Advanced Review

Climate change in Argentina: trends, projections, impacts and adaptation

Vicente Ricardo Barros,[1*] José Armando Boninsegna,[2] Inés Angela Camilloni,[1] Martina Chidiak,[3] Graciela Odilia Magrín[4] and Matilde Rusticucci[5]

In most of Argentina, the warming since 1901 was a little lower than the global average, although with strong trends in temperature extremes and in heat waves during the most recent decades. There was a remarkable increase in precipitation over most of subtropical Argentina, especially since 1960. This has favored agriculture yields and the extension of crop lands into semiarid regions, but this increase also came with more frequent heavy rainfalls and consequent flooding of rural and urban areas. Since the early 1970s, the main rivers of the Plata Basin have increased their mean flows, but this was attributable not only to increased precipitation, but also to land use changes. In contrast, over the Andes Mountains, reduced rainfall and increased temperature has led to glaciers receding and reduced river flows. Climate projections for the first half of this century maintain observed trends and raise additional concerns that in most cases can be dealt with timely adaptation policies. However, by the end of this century, under an extreme emissions scenario, the projected warming reaches 3.5°C in the north of the country with respect to present-day conditions. There is insufficient knowledge to assume that this warming would not create severe damages to the people and the economy of Argentina. Because of the damages and casualties that heat waves and extreme precipitation events are already producing, the first and most urgent adaptation required is to reinforce early warning systems and contingency planning to cope with climatic extremes and their consequences on health.

How to cite this article:
WIREs Clim Change 2014. doi: 10.1002/wcc.316

INTRODUCTION

Mainland Argentina extends from the tropic of Capricorn to almost 60°S (Figure 1). Although the country is known for having fertile plains, two-thirds of its territory is either arid or semiarid. It has a variety of biophysical systems: mountains, plains, cold and warm deserts, dry and wet forests, wetlands including a delta, huge rivers and a long maritime coast. Most of the agriculture takes place in the fertile plains to the east of the country and also in irrigated valleys at the foot of the Andes Mountains. Although the country has a diversified industry, agriculture and its direct manufactures add up to 55% of the export revenue.[1] More than 90% of the population is urban and it is unevenly distributed, being concentrated in high proportion in the Greater Buenos Aires area and a few other large cities. The interactions of all these geographic features with the

*Correspondence to: barros@cima.fcen.uba.ar

[1]Departamento Ciencias de la Atmósfera y los Oceanos, Facultad de Ciencias Exactas y Naturales, UBA/CIMA, CONICET, Buenos Aires, Argentina

[2]IANIGLA, CRICYT, Mendoza, Argentina

[3]Facultad de Ciencias Económicas, UBA, Buenos Aires, Argentina

[4]Clima y Agua, INTA Castelar, Hurlingham, Argentina

[5]Departamento Ciencias de la Atmósfera y los Oceános, Facultad de Ciencias Exactas y Naturales, UBA/CONICET, Buenos Aires, Argentina

Conflict of interest: The authors have declared no conflicts of interest for this article.

FIGURE 1 | Argentina: regions, major cities, and rivers.

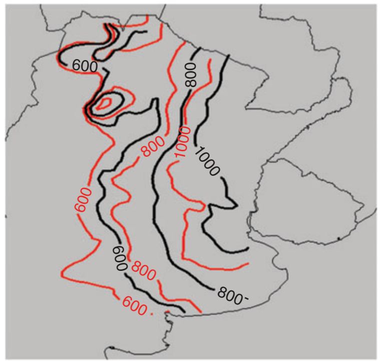

FIGURE 2 | Precipitation change in subtropical eastern and central Argentina; isohyets in mm; 1950–1969 in black and 1980–1999 in red.[22]

climate of the country shape the influence of climate change in Argentina.

This article includes an overview of the more relevant observed and projected climate change trends and impacts. The focus of the overview is on surface temperature and precipitation and their impacts on hydrology and agriculture, although other vulnerable systems, namely glaciers, the Plata River coasts and the irrigated valleys at the foot of Andes are also addressed. Greenhouse gas emissions since 1990, disaggregated by activity sectors, are summarized and briefly discussed. Finally, this study has an overview of the main public and private sector responses to climate change, as well as identifying the main concerns that should be attended to in the upcoming years.

CLIMATIC BACKGROUND

Mainland Argentine is located within the region of subtropical and mid-latitudes climates. Along with its neighboring countries, it is located between the two great oceans of the Southern Hemisphere, the Atlantic and Pacific Oceans. Except in the north of the country, this ocean proximity makes the daily and annual thermal amplitudes in general lower than in the continental regions of similar latitudes of the Northern Hemisphere. The other important geographic influence on the regional climate is the Andes Mountains, which to the north of 40°S has an average height of more than 4000 m and so blocks the air coming from the west. This prevents the passage of moisture from the Pacific Ocean toward Argentina.

In the lower layers of the atmosphere, close to the surface, two types of predominant circulation flows over Argentina can be distinguished. Winds from the west prevail over Patagonia, while in the rest of the country winds are driven by the South Atlantic high pressure system (hereafter 'high'), which brings humid and sometimes hot air from the east and the north. Hereafter, the region under the influence of the South Atlantic high will be called subtropical Argentina. In Patagonia, from 40°S to the southern tip of the country, the Andes Mountains are progressively lower allowing the passage of westerly winds coming from the Pacific Ocean. This air, forced to ascend, produces abundant rainfall and cloudiness in Chile and in a narrow strip along the Andes on the Argentine side where it loses its humidity. Thus, the prevailing westerlies become dry and the rest of the Argentine Patagonia receives very little precipitation. In the subtropical region, the average annual rainfall varies from a maximum of more than 1200 mm in the northeast to about 100 mm in the desert plains of the southwest; i.e., the isohyets are aligned roughly north to south (Figure 2). This zonal gradient in precipitation is due to the fact that moist air from both the tropical continent and from the Atlantic Ocean arrives more frequently in the east than in the west of the region.

OBSERVED CLIMATE CHANGE

Circulation Patterns

The boundary between the western edge of the South Atlantic high and the middle latitude circulation at the surface level shifted toward the south by approximately 250 km in eastern Argentine between 1951–1960 and 1991–2000.[2] Accordingly, the more frequent wind directions over the east of the country between 35 and 39°S, namely over the Rio de la Plata and the Buenos Aires province, have rotated from the northeast to east–northeast or even to the east.[3] This displacement of the near surface circulation also reached northern Patagonia with a weakening of the westerlies and a shift of the maximum zonal wind axis from 46 to 48°S.[4] As the near surface circulation has a seasonal shift toward the south (north) in summer (winter), its observed displacement has been consistent with more frequent weather patterns associated with the mean summer circulation, especially in the transition seasons.[5] This change enhanced the advection of humid air from the Atlantic Ocean over most of the region.[6]

Surface Temperature

In the period 1901–2012, the mean temperature increased by about 0.5°C across most of Argentina.[7] This warming has been a little lower than the global average. The strongest positive changes since 1960 occurred in the mean summer minimum temperature, even though in this season the mean maximum temperatures mostly decreased, except in Patagonia.[8] In the second half of the past century, there was a general warming in Patagonia[9] where both the maximum and the minimum temperature had a positive trend that was consistent with a more frequent northern flow component in the low levels of the atmosphere. Stratospheric ozone depletion could have contributed to this warming over the Patagonia, as it has played a major role in the atmospheric circulation changes in the Southern Hemisphere during the second half of the 20th century.[10–12]

Extreme Temperatures

For all Argentine meteorological stations, trends in temperature extremes from 1901 to 2010 show a strong warming of the night-time temperature, with fewer cold nights and more warm nights.[8,13–16] However, the highest annual maximum temperature decreased between 1956 and 2003 consistently with more precipitation in summer months, while the lowest annual minimum temperature increased in central Argentina. This has led to a decrease in the maximum annual range of temperature.[17] No matter which definition is used to define them, heat waves have been increasing in Argentina. For example, the number and intensity of heat waves defined as at least three consecutive days over the 90th percentile temperature of the 1961–1990 record has increased between 1961 and 2010, with the strongest increase in the intensity and number of heat waves of short duration (3–5 days). Although there is large decadal variability, the decade 2001–2010 has generally seen the largest number of heat waves.[18]

The Extreme December 2013 Heat Wave

From December 13 to 31, 2013, a strong heat wave occurred over central Argentina with maximum temperatures over 40°C and minima over 28°C. This heat wave was the longest and the most intense, considering the accumulation of degrees over thresholds, ever registered in the region. Record values of minimum temperature were verified in a station close to Buenos Aires with an estimated 100-year return period.[18] The power system collapsed in many sectors of Buenos Aires and of other cities because of the intense use of air conditioning. There is not yet a comprehensive assessment of casualties, but they may have been significant, according to the international experience of similar events.

Precipitation

Precipitation increased over most of subtropical Argentina during the period 1916–1990.[19] Until the 1960s, precipitation trends were small, but later became considerable,[19,20,6] annual precipitation trends since 1960, updated until 2005, were positive for all subtropical Argentina, with some trends of over 5 mm year^{-1} and a maximum exceeding 8 mm year^{-1} over northeastern Argentina.[21] In some places of the dry west and southwest of the subtropical region, the percent increase during the 30–40 years of positive trends reached 30% of their initial values (Figures 2 and 3). In spite of the high interannual variability, many of the positive trends in the precipitation series are statistically significant at the 10%, and in a few cases even at the 5%, confidence level. There is paleoclimatic evidence that the wetting trend that started in the 1960s has been without precedent in at least 250 years according to the sediments found in the Mar Chiquita lagoon.[23]

In the north of the country, most of the change was concentrated in a step change during the 1970s.[24] In this region, half or more of the annual rainfall trend occurred in the months of El Niño phase, with less contribution from La Niña and the neutral phases. However, in the rest of subtropical Argentina and especially south of 30°S, increased precipitation occurred mostly during months of the neutral phase of El Niño/Southern Oscillation (ENSO), with only small trends during months of El Niño and La Niña

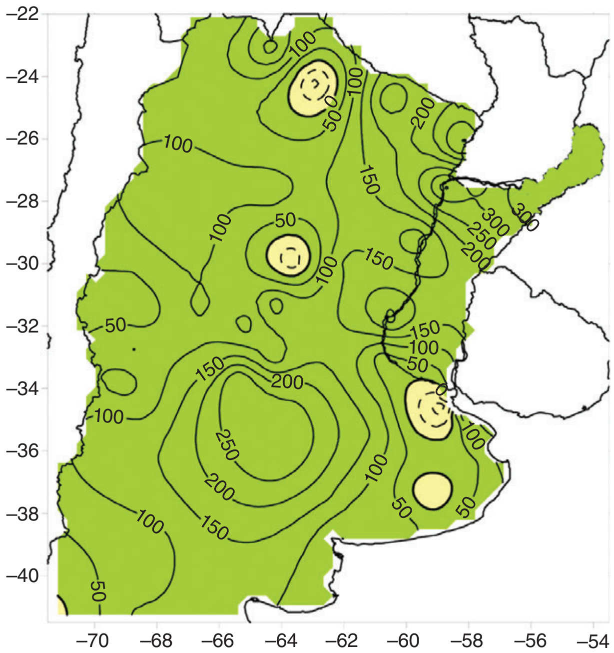

FIGURE 3 | End-to-end change in annual precipitation through the 1960–2000 period (mm). Green (yellow) positive (negative) changes.

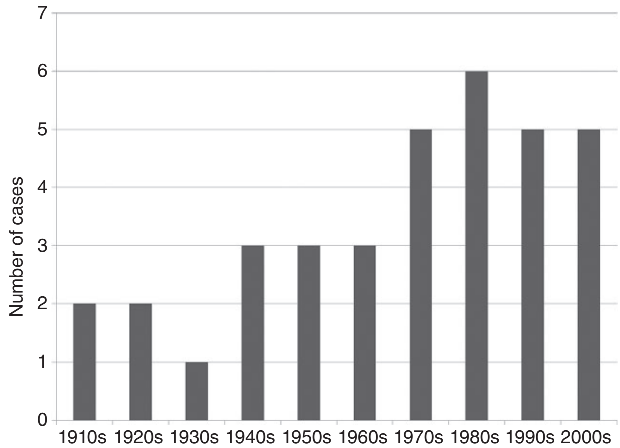

FIGURE 4 | Number of days per decade with precipitation over 100 mm in the city of Buenos Aires.

phases.[6] Accordingly, most of the annual precipitation trends since 1960 in subtropical Argentina can be accounted for by two modes. The first mode, which is positively correlated with precipitation in northern Argentina and with ENSO indices, had a steep increase in precipitation at the end of the 1970s. The second mode, which has a maximum positive correlation with annual precipitation between 30 and 40°S, had a regular positive trend starting in the early 1960s and it is correlated with the southward displacement of the South Atlantic high.[20,6]

In conclusion, in northern Argentina, annual positive precipitation trends can be attributed in part to changes in the frequency and intensity of the ENSO phases, but in the rest of subtropical Argentina they were at least partially attributable to the southern shift of the western edge of the South Atlantic high that enhanced the moist advection from the Atlantic Ocean. The only exception to the regional increase of precipitation occurred over the Andes Mountains between 30 and 42°S, where negative trends in precipitation since the beginning of the last century can be inferred from trends in river flows. Also, in the narrow humid strip near the Andes in northern Argentine Patagonia precipitation has declined since at least the middle of the last century when meteorological observations started. The precipitation reduction reached 30–50% in some localities, being similar in percent to the decrease observed in the neighboring Chilean gauge stations.[25]

Extreme Precipitation

In the subtropical region of Argentina, the positive trends in precipitation were part of a more general change in the statistical distribution, with increasing amounts of rain concentrated in the heaviest rainfalls. The annual maximum of 1- and 2-day accumulated rainfalls had positive trends since 1960, as also did the frequency of heavy rainfalls over thresholds ranging from 50 to 150 mm.[26,27] An example is shown in Figure 4. These trends in extreme rainfall intensity and in frequencies over thresholds are statistically significant for precipitation aggregated at either regional or subregional scales, especially in central and eastern Argentina between 30 and 40°S.[28] There was also a trend in the monthly aggregated precipitation distribution with a marked drift toward a greater percentage of rain falling in the 'above normal' (65th to 90th percentile) and 'extreme high' precipitation months (over the 90th percentile).[21] This intensification trend had consequences over extended and very flat plains of the country, where flooding is driven by precipitation on the scale of a month or more.

IMPACTS

Hydrology

Since the early 1970s, the main rivers of the Plata Basin, namely the Paraguay, Paraná and Uruguay rivers, which run into the eastern part of Argentina (Figure 1) have increased their mean flows,[28–30] as well as the frequency of their extreme discharges. Given the importance of these rivers for power generation, navigation and livelihood in their geological flood valleys, these changes have had important geophysical and social impacts and consequences. The increase in the annual discharges until the 1990s was of the order of 20–35%, with a reduction after 2000 that however did not reverse the former growth. Therefore, these rivers maintained their discharges at levels well above those of the 1950s. Similar trends were observed also in important tributaries such as the Bermejo, Salado and Iguazú rivers.

The upper basins of the Paraná and Paraguay rivers have suffered substantial land use change that was the driver of positive discharge trends in those rivers, enhanced in their southern courses by the precipitation trends mentioned previously. In the south of the Plata Basin and particularly in the Uruguay River, the main driver of the river flow trends was precipitation change.[31,32] In contrast with the great rivers of the eastern subtropical region, the discharges of the rivers that come from the Andes Mountains between 30 and 42°S have had strong negative trends in flow since the beginning of the last century, which in some cases led to reductions of 50%. These trends were caused by the reduction of precipitation over the Andes. The declines in flow were not more pronounced only because of the long-term melting of the glaciers.

Floods

The Paraná and Paraguay basin have very gentle large-scale slopes that in the most stepped areas do not exceed 0.3 m km^{-1}.[33] Thus, high rainfall persisting during some months on extended areas of small slopes may lead to river overflows enduring for months.[34,35,30] The extreme discharges of the Paraná and Uruguay rivers became considerably more frequent in the 1980s and 1990s (Figure 5). Many of the greater discharges, but not all, occurred during El Niño phases, but their increase in frequency responded to precipitation trends, which only in part were explained by El Niño changes.[6] In the first half of the last century, there were few major floods caused by overflows of rivers and brooks. For instance, in the case of the Paraná River, there were no major flood events for more than 60 years following the great flood of 1905. This long period without major floods led to the occupation of the flood valleys with agricultural activities and even with urban settlement. This increased the human and economic risks that materialized when floods became more frequent from the early 1980s. In 1983 and 1997, floods along the coasts of the Paraná and Uruguay rivers forced the evacuation of hundreds of thousands of people and an estimated cost of over a billion dollars.[36] In the case of the Paraná River, in its major floods of 1982/1983, 1992 and 1997, the surface affected in Argentine territory was of the order of 40,000 km^2.

While in the Parana River floods may endure for several months, in the Uruguay River flooding only

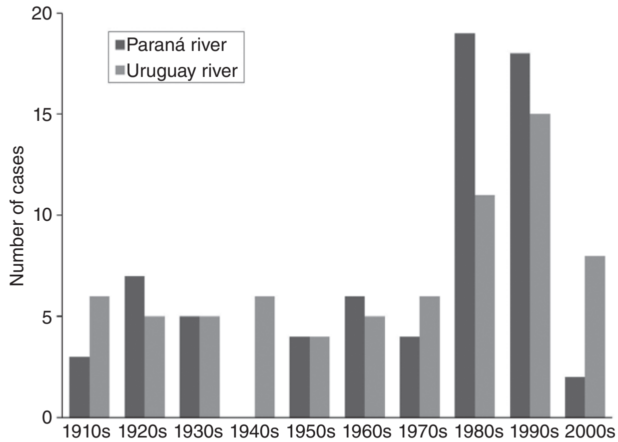

FIGURE 5 | Number of monthly flow anomalies at Corrientes (Paraná River) and Paso de los Libres (Uruguay River) higher than at least two times the standard deviation of the corresponding month.

lasts for 3–10 days because its basin is considerably smaller than the Paraná basin. Peak streamflows respond quickly to one, or at most, two storms. As with the Paraná River, the frequency of the major discharges in the Uruguay River increased during the last two decades of the 20th century, but in a lower proportion, only doubling relative to previous decades (Figure 5). Like in the two other great rivers of the Plata basin, most of the major discharges of the 20th century in the Paraguay River took place in the last decades of the century. Two-thirds of the 16 major floods of the last century occurred after 1975. This trend was even more evident in the largest discharges as four of the five largest discharge events occurred after 1975.[30]

Lingering floods also take place in the Buenos Aires Province, not only from overflows of water courses, but also from stagnation of water excess in low areas of plains with very little drainage.[37] The most severe flooding in recent times in this Province took place in 1987, 2002/2003 and 2012 and again in 2014 causing considerable damage to agriculture production. In subtropical Argentina, heavy storms mainly originate in meso-scale systems that produce sudden floods in low-lying areas, which in some cases have become urbanized. Since the beginning of this century urban floods have become more frequent and have caused great damage and in some cases substantial casualties. The more relevant and well-known cases occurred in the cities of Santa Fe in 2003 and 2007 and La Plata in 2013, but in addition several disasters by flash floods or landslides in smaller cities and towns are reported by the media almost every year. In 2003, the overflow of the Salado River surpassed the defenses and flooded almost a third of the city of Santa Fe causing dozens of casualties.[36] A great part of this city was flooded again in 2007, this time from a heavy rainfall *in situ*, but with considerably fewer casualties. In 2013, over La Plata, the capital city of the Province of Buenos Aires, there was an unprecedented heavy storm that in less than a half-a-day poured hundreds of millimeter over the city and its surroundings, reaching in one pluviometer more than 400 mm. Large parts of the city were flooded causing great damage to housing and more than 80 documented deaths.[38]

Agriculture

Increase in crop yields in the Pampa region since the 1960s was caused by both technology and climate trends. The increase in spring and summer rainfall observed in several regions of Argentina, importantly favored annual crop and forage productivity. Crop simulation models indicate that after filtering technology-induced trends, greater water availability for crops in the Pampa region during 1970–2000 (as compared with 1930–1960) led to yield increments in soybean (38%), maize (18%), wheat (13%), and sunflower (12%), as well as in the productivity of temperate grasses (7%) especially in the southern and western zones.[39,40] However, in the case of wheat, model simulations also indicate that the gains due to precipitation changes were reduced in response to higher minimum temperatures.[41] In addition, the more humid climate, together with a number of other factors such as new production technologies and genotypes, the enhanced global food demand, and the increase in grains price, allowed the expansion of agriculture toward the western zones and the inclusion of new lands for agriculture.[42]

Although observed climate change has favored the yields of the main crops, the increased frequency of extreme weather events constitutes a growing risk. A number of extreme precipitation events occurred during recent years leading to flooding with important economic agricultural impacts. In 2000–2001, e.g., extended flooding in the plains of Buenos Aires caused loses attaining 700 M USD in forage output, wheat and maize yields and in milk production.[43] Another example was the drought of 2008/2009, when precipitation in some localities was almost half its mean value. This led to production loses of 29% in soybean, 20% in wheat, 19% in sunflower, and 12% in maize, and a 40% reduction in wheat's planted area in 2009.[44]

Glaciers and Andean Rivers

Between 30 and 40°S, the Andes is a mountain region where socioeconomic activities are highly conditioned by climate. During winter, snow accumulates in the high mountains, and occasionally in the elevated valleys, and starts to melt during the spring leading to the rise of river flows. The hydrological cycle is therefore conditioned by snow precipitation and temperature with the maximum runoff in the summer months of December and January. This provides water for the population, agricultural activities and hydroelectric power. The stability of this cycle is crucial to sustain human activities in the region. The variability of snowfall is very high, with years of abundance and years of scarcity. High precipitation periods coincide with the occurrence of El Niño events and large-scale paleoclimate reconstructions of precipitation reveal the existence of cycles of prolonged drought.[45] More importantly, instrumental observations and paleoclimate proxy data over the Andes Mountains reveal a positive trend in temperature, especially in winter, and a declining trend in precipitation.

FIGURE 6 | Photographs of the Glaciar del Humo, Atuel River basin. The upper picture was taken by W. Von Fischer in 1914 and the bottom one by D. Cobos in 1982.[47]

These trends in precipitation and temperature have caused a reduction of the ice mass in the Andes. Glacier retreats have been observed since the 19th century.[46] They were in general easily perceived by the local population, increasing awareness about changes in climate and landscapes.[47] Two photographs from the Atuel River Basin, taken in 1914 and 1982, are shown in Figure 6 as an example of the retreat of one of the many glaciers documented by photographs and/or satellite images on the Andes south of 30°S.

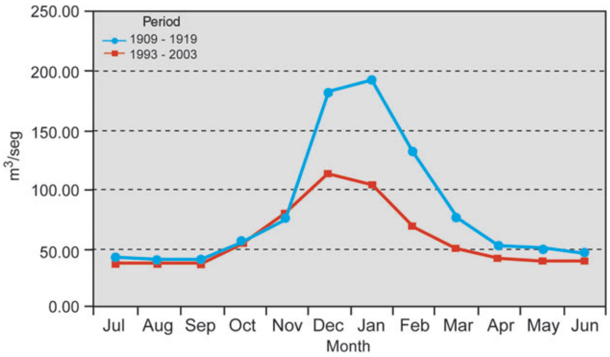

FIGURE 7 | Rio San Juan hydrograph for the periods 1909–1919 and 1993–2003.

The volume of the river runoff depends mainly on the amount of snow falling during the winter months, but it is temperature that regulates the snowmelt velocity. Higher temperatures make the process of snowmelt begin earlier, increasing the flow rate during the spring and shifting the maximum peak earlier, from January to November–December with consequently less flow during summer.[48] Figure 7 shows both the trend toward less flow and the phasing to an early peak, typical of the rivers of the region between 30 and 40°S. Both trends have implications for water availability, as most of the agriculture demand is concentrated in summer.

In the extreme south of the country, in the so-called 'south continental ice field' in the Andes, of 50 glaciers, 48 are receding and only 2 are stationary.[49,50] The impact of glacier retreat on the river flows of the region is still not well understood, but without doubt implies the loss of major water reserves.

21ST CENTURY CLIMATE PROJECTIONS

Figures 8 and 9 show the regional patterns of the annual surface air temperature and precipitation change in response to increased greenhouse gas concentrations computed from the multi-model ensemble mean of global climate model (GCM) outputs originating from the Coupled Model Intercomparison Project, Phase 5.[51] Projected changes under scenarios RCP4.5 and RCP8.5 are presented as in the IPCC Fifth Assessment Report (AR5)[52] for the near-term (2016–2035) and for the long-term (2081–2100) relative to the reference period (1986–2005). These individual model projections were used to construct an ensemble of the 42 GCM experiments available through the Program for Climate Model Diagnosis and Intercomparison (PCMDI; http://cmip-pcmdi.llnl.gov/cmip5/).

For the next two or three decades, there is a general warming projected all over the country in the range of 0.5–1.0°C, a range almost similar for both RCP 4.5 and 8.5 scenarios (Figure 8). Warming for this period is already committed and independent of different emissions scenarios, the rate of change being uncertain only due to interdecadal natural variability (and to the skill of the climate models).[53] The projected temperature increase for the coming decades is greater than the observed warming of the last 60 years in Argentina, but occurring over half the duration. This constitutes an acceleration in the regional warming rate.

By the end decades of the 21st century, differences between the two scenarios are important. In the RCP 4.5, the projected temperature increase is more than 1.0°C over the whole country, being more pronounced in the north and west than in the south and east, in the northwest being in the range of 2.0–2.5°C. For the scenario RCP 8.5, the geographical pattern is similar, but the warming is considerably higher, reaching 3.5° C in the northwest of the country. The projected warming is in general more intense during the summer months (not shown).

For the next two or three decades, projected precipitation changes are positive in the northern and central regions, but in magnitude only less than 100 mm a year, while precipitation reductions are projected for the dry area in the central-western region and for the whole of Patagonia (Figure 9). The projection patterns are similar for the end of the century and for both RCP scenarios. According to these scenario projections, it appears that the general precipitation increase experienced over the last 50 years for the east and central subtropical Argentina would not be reversed during the rest of this century. In the northwest Patagonia, the observed negative precipitation trend of the last century is also projected to continue and, as in the case of the observed trends, most of the projected precipitation reductions would occur in winter.

All the projections of extreme temperature indices for the end of the century are consistent with a warmer climate in Argentina.[54,55] In the case of CMIP3 projections, the 20-year return period of the observed annual maximum temperature for the late 20th century (1981–2000) for southeastern South America is projected to be substantially reduced. In scenario SRES B1, the 20-year return period reduces to 2–5 years for 2046–2065, and to just 1 year for 2081–2100 for the SRES A2 scenario.[55] The more recent CMIP5 climate scenarios suggest changes toward more extreme warm temperature indices.

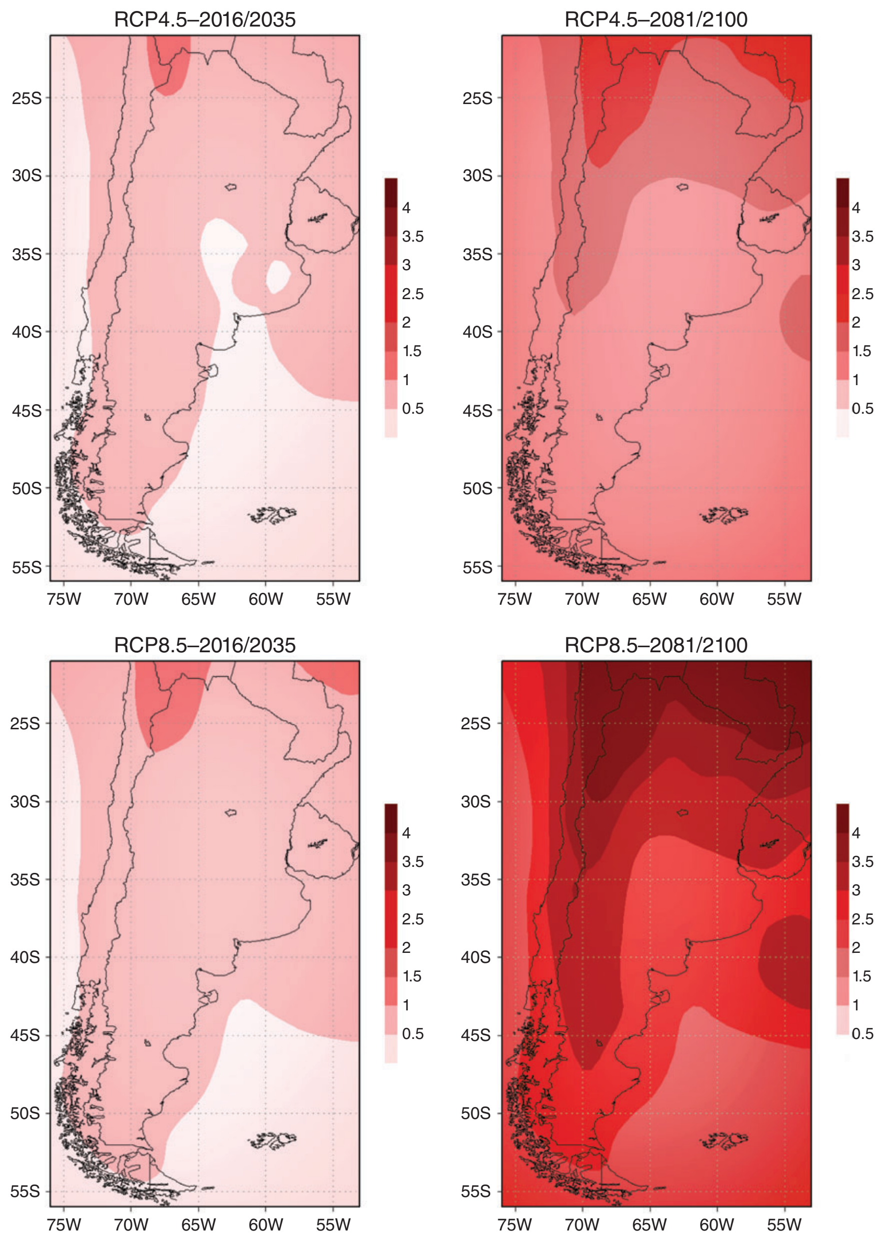

FIGURE 8 | CMIP5 multi-model ensemble mean of projected changes (°C) in annual temperature for the near-term (2016–2035) left, and long-term (2081–2100) right relative to 1986–2005 under RCP4.5 top and RCP8.5 bottom.

According to the multi-model average of these scenarios, the 20-year return value of the maximum daily temperature would increase over Argentina with respect to 1986–2005 by 0–1°C in the RCP2.6 scenario and 2–3°C in 2081–2100 in the RCP8.5 one. Similarly, for the same two periods, the 20-year return value of the minimum temperature would increase 0–1 and 3–4°C, respectively, for the RCP2.6 and RCP8.5 scenarios.[56]

Based on the outputs of four regional climate models nested in three different GCMs, driven with the IPCC SRES A1B emissions scenario, distributions of monthly precipitation averaged across two regions of eastern Argentina have been projected for 2011–2040 and 2071–2100.[57] One of these regions encompasses most of northeastern Argentina and the second region comprises the east of the country and the west of Uruguay between 32 and 36°S. The observed positive trends in extreme monthly precipitation since 1960[21] are projected to continue,[57] especially in the second region where they are related to the long-lasting floods that take place over the flat plains with little drainage. Thus, assuming no change in other flood drivers, such as

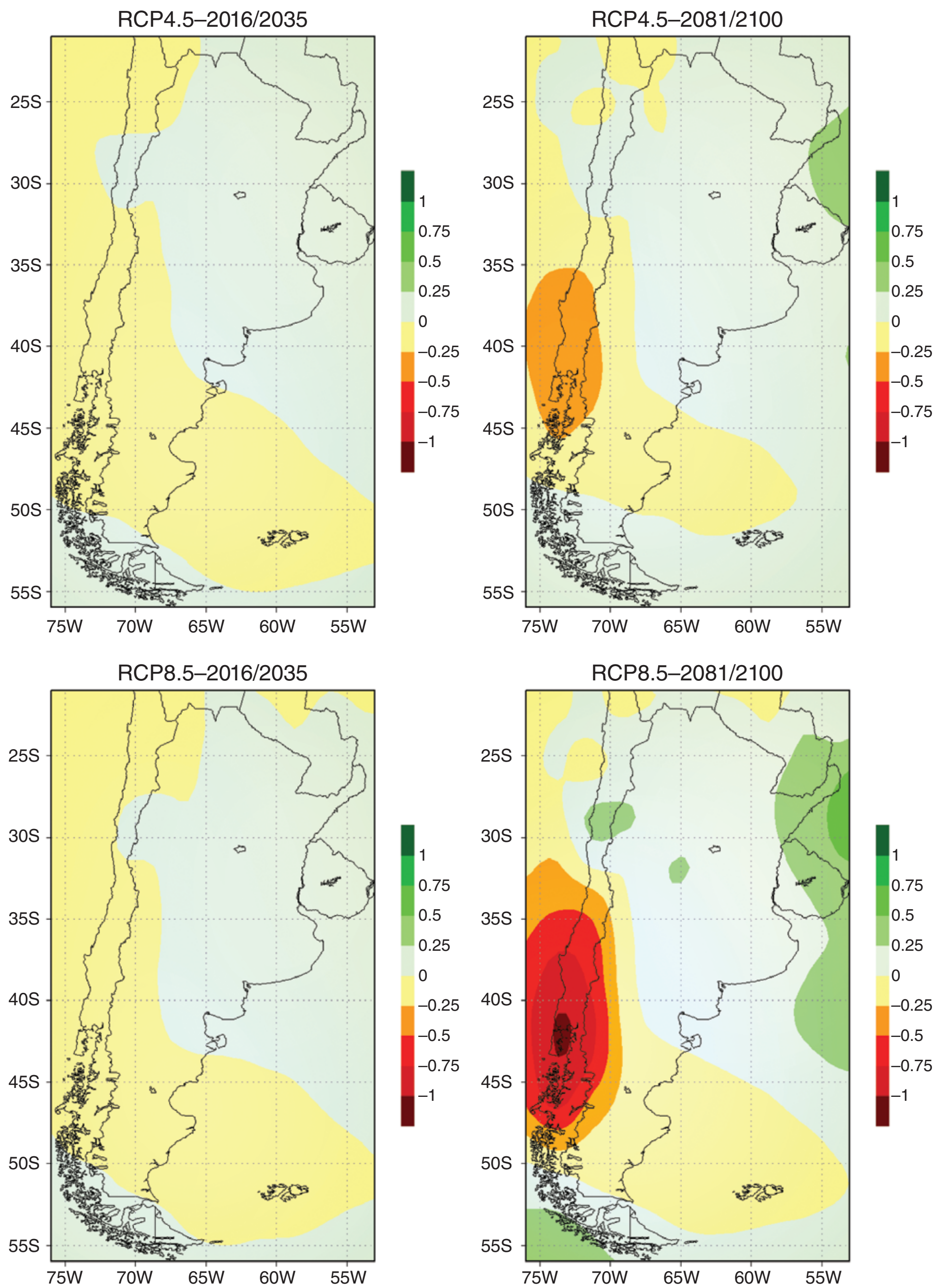

FIGURE 9 | CMIP5 multi-model ensemble mean of annual precipitation (mm day^{-1}) for the near-term (2016–2035) left, and long-term (2081–2100) right relative to 1986–2005 under RCP4.5 top and RCP8.5 bottom.

land use or drainage works, it could be expected that the future recurrence period of such floods will be the same or even shorter.

PROJECTED IMPACTS

Coasts

The maritime coasts of Argentina are in general high with cliffs or stepped terrain near the shore. For that reason, although the situation of these coasts under the projected 21st century scenarios of sea-level rise (SLR) have not been studied in detail, it is not expected that significant loss of land would result from permanent flooding during this century. The exception would be some tidal islands south of the city of Bahia Blanca in the extreme south of the Province of Buenos Aires (Figure 10). The coast of the estuary of the Plata River, which basically has a tidal dynamic, has been studied under a global mean SLR scenario of 50 cm.[52] Under this projection, it is unlikely that the permanent sea

FIGURE 10 | Buenos Aires Province and the Plata River.

intrusion would result in appreciable loss of land for most of the coast between the Parana delta and the Samborombón Bay.[58]

The case of the southern coast of the Samborombón Bay is different. Here, there is a loss of land to be expected, not only because of the shallower slope of some coastal areas, but also because the coastal sediments have soft structural features.[59] These favor rapid marine erosion by the higher frequency of higher tides, and by a greater frequency of high-energy waves generated in the ocean by the more frequent easterly winds. A full quantification of the surface likely to be lost in this area is still pending, but it is estimated that it will be important in the coming decades.[58]

Aside from their ecological importance, the land areas projected to be lost in this coastal region are neither significant in size nor of great economic value. Thus the greatest human impact of SLR will occur through the increased recurrence and spatial reach of storm surges on the Plata River coastal areas, including those of the Greater Buenos Aires city.[58] Presently, in this city nearly 200,000 people are potentially affected by storm surges with an average recurrence of one in 20 years. In the SLR scenario of 50 cm, this number would be near tripled. This is a conservative estimate because it assumes no demographic growth, an outcome which according to current trends is highly unlikely.[58]

Hydrology

Hydrological scenarios for the Plata basin were developed for two future periods, 2021–2040 and 2071–2090 based on four regional climate models driven by three CMIP3 GCMs. Using the hydrologic distributed VIC model,[60] a moderate increase in discharge for the majority of the rivers in the Plata basin was simulated for the near future. There is a less uniform variation toward the end of the century[61,62] with strong differences between emission scenarios.[56] Nonetheless, an increase in frequency and duration of fluvial floods is projected for the Paraná and Uruguay Rivers.[63]

The Iberá Wetland, located in northeastern Argentina, is one of the largest inland freshwater ecosystems in the world, only second in size to the Pantanal in the South American interior. It has a rich biodiversity and recent changes show sensitivity to climate that raised concerns of a loss of this system under a high-emissions scenario. The main features of the system dynamics were successfully simulated with a distributed hydrological model,[64] including the daily streamflow of the river that drains the wetland and the daily level of the Iberá Lake. Sensitivity tests, performed by varying regional temperature and precipitation conditions according to the outputs of a set of CMIP5 climate models, showed a strong dependence of the basin hydrology on possible changes of precipitation rather than on changes in temperature. In fact, a warming of +1.5°C in the regional mean temperature would produce a reduction in the river streamflow that would be compensated by an increment of only 1.8% in rainfall. Projections of future changes in the Iberá Lake level for the 21st century based on regional climate model experiments under the SRES A1B scenario show an increment in the annual mean water level of around 10 cm both for the near future and for the end of the century.[64] According to these results and the precipitation projections of CMIP5 (Figure 7), the risk of losing this wetland appears relatively low.

Agriculture

Several studies that assess climate change impacts in the Pampa region suggest that the productivity of the main extensive crops (wheat, maize, and soybean) would not change much by the mid-21st century. If the benefits of increasing CO_2 concentration on crop physiology occur (increasing photosynthesis and reducing stoma conductance), then slight yield increases may arise. Model simulation results show important spatial variability, however, and differences among species. In general, total crop production for the country might balance because of increase in productivity in the southern and western Pampa region[65,40] and of some loses in the core production region and in the north of the country. Here, water deficits could intensify due to more evapotranspiration resulting from higher temperatures.[66] In northern Argentina, occasional problems in water supply for agriculture under the current climate may be exacerbated in the future and may require investments to cope with future additional stress.[67]

Soybean crops could be more favored than wheat or maize in the future, maintaining their yields even with 3°C temperature increase.[68] Warmer and wetter conditions may favor the extension of crops toward the southern and western areas of the Pampa region. In addition, new crops will be possible, as e.g., Arabica coffee, which is expected to be expanded in the north of Argentina with a warming of +3°C.[69] However, there are uncertainties related to different climatic scenarios, the true effects of increasing CO_2 concentration, and the relative lack of knowledge about the future behavior of biotic factors such as pests, diseases, and weeds. Climate change may alter the current distribution scenario of plant diseases and their management, having effects on crop productivity. Years with severe infection of late cycle diseases in soybean could increase, severe outbreaks of the Mal de Rio Cuarto virus in maize could be more frequent, and wheat fungi will possibly increase slightly in the south of the Pampa region by the end of the century.[70]

In northern Patagonia, fruit and vegetable growing could be negatively affected in the future because of a reduction in the available water for irrigation from rivers. In the irrigated oases at the foot of the Andes between 32 and 37°S, increases in water demand due to population growth, and reduction of the river streamflow, would likely lead to additional use of ground water for irrigation, pushing up irrigation costs and possibly forcing producers out of farming toward 2030. Also, water quality could deteriorate with the worsening of the already existing salinization processes.[71] In this region, in general, reduced water availability would pose serious questions about the sustainability of viticulture at its present scale.[72]

Glaciers and Andean Rivers

In recent years, there has been increasing concern about the implications of global climate change for the Andean region. Climate projections indicate a probable decrease of snow in the mountains and a rise in temperature during the current century. A rise in temperature means that the isotherm of 0°C will move up the mountains leaving less surface for accumulation of snow. In such a scenario, glaciers will probably melt and, in some basins, completely disappear.[72] These changes could seriously increase water deficits in downstream locations and compromise the survival of the oases.

Climate change assessed by different regional circulation models indicates that by the end of the century there will be an increase in temperature (+2.0 to +3.5°C in the 8.5RCP scenario) (Figure 6) and less snowfall and runoff in the oases at the foot of the central Andes (Figure 7). These changes would set new conditions to which oases' activities would need to adapt. It is important to take into account all the interactions among the variables. For instance, if mountain temperatures rise steadily, snow cover will melt earlier in the year causing a rise of runoff during the early spring months and a drop during the summer, just when agriculture most needs irrigation. Such changes in the hydrograph of Andean rivers have already been observed and are also projected using results from regional climate modelling.[73,74]

GREEHOUSE GAS EMISSIONS

The literature on greenhouse gas (GHG) emissions in Argentina is mostly from official documents, e.g., national communications to the United Framework Convention on Climate Change (UNFCCC)[75,76] and studies elaborated by think tanks and international organizations. National communications are the only comprehensive studies covering all emissions, sources, and sectors using the standard methodology of the IPCC. In contrast to their extensive and wide coverage of emissions inventories, national communications only provide partial information about mitigation potentials from a small number of selected priority sectors and mitigation options. Until now, Argentina submitted two national communications. The first had the GHG emission inventories of 1990 and 1994. Its revision included the 1997 inventory and the second national communication the 2000 inventory. There is an ongoing process aimed to develop the third national communication to the UNFCCC. This study will provide key and updated elements regarding national emissions pathways, mitigation options as well as adaptation and impacts research, http://www.ambiente.gob.ar/archivos/web/ProyTerceraCNCC. The third national communication will likely be public by 2016. Additional sources of information for emissions projections, mitigation potential, and technology options used here are the recent study on the Economics of Climate Change,[77] the Technology Needs Assessment

(TNA) Study for Argentina,[78] and a report of the Bariloche Foundation for an energy firm.[79]

The composition of Argentina's total GHG emissions in 2005, excluding land use, land-use change, and forestry (LULUCF) and measured as CO_2 equivalent through each gas's global warming potential, is 47.4% CO_2, 31.2% CH_4, and 20.5% N_2O. The remaining 0.9% comprises other GHGs. Methane emissions come mainly from cattle (enteric fermentation) and landfills, and N_2O emissions mainly from agriculture.[75,76,79] The bulk of emissions come from the energy (almost half) and agriculture (42%), as is the case in countries with similar economic structure. Minor contributions come from waste and industry[79] (Table 1). Net emissions from LULUCF were negative mainly because of forest regrowth. The forest sector therefore constitutes a net carbon sink reducing net GHG emissions by 4%. GHG emissions from the energy sector mostly concentrate in the transport and energy industries, together constituting about 63% of the sector emissions. The rest of industries accounts for 14%, and household, commercial, and public consider for 24%.[79]

Between 1990 and 2005, Argentina's GHG emissions grew about 40% (39% excluding LULUCF sector and 43% including LULUCF). As of 2005, per capita GHG emissions were 8.2 tons CO_2 eq.,[79] over the world average of about 7.5 tons CO2 eq., but well below the average for OECD countries of 15 tons CO2 eq.[80] The waste sector showed the highest growth, 497%, due to the increase in waste, but more importantly because of the trend to its burial disposal in landfills and better accounting. The industry sector, which only includes process emissions and not the energy used, had also an important increase of 135%, while agriculture had the smallest sectoral increase of only 15%[78] (Table 1). If total GHG emissions estimates include LULUCF, the emissions intensity ratio (GHG emissions/GDP) of Argentina declined in the period between 1990 and 2005, falling by about 5% from 1.16 million tons CO_2 eq./M USD in 1990 to 1.10 million tons CO_2 eq./M USD in 2005.[78]

As mentioned above, the second national communication (SNC) does not provide a thorough estimate of emission mitigation potential. Rather, after identifying the main and fastest growing emissions source sectors, five mitigation options of high potential were identified and its mitigation potential assessed over a 15- to 20-year time horizon. With this approach, a total annual mitigation potential of 60 million tons CO_2 eq. (about 20% of the national emissions) was identified through mitigation measures aimed at renewable energy, energy efficiency, modal transport systems, methane avoidance, but most of all from afforestation.[81] The TNA for Argentina[78] identified four priority sectors (energy production, transport, waste, and agriculture), selected because of their high share in total emissions and because of their high mitigation potential. A total of 24 priority technologies (or groups of technologies) were identified. Implementation of the priority technologies in these four sectors would have an annual mitigation potential of 5.8 million tons CO_2 eq. However, this study did not include afforestation that the SNC identified as the sector with the highest mitigation potential. The TNA study also identified a number of institutional, financial, and technical barriers to the implementation of each technology.

PUBLIC AND PRIVATE RESPONSES

Public Sector

The public sector in Argentina has addressed climate change since the early 1990s with specific polices and also through certain sectoral measures aimed to attain other national policy goals, but with implications for adaptation to, or the mitigation of, climate change. The institutional framework within the country consists of a Climate Change Division within the Environmental and Sustainable Development Secretary. Argentina is currently developing its National Strategy on Climate Change. This process, initiated in 2009, involves government agencies and the scientific and private sectors as well as the social society and labor organizations, and it is now focused on the identification of specific targets and indicators for sector policies in mitigation and adaptation. In the international arena, Argentina has participated actively in the UNFCCC negotiations, including the hosting of two COPs in 1998 and 2004. The country has also contributed to IPCC activities with the involvement of many Argentinean scientists and as an active member of the Panel.

Mitigation

As of April 2014, Argentina hosted 55 Clean Development Mechanism (CDM) projects in the 'CDM pipeline' according to CDM/JI Pipeline Analysis and Database, 44 of them approved and 11 in the process of validation. These projects are expected to lead jointly to an annual reduction of 9.3 million tons CO_2 eq. relative to a counterfactual baseline.[82] The most relevant program types are related with renewable energy (wind, solar, and biomass) and landfill emissions. The national government has launched programs aimed at improving energy efficiency including the phasing out of incandescent light bulbs and a program to promote the use of

TABLE 1 | Argentine GHG Emissions by Source (million of tons CO_2 eq.)[72]

	1990	1994	1997	2000	2005	2010 (projected)	Sector share in 2005 (%)	Growth 2005–1990 (%)
Energy	104	122	1301	132	149	192	49.9	43.7
Industry	7	8	11	11	17	16	5.5	134.7
Agriculture	110	117	119	125	126	152	42.3	15.2
Waste	3	2	12	14	20	24	6.6	497.2
LULUCF	−15	−34	−28	−43	−12	—	−4.1	−16.3
Total (incl. LULUCF)	209	215	243	2393	298	—	100.0	42.9
Total (exc. LULUCF)	224	249	271	282	311	384	—	39.3

GHG emissions of 2010 were projected during 2008 using economic trends and then applying the IPCC methodology used to estimate the former five GHG inventories from 1990 to 2005. The professional team that worked on the 2010 projection was also the same that calculated the 2000 and 2005 GHG inventories.

off-grid renewable energies for rural areas. It provides subsides and other fiscal benefits for afforestation, the protection of the natural forests, and for the use of alternative clean energies.[83] In addition, some provinces have their own mechanisms to promote renewable energy, which in the case of wind energy are in force in several provinces. Regulations for the mix of biodiesel in diesel oil for transportation were established by law in 2010,[83,84] and currently the biodiesel content of gas oil should be of 7%.

Adaptation

As a reaction to flooding events, several infrastructure constructions have been built to alleviate flood risk and reduce exposed numbers of people and assets, although they are still not sufficient. As a response to the floods of 1983 and 1992 in the Paraná and Uruguay rivers, both attributed to El Niño, defenses were constructed in many cities along these rivers and an early warning system for floods was implemented. As a result, the people displaced during the flood of 1997 numbered only 100,000 compared with 300,000 in the 1982 flood, which affected about the same area.[35] In addition to the national early warning system, some provinces have developed their own local systems, like in the case of Santa Fe. More recently, the Province of Buenos Aires, which has 40% of the national population, is starting to implement its own early warning systems of extreme meteorological and hydrological events.

National Institute Agriculture Technology (INTA) scientists developed some strategies to cope with, or take benefit from, climate variability. This can be seen as an ongoing process of implementation and learning in the adaptation to climate change. During El Niño years, usually with good water availability during spring and early summer, early plantings and good nutrient availability benefits maize and soybean productivity in the Pampa region. On the contrary, during La Niña years, when lower yields are expected, the best option should be late plantings with low fertilization doses. Moreover, there are differences among crops in their response to climatic variability related to ENSO). Winter crops (wheat and barley) are less sensitive as their growing seasons occur out of the time of the year when there is ENSO signal or because, such as sunflowers, they have lower water needs.[85] As for the selection of crop seeding in certain years, it has been established that for maize the best indicator of annual crop yield variability in Argentina is the Southern Oscillation Index,[86] whereas for soybean and sunflower yields the equivalent best indicator is the South Atlantic sea surface temperature

To cope with extreme weather events, one option for transferring weather-related risks is by using different types of rural insurance. Index insurance is one mechanism that has been introduced to overcome obstacles to traditional agricultural and disaster insurance markets. In Argentina, index insurances have been developed for the milk sector.[87] The parametric insurance protects milk farms against heavy precipitation events using the standardized precipitation index. The same approach was developed for annual crops such as maize and soybean.[88] Specific productive early warning systems have been developed using predictive models and weather forecasts to warn about the intensity of fungi in wheat[89–92] and the impact of heat waves on milk production.[87]

Private Sector

The private sector has contributed to global climate mitigation by developing a competitive industry of biodiesel based mainly on soybean, which led to the export of 1,557,800 tons of biodiesel in 2012.[84] This industry is now helping to substitute fossil fuels in the domestic market. The private sector was also the major player in the national CDM implementation, as mentioned earlier.

The annual isohyets of 600 mm in the south and 800 mm in the north of the subtropical region are the approximate boundaries for rainfed crops. The change to a more humid climate in recent decades has shifted this boundary, adding almost 10 million hectares with annual precipitation over those values. As the humid frontier moved west and persisted for decades, land owners took advantage of these new conditions and increasing land extensions were dedicated to crop production. This was a process of autonomous adaptation, not planned or recommended by any centralized agency. Huge short-term revenues for land owners and economic benefits for the regions involved have resulted. However, in many cases, this adaptation produced and will continue to produce considerable damage to ecosystems and soil conservation.[93]

As a result of this land-use change facilitated by recent climate change, around 29% of the Atlantic forest and 28% of the Yunga forest were lost since 1960,[94] with large areas in which the changes were even more pronounced. In central Argentina (northern Córdoba Province), forest cover has decreased from 52.5 to 8.2% between 1969 and 1999.[95] Between 1972 and 2007, 1.4 Mha of dry forest were cleared in the northwest of Argentina, especially in Tucumán and Salta provinces.[96,97] In the Espinal, an ecoregion of the Chaco-Pampean plains, 20% of ecosystems were lost and 60% of the forests were removed between 1987 and 2009.[98] In the Pampa region, flood extension has been associated with the dynamics of groundwater levels that have been influenced by precipitation and land-use change.[99] In addition, the disappearance of natural and semi-natural habitats in these heavily transformed agricultural landscapes will have substantial negative effects on the provision of natural pest control services.[100]

The intensification of fluvial erosion depends on the interaction of environmental factors and human activities, such as deforestation, land-use change, and unrestricted agriculture.[101] According to several authors, current land-use changes are disrupting water and biogeochemical cycles and may result in soil salinization, altered C and N storage, surface runoff, and stream acidification.[102–104] Agricultural exploitation of new climatic conditions in Argentina has come at a price.

CONCLUDING REMARKS

Observed climate change since the middle of the last century has caused multiple impacts in Argentina, both positive and negative. Negative impacts call for adaptation actions, some of them, such as improved flood management, are rapidly needed. For the near future, in particular until the middle of this century, climate projections raise additional concerns that also require consideration. Nevertheless, neither already observed nor near future projected climate change implies problems that cannot be overcome with proper and timely adaptation policies and measurements. However, by the end of this century under the 8.5 RCP scenario, warming could create unfavorable severe conditions which might cause great damage to the people of Argentina and the country's economy.

For the present, as well as for the near future, although many aspects should be considered, three main issues appear to require special attention. The first and more urgent need is public adaptation to heat waves and extreme precipitation events and their associated floods and destructive winds. Reducing damages and casualties from such events requires enhancing early warning systems, both in equipment and personnel. Improving contingency planning is also called for, as well as modifying building designs of new infrastructure when needed. It is also necessary to raise the public awareness and understanding of these impacts of such events, as well as the manner to avoid their impending damages.

Given that agriculture is one of Argentina's core economic activities and it appears quite vulnerable to climate change impacts, the second need is for expanded research, information provision and assistance to stakeholders in the sector are crucially needed. This should start with already observed changes and current climate variability for which several risk management options are already available. The oases at the foot of the Andes, whose practically only source of surface and groundwater is the declining precipitation over the Andean mountains, are at risk of being limited in their future development. Several suggested actions to delay the water crises by several decades have been proposed, which comprise the third priority action that we identify. They include improving efficiencies in farm irrigation systems and in water distribution channels, dam constructions in the upper river basins to augment water storage capacity, and the capture of water from the summer storms in cisterns, dams, and small reservoirs. However, any adaptive measures should be based on a complete assessment of the hydrological cycle and its variations. An integrated approach to adaptation, shared and produced by all stakeholders involved, is called for.

REFERENCES

1. Instituto Nacional de Estadísticas y Censos. Intercambio Comercial Argentino, datos del año (In Spanish). 2012. Available at: http://www.mecon.gov.ar/comercioexterior/docs/ica_05_13.pdf.
2. Escobar G, Barros V, Camilloni I. Desplazamiento del anticiclón subtropical del Atlántico Sur y su relación con el cambio de vientos sobre el estuario del Río de la Plata (In Spanish). X Congreso Latinoamericano e Ibérico de Meteorología, La Habana, 2003.
3. Simionato C, Vera C, Segiesmund F. Surface wind variability on seasonal and interanual scales over Río de la Plata. *Cont Shelf Res* 2004, 4:770–783.
4. Barros V, Camilloni I, Frumento O, Rivero M. Estudio del potencial eólico en la República Argentina (In Spanish). In: *Programa de Abastecimiento Eléctrico a la Población Rural Dispersa*. Subsecretaría de Energía de la Nación, Buenos Aires, 1997.
5. Di Luca A, Camilloni I, Barros VR. Sea-level pressure patterns in South America and the adjacent oceans in the IPCC AR4 models. In: *8th International Conference on Southern Hemisphere Meteorology and Oceanography*. AMS, Foz de Iguazú, 2006, 235–244.
6. Barros VR, Doyle ME, Camilloni I. Precipitation trends in southeastern South America: relationship with ENSO phases and the low-level circulation. *Theor Appl Climatol* 2008, 93:19–33.
7. Hartmann DL, Klein Tank AM, Rusticucci M, Alexander LV, Brönnimann S, Charabi Y, Dentener FJ, Dlugokencky EJ, Easterling DR, Kaplan A, et al. Observations: atmosphere and surface. Stocker TF, Qin D, Plattner GK, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, IPCC*. Cambridge University Press, Cambridge, 2013, 159-254.
8. Rusticucci M, Barrucand M. Observed trends and changes in Temperature Extremes over Argentina. *J Climate* 2004, 17:4099–4107.
9. Hoffmann J, Nuñez S, Vargas W. Temperature, humidity and precipitation variations in Argentina and the adjacent sub-antartic region during the present century. *Meteorol Z* 1997, 6:3–11.
10. Arblaster JM, Meehl GA, Karoly DJ. Future climate change in the Southern Hemisphere: competing effects of ozone and greenhouse gases. *Geophys Res Lett* 2011, 38:L02701. doi: 10.1029/2010GL045384.
11. McLandress C, Shepherd TG, Scinocca JF, Plummer DA, Sigmond M, Jonsson AI, Reader MC. Separating the dynamical effects of climate change and ozone depletion, part II: Southern Hemisphere troposphere. *J Climate* 2011, 24:1850–1868.
12. Polvani LM, Waugh DW, Correa GJ, Son SW. Stratospheric ozone depletion: the main driver of twentieth-century atmospheric circulation changes in the Southern Hemisphere. *J Climate* 2011, 24:795–812.
13. Vincent LA, Peterson TC, Barros VR, Marino MB, Rusticucci M, Carrasco G, Ramirez E, Alves LM, Ambrizzi T, Berlato MA, et al. Observed trends in indices of daily temperature extremes in South America. *J Climate* 1960-2000, 2005:5011–5023.
14. Alexander L, Zhang X, Peterson TC, Caesar J, Gleason B, Klein Tank A, Haylock M, Collins D, Trewin B, Rahimzadeh F, et al. Global observed changes in daily climate extremes of temperature and precipitation. *J Geophys Res* 2006, 111. doi:10.1029/2005JD006290.
15. Rusticucci M. Observed and simulated variability of extreme temperature events over South America. *Atmos Res* 2012, 106:1–17.
16. Donat MG, Alexander LV, Yang H, Durre I, Vose R, Dunn RJ, Willett KM, Aguilar E, Brunet M, Caesar J, et al. Updated analyses of temperature and precipitation extreme indices since the beginning of the twentieth century: The HadEX2 dataset. *J Geophys Res-Atmos* 2013, 118:2098–2118.
17. Rusticucci M, Tencer B. Observed changes in return values of annual temperature extremes over Argentina. *J Climate* 2008, 21:5455–5467.
18. Rusticucci M, Kyselý J, Almeira G, Lhotka O. Long-term variability of heat waves in Argentina and recurrence probability of the severe 2008 heat wave in Buenos Aires. WCRP Conference for Latin America and the Caribbean, Montevideo, 2014. Available at: http://www.cima.fcen.uba.ar/WCRP/docs/pdf/Abstract_M-Rusticucci.pdf. (Accessed October 14, 2014).
19. Castañeda ME, Barros VR. Las tendencias de la precipitación en el Cono sur de América al Este de los Andes (In Spanish). *Meteorológica* 1994, 19:23–32.
20. Barros VR, Castañeda ME, Doyle ME. Recent precipitation trends in Southern South America East of the Andes: an indication of climatic variability. In: Smolka PP, Volkheimer V, eds. *Southern Hemisphere Paleo and Neoclimates: Key Sites, Methods, Data and Models*. Berlin; Heidelberg; New York: Springer-Verlag; 2000, 187–206.
21. Doyle M, Saurral R, Barros VR. Trends in the distributions of aggregated monthly precipitation over the Plata Basin. *Int J Climatol* 2012, 32:2149–2162.
22. Berbery EH, Doyle M, Barros VR. Regional precipitation trends (In Spanish, English and Portuguese). In: Barros VR, Clarke R, Silva Dias P, eds. *Climate Change in the Plata basin*. Buenos Aires: CIMA; 2006, 61–71.
23. Piovano EL, Ariztegui D, Moreira SD. Recent environmental changes in Laguna Mar Chiquita (central Argentina): a sedimentary model for a highly variable saline lake. *Sedimentology* 2002, 49:1371–1384.

24. Minetti JL, Vargas WM. Trends and jumps in the annual precipitations in South America, south of the 15°S. *Atmósfera* 1998, 11:205–221.
25. Vera C, Camilloni I. Chapter 3.2: Vulnerabilidad de la Patagonia y sur de las provincias de Buenos Aires y La Pampa (In Spanish). In: *Enabling Study for the Second National Communication to the UNFCCC*. Buenos Aires: SAyDS-Fundación e Instituto T. Di Tella; 2006, 54–88.
26. Re M, Barros VR. Extreme rainfalls in SE South America. *Clim Change* 2009, 96:119–136.
27. Penalba OC, Robledo FA. Spatial and temporal variability of the frequency of extreme daily rainfall regime in the La Plata Basin during the 20th century. *Clim Change* 2009, 98:531–550.
28. García NO, Vargas W. The temporal climatic variability in the Rio de la Plata basin displayed by river discharges. *Clim Change* 1997, 102:929–945.
29. Genta JL, Perez-Iribarren G, Mechoso CR. A recent increasing trend in the streamflow of rivers in southeastern South America. *J Climate* 1998, 11:2858–2862.
30. Barros VR, Chamorro L, Coronel G, Báez J. The major discharge events in the Paraguay River: magnitudes, source regions and climate forcings. *J Hydrometeorol* 2004, 5:1161–1170.
31. Camilloni I. Tendencias hidrológicas en la Argentina (In Spanish). In: Barros VR, Perczyk D, eds. *República Argentina: Vulnerabilidad a cambios climáticos e hidrológicos*. Buenos Aires: Secretaría de Ambiente y Desarrollo Sustentable de la Nación – Fundación Di Tella; 2006, 147–174.
32. Saurral RI, Barros VR, Lettenmaier DP. Land use impact on the Uruguay River discharge. *Geophys Res Lett* 2008. 35: L12401. doi:10.1029/2008GL033707.
33. Coronel G, Menéndez A, Chamorro L. Physiography and hydrology of the Plata Basin. In: Barros V, Clarke R, Silva Dias P, eds. *Climate Change in the Plata Basin*. Buenos Aires: CIMA; 2006, 81–92.
34. Bischoff S, García N, Vargas W, Jones P, Conway D. Climatic variability and Uruguay River flows. *Water Int* 2000, 25:446–456.
35. Camilloni I, Barros VR. Extreme discharge events in the Paraná River and their climate forcing. *J Hydrol* 2003, 278:94–106.
36. Rosa R, Berridi M. Recopilación sobre daños históricos en inundaciones en la Argentina (In Spanish). In: *El cambio climático y sus consecuencias territoriales*. 51° Convención Anual. Cámara Argentina de la Construcción, Buenos Aires, 2003, 107–173.
37. Latrubesse E, Brea D. Floods in Argentina. *Dev Earth Surf Process* 2009, 13:333–349.
38. Confirman que fueron 89 los muertos por la inundación en La Plata (In Spanish). La Nacion Edition, July 4 2014. Available at: http://www.lanacion.com.ar/. (Accessed October 14, 2014).
39. Magrin GO, Travasso MI, Rodríguez GR. Changes in climate and crops production during the 20th century in Argentina. *Clim Change* 2005, 72:229–249.
40. Magrin GO, Travasso MI, Baethgen WE, Grondona MO, Giménez A, Cunha G, Castaño JP, Rodriguez GR. Past and future changes in climate and their impacts on annual crops yield in South East South America. In: *IPCC/TGICA Expert Meeting on Integrating Analysis of Regional Climate Change and Response Options*. Intergovernmental Panel on Climate Change (IPCC), Nadi, Fiji, 2007, 121–124. Available at: http://www.ipcc.ch/pdf/supportingmaterial/tgica_reg-meet-fiji-2007.pdf. (Accessed October 14, 2014).
41. Magrin GO, Travasso MI, Rodríguez GR, Solman S, Núñez M. Climate change and wheat production in Argentina. *Int J Global Warm* 2009, 1:214–226.
42. Viglizzo EF, Roberto ZE, Filippin MC, Pordomingo AJ. Climate variability and agroecological change in the central Pampas of Argentina. *Agric Ecosyst Environ* 1995, 55:7–16.
43. Occhiuzzi SE, Mercuri P, Pascale C. *Herramientas para la evaluación y gestión del riesgo climático en el sector agropecuario, Argentina. (In Spanish)*. Buenos Aires: Ministerio de Agricultura, Ganadería y Pesca de la Nación; 2011, 130.
44. Magrin GO, Travasso MI, Mehzer R. *Impacts of Climate Variability and Extremes on Crop Production in Argentina*. Planet Under Pressure 2012, London. 2012. Available at: http://elsevier.conference-ervices.net/reports/template/onetextabstract.xml?sl=template/onetextabstract.xsl&conferenceID=2808&abstractID=574302. (Accessed October 14, 2014).
45. Christie DA, Boninsegna J, Cleaveland M, Lara A, Le Quesne C, Morales MS, Múdeles M, Stahle D, Villalba R. Aridity changes in the Temperate–Mediterranean transition of the Andes since AD 1346 reconstructed from tree-rings. *Climate Dynam* 2011, 36:1505–1521.
46. Le Quesne C, Acuña C, Boninsegna J, Rivera A, Barichivich J. Long-term glacier variations in the Central Andes of Argentina and Chile, inferred from historical records and tree-ring reconstructed precipitation. *Palaeoecology* 2009, 281:234–244.
47. Cobos DR, Boninsegna J. Fluctuations of some glaciers in the upper Atuel river basin, Mendoza, Argentina. *Quat S Am A* 1983, 1:61–82.
48. Aniya M, Sato H, Naruse R, Skvarka P, Cassasa G. Recent glacier variations in Southern Patagonia Icefield, South America. *Arct Antarct Alp Res* 1996, 29:1–12.
49. Skvarka P. Vulnerabilidad de la Patagonia y sur de las provincias de Buenos Aires y La Pampa (In Spanish). In: Barros VR, ed. *Enabling Study for the Second National Communication to the UNFCCC*. Buenos Aires: Fundación e Instituto T. Di Tella; 2006, 129–146.

50. Boninsegna J, Villalba R. *Documento marco sobre la oferta hídrica en los oasis de riego de Mendoza y San Juan Los condicionantes geográficos y climáticos (In Spanish)*. Buenos Aires: Proyecto SA y DS – Fundación T. Di Tella; 2005, 19.
51. Taylor KE, Stouffer RJ, Meehl GA. An overview of CMIP5 and the experiment design. *Bull Am Meteorol Soc* 2012, 93:485–498.
52. Alexander LV, Allen SK, Bindoff NL, Bréon FM, Church JA, Cubasch U, Emori S, Forster P, Friedlingstein P, Gillett N, et al. IPCC. Summary for policymakers. In: Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM, eds. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge; New York, NY: Cambridge University Press; 2013.
53. Flato G, Marotzke J, Abiodun B, Braconnot P, Chou SC, Collins W, Cox P, Driouech F, Emori S, Eyring V, et al. Evaluation of climate models. In: Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM, eds. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge; New York, NY: Cambridge University Press; 2013.
54. Orlowsky B, Seneviratne SI. Investigating spatial climate relations using CARTs: an application to persistent hot days in a multimodel ensemble. *J Geophys Res Atmos* 2011. doi: 10.1029/2010jd015188.
55. Collins M, Knutti R, Arblaster J, Dufresne J-L, Fichefet T, Friedlingstein P, Gao X, Gutowski WJ, Johns T, Krinner G, et al. Long-term climate change: projections, commitments and irreversibility. In: Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM, eds. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge; New York, NY: Cambridge University Press; 2013.
56. Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner GK, Allen SK, et al., eds. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (Summary for Policy makers): A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change, IPCC*. Cambridge: Cambridge University Press; 2012, 19.
57. Barros VR, Garavaglia CR, Doyle ME. Twenty-first century projections of extreme precipitations in the Plata Basin. *Int J River Basin Manage* 2013, 6:373–387.
58. Barros V. Inundación y Cambio Climático. Costa argentina del Rio de la Plata (In Spanish). In: Barros V, Menendez A, Naggy G, eds. *El Cambio Climático en el Río de la Plata*. Buenos Aires: CIMA; 2005, 41–52.
59. Codignotto J, Kokot R. Geología y Geomorfología (In Spanish). Barros V, Menendez A, Naggy G, eds. *El Cambio Climático en el Río de la Plata*. CIMA, Buenos Aires, 2005, 107-114.
60. Liang X, Lettenmaier DP, Wood EF, Burges SJ. A simple hydrologically based model of land surface water and energy fluxes for GSMs. *J Geophys Res Atmos* 1994, 99:14415–14428.
61. Barros V. Escenarios hidrológicos de caudales medios del río Paraná y Uruguay (In Spanish). ECLAC Medio Ambiente y Desarrollo N°154, LC/L.3741, Santiago de Chile, 2013, 57.
62. Saurral R, Montroull N, Camilloni I. Development of statistically unbiased 21st century hydrology scenarios over La Plata Basin. *Int J River Basin Manage* 2013, 11:329–343. doi: 10.1080/15715124.2014.885440.
63. Camilloni I, Saurral RI, Montroull NB. Hydrological projections of fluvial floods in the Uruguay and Paraná basins under different climate change scenarios. *Int J River Basin Manage* 2013, 6:389–399.
64. Montroull N, Saurral R, Camilloni I, Grimson R, Vásquez P. Assessment of climate change on the future water levels of the Iberá wetlands, Argentina, during the 21st century. *Int J River Basin Manage* 2013, 11:401–410.
65. Murgida AM, Travasso MI, González S, Rodríguez GR. Evaluación de impactos del cambio climático sobre la producción agrícola en la Argentina (In Spanish). ECLAC Medio Ambiente y Desarrollo N°155, LC/L.3770, Santiago de Chile, 2014, 70.
66. Travasso MI, Rodriguez GR, Magrin GO. Climate change impacts on Argentina's crop production. Planet Under Pressure. 2012. Available at: http://www.planetunderpressure2012.net. (Accessed October 14, 2014).
67. Rosenzweig C, Strzepek KM, Major DC, Iglesias A, Yates DN, McCluskey A, Hillel D. Water resources for agriculture in a changing climate: international case studies. *Glob Environ Chang* 2004, 14:345–360.
68. Magrin GO, Travasso MI. An integrated climate change assessment from Argentina. In: Doering O III, Randolph JC, Southworth J, Pfeifer RA, eds. *Effects of Climate Change and Variability on Agricultural Production Systems*. The Netherlands: Kluwer Academic Publishers; 2002, 193–219.
69. Zullo J Jr, Pinto HS. Assad ED, Heuminski de Avila AM. Potential for growing Arabica coffee in the extreme south of Brazil in a warmer world. *Clim Change* 2011, 109:535–548.
70. Podestá G, Bert F, Rajagopalan B, Apipattanavis S, Laciana C, Weber E, Easterling W, Katz R, Letson D, Menendez A. Decadal climate variability in the Argentine Pampas: regional impacts of plausible climate

scenarios on agricultural systems. *Climate Res* 2009, 40:199–210.

71. Schwank J, Escobar R, Girón GH, Morán-Tejeda E. Modeling of the Mendoza river watershed as a tool to study climate change impacts on water availability. *Environ Sci Policy* 2014, 43:91–97.
72. Boninsegna JA. Impacto del cambio climático en los oasis del oeste argentino (In Spanish). *Cienc Invest* 2014, 64:45–58.
73. Nuñez M, Solman S. Desarrollo de escenarios climáticos en alta resolución para Patagonia y zona cordillerana. Período 2020/2030 (In Spanish). Enabling Study for the Second National Communication to the UNFCCC, SAyDS, Buenos Aires, 2006.
74. Boningseña J, Villalba R. *Documento marco sobre la oferta hídrica en los oasis de riego de Mendoza y San Juan: Los escenarios de Cambio Climático y el impacto en los caudales (In Spanish)*. Buenos Aires: Proyecto SA y DS /Fundación T. Di Tella; 2006, 25.
75. Government of the Argentine Republic. *Revisión de la Primera Comunicación del Gobierno de la República Argentina a la Convención Marco de Naciones Unidas sobre el Cambio Climático (In Spanish)*. Buenos Aires: Government of the Argentine Republic; 1999, 105.
76. Government of the Argentine Republic. Government of the Argentine Republic, ed. *Segunda Comunicación Nacional de la República Argentina a la Convención Marco de Naciones Unidas sobre Cambio Climático (In Spanish)*. Buenos Aires; 2006, 197.
77. La Economía del Cambio Climático en la Argentina. *Primera Aproximación (In Spanish)*. Santiago de Chile: Economic Commission for Latin America and the Caribbean; 2014, 241; LC/W.567.
78. Evaluación de Necesidades Tecnológicas ante el Cambio Climático. *Informe Final sobre Tecnologías de Mitigación (In Spanish)*. Buenos Aires: Ministry of Science, Technology and Innovation for Production; 2013, 182.
79. Bouille D, Dubrovsky H, Kozulj R, Di Sbroiavacca N, Girardin LO, Groisman F. Argentina: Diagnóstico, prospectivas y lineamientos para definir estrategias posibles ante el cambio climático Producto 1, evolución anual de las emisiones de gases de efecto invernadero en la República Argentina en el período 1990–2005 (In Spanish). Report to ENDESA. Bariloche Foundation, Buenos Aires, 2008, 85. Available at: http://www.endesacemsa.com. (Accessed October 15, 2014).
80. Blanco G, Gerlagh R, Suh S, Barrett J, Coninck H, Diaz Morejon C, Mathur R, Nakicenovic N, Ofosu Ahenkorah A, Pan J, et al. Drivers, trends and mitigation in IPCC. In: Edenhofer O, Pichs-Madruga R, Sokona Y, Farahani E, Kadner S, Seyboth K, Adler A, Baum I, Brunner S, Eickemeier P, et al., eds. *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge; New York, NY: Cambridge University Press; 2014.
81. Arrayanes G. *Mitigación del Cambio Climático mediante la Captura de Carbono (In Spanish)*. Buenos Aires: Enabling activity for the Second National Communication SA y DS; 2006, 168.
82. UNEP DTU. CDM/JI Pipeline Analysis and Database. Available at: www.cdmpipeline.org. (Accessed October 15, 2014).
83. Secretaría de Ambiente y Desarrollo Sustentable. *El Cambio Climático en Argentina (In Spanish)*. Secretaría de Ambiente y Desarrollo Sustentable, Buenos Aires, 2008, 90.
84. Cámara Argentina de Biocombustibles. Available at: http://www.carbio.com.ar (In Spanish). (Accessed October 15, 2014).
85. Podestá GP, Messina CD, Grondona MO, Magrin GO. Associations between grain crop yields in Central-Eastern Argentina and El Niño-Southern Oscillation. *J Appl Meteorol* 1999, 38:1488–1498.
86. Magrin GO, Travasso MI, Baethgen WE, Boca RT. Improving applications in agriculture of ENSO-based seasonal rainfall forecasts considering Atlantic Ocean surface temperatures. In: Sivakumar MVK, Hansen J, eds. *Climate Prediction and Agriculture, Advances and Challenges*. Berlin; Heidelberg; New York: Springer; 2007, 249–257.
87. Gastaldi L, Galetto A, Lema D. El seguro como herramienta para la administración de riesgo climático en empresas tamberas del norte de Santa Fe, Argentina (In Spanish). *Rev Argent Econ Agrar* 2009, 11: 5–28.
88. Gastaldi L, Osgood D, Podestá G, Lema D. *Seguro climático índice para la producción de soja en Argentina. Revista, Artículo Breve. III Congreso Regional de Economía Agraria (In Spanish)*. Santiago de Chile: XVI Congreso de Economistas Agrarios de Chile; 2011.
89. Moschini RC, Fortugno C. Predicting wheat head blight incidence using models based on´meteorological factors in Pergamino, Argentina. *Eur J Plant Pathol* 1996, 102:211–218.
90. Moschini RC, Perez BA. Predicting wheat leaf rust severity using planting date, genetic resistance, and weather variables. *Plant Dis* 1999, 83:381–384.
91. Moschini RC, Martínez MI, Sepulcri MG. Modeling and forecasting systems for Fusarium head blight and deoxynivalenol content in wheat in Argentina. In: Alconada Magliano T, Chulze SN, eds. *Fusarium head blight in wheat in Latin-America*. Berlin; Heidelberg; New York: Springer; 2013, 205–227.
92. Moschini RC, Martínez MI, Sepulcri MG. Sistemas de pronóstico de enfermedades (In Spanish). In: Murphy

GM, Hurtado RH, eds. *Agrometeorología*, vol. 21. Buenos Aires: Facultad de Agronomía UBA; 2013, 409–441.

93. Barros V. Adaptation to climate change: lessons from the Argentine experience, chapter 17. In: Leary N, Adejuwon J, Barros V, Burton I, Lasco R, eds. *Climate Change and Adaptation*. London: Earthscan Publishers; 2007, 296–314.
94. Viglizzo EF, Frank FC, Carreño LV, Jobbágy EG, Pereyra H, Clatt J, Pincén D, Ricard MF. Ecological and environmental footprint of 50 years of agricultural expansion in Argentina. *Glob Chang Biol* 2011, 17:959–973.
95. Zak MR, Cabido M, Caceres D, Diaz S. What drives accelerated land cover change in Central Argentina? Synergistic consequences of climatic, socioeconomic, and technological factors. *Environ Manage* 2008, 42:181–189.
96. Gasparri NI, Grau HR. Deforestation and fragmentation of Chaco dry forest in NW Argentina (1972–2007). *For Ecol Manage* 2009, 258:913–921.
97. Volante JN, Alcaraz-Segura D, Mosciaro MJ, Viglizzo EF, Paruelo JM. Ecosystem functional changes associated with land clearing in NW Argentina. *Agric Ecosyst Environ* 2012, 154:12–22.
98. Johnson BG, Zuleta GA. Land-use land-cover change and ecosystem loss in the Espinal ecoregion, Argentina. *Agric Ecosyst Environ* 2013, 181:31–40.
99. Viglizzo EF, Jobbagy EG, Carreno L, Frank FC, Aragon R, De Oro L, Salvador V. The dynamics of cultivation and floods in arable lands of Central Argentina. *Hydrol Earth Syst Sc* 2009, 13:491–502.
100. Gavier-Pizarro GI, Calamari NC, Thompson JJ, Canavelli SB, Solari LM, Decarre J, Goijman AP, Suarez RP, Bernardos JN, Zaccagnini ME. Expansion and intensification of row crop agriculture in the Pampas and Espinal of Argentina can reduce ecosystem service provision by changing avian density. *Agr Ecosyst Environ* 2012, 154:44–55.
101. Busnelli J, Neder L, Sayago JM. Temporal dynamics of soil erosion and rainfall erosivity as geoindicators of land degradation in Northwestern Argentina. *Quatern Int.* 2006, 158:147–161.
102. Berthrong ST, Jobbágy EG, Jackson RB. A global meta-analysis of soil exchangeable cations, pH, carbon, and nitrogen with afforestation. *Ecol Appl* 2009, 19:2228–2241.
103. Farley K A, Piñeiro G, Palmer S M, Jobbágy E G, Jackson R B. Stream acidification and base cation losses with grassland afforestation. *Water Resour Res* 2009, 44:W00A03. doi:10.1029/2007WR006659.
104. Nosetto MD, Jobbágy EG, Tóth T, Jackson RB. Regional patterns and controls of ecosystem salinization with grassland afforestation along a rainfall gradient. *Global Biogeochem Cy* 2008, 22. doi:10.1029/2007GB003000.