Sustainability **2011**, *3*, 1-x manuscripts; doi:10.3390/su30x000x

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Article,

MONITORING EXTREME HYDROLOGICAL EVENTS TO MAINTAIN AGRICULTURAL SUSTAINABILITY IN PAMPEAN FLATLANDS, ARGENTINA

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Received: / Accepted: / Published:

Abstract: This is the abstract section. One paragraph only. (M_abstract) For environmental and economic conditions, precipitation can be considered as the most important climatic element. Its drought and wet periods are known to change the natural water supply, river discharges, and crop yields, as well as natural vegetation.

Argentine agriculture was and surely will drive the national economy and the most important agriculture region is Pampa or pampean flatlands, mainly because it allows the rain - fed crops production.

The grain production increased from 23 to 90 million tones during the period 1970 – 2010 by means of the best available technology application and this growth had two components: a) the soybean which has now a ratio of 6 to 1 with respect to corn and b) the increase of precipitation amounts during the last decades of XX century. There is a need to maintain agricultural sustainability and for that changes in production patterns would be considered.

On the other hand, the pampean flatlands experienced a succession of extreme hydrological events related to precipitation. Droughts and floods were a constant, according ancient documents during the Spanish domain, the argentine government and the installation of meteorological stations near 1870. Documented droughts occurred during 1604, 1614, 1620 and 1824 and floods in 1636, 1770, 1817, 1857 and 1900 can be mentioned as examples.

The climate of the studied region according Thornthwaite classification is Perhumid, Humid and Subhumid from East to West, with fluctuations in their limits answering climate variability. And so, the agriculture was influenced. The surface of croplands is greater in the Perhumid and Humid

climates regions than in the last one, where livestock is important. Subhumid region had suffered important changes in its land uses and surely, it will be vulnerable in the future.
In this paper the three zones are studied using meteorological data, soil water balance and crops data.
More recently there were important floods in 1980, 1985, 1993, 2001 and 2002 and severe droughts in 1978, 1983, 1989, 1995 and 2008.
Extreme hydrological events acted in short periods but the losses reached high importance because precipitation variability acts over the soil water balance, influencing its parameters and the water table depth.

Keywords: drought, flood, pampean flatlands, soil water balance, agriculture.

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1. Introduction

Precipitation can be considered as the most important climatic element. Its drought and wet periods are known to change the natural water supply, the soil water balance, river discharges, and crop yields, as well as natural vegetation.

There is a cyclical pattern of precipitation in pampean flatlands which has dry and wet periods and involving changes in land uses.

At different times have been noted numerous "anomalies" in regard to precipitation annual march and there are many studies at different scale and generalization level about this theme [1-9].

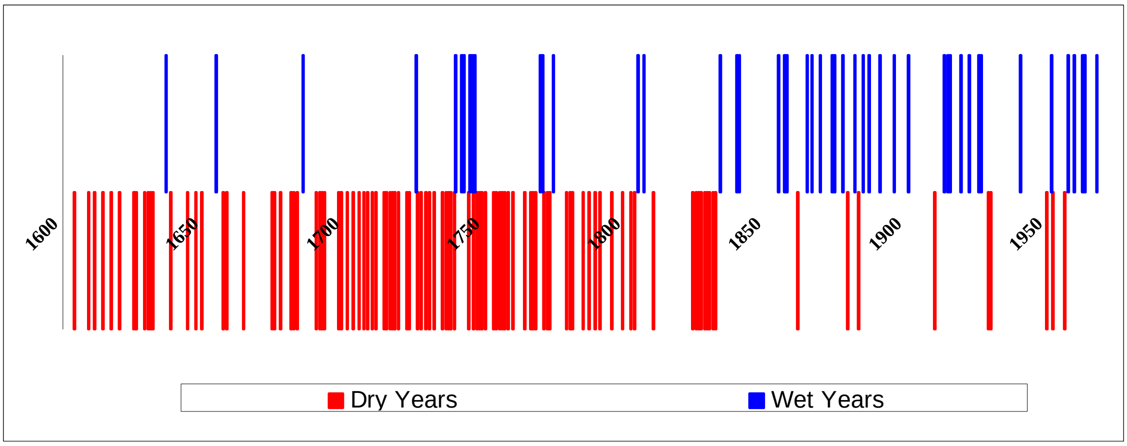
Argentina is a relatively young country because its territory was conquered by Spain in the XVI century and so, the climatic knowledge has two distinct stages: the first one, pre-scientific and named "non systematic" is based on travelers' accounts, news directly observed and phenomena perceived by the residents and, the second, called "systematic" which began with the creation of the National Weather Service in the mid-nineteenth century. The "non systematic" information is devoid of mathematical precision but as it is the only existing, we can take it into account as a contribution to knowledge of the climate of the region.

The oldest observation refers to weather conditions comes from the Spanish people was based on the correspondence collected in the Archivo de Indias in Seville (Spain), for the period 1540 to 1596, which was coordinated and published [10].

According to [11] the information about the weather conditions of the colonies began in 1604, which was engaged in a journey of Hernandarias, which is in the 46 volumes of the Acuerdos (Agreements) of the Buenos Aires Cabildo (government). They include the long period that runs from 1589 until 1821, year that this was abolished. Other two researchers about this theme are [12-13]. Figure 1 has been done with joined information from these three mentioned authors and where the succession of wet and dry years can be seen since the year 1604 to 1970.

The resulting analysis is very general and is often difficult to deduce from it the duration and severity of drought or flood, the area covered and the damage caused. Exception of these limitations, acknowledged by scholars, it is evident an often-repeated critical situations, followed by serious consequences.

Figure 1. Distribution de of dry and wet years during the centuries XVII, XVIII, XIX and XX. Realized by the authors.



It is interesting to comment the Darwin concepts [14], when he visited the country in 1832 and saw that birds, cows and horses were dying of hunger and thirst, This period (1827 – 1832) is known as "Great dry" and after that, during the decade of 1840, and important flood lasted some years [13].

Systematic information started with the installation of meteorological stations and for example Buenos Aires city has it since 1876.

In 1900 a new flood occurred and occupied 6,000,000 hectares and began the construction of drainage channels (Channels 11, 12 and 9) in pampean territory. These works did not give the expected results and in some cases worsened the damages.

The greatest flood, according [13], took place in 1980 when precipitation reached 30,000,000 litres of water and affected 4 millions hectares.

The drought occurred at later 1996 and early 1997 allowed an important archaeological discovery: elements of a wall of the XVIII century.

The last important flood occurred during 2001 – 2002 and reached losses of U$S 700 millions [15-16]. In this case the soil water balance and the depth of the water table were the most important parameters.

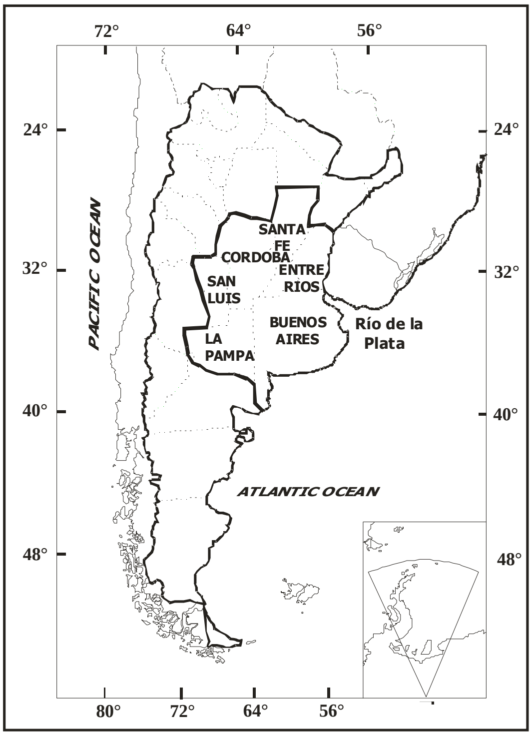
Kruse *et al*. [17] described the relationship between precipitation, evapotranspiration, soil water storage, the water table, subsurface and surface runoff under different scenarios in an area of the pampean flatlands and finding a good temporal relationship between water table levels and soil water content.

The goal of this paper is analyze the precipitation and soil water balance variability and the consequent land use in pampean flatlands during the last decades and the vulnerability of the different environments involved.

2. Materials and Methods

The data source used in this paper belongs to the argentine provinces presented in Figure 2 and pampean flatlands occupied an important area of them.

Figure 2. Location of the argentine provinces. Realized by the authors.



This section is divided in several parts related to the different sources of information and methodologies utilized in the elaborations.

2.1. Data and Meteorological Stations

Daily precipitation data for the period 1968–2008 were provided by the National Meteorological Service—SMN (29 stations) and by the National Institute of Agronomic Technology—INTA (five stations). The meteorological stations were selected according to their long record, homogeneity and historical development.

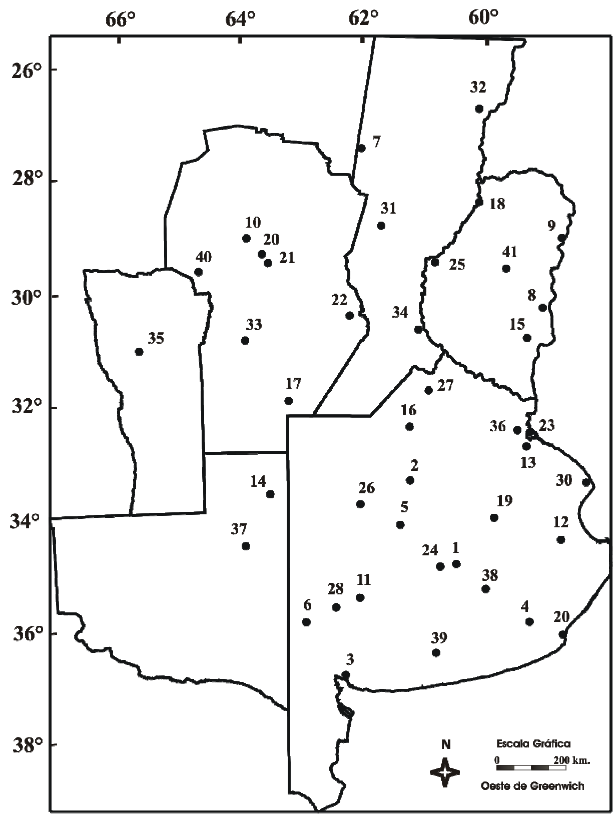
Figure 3 shows the position of the meteorological stations used in the work, which are listed in Table 1.

Table 1. Meteorological stations used in precipitation study. Realized by the authors.

N°	Station	Latitude	Longitude	Height (m)
1	Azul	36° 45’	59° 50’	132
2	Nueve de Julio	35° 27’	60° 53’	76
3	Bahía Blanca	38° 44’	62° 10’	83
4	Balcarce INTA	37° 45’	58° 18’	130
5	Bolívar	36° 15’	61° 06’	93
6	Bordenave INTA	37° 51	63° 01’	212
7	Ceres	29° 53’	61° 57’	88
8	Concepción del Uruguay INTA	32° 29’	58° 20’	25
9	Concordia	31° 23’	58° 01’	37
10	Córdoba Aero	31° 24’	64° 11’	425
11	Coronel Suárez	37° 26’	61° 53’	233

12	Dolores	36° 21’	57° 44’	9
13	Ezeiza	34° 49’	58° 32’	20
14	General Pico	35° 42’	63° 45’	145
15	Gualeguaychú	33° 00’	58° 37’	21
16	Junín	34° 43’	60° 55’	81
17	Laboulaye	34° 08’	63° 22’	137
18	La Paz	30° 46’	59° 38’	48
19	Las Flores	36° 02’	59° 06’	33
20	Mar del Plata	37° 56’	57° 35’	25
21	Manfredi INTA	31° 50’	63° 45’	292
22	Marcos Juárez	32° 41’	62° 07’	110
23	Observatorio Central Buenos Aires	34° 35’	58° 29	25
24	Olavarria	36° 53’	60° 13’	166
25	Paraná	31° 47’	60° 29’	78
26	Pehuajó	35° 52´	61° 52’	87
27	Pergamino INTA	33° 56’	60° 33’	65
28	Pigüé	37° 36’	62° 23’	304
29	Pilar (Observatorio)	31° 41’	63° 53’	338
30	Punta Indio	35° 22’	57° 17’	22
31	Rafaela INTA	31° 11’	61° 33’	100
32	Reconquista	29° 11’	59° 42’	42
33	Río Cuarto	33° 07’	64° 14’	421
34	Rosario	32° 55’	60° 47’	25
35	San Luis	33° 19’	66° 21’	713
36	San Miguel (Observatorio)	34° 33’	58° 44’	26
37	Santa Rosa	36° 34’	64° 16’	191
38	Tandil	37° 14’	59° 15’	175
39	Tres Arroyos	38° 20’	60° 15’	115
40	Villa Dolores	31° 57’	65° 08’	569
41	Villaguay	31° 58’	59° 05’	43

Figure 3. Location of the meteorological stations. Realized by the authors.



According to [5] two different amounts in precipitation that modify the soil water balance two periods 1947-1976 and 1977-2006 were analyzed in their annual, cold semester (April – September) and warm semester (October to March) values.

2. 2. Statistical Analysis

To show the different behaviour of Dolores, Nueve de Julio and General Pico annual precipitation trends a forth degree polynomial equation were calculated.

Five meteorological stations were selected for the statistical analysis, using their geographical location in the pampean flatlands and according the Thornthwaite classification: Dolores and Nueve de Julio: Perhumid climate, Pergamino and Pehuajó: Humid climate and General Pico: Subhumid climate.

They were selected because they have long data series of daily precipitation, long data series and high homogeneity. The precipitation data were used in their annual, cold semester (April – September) and warm semester (October to March) values for the period 1910 to 2006.

The non parametric Mann-Kendall test was applied to the complete series of data. In addition, an Excel template, called MAKESENS and described in [18], was used for detecting and estimating trends in the time series of annual and six-months values of precipitation. This procedure is based on the nonparametric Mann-Kendall test for the trends, and the nonparametric Sen's method for estimating the magnitude of the trend. In detail, in the first step, the Mann-Kendall test allows detection of a monotonic trend in the time series of data without seasonal or other cycles. Subsequently, the Sen's method tries to fit the data with a linear model, reported in Equation 2, where t is the time expressed in years:

$$f(t) = Qt + B \quad (1)$$

where Q is the slope and B the offset to be determined. Finally, MAKESENS evaluates the test statistical significance using the α levels 0.001, 0.01, 0.05 and 0.1 [16].

The Sen's method gives the following results, depending on the number of years n:

Test Z for the trend assessment: if the number of samples n is greater than 10, the value of the statistic test Z is displayed. The absolute value of Z is compared to the standard normal cumulative distribution for assessing the presence of a trend at the selected significance level α, while a positive (negative) value of Z indicates an upward (downward) trend.

Statistical significance: α represents the smallest significance level at which the null hypothesis (absence of trends) must be rejected. If n is lower than 10, the test uses the S statistic, while if n is larger or equal to 10, the test uses the Z (normal) statistic. To show the significance levels, the following symbols are used:

*** existence of a trend with level of significance α = 0.001;
** existence of a trend with level of significance α = 0.01;
* existence of a trend with level of significance α = 0.05;
+ existence of a trend with level of significance α = 0.1.

2. 3. Soil water balance

In this paper the daily soil water balance was realized considering daily precipitation and temperature data of the meteorological stations listed in Table 1.

Looking for more accuracy the normal daily mean reference evapotranspiration was estimated by the Penman-Monteith method [19], and the daily soil water balance data were obtained using the method of Forte Lay *et al*., [5], based on Thornthwaite and Mather daily soil water balance (eq. 2).

The Model of soil water balance used is:

$$PP - EP + \Delta St + Su + Def = O \tag{2}$$

where:
PP: Daily precipitation
EP: Normal daily mean potential evapotranspiration
Δ *St*: Soil water storage variation
Su: Soil water surplus
Def: Soil water deficit

2. 4. Map Graphical Representation

The maps showing the isohyets corresponding to annual cold and warm semester values, soil water surplus and soil water deficit were done using daily meteorological data of each meteorological station and for each period and the results of the soil water balance realized. They were performed utilizing the software SURFER 8.0, which allows the construction of the isolines maps.

2. 5. Crops data

The soybean sown surface (ha), the harvested surface (ha) and yields of (qq/ha) series data were provided by the National Ministry of Economy and Production. They belong to Buenos Aires and La Pampa provinces and for the departments (counties) of Pergamino and Nueve de Julio of the first province and for the department (county) of Maracó in the last one. The period used was 1970 – 2006. They were selected because they are situated where the meteorological stations Pergamino, Nueve de Julio and General Pico are located respectively. For the statistical analysis linear trend and R^2 were used.

3. Results and discussion

3. 1 Precipitation

Figure 4 shows the annual oscilation of five selected meteorological stations corresponding to different Thornthwaite climate: Dolores, Pergamino, Nueve de Julio, Pehuajó and General Pico for the period 1910 -2008.

Figure 4. Annual precipitation of five selected stations. Realized by the authors.

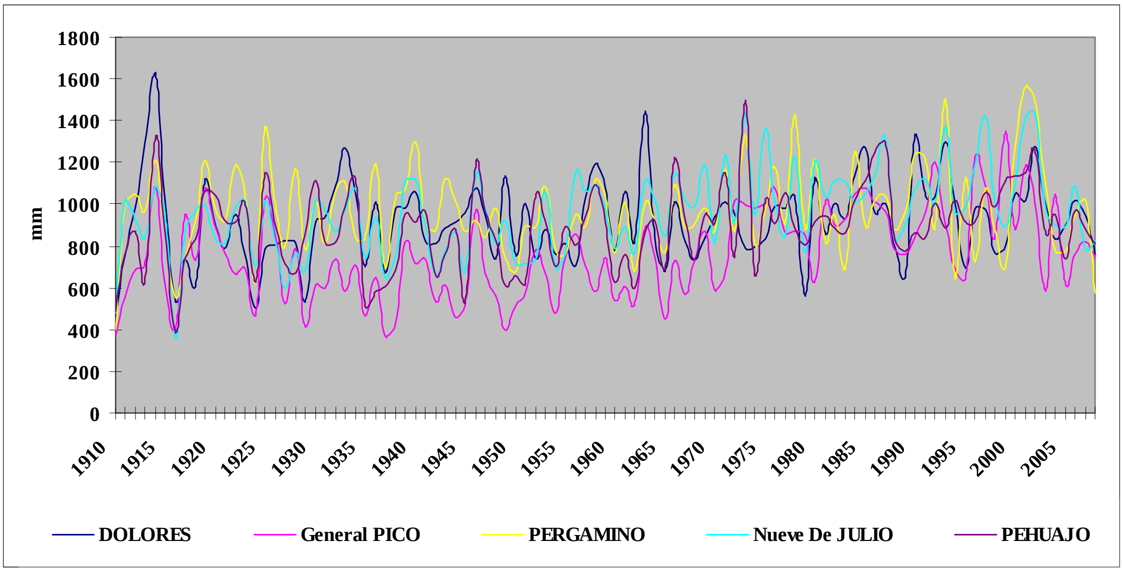


Figure 5 presents the annual variability of the precipitation corresponding to the warm semester (October to March) of the five selected stations for the period 1910 -2008.

Figure 5. Warm semester precipitation of five selected stations. Realized by the authors.

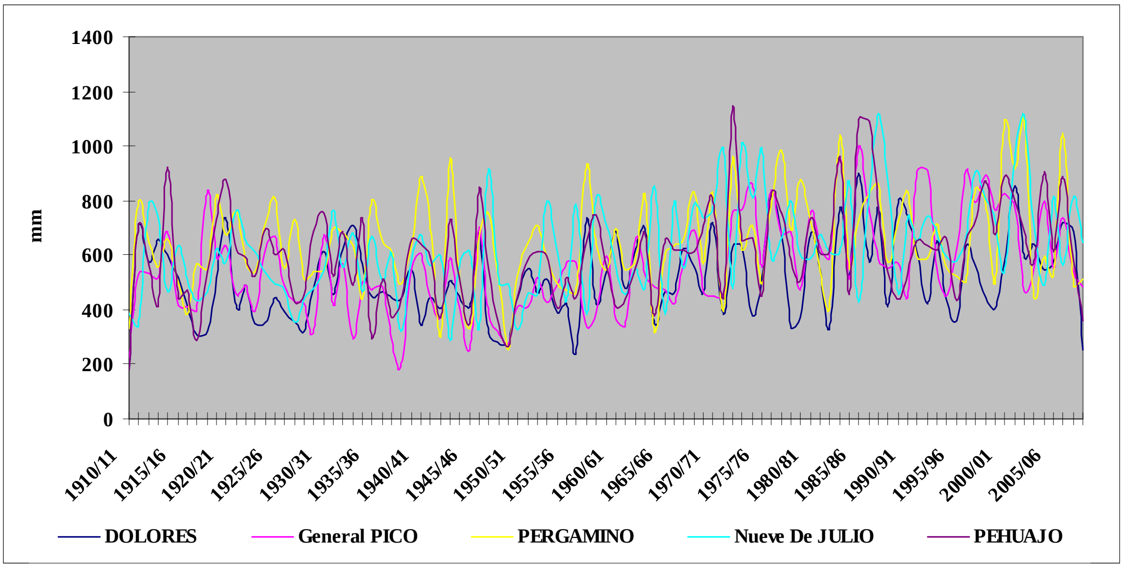
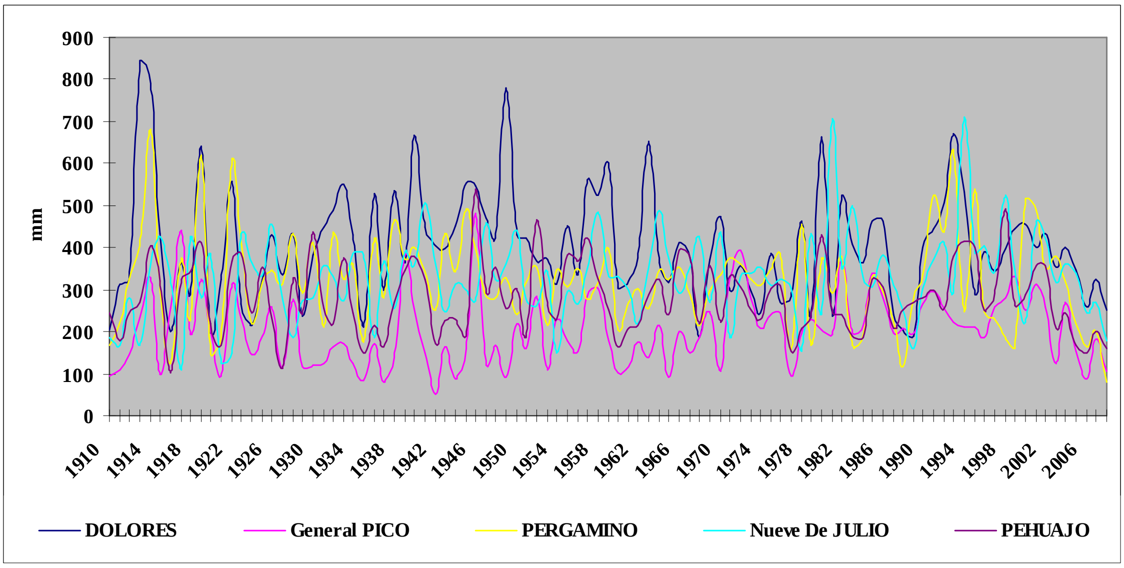


Figure 6 presents the annual variability of the precipitation corresponding to the cold semester (April to September) of the five selected stations for the period 1910 -2008.

Figure 6. Cold semester precipitation of five selected stations. Realized by the authors.



These figures show clearly the climate fluctuations or variability in rainfall that has always been part of the characteristics of the Pampas.

Figure 7, 8 and 9 present the annual precipitation for a long number of years, more than a century, in three stations of selected ones. The first one, Dolores (1889 – 2008) presented an almost uniform line in its trend while General Pico (1907 – 2008) has several variations in its precipitation (two waves). All of them allow observing the decrease for the last years. Their trends were calculated by a forth degree polynomial equation.

Figure 7. Annual precipitation of Dolores and its trend. Realized by the authors.

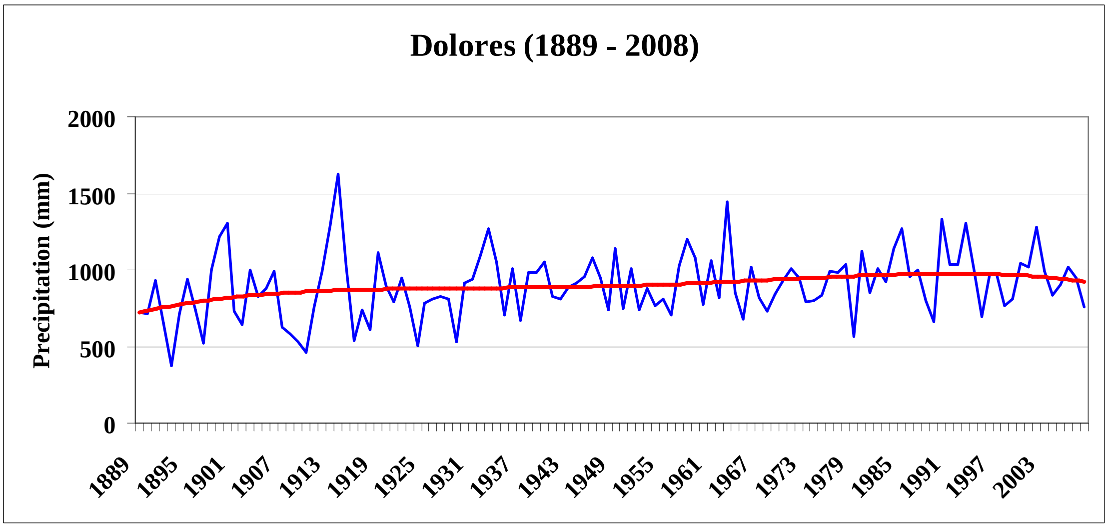


Figure 8. Annual precipitation of Pergamino and its trend. Realized by the authors.

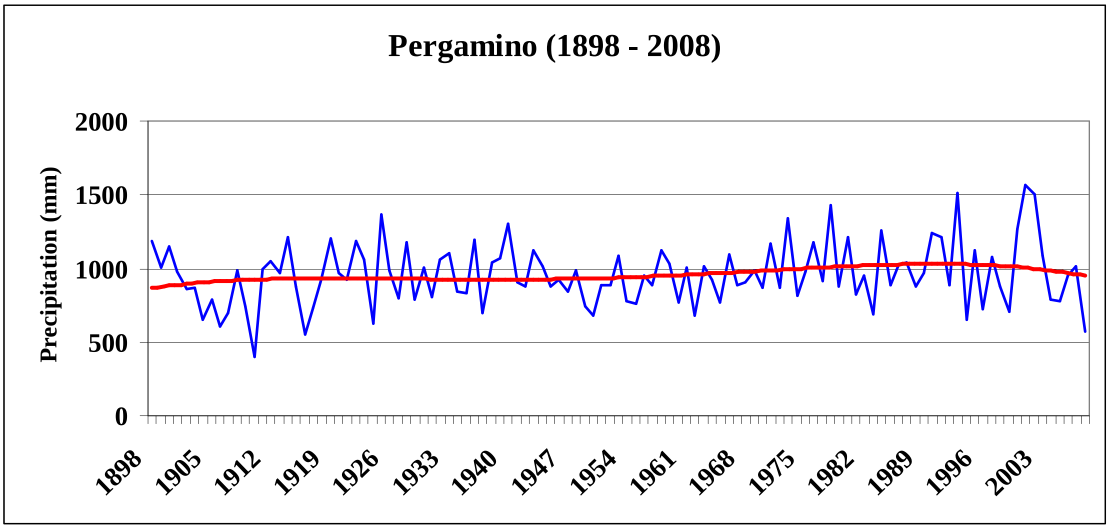
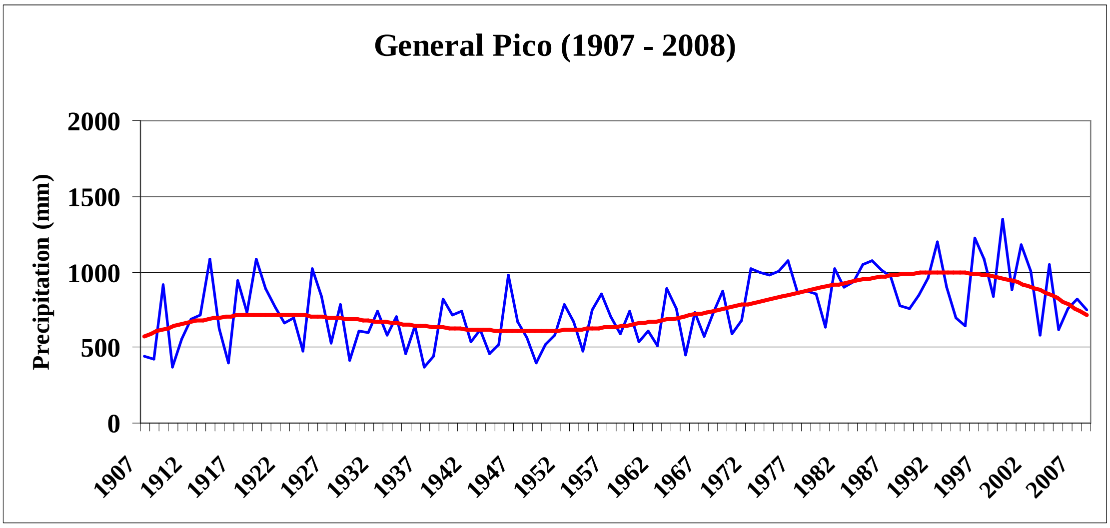


Figure 9. Annual precipitation of General Pico and its trend. Realized by the authors.



It can be seen a "jump" mentioned by [4,5] in annual precipitation. According [5] the mean annual precipitation showed an increase in the period 1977-2006 respecting 1947 – 1976 and a displacement to west of the isohyets by the increase in its amounts. The differences are all larger than 50 mm and there is an important area in the pampean flatlands with differences between 100 and 150 mm. Figure 10 presents the mean annual precipitation isohyets for the period 1947-1976 and in Figure 11 the isohyets for the period 1977-2006 as can be seen in Figures 10 and 11.

Following this criterion the precipitation registered for the warm and cold semesters were analyzed using these two periods.

Figure 10. Mean annual precipitation for the period 1947-1976. Realized by the authors.

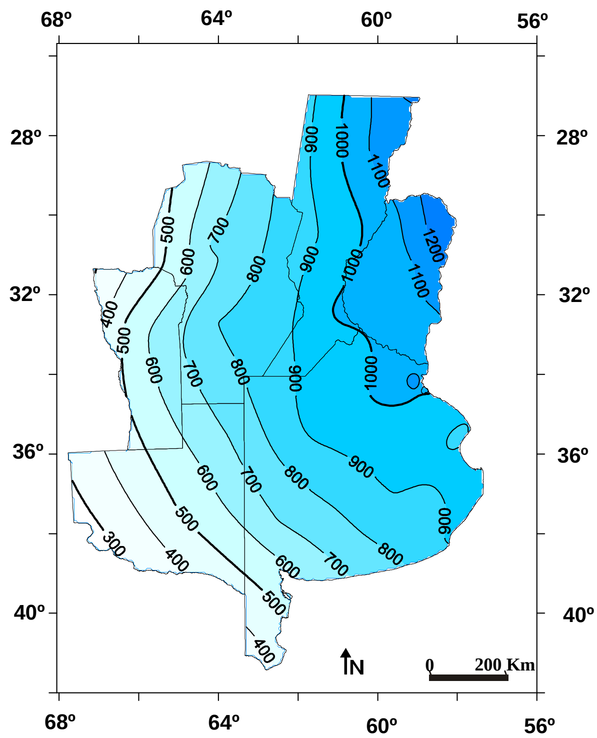


Figure 11. Mean annual precipitation for the period 1977 2006. Realized by the authors.

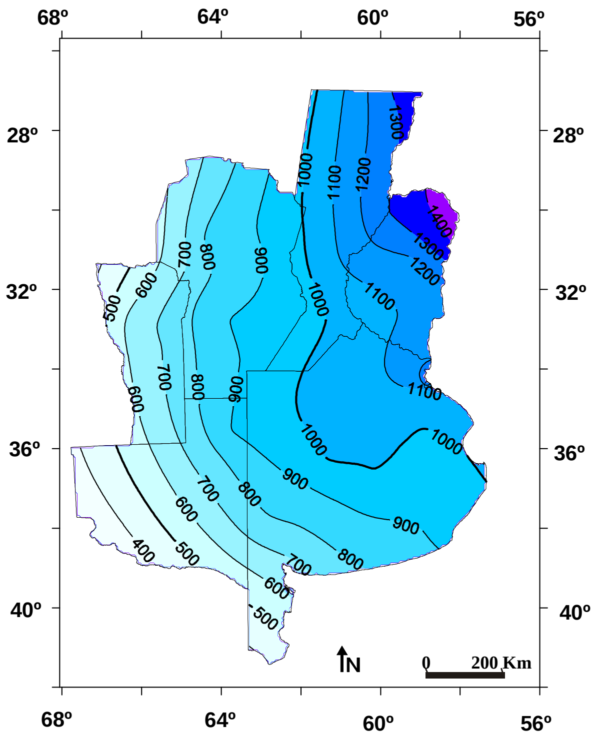


Figure12. Warm semester precipitation for the period 1947-1976. Realized by the authors.

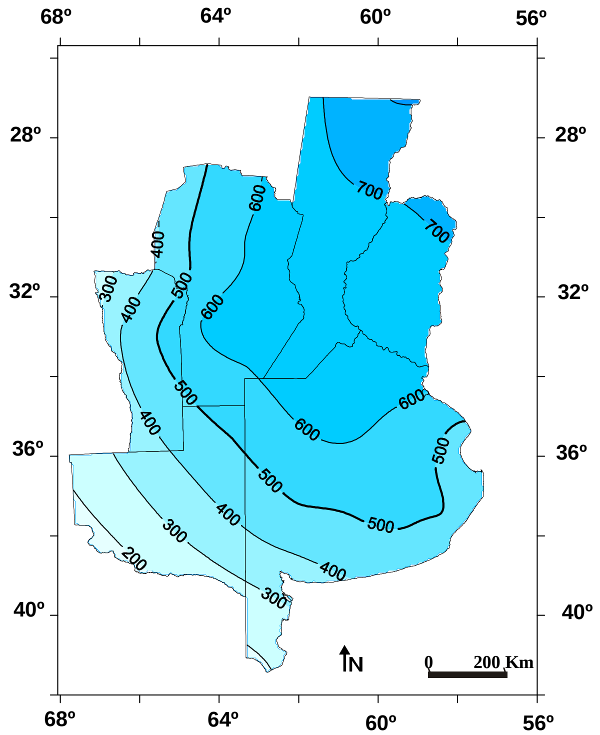


Figure 13. Warm semester precipitation for the period 1977-2006. Realized by the authors.

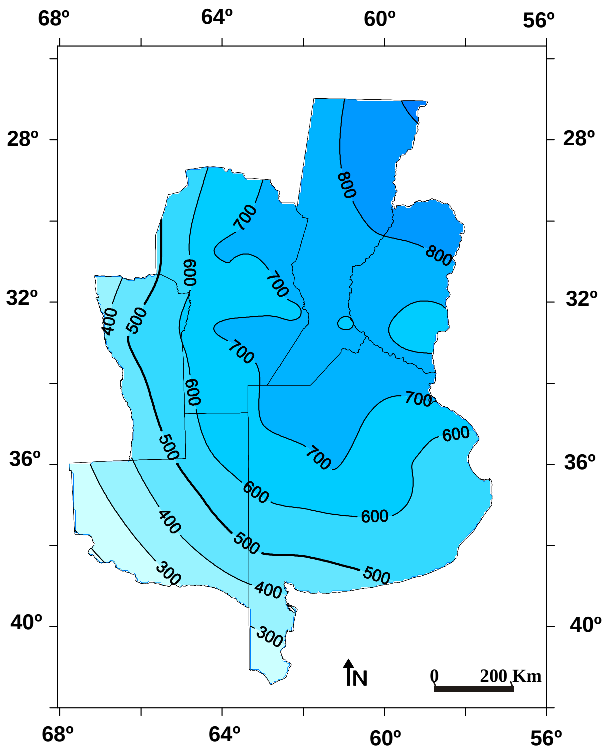


Figure 14. Cold semester precipitation for the period 1947 1976. Realized by the authors.

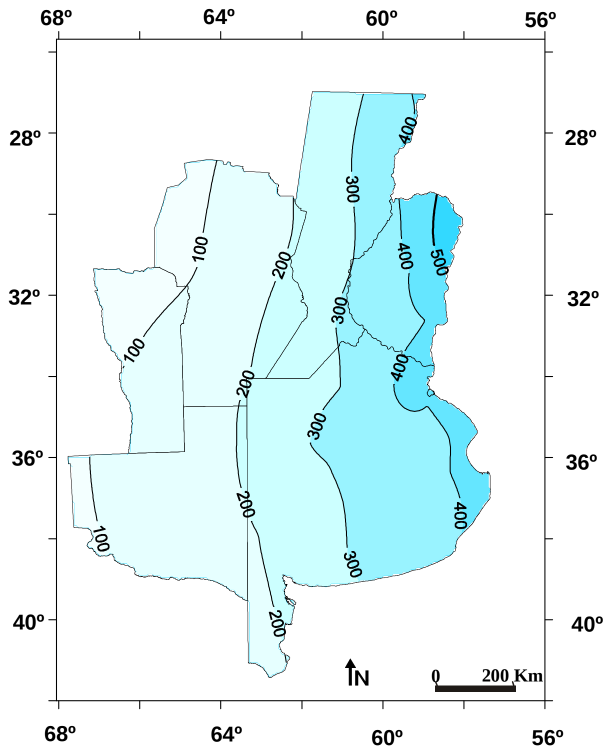
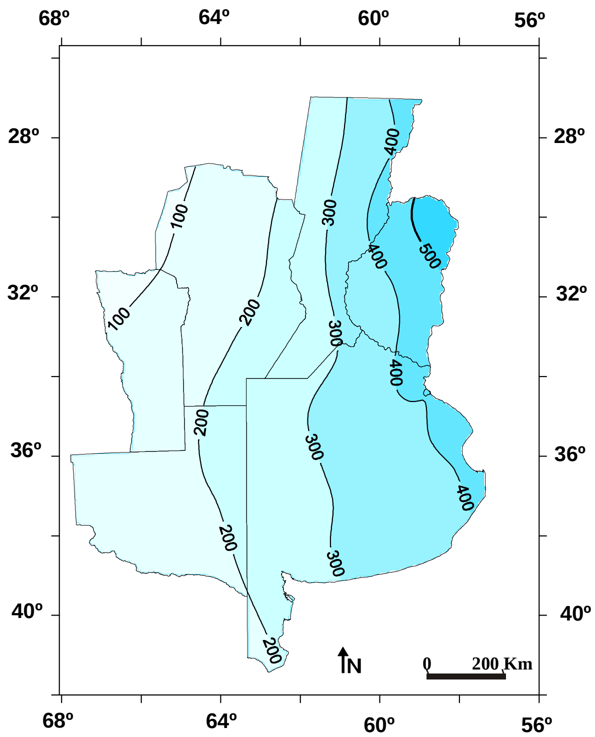


Figure 15. Cold semester precipitation for the period 1977 2006. Realized by the authors.



The study of the results shown in the figures 12, 13, 14 and 15 is that the largest precipitation increase occurred in the warm semester and in the center-west region in the second period (1977 – 2006). The precipitation during the warm semester increased 150 mm in the NE of La Pampa and NW of Buenos Aires provinces. In the cold semester the increase reached 25 mm only in the northern area of La Pampa province and less in the rest of the studied area, including it decreased in some areas of Buenos Aires province.

The main consequence of this was the increase in soil water availability of fundamental importance in agricultural development and the displacement of agricultural frontier.

Tables 2, 3 and 4 allow the observation of statistical results for the five selected stations. For them the MAKESENS test were used and several temporal periods.

Table 2. Temporal distribution of annual precipitation in five selected stations.

Period	Dolores	General Pico	Pergamino	Nueve de Julio	Pehuajó
1910 - 2006	↑ *	↑ ***	↑	↑***	↑ **
1947 - 2006	↑	↑ ***	↑ +	↑ **	↑ **
1947 - 1976	↑	↑ **	↑ +	↑ **	↑
1977 - 2006	↓	=	=	=	↓

References: ↓ decrease, ↑ increase and = no variation, + significance trend at $\alpha = 0.1$ level, * significance trend at $\alpha = 0.05$ level and ** significance trend at $\alpha = 0.01$ level.

Table 3. Temporal distribution of warm precipitation in five selected stations.

Period	Dolores	General Pico	Pergamino	Nueve de Julio	Pehuajó
1910 - 2006	↑**	↑***	↑ +	↑ ***	↑ **
1947 - 2006	↑*	↑***	↑	↑ **	↑ **
1947 - 1976	↑	↑*	↑	↑ *	↑ *
1977 - 2006	↓	↓	↓	↑	↑

References: ↓ decrease, ↑ increase and = no variation, + significance trend at α = 0.1 level, * significance trend at α = 0.05 level and ** significance trend at α = 0.01 level.

Table 4. Temporal distribution of cold precipitation in five selected stations.

Period	Dolores	General Pico	Pergamino	Nueve de Julio	Pehuajó
1910 - 2006	↓	↑**	=	↑ +	=
1947 - 2006	↓	↑*	↑	↑	↓
1947 - 1976	↓**	↑+	↑ +	=	↓
1977 - 2006	↓	↑	↑	↑	↑

References: ↓ decrease, ↑ increase and = no variation, + significance trend at α = 0.1 level, * significance trend at α = 0.05 level and ** significance trend at α = 0.01 level

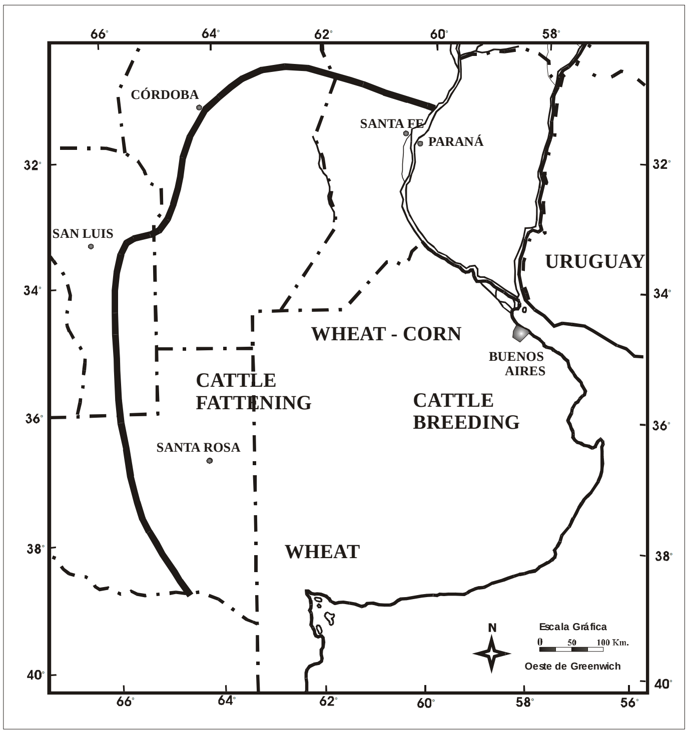
Pergamino, Nueve de Julio and General Pico are the stations with more significant statistical results in the increase of their annual and warm semester precipitation, while Dolores had no statistical significant results but its precipitation decreased and Pehuajó presented statistical significant results during 1910 – 2006, 1947 – 2006 and 1947 – 1976 in warm semester precipitation and in the two first period for annual precipitation.

3. 2 Agriculture evolution in pampean flatlands

Pampean flatlands had, over the past two centuries, few important innovations, first the “estancia” (big farm), then the immigration of settlers and finally the process of *agriculturization*.

Traditionally it had the following zoning for agricultural use (Figure 16).

Figure 16. Traditional land uses in Pampean region. The line delimits the pampean flatlands. Realized by the authors.



Today these agricultural areas have changed. Recent innovations in land use based on new demands for food in the world market re-enforce the importance of agricultural capacity of the study region.

Historically, the production has been determined by a combination of factors:

1. *Environmental*: climate fluctuations, fitness productive of soils, nutrient supply, water availability, etc.

2. *Political and economic*: macroeconomic policy interests that were implemented through credits, subsidies, market access for products and inputs. Also, the domestic and external dependence translated into fluctuations in international prices.

3. *Technology:* adapting technological packages (pesticides, herbicides, improved seeds, direct seeding, etc.).

4. *Social: the* structure of ownership and land tenure.

Argentine agriculture is strongly identified with tour crops: wheat, corn, sunflower and soybean.

Until the early 70´s the dominant production model was based on a pattern "agriculture and livestock" considered as soil fertility conservative with moderate increase of production. From this date it has been replaced by a pattern of "continuous cropping", a dominant production style focused on a few crops (corn, wheat and soybean) both for domestic consumption and exportation. This process moved about 5 million hectares for livestock use in agriculture (Casas, 2007).

The process of *agriculturization* does not happen only in Argentina, it took place in Bolivia, Brasil and Paraguay too (Paruelo *et al*. 2004).

Originally, "continuous cropping" consisted in two crops per year: wheat – corn. Later, corn was replaced by soybean (more demanding in soil fertility) long fallow was eliminated and joined a destructive practice, the burning of stubbles. Fallow is an agricultural practice that allows the soil oxygenation, the nutrient enrichment and the soil water conservation.

On the other hand, rangelands and natural prairies were replaced by the expanding agricultural frontier.

The Low-Disturbance Direct Seeding allowed the double crops wheat – soybean determining in many cases the domain of soybean practice over wheat practice.

The process of *agriculturization* was favoured by international prices and the introduction of soybean, whose production was increasing faster the domestic demand which, coupled with international demand and high prices allowed Argentina turning out an exporter of soybean.

In pampean flatlands soybean replaced crops like corn, sorghum and alfalfa (Spescha y Scarpati, 2002).

The changes mentioned above can be checked analysing the evolution of the soybean crops since 1970 in Buenos Aires Province and since 1980 in La Pampa province, when it began. The agricultural technology of an earlier period was more depended on the environment, so their comparison is incompatible.

Table 5 shows the evolution of soybean crop in two provinces: Buenos Aires La Pampa located in pampean flatlands

Table 5. Evolution of soybean crop

Year	**Sown Surface (ha)**		**Harvest Surface (ha)**			**Yield (q/ha)**		
	1970 (*)	2005	1970 (*)	2005	Δ (%)	1970 (*)	2005	Δ (%)
Buenos Aires	1,270	3,324,129	1,270	3,249,179	255	1,260	3,078	244
La Pampa	7,850	187,628	6,050	183,034	300	1,223	2,603	213

References: (*) in La Pampa province the crop began in the season 1979- 80, Δ: difference

The Figures 17 and 18 present the evolution of sown surface and harvested surface in Buenos Aires and La Pampa provinces for the studied period, while Figures 19, 20 and 21 show the same for the departments Pergamino, Nueve de Julio and Maracó.

Figure 17. Evolution of sown surface (blue) and harvested surface (red) in Buenos Aires province. Realized by the authors.

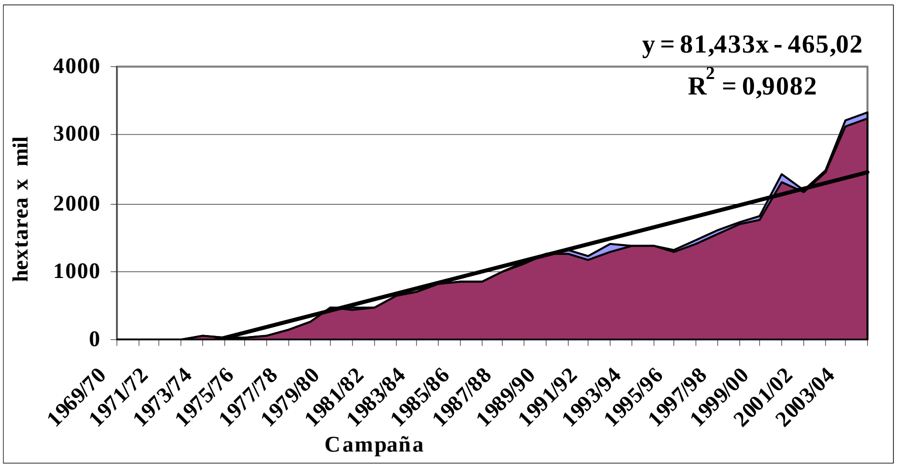


Figure 18. Evolution of sown surface (blue) and harvested surface (red) in La Pampa province. Realized by the authors.

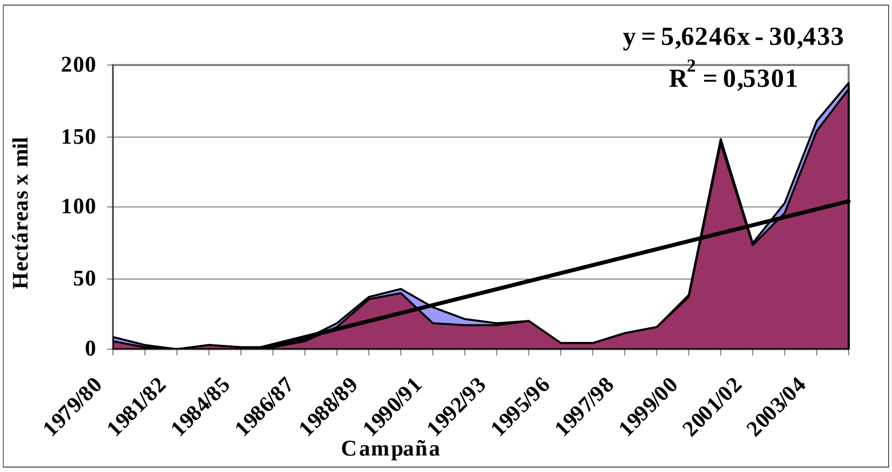


Figure 19. Evolution of sown surface (blue) and harvested surface (red) in Pergamino (Buenos Aires province). Realized by the authors.

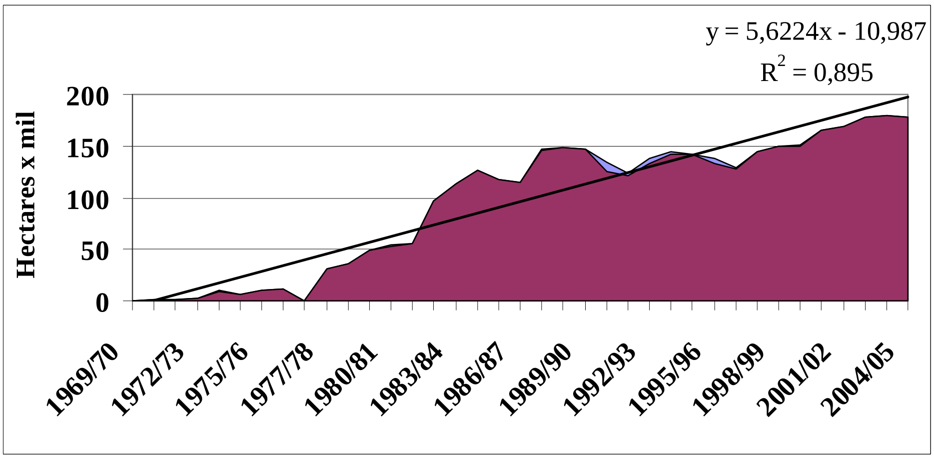


Figure 20. Evolution of sown surface (blue) and harvested surface (red) in Nueve de Julio (Buenos Aires province). Realized by the authors.

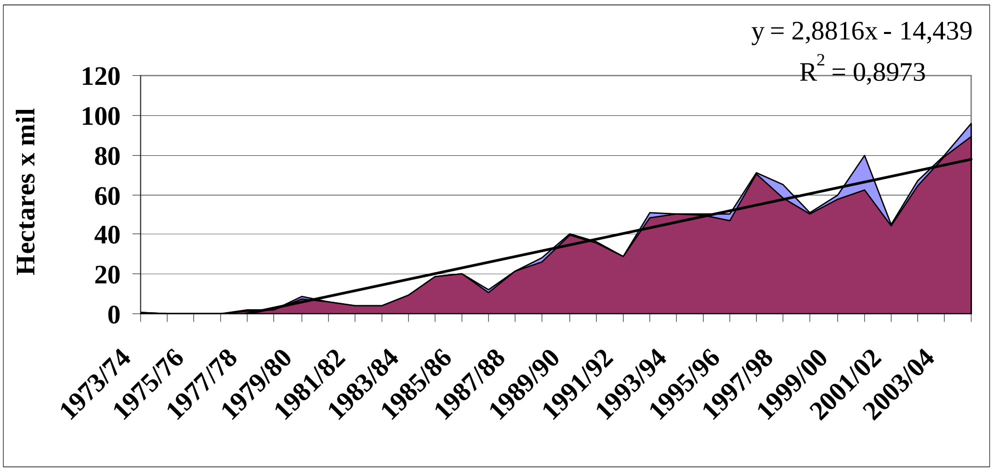
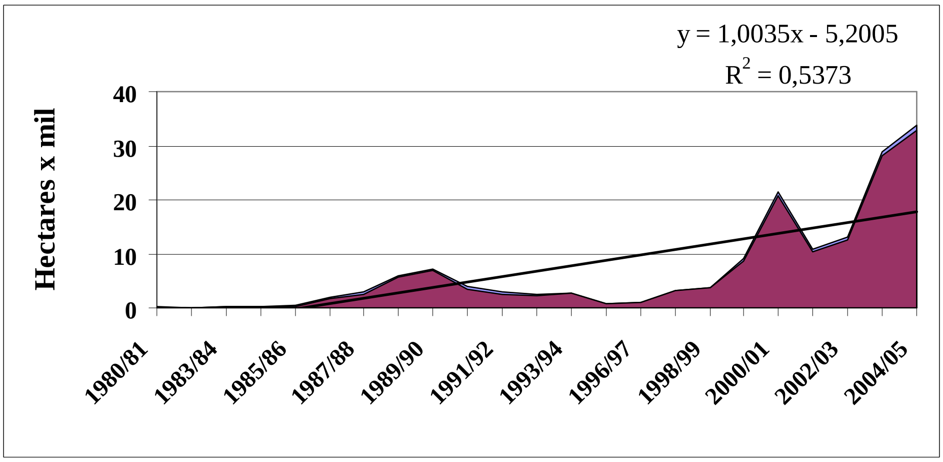


Figure 21. Evolution of sown surface (blue) and harvested surface (red) in Maracó (La Pampa province)- Realized by the authors.



It is interesting to observe the security of harvest in Pergamino and Nueve de Julio; there are no losses and the low interannual variability and the increase registered in Maracó, surely related to the increase in precipitation.

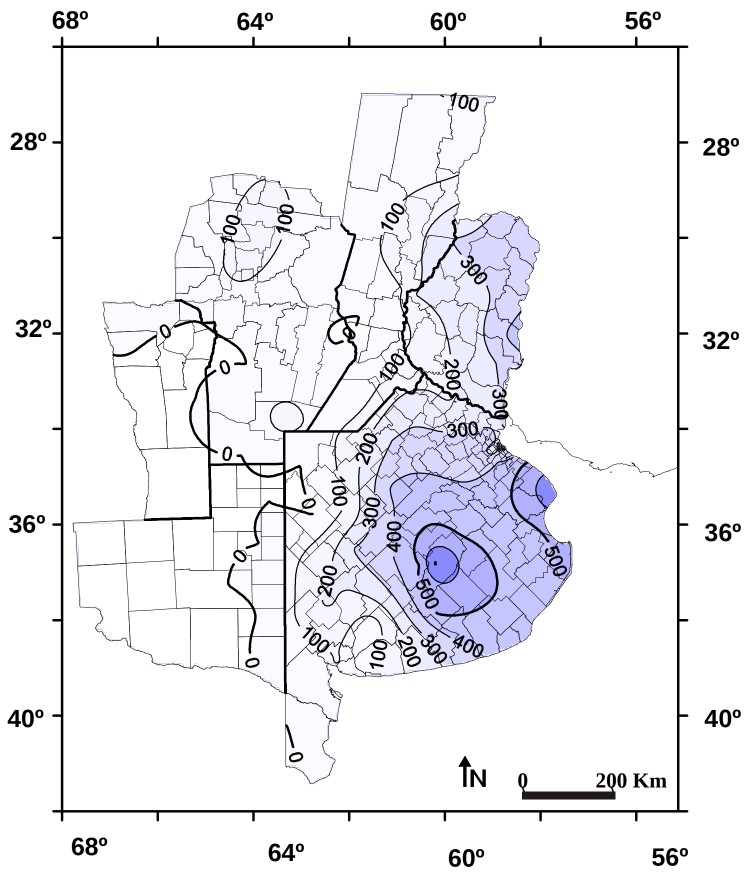
3.3. Hydrological extreme events in Pampean Flatlands

As a consequence of precipitation temporal variability diverse hydrological extreme events (flood and droughts) happen in Pampean flatlands because there are other processes related. There are associated oscillations in soil water content and soil water table depth. The extreme events occurred in the last fifty years are studied using two soil water balance parameters as indexes: soil water surplus for flood and soil water deficit for drought.

3.3.1- **Floods**

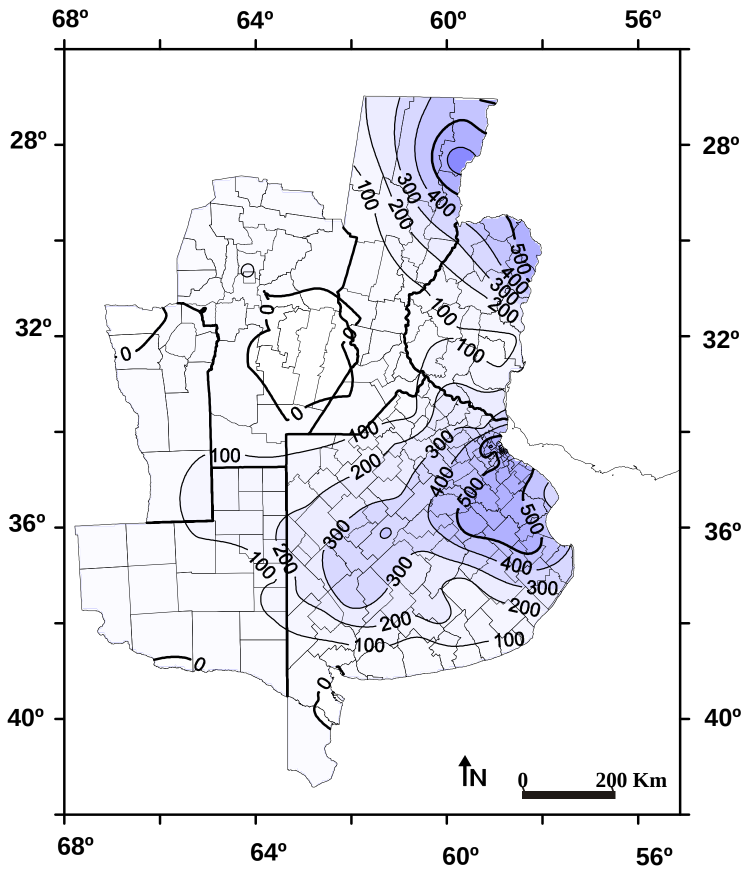
Figure 22 presents the soil water surplus occurred during 1980. It can be seen soil water surplus reaching 400 – 600 mm in Buenos Aires province [13]. The rest of Pampean flatlands had not flood problems.

Figure 22. Soil water surplus during 1980. Realized by the authors-



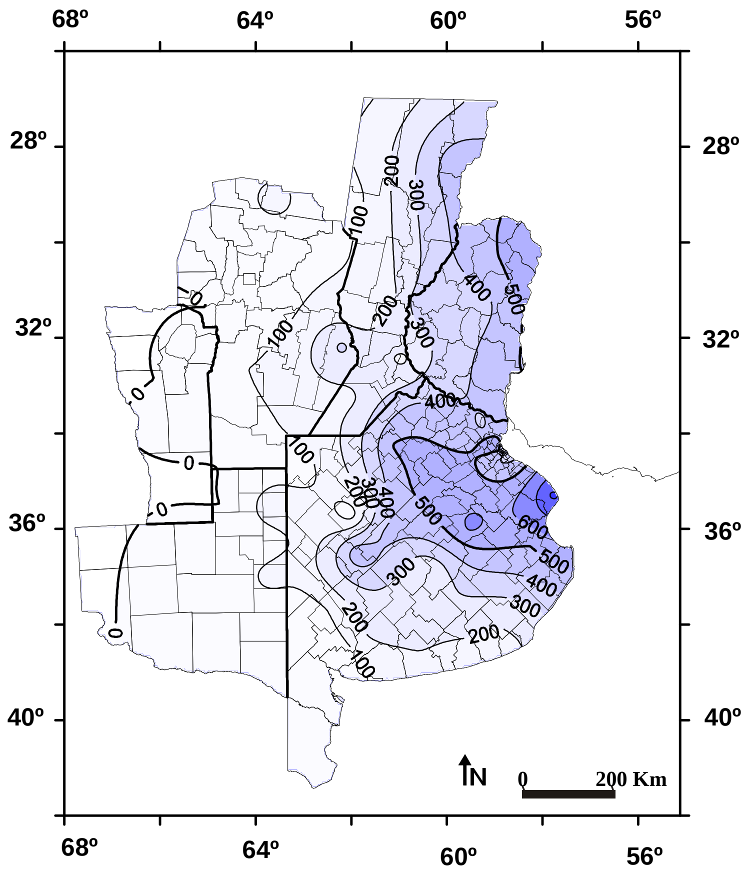
The year 1985 had too important flood in Buenos Aires province affecting a more little surface than during 1980.

Figure 23. Soil water surplus during 1985. Realized by the authors-



The flood occurred during 1993 was considered very important and the losses were very high [8].

Figure 24. Soil water surplus during 1993- Realized by the authors.



Figures 25 and 26 present the last flood in Pampean flatlands. The processes began in November 2002 and the oscillations in monthly precipitation made that the soil water surplus decreased by evapotranspiration [15]. But 2001 and 2002 were two bad years for habitants, urban areas, livestock and agriculture.

Figure 25. Soil water surplus during 2001. Realized by the authors.

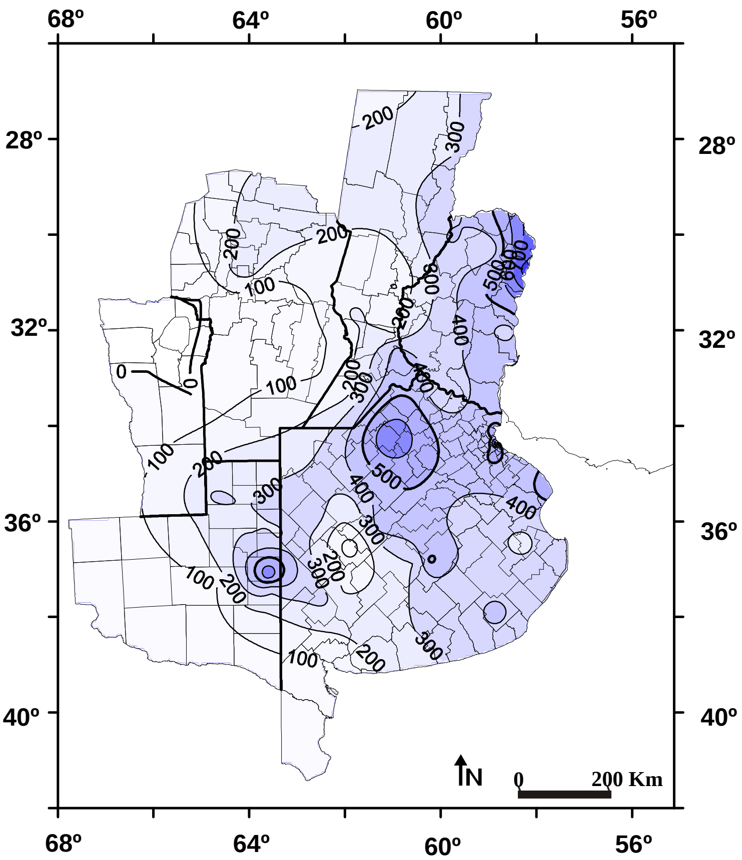
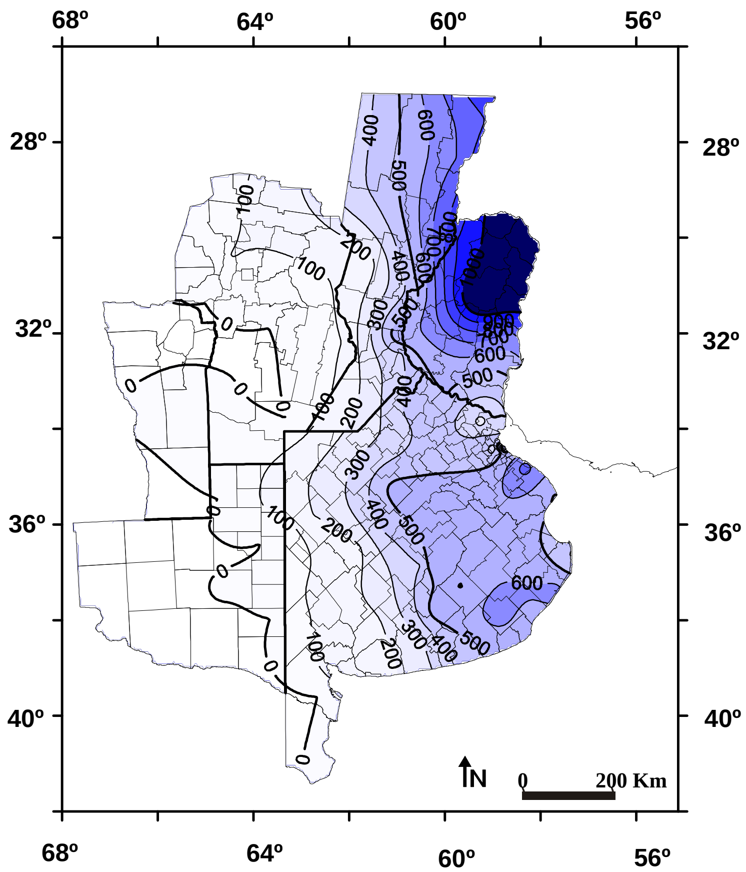


Figure 26. Soil water surplus during 2002- Realized by the authors.

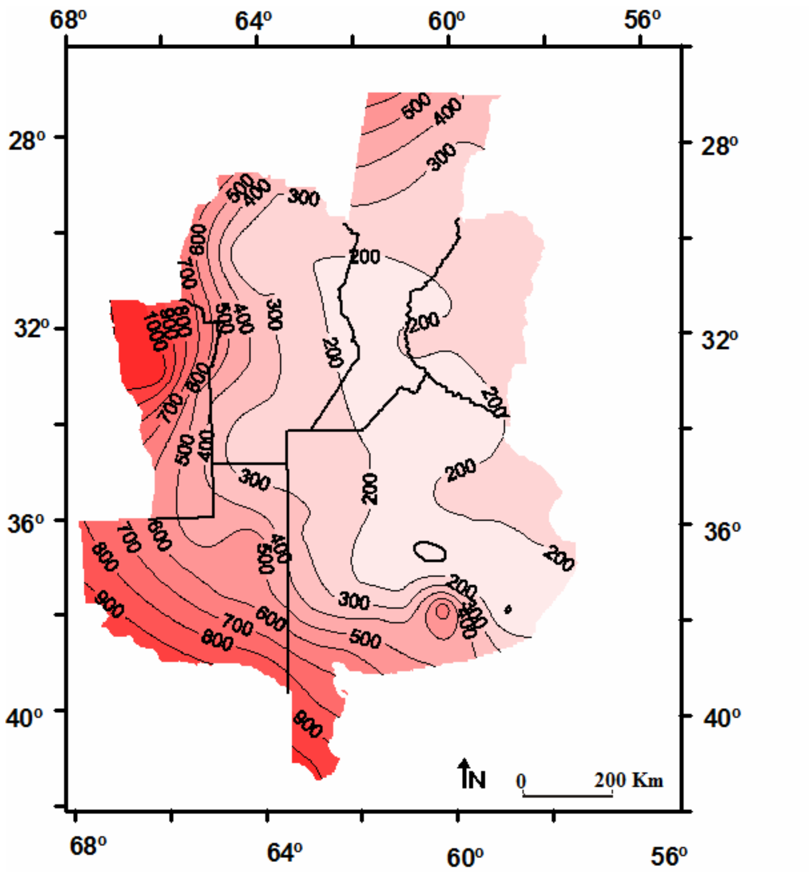


3.3.2- Droughts

Figures 27, 28, 29, 30 and 31 show the most important droughts happened in the pampean flatlands in the above mentioned period.

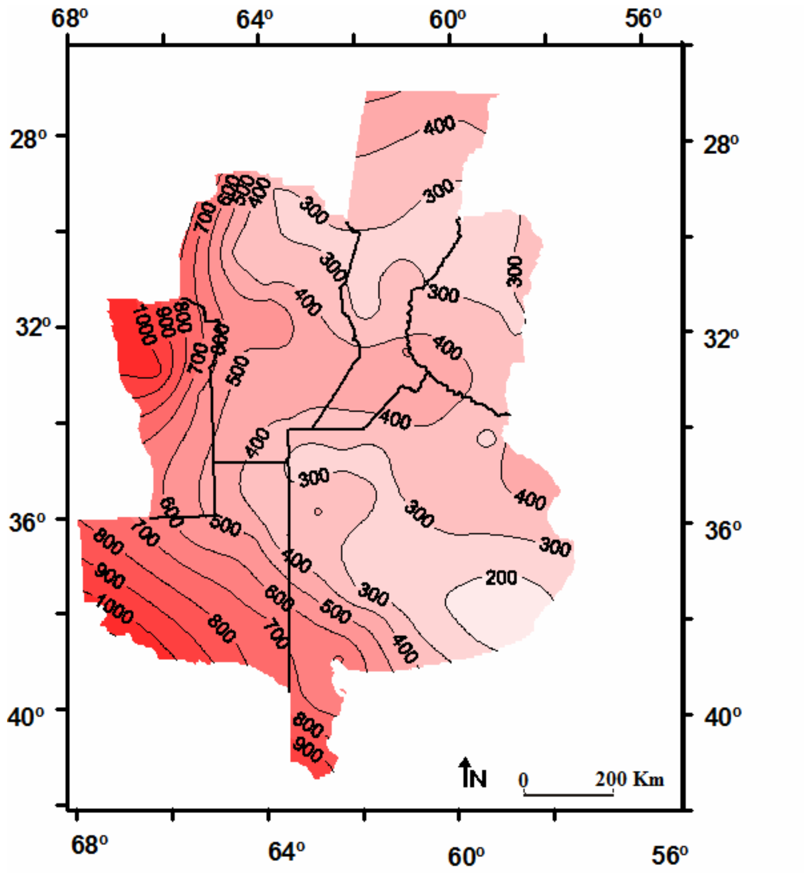
The drought of 1978 had important soil water deficit in the western area of the studied region but not so high in the rest.

Figure 27. Soil water deficit during 1978. Realized by the authors.



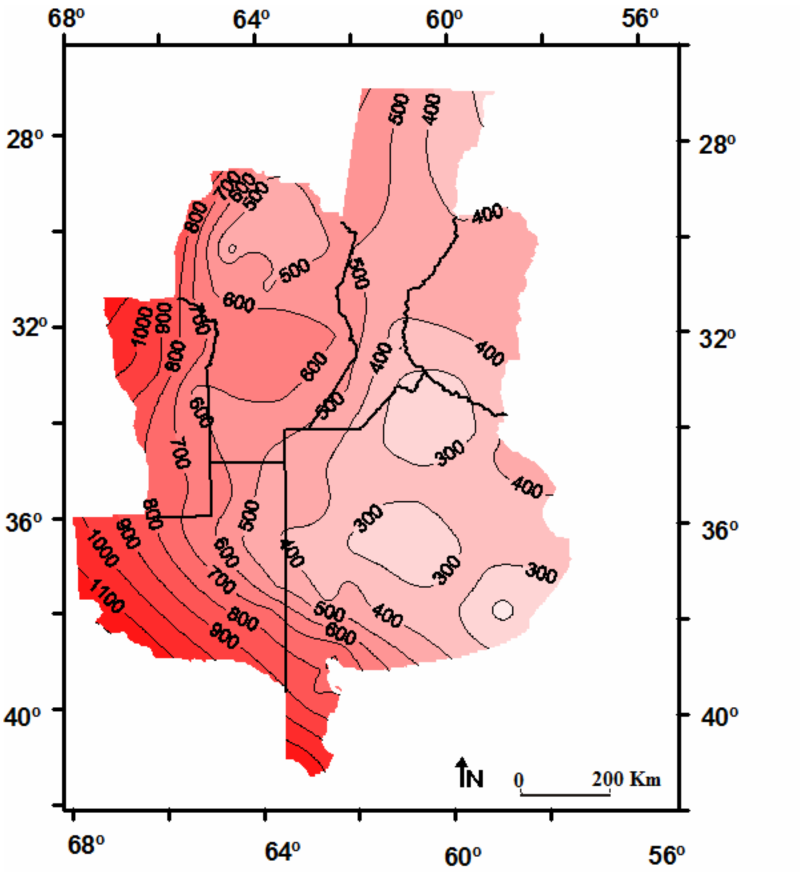
The drought occurred during 1983 was more serious than previous one, mainly in Buenos Aires province.

Figure 28. Soil water deficit during 1983. Realized by the authors.



The drought of 1989 reached soil water deficit values of 300 and 400 mm in Buenos Aires province while in La Pampa province more than 500 mm. Figure 29 presents several circles (soil water deficit equal to 300 mm) distributed in the surface of Buenos Aires province.

Figure 29. Soil water deficit during 1989. Realized by the authors.



Soil water deficit during occurred during 1995 reached values similar to those of 1989 but the distribution was different. In this case it is more generalized and worse.

Figure 30. Soil water deficit during 1995. Realized by the authors.

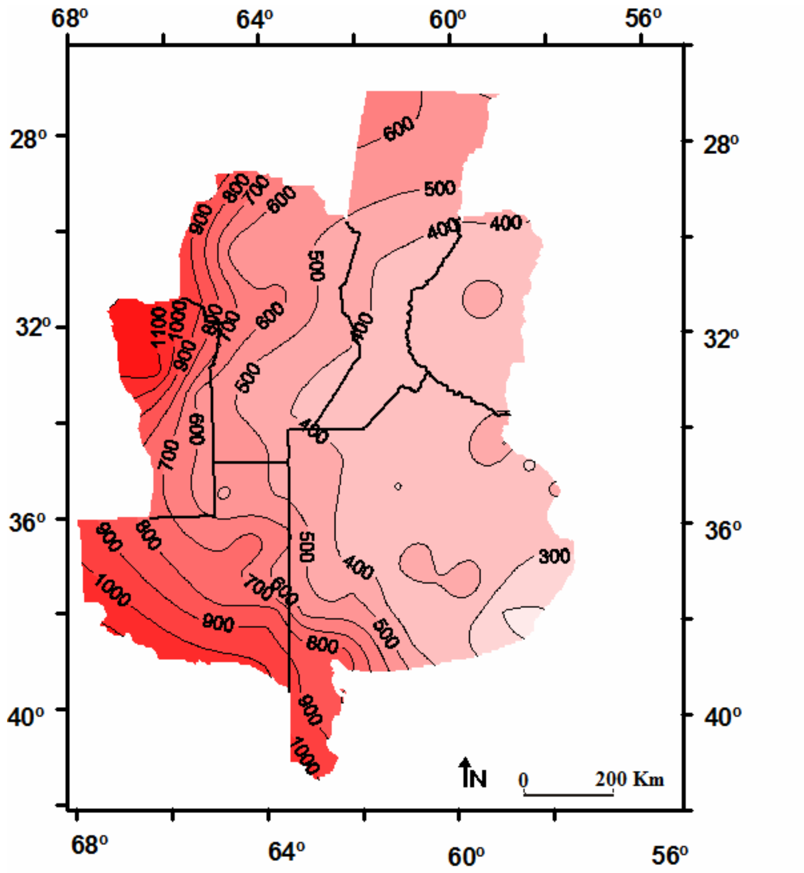
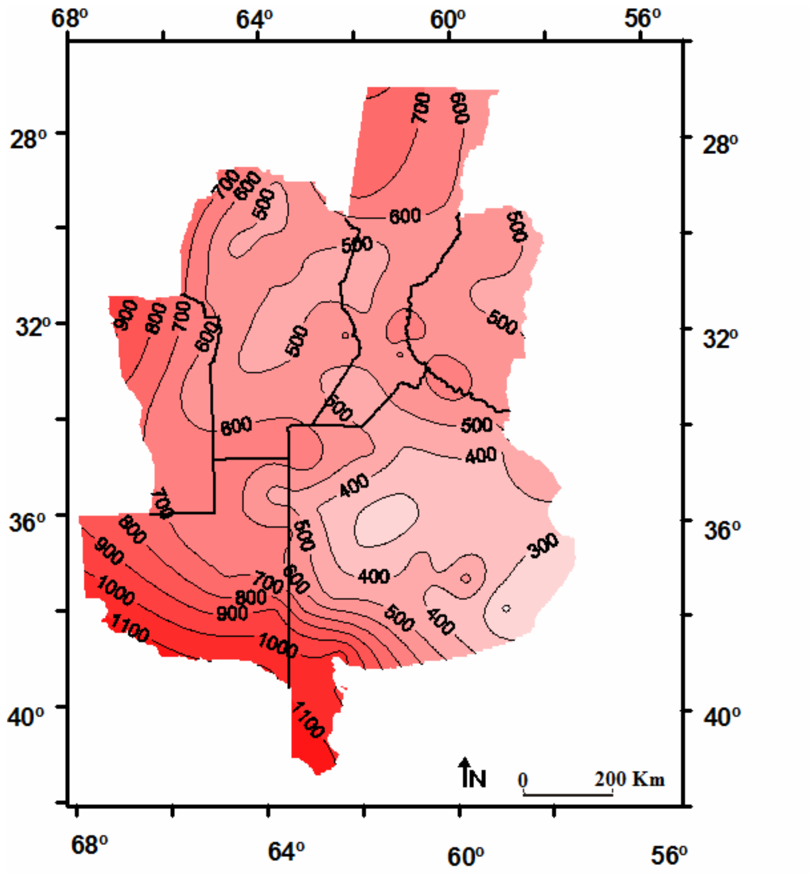


Figure 31 shows the last drought occurred in the studied region. In Buenos Aires province had almost its whole territory with 400 mm of soil water deficit and in La Pampa province it reached 700 mm.

Figure 31. Soil water deficit during 2008. Realized by the authors.



The hydrological extreme events have been related with the ENSO phases by different authors [3,19,20,21], so it will not be discussed in this paper.

4. Conclusions

The spacial precipitation variability for different periods and its consequences, were analyzed in Pampean flatlands.

During the period 1977 – 2006 an increase in annual mean precipitation occurred in comparison to the preceding 30 years and the annual increase varied between 50 and 200 mm according to different zones.

An important increased had been found during the warm semester (October-March) precipitation. The cold semester (April-September) precipitation had not so high difference in its values during the periods studied.

The north western area of La Pampa province changed its climate according Thornthwaite classification, from Subhumid to Humid and it is related with the mean annual precipitation amount.

The change verified in precipitations has had, as main consequence, an increase in the soil water availability and as rain fed agriculture is the predominant practice it favoured the success of summer crops as soybean. The soybean production had been increased in the whole study region.

So, changes in land uses were other of the consequences, mainly in centre west area of the region where rangelands and prairies passed to crop fields. It is inferred that the verified change is not permanent, and it simply deals with a climatic fluctuation. The return to the previous situation before the ´70 decade could have negative impacts on farming production.

Argentina increased its soybean production mainly for exportation answering to the world food growing demand that makes that the increase of agricultural surface appears as an inevitable process.

The continuous need for improve the agricultural production incorporating new technology with growing social demand creates a risk of causing severe environmental disturbances, which may compromise the production itself and even affect non-renewable natural resources.

Acknowledgments

The authors are very grateful to Juan Alberto Forte Lay for his kind comments.

Conflict of Interest

"The authors declare no conflict of interest"

References

1. Barros, V.; Gonzalez, M.; Liebmann, B.; Camilloni, I. Influence of the South Atlantic convergence zone and South Atlantic sea surface temperature on interannual summer rainfall variability in South-Eastern South America. Theor. and Appl. Climtol. 2000; 67, 123–133.
2. Barros, V.; M. Doyle; I.Camilloni. Potential impacts of climate change in the Plata basin. 2005. In: Regional Hydrological Impacts of Climatic Change. Impact Assessment and Decision Making. T.Wagener, S.Franks, H.Gupta, E.Bogh, L.Bastidas, C.Nobre and Oliveira Galvao (eds.). Ed. International. Association of Hydrological Sciences (IAHS), 2005; 11-18.
3. Barros, V; M. Doyle; I. Camilloni. Precipitation trends in southeastern South America: Relationship with ENSO phases and with low-level circulation. Theor. and Appl. Climatol. 2008; 93, 19-33.
4. Minetti, J.; Vargas, W. Trends and jumps in the annual precipitation en South America on the 15°S. Atmósfera. 1997, 11, 204–221.
5. Forte Lay, J; O. E. Scarpati; A. Capriolo. Precipitation variability and soil water content in pampean flatlands (Argentina). Geofísica Internacional, 2008; 47 (4), 341-354.
6. Quintela, R.M.; Forte Lay, J.A.; Scarpati, O.E. Modification of the water resources characteristics of the Argentine's Pampean subhumid-dry region. In Proceedings of the 19th Conference on Agricultural & Forest, 9th Conference on Biometeorology and Aerobiology (19th AGMET), Miami, FL, USA, 1989; J-30-J-35.
7. Rusticucci, M.; Penalba, O. Interdecadal changes in the precipitation seasonal cycle over Southern South America and their relationship with surface temperature. Clim. Res. 2000; 16, 1–15.
8. Scarpati, O. E.; L. Spescha; A. Capriolo. Occurrence of the severe floods in the Salado River basin, Buenos Aires province, Argentina. Mitigation and Adaptation Strategies for Global Change. 2002; Guest Editors: J. A. A. Jones & Ming - Ko Woo. Kluwer Academic Publishers. 7, 3 285 - 301.
9. Magrin, G. O., M. I. Travasso; G. R. Rodríguez. Changes in Climate and Crop Production during the 20th Century in Argentina. Climatic Change. 2005; 72, 1-2, 229-249

10. Levillier, R. & Archivo General de Indias. Antecedentes de politica economica en el Rio de la Plata: documentos originales de los siglos XVI al XIX seleccionados en el Archivo de Indias de Sevilla / coordenados y publicados por Roberto Levillier, 1915; Tip. Sucesores de Rivadeneyra, España.
11. Ras, N. Crónica de la frontera sur. Academia Nacional de Agronomía y Veterinaria. 1994. Editorial Hemisferio Sur. Buenos Aires, Argentina. 1994; 626 pag
12. Durán D. Sequías e Inundaciones. Propuestas. OIKOS. Asociación para la promoción de los estudios territoriales y ambientales. Argentina, 1987; 190 pag
13. Moncaut, C. A. Inundaciones y sequías tienen raíces añejas en la pampa bonaerense (1576 – 2001). In: Inundaciones en la región pampeana. Honorable Cámara de Diputados de la provincia de Buenos Aires. Universidad Nacional de La Plata. Editors: O. C. Maiola, N. A. Gabellone and M. A. Hernández. Editorial Universidad Nacional de La Plata. Argentina. 2003; 281 pág.
14. Darwin, C. Diario del viaje de un naturalista alrededor del mundo. Editorial El Elefante Blanco. Argentina, 2009; 449.
15. Scarpati, O. E., J. A. Forte Lay; A. D. Capriolo. La inundación del año 2001 en la Provincia de Buenos Aires, Argentina. Mundo Agrario. 2008; Centro de Estudios Rurales. UNLP. Argentina; 9, 17.versión on-line.
16. Andrade M.; O. E. Scarpati. Flood risk in the Gran La Plata, (Buenos Aires province, Argentina) considering the available information and management of the area. GeoJournal. 2007; 70, 4, 245-250.
17. Kruse, E.; Forte Lay, J.A.; Aiello, J.L.; Basualdo, A.; Heinzenknecht, G. Hydrological processes on large flatlands: Case study in the northwest region of Buenos Aires Province (Argentina). IAHS, 2001; 267, 531–535.
18. Salmi, T.; Mata, A.; Anttila, P.; Ruoho-Airola, T.; Amnell, T. Detecting Trends of Annual Values of Atmospheric Pollutants by the Mann-Kendall Test and Sen’s Slope Estimates—The Excel Template Application MAKESENS; In Publications on Air Quality; Ilmatieteen laitos Meteorologiska Institutet, Finnish Meteorological Institute Painopaikka: Edita Oyj, Helsinki, Finland, 2002.
18. Allen, R.G.; Pereira, L.S.; Raes, D.; Smith, M.; Irrigation and drainage. Crop Evapotranspiration—Guidelines for Computing Crop Water Requirements; FAO: Rome, Italy, 2004; Paper 56, p. 301.
19. Spescha, L., J. A. Forte Lay, O. E. Scarpati; R. Hurtado. Los excesos de agua edáfica y su relación con el ENSO en la Región Pampeana. Revista de la Facultad De Agronomía UBA, 2004; 24 (2): 161-167.
20. Aceituno, P., On the Functioning of the Southern Oscillation in the South American Sector, Part I: Surface Climate, Mon, Wea. Rew, 1988; 116, 505-524.
21. Labraga, J., Scian, B.; O. Frumento, Anomalies in the atmospheric circulation associated with the rainfall excess or déficit in the Pampa Region in Argentina, Journal of Geophysical Research, 2002; 107, 2-15.