yield range reach 3500 – 4000 kg ha^{-1}, and when the temperature reached 5ºC, the yield range expected is around 2500-3000 kg ha^{-1} (Figure 35).

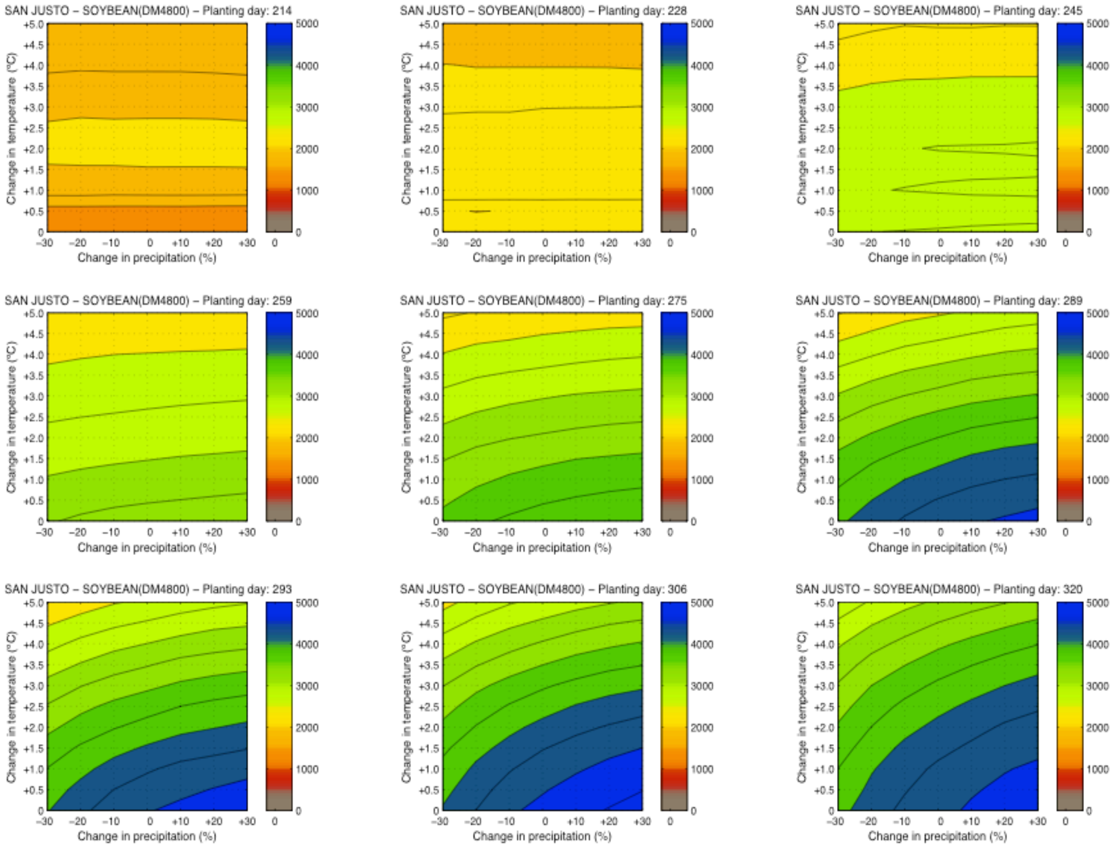


Figure 35: Response of soybean crop against scenarios variation in temperature and rainfall built with incremental method for San Justo environment, in nine planting dates from August 01 to November 15, including the current planting date (day 293).

The Junín environment shows higher yield frequency in the later planting dates, with similar yield range to San Justo, but when the percentage of rainfall decreased to negative percentage values (0 -20%) the yield range drop to 3000-4000 kg ha^{-1}. The yield is affected by temperature when the threshold of 4ºC is reached and the expected yield range was 2000-2500 kg ha^{-1} (Figure 36).

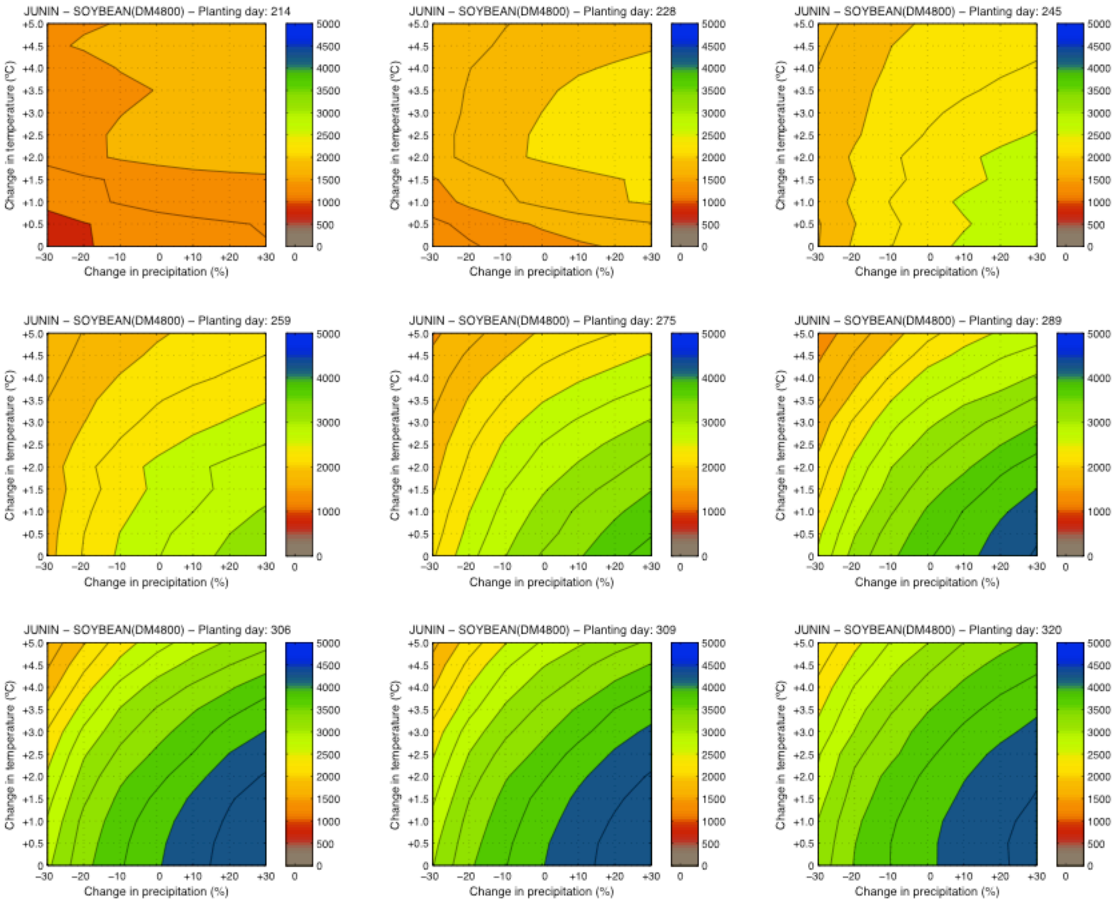


Figure 36: Response of soybean crop against scenarios variation in temperature and rainfall built with incremental method for Junín environment, in nine planting dates from August 01 to November 15, including the current planting date (day 306).

The Balcarce environment shows the higher yield sensitivity to rainfall changes. From planting date in day 259, the higher yield frequency is reached when the percentage of rainfall is higher than 15% respect to the actual rainfall values. Even when the yield frequency later than day 259 showed the higher yield, the yield variability decreased with the later planting date. In the last planting date, when the temperature reached 4ºC, the yield dropped to the range of 3500-4000 kg ha^{-1}.

When current percentages of rainfall drop, the early planting dates showed a strong impact in yield compared with late planting dates. Planting dates after day 259 decreased yield when the percentage of rainfall drop lower than 15% - 20% (Figure 37).

From planting date in day 259 when the percentage decreased between 17% a 20%, the expected yield range is 2500-4000 kg ha-1, and is proportional to the increment in percentage of rainfall. When the temperature increased more than 1.5 ºC and -30% of rainfall, the impact on yield will be important with a yield range of 1500-2000 kg ha-1.

For soybean crop, these results suggest that the expected increase in temperature and the possible modifications in the percentage of rainfall will impact the crop yield in different way, according to the environments under study.

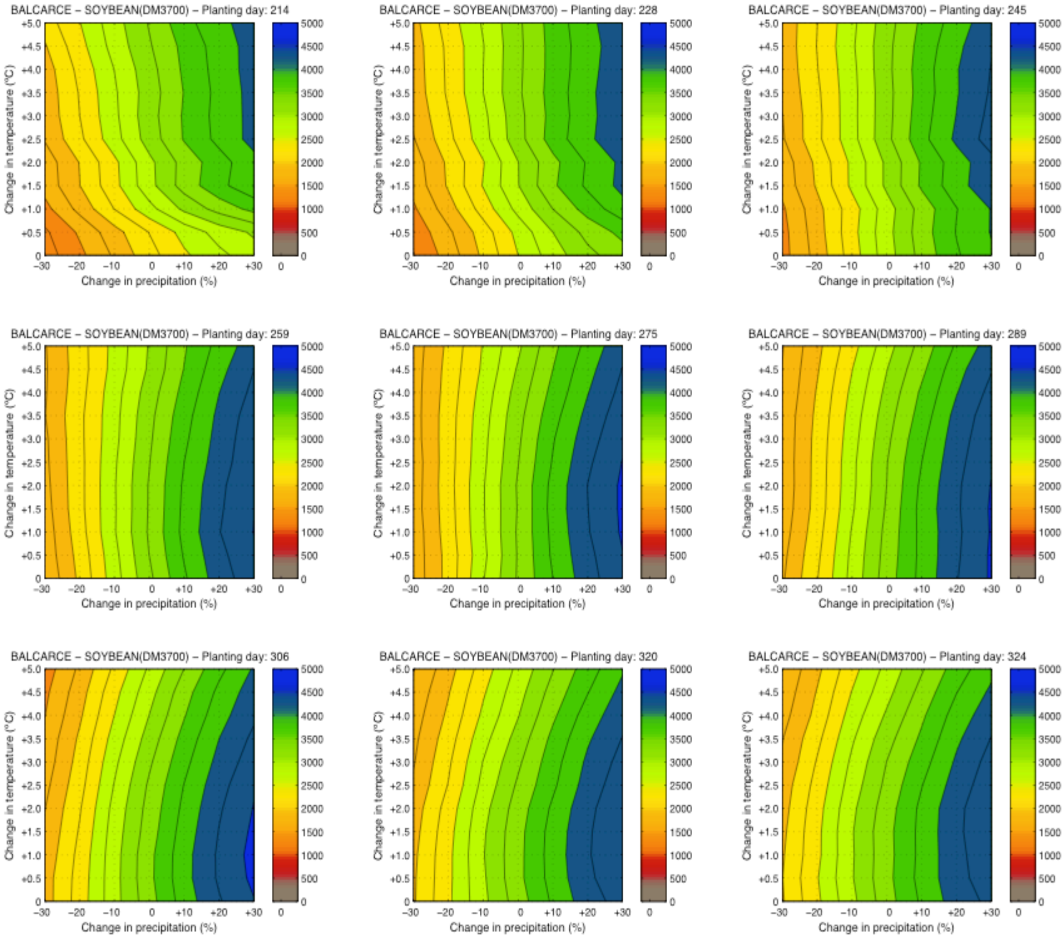


Figure 37: Response of soybean crop against scenarios variation in temperature and rainfall built with incremental method for Balcarce environment, in nine planting dates from August 01 to November 15, including the current planting date (day 320).

4.4 EFFECT OF ADAPTATION STRATEGIES

4.4.1 Planting date

4.4.1.1 Maize

In Chapecó and Passo Fundo the influence of the crop model initial conditions affected the yields: in order to balance the soil water content with precipitation, the model is instructed to start the simulation one month prior to the first planting date with 70% of field capacity. Due low temperatures of July, less water was lost due evaporation, resulting in an artificially increase soil water content, which improved plant germination and establishment. The results for 01/Aug are shown but will not be considered in this analysis.

For Chapecó, due the high variability of results each RCM should be analyzed individually. As trends for the 2011-2040 period, all RCMs presented a crescent function observed in both varieties and related to planting date: the later planting date is, the higher the yield. The later planting dates are favored by increasing in precipitation (Figure 15, Figure 16 and Figure) during planting months and grain filling period. The three best RCMs (ECHAM5, ETA and IPSL) present a lower variation of precipitation amount during the crop season, and moderate increments in temperature, which also plays an important role by somewhat shortening the phenophases of maize. For the end-of-century period climatic changes are intensified, impacting more the yields: extremes of temperature increment (more frequent in September and October) increase dramatically the atmospheric evaporative demand, which is not always compensated by eventual increment in precipitation. The increment in temperature can also shorten the maize cycle in such a way that the phenophases are not long enough adequate plant development or grain filling, for example. In a generalization it could be stated that the less negative planting dates would be after 15/Oct, which reduces the risk of water stress.

For Passo Fundo, the effect of crop model initialization was not absent, but less pronounced: the reason is that, compared to Chapecó, Passo Fundo has higher precipitation in August, followed by precipitations even higher in the subsequent months, recharging the soil water content, which in its turn also has a higher water holding capacity. The reduced yield variation observed in Figure and Figure can be attributed to a reduced precipitation variation (when compared to Chapecó) during the crop season, reducing the negative impacts. Soil characteristics also play a crucial role due its inherent water holding capacity and depth. Regarding planting dates, it is difficult to identify common trends among the RCMs. What can be observed is that early planting dates show higher variability among RCMs and late planting dates tend to produce lower yields, especially in the end-of-century period.

In Argentina locations, modifying the planting dates was analyzed as strategy of adaptation, and did not compared cultivars due to similar behavior among them in terms of phenology as well as yield components and yield potential.

The different planting dates presented differences among environments, where in the warmer environment (San Justo) the earlier planting date at the end of the century showed a slight mitigation of the impact of future scenarios in five of them. In the period 2011-2040, the results obtained did not allow to define any strategy due to the unpredictable behavior of RCMs. For Both periods, higher yield variability was found in the warmer RCMs (LMDZ-IPSL and PROMES).

For the Junín environment, except the RCM PROMES, the other RCMs showed the same yield behavior than yield base line with slight mitigation in the early planting date.

At the end of the century, four RCMs showed a yield increment during the first four planting dates compared with the yield base line.

In the Balcarce environment, except PROMES during the period 2011-2040 showed the lower yield for all planting dates, the rest of RCMs showed yields higher than the base line but without significance difference. At the end of the century, all RCMs except LMDZ-IPSL and PROMES showed high response to the planting dates. The earlier planting date showed the higher yield and was constant for all planting date and with significance difference compared with the yield of the base line and with the warmer models (LMDZ-IPSL and PROMES). The future combination of early planting dates with genotype and higher temperature requirements could improve the genotype-weather interaction.

4.4.1.2 Soybean

In Chapecó there is a widespread reduction in yields according RCMs in the 2011-2040 period. PROMES, RCA1, RCA2 and RCA3, for all planting dates, result in yields of 1000 $Kg.ha^{-1}$ or less, making this crop impracticable from economical terms. Results indicate that, depending on the RCM, losses can be reduced by shifting the planting date to 01/Oct (one month later than the present best planting date) for ECHAM5 and ETA. For IPSL scenario the best planting date is two months later than the present best planting date. For the end-of-century period almost the same trend can be observed: ETA, ECHAM5 and IPSL still present the best yields among the RCMs, but with a sensible delay (one month) for the best planting date.

Figure , low, was identified a slight anticipation of best planting date for all RCMs, except PROMES. The main reason behind this is the increment in precipitation in Sep-Oct months, which facilitate crop establishment. The yield peaks of observed data can be seen as a plateau between01/Sep and until 01/Nov, while for RCMs different trends were observed. It is important to note that the RCMs did not create a plateau of best planting date; instead they generated peaks between 01/Set and 01/Oct, a much narrower time window for planting.

The three environments of Argentina presented different patterns of planting dates windows, and for all of them, these patterns are similar to the observed planting date's pattern. For San Justo environment early and late planting date's decreased yield for both periods analyzed with higher yield variability in the last one, but the range of expected yield are similar between the early and late period.

For this environment the possible mitigation modifying planting dates did not show any advantage, because only one RCM showed higher yield compared with the yield of observed values, for both scenarios.

Junín for the period 2011-2040 showed the lower yield for almost all RCMs except one RCM in earlier and later planting dates compared with the observed values, while at the end of the century, all RCMs showed higher yield compared with the observed values. For this environment late planting dates showed advantage for all RCMs at the end of the century. The period 2011-2040 this slope was smooth compared with the end of the century. For this environment will be possible mitigated the climate change impact using different planting dates only at the end of the century.

For Balcarce environment mitigation using different planting dates it is clear at the end of the century, with high yield variability among RCMs, but with higher yields compared with yields of period 2011-2040. In the first period, most of the RCMs showed yield increment when were compared with the observed yield with smooth slope among different planting dates.

4.4.2 Variety

4.4.2.1 Maize

The two tested varieties, namely MPA01 and AS1548, present almost the same behavior in actual conditions, as seen in *Figure* and *Figure* . It can also be observed the influence of environment in yield, while Passo Fundo has significantly higher yields than Chapecó, for both varieties. As each variety has distinct genetic coefficients, different responses are expected.

The responses of AS1548 for each RCM usually produce mainly lower yields when compared to actual conditions. The exceptions are only observed in mid-late planting dates in Chapecó for both periods, and only for ECHAM5, ETA and IPSL, RCMs with lower risk of water stress during crop season. In Passo Fundo, the yields of this variety presented a high level of stability across the crop season.

MPA01 presented a higher variability among the different RCMs, without the across season stability effect observed for AS1548. In other hand, MPA01 performed higher yields in many planting dates in Chapecó and Passo Fundo during the 2011-2040 period. For end-of-century period only ETA produced yields above actual conditions, and for few planting dates. Summarizing, the variety AS1548 presented lower yields when compared to MPA01, so as a lower variability among RCMs; MPA01 presented higher yields, but is also more responsive to different RCMs, resulting in a wider range of yield.

4.4.2.2 Soybean

Both genotypes tested (CD202 and CD204) did not presented significant differences among them. Unfortunately, for the Brazilian part of LPB no other suitable soybean data sets are available to calibrate and validate the crop model in the study region. This undermines the assessment of the role of soybean variety as adaptation strategy. However, as soybean is part of a large industrial complex, evidently breeding companies already offer contrasting genotypes to fit in distinct environments.

5 RECOMMENDATIONS FOR POLICY AND DECISION MAKERS

- Adoption and improvement of agroecological zoning for main crops in the region;
- Use of short and medium-term weather forecasts to support farmers decision making;
- Employment of crop models as tool to support technical advice and decision makers;
- Improve weather forecast capacity, so as weather monitoring capacities;
- Foster implementation of irrigation, conservation tillage and other agronomic managements that can reduce crop vulnerability to climatic stressors;
- Build human and structural capacities to design and promote adaptation and mitigation strategies al local and regional level.

6 CONCLUSIONS

- Climate change, represented by the scenarios, can negatively impact yields of maize and soybeans;
- Amplitude of impacts for near-future periods (2011-2040) is lower than the ones projected for end-of-century periods (2071-2100);
- Study sites can respond differently for the same RCM;
- Planting date shifting is one of the main tools to avoid and mitigate negative effects of climate change and variation, followed by crop variety;
- For maize, RCMs produced divergent results: some RCMs project severe losses, regardless of planting date and/or variety; other RCMs indicate even increments in yields. For Chapecó, region where maize is more prone to suffer water stress, RMCs show a trend of yield losses in the end-of-century period, while for the 2011-2040 period RCMs are divided in one group indicating losses and other indicating increases. Maize variety plays an important role in the crop response for each RCM, so as planting date, especially in Chapecó;
- Soybean is the main crop in Passo Fundo and yields can be negatively affected by climate change. However, various RCMs presented possible increments in yield for the tested varieties, especially when planting date is anticipated. In Chapecó, the tested crop varieties are threatened by non-favorable environment, according RCMs;
- Crop models can be used to explore and test successfully different adaptation and mitigation strategies.

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